Economics of Climate Resilience Natural Environment Theme: Natural Flood Management CA0401

A REPORT PREPARED FOR DEFRA AND THE DEVOLVED ADMINISTRATIONS

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Context of this report

The Economics of Climate Resilience (ECR) has been commissioned by Defra and the Devolved Administrations (DAs) to develop evidence to inform the National Adaptation Programme and the adaptation plans of the DAs. The report should be read in the context of other programmes of work on adaptation being taken forward separately.

The scope of the ECR

The ECR follows the publication of the UK Climate Change Risk Assessment (CCRA) in January 2012 and differs in scope from work envisaged prior to that date. While its original aim was to consider individual climate change risk metrics from the CCRA and specific adaptation options, this evolved as the project was considered across government departments. The current ECR therefore focuses on broader policy questions, with each report covering multiple climate risks and CCRA risk metrics. In this context, the economic assessment is broader than a quantitative assessment of costs and benefits – it concerns identifying and assessing market failures and other barriers to effective adaptation action, seeking to understand drivers of behaviour which hinder or promote the adoption of adaptation actions. The framework for assessing the costs and benefits of adaptation actions is considered in a separate phase of the ECR.

Questions addressed

The questions addressed by the ECR were chosen following cross-government engagement by Defra. They ask whether there is a case for further intervention to deliver effective adaptation given the current context – i.e. the current adaptive capacity of those involved and the policy framework. Criteria for the choice of questions by policy officials include: the current and projected degree of the climate change risk; priorities for additional evidence gathering beyond that already being considered in other work-streams, and the data and evidence currently available. Questions were deliberately broad to allow the wider context to be considered, rather than just individual climate metrics. However, this approach prevents a detailed evaluation of individual risks or localised issues being made. Detailed assessments of climate thresholds and the limits of specific adaptation options have also not been possible.

Analysis undertaken

The analysis has sought to build on existing assessments of current and projected climate change risks (such as the CCRA). The context in which sectors operate has been assessed, including the current adaptive capacity of relevant actors and the policy framework in which those actors function. Categories of actions currently being taken to adapt to climate change have been explored, including those which build adaptive capacity where it is currently low, and those which limit the adverse impacts or maximise opportunities, allowing identification of barriers to effective adaptation. The case for intervention is then presented.

The degree to which an adaptation action is likely to be cost-effective requires more detailed assessment, reflecting the particular context in which adaptation is being considered.

This report is underpinned by stakeholder engagement, comprising a series of semi-structured interviews with sector experts and a range of other stakeholders. This has enabled the experiences of those who undertake adaptation actions on the ground to be better understood. We are grateful to all those who have given their time.

1 Executive Summary

In combination with sea level rise (and coastal erosion), changing rainfall patterns, including events of higher rainfall intensity, could contribute to an increased risk of flood events in the future (Lowe *et al.,* 2009). Furthermore, areas not currently considered at risk could experience pluvial or fluvial flooding.

Several options exist to address flood risk, including hard engineering solutions (e.g. flood barriers) and Natural Flood Management (NFM) measures. The focus of this particular analysis is the latter.

In response to the projected increase in flood risk and the request for more evidence by policy officials, this report addresses the question set by Defra:

"What is the case for further intervention to encourage the use of soft engineering/habitat management for flood risk management?"

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 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 including improving water quality, carbon sequestration or habitat restoration, among others. They are only likely to be pursued effectively if these benefits are incorporated within the overall assessment of their costs and benefits.

Context for NFM adaptation

The adaptive capacity of actors involved in flood risk management in the UK to seize the opportunities from NFM is considered in general to be relatively low. NFM involves multiple organisations and the ability to take a long-term view of benefits. Furthermore, although actions have to be taken at a local scale, benefits are realised mainly at the scale of the wider catchment.

For individual actors, adaptive capacity is varied and there are a number of key considerations. The Agencies (e.g. Scottish Environment Protection Agency (SEPA) and the Environment Agency (EA)), play a critical role in structuring the approach to flood management, including NFM measures. However, the range of relevant associated organisations each has its own objectives, which in some cases do not align with others'. Given the reliance on land to deliver NFM measures, land-owners, such as farmers, are often critical for measures to be taken forward, but they are driven by commercial and other objectives.

Barriers to consideration and implementation of NFM measures

This report assesses key barriers to adaptation across a decision-making process: option generation, appraisal, implementation and monitoring.

Key barriers related to **option generation** include organisational or cultural barriers to considering NFM. In part, this is driven by a lack of information on effectiveness of measures and associated uncertainty, as well as uncertainty in the evidence-base and the level of monitoring in place. Other barriers include the lack of awareness of potential opportunities for effective NFM and missed opportunities for dissemination of learning from pilot projects. There are also cases of missed opportunities owing to flood defence benefits not being maximised when schemes are implemented to meet other objectives.

For **appraisal**, key barriers include the variation in forms of appraisal for different funding sources (e.g. funding and appraisal criteria for flood defence grants differ from those for woodland grants); difficulty in assessing costs and benefits compared to traditional hard engineering; difficulty for local communities to understand the benefits of NFM, and challenges in assessing and monetising co-benefits of NFM to ensure they are appropriately accounted for in appraisals.

For **project implementation and monitoring**, the critical barrier is the reluctance of land-owners to adopt the measures proposed. There are many considerations underpinning this, not least the lack of a private return from changing land-use from agricultural production. Other barriers include the lag periods between implementation and benefits being realised, and the number of parties involved.

Based on these barriers, a number of recommended interventions have been identified.

Recommendations

In order to ensure appropriate **consideration of NFM measures at the option generation stage**, there is a need to:

- **Use a checklist for flood management options to highlight the full range of options available**, along with guidance on when each may be suitable for further analysis. This should facilitate identification of opportunities for use of NFM in areas currently prone to flooding, or where flood risk is projected to increase.

- **Develop and collate evidence on the costs and benefits of actions taken, their effectiveness and the conditions under which they are likely to be effective, and when they are not.** The process of gathering such evidence should be continual as schemes develop in different locations and across different geographical scales.

- **Using existing or enhanced channels of communication, disseminate lessons learned** from pilot projects in a clear and practical way to allow others to identify best practice.

- **Support development of expertise in NFM**, including land management, engagement with land-managers and underlying science.

- **Undertake research to understand the drivers of flood managers' behaviour and identify potential efforts to "nudge" decision-makers to consider NFM as an option**.

To enhance the **appraisal of NFM measures**:

- **Undertake assessments of the ecosystem benefits associated with NFM measures based on previous case studies**. This should draw on a range of appropriate appraisal methodologies, including monetisation and multi-criteria analysis. This should identify both the conditions under which ecosystem benefits are more likely and how they can be maximised, along with associated opportunity costs.

- **Incorporate resources for the ex ante pre-NFM measure baseline and the ex post monitoring and evaluation** into the project planning processes.

To **deliver NFM measures where they are likely to be effective**:

- **Undertake a review of available funding streams and the associated appraisal requirements to identify where better alignment could be achieved** in order to minimise complexity and increase transparency in obtaining partnership funding.

- **Investigate the effectiveness of alternative funding structures** to increase overall longer term resilience.

- **Assess the costs and benefits of organisations currently acting as champions**, to identify circumstances where champions are more likely to be effective.

- **Undertake wider stakeholder engagement (including activities at the community level) to raise awareness of NFM measures** and enhance acceptance where they may be worthwhile.

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2 Introduction

2.1 Focus of the work

A wide range of options exists to manage flood risk. Substantial work has been undertaken, and is on-going, to consider the most effective measures. This particular analysis focuses on one area in which policy officials identified a need for greater evidence: natural flood management (NFM).

NFM is defined as the "alteration, restoration or use of landscape features to reduce flood risk" (Postnote, 2011). It often includes "soft-engineering", which has been defined as engineering with natural materials or "greater working with natural processes" (Pitt, 2008b).

Specifically, this work addresses the following question set by policy officials:

What is the case for government action to encourage the use of soft engineering/habitat management for flood risk management?

This question focuses on NFM methods to address fluvial (river-related) and pluvial (rainfall generated overland flow) flooding. Coastal flood risk is not included.

NFM measures are by their nature very location specific – the design, impacts and effectiveness of each will vary substantially. Therefore, this report does not provide a detailed cost-benefit analysis of these actions but rather identifies key barriers where such schemes could otherwise provide a valuable contribution to flood management and wider environmental benefits. Recommendations for interventions to overcome those barriers are set out.

2.2 Approach

The analysis was undertaken over a period of two months and draws on a wide range of published evidence coupled with evidence from stakeholder engagement.

2.2.1 Stakeholder engagement

More than 15 interviews were held with stakeholders, alongside on-going guidance and input from expert advisors. Stakeholders are listed in **Annex 1** and include the Environment Agencies of Scotland and England, organisations that have implemented NFM measures, academics, funders of NFM measures and facilitators of NFM measures.

2.2.2 Analysis

The analysis draws on a wide range of published literature including academic publications, research reports, grant scheme guidance documents, appraisal methodologies and case study material. published data and statistics have been used. Much of the analysis is drawn from results from pilot projects (e.g. Pickering, Belford, Allan Water, Holnicote) as well as the Regional Flood and Coastal Committees (RFCC) programmes. The project has drawn extensively from the three Defra Multiple Objective Projects (MOP's), which include Pickering 'Slow the Flow'; Moors for the Future, Derwent, 'Making Space for Water'; and Holnicote 'Source to Sea' Project.

2.3 Limitations and further research

This study has explored a wide range of information and stakeholder views on NFM measures and their implementation. Although some important insights are presented, the extent of detailed analysis possible has been constrained by the availability of data and evidence. It is important to recognise that the development of NFM measures, their appraisal, implementation and monitoring are at a very early stage. Many NFM measures have been implemented alongside more traditional forms of flood alleviation, such as infrastructure. This makes the assessment of the incremental benefits of NFM measures more difficult.

In addition, the key drivers for implementing NFM schemes are likely to be strongly influenced by factors such as achieving water-quality benefits. This means that the design of NFM components may deliver some flood-alleviation benefits but may not meet their full potential.

Several important observations associated with the available evidence are:

- **Focus of evidence on hydrological impacts of specific interventions:** There are many academic studies and pilot projects assessing the potential for NFM measures. With some notable exceptions, these studies consider the hydrological effects of options without a detailed assessment of underpinning costs and benefits.

- **Limited evidence of co-benefits associated with NFM measures**: A key aspect of this report is the co-benefits of NFM, such as improvement in water quality, habitat creation and recreational opportunities. Very few NFM projects have attempted to quantify these or determine the extent to which they can be monetised.

- **Scaling the impacts:** The assessments of the potential application and net benefits of most NFM measures are site-specific. With the differences in land-use, geology, vegetation and hydrology between different sites, it can be difficult to transfer the lessons from one pilot project more widely.

Although this report is looking at the extent to which there is a case for intervention to ensure the uptake of NFM measures, it should be noted that such initiatives should only be implemented where the benefits of such interventions, for flood risk management or other ecosystem services, outweigh the costs.

To address this question, this report is structured in the following way:

- Section 3 discusses the climate change projections and the role for flood management measures with a focus on NFM options.
- Section 4 discusses the context for adaptation including the adaptive capacity of stakeholders of flood risk management schemes and relevant policies
- Section 5 discusses the evidence on the potential effect of NFM measures and the barriers to their consideration and implementation
- Section 6 concludes with the case for intervention.

3 Managing flood risk

Key messages

- There are various options to address flood risk, natural flood management is just one – and can be applied either alone or as part of a package with other measures.
- Various different types of NFM exist to either reduce runoff (e.g. farm management to increase filtration) and/or attenuate flows (e.g. riparian tree planting, flood plain reconnection).
- NFM measures are likely to provide wider benefits than flood alleviation including improving water quality, carbon sequestration and habitat restoration, among others. These benefits can be key drivers of their implementation.
- It will be important to ensure the design of NFM measures does not inadvertently increase the risk of flooding by adversely affecting the flow of water. Interdependencies and cross-sectorial issues are numerous. Accounting for them appropriately will be important as part of an effective strategy to manage flood risk

This section provides an overview of the projected change in flooding over future years; the range of options that exist to manage that risk (alone or in combination), and the evidence on the effectiveness of such actions.

3.1 Climate change and flood risk

The impacts of increases in flooding due to climate change are expected to vary, particularly between fluvial and surface water flooding. 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, in particular, are at higher risk of being polluted by sewage, leading to 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 (the UK Climate Risk Assessment (CCRA) (HR Wallingford et al, 2012) estimated that about six million properties are currently at risk of flooding, comprising three million properties at risk of flooding from rivers or the sea, and four million from surface water flooding; one million of the former are also susceptible to surface water flooding (Ramsbottom *et al.,* 2012). Flooding from groundwater also poses a threat in some areas, further increasing the risk (Ramsbottom *et al.,* 2012).

The number of properties at risk of flooding with an annual probability of 1.3% or greater from rivers or the sea in England and Wales is projected to increase from the existing baseline[1] of about 560,000 (370,000 residential and 190,000 non-residential) properties. Depending on the climate change emissions scenario (ranging from low (p10) to high (p90) under UKCP09 projections), the number could reach between 800,000 and 2.1 million properties by the 2050s (with principal population growth), of which around two-thirds are residential

This implies areas which are already at risk from flooding may not be adequately protected for increasing volumes of water during a flood; furthermore areas not currently considered at risk, could experience flooding.

[1] Baseline is the period 1996-1990.

Projected flooding to the 2050s

CCRA findings on river flooding

Projections suggest increased river flows are likely owing to increases in extreme precipitation, particularly in winter. Many current flood prone areas may already have some form of flood defence, which may need maintenance or replacing in the future to maintain current levels of defence.

The CCRA (Ramsbottom *et al.,* 2012) assessed additional costs of flooding through impacts on: people[2], property, scheduled ancient monuments, agricultural land, business interruptions, transport infrastructure, building infrastructure[3] and additional insurance costs. The assessment estimated that the incremental cost of additional flooding due to climate change (for river and coastal flooding combined) could be **in excess of £4.8 billion**[4] per annum by the 2080s under a medium emissions scenario.

CCRA findings on surface water flooding

Surface water flooding resulting from direct run off from rainfall is projected to increase due to increases in the amount and intensity of that rainfall. Surface water flooding also includes flooding from sewers.

It is difficult to outline the impact of climate change on surface water flood risk as there is a lack of available information. However, estimated increases in the amount and intensity of rainfall point towards an increased risk of surface run-off (Ramsbottom *et al.,* 2012). The Evidence Report for the CCRA noted: "Overall it can be concluded that surface water flooding is a serious problem that is projected to increase. Whilst a quantitative estimate of the magnitude of the increase cannot be made, projections of a 12 to 30% increase in mean winter rainfall and a doubling of the frequency of heavy rainfall events suggest that the increase could be significant" (HR Wallingford et al, 2012).

The CCRA (Ramsbottom *et al.,* 2012) concluded that by the 2080s patterns of flood events experienced across the UK could be different from today due to the

[2] Flood related deaths, injuries and mental stress.
[3] Hospitals, power stations, electricity substations, schools.

[4] At 2010 prices, under p50 medium emissions and principle population growth estimates for the 2080s, including: £66m for the value of additional flood related deaths; £63m for the value of additional flood related injuries; £11-15m for additional people who will suffer mental stress as a result of flooding; £2.5bn property flooding; £1.1bn for the marginal increase in non-residential properties at significant risk of flooding; £40m additional business interruption costs; £1.7m river flood cost to transport; >£100m for the cost of power outages where power stations are at significant risk of flooding; £167m flood costs to hospitals; £600m for increase pay-out costs by the insurance industry due to flooding; £0.5-09m damage costs to areas of scheduled ancient monuments, and £138m for damage to grade 1-5 agricultural land. Costs were not assessed but could also be included for damage to water treatment plants, schools, tourist assets and road or bridge failure due to scour.

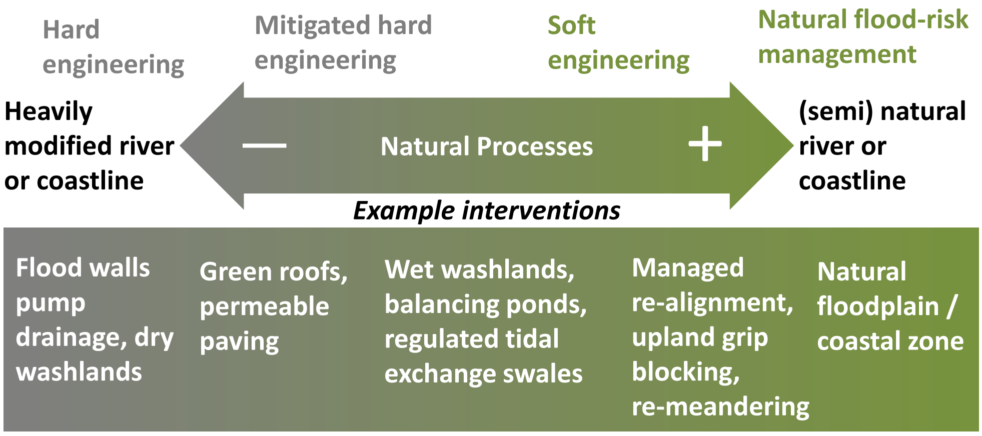
changes in climate. Both the projected increase in threat of flooding (as identified by the CCRA: Ramsbottom *et al.,* 2012) and the location-specific nature of those threats means that there is likely to be a greater role for a broader range of flood management options to be considered.

3.2 Flood risk management measures

During high flow conditions, rivers spread out into their floodplains, creating a diverse range of habitats that support many important species. Man-made hard engineering measures to protect against the adverse effects of flood inundation can therefore damage associated riparian and wetland habitats (Brown *et al.,* 2012). One response to climate change is anticipated to be an increase in the extent of engineered flood defence structures, which in turn can affect habitats (Harries and Penning Rowsell, 2011). More recently, NFM measures, which do not necessarily result in these impacts on the natural environment, have been explicitly identified as making a valuable contribution to flood alleviation across a range of locations and circumstances. This is either alone or in combination with other measures.

For the purpose of this analysis, NFM refers to a broad range of measures, which include those classified by the Environment Agency (EA) as soft engineering and those that are natural flood-risk management techniques. Examples of these measures are shown in **Figure 1**.

Figure 1. Examples of classifications of NFM

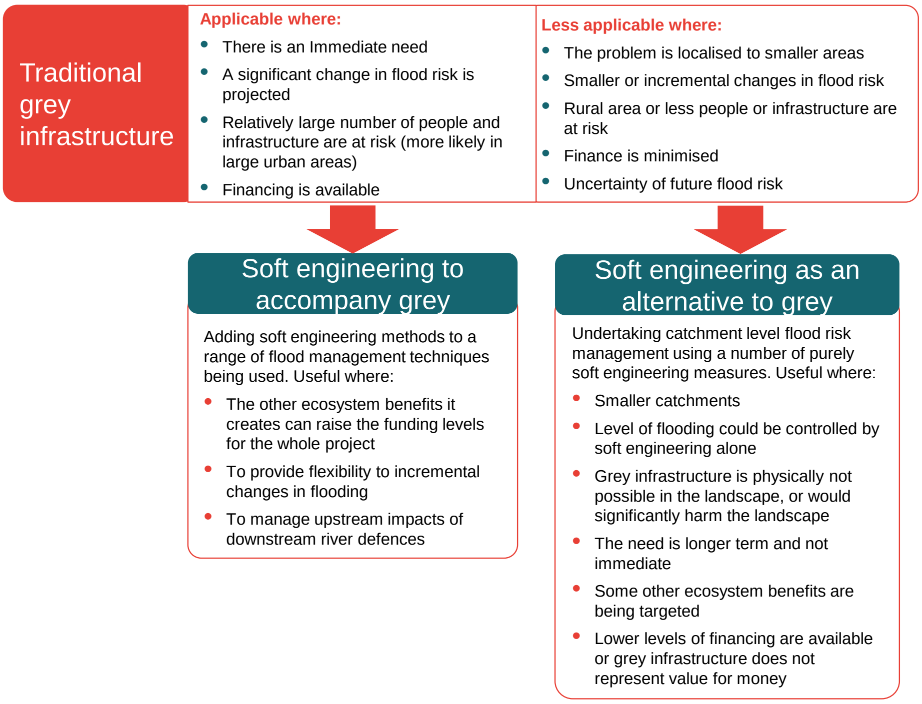


Source: Adapted from EA (2010a)

3.3 Options for extending the use of NFM

There are some key differences between traditional measures to manage flood risk and NFM measures. These are shown in **Figure 2**.

Figure 2. Options to address flood risk, illustrative comparison



Stakeholders consider NFM measures to be most effective at reducing the frequency of flooding for high probability fluvial events (e.g. less than a one in twenty year return period) compared to extreme events (e.g. one in 200 year return period). Some have mentioned that there is limited evidence to demonstrate the effectiveness of these types of measures in return periods over a one in fifty year period. As a result, these measures have not been prioritised in situations such as pluvial flooding in urban areas, where the legacy of inadequate infrastructure has received more focus (e.g. in many locations within Northern Ireland according to stakeholders).

However, research studies (e.g. O'Connell *et al*, 2004) identify that NFM techniques would be effective in managing flood runoff at a local scale. These findings were captured in the Government response to the Autumn 2004 'Making Space for Water' consultation exercise and (the update to the) Pitt review (Pitt, 2008b), as illustrated in the box below.

Government Response to Making Space for Water

"Consultees considered rural land management practices (such as cultivation practice and woodland creation) to be capable of ameliorating run-off and reducing the incidence of flooding on a local scale. The Government will therefore continue to employ the means identified in Making Space for Water for promoting such changes. These relate to taking maximum advantage from the status of flood management as a secondary objective in the Environmental Stewardship Scheme, and to the potential benefits for the control of water run-off from soils under the new Single Payment arrangements of the reformed Common Agricultural Policy." (Defra, 2005)

The need for flood risk management and the extent to which NFM options would be effective depend on the localised factors of each river catchment. Catchment Flood Management Plans (CFMPs) developed by the EA have served as an important strategic planning and engagement tool. CFMPs were developed for 77 river catchments across England and Wales in 2008/9 and set out options for schemes to manage risks over the next 50-100 years, either in combination with other measures or on their own (EA, 2011). Annex 3 contains a graphical representation of areas where further flood management activity is important. This shows more than half of England and Wales is in need of more action. The progress of CFMP will be monitored over three planning cycles: the short-term (to 2015), medium-term (2015 to 2021) and long-term (after 2021), and will be reviewed and refreshed periodically.

In addition, the Forestry Commission is currently mapping areas that are eligible for the English Woodland Grant Scheme (which has within it an element of flood risk management). This process should be completed by 2015 and will help identify where potential opportunities exist for woodland creation.

3.4 Overview of NFM options

The wide range of NFM measures can be categorised in terms of their function (e.g. reducing run-off, attenuation of floods, or desynchronising floods), the type of flooding they address (e.g. fluvial, pluvial or coastal) and where in the catchment they are usually used (e.g. upper, mid or lower). They are summarised in the table below.

This analysis is based on multiple case-studies where one, or more often, several of these NFM measures have been used to manage flood risk. For this particular analysis, the measures focus on those which are considered in rural, not urban, contexts.

Table 1. NFM Measures

Type of measure	Action	Location	Description
Run-off reduction (fluvial & pluvial)	1. Increasing soil filtration	Upper and mid-catchment	This includes a number of farm management practices such as reducing grazing pressure on pasture, reducing soil compaction in arable areas. This is also related to the need to increase infiltration in lower catchments and urban areas to reduce risk of pluvial flooding
Run-off reduction (fluvial & pluvial)	2. Creation of cross-slope tree shelter-belts	Catchment wide	Run-off generated in uplands can be infiltrated at a shelter-belt.
Run-off reduction (fluvial & pluvial)	3. Changing agricultural field drainage	Upper and mid-catchment	Drains in fields determine the route for water to reach water-courses.
Flood attenuation (fluvial)	4. Floodplain reconnection	Mid – lower catchment	This slows down water travel time through the catchment and is particularly applicable in wide floodplains.
Flood attenuation (fluvial)	5. Planting trees in flood plains	Mid – lower catchment	Afforestation can reduce flow velocity. In particular, trees and plants can increase channel roughness. This can be further enhanced by use of large woody debris as natural dams. Floodplain planting is not appropriate downstream of critical flood receptors.
Flood attenuation (fluvial)	6. Riparian planting	Catchment-wide	
Flood attenuation and reduction of discharges (fluvial and pluvial)	7. Storing water in rural areas (i.e. Rural Sustainable Drainage Systems)	Catchment-wide	There are a number of mechanisms to store water and use sustainable drainage systems. These include: ponds, ditches, reservoirs, channels or allowing land to flood (e.g. retention ponds, wetland creation).

Source: POSTNOTE, (2011), EA, (2012a), SEPA and FCS (2012), Woods-Ballard, (2007)

3.5 Wider benefits of NFM options

NFM options are a relatively new concept and there are few examples of them being implemented alone and with the single objective of managing floods. When delivered, because they rely on and are formed of natural resources (trees, planted vegetation, etc.), they are very likely to have a wider range of impacts beyond flood management. These can be described in terms of ecosystem services, which can be divided into four broad categories (Brown *et al.,* 2012):

- **Regulating services:** those parts of the ecosystem that mediate the interactions of materials both within and between ecosystems – hazard regulation (floods are an example of this); also climate (carbon sequestration); water quality (reducing sediment flow), and soil quality (reducing soil erosion).

- **Provisioning services:** the products of ecosystems such as trees, standing vegetation, water.

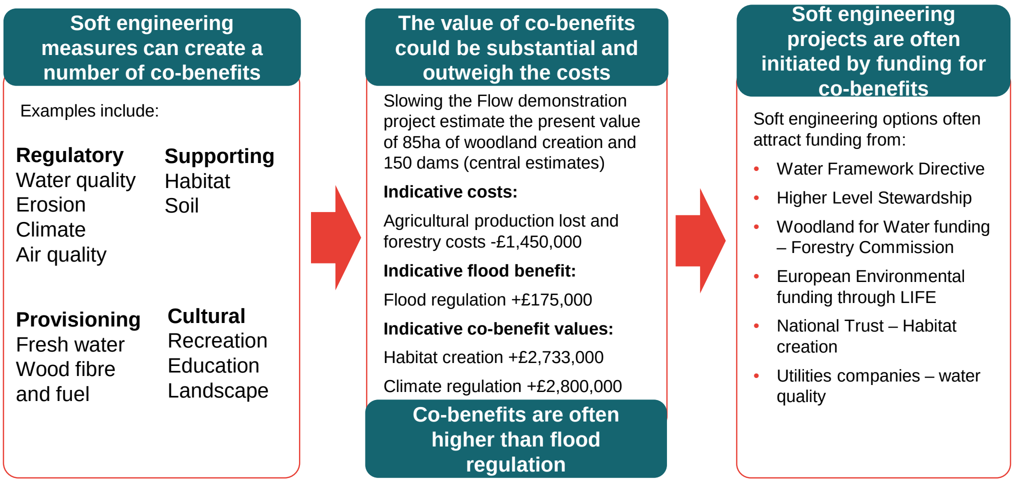
- **Cultural services:** those parts of the ecosystem that provide spiritual, recreational or educational experiences, for example landscape enhancement.

- **Supporting services:** necessary for the creation of all other ecosystem services, such as habitat creation and soil formation.

Each of these outcomes is able to deliver benefits to society that often exceed the private value that can be realised by the landowner (i.e. there are external benefits). This is owing to the lack of market for such benefits, meaning that the return on investment for landowners is extremely low.

These wider effects therefore form a valuable and important component of the assessment of the effectiveness of NFM measures, as illustrated below (Nisbet *et al.,* 2011).

Figure 3. Summary of wider benefits of natural flood management measures



Source: Analysis based on Nisbet *et al.*, (2011).

Note: Only central valuations of large ranges are shown.

Given the likely presence of external, or wider, benefits and costs, government intervention may be justified in order to ensure that they are accounted for and to prevent under-provision. The following box is an example of wider benefits arising from the Pickering NFM project.

Example: Wider -benefits of NFM methods identified in the Slowing the Flow in Pickering project

This project highlights the relative ecosystem benefits of dams (150 created) and 85 ha of woodland planting. While agricultural production declines by £0.306 - £1.113 million following woodland planting (this is an opportunity cost to the land-owner owing to the change in land-use); and forestry costs are £369,000 – 710,000, there are a range of benefits. These include: flood regulation (£88,000-292,000), habitat creation (£1.6-4.4 million), and climate regulation (£0.9-5.4 million), among other services. The study identified a net present value of £0.810 - 9.6 million (high and low estimates in 2011 prices).

Source: Nisbet *et al.,* (2011)

Government support is currently paid through a grant system, of which there are many forms and sources available. The diversity of benefits of the intervention leads to multiple sources of funding to support a project. In particular, several sources of funding are driven by the requirements for managing water quality (associated with Water Framework Directive requirements). (Sources of funding are considered in more detail in **Figure 8**, later in this analysis).

Where flood risk management is a second order priority (e.g. within the Higher Level Stewardship scheme), benefits such as habitat protection or water quality can take precedence. But, this suggests that there may be opportunities in terms of increased resilience to flooding that could arise from consideration of options to address those other objectives. Being aware of the potential for such opportunities and maximising them could allow a higher net benefit to be achieved. Similarly, awareness of this potential could play an important role in avoiding maladaptation. For example, if action is taken to meet one objective (such as improving water quality), it will be important to ensure the design does not inadvertently increase the risk of flooding by adversely affecting the flow of water. **Interdependencies and cross-sectorial issues are therefore numerous**. **Accounting for them appropriately will be important as part of an effective strategy to manage flood risk**.

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4 Context for adaptation

Key messages

- **Adaptive capacity** of the sector overall is relatively low as NFM involves multiple organisations and the ability to take a long-term view of benefits. Furthermore, whilst actions have to be taken at a local scale, benefits are realised mainly at the scale of the wider catchment.

- The most substantive adaptive capacity hurdles include those that are structural, such as the need to bring different organisations together. Also, there is often a lack of common understanding of all the benefits and costs of the different NFM activities and the conditions under which they are effective. Co-ordination of a variety of funding streams is also a challenge.

This section explores the context for adaptation in terms of the policy framework in which flood management decisions are made and the adaptive capacity of key actors.

4.1 Policies influencing NFM

Reviews of flood risk management processes were prompted by flooding events at the turn of the century. They advocated more comprehensive, integrated and sustainable approaches to flood risk management. All of which create opportunities for the use of NFM methods.

The "Making Space for Water" (Defra, 2005) government strategy for England, sought a more holistic approach to the assessment of flood risk management options, through seeking to "create" more space for water in the environment. This was further emphasised in Recommendation 27 (2008) of the Pitt Review, which stated that "Defra, the Environment Agency and Natural England should work with partners to establish a programme…to achieve greater working with natural processes" (Pitt, 2008a). As part of delivering flood risk management, the EA prepares CFMPs (see Section 3). Policy 6 within those plans states that the EA will "Take action with others to store water or manage run-off in locations that provide overall flood risk reduction or environmental benefits…"

Recently, the Flood and Water Management Act (2010) and the Flood Risk Regulations (2009) both sought to provide for improved management of flood risk in respect of people and property, as well as the promotion of more sustainable flood management and clear designation of responsibility for identifying and managing flood risk. Key players in this process are the local authorities, who have the responsibility for developing a local flood risk management strategy for their area that must be consistent with the national strategy.

In Scotland, the promotion of NFM is taken one step further, as NFM is explicitly included within the 2009 Flood Risk Management (Scotland) Act (2009). This requires the use of a catchment scale approach and "the use of more natural and sustainable ways to manage flood risk to complement other initiatives, such as engineered flood defences" (Scottish Government, 2011). As part of this act, the Scottish Environment Protection Agency (SEPA) and local authorities are required to consider the role which NFM can play in reducing flood risk (SEPA and Forestry Commission Scotland, 2012). Furthermore, local flood risk management plans, which will set out the agreed measures to address flood risk in a catchment area, will be required by 2015.

4.2 Adaptive capacity

This Section assesses adaptive capacity as part of the overarching context for the implementation of adaptation actions.

Adaptive capacity, or the ability to adapt, is analysed in this report using a simplified framework informed by the Performance Acceleration through Capacity Building (PACT)[5] model (Ballard *et al.,* 2011), which focuses on adaptive capacity within organisations, and the "weakest link" hypothesis[6] (Yohe and Tol, 2002; Tol and Yohe, 2006). For this project, adaptive capacity is defined using the CCRA (2012) definition in the box below:

> "The ability of a system/organisation to design or implement effective adaptation strategies to adjust to information about potential climate change (including climate variability and extremes), moderate potential damages, and take advantage of opportunities, or cope with the consequences"
>
> Source: Ballard *et al.,* 2011 (CCRA – modified IPCC definition to support project focus on management of future risks), (Ramsbottom *et al.,* 2012)

[5] This model was chosen as it was used in the CCRA, from which this project follows, and because in a UKCIP review of adaptation tools it was ranked as the most robust (Lonsdale *et al.,* 2010). The PACT model identifies six clear stages of development when organisations take on the challenge of climate change. These are called response levels (RLs) rather than stages because each level is consolidated before moving to the next. RLs 2 and 3 are characteristic of 'within regime' change, RL4 is characteristic of 'niche experimentation' (or 'breakthrough projects') and RL5 is conceptualised as regime transformation. RL6 would be conceptualised at the landscape level. In this report, the RLs were used very simplistically as a comprehensive assessment of the adaptive capacity of the sector using PACT could not be undertaken.

[6] The weakest link hypothesis enables assessment of the potential contribution of various adaptation options to improving systems coping capacities by focusing on the underlying determinants of adaptive capacity. In this report, the determinants were used to assess capacity of an actor rather than an adaptation option. This was used as it provides socio-economic indicators by which an actor's adaptive capacity may be categorised. It enables the weakest part of an actor's capacity to be shown providing an area to focus.

Flood risk is a complex challenge. The benefits of taking action to lower the potential adverse consequences are likely to accrue to more than one individual or group of funding organisations. The inability to realise returns from such an investment can lower investment below its optimal level.

Adaptive capacity is a necessary condition for the design and implementation of effective adaptation strategies, so as to reduce the likelihood and magnitude of harmful outcomes resulting from climate change (Brooks and Adger, 2005). In assessing the role of NFM solutions to address flood risk, this analysis considers two aspects of adaptive capacity:

- the **structure** of the sectors involved in responding to flood risk (i.e. the role and size of different organisations involved); and,
- the **organisations** involved: the function of key players who make critical decisions and their performance (i.e. gross margins, outputs and benefits delivered).

An analysis of these two factors informs an assessment of the ability of the sector to adapt to climate change and the extent to which flood risk threats are likely to be addressed. It should be noted that adaptive capacity is not only needed to optimise decisions based on climate change adaptation, but for other decisions with long-term implications (Ballard *et al.,* 2011).

4.2.1 Structural adaptive capacity

The analysis of structural adaptive capacity has been derived from evidence from published studies and case study evidence obtained via interviews undertaken for this analysis (listed in Annex 1). Interviews were held with a wide range of experts drawn from government departments and agencies, universities, research institutes, non-government organisations (NGOs) (both catchment-based and national), other project practitioners, funders and sponsors. **Adaptive capacity of the sector overall is varied and considered relatively low** as NFM involves multiple organisations and the ability to take a long-term view of benefits. Furthermore, whilst actions have to be taken at a local scale, benefits are realised mainly at the scale of the wider catchment. The assessment is based on the evidence in the following sections.

Sector complexity

Implementation of natural flood management involves the integration of a range of different competencies. In particular there are a number of complexities that reduce the capacity of the sector:

- Many initiatives often need to be closely integrated into hard engineering processes and management of assets to increase their effectiveness. This can make it a complex process, as decisions need to be made by different parties at different times.

- Measures require the involvement of a range of different land managers, including arable and livestock farm managers, water companies, forest managers, etc., each of which has different objectives.

- There are often many stakeholders with specific and contrasting perspectives and expectations. For example, nature conservation organisations, local communities and local authorities, amongst others.

Furthermore, at the larger scale, those who benefit from flood risk reduction, such as residents of urban areas downstream, often have little connection to those who can influence the implementation of flood management (e.g. rural upstream communities).

Such interdependencies and the range of stakeholders involved can weaken adaptive capacity because of the lack of a single desired direction and clarity of responsibility and ownership of risks in design and delivery.

Decision lifetime and activity levels

According to experts from NGOs, universities and government agencies with direct experience in NFM, once identified, a given NFM measure can take under a year to scope and reach planning approval, and can take a further 2-3 years to implement. This is illustrated in the example below, along with how this issue was overcome.

Example of decision lifetime

The small rural community of Belford in Northumbria has a population of about one thousand. It is at high risk of flash-flooding from the Belford Burn, which runs through the town. As expenditure could not be justified for a traditionally-engineered scheme, the Regional Flood Defence Committee allocated £650,000 for an alternative, effective yet economically-viable approach.

Construction of a NFM scheme can be much quicker than traditional approaches as long as the land-owners are willing. The nature of the catchment and the level of flood risk in Belford were suited to local solutions involving temporary natural storage upstream of Belford. Consequently, there is no need for lengthy feasibility, modelling, design or approvals. "You simply need to agree what will be done with the farmer, check with utility providers, consider the environmental constraints, ensure the work can be done safely, then hire a man with a digger," commented Peter Kerr, Local Levy Programme Manager (EA, 2009).

However where there is a need to demonstrate benefits of NFM and secure the buy-in from a wider range of parties, time-frames can be much longer. For example, Holnicote was initially a three year demonstration project for NFM. In practice, it has taken many more years to develop a suitable baseline to demonstrate the effectiveness of NFM measures (and therefore a case for land-use change).

Even if a given measure can be implemented relatively quickly, it can take longer for benefits to be realised across a (sub-) catchment. For example, one expert stated that it has taken over 15 years to identify the benefits from measures taken at Pont Bren, Wales, in addition to flooding. Benefits eventually identified included biodiversity, sequestration of CO_2, and employment.

Finally, for implementation of wider schemes, activity levels are much lower. Efforts are needed to co-ordinate multiple stakeholders where there is often inertia in relation to land-use change (e.g. with woodland planting, only 0.2% of forests in England are currently being felled and re-planted each year (Forestry Commission England, 2012).

Maladaptation

Maladaptation is defined by UKCIP as "Action or investment that enhances vulnerability to climate change impacts rather than reducing them" (UKCIP, 2012). Given the uncertainty around NFM measures, there are several areas where maladaptation could be a concern:

- Managing flood in one sub-catchment could result in synchronising peak-flows, thus making flood management over the wider catchment more difficult. There is currently considerable uncertainty regarding the role of NFM in synchronisation (e.g. SEPA and SFC, 2012).

- Where poorly designed and/or implemented, NFM can increase flood risks both upstream and downstream. For instance incorrect riparian woodland placement can increase risk for upstream communities.
- While there are several co-benefits identified in this report (discussed in Section 3), there are a number of areas where NFM could have negative implications in relation to climate change:
  - Many measures involve changing land-use and reducing agricultural production. As outlined in the ECR: Agriculture theme report, in some circumstances there are opportunities to enhance production related to climate change; if land is used for NFM instead these opportunities could be reduced or not realised;
  - Measures to increase responses to flooding can reduce water availability. For instance, increased tree cover can increase evapo-transpiration and reduce soil moisture content. Similarly, maintaining water storage bodies at low levels before winter to accommodate potentially higher winter rainfall, there may lead to water shortages in the subsequent year.

4.2.2 Organisational adaptive capacity

In addition to the structural issues discussed above, the overall capacity to implement NFM is driven by the many actors who have an interest or involvement.

The table below sets out a summary of the adaptive capacity of actors involved in the identification, appraisal, and implementation of soft engineering measures. **Unless otherwise specified, the data have been compiled from interviews with stakeholders and experts.**

Table 2. Organisational adaptive capacity

Actor	Resources	Processes	Organisation	Summary
Environment Agency (EA) **and Scottish Environment Protection Agency (SEPA)**	Awareness of relevant climate issues to the 2050s and beyond is high. Able to invest in research and develop best practices. Reduction in budgets limits local engagement. Respected authority with mandate to reduce flood risk.	CFMPs have to consider working with natural processes. Few mechanisms to ensure CFMP actions for NFM are implemented (EA, 2012).	Management see climate change as a key issue. Culture of focus on flood-risk solutions. Strong network between geographic areas. Barriers to engagement with land managers due to role as regulator.	Plays a key role in flood risk management and considering application of NFM measures.
Local Authorities	LAs have experience and funding for hard-engineering.	Responsible for implementing NFM in Scotland. In England and Wales, responsible for developing a local flood risk management strategy.	Variable use of structures to engage with land managers.	Varies but often have limited resources/ connections to leading NFM thinking.
Nature and conservation related agencies	Expertise in nature conservation and climate change and broad awareness of full range of ecosystem services. Administer funding related to their objectives.	Use of grants for co-benefits and role as statutory consultee to influence NFM activities.	Examples of strong engagement at local level with NFM organisations.	Plays a key role in supporting co-benefits; NFM is not a key priority.
Forestry-related agencies (e.g. Forest Research, Forestry Commission)	Expertise in relevant climate issues and implications for forestry. Able to invest in research and development. Difficulty of engaging land-managers.	Established processes for forest design planning and operations. Conducted climate change risk assessments. Monitoring and evaluation data are collected but limited processing capacity.	Strong collaboration between different forest districts and between DAs. Through felling licenses, grants able to engage with forest managers.	Able to implement some break-through projects. However flood risk management is one of several priorities.

Farmers	Family-run farms often operating with tight margins – commercially driven behavior. Lack of NFM knowledge (e.g. only 4% farmers seeking advice about climate change impacts: FPS, 2011)	Prominence of short-term decision making driven by productivity and market forces. Uncertainty of legislation (e.g. CAP) makes it difficult for farmers to adapt.	Limited collaboration with those affected by flood. Historically some resistance to change, however this is changing with younger generations.	Variation in adaptive capacity. As flood management is often not a core part of the business capacity is often low.
Other land owners (e.g. mixed estates, water companies)	Multiple sources of income can include water provision, property, sporting activities, agriculture (depending on type of owner) Operates at a scale sufficient to employ professional advisors.	Decision-making conducted can consider implications beyond 50 years.	Some engagement with others through associations, and through advisors.	Adaptive capacity affected by sources of income, size, owner characteristics,
Community based organizations (e.g. Tweed Forum)	Generally high levels of awareness of climate issues. Resources depend on diverse sources of income.	Close engagement with land managers. Able to act with agility to exploit funding and other opportunities.	Able to convene wider partnerships of communities, agencies etc.	Adaptive capacity varies by type of organization.
Non-governmental Organisations (e.g. National Trust)	Generally high levels of awareness of climate issues, Resources depend on diverse sources of income.	Established processes for management planning.	Collaboration with similar organisations and surrounding land-owners.	Adaptive capacity varies by type of organization.

4.2.3 Overview of adaptive capacity

The most substantive adaptive capacity hurdles include those that are structural, such as the need to bring different organisations together. Also, there is often a lack of common understanding of all the benefits and costs of the different NFM activities and the conditions under which they are effective. Co-ordination of a variety of funding streams is also a challenge.

Therefore, while adaptive capacity of the individual actors within the sector overall is considered to be varied, adaptive capacity should be considered alongside the decision-making process which is discussed in the next section.

Nevertheless, there are a number of key implications for the extent of adaptation actions that are likely to be taken:

- Agencies such as Natural England and the Forestry Commission play an important role in setting standards for receiving grant aid (e.g. SEPA and SFC, 2012, EA, 2012) which is a key source of funding given the externalities and co-benefits of NFM.

- Responsibilities for local flood risk management strategies normally reside with Local Authorities (normally County Councils or unitary authorities); however, they are able to draw on a range of other capacities locally. As such, the Agencies (e.g. SEPA, EA) play a critical role in structuring the approach to flood management. The challenges lie in how they are able to work with many Local Authorities, land-owners and others. There are many barriers to co-ordinated action and successful projects often involve convening a range of organisations with different objectives (e.g. Tweed Partnership, Moors for the Future, etc.).

  According to experts interviewed for this study (Annex 1), the different players that have to be involved in successful NFM are not at present joined up as a community. There are initiatives in many universities (e.g. Leeds, Newcastle, Dundee among others), companies (e.g. Severn Trent, United Utilities), agencies (Environment Agency, SEPA), and other NGOs (Natural England, Woodland Trust). However, **there are no formal means through which information and intelligence about the implementation and outcomes of NFM measures are shared**. They each have different objectives so will take a different view of the components and co-benefits of NFM. Although a 'Slowing the Flow' Working Group has been established to work together to map where the opportunities for NFM may be greatest, for example, their core mission statements remain distinct.

- There are many pressures that limit the extent to which farmers consider the need to respond to flood risk priorities – they are commercially driven entities so will seek to maximise their returns. The Common Agricultural Policy (CAP) funding streams and commodity prices more generally may make NFM measures (of which the return for the farmer may be uncertain) less commercially viable.

- There are some areas of strategic experimentation, such as projects to reduce impacts of flooding from forestry (Odoni and Lane, 2010), and activities instigated by the Environment Bank[7], where organizations can "purchase credits to fund the creation and/or management of an ecological or

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[7] The Environment Bank is an example of a private company set up to deliver biodiversity gain through offsetting, working with local planning authorities to ensure that biodiversity offsetting appears in development proposals. (www.environmentbank.com.)

environmental resource." (Environment Bank, 2012). However there are very few examples of projects being considered for wider application across the UK.

5 Effectiveness of NFM measures

Key messages

- NFM measures may not be possible or justified in many cases as a flood management measure in their own right, but their wider benefits could be notable and contribute to wider objectives.

- The evidence surrounding the effectiveness of alternative NFM measures is mainly based on modelling exercises supported by a small number of demonstration projects. However, full assessment of all costs and benefits is rarely available.

- Key barriers related to **option generation** are often organisational or cultural constraints. In part, this is driven by a tendency to consider hard engineering before NFM, a lack of information on effectiveness of measures as well as uncertainty in the evidence base. Other barriers include the lack of awareness of potential opportunities for effective NFM and missed opportunities for dissemination of learning from pilot projects. Also there are cases of missed opportunities owing to flood defence benefits not being maximised when schemes are implemented to meet other objectives.

- For **appraisal,** key issues include: sources of funding and the variety of associated appraisal requirements; difficulty in assessing costs and benefits compared to traditional hard engineering; challenges for local communities to understand the benefits of NFM, and challenges of assessing and monetising co-benefits of NFM (as well as negative impacts of hard engineering solutions) to ensure they are appropriately accounted for in appraisals.

- For **project implementation and monitoring**, the critical issue is the reluctance of land-owners to adopt the measures proposed. There are many considerations underpinning this, not least the lack of private return from changing land-use from agricultural production. Other barriers include a lag period between implementation and benefits being realised, the co-ordination of a number of parties involved and a lack of consistent approach for monitoring.

This Section explores the potential effectiveness of NFM measures and identifies particular barriers to their implementation and effectiveness.

5.1 Effectiveness of measures for flood risk management

A number of research projects (FD2114, FD2112, and FD2021) commissioned by Defra, the EA and others support a view that NFM techniques applied at the local scale can deliver measurable benefits. However, such is the complexity of the systems involved that the extent to which this approach can be scaled-up is less certain.

The evidence surrounding the effectiveness of alternative NFM measures is mainly based on modelling exercises supported by a small number of demonstration projects, generally based in small catchments of approximately 10 km^2. In cases where data have been collected, a long time-series does not exist. This section therefore provides an illustration of potential benefits under given scenarios, as shown in

Table 3,

Table 4,

Table 5, and Table 6, below.

Table 3. Evidence of land management actions and changes to land-use

Actions	Examples of flood benefit	Uncertainty	Co-benefits
Land management actions: Increasing soil filtration. Creating cross-slope shelter belts. Changing drainage in agricultural fields.	Reducing grazing pressure can increase infiltration; it can **reduce run-off between 13-41%** in areas of pasture in English/Welsh catchments [2] Strips of trees can improve water infiltration and **reduce water height by 29%** (for small flood) **or 5%** (large flood) (in a small ~10 km catchment). [1] A series of interventions in Pontbren catchment **reduced peak flows by 2-11%** during large events [2] Modelling suggests field drainage can **speed or slow run off rates by 2-3 times** in both directions [2]	Effects of management practices are **highly dependent on soil types, condition and land-use**. There is less sensitivity to land management in large catchments	**Soil protection** (agricultural productivity) **Sediment retention** (links to water quality)

Table 4. Evidence of reducing water flow-connectivity and woodland creation

Action	Examples of flood benefit	Uncertainty	Co-benefits
Floodplain reconnection to attenuate flood	Benefits for entrenched watercourses could be **10-15% reduction in flows.** [2] A 50-150% increase in flood flows for water-courses which are entrenched and completely disconnected from the flood plain has been reported by some studies [2]	**Each case is unique** and needs to be modelled. Benefits associated with descynchronisation are speculative [2]	**Wetland habitat** improvement /recreation

Table 5. Evidence on storing water (SuDS) in rural areas

Action	Examples of flood benefit	Uncertainty	Co-benefits
Storing water in rural areas to attenuate floods and reduce discharges	With 2-3% of land in Parrett catchment used as storage reservoirs**, flood peaks could be reduced** – quantified benefit undefined [1] **Peak flow can be reduced by 8-60%** with detention basins based on reviews of multiple locations [3]	Uncertainty driven by engineering to control inlet and outlet and **need for multiple interventions.** Long term effectiveness is also **affected by maintenance regime** [2]	Both retention and infiltration basins are good at **trapping phosphorus, nitrogen pesticides and pathogens** [3] Retention ponds, wetlands, etc. can provide water storage for irrigation which can be useful during drier summers [3]

Table 6. Action: Slowing water: riparian planting, floodplain planting

Action	Examples of flood benefit	Uncertainty	Co-benefits
Flood attenuation through **planting trees in flood plains riparian areas and gullies**	Foresting 2.2 km reach of floodplain on river Parret could **reduce flow velocity** of floods **by 78%** [4] After planting 40 ha on River Laver, a **0.3% reduction in** 1 in 100 year **flow** was predicted [2] **7.5% reduction in flood flows** was estimated following use of 100 woody debris dams in Pickering [2] Reforestation of steep gullies can **reduce coarse sediment supply by 85%** in Upper Wharfdale [2] Modelling suggests that planting a 10 km^2 catchment could **reduce water height by 50%** (small flood) **or 36%** large flood [1]. Realistic upper limits are 10-20% [2]	Benefits depend on site circumstances. **In some cases, afforestation can increase flood risk** For example woody debris and dams can be washed out **Requirement for large number of interventions** to capture signature of impact	Enhancing riparian **habitats** Reducing **sediment** yield [3] Many measures may also reduce phosphorus, nitrogen pesticides and pathogens (e.g. wetlands within ditches) [3]

Sources for Tables 2: [1]: Postnote, (2011); [2] SEPA, (2012), [3]: EA, (2012) and Woods-Ballard, (2007); [4]: Nisbet and Thomas, 2006. These sources are reviews of multiple academic studies, as such they reference but do not characterise each case-study catchment included..
Note: Benefits of interventions are affected by return periods analysed and size of the catchments examined. Further assessment of characteristic of each location mentioned is necessary when considering the specifics of examples. For some examples, the ranges listed could increase if climate variability is considered.

This evidence suggests:

- Although the outcomes of NFM measures are assessed to some extent, there **is little evidence that they have been quantified and monetised as part of a full appraisal**. Some are quantified, some are not. Comparing their relative magnitude is therefore difficult, and in many cases, not possible.

- **Potential outcomes are very case- or site-specific** and depend on a wide range of factors, such as amount of land used, design, topography, existing risk of flooding and expected degree of projected change in the future, etc. For example, gulley planting is best conducted in upper catchment locations where there are high-energy watercourses.

- **The magnitude and types of co-benefits vary considerably across different interventions**. The benefits to water quality are widespread across all options; some farm management interventions can improve productivity on the farm; a number of measures are effective at restoring or developing habitats; many measures will be less intrusive on the landscape, and woodland planting interventions provide carbon sequestration ecosystem services, amongst others.

5.2 Economic appraisal of NFM measures

Modelling is needed to measure the flood risk reduction effectiveness of these methods, which are often subject to many dependencies, such as:

- Hydrology of the area.
- Soil types.
- Land-use.
- Probabilistic flood projection, (e.g. 1 in 100 return period).
- Number of measures, or extent of measure applied at one time.
- On-going maintenance.

In addition to the flood risk reduction effectiveness, wider benefits and costs of flood risk reduction measures, in particular NFM measures which can provide a variety of co-benefits, may not be captured by the assessment of individual funding providers. To reflect the value of these additional costs and benefits, appraisal methods should capture the full range of impacts.

Underpinning appraisals of climate change interventions is the need to inform decisions in the context of uncertainty. Hunt *et al.,* (2011) summarise a number of decision-support tools which could be used to do this, including:

- social cost-benefit analysis;
- social cost effectiveness analysis;

- real options analysis;
- portfolio analysis;
- robust decision making; and,
- risk-based rules.

In addition, Ranger *et al.,* (2010) discuss approaches to account for uncertainty in projected climate change. Building in robustness to a measure is discussed, such as designing the intervention such that flexibility for the future is built-in from the start, through, for example, designing measures so that they can be expanded if required, or using a flexible adaptation process to allow for learning, monitoring and review over time. Real options assessments are also discussed. These allow the benefits of delaying action to be assessed and incorporated into the decision-making process - for example, retaining the option to implement or enhance a hard infrastructure option to accompany NFM if flood risk increases. The ECR Framework for Appraising Flood Defence Initiatives report discusses each of these methods and provides step-by step guidance on how to select the most appropriate form, and how it can be operationalized to appraise an intervention when there is uncertainty over the climate risk.

Frameworks for assessing the costs and benefits of the flood risk itself capture and monetise a broad range of economic, environmental and social impacts. A strategic framework for appraising flood risk and coastal erosion interventions has been developed in the Appraisal of Flood and Coastal Erosion Risk Management (FCERM: Environment Agency, 2010a).

This guidance highlights that there are many components that need to be assessed as part of an appraisal. It should cover all costs and benefits to the extent that evidence allows and these should be presented in a transparent and consistent way across projects and interventions.

Such appraisal methods have been applied to a number of projects. **Table 7** presents, as an example, the decision criteria considered during the appraisal of measures for the Allan Water Project.

Table 7. Categories considered when appraising different flood management measures for the Allan Water Scoping Project

Financial costs	Flood risk benefits	Environmental co-benefits	Social co-benefits	Other considerations
Captial costs (present value) Maintenance costs (present value)	Flood risk reduction for properties	Flora and fauna Soil Water Air Use of natural resources Landscape Cultural heritage	Way of life Culture Community Fears and Aspirations	Uncertainties Future adaptation Fruition timescale Health and safety risk

Source: Adapted from Halcrow and CRESS (2011)

The effectiveness of measures needs to account for the **whole life cost** of a scheme. This can change over time from development (through partner negotiation) to after the scheme has been constructed (e.g. due to maintenance cost changes, or modifications to the scheme).

For instance, studies on alternative approaches to drainage, (which incorporates some forms of NFM considered in this report), have compared costs of approval, capital and maintenance. These assessments conclude that the costs of schemes are highly dependent on locational factors (e.g. soil, slope, access, space requirements) and are considered more variable than hard engineering approaches.

Similarly, while maintenance costs can be greater than traditional solutions, they vary depending on the type of measure (e.g. tree planting vs. retention ponds); level of service expected by stakeholders, and other factors (Defra, 2009; Maslem Environmental, 2011; Woods-Ballard *et al.,* 2007). For sustainable drainage solutions, economic assessments for Defra have considered capital costs as broadly equivalent to costs of traditional drainage and have used assumptions that maintenance costs are 15% higher than for conventional drainage[8].

As well as the flood risk management benefits of these measures, as FCERM notes and as discussed throughout this analysis, there are often a number of additional **social costs and benefits** which are important to consider when evaluating an investment in NFM measures in particular, or in making cost

[8] The assumptions are that maintenance costs are £6 greater than the estimated £40 per property per annum for conventional drainage and this does not include additional demands for land costs (Defra, 2009).

effectiveness comparisons with traditional engineering methods. **Co-benefits,** in addition to the flood risk reduction, could be considered across a full range of **ecosystem services** (as described in Section 2). Indicative assessments of ecosystem benefits made for one measure in the 'Slowing the Flow' project (shown in **Figure 1** in Section 2) showed that **habitat creation and climate regulation benefits produced by that measure were 32 times larger than the flood risk-reduction benefit.**

Similarly the project costs relating to all ecosystem services also need to be included in a project evaluation. **Opportunity costs** (e.g. farmland used for producing crops replaced with riparian woodland; or the carbon sequestration value of wood used to construct dams); **carbon sequestration** (changes in greenhouse gas emissions, notably CO_2), and **existent values** (changes to current landscapes and recreational use caused by the implementation of the measure) could be particularly relevant in the comparison of NFM with traditional measures.

Any transfer payments should be identified and removed from a cost benefit analysis. It may be additionally useful to capture **the nature of the stakeholders to which costs or benefits occur** (potentially in these cases where these occur between high- and low-land communities or rural and city communities; perhaps particularly where farmland is required for woodland planting).

Social time preferences are also likely to be particularly relevant for NFM measures; some smaller measures may be much quicker to implement than approving and constructing larger grey infrastructure. However, planting riparian woodland, for example, may take many years (as the trees grow) to be effective. Discounting benefits by social time preference rates could highlight important advantages or disadvantages of NFM measures. In addition to the costs and benefits, **the option value** of delaying the implementation of NFM projects or expanding the project at a further point in time could also be considered.

The uncertainty of climate change impacts on flood risk should be accounted for with an **appropriate range of probabilities and consequences**. These should span a range of scenarios from high-consequence-low probability events to low consequence-high probability.

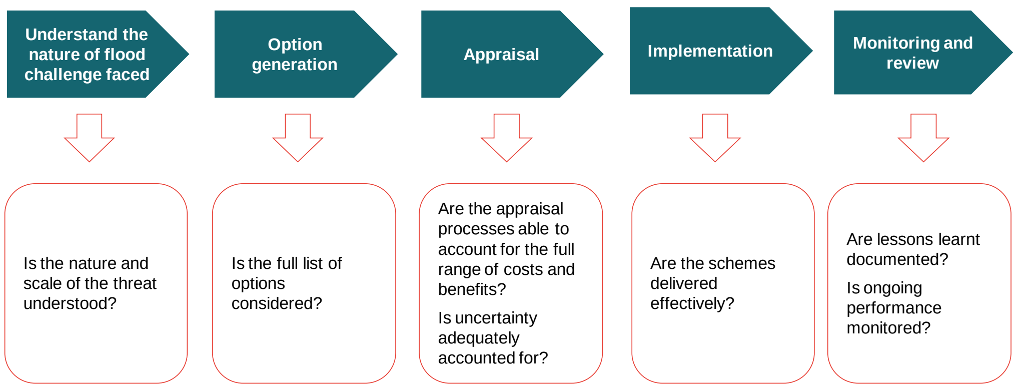
In addition to a cost benefit analysis, other implications may be important to consider if comparing NFM options with traditional measures. Exposure to **optimism bias** is one example, as the number of unknown factors may be greater for NFM projects, capturing the value of this additional risk exposure will be necessary when making comparisons.

5.3 Potential barriers associated with the decision-making process for NFM

This section addresses the question as to whether adaptation would be expected in the absence of further intervention, by considering the decision-making process as displayed in **Figure 4**. The stages are:

- Ensure the nature and **scale of the flood challenge** is understood;
- **Consider the full range of options that may be able to address the particular flood** challenge cost-effectively;
- **Undertake appraisal of the options** to ensure that all costs and benefits (including unintended consequences) are articulated and assessed on a consistent basis to compare across options. Sensitivity testing to understand the impact of uncertainties and alternative assumptions on expected outcomes should be undertaken. The highest return option should be selected;
- **Implement the scheme** by engaging with appropriate authorities and organisations to minimise disruption and enhance efficiency in delivery; and,
- Once delivered, **monitor and review** the outcomes to ensure that those achieved in practice are aligned with what was expected *ex ante*. Lessons learned may be articulated and shared.

Figure 4. The five stages of the decision-making process

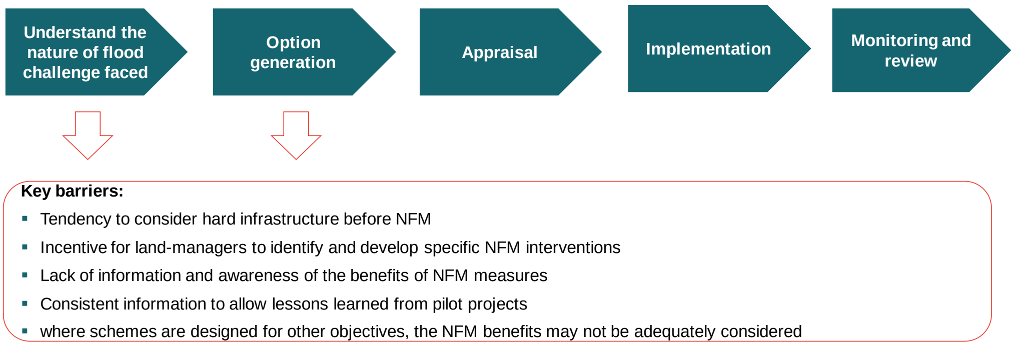


It is assumed in the following discussion that the nature and scale of the flood challenge faced is already assessed and understood. This section assesses the issues and potential barriers for the remaining stages.

5.3.1 Option generation

There are a number of key barriers to the consideration of NFM as part of the option generation process (recognising that they may not be viable options once fully assessed); these are summarised in **Figure 5**.

Figure 5. Barriers associated with option generation



Source: based on published information as cited or stakeholders interviewed for this report

Five particular option generation barriers have been identified on the basis of discussions with experts and on the basis of evidence from case studies.

Tendency to consider hard infrastructure before NFM

Traditionally within the EA and other bodies responsible for flood risk management, hard engineering solutions have been favoured over the wider range of options.

This is in part linked to experience and perspectives of asset managers. According to experts interviewed for this study, experience in engaging with a wide range of different land-owners and being able to put flood defence in the context of their business also constitute barriers to NFM. (This is also mentioned in the literature such as Woods-Ballard *et al.,* 2007)

However, the preparation of the 77 Catchment Flood Management Plans in England and Wales has resulted in the identification of a number of opportunities for the use of NFM measures for flood risk management, either in combination with other measures or alone. These are considered in detail by a local flood authority (involving local authorities) and the Environment Agency.

In Scotland, it is reported by stakeholders, that there has been a shift in how those working in government, agencies and local authorities see the potential for NFM measures. Over the years, the Scottish Government and SEPA have been proactive in talking to and involving local authorities through different fora to consider the potential for NFM opportunities. Consideration of such options to address flood risk then became a regulatory requirement in the Flood Risk Management (Scotland) Act (2009). The Act requires local authorities and SEPA to consider natural processes as part of each strategy (it may not be effective in all cases, but it should have at least been considered among other options). This will be supported by the requirement by 2015 in Scotland for local flood risk management plans, which will set out the agreed measures to address flood risk in a catchment area.

Experts consider the Scottish approach (of initially building capacity among local authorities and others) to be effective in encouraging local authorities to consider NFM (with SEPA playing a role for targeting and planning). However, organisations can be short staffed, limited by their traditional training and not experienced in dialogue with land managers, so in practice, the effectiveness of this requirement may be limited. There is little information available at this stage on the outcomes and impacts on incentives of the regulation given that it was only introduced recently, so this monitoring and review should take place over coming years.

An example scheme in which the Act did appear to encourage the consideration of NFM measures where they may not otherwise have been considered is Allan Water:

Example: Identification of opportunities at Allan Water

Project contractors Halcrow and CRESS, working through a steering group including the Forestry Commission Scotland, SEPA, Perth and Kinross Council, the RSPB, the Scottish Government, SNH and Stirling Council, investigated factors which would influence the implementation of natural flood management measures within the Allan Water catchment. This informed the development of a natural flood management strategy for the 216 km^2 catchment.

Early stages of the project included a comprehensive catchment reconnaissance survey, meetings with land managers and a desk-based GIS analysis. This allowed the identification of priority areas for land-use change, reach restoration and flood plain reconnection. The strategy is intended to form the basis of guidance which can be provided to land managers, Local Authorities, community groups and charities. The work then identified 19 options with NFM elements across the catchment, of which the four were assessed in detail (Halcrow and CRESS, 2011).

The tendency to focus on hard infrastructure extends beyond those responsible for designing and implementing flood management schemes: Local communities can also struggle to understand the benefits of NFM. In some cases, stakeholders have mentioned that some people can become concerned that government agencies are "more concerned about birds and trees than people"; it was also noted that "as hard engineering is more visible, it has greater political appeal".

Incentive for land-managers to identify and develop specific NFM interventions

In some cases, while the role of NFM in flood defence is acknowledged by agencies, local authorities and other stakeholders, there is **limited incentive for land managers to develop specific interventions.** For example, for a scheme such as the Entry Level Stewardship (the basic scheme for environmental management on farms covering 56% of utilised agricultural area in England in 2012), as long as the criteria are met, **it is up to land managers to decide which choice of measures they want to implement**. There is an opportunity to refine agreements with land-owners to focus on local flood risk priorities (EA, 2012a).

However there are examples of more targeted agri-environment schemes, such as in Glastir, the agri-environment scheme operating in Wales. Under this scheme, a number of objectives were identified (of which "managing water quantity" was one). The government then did an extensive engagement exercise with partners to identify locations to target action. For water quantity, the local Flood and Coastal Erosion Risk Management (FCERM) staff (EA, 2012a) played an important role. Farms located within areas identified where land management can reduce run-off are able to apply for the Glastir Advanced scale and include NFM measures as part of their proposal.

Furthermore, where there is a partnership approach to bring together land managers, the research community and agencies, stakeholders mentioned NFM options are more likely to be addressed. A partnership approach has been considered in the Tweed catchment, described below.

Example: Use of catchment champion to identify opportunities

In the Tweed catchment, a critical key success factor is having a "catchment co-ordinator" or "catchment champion" – The Tweed Forum. This organisation is:

- Considered as independent to government departments and agencies (farmers may not trust SEPA, SG, etc.)
- Able to take a view of the whole catchment and understands the science underlying different NFM measures
- Knows the catchment at a local scale and understands the concerns of farmers
- Understands different co-benefits (and can bring together different funding streams, such as SRDP, SEPA).

This approach ensures measures identified are pragmatic and will be effective.

Source: ECR interview.

Lack of information and awareness of the benefits of NFM measures

Identifying potential NFM measures is, in many cases, hindered by the perceived **weak evidence of effectiveness at a catchment scale**. A study commonly cited by stakeholders interviewed is the "review of impacts of rural land-use and management on flood generation." (Beven *et al.,* 2004). This evidence of the *catchment-scale* benefits from NFM was limited and inconclusive. In several of the discussions in different Environment Agency areas, this is interpreted as indicating that NFM measures are not effective and they have therefore not been prioritised.

In several cases where NFM measures have been identified, only specific interventions are evidenced. For example, in one river catchment, a stakeholder interviewed for this study noted that they had estimated that if 25% of the catchment was planted with woodland, it would only reduce the flood flow by 3% -5%. However projects such as Belford, in NE England have monitored and considered the impacts of multiple interventions together and are better placed to assess multiple benefits. This is due to the involvement of an academic partner able to monitor/evaluate interventions, and active engagement of local farmers.

Furthermore while there are situations where NFM could be a preferred measure, these are not consistently identified by stakeholders across the UK. Factors influence the ability to overcome the barriers in some circumstances include:

- **Payment:** Experts interviewed for this analysis indicated that it is becoming increasingly common for downstream communities to be prepared to pay for benefits created by upstream management. For example, stakeholders mentioned that fishermen may be prepared to pay additional fees for habitat maintenance to enhance local fisheries;

- **Cost-efficiency:** Upstream measures could in some cases be more cost effective than direct intervention using hard infrastructure. For example, Scottish Water has a Best Practice Incentive Scheme to finance land-based measures to allow land managers and farm businesses to manage water (Scottish Water, 2012); and,

- **Location:** NFM may be more cost effective in rural areas where the relative cost per person of infrastructure options would otherwise be high. A good example is the small rural community of Belford as described above.

Consistent information to allow lessons learned from pilot projects

While there are several tools that exist to identify and prioritise the location of soft engineering measures (e.g. Land-Use jigsaw, land management CFMP tool, (EA, 2012a) and the SUDS handbook (Woods-Ballard *et al.,* 2007), there are opportunities for **further dissemination of lessons learnt and priorities for future research.** For example, further engagement efforts between pilot projects and local authorities (e.g. building on efforts associated with projects such as Beaumont catchment in Scotland) would provide a valuable evidence-base to facilitate consideration of NFM measures at the option generation phase.

In addition, further work between research institutions (e.g. Dundee University, James Hutton Institute, Newcastle, among others) is likely to be important in developing the NFM knowledge-base. In practical terms, experts have noted that this involves **documenting projects using consistent standards,** including flood risk management benefits, co-benefits, and associated issues (including costs and governance). This also includes being able to understand potential performance of measures under different climate scenarios. Although such projects have a cost (e.g. the pilot project at Eddleston cost £400,000 over 3 years), they are essential if there is to be a consistent evaluation across a range of projects, and confidence in conclusions about the effectiveness of NFM over the longer term.

Where schemes are designed for other objectives, the NFM benefits may not be adequately considered

In several case-studies (e.g. Tweed, Pont Bren, Holnicote, Belford), experts have highlighted the importance of **identifying soft engineering interventions at an individual farm-scale which do not have a major opportunity cost**. This can involve understanding a business at the farm-level and identifying locations of less-productive land, suitable for natural flood management. Related to this, one stakeholder has referred to the importance of working at multiple scales (e.g. taking account of narrow woodland belts, hedgerows and other key landscape features, as well as blocks of trees).

Furthermore, **securing co-benefits is often a key enabler for investment in soft engineering measures.** Most of the experts interviewed referred to investments made primarily to meet water quality requirements, including those contained in the EU Water Framework Directive[9] (WFD). There is a perception that the evidence-base for assessing the impact of measures on water quality is easier to prepare given relevant available evidence.

The following box describes an example of co-benefits identified by United Utilities at multiple scales.

Example: Securing co-benefits

United Utilities owns 56,385 hectares of land in the North West, which it manages to protect the quality of water entering the reservoirs. The company has worked with the RSPB to develop a Sustainable Catchment Management Programme (SCaMP), to secure multiple benefits at a landscape scale, including reducing water treatment costs, delivering government targets for biodiversity conservation, and increasing resilience of habitats to climate change. The approach has included detailed monitoring and assessment using nested multi-scale approaches.

Source: United Utilities (http://corporate.unitedutilities.com/scamp-index.aspx)

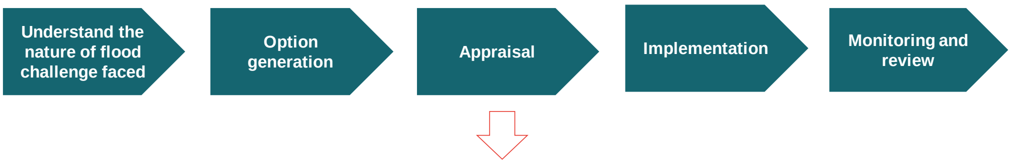
5.3.2 Appraisal

Following the identification of potential soft engineering measures, appraisal includes the detailed assessment of the costs and benefits associated with the intervention (relative to the case of no action having been taken) and prioritisation of alternatives.

The key issues associated with the appraisal processes are shown in **Figure 6**.

[9] Directive 2000/60/EC

Figure 6. Barriers associated with option appraisal



Key barriers:

- Appraisals may only partially cover the full range of costs and benefits
- Challenges in assessing co-benefits
- Appraisal process requirements associated with funding sources differ

Source: based on published information as cited or stakeholders interviewed for this report

There are three types of issues related to the reasons why NFM options are not selected once identified.

Appraisals may only partially cover the full range of costs and benefits

An important factor contributing to the reduced emphasis on NFM is the difficulty in assessing costs and benefits compared to traditional hard engineering. According to one expert interviewed, although it is possible to estimate benefits in the case of infrastructural defences on the basis of the properties directly protected, the benefits associated with NFM are more opaque and complex and may not be immediately apparent. For example, it has taken 15 years for the Pont Bren scheme to deliver current flood risk management benefits. The nature of natural resources costs and benefits such as ecosystem services is such that there is much uncertainty over potential outcomes – such uncertainty can be a barrier when compared to hard infrastructure options, which are able to deliver more certain flood alleviation.

In 2009 4,193 flood management actions were identified (for river and coastal flood risk), many of which will include or solely use NFM. The 2011 update indicates that while 29% of overall projects remain on hold or not started, for those including land management and habitat creation, the proportion on hold or not started increases to 70% (Environment Agency, 2011). According to experts, an important factor is the uncertainty about how the measures will perform and the time required to understand the wider economic benefits of this kind of intervention. However, as illustrated below, there are examples where the small-scale benefits from NFM have resulted in initiatives still being supported.

Example: Assessment of NFM opportunities at Allan Water

A scoping study commissioned by SEPA and conducted by Halcrow and CRESS considered opportunities for NFM in the Allan Water catchment. The modelling indicated for the measures considered (e.g. riparian planting, realignment of channel, tree planting), the actual benefit would be only a 0.5% - 1.6% decrease in flood flows at Bridge of Allan, located at the most downstream point of the catchment. However, a 16 -27% reduction in flood flows could be achieved at a more local scale. In particular the assessment considered four options for which annual damages from flooding were estimated at an average of £105,000 per annum. Damages avoided through different NFM measures varied from £972 to £2,574 per annum. The project considered flooding benefits alongside additional social and environmental benefits using a qualitative methodology. These additional benefits were important considerations in the selection of the final proposed interventions.

Source: Halcrow and CRESS (2011) and ECR interview.

Challenges in assessing co-benefits

The form of appraisal undertaken is important. The ideal appraisal would be able to consider all costs and benefits and be able to present them in a transparent and consistent way. This should cover all economic, social and environmental effects and assess them, as far as possible, using a constant monetary metric to allow comparability over options for the decision-maker; though relying on qualitative measures where this is not possible (for example, multi criteria analysis). It should also note the key drivers of the assessed outcomes and the extent to which they may differ under alternative assumptions. Appraisal methodologies are discussed in greater detail in the ECR Framework for Appraising Flood Defence Initiatives report.

In many cases, **co-benefits are identified but not quantified; it is even rarer for them to be monetised**. However there are some examples where catchment champions have worked to quantify and try to monetise benefits:

- One project in North East England identified the angling industry and estimated that its value was £80m/year, including 500 jobs. These would be enhanced by NFM measures which improve riparian habitats.

- The West Country Rivers Trust, in work on water quality, convinced the local water company to invest £10 million with a business case cost: benefit ratio of 1:10 for investment today and savings related to water quality in the future.

- The assessment of the Holnicote scheme included the implications of sediment moving from fields onto roads during floods in terms of the cost to the District Council of cleaning up, and to farmers of productivity loses due to soil movement.

Furthermore, there are a number of other assessments and interventions which have resulted in benefits of NFM being quantified, such as Pickering (Nisbet *et al.,* 2011) and Belford (Wilkinson *et al.,* 2010)

The risk of not adequately accounting for co-benefits of interventions could be minimised through more strategic involvement of a range of organisations and a requirement for such interdependencies with other policy objectives to be assessed. The increasing involvement of local authorities in flood risk management is thought by some stakeholders to be important in encouraging the consideration of co-benefits.

The complexity of assessing co-benefits is exacerbated by the fact that NFM measures are often implemented as a package, either with other NFM measures or with hard infrastructure options. The interactions and interdependencies across the suite of measures can create issues for an appraisal because the sum of the overall costs and benefits could differ from the sum of the individual components.

Appraisal process requirements associated with funding sources differ

Appraisal processes should ideally be consistent across schemes so that the key drivers and outcomes can be compared, relative to their costs. To facilitate this, the Environment Agency has developed, for example, Flood and Coastal Erosion Risk Management appraisal guidance (Environment Agency, 2010c).

However, there are a range of barriers to ensuring that a consistent, transparent and comprehensive appraisal is undertaken in all cases. These would include the capacity to carry out such studies to appropriate standards for effective decision-making owing to a lack of required data.

Three key factors are important to recognise with NFM measures:

- Many sources of funds have flood alleviation benefits as a co-benefit with the primary objective of the scheme being, for example, improving water quality;

- A wide range of organisations are likely to be involved – various landowners, sponsors, funders etc.; and,

- The sources of funding are likely to be numerous and may require different forms of appraisal.

These factors add complexity to the appraisal process.

The first issue implies that the scheme design may aim to maximise the benefits of improving water quality, for example, as opposed to maximising the benefits associated with flood alleviation. The second means it is less likely that there is a designated organisation to lead a robust and evidence-based appraisal (including having, or having access to, the appropriate range of skills). The third is important because it can affect the process of appraisal undertaken, and the extent to which all costs and benefits (economic, social and environmental) are considered.

As described in the next section, the various grants available may influence the nature of the appraisal undertaken. While the Environment Agency has a detailed and comprehensive appraisal process for assessing flood risk (FCERM), grants received through other channels are subject to different criteria.

For example, the Forestry Commission offers a Woodland Creation Grant. Within this process, Woodland For Water Additional Contributions are available which have eligibility criteria, which go over and above those of the standard Woodland Creation Grant (which include, for example, the need to meet the UK Forestry Standard and associated guidelines: Forestry Commission, EWGS 7). Three features described in the Forestry Commission Guidance for this grant that are of note are:

- If an application meets the relevant criteria, decisions will be made initially on a first come first served basis (Forestry Commission, EWGS 7);
- The application form does not appear to require the assessment of all economic, social and environmental benefits (it focuses on the woodland, grant level applied for etc.); and,
- The Forestry Commission may seek the advice of the Environment Agency on an application for the Woodland for Water Additional Contribution before making a decision. The advice sought would be on the likely benefits of an individual planting proposal (Forestry Commission, EWGS 7).

It is not clear from the guidance that a full and detailed assessment of all costs and all benefits is required owing to the targeted nature of the funding. Therefore, this could introduce the risk that if the proposed intervention is not also seeking funds from, for example, the Environment Agency's Flood Defence Grant in Aid (FDGiA) process (which requires the Environment Agency's detailed FCERM appraisal methodologies to be applied), it may not be assessed in the same transparent and consistent way as other NFM measures. The opportunity might therefore be missed to generate important information that could otherwise be used to build lessons learned or help others. Furthermore, under the recent developments of partnership funding, local authorities and other local stakeholders are responsible for calculating the cost of achieving the outcomes they want; it is not clear how this will be conducted consistently in each location.

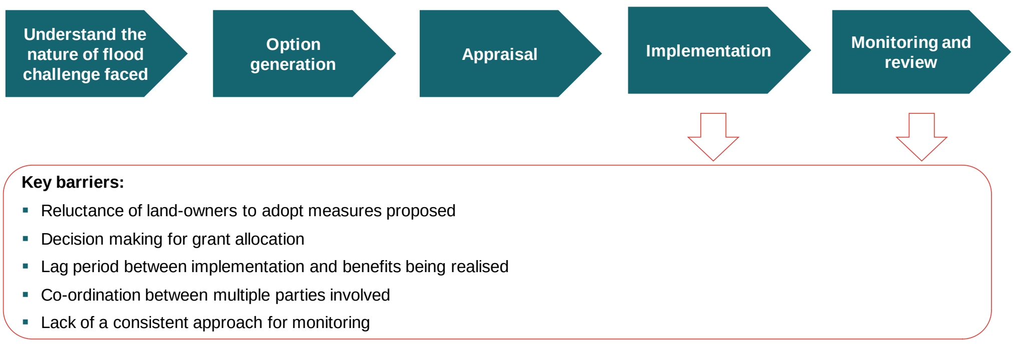
If this is indeed the case, then it could be possible that flood alleviation design may not be maximised, and information on all costs and benefits may not be generated.

For many sources of funding, the monetisation of all benefits is considered critical to secure transparent and consistent decision-making and hence project approval. However, the ability to factor in the full set of costs and benefits is limited where the **organisations and processes used to identify and appraise environmental issues are different**. In particular, organisations responding to the Water Framework Directive and Flood Directive are generally not aligned in their objectives. For example, NFM measures such as creation of woody debris dams can also act as a barrier to migrating fish as well as responding to a flood risk (Forest Research, 2010). This has probably occurred for organizational reasons where there has been a longer track record of addressing pollution than aspects of flood management. However, there is a trend for organisations to close the gap between these different policy areas, such as the use of Area Based Planning for managing river systems in Scotland.

5.3.3 Implementation and monitoring

Implementation includes undertaking the work necessary to deliver a flood risk management plan. It involves securing buy-in from key stakeholders to translate plans into action. It also includes resolving deviations from original plans, and integrating new and existing measures into the overall programme. The key issues associated with the implementation and monitoring are shown in **Figure 7**.

Figure 7. Barriers associated with implementation and monitoring



Source: Based on published information as cited or stakeholders interviewed for this report

There are five types of issues related to the reasons why NFM options are not implemented and monitoring effectively.

Reluctance of land-owners to adopt the measures proposed

This reluctance among land-owners can be linked to a number of separate barriers:

Agricultural land has a strong tendency to cause run-off and is therefore often a priority in NFM schemes. However, there is a continued increase in farming profit margins (Crew, 2012) and with expected increases in returns over the long-term due to food security issues, land is likely to retain its value for production. This view is backed up by surveys, which have indicated that over 50% of farmers considered their land to be too valuable for NFM (Postnote, 2012).

Returns from different land-uses

The Scotland Rural Development Programme (SRDP) could yield payment for management of flood plains at £39/ha/annum for 5 years and management of wetlands at £226/ha/annum also for 5 years; this compares with gross margins of £431/ha (spring barley), £808/ha (winter oats), £436/ha (spring oilseed rape) in 2010/11. From interviews, returns from grazing in uplands can be £2-300/hectare.

Source: Crew, 2012; interviews for this study.

Relative returns available are a key driver of land-owner behaviour. There is no incentive for land-owners to change the use of their land unless the return from doing so is at least as great as would otherwise be achievable from, for example, agricultural production. Beyond the direct support for flood defence, a common source of support draws on the agri-environment schemes – High Level Scheme (England), Scottish Rural Development Programme, Glastir (Wales). Other sources can include: carbon credits, wind farm developers/quarry companies, water companies and others. **Table 8** presents an illustrative list of some of the key grants available to fund NFM measures.

Table 8. Potential sources of funding for NFM measures

Source of fund	Eligibility	Award requirements	Illustrative value
Environment Agency: Flood Defence Grant in Aid	All types of project.	Alignment with FCERM appraisal. Current approach to partnership funding has emphasis on metrics related to houses protected but does recognise NFM.	Large sums available – about £2.1 billion over 4 years. Where wider benefits such as ecosystem benefits are delivered, 5.56 pence per £1 is paid.
SEPA Water Environment Restoration Fund		Must contribute towards achieving WFD objectives. (NFM only benefits if it is a secondary benefit after WFD).	Total fund value of £1million.
Scottish Rural Development Programme (currently under reform	Landowners (and organisations such as public sector and charities).	Meet criteria laid out in SRDP and local priorities set by Regional Project Assessment Committees. It is possible to apply for capital money to implement work and payment for acres of land lost.	Typically 70% for woodland creation.
Rural Development Programme for England (Higher Level Scheme, Entry Level Scheme)	Farmers and land-owners.	ELS: Implementation of specified management options. HLS: 10-year tailored agreements of high environmental value involving complex and specialised land management.	Entry Level Stewardship: flat rate payment of £30 per hectare, per year.
Glastir (Wales)	Farmers and land owners in Wales	Requirements vary depending on scheme applied to by farmers and land-owners	Entrants to the scheme will receive a flat rate of £28 per hectare In addition, entrants to Whole Farm Code will receive £15 per hectare for the first 20 hectares, £8 per hectare for the next 30 hectares and £2.75 per hectare for the next 50 hectares
Forestry Commission	Land-owners	In England, the Woodland Creation Grant is a capital grant that covers the cost of implementing new woodland. 80% on completion and 20% 5 years later. All schemes	For the capital grant, they are not able to fund more than 80% of the total cost of the investment. Woodland for Water Additional Contribution could be paid if

		must meet the UK Forestry Standard.	eligibility criteria are met – in particular, the area of the intervention is highlighted in the maps of potential opportunities.
Local authority capital funding	Local authority projects.	As specified by local authorities. Specific requirements for Community Infrastructure Levy, Rates supplements. Local authorities in Scotland can fund NFM measures if presented in a flood risk management plan.	Variable (e.g. Gloucestershire increased tax by 1.1% pa (£2.3m pa) (e.g. Woking Borough Council spent £7.4m on regeneration project; FDGiA contributed £3.7m)
Heritage Lottery Fund	Large charitable organisations, partnerships, etc.	Meet conservation of heritage requirements (and include learning).	£50,000 - £2 million depending on fund.
Water abstractors in catchment	Alignment to corporate objectives of abstractor (informed by price review).	At discretion of company Tends to be used for managing increased surface water drainage capacity and combined sewers.	
Private beneficiary investment	Any party – but needs to be able to establish and agree legal agreements.	At discretion of company or specified by planning requirements for developers.	Potential for multi million pound contributions.

Sources: Halcrow and Cress (2012), SmithsGore, (2012), Environment Agency (2010), Forestry Commission (EGWS 7)

There are several further reasons why farming businesses may not be interested in implementing NFM measures. These include:

- In some cases, where farms provide water storage, **financial provision is not provided for income forgone** during and after periods of inundation (Crew, 2012).
- The **fall in (perceived) capital value of the land** can be a major barrier in some cases (e.g. Eddleston catchment: Crew, 2012).
- NFM measures can affect the **economies of scale** in a farm (by reducing the amount of land that is used for crop production), which impacts on the viability of the business.

- **Compensation for lost-production** can also be an area of concern. In the case of Allan Water, farmers have referred to the negative experience of land-owners in obtaining compensation following major infrastructure projects (e.g. Beauly-Denny transmission lines) (Halcrow and Cress, 2011).

The extent to which these issues are important to farmers and land managers will vary according to farm business and location: some operate with very tight margins and cannot afford to lose land, others may have unproductive land or waste-land.

While the above discussion focuses on incentives, there may be instances where land managers are required to maintain assets or features to avoid increasing flood risk. Stakeholders were not clear as to how a natural feature could be designated but indicated this could occur under the 2010 Water and Flood Management Act.

The following boxes describe two examples in which the barriers to NFM from farmers' perceptions that they will not be able to realise an adequate return have been identified.

Example: Holnicote – factors influencing attitudes to NFM

Of the potential measures which were initially modelled, possibly less than a half have been actually implemented.

A key underlying reason is considered to be the difficulty in convincing farmers of the case, especially when they already receive payment from agri-environment schemes. There were also specific barriers to particular measures:

- In the case of changing farming practices (e.g. arable soil management), the survey on farms showed 17% of soils heavily degraded. However, there was resistance from some farmers to the advice given on soil management improvement.
- With respect to woodland creation, farmers were often reluctant to turn farmland to tree plantations due to the opportunity cost. In the uplands, where farmers have grazing rights, there is a concern that payments can go down.

Source: ECR Interviews

Example: Tweed – factors influencing attitudes to NFM

From the experience of extensive engagement across the Tweed Catchment, there are a number of factors that result in uptake of measures:

- If measures are taken between adjacent farms, the visibility of benefits is clearer.
- Events can make a difference: In one catchment, Beaumont, there have been two 1:100 flood events in two years. As a result, the community is more attuned to potential impacts and more inclined to adopt measures to alleviate them.
- In some of the headwaters, there is more marginal land, which can be proposed for NFM without adversely affecting farming businesses.

Source: ECR Interviews.

Decision making for grant allocation

Even under a situation where a land-manager is interested in implementing NFM measures, the process of securing a grant can act as a barrier. In particular, there is:

- Uncertainty about the **long-term duration of grants**. In particular, funding streams need to compete with a dynamic and fluctuating market for land (which even at its lowest level is still likely to be higher than the level of support provided from grants). Farmers will look at opportunity cost beyond the duration of a grant.
- Lack of a simple, well-structured funding stream for farmers. In Allan Water for example, it was felt that "promoting the Scottish Rural Development Programme as a mechanism to fund projects is likely to discourage farmers as many consider the application process to be complex and unreliable" (Halcrow and Cress, 2011).
- Given overall funding constraints on the pot available for grant making, decision-making on a case by case basis could result in the highest return interventions not receiving funding if they come later in the financial year.

Lag period between implementation and benefits being realised

There can be a long lag-period between implementation of NFM measures and benefits being realised. In response to this, some experts interviewed for this study referred to projects containing multiple works (i.e. immediate hard engineering and re-alignment as well as longer term NFM measures). As a result, communities and land-owners can see benefits quickly and as a result are more supportive.

Co-ordination across multiple parties involved

Interviews with practitioners and funders of NFM measures identified the number of parties involved with schemes that cross landownership boundaries and deliver multiple co-benefits, can be a barrier. This is for several reasons:

- Accountability and risk allocation may not be clear – if something goes wrong, there may be a lack of clarity over responsibility to find a remedy if there are many parties involved;
- Discussion and negotiations involving multiple parties can be both time and resource intensive; and,
- A greater number of parties involved could make the process of delivery less certain because if one party were to back out, it is not clear that remaining partners would be strong enough to manage. This is particularly the case in the recent move towards partnership funding, where national flood defence funding in FCERM partnerships is closely aligned to priorities set by local authorities, in consultation with communities or local flood action groups.

To overcome this barrier, **someone locally based and with the drive to push the initiative forward** could take the lead. In several case-studies, such as Pont Bren, experts interviewed noted that being able to share positive experiences of (neighbouring) farmers is a key enabler. Conversely, as agencies such as the Environment Agency, Natural England and/or SEPA are seen as regulators, land owners/ managers can often be hesitant to engage with them. The example of the Tweed Forum illustrates the importance of this.

Example: Tweed Forum and engagement

EA and SEPA have regulatory responsibilities (including permitting and, taking action against farmers where terms of permits are breeched). As a result, some land managers may be reluctant to engage with them. There is a perception that many of the larger nationally-based organizations do not focus on the most pressing issues of concern to farmers and their businesses.

The Tweed Forum is an NGO and comprises a broad membership of organisations and individuals all with an interest in the sustainable management of the Tweed catchment. Its membership includes both statutory and non-statutory bodies, local stakeholder groups, the private sector and environmental NGOs.

It works to promote the sustainable use of the whole of the Tweed catchment through holistic and integrated management and planning. As a small organisation it is considered to be "light on its feet" and "can get work done quickly". The forum works with farm managers and land managers to get things done and to ensure that appropriate measures are taken at the right scale. The forum is proactive, finding suitable schemes and then finding which farmers are interested in being involved. As an NGO, they work directly with land-owners and farmers, relying on good will and persuasion. They try and get good levels of income for farmers – and show how interventions can improve resilience.

Source: ECR interviews

Lack of a consistent approach for monitoring

A major gap identified in several of the case studies is the sufficient level of monitoring to determine the 'signature' or effect of specific interventions. This is necessary to allow an understanding of the role of natural flood management.

Several experts mentioned that the key to understanding this signature is allowing sufficient time for determining baseline hydrometry. This process itself can include two to three years monitoring, with data gathered at a fine time-scale (every 15 minutes) and telemetry for data collection. For a project such as Holnicote (SW England) operating over 5000 ha area, 20% of the £500,000 project was allocated to monitoring.

5.3 Implications for uptake

The previous section discussed a range of issues across the decision-making process. A range of issues can be identified that are common to several projects and form the most significant barriers which are likely to point to a case for intervention to facilitate NFM measures where they are a viable option. The framework used to identify common barriers is:

- **Behavioural barriers**: including inertia, 'short-sightedness'
- **Market failures**: those relating to pricing signals; externalities[10]; ownership of risk and assets which lead to misaligned incentives, and where information may not be timely, accurate, relevant or is incomplete;
- **Policy**: the framework of regulation and policy mechanisms (grants, subsidies, funding, etc.);
- **Governance**: institutional decision-making processes.

It should be noted that this study does not comment on the viability or otherwise of particular case studies; that is beyond the scope of this work. Whether a scheme is worth taking forward should always be assessed using appropriately detailed case-specific analysis of all costs and benefits. The barriers to the consideration of NFM measures where they may be effective are discussed below.

Behavioural

The **reluctance of land owners to adopt measures proposed by external parties** is often mentioned by stakeholders. While it is highlighted in many case studies, it is very specific to the land-ownership patterns within a catchment. Also, it affects some measures more than others – interventions in flood plains or areas which have experienced more flooding in the past have tended to experience less opposition to NFM than others.

The **extent to which staff in agencies and other organisations consider NFM alongside hard engineering depends on the culture and experience of those involved**. There are several NFM mechanisms which will be less familiar; these include those which are more distributed or diffuse (such as land management practices), or those with an ecosystem function which is not clearly understood (e.g. riparian planting).

> **Hypothesis 1**
>
> Traditional hard infrastructure options are likely to be considered ahead of NFM measures because they are better understood – intervention to encourage their consideration should be explored.

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[10] Where there are costs or benefits imposed on others that are not accounted for in individual decision-making.

Market failures

Several forms of market failure have been identified:

- **Externalities:**
  - **NFM measures are in most cases likely to deliver benefits to the wider society or community that exceed the private benefits** that can be realised by land-owners. Although grants address this in part, the level of grants can in many cases be too low or limited. In addition, the profile of funding available is often unlikely to match the costs and benefits associated with the implementation of an intervention. For example, the opportunity costs associated with land-use change are a permanent cost incurred by a land-owner but grants tend to be time limited. This can lead to under-investment in such interventions.
  - Given the multiple objectives that NFM measures are often able to target, it is rare for them to be considered as the sole flood defence measure. Rather, their **value comes in their ability to provide flood defence benefits, alongside other services which have an external (or wider) value to society (such as climate regulation through carbon sequestration or water purification, for example**). Flood defence grant requirements may not therefore fully recognise the package of benefits with equal weight. For example, the Environment Agency Flood defence Grant in Aid offers grants on the basis of households protected from flooding. This is, of course, a key consideration, but the returns available for the wider benefits are only funded up to the value of £0.056 per £1 of assessed wider benefit. Funding from this particular grant may therefore not be provided in many cases, meaning that wider benefits to society could be missed. This could be an issue for interventions where there are few direct beneficiaries (e.g. some land management practices in rural areas),
- **Information** issues arise in various forms:
  - **Uncertainties in the evidence-base** in terms of the costs and benefits that are likely to arise as a result of the implementation of the NFM measure, and how these vary under alternative climate change emissions scenarios (and in turn the risk of flooding) can restrict identification of suitable NFM opportunities. Work is currently underway to address this in part - for example, the work of the Forestry Commission and Environment Agency as part of the CFMPs and the mapping process linked with the eligibility criteria for the Woodland Creation Grant.

- **Awareness of opportunities and dissemination of lessons and results from pilot projects** is seen as a barrier for a range of measures including rural Sustainable Drainage Systems (SuDS), tree planting and land management practices. There are no formal channels for such learning to be distributed widely.

Hypothesis 2:

A lack of consistent and collated information on the effectiveness of such measures means that opportunities to learn and incorporate such measures where they may be appropriate are likely to be missed.

Policy

Funding sources play a crucial role in the extent to which NFM measures will be delivered given the external benefits that such interventions give rise to. The complexity of NFM measures – delivering multiple benefits to meet a wide range of objectives – means that multiple sources of funding are often sought (the Environment Agency, the Forestry Commission, Water Framework Directive etc.). However, **providers of funding streams place different requirements on those leading on the projects in terms of eligibility criteria and the depth of appraisal information required**. This inconsistency could have two implications. Firstly, information on the effectiveness of interventions is not collated in a consistent format to allow learning over time. Secondly, flood defence may not be optimised if eligibility criteria point to the importance of other aspects.

Hypothesis 3

Alternative funding options should be explored to ensure benefits of NFM and co-benefits are secured

Governance

The large numbers of landowners involved means that co-ordination of those parties is likely to be a challenge. This applies particularly to those measures involving engagement with multiple land-owners whose primary consideration is not flood management (e.g. land management practices).

Hypothesis 4

Behavioural and governance issues mean that further intervention to enhance co-ordination across land-owners and interested parties should be considered

These barriers are expanded in the following section to explore the case for intervention. This is supported through discussion of qualitative hypothesis testing.

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6 Case for intervention

Key messages

This section considers actions which could overcome barriers by testing several hypotheses to facilitate NFM option generation, appraisal, implementation and monitoring:

- Hypothesis 1: Consideration of NFM measures alongside others is always standard practice at the beginning of a decision-making process (even if they are dismissed upon consideration).

- Hypothesis 2: Evidence of NFM effectiveness from trials is collated and used to inform the effectiveness of prospective opportunities.

- Hypothesis 3: Sufficient and effective funding is in place to encourage uptake of identified and effective NFM measures.

- Hypothesis 4: Local champions are identified and incentivised.

Recommendations for intervention are provided which are intended to overcome barriers and facilitate NFM to be considered and implemented where it is justified.

While NFM measures may not be viable in all locations, there may still be a case for intervention to facilitate their delivery in some situations. Therefore, the range of barriers affecting the identification, appraisal and implementation of NFM considered earlier are assessed in more detail in this Section by testing hypotheses.

Adaptive management is discussed and explored by offering illustrative adaptation roadmaps. These present a suite of interventions that could be taken over time to increase the degree to which NFM options are considered.

6.2 Exploring interventions to address barriers

This section explores a number of interventions that could address the barriers identified in Section 5. These are explored by qualitatively testing four hypotheses. It is important to note that more detailed analysis would be required to develop accurate estimates of the scale of the effects.

Interventions explored are:

- In relation to Hypothesis 1: Consideration of NFM measures alongside others is always standard practice at the beginning of a decision-making process (even if they are dismissed upon consideration).
- In relation to Hypothesis 2: Evidence of NFM effectiveness from trials is collated and used to inform the effectiveness of prospective opportunities.
- In relation to Hypothesis 3: Sufficient and effective funding is in place to encourage uptake of identified and effective NFM measures.
- In relation to Hypothesis 4: Local champions are identified and incentivised.

For each intervention considered below, the current situation and potential outcome with no intervention is described. The section then discusses what actions could be considered and the underpinning economic analysis required.

6.2.1 Testing hypothesis 1: Consideration of NFM measures alongside others is always standard practice at the beginning of the decision making process

Current situation

Traditional flood management methods, such as hard engineering methods, are widely understood and commonly implemented. It is still common for stakeholders to focus on traditional methods.

Employees in local authorities, agencies and other organisations, who develop and appraise alternative solutions often have greater technical experience with traditional hard engineering methods and will often consider them first before looking at a broader range of measures. For measures, such as tree planting in riparian zones, the full scale of benefits takes some years to achieve; as a result they may not meet immediate targets and risk being de-prioritised.

Communities have an expectation to see a tangible and well-understood flood defence. They have less understanding of NFMs and show less support for them.

Scotland has a regulatory requirement for NFMs to be considered by Local Authorities and SEPA in flood risk management planning. Within England and Wales, it is an option which might (or might not) be considered.

Within some grant schemes, land-owners and farmers can be encouraged to consider options which address flood risk (e.g. HLS in England, Glastir in Wales). However, in many cases, flooding is secondary to other objectives.

Possible outcome with no intervention

Without intervention:

- The potential for NFM measures could be mentioned within CFMPs within England and Wales but specifics may not be further developed.
- NFM measures may not be wholly integrated into other flood risk management methods.

Potential requirements to address barrier

Intervention should aim to:

- Enhance the evidence-base in a consistent and collated way to ensure lessons learned from pilot projects can be clearly articulated and communicated to Local Authorities, practitioners, farming organizations (NFU etc.). This also includes building on best practices through workshops, training sessions, etc.
- Use of a checklist for flood management appraisal, which includes identification of potentially vulnerable areas that have natural flood management opportunities (e.g. SEPA, 2012). This could be supported by gap analysis of where future efforts in NFM need to be targeted.
- Support more local expertise in NFM. This includes developing a wide range of competencies, including NFM project experience, land management and engagement with owners or farmers, underlying science behind NFM, as well as flood risk management more broadly. It also needs to be possible for agencies and others to identify suitable competent bodies to implement NFM measures, analogous to chartered engineers, environmental managers, foresters used in other domains.

The experience of those involved in pilot projects is that prior to their engagement with others, a minority of other catchment managers have an interest in NFM measures beyond a basic consideration of the importance of land management. However, where the above conditions are applied - including many of the case studies considered for this study - a wide range of NFM measures are considered.

Analysis required or trials to test interventions which may address barriers

While there are high level, catchment-scale estimates considering the role of NFM interventions, most benefits are based on local assessments. For example, Holincote and Belford surface water projects provide examples of identifying options in a specific local area. However, this analysis was unable to identify and review the full list of proposed and approved investments held buy the Environment agency and identify which of these were NFM opportunities.

Further analysis is needed at an intermediate scale; this includes action to:

- Identify the cost and benefits associated with current work to support identification of measures (beyond very local scale schemes). This could include, for example, mapping efforts like the Derwent Land Management Project. The current revisions of the Long Term Investment Strategy may be an appropriate forum for testing the cost effectiveness of more regular scoping of NFM options. Furthermore, development of methodologies to assess costs and benefits should address key uncertainties related to the effectiveness and uptake of NFM measures and explicitly consider implications of working at different geographical scales.

- Identify a number of cases where NFM could have been applicable but were not considered fully – this would allow context-specific barriers to be identified from which to learn. This can include comparing levels of NFM option generation in Scotland (where the Flood Risk Management Act requires consideration of NFM) and other catchments in England and Wales. The analysis should also evaluate the consideration of NFM measures at both the strategic level, feeding into CFMPs (including the forthcoming CFMP review) as well as a scheme by scheme basis. This could also include the potential to target NFM measures to ease surface water flooding.

Within this assessment, it would be valuable to undertake research to assess the extent to which efforts to "nudge" decision-makers (i.e. encourage behavioural change without formal requirement), to consider NFM would be effective. This would need to be backed up by an evaluation of specific interventions and the role of key influencers. This latter aspect is important because of the potential burdens on businesses and others in relation to formal regulatory requirements and the need to minimise associated costs.

Further analysis to assess the effectiveness of these approaches should include assessing the synergies (in costs and benefits) of undertaking options collectively.

6.2.2 Testing hypothesis 2: Evidence of NFM effectiveness from trials is collated and used to inform the effectiveness of prospective opportunities.

Current situation

Research reports commissioned by Defra (2005) are widely known in the industry. These state that NFM can be effective in small-scale catchments. However, at a broader catchment scale, the ability to measure effectiveness is limited and so potential impacts remain unknown. Although NFM may be effective, the absence of, or uncertainty around, its effectiveness is interpreted to mean that they are not.

A number of pilot projects, including the Defra Multiple Objective Projects (MOP's) (Pickering 'Slow the Flow', Moors for the Future, Derwent - 'Making Space for Water', National Trust Holnicote 'Source to Sea' Project, amongst others) are measuring results of NFM at a larger scale.

Possible outcome with no intervention

There are a number of possible outcomes if there is no further intervention:

- Experience of case studies are known to some but not formally centralised or translated into a usable form for future projects.
- Initiatives continue to be pilot projects / local initiatives with limited opportunities for scale-up.
- Lack of suitable standards for reporting, with the result that it is difficult to compare results from different projects.

Potential requirements to address barrier

There are a number of actions which would need to be in place to ensure the active collation and dissemination of evidence concerning the effectiveness of NFM initiatives. These include:

- Better monetisation of ecosystem benefits and dis-benefits to improve the accuracy in comparing grey and NFM measures.
- Better assessment of how the split of funding between funding sources targeting different ecosystems benefits impacts the appraisal process.
- Increased funding for the post implementation stages of the project in order to monitor, evaluate and review.

- Better measurement systems for river and surface water flood management, similar to those used in coastal management.

- Having a system for recording these results centrally and translating this information through a decision support mechanism to help inform future projects and funding decisions.

- Building increased consistency between approaches for measurement, including reporting standards to ensure comparability.

- Ensuring sufficient support is provided to establish an adequate baseline prior to interventions being made.

Results from pilot projects indicate that where there is a comprehensive evidence-base, the case-study is more likely to be considered to be transferable by managers based in other catchments.

Analysis required or trials to test actions which may address barriers

In particular, analysis could include:

- Assessing projects which failed under flood-grant approval criteria and identifying whether decisions would have been different if greater evidence was available. This includes reviewing recent projects supported through FDGiA and identifying the extent to which uncertainty around the benefits of NFM measures have accounted for their not progressing. This can be further supported by future strategic assessments of Local Authority approaches to flood response.

- Use data on ecosystem benefits from a range of evidence sources and consider the extent to which benefits transfer could be applied and whether this would have affected the decision. For example, in the assessment of ecosystem services at Holnicote, quantified key benefits from NFM included categories such as recreation (Taylor, 2010).

- Similar to the assessments of ecosystem benefits for NFM measures (e.g. Holnicote and Pickering projects), it would be worthwhile assessing the extent to which the adverse impacts on ecosystems from hard infrastructure options are assessed within appraisals.

- As part of the development of approaches to appraise NFM measures in the context of climate change, it is important to assess applicability of alternative methodologies to address pluvial as well as fluvial flooding.

6.2.3 Testing hypothesis 3: Sufficient and effective funding is in place to encourage uptake of identified and effective NFM measures.

Current situation

Current returns for a given area of farmland depend on land-use: gross margins per annum from crops can be: £431/ha (spring barley), £808/ha (winter oats), £436/ha (spring oilseed rape) in 2010/11. Returns from grazing in uplands can be £200-300/ha. Beyond these returns, farmers also benefit from other support, such as the single farm payment.

Table 8 illustrates the range of funding sources available. For example, a given land manager in Scotland could secure £39/ha/annum for 5 years and management of wetlands at £226/ha/annum for 5 years (SDPE).

Sources of funding from FDGiA are subject to a defined target assessment, which requires defined impacts and certainty levels; these are not often known for NFM measures. This challenge is not assisted by the new partnership requirements influencing funding for flood risk management in England and Wales.

Possible outcome with no intervention

In 2009 4,193 flood management actions were identified (for river and coastal flood risk) in England & Wales. Annex 3 shows the update in 2011, which highlights that 29% of the projects remain on hold or were not started. For those that include land management and habitat creation, the proportion on hold or not started increases to 70%. According to experts, an important factor in these projects not progressing is lack of finance, including co-funding in response to multiple benefits of projects.

Current levels of uptake are restricted to pilot projects where there are additional sources of income (e.g. Belford received £650,000 from the Regional Flood Defence Committee). Additional funding associated with co-benefits have enabled some additional projects to progress. However, at present these tend to be *ad hoc*.

Potential requirements to address barrier

There are a number of interventions which would need to be in place to ensure that potential NFM projects are adequately funded. These include:

- Aligning appraisal systems (for example, with the Water Framework Directive) where feasible, to improve the ability to assess partnership funding. In particular, key issues to consider include:

  - If catchments are already good quality, they may not receive funding; however some opportunities for enhancement could be attractive when considered alongside other benefits.
  - Guidelines for appraisal processes specify strict outcomes to ensure eligibility for funding with a narrow focus on particular benefits. There is little provision for relaxing these to consider advantages of multiple benefits.
  - According to stakeholders, land managers and others applying for multiple grants often do not get clear signals as to whether their grant will be successful. This can limit appetite for attempting to implement multi-benefit projects.

- Ensuring grant schemes are designed to be locally responsive (e.g. one expert noted that it is not possible to apply mechanisms used at Pont Bren 30 miles away in Shropshire).

- Ensure cost-benefit analyses reflect all costs and benefits of the measure. This can include incorporating an ecosystems services assessment approach to ensure that wider environmental benefits (and costs) are consistently and transparently identified and assessed.

- Support mechanisms for farmers and land-owners to capture and store information in one location for multiple funding applications. (e.g. 'myforest' platform to support forest planning – http://sylva.org.uk/myforest). Associated with this, land managers mentioned opportunities for further harmonising different funding sources.

- Investigate the effectiveness of providing funding over the longer term to enable the benefits of more permanent land-use changes to be better aligned to the grant payments. This would include exploring alternative structures of financing based on market mechanisms. These can include land purchase, land purchase and leaseback, and easements/covenants, grants/annual payments as well as economic instruments (Beedell *et al.,* 2011). These are illustrated in **Table 9**.

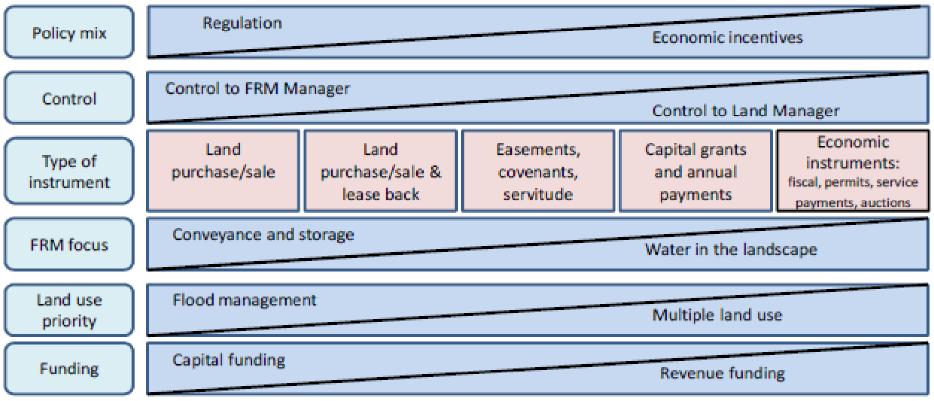
Table 9. Options for financial returns to landowners to reflect flood defence and wider benefits

Option	Description
Easements (for example, Deed of Grant easement)	When a measure is to be implemented by a third party, that party agrees a permanent easement with the landowner. A one-off capital sum is paid to the land-owner and, in return, the third party will take an agreed action on the land in perpetuity.
Wayleave agreements	This is a terminable licence for which a third party pays the land-owner annual compensation or rent for having access to a particular piece of land for a given purpose. Rates would need to be negotiated.
Payment for Ecosystem Services	Market based measures that involve the beneficiary of an action (for example, the community that has reduced flood risk) paying the supplier (land-owner). There are similarities to easements and wayleaves in some cases, differing only by who compensates the land-owner
Community right to buy (as in Scotland)	A community is able to register an interest in land if a land-owner is willing to sell it. For example, if there is a community need or community benefit. This could be explored in the context of flood defence.

Source: National Grid (http://www.nationalgrid.com/uk/LandandDevelopment/LO/ElectricityAgreements/), Scottish Government (http://www.scotland.gov.uk/Topics/farmingrural/Rural/rural-land/right-to-buy/Community), Defra “Payments for Ecosystem Services” (http://www.defra.gov.uk/publications/files/ecosystem-payment-services-pb13658a.pdf)

The role of each depends on the focus of flood risk management, the importance of co-benefits, funding available and the need to control management of measures; this is summarised in **Figure 8**:

Figure 8. Alternative funding structures to grants, and where they may be most appropriate



Source: Bedell *et al.*, 2011

However, it is noted that even if the structure of funding were more flexible to the needs of NFM, many projects may still not be approved, as funding may still be insufficient to cover the opportunity costs.

Beedell *et al.*, (2012) interviewed Scottish farmers and landowners about financing for flood managements actions and found that the overall perception is that the current agri-environment schemes are not ideal for incentivising Flood Risk Management work. *"They could be made more effective and more attractive to both land managers and FRM by making them longer-term and better integrated with instruments suited to FRM services such as sale/leaseback, easements and economic instruments. There is also an opportunity to encourage collaboration across catchments and sub-catchments, and to reward collective action at the landscape rather than individual field or farm scale."*

Analysis required to test actions which may address barriers

- To assess whether alternative funding sources would indeed have enabled projects to go ahead, a sample of those NFM projects from the national programme of flood management measures (All Regional Flood and Coastal Risk Management Programmes 2012/13) which are on hold or not going ahead because of lack of funding could be reviewed to see if any alternative forms of financing would be possible to support the go-ahead of the project.

- A specific area of analysis is a consideration of the implications of recent reductions in flood risk funding by 15% and subsequent focusing of measures to address moving houses from high to low risk bands. In particular, it is important to consider whether the reduction in emphasis of "softer" benefits will reduce overall resilience to longer term flood risk.

6.2.4 Assessing hypothesis 4: Local champions are identified and incentivised.

Current situation

There are a several locally-based organisations or 'champions' working in specific catchments to improve water quality or flood risk management. They bring together a number of partners and help drive action.

Outside the areas where these groups operate, measures are identified through CFMPs (England and Wales) and local FRMPs (Scotland) and implemented by the EA and Local Authorities.

Possible outcome with no intervention

There are a number of possible outcomes if there is no further intervention:

- Where there is active engagement with farmers and land-owners, it is estimated that still only 40-70% of projects identified on paper are actually implemented (based on interviews with managers involved in several of the case studies considered in this report). Where engagement is limited, this level of uptake is much lower due to a number of different factors (e.g. understanding of which areas of land are considered marginal by farmers).
- Effectiveness of measures can be reduced where there is reduced understanding of local land management practices.
- Fewer opportunities to secure funding for co-benefits through the lack of a co-ordinator.

Potential requirements to address barrier

There are a number of actions which would need to be in place to ensure local champions are identified and incentivised. These include supporting independent third parties to:

- Convene multiple stakeholders.
- Engage with local farmers and land-owners.
- Identify, quantify and secure funding for co-benefits.
- Conduct action-research to assess and monitor effectiveness of measures.

In particular, it is important to allow greater flexibility to understand where NFM could fit into a farming business. Several experts have indicated that there are benefits in starting at a local scale and working with farmers to understand their needs (e.g. at Pont Bren, land managers needed to adapt farming systems to enhance production – but benefits also included reduced flood peaks etc.).

Analysis required to test actions which may address barriers

In particular, analysis can include:

- An assessment of the costs and benefits of organisations currently acting as champions, (e.g. Tweed Forum), may identify circumstances where these groups should be supported. Independent champions often have turnovers in the region of £0.5-1 million per year and deliver a wide range of benefits; assessments could conduct appraisals on organisations working at a range of scales to identify where a champion can achieve most benefit.

- The benefits to be considered include assessing the impacts of an organisation with a facilitating and enabling role, seizing additional funding opportunities, identifying co-benefits, filling gaps (encouraging others to take action or taking direct action) and improving flow of information.

- Furthermore, it is important to review the national programmes to assess how many catchments or NFM projects proposed do not have an identifiable champion, and have appropriate characteristics to benefit from a local champion.

This Section has so far tested hypotheses relating to overcoming barriers. The next Section discusses how actions can be taken effectively to manage the impacts of flooding and related uncertainty.

6.3 Managing uncertainty: adaptive management

There is uncertainty over the future impacts of climate change in the UK, particularly how impacts will be felt at a local level, and when. However, this uncertainty should not be taken as a reason for inaction. Decisions must therefore be resilient to a fast changing and uncertain climate (Hall, 2007).

In this analysis, adaptive management is illustrated through adaptation roadmaps as a pragmatic and effective way to facilitate decision-making.

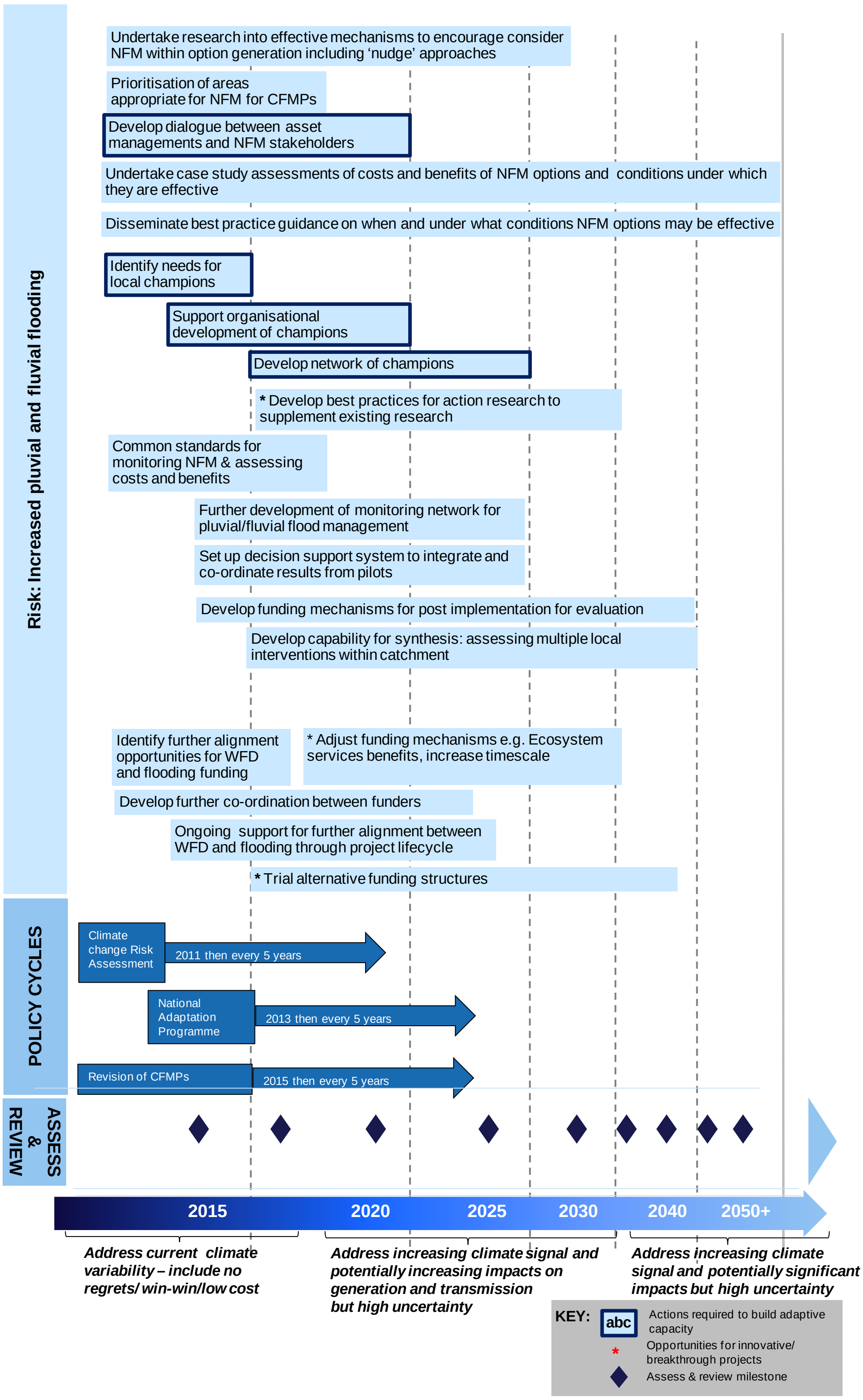
This approach allows flexibility to be incorporated into adaptation measures from the start, where possible, by using measures that are suitable over a broad range of possible future climates or by designing adaptation measures so that they can be adjusted over time (Fankhauser *et al.,* 1999). Flexibility is also incorporated into the overall adaptation strategy by sequencing the adaptation, so that the system adapts to climate over time, whilst options are left open to deal with a range of possible future scenarios. Having chosen a course of action, decisions are made with learning, reviewing and modifying actions as appropriate along the way.

The adaptation roadmap in **Figure 9** is intended to show interventions that can be iterated over time to ensure the potential of NFM can be realised. While the roadmap is focused on the role of NFM, it will need to be embedded in broader adaptation roadmaps responding to flood risk (and including other measures such as hard engineering). Furthermore, given the limited experience and evidence-base on NFM, many of the interventions involve building adaptive capacity in the sector, and improving the ability to evaluate interventions.

The roadmap developed in **Figure 9** is intended to illustrate "packages" of interventions that can be implemented over time. They are based on actions identified through case studies where barriers were overcome. They apply to all the key NFM measures and highlighted actions that were identified in the research as set out in Section 4 and Section 5.

In the long term, the direction of travel for NFM may need to change, and incremental interventions may no longer be appropriate as flood risks increase. Transformational adaptations will then be required: those that are adopted at a much larger scale, that are truly new to a particular region or resource system, and that transform places and shift locations (Kates *et al.,* 2012). Anticipatory transformational adaptation is extremely difficult to implement because of uncertainties about effectiveness of NFM and other measures, as well as climate-related risks. Building adaptive capacity to assess these and consider them as appropriate should form part of the roadmap.

Figure 9: Illustrative adaptation roadmap for NFM



Source: ECR team

The adaptation roadmap incorporates review points, where policy and practice can be assessed and evaluated in the light of new developments, new information and emerging understanding on climate risks and research outputs. The review points are designed to coincide with policy cycles (e.g. of the NAP and CCRA), as well as key stages in the development of CFMPs in England and Wales. These frequent review points will allow pathways to be developed iteratively and with consideration of inter-dependencies and linkages across options.

Underpinning all of these roadmaps is the need to consider the conditions under which actions are likely to be effective. Appropriately mitigating the impacts of climate threats, and making the most of opportunities, requires a range of conditions to be in place, such as the policy framework and other supporting mechanisms.

It is intended that interventions should avoid being maladaptive if climate change progresses at a rate different from expected today, and to review any and all unintended consequences. It should also be recognised that any action chosen should be taken with the engagement of stakeholders and that availability of data to allow progress and emerging outcomes to be monitored and reviewed.

6.4 Recommendations

This analysis has explored the many lines of evidence to assess the case for further action in relation to implementation of NFM measures in response to flood risk. The views of a wide range of experts from universities, agencies, NGOs and other stakeholders have fed into the analysis.

The purpose of this work is to consider if, on the basis of currently available evidence, NFM is adequately considered as an option for flood management, alone or as part of a package.

While there are no specific targets for the level of NFM action that should be taken, this work presents the evidence to consider the implications if barriers to NFM are addressed.

Based on these barriers identified, a number of recommended interventions have been identified.

In order to ensure appropriate **consideration of NFM measures at the option generation stage**, there is a need to:

- **Use a checklist for flood management options to highlight the full range of options available**, along with guidance on when each may be suitable for further analysis. This should facilitate identification of opportunities for use of NFM in areas currently prone to flooding, or where flood risk is projected to increase.

- **Develop and collate evidence on the costs and benefits of actions taken, their effectiveness and the conditions under which they are likely to be effective, and when they are not.** The process of gathering such evidence should be continual as schemes develop in different locations and across different geographical scales.

- **Using existing or enhanced channels of communication, disseminate lessons learned** from pilot projects in a clear and practical way to allow others to identify best practice.

- **Support development of expertise in NFM**, including land management, engagement with land-managers and underlying science.

- **Undertake research to understand the drivers of flood managers' behaviour and identify potential efforts to "nudge" decision-makers to consider NFM as an option**.

To enhance the **appraisal of NFM measures**:

- **Undertake assessments of the ecosystem benefits associated with NFM measures based on previous case studies**. This should draw on a range of appropriate appraisal methodologies, including monetisation and multi-criteria analysis. This should identify both the conditions under which ecosystem benefits are more likely and how they can be maximised, along with associated opportunity costs.

- **Incorporate resources for the ex ante pre-NFM measure baseline and the ex post monitoring and evaluation** into the project planning processes.

To **deliver NFM measures where they are likely to be effective**:

- **Undertake a review of available funding streams and the associated appraisal requirements to identify where better alignment could be achieved** in order to minimise complexity and increase transparency in obtaining partnership funding.

- **Investigate the effectiveness of alternative funding structures** to increase overall longer term resilience.

- **Assess the costs and benefits of organisations currently acting as champions**, to identify circumstances where champions are more likely to be effective.

- **Undertake wider stakeholder engagement (including activities at the community level) to raise awareness of NFM measures** and enhance acceptance where they may be worthwhile.

Annex 1 – Stakeholders

The ECR team is very grateful to the following stakeholders for their time and input to inform this report:

- Vince Carter, Advisor for Climate Change, Forestry Commission
- Luke Comins, Tweed Forum
- Bill Donovan, Flood and Coastal Risk Management, Environment and Climate Change, Environment Agency
- Heather Forbes, Scottish Environment Protection Agency (SEPA)
- Mark Halsham, Moores for the Future, Environment Agency
- Nigel Hester, National Trust
- Mike Keil, Climate Change Adaption Manager, Severn Trent
- Wendy Kenyon, James Hutton Institute
- Paul Lockheart, Leicester catchment manager, Environment Agency
- John Lymer, Upper Derwent Catchment, Environment Agency
- Vikki McCausland, Wetlands and Flood Storage projects in Aire catchment, Environment Agency
- Tom Nisbet, Forestry Commission England
- Tim Pickering, Midland catchments, Environment Agency
- Paul Quinn, University of Newcastle
- Mike Townsend, Woodland Trust
- Mark Wilkinson, James Hutton Institute
- Julian Wright, Environment Agency

Annex 2 – Case Study overview

Annex 2 provides an overview of some of the key case-studies considered in the report. The details are descriptions of location and activities only and largely drawn from project literature and other sources.

Allan Water

The Allan Water is a tributary of the River Forth and has a catchment area of 216km^2. The catchment is predominately upland and includes areas of agricultural land, moorland and forestry. In the lower reaches the river passes through several towns and villages are considered to be at risk from flooding.

For a project led by SEPA, Halcrow and CRESS investigated the factors influencing the implementation of natural flood management in order to develop an NFM strategy for the catchment. The project was overseen by a Steering Group including Forestry Commission Scotland & Forest Research, Perth & Kinross Council, RSPB, Scottish Government, SEPA, SNH, Stirling Council.

The project involved a comprehensive catchment reconnaissance survey as well as meetings with land managers to understand their experiences of past flooding events and preferences for future NFM strategy.

Following this study a catchment restoration strategy was developed and identified priority areas for activities such as land use change, reach restoration and flood plain reconnection for multiple organisations/ individuals.

The project then conducted a detailed option appraisal process to identify most effective NFM measures. Using best practices, the hydrological benefits of 19 options were assessed and for a short list considered the wider, social, environmental and economic benefits. Preferred measures were subsequently selected.

Source: Halcrow and Cress, 2011

Farming and Water for the Future

This is a demonstration project, to show how rural land management can contribute to sustainable flood risk management. Under a program across the Trent catchment Farming and Water for the Future (FWF) delivering a number of fold risk and ecosystem benefits from the management of agricultural land. The EA working with Natural England and OnTrent a voluntary partnership.

The project includes the upper reaches of the Rivers Soar and Sence and some of their key tributaries upstream of Leicester. The main urban areas at risk from flooding include Leicester itself and villages upstream within the catchments. Offering flood risk benefits to the area itself and the City of Leicester downstream.

Source: Interviews

Moors for the Future

This project is one of three Defra Multi-Objective Flood Management Demonstration Projects. The Moors for the Future Partnership was formed in February 2003, supported by a grant from the Heritage Lottery Fund. The partners include Peak District National Park Authority, National Trust, Natural England, United Utilities, Severn Trent Water, Environment Agency, Yorkshire Water, Derbyshire County Council and RSPB.

The partnership has undertaken restoration work on a range of moorland sites in the Peak District and South Pennines including Kinder Scout and Black Hill.

The project has conducted a range of interventions to stabilise the peat and prevent erosion, planting and supporting regeneration of heather.

As part of the work, they have closely assessed impacts on flood risk management.

Source: Moors for the Future Website

The National Trust Holnicote Project

The National Trust-owned Holnicote Estate, West Somerset, covers an area of 5,042ha. It contains a variety of small businesses, tenant farms and residential properties and a diverse array of semi-natural habitats, including ancient woodland, saltmarsh and estuary.

This project is one of three Defra Multi-Objective Flood Management Demonstration Projects. It aims to provide robust catchment scale evidence of the influence of land management change on flood risk.

The project is a partnership between Defra, Environment Agency and National Trust, the project considers the whole catchment and has identified opportunities to change agricultural practices and provide cost-effective support to flood management. At the same time, the project is identifying opportunities to enhance other ecosystem services such as landscape quality, biodiversity, amenity and recreation, making investment in land management change, as a means of approaching flood risk, potentially more beneficial to society at large.

For major interventions, the implications for key ecosystem services has been assessed. The tables below illustrate benefits for a) woodland extension of 35ha, b) grip blocking, c) flood plain planting:

a) Valuation of key ecosystem inputs for increase in woodland by 35ha

Ecosystem good	Qualitative description of impact		Valuation	
Agricultural output for food	0	Changed net margin on agricultural land use	£0	Assumed to be zero as grazing displaced to other areas
Drinking water	+	Avoided costs in water treatment and conveyance infrastructure	£700 - £3.5k pa	Assumes 1% – 3% reduction in annual cost
Equable climate	++	Reduced green house gas emissions arising from carbon sequestration in wood growth	£10.1k - £30.3k pa	Assumes 35ha of new beech/oak woodland, and tCO_2e marginal abatement L and H projected estimates from DECC
Pollution control	+	Improved recreational and aesthetic value of waterways to residents	N/A	Valuation not attempted due to lack of data. Note pollution control improvements to water provisioning are included within Drinking Water value above.
Flood control	+	Avoided damage costs to flood risk properties	£2.7k - £8.2k pa	Assumes additional woodland reduces flood probability by between 6% and 10% from current 1 in 100 year probability. Note that this level would be achieved gradually as the woodland matures
Recreation	+	Additional recreational value to visitors attracted to further walking in extended woodland	£0 pa - £4k pa	Assumes between 0 and 2,000 additional visits per year, with each visit worth approx £2.20. Note this is a gross value not taking into account potential additional costs to provide this land use, but is used as an (incomplete) proxy for economic value

b) Valuation of key ecosystem inputs for blocking grips and drains in 300ha of thin soiled landand improving management of water and soils on 200ha of pasture and grass ley land

Table 4.9: Valuation of key ecosystem impacts for grip blocking

Ecosystem good	Qualitative description of impact		Valuation	
Agricultural output for food	0	Increased net margin on agricultural land use	£0	No net impact assumed
Drinking water	+	Avoided cost in water treatment and conveyance infrastructure	£700 - £3.5k pa	Assumes 1% – 3% reduction in annual cost
Equable climate	+	Reduced green house gas emissions arising from carbon sequestration in new peat and avoided decomposition	N/A	Valuation not attempted due to lack of data for thin peat soils GHG balance (Natural England, 2010b)
Pollution control	+	Improved recreational and aesthetic value of waterways to residents	N/A	Valuation not attempted due to lack of data. Note pollution control improvements to water provisioning are included within Drinking Water value above.
Flood control	+	Avoided damage costs to flood risk properties	£2.7k - £8.2k pa	Assumes grip blocking reduces flood probability by between 6% and 10% from current 1 in 100 year probability
Recreation	0	Reduced visitor numbers arising from reduced access across wet areas vs more interesting wet landscape	£0	No net impact assumed

c) Valuation of key ecosystem inputs for increase in flood meadow by Creatinging 20ha of flood meadow from pasture, greass ley, wetting 7ha of woodland, and applying stream buffer strips across 225ha of farmland.

Ecosystem good	Qual. Impact		Valuation	
Agricultural output for food	-	Decreased total net margin on agricultural land use for beef production	-£100 to -£250 pa	Costs are driven by depth, duration and timing of flooding. Range is for 10 ha improved grassland affected by 750mm flood for <1 week to 1-2 weeks
Drinking water	+	Avoided cost in water treatment and conveyance infrastructure	£900 - £2.8k pa	Assumes 1% – 3% reduction in annual cost
Equable climate	0	Reduced green house gas emissions	£0	Assumed to be zero impact
Pollution control	+	Improved recreational and aesthetic value of waterways to residents	N/A	Valuation not attempted due to lack of data. Note pollution control improvements to water provisioning are included within Drinking Water value above.
Flood control	+	Avoided damage costs to flood risk properties	£3.2k - £12k pa	Assumes flood meadow reduces flood probability by between 7% and 15% from current 1 in 100 year probability
Recreation	+	Additional recreational value to visitors attracted to water meadow and wet woodlands to see waders and other wildlife	£0 pa - £11.6k pa	Assumes between 0 and 2,000 additional visits per year, with each visit worth approx £5.80. Note this is a gross value not taking into account potential additional costs to provide this land use, but is used as an (incomplete) proxy for economic value

Source: National Trust 2011, Taylor (2010)

The Tweed Forum

Tweed Forum is the umbrella organisation dedicated to integrated management of the Tweed and its tributaries. It uses a partnership approach to manage land and water. In particular it focuses on delivering action on the ground, as well as promoting efficient, innovative and cost effective ways for partners to work together.

Multiple actions related to water quality, water resources, riverworks, habitats and species and flood management. They have also been involved in projects such as Eddleston where a detailed hydrometric network has been established to look at effects of NFM.

Belford Burn

The Belford Burn (Northumberland, UK) catchment is a small rural catchment with a catchment area of 6km^2. Normal flood defences are not suitable for this catchment as it failed the EA cost benefit criteria for support. There was a desire by the local EA Flood Levy Team and the Northumbria Regional Flood Defence Committee at the Environment Agency to deliver an alternative catchment-based solution to the problem. Four different types of mitigation feature have been created in the catchment to reduce flood risk whilst also benefiting water quality and ecology. These measures include bunds disconnecting flow pathways, diversion structures in ditches to spill and store high flows, 'Beaver dams' placed within the channel and riparian zone management.

There have been a number of detailed studies assessing effectiveness of interventions. For instance, following a storm in 2008, detailed monitoring data indicated that the pilot feature held runoff for approximately 8ha. The effect that this had on the travel time of the peak was large: it increased from 20 to 35 min.

Source: Wilkinson et al (2010a); Wilkinson et al (2010b)

Slowing the Flow

This project is one of three Defra Multi-Objective Flood Management Demonstration Projects. 'Slowing the Flow at Pickering' in North Yorkshire aimed to consider how changes in land use and land management can help to reduce flood risk. Pickering has a long history of flooding, with the most recent event causing approximately £7 million of damage. Whilst a flood alleviation capital scheme was proposed in recent years, the assessment did not meet national cost-benefit thresholds. A number of measures with their associated impact were conducted as part of the project and are presented in the table below.

Effectiveness of NFM solutions

Action	Detail	Impact
Upland mire restoration	Using bog mosses, blocking drains	Benefit undefined (recommended for small floods)
Land management and land use	Strips of trees (or grassland buffers)	Reduce water height by 29% (for small flood) or 5% (large flood) (in a small ~10km catchment, no evidence of effectiveness in large catchment ~250km)
Woodland creation	Entire catchment planted with conifers Targeted planting along watercourses with wood dams	Reduce water height by 50% (small flood) or 36% large flood (in a small ~10km catchment) Reduce water height by 8-10% (in a ~69km catchment)
Sediment management	Management that reduces sediment supply (planting riverside trees) and allowing river channels to adjust naturally , can help maintain channel capacity.	Impact undefined (recommended for large catchments)
Built water storage	2-3% of land as storage reservoirs	Could reduce flood peaks – benefit undefined
River restoration	Restoring river meanders	Impact undefined
Washlands	Land allowed to flood	Impact undefined

The social and economic benefits of some of the measures were also assessed and are illustrated in the table below:

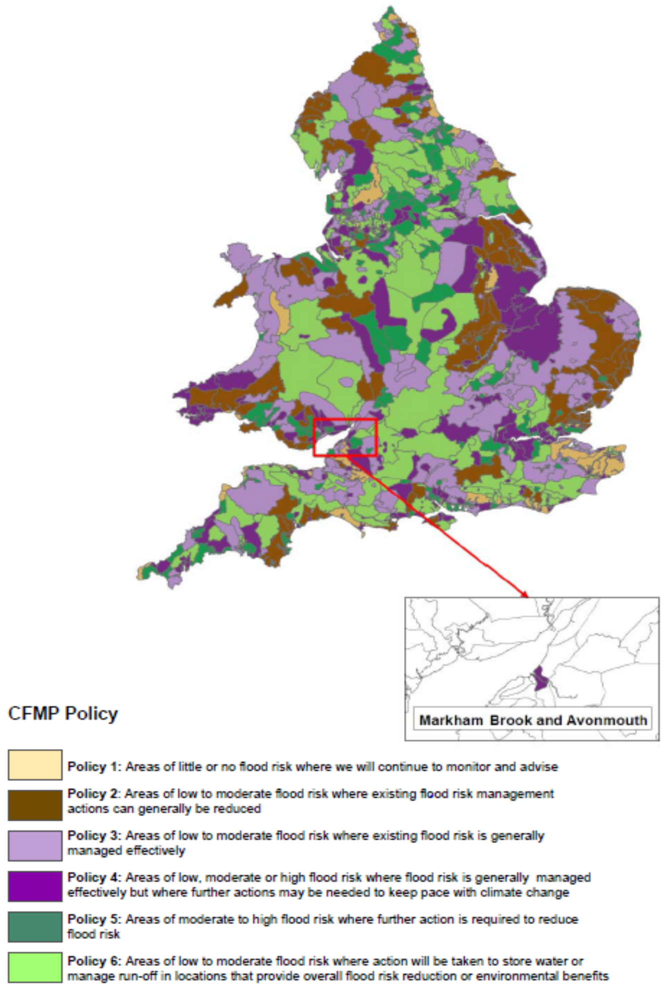
Estimate project valuation on 85ha woodland creation and 150 dams

	Low (£k)	Central (£k)	High (£k)
Flood regulation	88	175	292
Agricultural production	-1,113	-911	-306
Forestry costs	-710	-539	-369
Habitat creation	1,630	2,773	4,459
Climate regulation	923	2,800	5,464
Community development	0	16	62
Erosion regulation	0	5	10
Education and knowledge	0	1	6
Net present value	**819**	**4,321**	**9,618**

Annex 3 - Areas of flood management need identified under CFMPs

Catchment flood management plans were set in 2009 and identified areas where there is a need for flood risk management schemes. Figure 10 shows that there is a greater proportion of England and Wales falling within Policy's 4-6 where further action is required than 1-3 where existing management is generally effective.

Figure 10. Locations of flood management need



Source: CFMP annual report 2011 - Location for major revisions to 2009 CFMPs (Markham Brook and Avonmouth is a revision)

Opportunities for actions within the CFMPs have been categorised into seven themes. Within these themes a large proportion of the schemes are on hold or not started, this is particularly the case where they include land, cultural or environmental management.

Table 10. 2011 updates of the progress of schemes set under the 2009 CFMPs. (These relate to coastal, river, groundwater and surface run-off risks)

Action themes	Number of actions completed, progressing or programmed	Number of actions on hold or not started
Development planning and adaptation	537	124
Actions include those on spatial planning and water cycle studies.		
Land, cultural and environmental management	129	301
Water level management plans, influencing land management and habitat creation.		
Asset management and maintenance	790	103
Asset management plans for grey and green assets		
Studies, assessments and plans	798	384
Further understanding of flood risk issues and identifying the most sustainable approach to managing risk.		
Monitoring	15	3
Monitor and advise in areas where there is little current flood risk.		
High level awareness and engagement	42	21
Effective partnerships rely on sharing a common understanding of risks and aims.		
Flood forecasting, warning and response	671	275
Flood warning service improvements and emergency response.		

Source: CFPMs 2011

Annex 4 NFM co-benefits

An example tested through the Pickering demonstration project identified that the flood risk benefits could be less than the opportunity costs of the land use. However, when considering the additional ecosystem benefits the net present value of the project was estimated to be positive.

As part of the demonstration project, the Wider Program Delivery Group undertook a qualitative assessment by determining the 'likelihood of impact' of the planned land management measures across a full set of ecosystem services. The Group scored the impacts using the recommended UN millennium Ecosystem Assessment (2005) classified scheme which groups services into four main categories: provisioning, regulatory, cultural and supporting services. Figure 11 shows the results of the scoring.

Figure 11. Scores assigned to likelihood of impact of project measures on ecosystem services

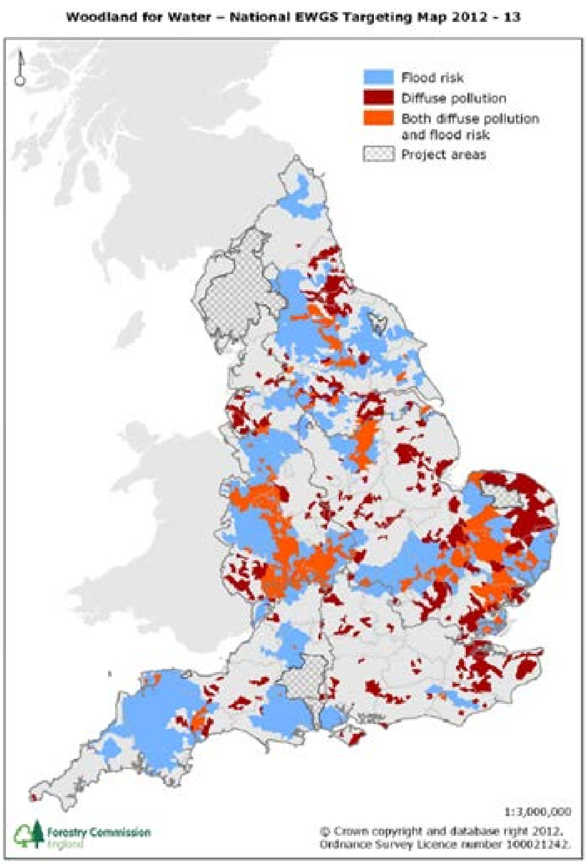
	Bunds	Woodland creation	Stream/drain restoration	Farm Measures	Combined
Provisioning					
Fresh water	0	0	0	+	+
Food	0	-	0	0	-
Fibre & Fuel	0	+	0	0	+
Genetic	0	0	0	0	0
Biochemicals	0	0	0	0	0
Ornamental	0	0	0	0	0
Regulatory					
Air quality	0	+	0	0	+
Climate	(-)	+(+)	+	0	+
Water/flood	++	++	++	++	++
Natural hazard	0	+	0	0	+
Pest	0	0	0	0	0
Disease	0	0	0	0	0
Erosion	++	++	++	++	++
Water quality	+	+	0	++	+
Pollination	0	0	0	0	0
Cultural					
Heritage	0	0	0	0	0
Recreation	++	+	+	+	++
Aesthetic	0	+	+	0	+
Spiritual	0	0	0	0	0
Art/folklore	0	0	0	0	0
Social relat.	++	++	+	+	++
Education	++	++	++	++	++
Supporting					
Soil	0	+	0	+	+
Primary prod.	0	+	0	0	+
Nutrient cycl.	0	0	0	0	0
Water recycl.	0	0	0	0	0
Photosynth.	0	0	0	0	0
Habitat	0	++	+	+	++

Source: Nisbet et al 2011, Pickering Project

Annex 5 Summary of Woodland for Water Additional Contribution Funding

Funding is available from the Forestry commission. The Forestry Commission have identified areas of woodland exposed to flood risk and specified areas within which if woodland is planted which carries water benefits it could be entitled to additional funding. Funding would be provided under New Woodlands for Water additional contribution grant at £2000/ha. To qualify the woodland would need to be planted in the key priority areas highlighted in blue or orange below.

Areas of flood risk identified from CFMPs, these areas are appropriate for obtaining Woodland for Water additional contribution grants



Source: EWGS 7 2012

Annex 6 – Background on UKCP09

UKCP09 projections[11]

The UK Climate Projections (UKCP09) provides projections of climate change for the UK. These projections cover changes in a number of atmospheric variables, using different temporal and spatial averaging. They are given for several future time periods under three future emission scenarios. Climate change over land includes more variables, at a higher resolution, than those over sea.

Projections of the climate variables in UKCP09 methodology are made using multiple climate models. The output of the climate models is used to estimate probabilities, rather than giving single values of possible changes. Probabilities are introduced to treat uncertainties associated with climate projections.

This annex begins with an explanation on the background on uncertainties associated with climate projections. It is followed by a paragraph that explains the UKCP09 methodology and how uncertainties are accounted for. The next paragraph explains how to interpret probabilities in UKCP09 output and the annex ends with a discussion on the limitations of UKCP09.

Background on uncertainties in climate projections

There are three major sources of uncertainties in estimating future climate change:

- Natural Climate Variability;
- Incomplete understanding of Earth System process and the inability to model the climate perfectly; and,
- Uncertainty in future greenhouse gas emissions

The major sources are discussed individually below.

Natural Climate Variability

Natural variability has two principle causes. One arises from natural internal variability which is caused by the chaotic nature of the climate system. Ranging from individual storms, which affect weather, to large scale variability due to interactions between the ocean and the atmosphere (such as El Nino). Climate can also vary due to natural external factors. The main causes are changes in solar radiation and in the amount of aerosols released (small particles) from volcanoes.

[11] This annex is largely based on Murphy et al., 2009 and UKCP09, © UK Climate Projections, 2009.

Representation of Earth's System in Climate Models

The second main source of uncertainty arises due to modelling of the future climate. The only way we can calculate how the climate will change due to human activity is through the use of mathematical models of the earth's climate system. These models are known as Global Climate Models (GCMs). They describe the behaviour of different climate components and interactions between them. The components include the atmosphere, the oceans, the land and the cryosphere. Each interact to produce many types of feedbacks, both positive and negative. The net effect will determine how climate evolves in response to changes in greenhouse gasses.

Uncertainty in models is caused by an incomplete knowledge of the climate system and the inability to model it perfectly. Representations of physical processes within the climate system are based on a mixture of theory, observations and representation. Representations may be limited by physical knowledge, as well as by computing power, and lead to errors, which inevitably cause uncertainty. All modelling groups seek to represent climate processes in the best possible way in their models. This is based on subjective judgement, which causes different strengths of feedbacks in different models. This means that different models give different results, although they all use plausible representations of climate processes.

Future Greenhouse Gas Emissions and SRES

The final source of uncertainty arises due to future emission scenarios of greenhouse gases and aerosols. This will depend on many socio-economic factors such as changes in population, GDP, energy use and energy mix. The Intergovernmental Panel on Climate Change (IPCC) published a Special Report on Emission Scenarios (SRES) (Nakicenovic and Swart, 2000), in which climate-relevant emissions were calculated based on a number of storylines. Each of these storylines describes a possible way of how the world might develop. Differences between them arise due to the different assumptions about future socio-economic changes. They assume no political action to reduce emissions in order to mitigate climate change.

UKCP09 methodology

In UKCP09, uncertainties mentioned above are accounted for when doing climate projections. Uncertainties are treated by generating projections of change as estimated probabilities of different outcomes. This means that probabilities are attached to different climate change outcomes, which provides information on the estimated relative likelihood of different future results.

To do this, UKCP09 assumes that uncertainties manifest themselves in different climate projections from different climate models. Probability distributions of the future climate can then be generated by using projections from a large number of models or variants from a single model.

UKCP09 use a combination of projections from the following models:

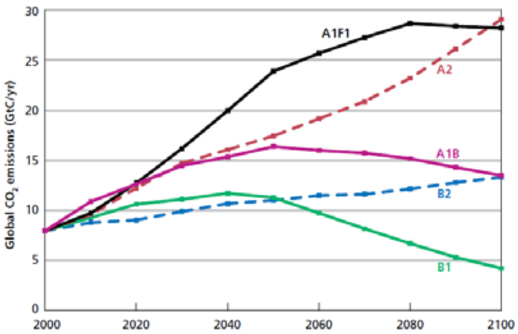
- A very large number of variants of the Meteorological Office Hadley Centre model; and

- 12 international models used in inter-comparison studies of the fourth IPCC report.

Probabilities are based on a large number (ensembles) of climate model simulations, but adjusted according to how well different simulations fit historical climate observations. This is done in order to make them relevant to the real world. By presenting probabilities based on ensembles of climate models, UKCP09 takes into account both modelling uncertainty and uncertainty due to natural variability.

It does not however include uncertainty due to future emissions. Currently there is no accepted method of assigning relative likelihoods to alternative future emissions. UKCP09 therefore presents probabilistic projections of future climate change for 3 future emission scenarios. They are selected from three scenarios developed in SRES and referred to as Low, Medium and High emissions, which corresponds to A1FI, A1B and B1 scenarios in SRES. Figure 1 indicates these scenarios in terms of CO_2 emissions with solid lines (black: High Emissions, purple: Medium Emissions, green: Low Emissions). Each scenario also includes emissions of other greenhouse gases. Although the three UKCIP emission scenarios span the range of marker scenarios in SRES, there are additional scenarios, both higher and lower, that they do not encompass.

Figure 12. Global annual CO_2 emissions under the three IPCC SRES scenarios



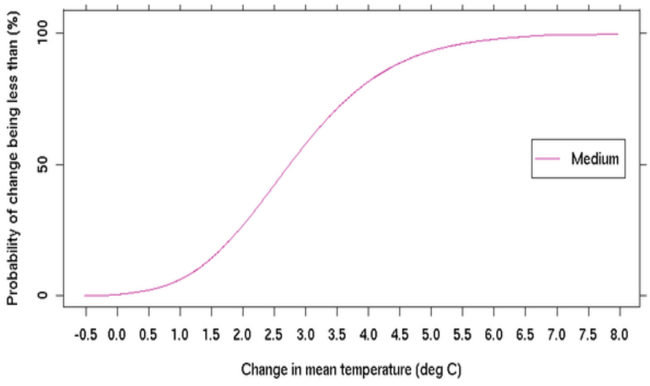
Source: Murphy *et al*., 2009
Note: The dotted lines are two SRES emission scenarios used in previous UK Climate Projections, but not in UKCP09.

Probability in UKCP09

Probabilistic projections assign a probability to different possible climate change outcomes. Probability given in UKCP09 output is seen as the relative degree to which each possible climate outcome is supported by the evidence available. It takes into account the current understanding of climate science and observations.

Probability in UKCP09 does not indicate the absolute value of climate changing by some exact value. Instead it states the probability of climate change being less than or greater than a certain value using the Cumulative Distribution Function (CDF). This is defined as probability of climate change being less than a given amount. An example is given in **Figure 13**. The CDF (for the 2050s mean summer temperatures in the London area, with a medium emission scenario) shows that there is a 10% probability of temperature change being less than 1 degree and 90% probability of temperature change being less than 5 degrees. These statements also work inversely, where one could say there is a 10% probability of temperature change being greater than 5 degrees and a 90% probability of temperature change exceeding 1 degree.

Figure 13. Example of cumulative distribution function for 2050s mean summer temperatures in the London area for the medium emission scenario



Source: UKCP09

The figure above does not say that the temperature rise will be less than 5 degrees in 90% of the future climates, because there will only be one climate. It rather indicates that there is 90% probability (based on data and chosen methodology) that the temperature rise will be less than 5 degrees.

Limitations

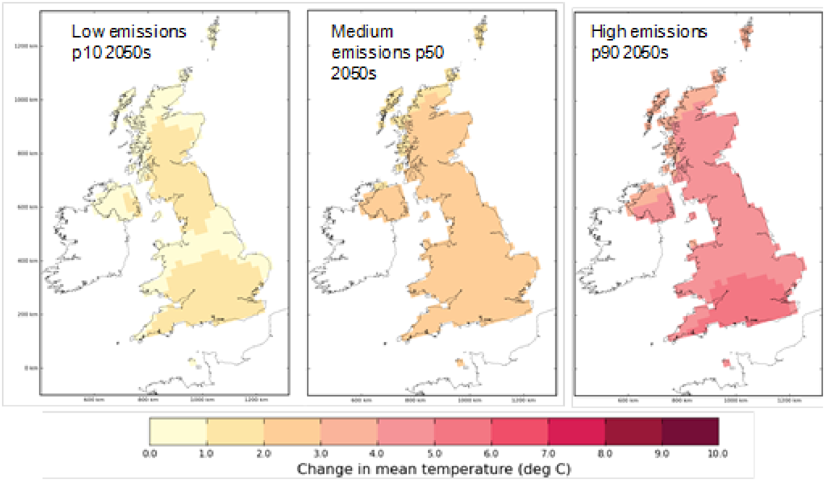
The procedure used in UKCP09 to convert ensembles of climate models into probabilistic estimates of future climate also includes some subjective choices and assumptions. This means that the probabilities themselves are uncertain, because they are dependent on the information used and how the methodology is formulated. Furthermore, the system cannot be verified on a large sample of past cases. Current models are, however, capable of simulating many aspects of global and regional climate with considerable skill. They do capture all major physical and biochemical systems that are known to influence our climate.

Mean summer temperature

Climate projections indicate an increase in summer temperature. By the 2050s, for the central estimate (p50) of the UKCP09 medium emissions scenario, the southern part of England could see temperature rises of between 2.3 ºC and 2.7 ºC (Murphy *et al.,* 2009). However, temperature increases will vary regionally. Parts of northern Scotland could experience temperature increases of around 1.5 ºC for the p50 medium emissions scenario. UK-wide, the projections for increases in mean summer temperatures range from 0.9 ºC under the p10 low emissions scenario, to 5.2 ºC under the p90 high emissions scenario.

The projected changes in mean summer temperature in the UK for the p10 low emission scenario (left), p50 medium emission scenario (middle) and p90 high emission scenario (right) are shown in **Figure 14**.

Figure 14. Projected changes in mean summer temperature



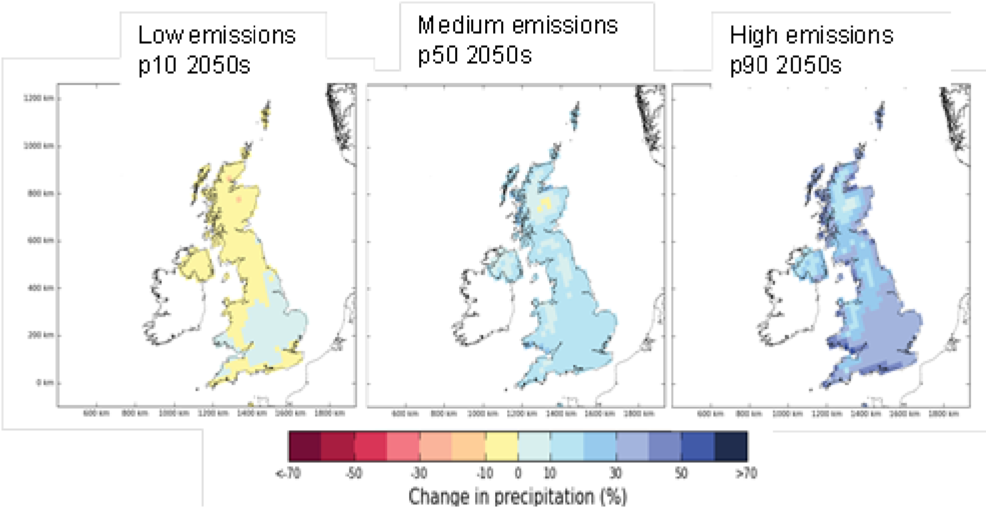
Source: UKCP09

Mean winter precipitation

In the p50 medium emissions scenario, mean winter precipitation is projected to increase by 9 - 17% (depending on location) in the 2050s, relative to the 1961-1990 baseline. The spread in projections is wide however, ranging from -2% for the lower bound of the UKCP09 low emissions scenario in Scotland East to +41% for the upper bound high emissions scenario in South West England (Murphy et al., 2009).

Changes in winter precipitation for the p10 low emission scenario (left), p50 medium emission scenario (middle) and p90 high emission scenario (right) are presented in **Figure 15**.

Figure 15. Projected changes in mean winter precipitation by the 2050s (emissions scenario from left to right: low p10; medium p50; high p90)



Source: UKCP09

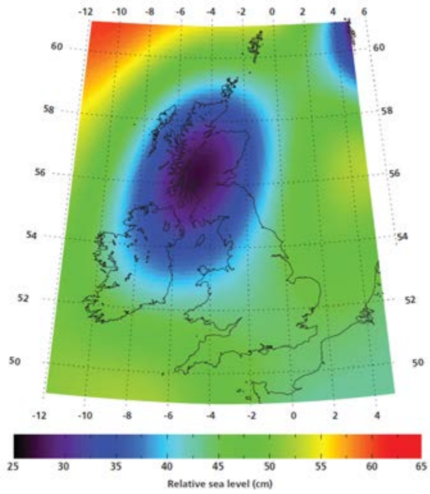
Sea level rise

According to the central estimates of relative sea level changes with respect to 1990s, sea level will rise between 18 and 26 cm between the low and high scenario in London and between 11 and 18cm in Edinburgh (Lowe *et al.,* 2009).

As the earth's crust is moving upward in the northern parts of the UK, relative sea level rise will differ over the regions. The north will be less affected by sea level rise compared to the south (Lowe *et al.,* 2009).

Figure 16 combines the absolute sea level change estimates averaged around the UK for the medium emissions scenario and vertical land movement. Values are shown for 2095 (Lowe *et al.,* 2009).

Figure 16. Relative sea level rise (cm) around the UK for the 21st century



Source: Lowe *et al.*, 2009
Note: This combines the absolute sea level change estimates averaged around the UK for the medium emissions scenario and vertical land movement. Values are shown for 2095

Table 11 displays the sea level rise forecast by the UKCP09 models by 2050, for the central estimates of the emissions scenarios. These estimates are equivalent to a sea level rise of roughly 1.8-4.3 mm per year.

Table 11. Central estimates of relative sea level changes (in cm) by 2050 compared to 1990 levels

	Low	Medium	High
London	18.4	21.8	25.8
Edinburgh	10.5	13.9	18.0

Source: Lowe *et al.*, 2009

Extreme weather events

As the climate warms, weather patterns and the frequency of extreme events may also change (Solomon *et al.*, 2007). Heavy rain days (>25 mm) will likely to be more frequent over most of the lowland UK, central estimates show an increase by a factor of 2 – 3.5 in winter and 1 – 2 in summer by the 2080s under the medium emissions scenario (UKCP09).

The frequency and intensity of heatwaves could increase in future, especially in southern parts of England. The results of the ARCADIA project suggest that by the 2050s, one third of London's summer may exceed the Met Office heatwave temperature threshold (32 °C). (CCRA: Capon and Oakley, 2012; Hall *et al.*, 2009).

The main climate driver for river flooding is increases in river flow arising from increased precipitation.

Figure 17 shows the increases in river flow that have been used in the CCRA (Ramsbottom et al, 2012) by UKCP09 Region (Kay et al, 2010). This data has been used in the CCRA (Ramsbottom et al 2012) to develop **Figure 18** showing increases in river flood frequency.

Figure 17. Increase in river flows

		Percentage increase in peak flow from 1961-90 baseline													
	Projection	2020s			2050s					2080s					
Nation	UKCP09 Region	Medium p10	Medium p50	Medium p90	Low p10	Low p50	Medium p50	High p50	High p90	Low p10	Low p50	Medium p50	High p50	High p90
England	East Midlands (48% Anglain, 47% Humber, 2% Severn, 2% North West, 1% Thames)	0.1%	8.6%	22.1%	0.0%	12.0%	15.2%	17.3%	34.3%	1.7%	17.7%	21.7%	27.4%	54.8%
England	East of England (87% Anglian, 13% Thames)	0.0%	7.0%	22.1%	0.0%	10.7%	14.0%	16.0%	36.4%	0.0%	17.0%	21.1%	28.3%	60.0%
England	London (100% Thames)	0.0%	7.0%	23.0%	0.0%	9.0%	14.0%	16.0%	39.0%	0.0%	17.0%	22.0%	30.0%	60.0%
England	North East (91% Northumbria, 8% Tweed, 1% Solway)	0.3%	10.2%	22.1%	0.0%	12.9%	16.3%	18.8%	36.5%	6.1%	18.3%	21.2%	27.4%	52.2%
England	North West (75% North West, 21% Solway, 2% Dee, 2% Northumbria)	5.0%	14.8%	23.9%	0.0%	13.2%	21.8%	30.5%	41.8%	10.0%	22.8%	26.7%	37.5%	59.5%
England	South East (53% Thames, 42% South East, 4% Anglian, 1% South West)	0.0%	7.1%	23.4%	0.0%	11.7%	15.8%	18.2%	45.2%	0.9%	19.6%	24.6%	33.4%	60.0%
England	South West (73% South West, 19% Severn, 8% Thames)	0.0%	12.0%	24.5%	0.0%	14.5%	19.9%	20.6%	41.2%	5.7%	23.1%	27.7%	36.6%	60.0%
England	West Midlands (71% Severn, 26% Humber, 2% North West,1% Dee)	0.1%	10.1%	22.7%	0.0%	14.4%	17.5%	20.4%	37.2%	3.2%	20.9%	24.2%	31.9%	57.0%
England	Yorkshire and The Humber (95% Humber, 3% North West, 2% Northumbria)	0.2%	10.2%	22.1%	0.0%	13.0%	16.2%	18.4%	32.4%	3.3%	18.2%	22.1%	26.4%	49.4%
Wales	Wales (59% Western Wales, 33% Severn, 8% Dee)	3.0%	13.0%	23.4%	0.0%	14.6%	20.8%	26.8%	39.0%	8.4%	23.5%	27.6%	36.8%	58.7%

Source: CCRA (Ramsbottom et al 2012)

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Figure 18. Change in river flood frequency

Data are shown as annual probabilities of flooding for present day events with annual probabilities of 0.1 (1:10), 0.04 (1:25) 0.02 (1:50) and 0.01 (1:100).

	P10 Return Period				P50 Return Period				P90 Return Period			
Northumbria	10	25	50	100	10	25	50	100	10	25	50	100
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.159	0.071	0.036	0.021	0.244	0.122	0.068	0.039
2050s Med	0.100	0.040	0.020	0.010	0.200	0.095	0.050	0.029	0.321	0.176	0.104	0.063
2080s Med	0.134	0.057	0.029	0.016	0.236	0.117	0.065	0.037	0.378	0.218	0.134	0.085
2080s High	0.159	0.071	0.036	0.021	0.282	0.148	0.085	0.050	0.481	0.303	0.200	0.133
2080s Low	0.134	0.057	0.029	0.016	0.214	0.103	0.056	0.032	0.329	0.182	0.108	0.066
2050s Low	0.100	0.040	0.020	0.010	0.179	0.082	0.043	0.025	0.267	0.151	0.087	0.052
2050s High	0.128	0.054	0.027	0.015	0.216	0.105	0.056	0.033	0.350	0.198	0.119	0.074
Humber												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.159	0.071	0.036	0.021	0.244	0.122	0.068	0.039
2050s Med	0.100	[illegible]	0.020	0.010	0.200	0.095	0.050	0.029	0.298	0.159	0.092	0.055
2080s Med	0.122	0.051	0.026	0.014	0.244	0.122	0.068	0.039	0.378	0.218	0.134	0.085
2080s High	0.159	0.071	0.036	0.021	0.274	0.143	0.081	0.048	0.458	0.283	0.184	0.121
2080s Low	0.116	0.048	0.024	0.013	0.214	0.103	0.056	0.032	0.321	0.176	0.104	0.063
2050s Low	0.100	0.040	0.020	0.010	0.179	0.082	0.043	0.025	0.263	0.135	0.076	0.045
2050s High	0.128	0.054	0.027	0.015	0.215	0.104	0.056	0.032	0.325	0.178	0.106	0.064
Anglian												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.124	0.050	0.025	0.012	0.178	0.075	0.037	0.018
2050s Med	0.100	0.040	0.020	0.010	0.149	0.061	0.030	0.015	0.221	0.092	0.047	0.023
2080s Med	0.100	0.040	0.020	0.010	0.174	0.073	0.036	0.018	0.306	0.129	0.067	0.033
2080s High	0.113	0.046	0.023	0.011	0.200	0.085	0.042	0.021	0.371	0.161	0.084	0.042
2080s Low	0.100	0.040	0.020	0.010	0.159	0.066	0.033	0.016	0.253	0.104	0.054	0.027
2050s Low	0.100	0.040	0.020	0.010	0.139	0.057	0.028	0.014	0.196	0.083	0.041	0.021
2050s High	0.107	0.043	0.021	0.011	0.156	0.065	0.032	0.016	0.243	0.100	0.052	0.026
Thames												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.125	0.051	0.026	0.013	0.186	0.081	0.041	0.021
2050s Med	0.100	0.040	0.020	0.010	0.151	0.064	0.032	0.016	0.244	0.108	0.057	0.029
2080s Med	0.100	0.040	0.020	0.010	0.182	0.079	0.040	0.020	0.325	0.149	0.080	0.041
2080s High	0.117	0.048	0.024	0.012	0.218	0.096	0.050	0.025	0.378	0.178	0.097	0.052
2080s Low	0.100	0.040	0.020	0.010	0.162	0.069	0.035	0.018	0.260	0.116	0.061	0.031
2050s Low	0.100	0.040	0.020	0.010	0.132	0.055	0.027	0.014	0.199	0.088	0.045	0.023
2050s High	0.107	0.043	0.022	0.011	0.158	0.068	0.034	0.017	0.265	0.118	0.063	0.032
South-East												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.125	0.051	0.026	0.013	0.190	0.083	0.042	0.021
2050s Med	0.100	0.040	0.020	0.010	0.166	0.071	0.036	0.018	0.314	0.143	0.077	0.039
2080s Med	0.110	0.045	0.022	0.011	0.207	0.091	0.047	0.024	0.378	0.178	0.097	0.052
2080s High	0.128	0.053	0.027	0.013	0.260	0.116	0.061	0.031	0.378	0.178	0.097	0.052
2080s Low	0.107	0.043	0.022	0.011	0.186	0.081	0.041	0.021	0.357	0.167	0.090	0.047
2050s Low	0.100	0.040	0.020	0.010	0.153	0.065	0.032	0.016	0.271	0.121	0.065	0.033
2050s High	0.114	0.046	0.023	0.012	0.176	0.076	0.038	0.019	0.347	0.161	0.087	0.045
Severn												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.144	0.060	0.030	0.016	0.211	0.093	0.049	0.025
2050s Med	0.100	0.040	0.020	0.010	0.184	0.080	0.040	0.021	0.288	0.133	0.072	0.037
2080s Med	0.121	0.050	0.025	0.013	0.224	0.099	0.052	0.027	0.394	0.196	0.109	0.060
2080s High	0.144	0.060	0.030	0.016	0.281	0.129	0.070	0.036	0.452	0.239	0.137	0.076
2080s Low	0.113	0.046	0.023	0.012	0.205	0.090	0.047	0.024	0.334	0.159	0.087	0.046
2050s Low	0.100	0.040	0.020	0.010	0.167	0.072	0.036	0.019	0.251	0.113	0.060	0.031
2050s High	0.121	0.050	0.025	0.013	0.198	0.087	0.045	0.023	0.315	0.148	0.081	0.042

	P10 Return Period				P50 Return Period				P90 Return Period			
South-West	10	25	50	100	10	25	50	100	10	25	50	100
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.159	0.070	0.037	0.019	0.223	0.105	0.058	0.032
2050s Med	0.113	0.046	0.023	0.012	0.199	0.092	0.050	0.027	0.317	0.161	0.094	0.054
2080s Med	0.135	0.057	0.030	0.015	0.247	0.119	0.067	0.037	0.443	0.251	0.156	0.094
2080s High	0.159	0.070	0.037	0.019	0.304	0.153	0.089	0.050	0.443	0.251	0.156	0.094
2080s Low	0.130	0.055	0.028	0.014	0.217	0.102	0.056	0.030	0.362	0.189	0.114	0.067
2050s Low	0.100	0.040	0.020	0.010	0.167	0.074	0.039	0.021	0.262	0.127	0.072	0.040
2050s High	0.126	0.053	0.027	0.014	0.201	0.093	0.051	0.027	0.332	0.170	0.100	0.058
West Wales												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.126	0.052	0.026	0.014	0.185	0.081	0.043	0.023	0.252	0.115	0.064	0.035
2050s Med	0.154	0.066	0.034	0.018	0.244	0.111	0.061	0.033	0.371	0.182	0.105	0.061
2080s Med	0.178	0.078	0.041	0.022	0.301	0.142	0.080	0.044		0.291	0.175	0.105
2080s High	0.220	0.098	0.054	0.029	0.388	0.193	0.112	0.065		0.326	0.198	0.121
2080s Low	0.166	0.072	0.037	0.020	0.260	0.119	0.066	0.036	0.423	0.217	0.128	0.075
2050s Low	0.100	0.040	0.020	0.010	0.185	0.081	0.043	0.023	0.289	0.135	0.076	0.042
2050s High	0.178	0.078	0.041	0.022	0.310	0.147	0.083	0.046	0.397	0.198	0.116	0.067
Dee												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.100	0.040	0.020	0.010	0.154	0.066	0.034	0.018	0.228	0.102	0.056	0.030
2050s Med	0.100	0.040	0.020	0.010	0.191	0.084	0.045	0.024	0.285	0.133	0.074	0.041
2080s Med	0.131	0.054	0.028	0.014	0.220	0.098	0.054	0.029	0.336	0.162	0.092	0.052
2080s High	0.154	0.066	0.034	0.018	0.260	0.119	0.066	0.036	0.423	0.217	0.128	0.075
2080s Low	0.120	0.049	0.025	0.013	0.205	0.091	0.049	0.026	0.293	0.137	0.077	0.043
2050s Low	0.100	0.040	0.020	0.010	0.157	0.067	0.035	0.018	0.228	0.103	0.056	0.030
2050s High	0.126	0.052	0.026	0.014	0.220	0.098	0.054	0.029	0.353	0.172	0.098	0.056
North-West												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.128	0.053	0.027	0.013	0.193	0.085	0.045	0.023	0.268	0.124	0.068	0.035
2050s Med	0.165	0.071	0.037	0.019	0.250	0.114	0.062	0.032	0.390	0.195	0.112	0.062
2080s Med	0.172	0.075	0.038	0.020	0.295	0.139	0.077	0.040		0.311	0.187	0.108
2080s High	0.216	0.097	0.052	0.027	0.399	0.201	0.116	0.064		0.367	0.228	0.135
2080s Low	0.159	0.068	0.035	0.018	0.259	0.119	0.065	0.034	0.428	0.222	0.129	0.072
2050s Low	0.100	0.040	0.020	0.010	0.181	0.079	0.041	0.021	0.300	0.142	0.078	0.041
2050s High	0.172	0.075	0.038	0.020	0.332	0.160	0.089	0.048	0.438	0.229	0.133	0.074
Solway												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.120	0.051	0.025	0.013	0.152	0.070	0.034	0.017	0.185	0.091	0.046	0.022
2050s Med	0.138	0.061	0.030	0.015	0.178	0.086	0.043	0.021	0.266	0.120	0.065	0.031
2080s Med	0.138	0.061	0.030	0.015	0.197	0.099	0.051	0.024	0.430	0.162	0.094	0.046
2080s High	0.167	0.079	0.039	0.019	0.297	0.128	0.070	0.033		0.191	0.116	0.059
2080s Low	0.138	0.061	0.030	0.015	0.182	0.089	0.045	0.021	0.318	0.134	0.074	0.035
2050s Low	0.100	0.040	0.020	0.010	0.149	0.068	0.033	0.016	0.201	0.101	0.052	0.025
2050s High	0.167	0.079	0.039	0.019	0.228	0.109	0.058	0.027	0.340	0.139	0.078	0.037
Tweed												
1961-90	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010	0.100	0.040	0.020	0.010
2020s Med	0.110	0.045	0.023	0.011	0.141	0.063	0.031	0.015	0.182	0.089	0.045	0.021
2050s Med	0.124	0.053	0.026	0.013	0.167	0.079	0.039	0.019	0.228	0.109	0.058	0.027
2080s Med	0.131	0.057	0.028	0.014	0.182	0.089	0.045	0.021	0.318	0.134	0.074	0.035
2080s High	0.148	0.068	0.033	0.016	0.228	0.109	0.058	0.027	0.475	0.173	0.103	0.051
2080s Low	0.124	0.053	0.026	0.013	0.174	0.084	0.042	0.020	0.257	0.117	0.063	0.030
2050s Low	0.100	0.040	0.020	0.010	0.140	0.062	0.031	0.015	0.184	0.090	0.045	0.022
2050s High	0.135	0.059	0.029	0.014	0.193	0.096	0.049	0.023	0.340	0.139	0.078	0.037

Source: CCRA (Ramsbottom et al, 2012)

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