Scottish Environment Protection Agency

# **Natural Flood** Management Handbook

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**Acknowledgements**

SEPA authors: Heather Forbes, Kathryn Ball and Fiona McLay with valued input from colleagues.

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Front cover image: A remeandered reach of the Eddleston Water, Scottish Waters. Remnants of the original channel can be seen to the left of the reach. This work, which forms part of a suite of measures implemented on the Eddleston Water, aims to reduce flooding in downstream towns and improve the river ecology of the watercourse (© Tweed Forum).

# Contents

## Preface

Climate change, population growth, economics, and environmental legislation such as the Floods Directive and Water Framework Directive all necessitate a move towards a more integrated, catchment based approach to the management of land and water. Working in this way creates efficiencies in how we manage our environment by recognising that many issues in catchments affect many different sectors and that where land and water are managed together at the catchment scale this can bring about whole catchment improvements and multiple benefits to society. A key component of this integrated, catchment based approach is the recognition that working with natural processes to manage the sources and pathways of flood waters can benefit flood risk in other parts of the catchment, including our coastline. This technique, commonly referred to as natural flood management, can help deliver more expansive landscape changes than has previously been the case, while also saving money and delivering other benefits alongside flood protection, thus benefiting the environment, society and the economy.

The purpose of this handbook is to provide a practical guide to the delivery of natural flood management to benefit flooding, while also bringing about many other outcomes. It is informed by a number of demonstration projects and studies commissioned by SEPA and partners in recent years that have highlighted some of the requirements for the effective delivery of natural flood management. The handbook is not static but will be updated and supplemented in the future as additional data becomes available. While the guidance provided is primarily aimed at local authorities tasked with delivery of actions set out in the Flood Risk Management Strategies, it is also intended to be of use to all those seeking to deliver natural flood management.

SEPA, December 2015.

# CHAPTER 1: Introduction

"Natural flood management involves techniques that aim to work with natural hydrological and morphological processes, features and characteristics to manage the sources and pathways of flood waters. These techniques include the restoration, enhancement and alteration of natural features and characteristics, but exclude traditional flood defence engineering that works against or disrupts these natural processes".[1]

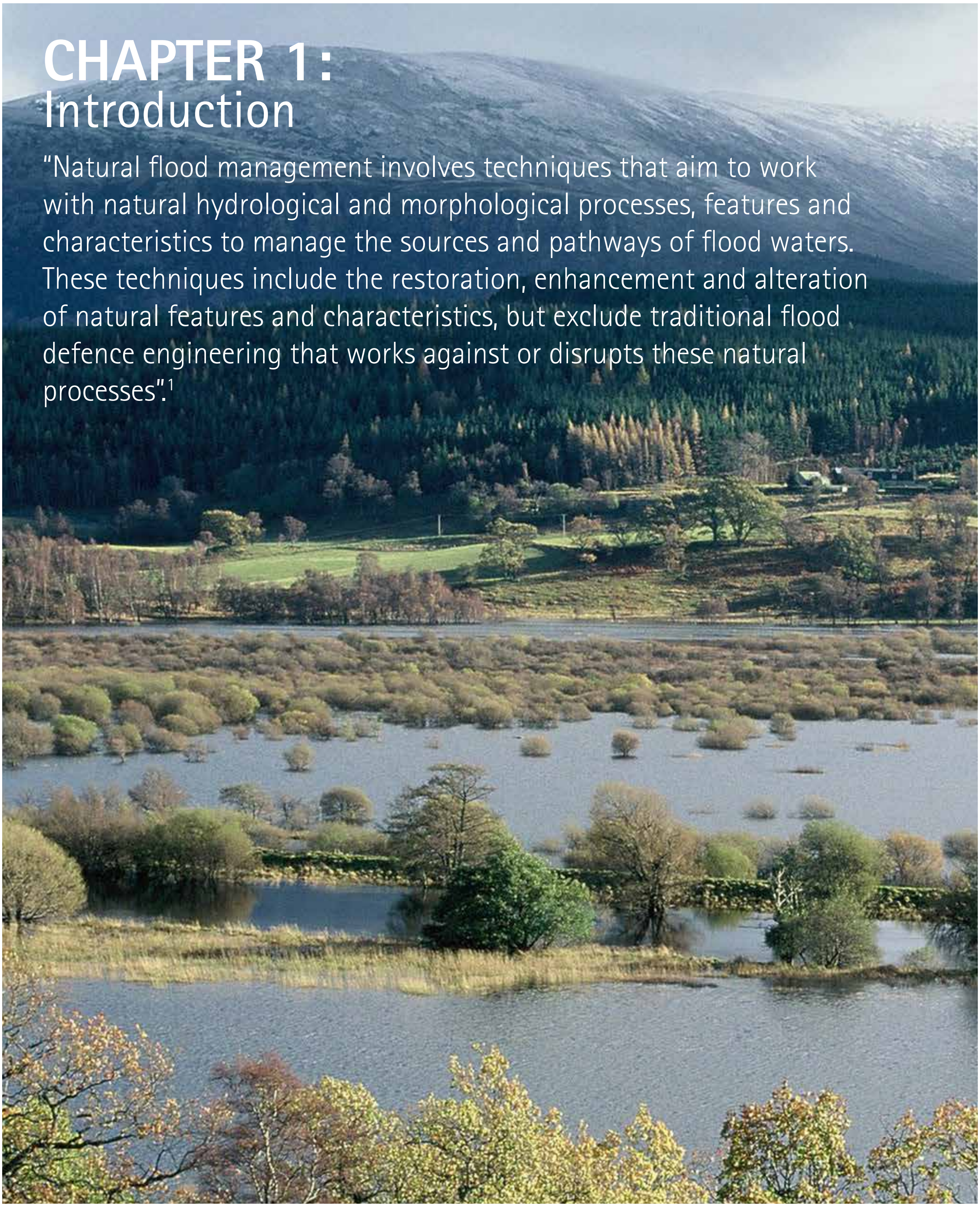


**Figure 1.1. The River Spey and the inundated Insh Marshes, Speyside: The marshes provide extensive wetland habitat and temporary storage of flood waters.**

**Figure 1.2. Approximately 79,000 homes and 29,000 non-residential properties are at risk of flooding in Scotland.**

Projected climate change over the next century is expected to increase the frequency and severity of floods in Scotland. This, coupled with the pressure of population growth, is likely to result in increasing pressure on flood risk management in order to maintain current levels of protection. To continue to focus only on traditional approaches to flood management, such as flood walls, will not be sustainable and therefore our approach to managing flood risk has to change. It needs to be more integrated, managing land and water throughout the river system and recognising that activities in one part of the catchment can influence flooding elsewhere.

This catchment wide approach is commonly based on measures that work with natural features and processes to manage the sources and pathways of flood waters, or what is commonly referred to as natural flood management. Natural flood management typically involves slowing or storing flood water (Figure 1.1) and covers a spectrum of techniques from full-scale restoration of the course of a river or intertidal habitat to smaller scale land management measures such as upland drain blocking. In addition to benefits to flooding, these techniques can also often easily incorporate, and contribute to, improvements in biodiversity, water quality, and carbon storage which in turn can improve access to wildlife, health and wellbeing, recreation, and jobs.

Natural flood management involves balancing and integrating the restoration of natural features and processes with existing land uses. It does not therefore involve large scale land set aside but seeks to provide additional protection and climate proofing where defences are vital or already exist. Natural flood management may be used alongside more traditional engineering methods to help reduce, for example, the required height of flood walls or embankments, or to extend their life. This is particularly important in light of projected climate change that suggests what we put in place today may not provide the designed standard of protection in future decades (Figure 1.2).

Where the cost of traditional flood defences cannot be justified, such as where the number of properties at risk is very small, natural flood management might also be the most cost effective way for local communities to address flooding. This will be increasingly relevant as the pressures on local authority funding become greater. Managing flood risk in this way can encourage communities and land managers to come together and seek out solutions that they themselves can deliver. It will not provide protection from large flood events, but can contribute to reductions in flooding during smaller, more frequent events, while simultaneously delivering many other targets.

In Scotland, the framework for delivering a more sustainable approach to flood risk management has been established in legislation under the Flood Risk Management (Scotland) Act 2009 (FRM Act). Under this Act, SEPA is required to work with local authorities and other responsible authorities to identify the most sustainable actions to manage flood risk, including natural flood management. Delivery of actions, including more detailed assessments of the potential for natural flood management to help reduce flood risk, will be the responsibility of local authorities. Successful delivery will require a clear understanding of the scope of natural flood management, what it can achieve, and the elements involved in facilitating delivery on the ground.

The purpose of this handbook is to provide those responsible for delivering natural flood management with the necessary information to achieve its targeted delivery. It highlights the different types of measures that may be adopted (Chapters 2 and 3) and the multiple benefits of these measures (Chapter 4). The tools available to help identify and assess the benefits of natural flood management are provided (Chapter 5) together with an overview of the process of implementing natural flood management projects (Chapter 6), project management approaches (Chapter 7), funding and compensation (Chapter 8), and monitoring (Chapter 9). Some successful case studies are provided at the end of the handbook (Chapter 10).

# CHAPTER 2:
## River and catchment based natural flood management

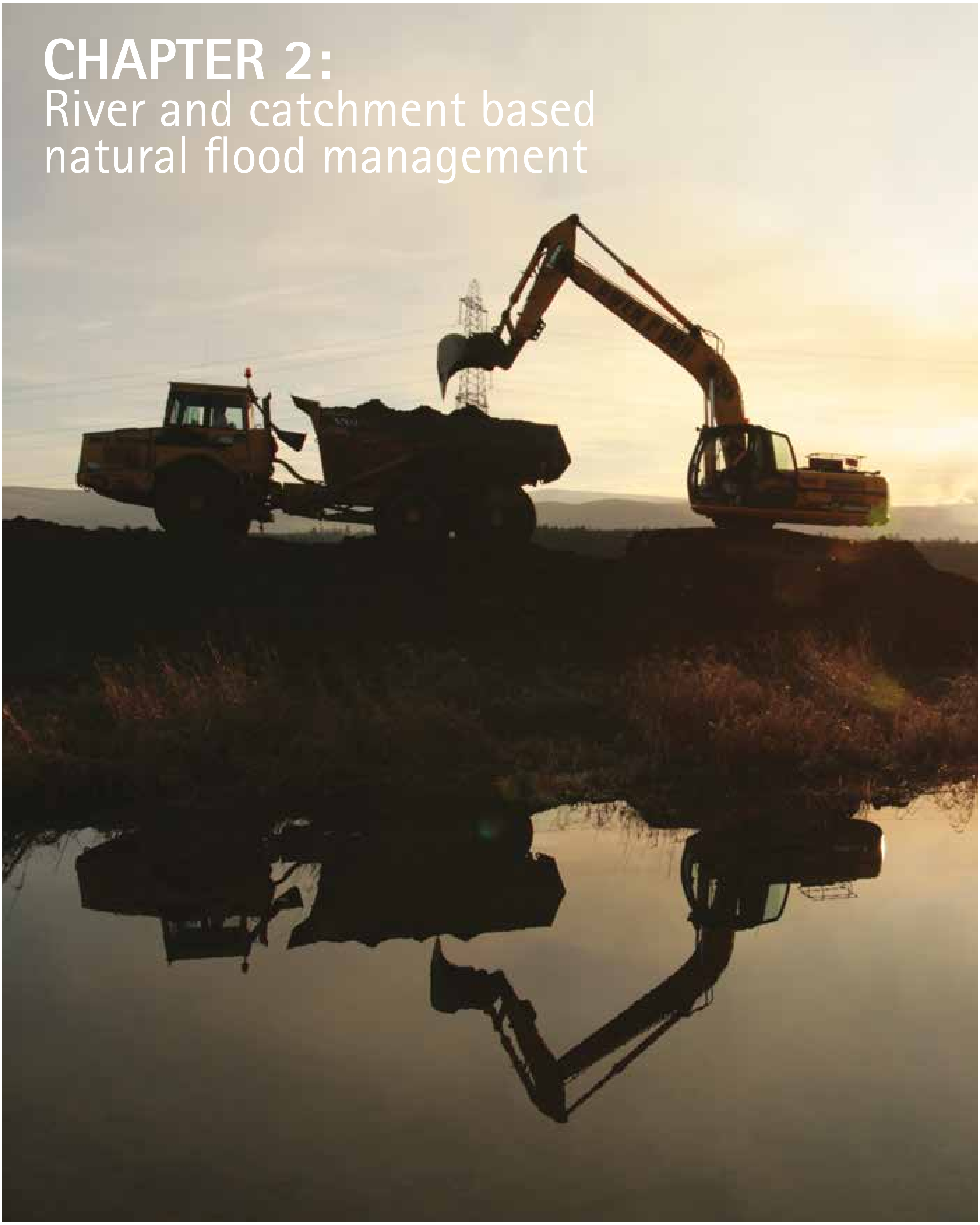


**Figure 2.1. Removing flood embankments to provide greater floodplain storage on the River Till, Northumberland (© Tweed Forum).**

The demands of a growing population have led to land management activities that have impacted the natural ability of the landscape to manage water. Much of the concept and the approach to river and catchment based natural flood management comes from our understanding of these impacts and how we can redress them. This chapter describes the natural flood management measures within a river catchment that seek to regain the natural ability of the land to store or slow water (i.e. to manage the source of flood waters) and of rivers to manage the pathway of water in order to help minimise the impact of flooding on people, homes and businesses (Figure 2.1).

**Figure 2.2. Flooding on the Allan Water, Stirlingshire in 2006: Large areas of the floodplain were flooded despite the presence of embankments, affecting homes and businesses.**

River flooding (Figure 2.2) is a natural phenomenon that occurs when a river cannot contain the volume of water reaching the river. It is an important process and fundamental to the ecology of floodplains and wetlands and the development of river features. Ever-increasing use of the floodplain for development and food production has impacted the natural functioning of rivers and led to increased management intervention to reduce flooding.

The way we have managed the land to meet the needs of a growing population has also increased the likelihood and severity of flooding by impacting the natural ability of the landscape to manage water. Understanding these impacts and how we can redress them underlie much of the concept and the approach to river and catchment based natural flood management. Consequently, to understand why river and catchment based natural flood management (NFM) measures may be appropriate it is necessary to understand the mechanisms that generate river flooding and the effects of land and river management on these mechanisms.

# 2.1. BACKGROUND

## 2.1.1. The water cycle

Understanding flood risk from rivers, and how land and river management can impact this flood risk, is best understood in the context of the constant movement of water between the atmosphere, land surface and subsurface geology (commonly referred to as the hydrological cycle or water cycle).

When precipitation (rain, snow, sleet or hail) hits the ground, this water can take several routes. It may fall directly into the ocean but it may also be intercepted by plants or end up on the land. Where water reaches the land, it may infiltrate into the ground or it may flow as surface runoff into rivers. The rate of infiltration will be dependent on the conditions on the soil surface, soil properties (e.g. soil structure) and soil moisture content[2] and anything that affects these factors such as the presence of vegetation. Water that infiltrates into the ground may also reach rivers via subsurface or groundwater flows.

The water that ultimately collects in the river channel flows to seas and oceans where it is heated by the sun to produce water vapour, thus starting the next cycle. However, the timing and magnitude of the flow of water within rivers on route to the sea will vary markedly both between different river systems and within a river system. These variations result from differences in factors such as the topography, geology, river network and local processes such as the channel slope, width, and roughness (see Box 2.1).

## 2.1.2. The impact of land management on the water cycle

Land management activities, particularly in the last 50 years, have had substantial impacts on the movement of water through the water cycle[3] (Figure 2.4). Deforestation, for example, has had an effect by reducing the extent of interception of precipitation by trees which in turn has increased the amount of precipitation reaching the ground in the first place[4]. Where precipitation does reach the ground, a great variety of land management practices, particularly those associated with agriculture and forestry, has brought about changes to soils that have resulted in reductions in their water-holding and infiltration capacities[5] (Figure 2.3). Intensive grazing, changes in the type and timing of crop production, and the use of heavy farm machinery[6], for example, have increased soil compaction, while deforestation and conversion of grassland to arable land have resulted in a loss of soil organic matter[7]. The loss of topsoil from Scottish soils as a result of the increased soil erosion brought about by increased arable production and activities such as ploughing up and down a slope[8] or the installation of artificial drainage systems has also contributed to reduced rates of infiltration.

Alterations to river channels too, predominantly in order to increase available land, have affected the water cycle by altering river flows. The creation of river embankments in many parts of Scotland, for example, has reduced the lateral connectivity of the river with the floodplain that normally stores and attenuates floodwaters. River channelisation (straightening of the channel) has had a similar effect in many places by increasing the channel slope and reducing the channel length, which in turn increase the rate of flow. Importantly, such activities affect wider river processes, for example, by increasing the transport of sediment downstream, all of which have consequences progressively downstream.

Excessive erosion and deposition of sediment is a particular problem for flood risk management as it reduces the capacity of the river to transport water. Sediment is a natural and important feature of rivers but excessive amounts can enter the watercourse from a number of different routes, including erosion from weakened banks (e.g. as a result of over grazing), or from poor river engineering practices. Land management activities, such as those outlined above, that increase soil erosion can also contribute to sediment laden runoff reaching the river network. Box 2.3 in Section 2.4 provides further discussion on approaches to sediment management.

The combined long-term effect of all of the above activities has been to increase surface runoff generation and reduce the ability of rivers to manage flood waters, which in turn has accentuated flood peaks, resulting in more extreme and damaging flood events[8,9,10].


**Figure 2.3. Good soil structure (left) and compacted soil structure (right): Very little surface runoff is able to infiltrate into the subsoil layers due to the surface crust and compacted soil layers while vegetation is deprived of oxygen due to the compression of pores that normally transport air and water.**

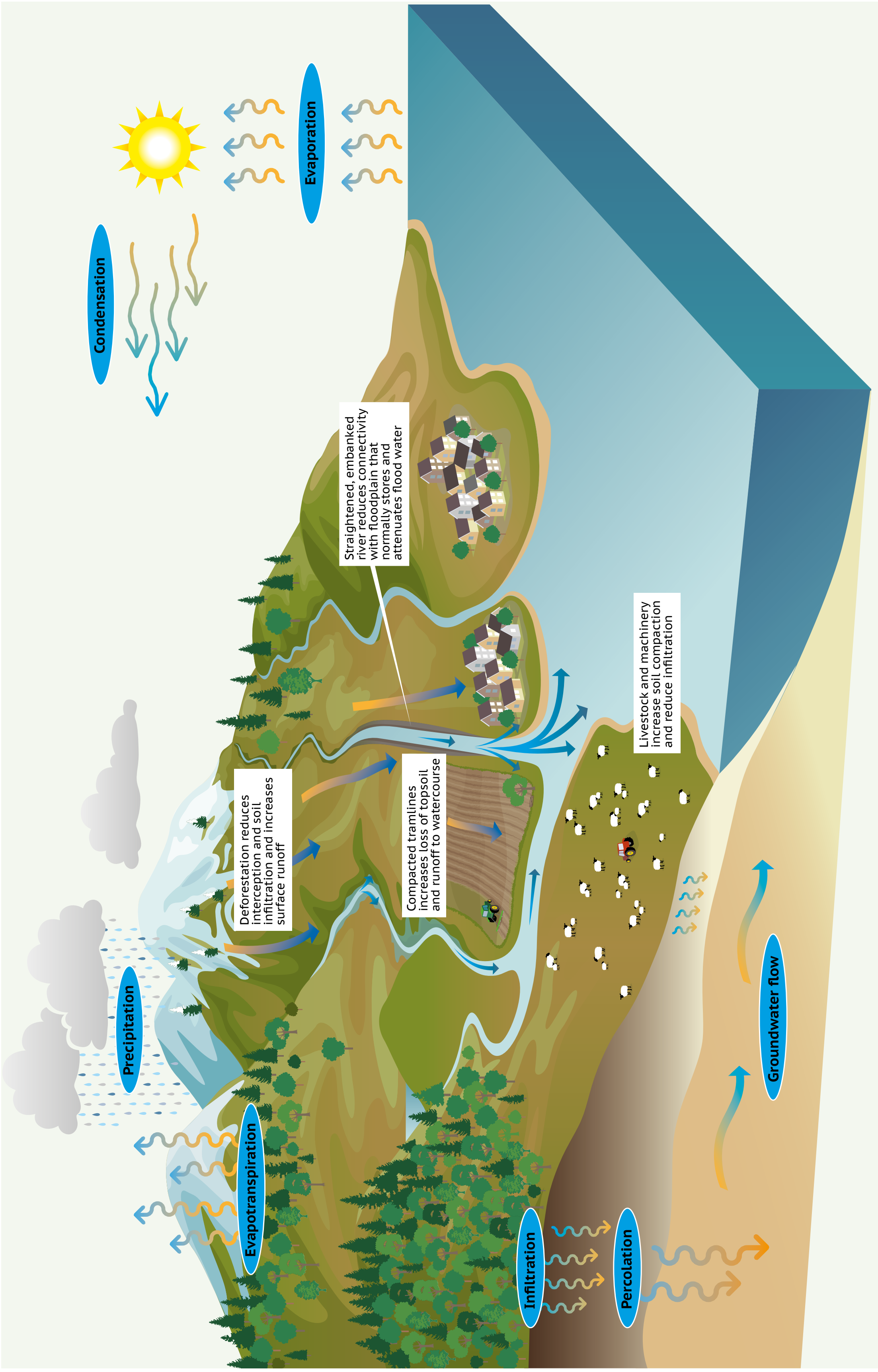



Figure 2.4: The impact of land management on the water cycle.

## 2.1.3. Scottish fluvial flood risk

Scotland has a moist temperate climate with a high average rainfall compared with the rest of the UK. The country has over 6,000 rivers and a total river network length of in excess of 10,000km[11]. High rainfall levels, low levels of evapotranspiration and the predominance of soil types which limit soil infiltration mean that runoff in Scotland is generally high with many catchments exhibiting flashy responses to rainfall, particularly in areas that are steep. This also means that river flows in many of Scotland's rivers are often high relative to the size of the catchment[12].

Flooding within a river catchment occurs when the amount of runoff (surface flow, subsurface flow and/or groundwater flow) reaching the river network exceeds the capacity of the river to convey this water. This typically happens during periods of high rainfall or snowmelt when there is so much water that it cannot infiltrate into the soil quickly enough (infiltration excess runoff), or the soil is already saturated (saturation excess runoff), resulting in ponding of water and/or large amounts of surface runoff reaching the river network.

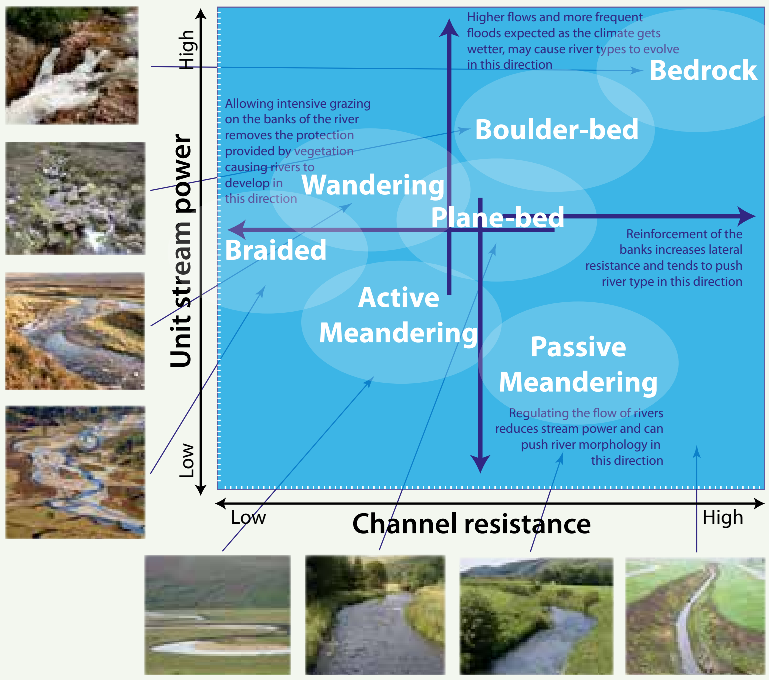
The extent of flooding is dependent on both the height of the flood peak (the maximum height of water levels during an event) as well as the total volume of runoff during that event. The resultant impact of flooding (flood risk) will be dependent not only on the extent of inundation but on the receptors that are flooded (such as houses, schools, businesses and roads).

In 2011, the National Flood Risk Assessment designated a total of 221 Potentially Vulnerable Areas (PVAs) in Scotland as having some risk of flooding from river sources. The high (1 in 10 year), medium (1 in 200 year) and low (1 in 1000 year) probability river hazard and risk maps can be viewed on SEPA's website together with the Potentially Vulnerable Areas[13]. SEPA's fluvial (river) flood maps estimate that 49,000 homes and 13,000 non-residential properties are at risk from river flooding from a 1 in 200 year probability event.

### Box 2.1. River processes

Scotland's rivers are extremely diverse, complex systems whose location and character change over time and across space – the same river may be slow-flowing and static in one place but be very changeable just half a mile downstream. Understanding river systems and processes as well as their links to the wider catchment is important when considering where, and what type of, NFM measures may be appropriate. The use of instream structures to encourage natural realignment of artificially straightened channels, for example, will need to balance the need for sufficient energy in the river to see any effect on channel migration, while avoiding areas where the energy is so high that it results in the structure being washed out.

Rivers consist of channel, bank and overbank or floodplain deposits and are responsible for transporting sediment from mountains to lowlands and the oceans. The extent of erosion, transport and deposition of sediment within a river is determined by the interaction between stream flow and channel slope ('stream power'). Stream power varies from source to outlet but is generally highest in the middle sections of the river where tributaries converge and the channel gradient is higher.




**Distribution of key river types in relation to different combinations of unit stream power and channel boundary resistance (© The James Hutton Institute, Centre for River Ecosystem Science (CRESS) and Scottish Natural Heritage).**

Variations in the factors that influence stream power and resistance to that stream power results in varying channel shapes ('morphologies'). For example, meandering channels tend to occur where there are low gradients and cohesive banks, causing only fine sediment to erode from the outer curve of each meander bend and deposit on the inner curve further downstream. Wandering and braided channels, conversely, occur where there are steeper gradients and erodible banks causing high bed load of coarser sediments which promote the development of sediment bars and the braided features characteristic of this river type. Artificial reinforcement of river banks results in predominantly straight rivers due to the increased lateral resistance of the river banks to erosion; in such cases the river will often erode more sediment from its bed to compensate.

While generalisations can often be made about the characteristics of channel morphology of a particular reach, changes in water flow will alter the interaction between stream power and resistance resulting in alterations to the size, number and location of fluvial features within a reach over time[3].

## 2.1.4. Future fluvial flood risk

Scotland's temperature records indicate a recent and rapid warming trend with average spring, summer and winter temperatures having risen by more than 1°C since 1961[14]. Since warmer air is able to hold more water the effect of this has been to, at least in part, result in an increase in precipitation in some parts of the country. Winter precipitation, for example, has increased by almost 60% in the north and west between 1961 and 2004[14]. The period of snow cover has also been affected with a decrease over the last 40 years, mainly as a result of snowfall occurring later in the year as a result of milder autumn and spring temperatures, producing less snowfall and earlier snowmelt. Early and rapid snowmelt may increase flood risk, particularly if it coincides with high rainfall intensity.

While the precise effects of climate change on flooding are impossible to predict, evidence already exists for increases to river flows in some parts of the country. Analysis of river flow data for some of Scotland's rivers shows that there has been an increase of around 30% between 1961 and 2005 for many of the rivers rising in the west of Scotland such as the Nith, Tay and Teith[15]. Winter river flows, in particular, have seen a substantial increase in some rivers, corresponding with changes in precipitation (Figure 2.5). These increases in flows will likely increase flood risk directly or indirectly by affecting channel processes, with greater flows potentially resulting in greater levels of channel instability, increased erosion and greater sediment loads. The UK Climate Change Projections (UKCP09) should be referred to for the most up-to-date sources of climate information for the UK[16].

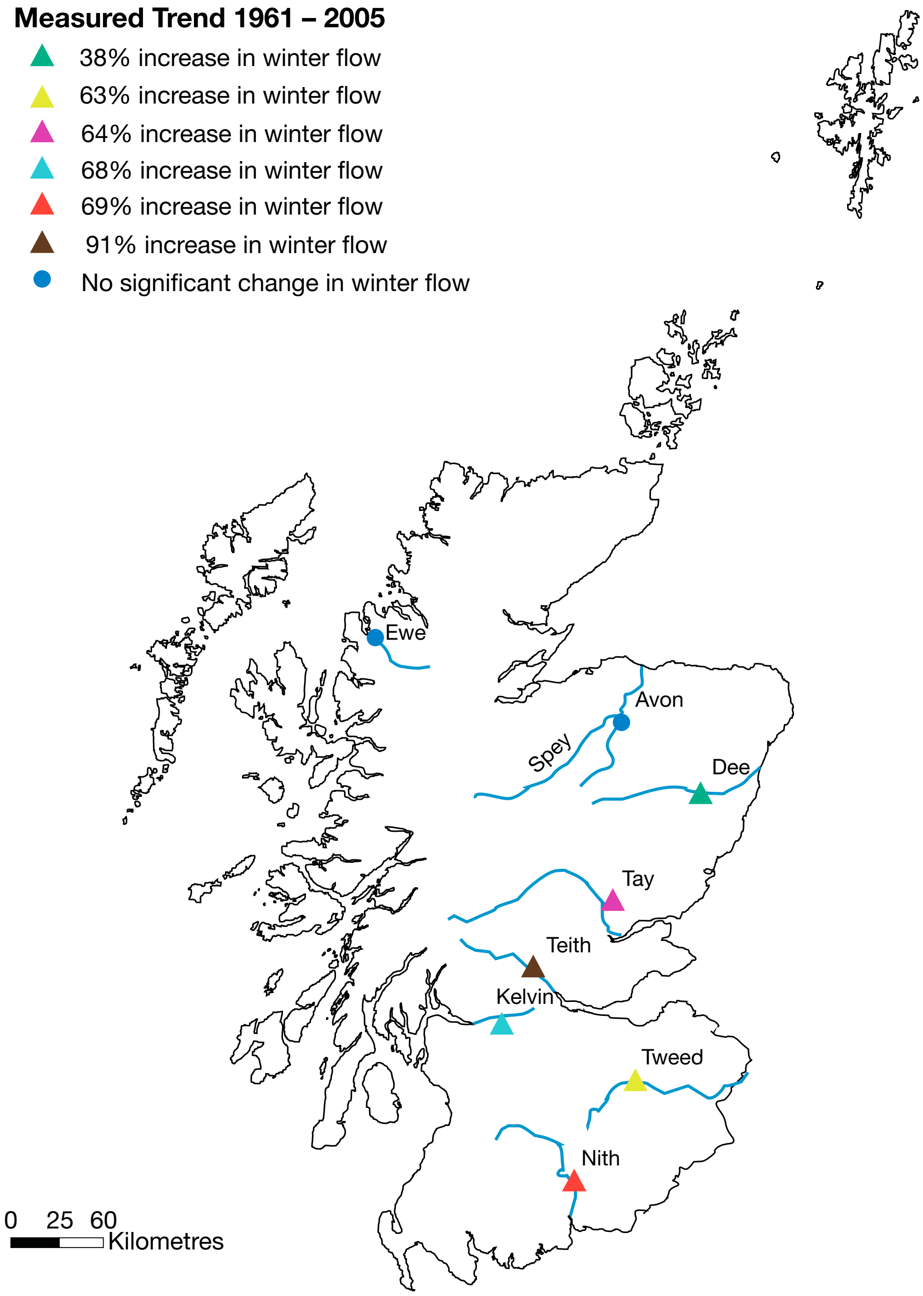



**Figure 2.5. Changes in winter river flows in some Scottish catchments between 1961 and 2005: There has been substantial change in winter river flows in some of Scotland's rivers, particularly those rising in the west of the country (© Crown copyright).**

### Box 2.2. Natural flood management measures, actions and projects

While natural flood management refers to the overarching approach of managing flooding by working with the natural features and processes within a catchment, natural flood management 'measures' are the individual techniques used to deliver that approach (Table 2.1). NFM 'actions' are groupings of NFM measures based on their main function, such as runoff reduction or sediment management. An NFM 'project' refers to the process of delivering an NFM measure from initial conception through to delivery on the ground.

## 2.1.5. The objectives of river and catchment based natural flood management

Natural flood management measures within a river catchment (Box 2.2, Table 2.1 and Figure 2.7) aim to:

- reduce the rate or amount of runoff; and/or
- improve the ability of rivers and their floodplains to manage flood water.

These aims are achieved by storing more water on the land and/or slowing the flow of water overland or instream. Some NFM measures also seek to maintain channel capacity by reducing the amount of sediment deposited within the river channel.

The desired effect of this on flooding is to:

- reduce the downstream maximum height of a flood (the flood peak) thus reducing the scale and impact of the flood; and/or
- delay the arrival of the flood peak downstream, thus increasing the time available to prepare.

Natural flood management measures within a catchment are associated with varying levels of certainty in terms of their effect on flooding. Measures implemented at source (in the headwaters of the catchment) and/or spread out over an area (such as catchment woodlands) are usually associated with a greater degree of uncertainty than those that are targeted to a specific area and/or located further down the catchment and nearer the receptors at risk (Figure 2.6).

More detailed information on the design of a range of river and catchment based measures at existing sites is provided in the **River Restoration Centre's (RRC) Manual of River Restoration Techniques**[18], derived from over 2,500 UK projects in the RRC National River Restoration Inventory which are shown on the RRC webmap[19]. Several hundred examples of EU-wide river restoration projects are also provided on **The RiverWiki**, a tool for sharing multiple benefit restoration and management projects across Europe[20]. Practical guidance on working in watercourses is provided in **SEPA's Good Practice Guides on Engineering in the Water Environment**[21]. A guide to the physical characteristics of Scotland's rivers, including more detailed discussion of river processes and how these should be considered in the design of river restoration measures, is provided in the **CREW publication: The Scottish Rivers Handbook**[3].

**Table 2.1. River and catchment based natural flood management measures**

| Measure group | Measure type | Main action* |
|---|---|---|
| Woodland creation | Catchment woodlands | Runoff reduction |
| | Floodplain woodlands | Runoff reduction/floodplain storage |
| | Riparian woodlands | Runoff reduction/floodplain storage |
| Land management | Land and soil management practices | Runoff reduction |
| | Agricultural and upland drainage modifications | Runoff reduction |
| | Non-floodplain wetlands | Runoff reduction |
| | Overland sediment traps | Runoff reduction/sediment management |
| River and floodplain restoration | River bank restoration | Sediment management |
| | River morphology and floodplain restoration | Floodplain storage/sediment management |
| | Instream structures (e.g. large woody debris) | Floodplain storage |
| | Washlands and offline storage ponds | Floodplain storage |

*Corresponding to opportunity areas identified by SEPA's NFM maps – see Chapter 5.

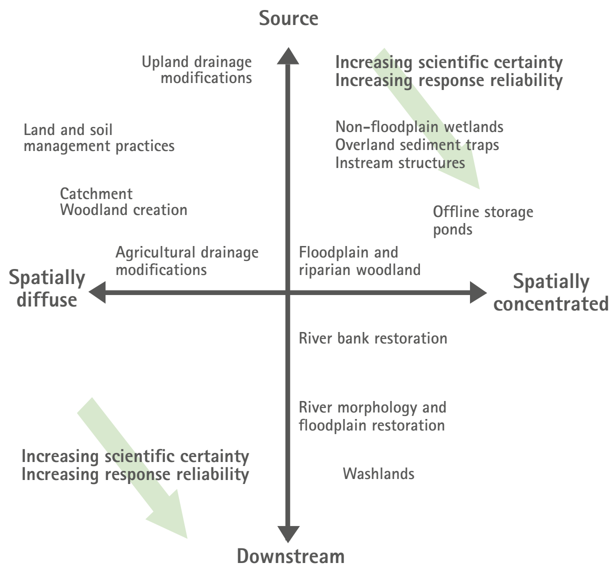



**Figure 2.6. A catchment scale classification of natural flood management measures: NFM measures can be broadly classified by the location of their likely implementation, either near the source of a flood or further downsteam, and by how the strategy may be spatially distributed on the ground (adapted from Thorne et al.[17]).**

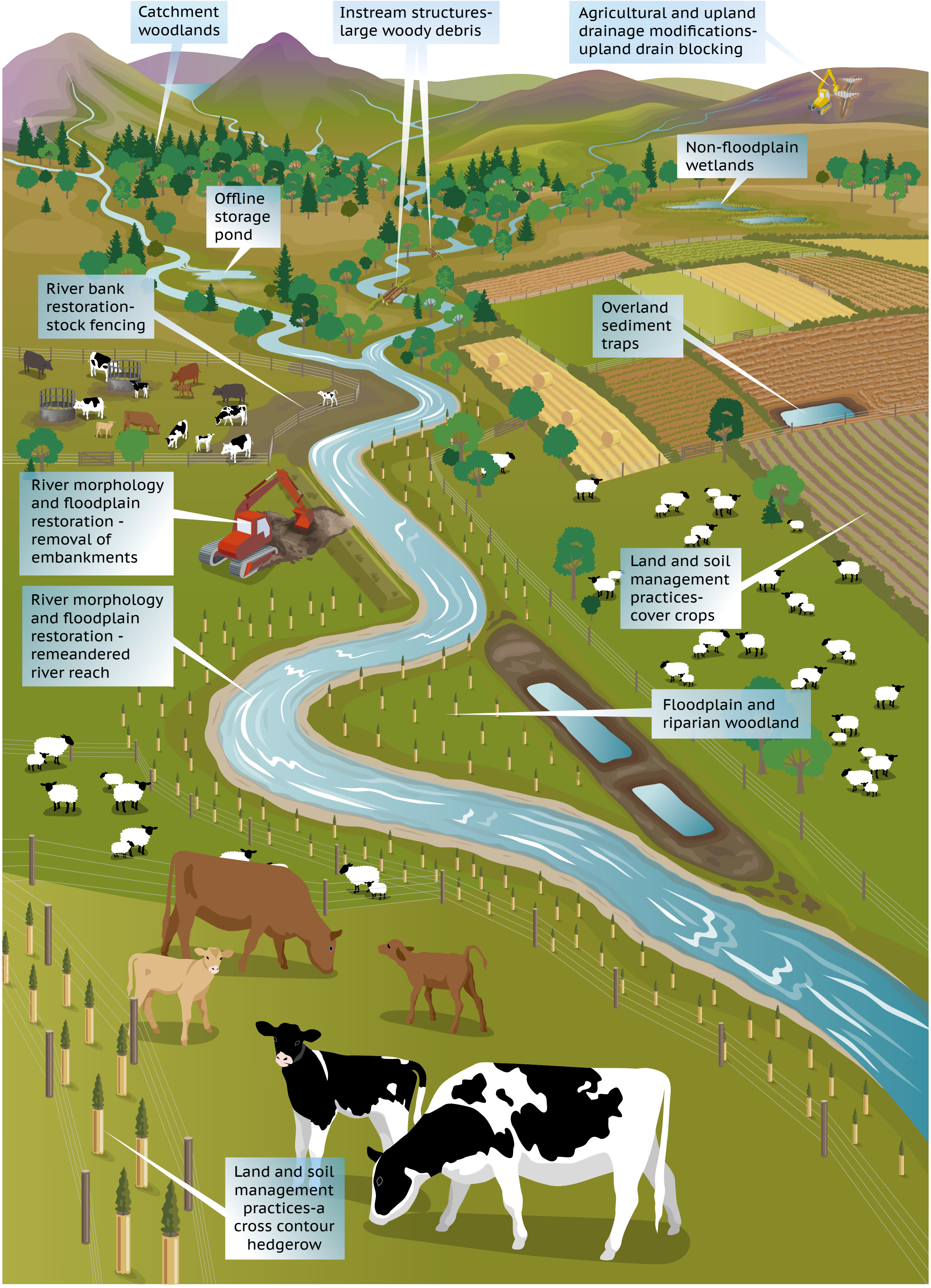



Figure 2.7. River and catchment based natural flood management measures: These measures typically seek to reduce the rate or amount of runoff and/or improve the ability of rivers and their floodplains to manage flood water.

## 2.2. WOODLAND CREATION

### WHAT IS IT?

The planting and management of woodland areas at a range of scales throughout the catchment from floodplains to headwaters.

Figure 2.8. Native woodland in Glen Affric, Inverness-shire (© Forestry Commission – Crown copyright).

Woodland cover in Scotland has decreased greatly over the past few centuries, reflecting pressures for timber and to clear land for agriculture and built development. This decline has been reversed in recent decades, and there is now a commitment in the Scottish Forestry Strategy[22] for the area of land under woodland cover to increase from 17% to 25% by the second half of the 21st Century. This, and our improved understanding of how to manage Scotland's diverse forests sustainably, provides an opportunity for woodland creation to play an important role in benefiting the environment.

Well-sited and well-managed floodplain and riparian woodland can contribute to the delivery of a host of outcomes (Figures 2.8 and 2.9). They provide important wildlife habitat and increased canopy shade and shelter for water-based flora and fauna. They can also provide shelter and shade for livestock and prevent damage to crops and soil erosion. Trees absorb and lock up carbon thus helping to reduce net carbon emissions, while riparian woodland can stabilise banks and help prevent excessive deposition of sediment instream. Strategically placed woodland can also reduce diffuse pollution by intercepting pollutant laden runoff.

Although the effects of trees on hydrological processes such as interception are well documented, the effects on flood risk are less well studied. This is partly due to the relatively short data records available and the difficulty with isolating any effect of woodland from the effects of varying land uses and climate change. However, while the effects of woodlands on large scale floods are very unclear, modelling data suggests that woodlands may have an effect on local flooding (catchments less than 100km$^2$) or more frequent flood events[23]. This appears to be particularly true for floodplain woodlands.

Trees have the potential to manage the sources and pathways of flood waters in a number of ways. Field-based evidence shows that they can reduce water yield by improving the infiltration rates of woodland soils and by 'sponging up' water through the process of evapotranspiration. In a review of 94 catchment studies, Bosch and Hewlett[24] concluded that a 10% increase in conifer or broadleaved forest cover within a given catchment could achieve a 40mm and 25mm decrease in water yield, respectively (although the effects for broadleaved woodland are generally less due to the leafless period when interception rates are greatly reduced).

**Figure 2.9. Recently planted floodplain woodland in the Gala Water catchment, Scottish Borders (© Tweed Forum).**

The high input of organic matter into the soils of well-managed woodlands can also protect soil from disturbance and improve its structure, in turn enhancing soil infiltration pathways and water storage capacity and reducing surface runoff, erosion and sediment loss. A study at Pontbren in Mid Wales, for example, found that soil infiltration rates were up to 60 times higher where young native cross slope woodlands were present compared to adjacent heavily grazed pasture (Figure 2.10)[27]. Notably, 90% of the improvement in soil infiltration rates occurred within two years of stock removal and tree planting. Woodlands can also act to slow down surface runoff by increasing the frictional resistance to this runoff[25]. This is why modelling of the effect of woodlands on flows often employs the use of the Manning coefficient to represent changes in the hydraulic roughness of the land in open channel hydraulic calculations (e.g. Thomas and Nisbet[26]).

The research on the effect of woodland creation and management that informs the position of Forestry Commission Scotland is available on the Forest Research website[28]. It is anticipated that more data on the direct effects of woodland creation on flooding will become available over the next few decades as monitored woodlands become established.

## 2.2.1. Different types of woodlands

### 2.2.1.1. Floodplain woodlands

Floodplain woodland is thought to offer the greatest potential for downstream flood mitigation, although its value as an NFM measure depends on the size and positioning of the woodland in relation to the size of the floodplain. A number of small blocks spread across the floodplain could be as effective as one large block spanning its entirety.

Planting on floodplains may more commonly lend itself to conifer or mixed species, or to short rotation coppicing/ short rotation woodland which is planted to provide wood fuel for fossil fuel substitution. The natural characteristics of the landscape could be developed to maintain or reinstate channels and backwater ponds. However, these larger woodlands must be carefully sited, to avoid them synchronising flood peaks.

### 2.2.1.2. Riparian woodlands

Riparian woodlands (Figure 2.11) are usually planted as buffer zones, in between the watercourse and adjacent land, which allows the maximum amount of contact between the trees and water. They are typically up to 30m wide on both sides of the watercourse, and offer the benefits of infiltration, hydraulic roughness and evapotranspiration and also the potential for woody debris (porous dams which can encourage out-of-bank 'spill over' and therefore delay downstream flood flows). Because of their proximity to watercourses, and their potential for improving woodland and river biodiversity, riparian woodlands are more commonly made up of broadleaved species. There are constraints to where riparian planting should be undertaken. For example, it should not be planted alongside flood embankments if there is a wind blow risk, and woody debris shouldn't be encouraged in areas where it could block pinch-points such as bridges or culverts.

### 2.2.1.3. Catchment woodlands

Woodlands planted in the wider catchment are characterised as being on soils that are prone to generating pathways where water flows to streams, or rapid run off (Figure 2.12). These are typically waterlogged soils or those that suffer from compaction or sealing. Species used on these soils preferably have a deeper rooting system, in order to maximise infiltration and soil stability. Tree spacing, density, forest type and structure also affect the ability to reduce flood flows (through their effect on evaporation, soil water storage and hydraulic roughness). Trees should not be planted above the natural tree line – further information on this can be found in the Land Capability for Forestry maps produced by the James Hutton Institute (available for download[29]).

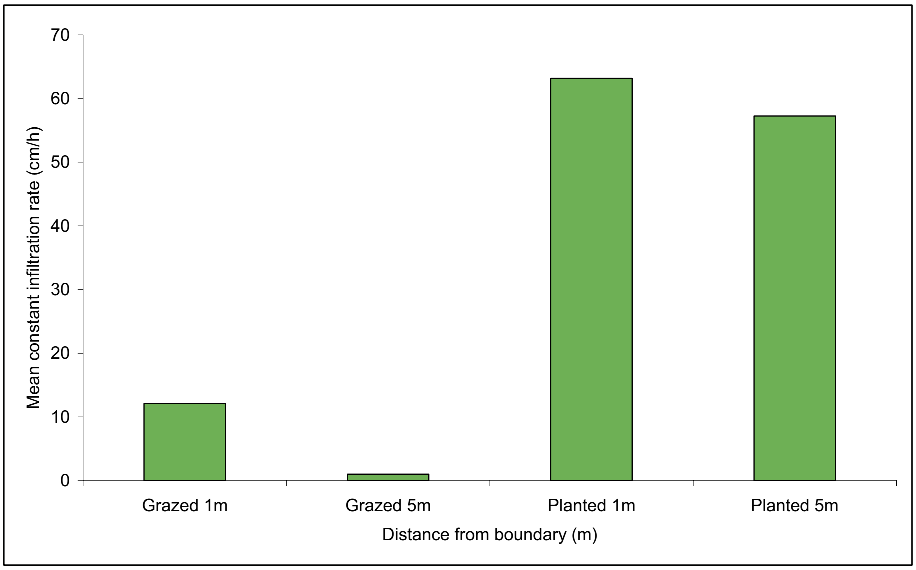



**Figure 2.10. Soil infiltration rates along a transect between sheep grazed pasture and a recently planted woodland shelterbelt (2–7 years after planting) at Pontbren, Wales (from Carroll et al.[27]).**

## 2.2.2. Technical considerations

The design and planting of woodland must comply with the UK Forestry Standard and the associated guidelines on water, soil, biodiversity, landscape, people, historic environment and climate change. These documents are available on the Forestry Commission website[30]. A new Forestry Commission practice guide is currently being prepared on forestry and flood risk management. This will detail how measures such as choosing a planting site, phasing clear felling to reduce the impact of woodland removal, remedying drainage systems, and enhancing water storage through the formation and retention of large woody debris dams must work so that the benefits of woodland creation are maximised. Once published, it will be available via the Forestry Commission Scotland website[31].

The planting of any new woodland should always consider the potential for an increased risk of flooding. For example, localised backing up of flood waters upstream could occur or instream woody debris could result in a blockage at culverts or bridges. Wash out of instream woody debris to downstream structures will be more likely in steep catchments. Identification of potential structures that may become blocked downstream of the planting site as well as vulnerable downstream receptors such as towns will permit an assessment of likely risk and the need for mitigation measures.

**Figure 2.11. Recently planted riparian woodland in the Bowmont Water catchment, Scottish Borders (© Tweed Forum).**

**Figure 2.12. Upland woodland blocks in the National Trust Holnicote Estate, West Somerset. (© Penny Anderson Associates).**

## 2.2.3. Cost

The costs associated with creating woodland will vary according to where it is sited, what species are planted, and what other management objectives are to be met. Advice on various regulations and grant support (for example creating a forest plan and planting farm woodland) is available online[32].

There is a higher payment rate available under the Forestry Grant Scheme (FGS) of the Scottish Rural Development Programme (SRDP 2014-2020) for woodland creation in areas where there are opportunities to deliver multiple water benefits. These priority areas (referred to as 'woodlands for water'), identified by analysing spatial data, are shown on the Forestry Commission Scotland map viewer[33].

## Further reading and guidance

FORESTRY COMMISSION (2011). Forests and Water: UK Forestry Standard Guidelines. Edinburgh: Forestry Commission.

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# 2.3. LAND MANAGEMENT

Land management measures are land based techniques and practices that seek to influence flood generation by reducing the amount of surface runoff reaching the river network. They achieve this primarily by improving soil structure (e.g. making it more porous), increasing infiltration, and ultimately increasing the capacity of the land to store water. In addition to reducing runoff, these measures can also reduce soil erosion and the transfer of sediment and pollutants to rivers.

Substantial bodies of evidence confirm that land management practices affect runoff generation although the effect of these changes on the propagation of flood waters downstream is less clear[34,35]. The overall effect on flood generation will be influenced by a number of factors such as the spatial location and the scale of the intervention, the extent of the landscape areas and river channel reaches affected, and the relative timings of runoff contributions[36]. O'Connell et al.[8] provide further information on the features of a catchment that influence the effect of land management on flood generation, while Halcrow[37] provides an overview of the evidence base.

The following describes some of the main land management measures associated with reducing runoff generation for the purpose of reducing surface water flooding and the amount of water reaching the river network. Other measures that can contribute to reductions in runoff exist, particularly those relating to rural sustainable drainage systems (rural SuDS), and further details of these can be found in the suggested further reading. Due to the uncertainty in the effects of land management measures on flooding, these measures should not be viewed as mutually exclusive of other measures described in this chapter. The greatest benefits to flooding will frequently be achieved by implementing many different types of measures together.

## 2.3.1. Land and soil management practices

**WHAT IS IT?**

Incorporating good practice into the management of land for the purpose of increasing infiltration of water and sediments into soils and reducing surface runoff.

The land's ability to slow down and store runoff is influenced substantially by how agricultural land is managed. Activities which result in a higher risk of soil erosion and soil compaction and leave less vegetative cover over the winter can reduce the potential for infiltration of surface runoff and associated pollutants (Figure 2.13). Certain land management practices such as high stocking densities, the use of heavy machinery and leaving soils un-vegetated over the winter can present particular risks.

The adoption of good land and soil management practices can reduce the risks to soil posed by certain land management practices and in many cases can improve overall yield by improving the productivity of soils (e.g. by relieving compaction and improving root penetration). These practices typically seek to improve soil structure and/or increase cover so as to reduce erosion, increase soil infiltration, and reduce runoff and transport of sediments. A variety of techniques may be adopted including:

- cover crops;
- checking for and relieving compaction where required;
- soil aeration;
- machinery practices that minimise compaction; and
- runoff control features (e.g. in-field buffer strips, hedges).

Figure 2.13. Soil erosion in an arable field in West Somerset (© National Trust).

### 2.3.1.1. Technical considerations

#### Soil and crop management measures

Over-wintering fields with a cover crop (typically grass or clover that is grown to provide cover rather than leave bare soil) reduces soil erosion and maintains soil structure and fertility thus reducing surface runoff. Cover crops also provide a host of additional benefits including a reduction in the leaching of nutrients, weed control and the provision of habitat for many species. Such techniques can be challenging to implement but can be successful where there are drier, more stable soils[38].

Undertaking soil cultivations along contours, rather than straight up and down field slopes, can be particularly effective in reducing surface runoff (although this needs to consider the safety risk of doing so). Carrying out regular assessments for soil compaction and taking any required action to remedy this such as sub-soiling can also help. Reducing the impact of machinery on soil compaction, for example, by increasing tramline spacing, using flexible tyres, decreasing loads, and using the correct tyre pressure can also increase infiltration and reduce runoff, particularly on weakly structured, wet soils[39]. The use of a soil aerator (mechanical spiking of the soil) and tramline management techniques can also improve infiltration in compacted grass fields and tramlines while also benefiting growth by increasing the amount of oxygen reaching roots (Figure 2.14).

**Figure 2.14. A soil aerator being used to aerate a field previously subject to heavy grazing pressure and compaction (© Tweed Forum).**

#### Runoff control features

The creation of vegetated strips of land running along the banks of watercourses (riparian buffer strips) can provide protection from grazing, stabilise banks, and reduce erosion and the amount of water and pollutants reaching the watercourse, while also improving biodiversity. This may be as simple as erecting fencing to allow natural regeneration and protection from stock or may include some additional elements such as planting of trees and other vegetation.

Sub-dividing arable fields through the planting of grass strips and hedgerows (Figure 2.15) along the contour of a field or within a natural gully can be particularly effective at intercepting surface runoff and increasing infiltration of water into the soil profile. Strategic placement of field entrances in locations that do not permit surface runoff to exit the field quickly, such as may be the case where entrances are located next to main roads, can also reduce connectivity with the river network. In general, the longer and steeper the slope and the less free draining the adjacent field is, the wider the grass strip or riparian buffer that is needed to slow and intercept runoff.

Other agricultural practices and interventions that can contribute to reductions in runoff, such as ditch/drain blocking and wetland creation, are described in more detail in subsequent sections.

### 2.3.1.2. Cost

The cost of adjusting soil and crop management practices or installing runoff control features is typically low but must be considered in conjunction with effects on yield. The purchase of specialist soil management and cultivation machinery can be much higher although it may be possible to reduce costs by renting such machinery or purchasing with neighbouring landowners/managers. A number of payments are available in the Scottish Rural Development Programme (in targeted areas) to support good land and soil management practices (see Chapter 8).

**Figure 2.15. Newly planted hedgerow in the Bowmont Water catchment, Scottish Borders: This hedgerow has been planted along the contour to intercept surface runoff (© Tweed Forum).**

## Further reading and guidance

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PARROTT, A., BROOKS, W., HARMAR, O. and PYGOTT, K. (2009). Role of rural land use management in flood and coastal risk management. Journal of Flood Risk Management, 2, 4, 272-284.

## 2.3.2. Agricultural and upland drainage modifications

### WHAT IS IT?

Modifications to agricultural drainage systems to reduce runoff and to improve the condition of peatlands.

Mechanisation and changes in agricultural policy following the Second World War resulted in huge increases in the extent of agricultural drainage aimed at maximising vegetative growth and yield. More sub surface drains (such as field tile drains or pipes) were installed to lower the water table and reduce the extent of saturation of soils. Surface drains and open ditches also increased in number to transport and dispose of the extra water. The result of these activities has frequently been to increase connectivity of sediment laden runoff contained within these drains with the river network. In the uplands, drainage has resulted in a significant decline in the condition of peatland and the associated benefits that peatlands provide.

Since the cessation of government drainage grants in 1985 there has been a general decline in the installation, overall maintenance and effectiveness of many agricultural drainage systems and with it the extent to which these drainage systems benefit production. As a result, opportunities exist to modify drainage to benefit the land manager as well as provide benefits to flooding by altering both the flow pathways over and through the soil, and the hydrological connectivity to the drainage network. Measures typically involve upland drain blocking (frequently termed 'grip blocking'). Modifications to field drainage systems are also possible, for example, in order to create wetlands (see also non-floodplain wetlands).

Modifying drainage systems creates a complex hydrological response, potentially creating both positive and negative impacts on runoff, which may also change over time as the characteristics of the soils are gradually altered. Upland drains, for example, may lower the water table and increase water storage potential (thus reducing flow peaks in the stream) but may also increase the velocity of the flow once it reaches the drain, thus increasing the peak flow[40]. Agricultural underdrainage and associated subsoil treatments can also increase or decrease peak drain flows and the time to peak flow, with the nature of the effect appearing to depend on the soil type and wetness[9].

While the effects of modifying drainage systems are inherently complex, there is increasing evidence that upland drainage blocking can, when targeted and delivered appropriately, create more stable water tables that are better able to respond to extreme events and achieve reasonable reductions in flows. A study by Wilson et al.[41], for example, found that drain blocking in the upland blanket bog of the Berwyn and South Clwyd Mountains reduced average downstream river flow by a third. Targeting of upland drain blocking to steeper, smoother channels appears to provide the greatest benefits in terms of reduction in the flood peak[42]. CREW[43] provides a review of studies investigating the effects of upland drain blocking.

### 2.3.2.1. Technical considerations

Any modification to drainage systems will require knowledge of the drainage system in place and the potential for impacts on biodiversity, archaeological, landscape and cultural features. This should include consideration of the effects of alterations to the water table on adjacent sites. Undertaking small scale works in the first instance will provide greater understanding of a site.

#### Upland drain blocking

The preferred method to block small moorland grips is to use compacted peat dams constructed from locally sourced, well-humified, more impermeable peat material (Figure 2.16). These are carefully compacted into the bed and banks of the grip. On larger grips (typically greater than 0.7m$^2$ cross sectional area) and on steeper slopes, the installation of more robust wooden or plastic dams may be required[44] (Figure 2.17). Dams should be constructed with a crest level slightly higher than that of the local grip bank top to encourage excess water to be redistributed back out onto the moorland surface. Site location and access conditions, especially for mechanical machinery, are major considerations when determining the type of dam that can be installed.

**Figure 2.16. Restoration of blanket bog by blocking small drains using peat dams at Forsinard Flows Nature Reserve, Caithness and Sutherland.**

### Lowland drain modifications

Barriers can be installed in lowland drains and ditches to slow water and encourage the settling out of sediment and increased infiltration (Figure 2.18). These barriers can be made from a variety of materials including wood, concrete, stone and earth. This risk of failure increases with the surface area of the structure and it is therefore important to carefully design and site these structures, particularly if the channel is steep. The damming of drains or ditches will need to consider the movement of aquatic wildlife up and down the channel. Further information on the design of lowland drain barriers is provided in Avery[51].

### In-field underdrainage interventions

Breaking of field underdrains can be carried out in areas to create wetlands. This may be desirable where the land is frequently saturated and agricultural production is not possible. The impact on the water table in areas surrounding the field drain break should be considered to avoid altering drainage patterns in productive, cultivated land. The Scottish Rural Development Programme guidance provides more information on the process of breaking underdrains[45]. Additional management options will need to be considered in the case of wetland creation, including livestock management and grazing. In some situations where land is to be kept in production and poor or ineffective drainage of arable or grass fields is being remediated, it may be possible to install a more integrated drainage that links the outflow to other features, such as wetlands or offline storage areas.

## 2.3.2.2. Cost

Costs will normally be low for drain or ditch blocking, with some ongoing low maintenance costs to remove sediment if required. Larger ditches may require a greater level of engineering to install dams and cost slightly more. A number of payments are available (in target areas) in the Scottish Rural Development Programme relating to agricultural and upland drainage modifications (see Chapter 8).

**Figure 2.17. Restoration of blanket bog by blocking wide drains using plastic piling supported by timber frames at Blawhorn Moss, West Lothian.**

**Figure 2.18. Small wooden ditch structures used to show flows and encourage settling out of sediment in ditches in the Belford catchment, Northumberland (© Newcastle University).**

## Further reading and guidance


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## 2.3.3. Non-floodplain wetlands

### WHAT IS IT?

The creation or restoration of wetlands to reduce and slow down runoff and capture sediment.

Wetlands are usually saturated areas in which the water table is either at or near to the ground surface for much of the year due to the physical, hydrological and climatic characteristics of the site. Many different types of wetlands exist, including peatlands and saltmarsh, some of which are discussed further in other sections of this book. As an aid to basic wetland identification, the Functional Wetland Typology for Scotland is freely available on SEPA's website[46]. This section refers to the construction or restoration of wetlands that do not directly experience river or coastal inundation (i.e. 'palustrine' wetlands) (Figures 2.19 and 2.20).

Wetlands can be viewed as areas of water storage in the landscape that can help to reduce the impacts of flooding and drought by slowing and holding flood water and then releasing this water during drier times. In addition to aiding flood prevention, wetlands can improve water quality by trapping sediments and retaining excess nutrients and pollutants. They are often highly productive ecosystems that support a diverse array of habitats and species and some wetlands, particularly peatlands, are effective in storing carbon, thus helping to mitigate the effects of climate change.



**Figure 2.19. A wetland in the Belford catchment, Northumberland. (© Mark Wilkinson).**

Many wetlands have been lost in the last century as a result of large draining projects that removed these ecosystems in order to improve land productivity. Of the wetlands that have survived, many are in poor condition due to the impacts of pollutants such as nutrients, water management and invasive species. Although the condition and extent of Scotland's wetlands is thought to be declining[47], wetlands are becoming increasingly recognised for the services they provide and are being afforded increased protection through legislation and policy.

While there are many examples of the benefits of wetlands to drought and flooding, the nature and scale of the effect will be site dependent and influenced by a range of factors such as location within the catchment, type and condition of vegetation, slope, location of the wetland in the flood path, and the degree of saturation of soils prior to a flood event. Bullock and Acreman[48] provide a review of studies on the effects of wetlands on flooding.

**Figure 2.20. A series of wetlands in the Leader Water catchment, Scottish Borders (© Tweed Forum).**

### 2.3.3.1. Technical considerations

Existing wetlands may be suitable for restoration (if previously damaged) or enhancement to increase the range of services that they offer. There may also be opportunities for the creation of entirely new areas of wetland. Approaches to the restoration of a wetland depend on the cause of the degradation but generally seek to restore the water table, chemical regime and vegetation structure of a particular type of wetland. This can be as simple as increasing the grazing regime to reduce scrub encroachment or adjusting the operation of existing water control structures such as sluices. More degraded sites will likely require greater interventions such as removal of nutrient rich sediment or restoring the desired topography to alter water levels and flows.

The creation of wetlands can be conducted on small or grand scales depending upon the overarching aim. Straightforward solutions such as the creation of wader scrapes in seasonally inundated areas can be equally valuable to a large designed reed-bed filtration scheme. The key is getting the right wetland in the right place. If the aim is to create a new area of wetland or extend an existing wetland there are several things to consider:

- Does the area earmarked for wetland creation offer an improvement? What is currently present in that area – protected species for example – and will the creation of a wetland area improve biodiversity?
- How can water levels be raised and controlled in order to create the wetland? Is water required to be diverted from a watercourse or will water need to be withheld or impounded in the wetland area?
- Does the area need to be planted with wetland specialist plants or is it expected that the wetland will naturally colonise? The RSPB provides advice on planting new reedbeds while Scottish Natural Heritage offers advice on whether planting is required for other types of wetland creation.

Further information on altering drainage to promote wetland conservation is provided in Droy[49].

Wetlands can also take the form of 'constructed farm wetlands': artificial structures that are primarily designed to intercept lightly contaminated surface water runoff from farm steadings. Water flows horizontally across the bed surface (surface flow wetland) or through a planted medium such as gravel (sub surface flow wetland) and in so doing is treated via a number of different physical (e.g. sedimentation, filtration), chemical (e.g. microbial processes and adsorption) and biological processes (e.g. plant uptake). Constructed wetlands can provide a flood storage capacity if there is enough space to store runoff during a storm event. Further information on constructed farm wetlands is provided in Carty et al[50].

A wetland's structure, functioning and longevity is greatly influenced by its location and hydrological condition (such as the inflows and outflows of groundwater and surface water and the timing and duration of soil saturation). Proper planning of wetland restoration or creation is therefore essential and should include reference to current and past land use, drainage activities, soils, topography, hydrology, water quality, and current and past species and habitats. Examining the least altered wetlands nearby for reference is always a useful approach. Once created or restored, it is likely that some low level maintenance will be required, including the repair of structures such as flow control mechanisms or fencing, control of non-native invasive species and commitment to the wetland management regime (such as appropriate levels of grazing).

### 2.3.3.2. Cost

Costs will depend on the extent of engineering required but are likely to be moderate, with some low cost maintenance required. There are multiple payments available in the Scottish Rural Development Programme (in target areas) for wetland creation such as moving and realigning ditches, installation of pipe sluices, and pond creation for wildlife.

## Further reading and guidance

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## 2.3.4. Overland sediment traps

### WHAT IS IT?

A containment area where sediment laden runoff is detained to allow sediment to settle out.

Sediment traps can take many forms but normally comprise an excavation located on a surface runoff pathway (Figures 2.21 and 2.22). Runoff enters the excavation and is detained there, allowing sediment to settle out before the runoff is discharged, usually via a gravel outlet. Sediment traps are unlikely to derive significant flooding benefits on their own. However, when used in conjunction with other runoff management features they can help to control the release of sediment to the river network and thus maintain the capacity of rivers to convey flood waters.

Sediment traps are one of a suite of measures collectively referred to as rural sustainable drainage systems (rural SuDS) that aim to mimic natural hydrological regimes to minimise the impact of human activity on surface water drainage discharges. These features are primarily aimed at reducing diffuse pollution but also derive a flood benefit by reducing surface runoff. More detailed information on rural SuDS is provided in Avery[51]. Sediment traps function in a similar way to in-ditch barriers (see Section 2.3.2).

**Figure 2.21. Three sediment traps constructed in series to intercept surface runoff and encourage settling out of sediment in the River Coquet catchment, Northumberland (© Nick Barber, Newcastle University).**

### 2.3.4.1. Technical considerations

#### Locating a sediment trap

Sediment traps are best targeted to the overland flow pathways of small catchments where they can make a meaningful reduction in the amount of sediment reaching the river network. They can be used alone or as a method of treating runoff before it reaches other rural SuDS features. The larger the feature (in terms of surface area) the greater the potential it will have to remove sediment.

The first step in deciding where to site a sediment trap is to identify all ditches, burns and rivers in the farm or area of land in question. The next step is to consider where the potential for soil erosion is greatest and where this can pose a risk to the water environment.

The assessment should consider the following:

- proximity to nearby watercourses – the closer the area is to a watercourse, the greater will be the risk;
- slope of the land will be one of the most significant factors- the steeper the downward slope towards the watercourse, the greater will be the risk. Slopes of over three degrees (1 in 14) should be considered moderate risk and those above eight degrees (1 in 7) considered high risk. Fields with slopes which tend to converge or fall to a specific low point or corner of the field near to a watercourse will have a particular high risk of causing pollution. Long, uninterrupted slopes are also of greater risk of erosion;
- gateways and tracks – areas which are frequently used can be at increased risk of erosion. Gateways can also act as exit points for runoff from a field;
- past experience – consider where it has previously been noted that surface runoff from entered a watercourse or soil erosion has occurred; and
- soil texture – light soils with a high sand content are at greater risk of erosion.

#### Designing a sediment trap

Sediment traps are normally created by:

- excavating a small area and installing an outlet pipe or overspill outlet; and/ or
- creating an earth bund.

**Figure 2.22. A series of sediment traps under construction in the Netherton Burn catchment, Northumberland. These sediment traps were constructed directly upstream of an offline storage pond in order to retain sediment and nutrients and slow the sedimentation rate in the main pond (© Tweed Forum).**

Other more complex designs also exist such as multiple chambers with baffles separating each chamber (commonly called sedimentation boxes).

Bunds are particularly useful on sloping fields where the runoff tends to exit the field at a particular point, such as a valley bottom, where slopes converge, or the low corner of a field. The bund should be created from compacted subsoils and should not exceed 1.3m unless designed by an engineer[51]. The slope of the sides should be less than 1 in 4 or gentler and vegetated. The field side of the bund should have a gentle gradient (ideally no steeper than 1 in 20) in order to provide a filter strip function[52].

Maintenance will need to include periodic removal of accumulated sediment (and therefore access for farm machinery) and the occasional cutback of vegetation on the bund. Outlets will need to be kept clear and any erosion resulting from the outflow addressed. Sediment traps should always be fenced off to protect the public.

### 2.3.4.2. Cost

Sediment traps are typically a low cost feature to construct with some regular low cost maintenance required. Payments are available (in target areas) in the Scottish Rural Development Programme for the creation of sediment traps (see Chapter 8).

## Further reading and guidance

AVERY, L. (2012). Rural Sustainable Drainage Systems (RSuDS). Environment Agency: Bristol.

CALIFORNIA STORMWATER QUALITY ASSOCIATION (2003). California Stormwater BMP Handbook: Construction. Menlo Park, CA: CSQA.

CIRIA (2015). The SuDS Manual CIRIA Report C753. London: CIRIA.

# 2.4. RIVER AND FLOODPLAIN RESTORATION

While NFM measures associated with land management seek to reduce flood water generation, NFM measures in the river channel or on its bank or floodplain seek to improve the ability of rivers to manage those flood waters. This is achieved by restoring a more natural hydrological response and regime, for example, by slowing flows (e.g. remeandering or the use of instream structures) and reducing excessive supplies of fine sediment (e.g. bank stabilisation) (Box 2.3), or by increasing the potential for the floodplain to store water (e.g. by decreasing the confinement of the river and reconnecting the floodplain). A suite of measures is often used, which may also include riparian and floodplain planting.

As with all works in and around a river, when implementing river and catchment based NFM measures the necessary permissions will need to be sought, including those required by the Controlled Activities Regulations (CAR), Waste Management Licensing Regulations and planning authorities. All necessary habitats and species surveys will need to be carried out in advance while works that impacts on designated sites for nature conservation will also require consultation with, and permissions from, Scottish Natural Heritage. Large ponds may be legislated under the Reservoirs (Scotland) Act 2011. Chapter 6 provides further information on the likely permissions needed for individual NFM measures.

## 2.4.1. River bank restoration

**WHAT IS IT?**

The stabilisation of excessively eroding river banks in order to reduce deposition of sediment downstream.

River banks provide valuable wildlife habitat that typically supports a diverse range of plant and animal species. They supply shelter, food and shade and protect the aquatic environment from polluted surface runoff. Riparian vegetation and the roots of that vegetation help to maintain bank stability and prevent excessive river bank erosion, helping to prevent excessive gravel deposition and flooding downstream.

Naturally occurring erosion of river banks is an important river process that maintains sediment supply to the watercourse, renews habitats and reduces the energy of river flows. However, in some cases human activity has increased levels of erosion to unnaturally high levels. Livestock, for example, can destabilise the river bank through poaching and through the removal of vegetation, while river engineering can increase the energy of the river and the resultant force impacting the river banks.

Measures to manage unnaturally high rates of erosion of river banks should, where possible, focus on better riparian management that allows the river bank to re-vegetate and stabilise naturally. This may be as simple as the installation of fencing where livestock are present (Figure 2.23) or direct re-vegetation of the banks through the planting of young plants and trees and the sowing of seeds. In some cases, however, the rate of erosion may be so severe or happening so quickly that intervention is required to stabilise


**Figure 2.23. Riparian fencing in the Eye Water catchment, Scottish Borders, before and one year after: The vegetation established along the river banks helps stabilise the banks, reduces erosion and reduces the amount of water and pollutants reaching the watercourse (© Tweed Forum).**

and re-profile the bank. Re-shaping the banks can damage habitats and disrupt the natural functioning of the river so it requires a clear justification for its use. Natural materials may need to be used to protect the bank from erosion in the future (Figure 2.24); this is also discussed here although it should be noted that the use of such techniques is not restoration in the strictest sense.

### 2.4.1.1. Technical considerations

Since erosion and deposition are naturally occurring processes resulting from the river's tendency to accommodate the average flow conditions, it is important to understand whether the erosion is natural and what the effect on the river's behaviour is likely to be if works are undertaken. Where bank protection is to be used, it should be appropriate and proportionate to the type, location and rate of erosion, as well as the extent of flood risk. SEPA's Good Practice Guide on Bank Protection[54] provides more detailed guidance on the approach to identifying whether bank protection is needed and what techniques may be appropriate.

#### Stock fencing

The fenced area should be wide enough to allow for natural channel adjustment (which will depend on the size and behaviour of the river). On stable parts of the river, fencing should be set back from the top of the bank at least two metres to comply with statutory guidelines. More active sections of river will require the boundary to be set back further to avoid the loss of the fence. Fencing off the channel may require new watering points, or an alternative means of watering for livestock. Maintenance requirements should be minimal and involve checking and repairing fences and regular monitoring of the rate of erosion (e.g. gauging whether the erosion has lessened by taking repeat photos). SEPA's Good Practice Guide on Riparian Vegetation Management[55] provides more information on establishing riparian vegetation.


**Figure 2.24. Willow spiling to protect a river bank weakened by grazing and prevent fine sediment input in the Gala Water catchment, Scottish Borders (© Tweed Forum).**

### Green bank works

This refers to a combination of measures that actively seek to reintroduce vegetation to stabilise an often bare bank (Figure 2.25). Long-term stabilisation is provided by the vegetation cover and its root network, with additional material specified to provide immediate short- to medium-term protection to the bank and vegetation while this establishes. Techniques often use different materials at different points, e.g. protection of the bank toe from continual scour, or reducing fine sediment input and protecting newly established plants and trees above the normal waterline. These techniques involve a risk of failure as they take time to become established and can be vulnerable to damage during large floods. Thus matching the size and scale of the measure used to the width and energy of the stream is critical.

Work should preferably be carried out by a contractor with experience of working in rivers, between spring to early autumn to reduce the risk of damage to the river environment and to allow time for vegetation to establish before winter. Further guidance on appropriate timings should be sought from SEPA. Care should be taken to prevent soils entering the watercourse during the works and vegetative cover should be re-established on any bare ground remaining after the works are complete. Maintenance requirements will depend on the type of technique, willow spiling for example, requires regular maintenance to avoid excessive growth of vegetation and needs to be coppiced every two to five years.

## 2.4.1.2. Cost

Restoration of river banks can be low in cost where it involves improvements to riparian management through planting. The cost of installing stock fencing is approximately £6 per metre while re-profiling and bank protection measures will be significantly more (approximately £50 to £200 per metre depending on the technique employed). Any engineering to the river bank will normally require pre-works assessments such as options appraisals and design works and there will be costs associated with this work. Payments are available (in target areas) in the Scottish Rural Development Programme for works relating to the restoration and protection of river banks (see Chapter 8).

**Figure 2.25. A river bank in the Tarland Burn catchment (Dee), Aberdeenshire, following installation of fencing and planting of vegetation (© S. Cooksley).**

## Further reading and guidance


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SEPA (2008-2010). Engineering in the Water Environment Good Practice Guides:

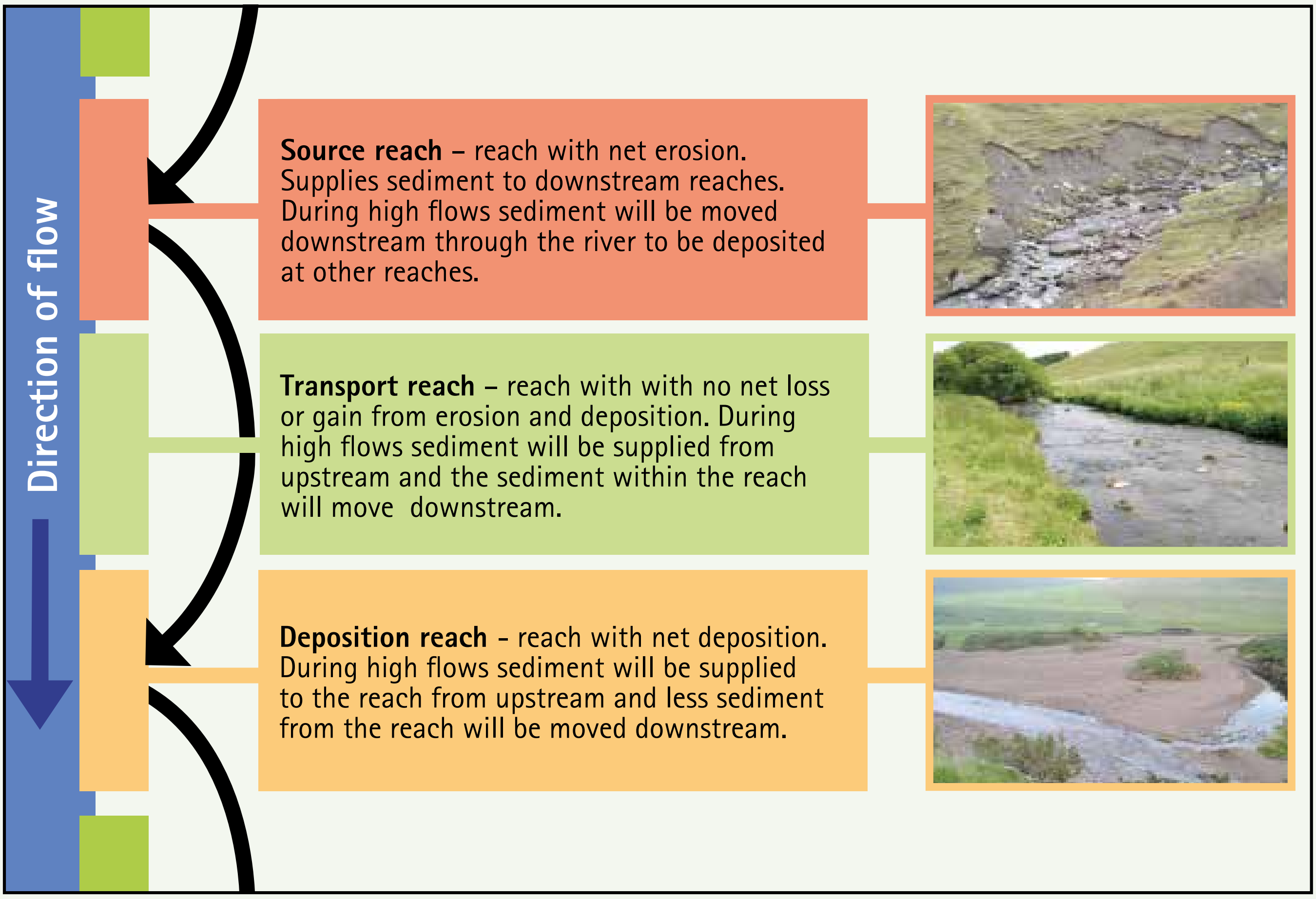
- Bank protection: rivers and lochs
- Riparian vegetation management
- Sediment management.

Stirling: SEPA. Available: http://www.sepa.org.uk/ [Accessed: January 2015]

## Box 2.3. Sediment management

Sediment is naturally eroded from the beds and banks of rivers and transported downstream, particularly during high flows and floods. Once the sediment reaches an area where the flow is slower and the river bed is flatter (an area of lower energy), the sediment is deposited. This process is repeated when, during the next period of high flow, the sediment is picked up and moved downstream once more.

A river will normally naturally adjust its shape to accommodate the amount of water and sediment moving through it. However, activities such as sediment removal or the straightening of the river channel will disturb natural processes and can cause excessive erosion or deposition. Land management activities on surrounding land may also contribute sediment to the river in the form of fine sediment laden runoff. Excessive deposition of sediment is a particular problem for flood risk management as it reduces the capacity of the river to transport water and may result in overtopping and flooding. Flood risk may also be increased in areas of high erosion where banks are retreating towards receptors such as property




**The movement of sediment through a river system**

The approach to managing excessive amounts of sediment depends on the underlying cause of the problem. For example, where sediment is being generated through land management activities, improvements to these practices will be the preferred route (see Sections 2.3.1 and 2.3.2). In many cases, however, this could take a long time to achieve so it may be more feasible to intercept the sediment laden runoff through, for example, the use of overland sediment traps (see Section 2.3.4).

Where alterations to the river channel or its banks have generated excessive amounts of in-channel sediment, river bank restoration or river/floodplain restoration may be appropriate. Direct removal of sediment from the river channel (dredging) is not a sustainable solution – further discussion on dredging is provided in a CIWEM publication (CIWEM[53]).

## 2.4.2. River morphology and floodplan restoration

**WHAT IS IT?**

Works that restore an altered river to a more appropriate shape and in turn reconnect the river with its floodplain.

This section focuses on larger scale river restoration projects that usually require a level of engineering to restore the shape (channel morphology) of a degraded river, such as channel realignment (remeandering) or embankment removal.

Traditionally many rivers have been managed in a way that increases the land available for agriculture or infrastructure (such as where a river has been straightened), or protects land from flooding (such as where embankments have been built). These actions have combined to disconnect rivers from their natural floodplains either directly (where an embankment has been built) or indirectly by altering channel morphology and reducing the potential for floodwater to spill out onto the floodplain. Generally, by reducing natural flood storage, the effect has been to increase the volume and speed at which the flood arrives downstream. In some cases the sediment dynamics of a river reach may also be adversely affected which in turn can impact ecology, including the habitats of aquatic species such as salmon and trout.

Restoring the channel morphology of rivers impacted in this way may involve works that increase the sinuosity of straightened channels (Figure 2.26) and/or directly reconnect the floodplain through removal, breaching or lowering of embankments (Figure 2.27). These measures are rarely implemented on their own, but in conjunction with other techniques such as riparian planting, creation of wetlands/ponds, instream gravel reinstatement, or the removal of artificial structures. In many cases it is not feasible to return the river to its original course (due to constraints or lack of knowledge about its original course). However, the objective should always be to restore as much of the natural functioning of the river as possible.

### 2.4.2.1. Technical considerations

The greatest benefits to flooding will be achieved by targeting measures to where floodplains are wide and flat and there is no risk to property or infrastructure. Pre-works assessments and surveys will be required to ensure that works do not increase flood risk (e.g. an embankment may be holding water back during a flood event and removal could increase flood risk). Where a watercourse is known to have been altered, remnant meanders can often be identified using aerial photos or historic maps. As might be expected, most studies of the effect of river and floodplain restoration on flooding report that the benefits are extremely site dependent. In particular, the extent of floodplain storage


**Figure 2.26. The Rottal Burn (South Esk), Angus, before, during and after work led by the Esks Rivers and Fisheries Trust to reintroduce meanders to a channelised reach: In addition to reducing flood peaks, this work sought to improve riparian and aquatic habitat and reduce the unnaturally high sediment load experienced downstream of the reach.**

available relative to the hydrograph volume appears to be a key factor in determining the influence of channel restoration on flood flows[56].

It is possible that some artificially straightened river reaches may begin to recover their original shape naturally. This depends on the energy of the river, and some straightened channels will be able to recover fairly quickly (over a period of years). In such cases the river can be allowed to recover sinuosity naturally, although a helping hand may be required in some locations. For example, some lower energy rivers may need instream structures such as woody debris to kick-start the processes of recovery by altering both the hydraulics and the distribution of flows in a channel and in turn the transport and deposition of sediments. Where the energy of the river is very low natural restoration may take decades to occur and a greater level of intervention may be required to achieve any benefits.

Care should be taken to avoid sediment entering the watercourse during the works and vegetative cover should be re-established on any bare ground. Works should be carried out by a contractor with experience in river works and preferably in spring to early autumn to reduce the risk of damage to the river environment. Best practice for engineering in the river environment should always be adhered to minimise these risks. Further information on best practice is available in SEPA's Engineering in the Water Environment Good Practice Guide on Temporary Construction Methods[57], which also includes references to additional guidance such as those produced by CIRIA.

Most large scale projects that involve changes to the morphology of a river will be informed by a feasibility study (or options appraisal) that identifies and reviews possible options. This is informed by a number of assessments and surveys, such as topographic, hydromorphological, flood risk and habitats/species surveys. Where a decision is made to progress works to implementation, design will also be required together with engineering drawings. Consultation should be undertaken with relevant specialists, including an experienced fluvial geomorphologist prior to starting any reach and floodplain restoration project and ideally throughout the duration of the project.


**Figure 2.27. The Braid Burn, Edinburgh, before and one year after work to lower an artificial raised bank and replace the concrete channel with sinuous meanders: This work formed part of wider flood alleviation works carried out by the City of Edinburgh Council that sought to also improve biodiversity and public amenity on this watercourse (© River Restoration Centre).**

### 2.4.2.2. Cost

The costs of works to restore a more natural shape to a river or to remove or lower embankments will depend on the scale and complexity of works as well as the extent of pre-works assessments and design required. Any loss of productive land may also require payment of compensation to the landowners/land managers affected. Payments are available (in target areas) in the Scottish Rural Development Programme for the removal, breaching or lowering of river embankments (see Chapter 8).

## Further reading and guidance

RIVER RESTORATION CENTRE (2002). Manual of River Restoration Techniques. Bedfordshire: The River Restoration Centre. [Online] http://www.therrc.co.uk/manual-river-restoration-techniques [Accessed: January 2015].

SEPA (2009). Engineering in the Water Environment Good Practice Guide - Temporary Construction Methods. Stirling: SEPA. Available: www.sepa.org.uk/. [Accessed: February 2015].

SEPA (2010). Engineering in the Water Environment Good Practice Guides: Sediment Management. Stirling: SEPA. Available: http://www.sepa.org.uk/ [Accessed: January 2015]

SEAR, D.A., NEWSON, M.D., and THORNE, C.R. (2003). Guidebook of Applied Fluvial Geomorphology. R&D Technical Report to Defra and the Environment Agency. FD1914. London: Defra. Available: www.randd.defra.gov.uk. [Accessed: January 2015].

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## 2.4.3. Instream structures

**WHAT IS IT?**

The introduction of woody material or boulders to a natural channel to slow the flow, increase instream water levels during moderate to high flows, and thereby increase water storage on the floodplain.

Historically, woody debris falling in rivers from surrounding vegetation was removed to increase channel capacity and reduce the likelihood of blockages downstream. While this approach is still necessary in some locations, there is an increasing understanding, particularly in the USA, of the potential for such structures to provide hydraulic resistance and so increase connectivity with the floodplain by backing up spate flows. The use of instream structures is associated with large amounts of uncertainty and may, in some cases, increase flood risk[59] by creating a blockage and/or backing up floodwaters where receptors are located. A clear understanding of the effect of any structure on water levels and direction of flows is therefore required.

Instream structures are typically locally derived as cut timber from large trees. Wooden structures can be designed with varying levels of complexity ranging from one or two pieces of wood located across a channel to dozens of stacked logs secured to the river bank (Figures 2.28, 2.29 and 2.30). Where possible, these instream structures are designed to emulate the natural complexity of rivers and create a diversity of habitats and flow conditions. Traditionally, these types of structures have been called ‘large woody debris’ or ‘engineered log jams’ but many other names exist (Box 2.4).

### Box 2.4. Instream wooden structures and engineered log jams

Wood that is purposely placed in the channel to improve biodiversity or slow flows has many names, including ‘large woody debris’, ‘wood placement’, ‘wood dams’ or, where built by beavers, ‘constructed beaver dams’. Engineered log jams (ELJs) also provide a similar function although, as the name suggest, the term usually refers to complex engineering structures. Further information on engineered log jams is provided in a SEPA commissioned document[58].

**Figure 2.28. An instream structure, secured with a wooden stake, in the Pickering Beck catchment, North Yorkshire (©Forest Research).**

**Figure 2.29. An instream structure in the Afon Gafenni catchment, South Wales: This structure is designed to slow high flows but does not impede fish passage. (© Forest Research).**

### 2.4.3.1. Technical considerations

The placement of any structure in a watercourse has the potential for both beneficial and adverse effects on habitats and flows. Assessment of whether instream structures may be appropriate therefore requires a comprehensive understanding of the hydromorphology of the reach in question, including the sediment regime and channel dynamics. This is particularly the case for larger structures such as engineered log jams. The type of structure used will depend on the objectives and acceptable levels of risk but should always consider what approach will be the most stable. Monitoring, such as fixed point photography, should be carried out following construction to ensure that there have been no adverse impacts of the works on flows or habitats (see Chapter 9).

Large wood structures placed in large rivers may need to be securely anchored in place using wooden anchors. The use of non-biodegradable materials such as wire cables should be avoided where possible, with the preferred aim being to mimic naturally occurring woody debris. Further discussion of the use of artificial stabilisation techniques is provided in Abbe et al[60]. Placing a log collector (trash screen) downstream of structures may be advisable where there is doubt about the extent to which the structure is secure. This could be as simple as timber piles in the ground across the floodplain.

Habitat surveys will be required prior to placement of structures in watercourses in order to establish that no important habitat is being damaged (e.g. otter and water vole habitat). Where trees are to be felled, it will also be necessary to check for the presence of nesting birds, bats and tree preservation orders. Structures must also be designed so as to permit fish passage. This can be achieved by placing the structure at a height that intercepts moderate to high flows but does not hinder low flows.

### 2.4.3.2. Cost

Cost is dependent on the amount of engineering required to install the structure and the extent of any pre works assessments. Felling and installation costs will typically range from £100 to £1000 per feature.

**Figure 2.30. An instream structure, which mimics naturally occurring woody debris, in the Pickering Beck catchment, North Yorkshire (© Forest Research).**

## Further reading and guidance

ENVIRONMENT AGENCY (2010). Water Framework Directive (WFD) Mitigation Measures Online Manual [Online]. http://evidence.environment-agency.gov.uk/FCERM/en/SC060065.aspx [Accessed: January 2015].

HERRERA ENVIRONMENTAL CONSULTANTS (2006). Conceptual Design Guidelines: Application of Engineered Log Jams. Report to the Scottish Environment Protection Agency. Available: http://www.sepa.org.uk/ [Accessed: January 2015].

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## 2.4.4. Washlands and offline storage ponds

### WHAT IS IT?

The controlled diversion of flood water on to the floodplain at time of high flows.

Washlands and offline storage ponds are areas next to a river or stream where flood water is directed at times of high flow. Typically, water is diverted and temporarily stored in purpose-designed areas of the floodplain where there is sufficient area for storage. These storage areas then drain back out into the watercourses after the main flood peak has passed downstream, usually via a controlled outlet. By diverting a proportion of the peak river flow out of the channel and into an offline pond or washland, a proportion of the flood flow can be attenuated. These features are significantly more engineered approaches to flood risk management than the other measures described in this handbook. They are included here as an example of how working with natural processes (floodplain storage), rather than restoring unconstrained natural conditions, can also provide sustainable flood risk management.

Offline storage ponds directly manage the flow of water via the use of intake and outlet structures and are usually separated from the river by structural barriers such as embankments or walls (Figure 2.31). Washlands differ in that they do not have a distinct inlet. Instead, raised banks are maintained at a height that permits overtopping during periods of high flow (Figure 2.33). Some washland schemes involve subdivisions of the floodplain into cells through the strategic placement of dividing embankments in order to maximise the retention of water on the floodplain.

The Belford project in Northumberland has highlighted the potential for a multifaceted approach to flow attenuation in the headwaters, that employs not only offline ponds, but the use of barriers such as earth bunds to intercept overland flow (together referred to as 'runoff attenuation features' or RAFs) (Figure 2.32). More details on this project can be found in the Case Studies at the end of this handbook.

**Figure 2.31. An offline storage pond in the Netherton Burn catchment, Northumberland: The pond has been designed in such a way as to offer additional water storage in times of high flow. The pond is supported by a series of sediment traps on the inflow points (© Tweed Forum).**

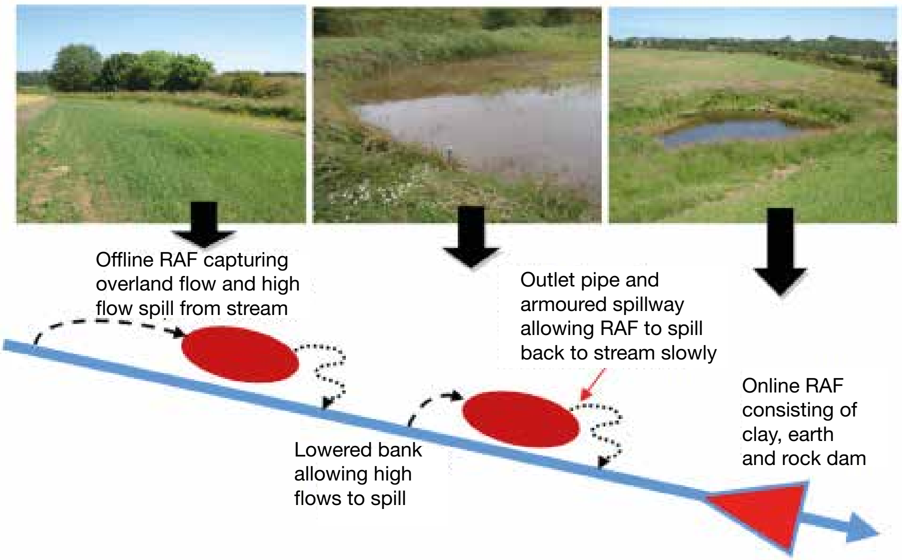


**Figure 2.32. Offline storage areas and other attenuation features (Runoff Attenuation Features) constructed in the Belford Burn catchment, Northumberland (from Wilkinson et al.[61]).**

### 2.4.4.1. Technical considerations

Planning and designing washlands and offline storage ponds is complex and requires a clear understanding of objectives in terms of the desired effects on the flood hydrograph (the change in flow over time during a period of rainfall). The Environment Agency's Fluvial Design Guide[62] should be referred to for detailed information.

Suitable sites for washlands or offline storage ponds will tend to be large floodplains with suitable foundations for supporting any embankments or control structures. Design will require consideration of the approach to transferring water to the storage area and back to the river (e.g. pipe or spillway) and how best to ensure that structures operate effectively during high flows. It will also need to consider where to direct water when the storage area reaches its capacity. Risk assessments should consider the potential for failure of any built components, such as embankments or walls, and monitoring and long-term maintenance should be carried out following construction to ensure that there are no adverse impacts of the works.

Where possible, the design should integrate flooding needs with those of biodiversity. Since the objective from a flooding perspective is normally to reserve the available storage area for the flood peak (rather than, for example, the ascending limb) this may mean that between floods the area is sometimes dry. From an ecological perspective, this may not be desirable and therefore a compromise between the two drivers may be necessary. Design of the feature should also consider the potential for impact on species and habitats, including the potential for stranding of fish when the storage area or pond drains following high flows.

Construction of offline storage ponds and washlands, together with the impoundment of a watercourse (if needed), may require formal consent/approval from the planning authority and SEPA. The level of consent required will depend on the volume of above ground storage, the existing environmental value of the watercourse and floodplain in question, and the nature of the downstream flood risk receptors. Large storage areas may be legislated under the Reservoirs Act (see Chapter 6 for further information about permissions).

### 2.2.4.2. Cost

Costs associated with these types of storage areas are extremely variable and will depend on the scale of the feature and associated structures. Most storage areas will also require pre-works assessments and surveys, formal consents and planning permission (for larger schemes) and periodic structural condition inspections, all of which will add to the cost.


**Figure 2.33. A washland in the Belford Burn catchment, Northumberland (© Newcastle University).**

## Further reading and guidance

ENGLISH NATURE (2001). Sustainable flood defence: The case for washlands. No. 406 – English Nature Reports. Peterborough: English Nature.

ENVIRONMENT AGENCY (2009). Achieving more: operational flood storage areas and biodiversity. Bristol: Environment Agency.

ENVIRONMENT AGENCY (2009). Fluvial Design Guide. [Online]. http://evidence.environment-agency.gov.uk/FCERM/en/FluvialDesignGuide.aspx

MORRIS, J., HESS, T.M., GOWING, D.J., LEEDS-HARRISON, P.B., BANNISTER, N., WADE, M. and VIVASH, R.M. (2004). Integrated washland management for flood defence and biodiversity. English Nature Research Reports. Silsoe, Bedfordshire: Cranfield University.

# CHAPTER 3:
## Coastal natural flood management

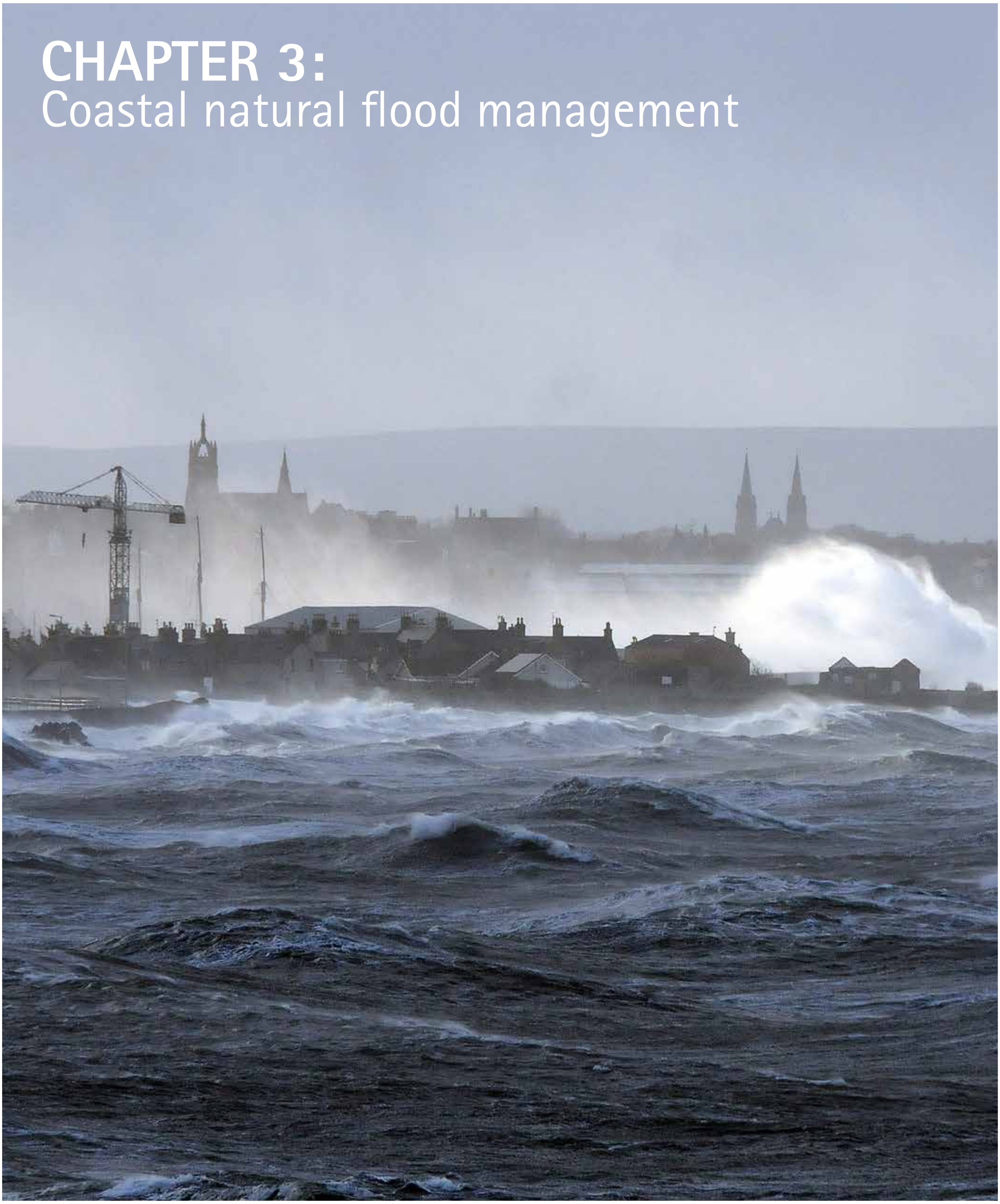

Figure 3.1. Coastal flooding in Buckie, Moray.

In our coastal regions, settlements, industry, tourism, agriculture and transportation sectors thrive. Nearly half (41%) of Scotland's population live within 5km of the coast, with 70% living within 10km[63]. This creates areas that can be vulnerable to coastal erosion and flooding (Figure 3.1). Many features of Scotland's coastline, such as sand dunes and beaches, provide a natural coastal flood defence. However, human activities such as land reclamation and the building of coastal structures can change the magnitude and direction of coastal processes, often accelerating erosion rates and increasing the risk of coastal flooding. This chapter describes the natural flood management measures on the coast and in estuaries that seek to work with natural coastal processes to help reduce the impact of coastal flooding on people, homes and businesses.

Our coastline is a dynamic environment that is constantly changing and influenced by a number of factors operating at a range of scales in space and time. These include the geological and glacial history, sea-level rise, sediment supply, wind, wave and tidal influences, and, increasingly over the last few hundred years, human activities. Coastal change can be extremely slow or extremely rapid depending on how these factors interact[64].

Coastal change includes cycles of erosion and deposition resulting from natural coastal processes. However, human activities such as land reclamation and building coastal structures can change the magnitude and direction of coastal processes, often accelerating erosion rates (Figure 3.2). In many areas engineering solutions to protect coastal infrastructure create a barrier between the land and the sea that prevents natural coastal retreat and reduces sediment supply to areas downdrift. This can accelerate erosion rates and increase the risk of flooding in areas that were previously stable or accreting. Research across the English and Welsh coast found that shorelines with sea walls experienced coastal steepening – a process whereby the high water mark is held in place by defences while the low water mark retreats landwards[65]. In the long term this lowering of the foreshore in front of coastal defences increases the risk of overtopping.

The NFM measures outlined in this handbook manipulate natural processes rather than restricting or opposing them. Where valuable assets and infrastructure are located close to the shoreline, fixed engineered structures often exist such as sea walls and revetments. Where there is opportunity, natural features should front engineered structures to improve the level of protection provided, help increase the design life of these structures and improve amenity and recreational value. If natural features such as beaches and saltmarsh are not present, expensive repairs and more regular maintenance to engineered structures is often required. This is due to increased exposure to wave and tidal energy undermining and breaching these structures. Long term this can make the cost of maintaining engineered structures with no natural frontage unsustainable. Where there is space or opportunity to move assets or infrastructure back (known as managed realignment), the reinstatement of natural features can create a more stable coastal frontage from which these assets can be better protected in the future.

Coastal processes are site specific and as a result management recommendations should be based on a site specific basis.

Most coastal areas lack continuous data collection or monitoring which can make development of appropriate coastal morphological models difficult[66]. This makes appropriate engagement with stakeholders and experts particularly important when considering coastal NFM measures. This chapter is intended as a short guide to the different types of coastal NFM measures and key considerations when implementing these. Where available, more detailed guidance is referenced. However, this is no substitute to site specific expert advice.

To understand why coastal NFM measures are appropriate it is essential to understand the mechanisms of coastal flooding, coastal processes and changes that will affect these processes.

**Figure 3.2. Eroding saltmarsh in the Nith estuary, Dumfries and Galloway.**

# 3.1. BACKGROUND

## 3.1.1. Scottish coastline

Scotland's coastline is particularly long and diverse. The total length of our coastline has been estimated at nearly 19,000km (increasing accuracy of measurements gives a longer length of coastline). The geology of the coastline shapes the topography, with rocks that are susceptible to erosion generally forming bays and inlets and erosion-resistant rocks forming headlands[64]. The north and west of Scotland is characteristically rocky and deeply embayed with numerous sea lochs and narrow straits whereas the east has a much simpler morphology with longer continuous sections of soft sediments. Using a coastal length of 11,200km, it has been estimated that 70% is hard coastline (hard rocks or cliffs) and 29% is soft coastline (gravels, sands and silts). Of the soft coastline, 12% is estimated to be eroding (~1,300km$^2$), 8% accreting and 5% is unknown. This is very similar to the total length of English coastline estimated to be eroding, although in England this equates to 30% of the total coastline length[67].

Unlike other parts of the UK, Scotland's coastline is mainly composed of resistant types of bedrock (Figure 3.3). Therefore, the depth of unconsolidated sediments is a more important factor when considering the risk of erosion[68]. NFM measures target softer coastlines and are the focus of this chapter. In practice NFM measures will reduce both coastal erosion and coastal flooding as it is coastal processes that result in both.

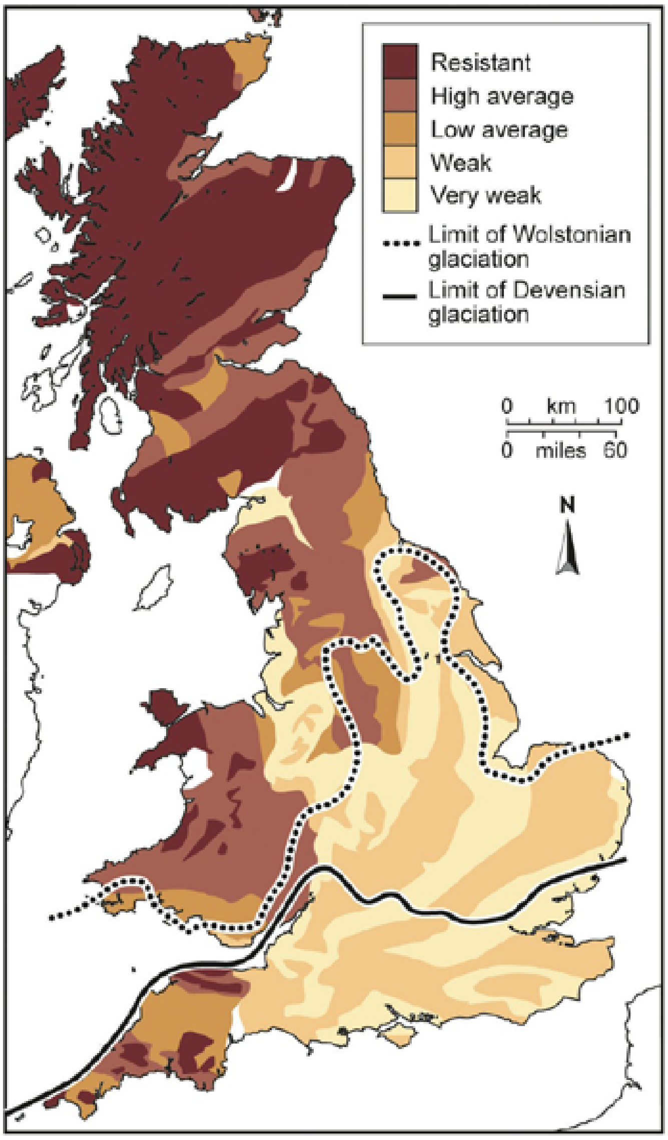


**Figure 3.3. Relative resistance of geology and extent of last glaciations: White areas are unclassified (from Clayton and Shamoon[69]).**

## 3.1.2. Scottish coastal flood risk

In 2011, the National Flood Risk Assessment identified 125 PVAs with some risk of coastal flooding. This was based on the extreme still water sea level using the POL 112 method. The coastal flood hazard maps developed by SEPA in 2013 use the Coastal Flood Boundary method. This method improves how to calculate extreme sea level but both methods project sea level onto the land, flooding everything located below this height. This is known as a still water projection model. The high (1 in 30 year), medium (1 in 200 year) and low (1 in 1000 year) probability coastal flood hazard and risk maps can be viewed on SEPA's website[13]. These maps estimate that approximately 11,000 homes and 4,000 non-residential properties are at risk from coastal flooding from a 1 in 200 year probability event.

Still water projection models do not take into account the potential effects of local wave action, topographic funnelling or local bathymetry and do not explicitly account for storm surge. These models can therefore under-estimate the risk of coastal flooding (although in some areas over-estimates are possible due to uncertainties associated with ground height and projected height of sea level). In some locations where local more detailed modelling was available this has been incorporated into the national maps.

# 3.2. COASTAL PROCESSES

## 3.2.1. What is coastal flooding?

The risk of coastal flooding (Figure 3.4) is a combination of the probability of the sea flooding land that is usually beyond the reach of astronomical tides and the presence of receptors that are damaged as a consequence (e.g. farmland, houses or industry). Most areas vulnerable to coastal flooding or erosion already have engineered structures present that affect coastal processes. This is due to historical actions taken to protect the shoreline, reclaim land or create ports and harbours.

The main mechanisms of coastal flooding (Figure 3.5) are:

1. Sea level is temporarily higher than existing structures (natural or engineered) due to storm surge and overtops these, flooding low lying land.
2. Wave and tidal energy causes a breach in existing structures (natural or engineered) due to storm surge or strong local winds, causing flooding of low lying land.
3. Waves are higher than existing structures (natural or engineered), allowing wave overtopping and/or waves to be blown onshore by strong local winds, flooding the land.

Mechanisms 1 and 2 can cause extensive flooding for kilometres where land is low lying because the volume of water is only limited by the length of time high water overtops these structures or exceeds the height of any breaches caused. The land is effectively reclaimed by the sea. Where a structure has been breached, it is possible that flooding will continue or reoccur even after a storm surge has passed if these structures are now lower than the next high astronomical tide. The third mechanism is only likely to affect receptors immediately behind existing structures for the duration of the storm surge or large waves, but can still result in significant damages.

**Figure 3.4. Coastal flooding caused by storm surge at Findochty, Moray.**

Sea level rise and climate change could result in higher tides, increased wave energy, waves from different directions and less space for intertidal habitats. This would increase the chances of all three coastal flooding mechanisms occurring.

## 3.2.2. Astronomical tides

Astronomical tides are very well understood and can easily be viewed from the United Kingdom Hydrographic Office (UKHO) Admiralty EasyTide website[70]. Tide heights are the result of the gravitational effects of the moon and the sun. The highest tides occur when the moon and sun align, pulling in the same direction. The height of tides also changes due to the elliptical shape of orbits, varying the Earth-sun and Earth-moon distances and thus the strength of the gravitational forces.

Tide tables usually show the time of high water and low water and the height in metres above chart datum. The UKHO use the Lowest Astronomical Tide (the height of water at the lowest possible spring tide predicted to occur under average meteorological conditions) as chart datum. In practice tides can be lower than chart datum due to meteorological conditions such as high atmospheric pressure or strong winds blowing away from the coast.

In Scotland there are usually two high tides and two low tides within a 24-hour period (known as semi-diurnal tides), with each tide recurring approximately every 12 hours. Spring tides have the largest tidal range and usually occur two days after the new and full moon (this can be anywhere from zero to four days after the new and full moon)[71]. The highest spring tides occur at equinoxes. Neap tides occur around the time of a half moon, known as the first quarter and third quarter moon. Neap tides have a more moderate tidal range, with lower high water levels. The moon takes about 27 days to orbit the earth, with spring tides occurring approximately every 14 days throughout the year (Table 3.1). The term 'spring' relates to the idea of tides 'springing forth' quickly due to the larger tidal range, not the season of spring.

**Table 3.1. An example of a tidal cycle in April in Aberdeen (high water level will change continuously as the moon orbits the earth) (from UKHO predicted tides).**

| Week 1* | Week 2* | Week 3* | Week 4* |
|---|---|---|---|
| Full Moon | Last Quarter Moon | New Moon | First Quarter Moon |
| Spring Tides | Neap Tides | Spring Tides | Neap Tides |
| Large tidal range | Small tidal range | Large tidal range | Small tidal range |
| 4th April Tides:<br>**HW** 01:18: **4.0m**<br>**LW** 07:13: **0.9m**<br>**HW** 13:29: **4.1m**<br>**LW** 19:32: **0.7m** | 12th April Tides:<br>**LW** 00:05: **1.6m**<br>**HW** 06:32: **3.5m**<br>**LW** 12:44: **1.4m**<br>**HW** 19:27: **3.5m** | 18th April Tides:<br>**HW** 00:36: **4.3m**<br>**LW** 06:38: **0.6m**<br>**HW** 12:46: **4.5m**<br>**LW** 19:03: **0.3m** | 25th April Tides:<br>**HW** 05:56: **3.6m**<br>**LW** 12:06: **1.3m**<br>**HW** 18:42: **3.4m** |

*The tidal cycle occurs over 27 days so each period is slightly less than a week (6.75 days).

Scotland has large tidal ranges; mean spring tides generally range between 3-5m. Therefore, the point in the tidal cycle is extremely important to the risk of coastal flooding. If storm surge and/or strong onshore local winds coincide with low spring tides in an area with a large tidal range, coastal flooding will not occur. If storm surge and/or strong onshore winds coincide with high spring tides, coastal flooding is very likely to occur. The tidal range is also extremely important to determine the type and extent of habitats that can establish. Frequency of inundation is a key factor, for example, in determining whether saltmarsh can establish.

## 3.2.3. Waves

Waves are generated by the wind blowing over the sea surface. When waves are generated due to offshore winds they are known as swell waves. When waves are generated due to local winds they are known as wind waves. Swell waves are generated over larger regions and as such have a longer wave period and more power. Wave run-up and overtopping is also much greater in swell waves than wind waves of equivalent height[72]. The larger the distance of uninterrupted open water that wind can blow over in the same direction (known as fetch), the larger swell waves can be. The largest significant wave heights come from winds from the north, due to the larger fetch. Storm surge is the increase in height due to swell waves and low atmospheric pressure.

## 3.2.4. Storm surge

Storm surge is the temporary increase in the height of the sea due to meteorological conditions (low atmospheric pressure and strong winds). Areas of low atmospheric pressure (depressions) cause corresponding rises in sea level; a 10millibar decrease in pressure raises sea level by about 10cm. However, it is strong offshore winds that contribute most to increases in sea level height. Storm surges have a characteristic timescale of several hours to one day and a wavelength equivalent to the width of the centre of the depression; typically between 150km to 800km. The atmospheric pressure in normal conditions is usually 1013 hPa.

Storm surge can change the time of high water from what would be expected from astronomical tides (Figure 3.6). When storm surge occurs at the same time as high astronomical tides, coastal flooding is often the result. This is particularly important in Scotland, where the mean spring astronomical tidal range is generally between 3-5m and as much as 8m in the inner Solway Firth. The greatest loss of life caused by a surge recorded in the last 100 years was in 1953 where levels of 0.6m were recorded at Aberdeen and 0.83m recorded at Leith. The atmospheric pressure fell to 964hPa contributing to 0.4m of the storm surge. Northerly gales propagated the storm surge southwards along the relatively shallow North Sea where it amplified, reaching 2.97m in southern England and 3.36m in the Netherlands[73]. This caused huge loss of life; 19 people in Scotland, 307 in England and 1,800 in Netherlands. In the UK, 160,000 acres of land was flooded with huge damages caused to infrastructure and thousands of people evacuated[74].

## 3.2.5. Sediment dynamics

Coastal erosion and deposition are natural processes. For sections of coasts to erode, more material has to be removed than supplied. Shorelines that are eroding at noticeable rates are often typified by soft or loose sediments that are subject to high wave energy and/or accelerated sea level rise.

Natural sources of sediment include:

- rivers transporting sediment to the coast;
- glacially derived sands and gravels from offshore sediment deposits brought to the shoreline by currents and tides; and
- active erosion of the shoreline (e.g. cliffs or soft sediments located updrift).

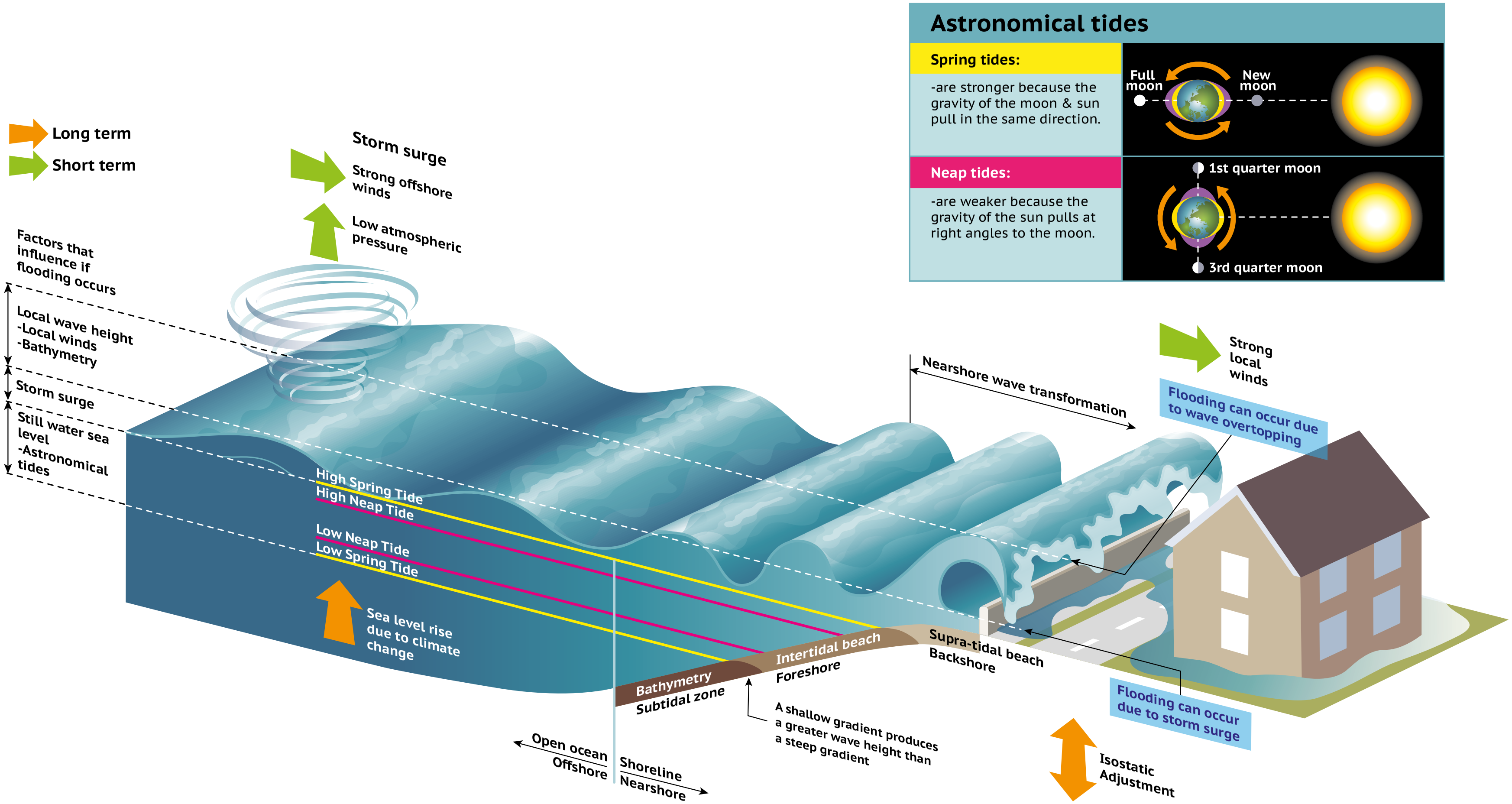


Figure 3.5. Coastal flooding mechanisms: The processes that influence sea level and wave height. Coastal flooding often occurs when storm surge coincides with high spring tides.

Offshore sediment deposits, resulting from glacial erosion, have historically supplied most of Scotland's coastal sediments. However, these deposits are finite and have become progressively less important, with less sediment within reach of an effective wave base to be brought to the shoreline[75]. Changing land use patterns in river catchments can also lead to significant indirect or direct changes to sediment supplied to the coast, accentuating erosion or accretion. Dam construction significantly reduces sediment supplied to the coast from rivers, as do river bank protection measures. Most rivers in Scotland are thought to no longer supply a significant amount of sediment to the coast, with the exceptions of the Findhorn, Spey and to a lesser extent the Dee[77].

Once at the coast, sediment is transported along the shoreline (known as longshore drift). The direction of sediment transport is largely determined by the angle of wave approach. However, human activities can interfere with coastal sediment movement and coastal sediment balance. It is important to understand what has caused a reduction in sediment supply when this is the underlying cause of coastal erosion and flooding. To determine this, any recent or historic changes to areas updrift that could be causing this should be identified. This could include past removal of sediment for aggregates, dredging for navigational purposes or construction of structures such as piers, sea walls, revetments or groynes.

Analysis of historical data sets and recent surveys can inform understanding of the sediment budget. This along with other factors will help inform if coastal recharge is an option and if so indicate the volume, extent and frequency of repeated recharge that may be required to maintain a stable beach. Scotland has been divided into 11 sediment cells (Figure 3.7)[76]. Sediment movement should be confined within these cells, with longshore drift generally occurring within sediment sub-cells.

The sediment cell approach, for considering appropriate coast protection actions based on an understanding of sediment movement around the coast, is most appropriate within cells 1, 2, 3 and 6[77]. The impacts of any flood protection measures on sediment transport and potential effects up or down-drift should be carefully considered, particularly within these four cells. Shoreline Management Plans prepared in these areas should geographically cover the entirety of these cells. The various sediment cell reports are available to download from the publications section of the Scottish Natural Heritage website[78].

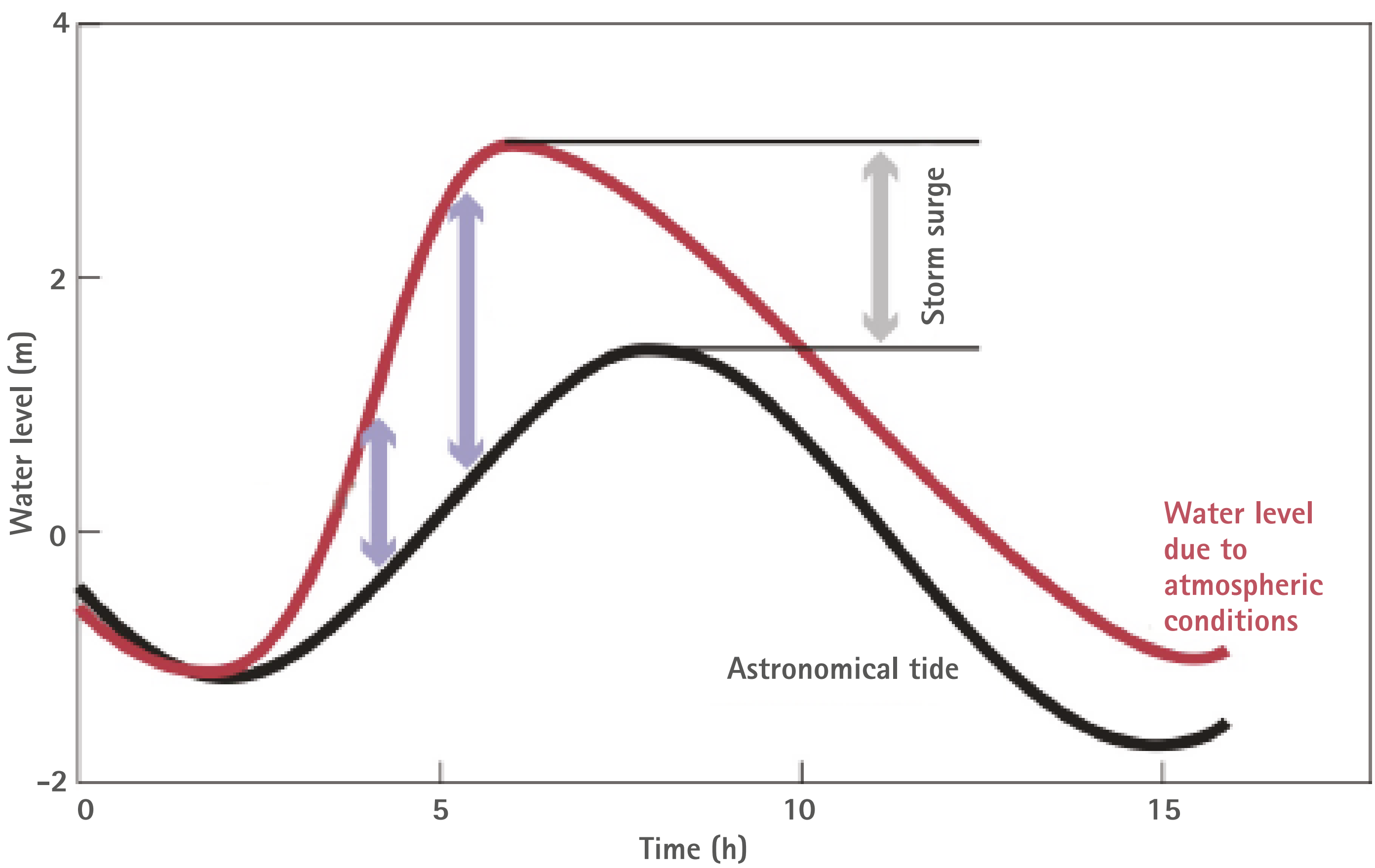


**Figure 3.6. Storm surge can change the time of high water and significantly increase the height of sea level from that predicted by astronomical tides (adapted from Lowe et al.[79]).**

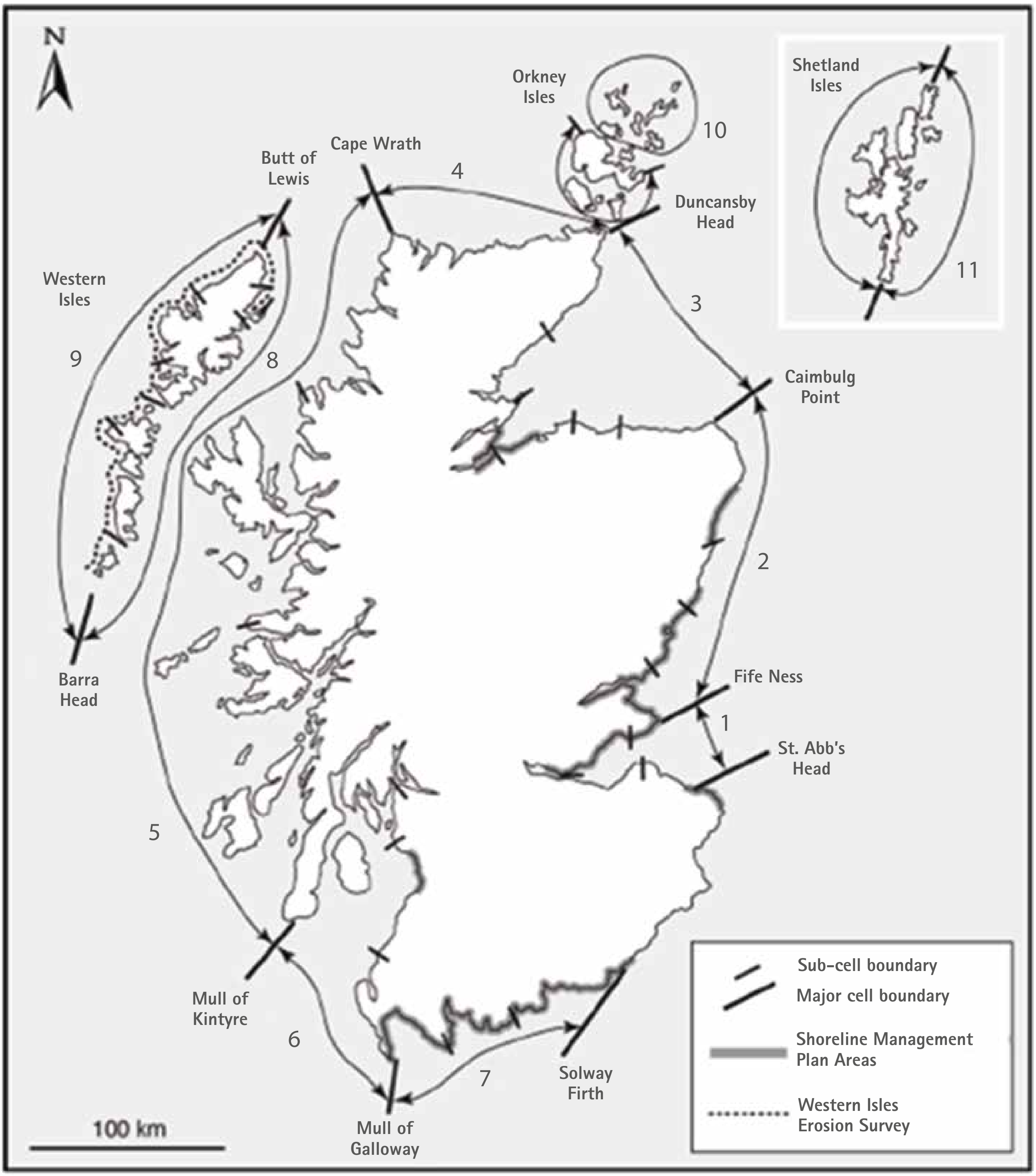


Figure 3.7. Coastal sediment cells and sub-cells in Scotland as identified by HR Wallingford in 1997: The coast covered by Shoreline Management Plans is also shown - although not an SMP, the Western Isles Coastal Erosion Survey is shown (from Hansom et al.[75]).

## 3.3. FUTURE COASTAL FLOOD RISK

There are three main factors important for future coastal flood risk. These include:

- relative sea level rise;
- future wave climate (wave height, period and direction); and
- future storminess.

Sea level is rising; the only uncertainties are around the rates of relative sea level rise. It is very likely that rates of relative sea level rise will increase in Scotland. There is less certainty around potential changes to wave height and prevailing wind direction or changes to the frequency and intensity of low pressure systems. It is possible that climate change could result in an increase in the frequency or intensity of storm surges and/or the impacts could be worse due to changes to the angle of approach of waves. However, the factors influencing this are very complex and evidence of long term trends very variable.

### 3.3.1. Relative sea level rise

The key drivers for sea level rise are thermal expansion of water and meltwater from ice caps, glaciers and the Greenland and Antarctic ice sheets. It is estimated that in the 21st century, 70% of global sea level rise will be due to thermal expansion with the remainder due to melting of ice caps, glaciers and ice sheets[72]. At the last glacial maximum, approximately 18,000 years ago, sea water was locked up in huge ice sheets up to 3km thick and global sea level was some 120-140m below the present day. Some 10,000 years ago, sea level was approximately 40m below present and 5,000 years ago came within 10m of present sea levels[75]. Sea level has continued to rise, with an observed approximate rise of 14cm in global mean sea level since 1900[80]. Global sea level rise has accelerated between the mid-19th century and mid-20th century and is now around 3mm per year[79]. It is very likely that human activities (emissions) have contributed to sea level rise during the latter half of the 20th century.

However, it is relative sea level that is important (absolute sea level relative to vertical land movement) (Figure 3.8). The weight of the last ice sheets depressed land beneath them and forced land in surrounding non-glaciated areas upwards. The melting of these ice sheets has resulted in glacial isostatic adjustment, with uplift of land occurring where ice sheets were located and subsidence of land occurring beyond these extents[81]. This causes variable relative sea level change around Britain. Most of central Scotland benefits from isostatic uplift. This isostatic uplift varies locally and currently occurs at rates of between 0.2mm per year in Western Isles and 1.4mm year in the Clyde [81].

The UK Climate Change Impacts Programme (UKCP) has projections of future mean absolute sea level rise calculated in 2009 (Table 3.2). These are based on model frequency distributions (not probability distributions as with other climate change projections). Three emissions of greenhouse gases scenarios were developed by the Intergovernmental Panel on Climate Change (IPCC) to inform these climate change projections (high, medium and low).

When land movement is taken into account the central estimates for relative sea level rise are lower for many areas of Scotland, but still within the ranges for each emissions scenario (Table 3.2). Recent research found the short-term tidal records of Scottish ports (between 1992 and 2009) correspond with high emissions scenario projections. Under high emissions scenarios the rate of local sea level rise is greater than currently expected rates of isostatic uplift. As a result, many areas of Scotland are likely to experience accelerated rates of relative sea level rise. The present rates of relative sea level rise for Islay, Aberdeen, Wick and Stornoway lie between 5.5-6.2mm per year, corresponding with high emissions scenarios[82]. SEPA use high emissions 95th percentile scenarios to appraise appropriate measures to reduce the risk of coastal flooding in the Flood Risk Management Strategies.

Sea level also varies regionally and locally, affected by ocean circulation and geographical variations in the temperature or salinity of the water column. These factors are also likely to change with global warming. However, the implications of these changes are currently not well understood. These factors have not been included in climate change projections so it is possible that sea level rise could exceed 95th percentile high emissions scenarios. It is also recognised that there is a lack of current scientific understanding of some aspects of ice sheet behaviour and thus estimates of melting rates included in climate projections may not be accurate[79]. As such a high-plus-plus scenario was also developed that can be viewed in UKCP09 marine and coastal projections report[79].

**Table 3.2. Predicted UK mean sea level change (cm) over the 21st century (representing average in UK region) including ice melt, under three different scenarios, with 5th to 95th percentile confidence intervals – changes are given for the period 1980–1999 to 2090–2099 (from Lowe et al.[79]).**

| Emissions scenario | 5th Percentile | Central estimate | 95th Percentile |
|---|---|---|---|
| **High** | 15.4 | 45.6 | 75.8 |
| **Medium** | 13.1 | 36.9 | 60.7 |
| **Low** | 11.6 | 29.8 | 48.0 |

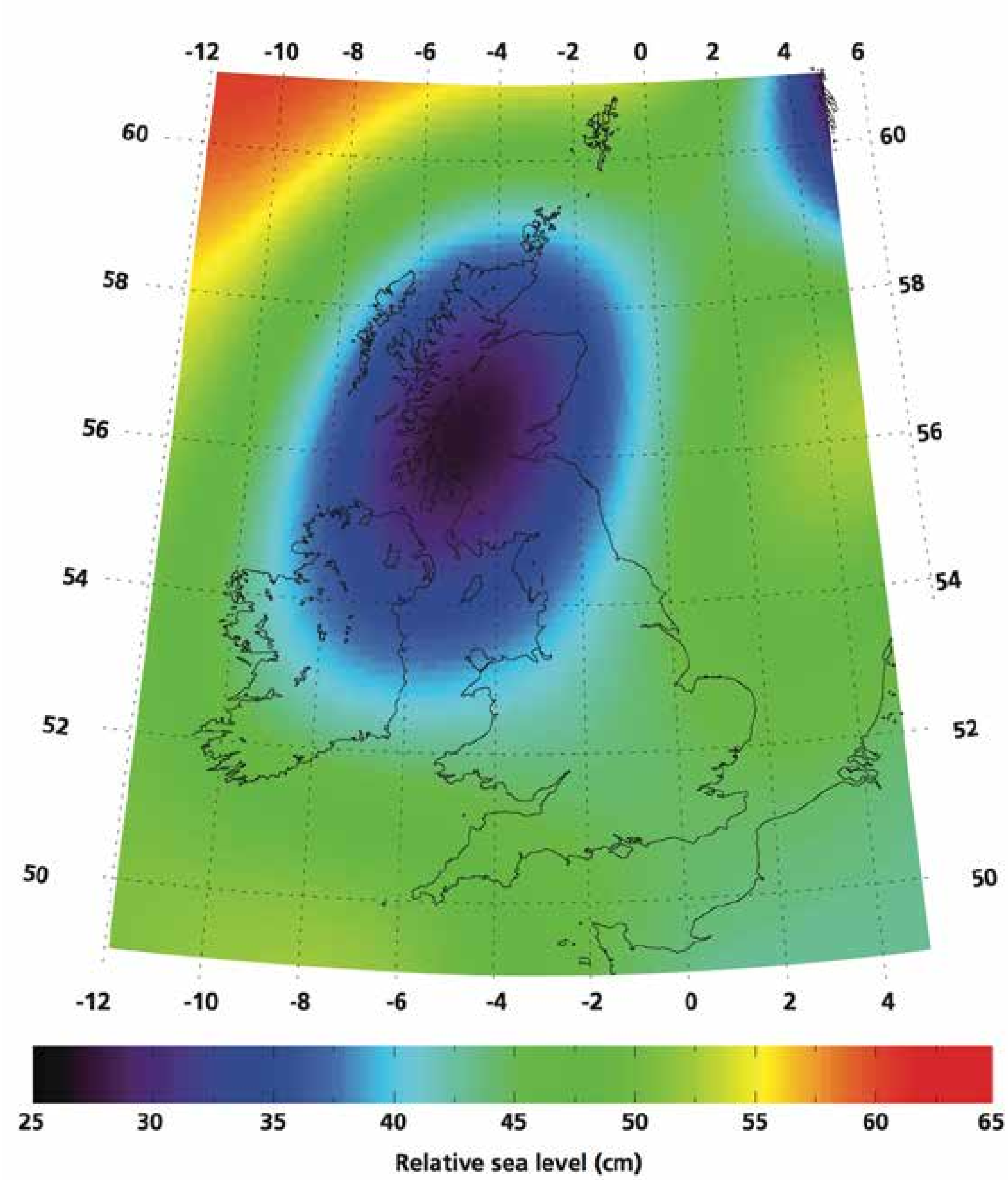


**Figure 3.8. Predicted relative sea level change (cm) around the UK over the 21st century: This combines the absolute sea level change estimates averaged around the UK for the central estimate for the medium emissions scenario and vertical land movement. Values are appropriate to 2095 (from Lowe et al.).[79]**

## 3.3.2. Storm surge and waves

The UKCP09 statistical analysis found that surge levels for return periods between two and 50 years was not projected to increase by more than 9cm by 2100 anywhere in the UK (not including mean sea level change)[16]. There is no observational evidence for regional trends in either storm surge frequency or magnitude over recent decades.

Severe windstorms have become more frequent in the past few decades, however, not above storms seen in the 1920s. There is little evidence for any long-term trends in wind storms[83]. There may be a change in the prevalence of high and low pressure systems. Storm tracks may shift in latitude or become more or less intense. The effect on waves is an integration of the effects of wind speed, fetch and duration. If recorded reductions in Arctic sea ice continue, the increased fetch could increase wave height generated by northerly winds and thus the risk of coastal flooding from storm surge. Further work is needed to fully understand what the potential impacts of climate change could be[84].

# 3.4. COASTAL NATURAL FLOOD MANAGEMENT MEASURES

The following sections outline the various approaches that can be used to increase the natural resilience of the shoreline to improve flood and erosion protection. The common theme within these options is that they aim to improve the volume, altitude and health of natural buffers, thus helping to absorb wave and tidal energy. In addition to the further reading and guidance detailed in the individual sections below, a wide variety of coastal case study examples can be found in the Online Marine Registry[85].

In Scotland, the Crown Estate manages about half of the coastal foreshore and almost the entire seabed. Consent for the use of the foreshore and seabed within Crown Estate ownership must be sought from the Crown Estate Commissioners and a lease may be required. Many coastal NFM measures will also require a permission from Marine Scotland under the Marine (Scotland) Act 2010 (see Chapter 6 for further information on permissions).

## 3.4.1. Managed realignment

**WHAT IS IT?**

The removal of part (breach) or all of existing coastal structures. Where there is no naturally occurring high ground, new flood protection structures are created further inland, creating a new or 'set back' line of protection.

Managed realignment can be used in estuaries or along the coastline, making space for the habitats that would naturally occur (Figures 3.9, 3.10 and 3.12). It is most appropriate on softer coastlines, making space for mudflats, saltmarsh and shingle or sandy beaches. The necessary techniques to restore these habitats and their benefits for reducing the risk of coastal flooding is described in subsequent sections.

**Figure 3.9. Managed realignment and saltmarsh restoration at Hesketh Out Marsh, Ribble Valley Lancashire: Breaches were made in existing defences to create a new line of setback defence and encourage saltmarsh regeneration.**

In Scotland managed realignment schemes have been implemented at Nigg Bay in the Cromarty Firth and the Firth of Forth. Managed realignment is most often considered an option where land reclaim has historically occurred (land that was intertidal has been drained and structures built to prevent inundation, creating land used for agricultural or industrial purposes). Reclaimed land has often been developed without proper consideration for the long-term sustainability of maintaining the structures preventing this land from returning to intertidal habitat. This can result in houses or infrastructure located behind coastal structures that landowners have no obligation to maintain. In the future landowners may decide it is too costly to keep maintaining these structures; for example, if the benefits from cultivating reclaimed land are less than costs of repairing the coastal embankment. In the Firth of Forth, 50% of the formal intertidal area has been reclaimed over the last 400 years, along with substantial areas of the Clyde and to a lesser extent the Tay and Inverness Firths [75].

### 3.4.1.1. Technical considerations

#### Where is managed realignment appropriate?

There are many factors that influence whether managed realignment is appropriate at a location. For flood protection purposes it is only likely to be appropriate where the whole life costs are less than maintaining the current structures or no active intervention. Where existing structures are failing and not maintained, realigment can occur naturally. This is termed 'no active intervention'. In Scotland, this has been allowed to progress at Alloa and Tullibody Inches in the Upper Forth. In an estuary it is particularly important to consider the effects of managed realignment on the tidal prism to ensure that the measure does not result in an increase in flood risk elsewhere (see Box 3.1).

The consequences of no active intervention are considerably uncertain as breaches can occur in undetermined locations to unpredictable heights and widths[86]. As a result the planned and more predictable approach of managed realigment is often preferred. Managed realigment schemes create a more sustainable buffer between receptors and the sea. Sea level is rising, squeezing the space available for intertidal habitats where coastal strcutures exist. Where it is not possible to build up sediments fronting existing structures and this space is limited, managed realignment may be the only sustainable option (to avoid the base of existing structures being located below mean low water in the future, which could make future maintenance very costly, difficult or not feasible). Table 3.3 outlines some of the key considerations to determine whether managed realignment is appropriate.

### Implementing managed realigment

The are two main ways to achieve realignment:

- remove parts of the existing protection structure (creating a breach or several breaches); or
- remove the entire length of the existing protection structure.

The appropriate approach to take depends on the location. Complete removal interferes least with natural processes but is more expensive and may not always be feasible. Once partial inundation occurs the risks to continue working to remove the entire structure can be deemed unacceptably high.

The timing of works is important and is largely determined by the tides. If the existing structure is always above high water at neap tides this may be an appropriate time to carry out works. If not, it may be more appropriate to carry out works over one low spring tide. In estuaries it is generally not feasible to carry out works over the winter months as this can disturb protected over-wintering or feeding birds.

Where there is no naturally occurring higher ground, it is likely that construction of a secondary landward embankment or bund is required, particularly in estuaries. This structure must be impervious to water. Some of the key considerations when constructing an embankment include[87]:

- crest levels should be at least 1m above the maximum anticipated water level;
- the width of the structure should be at least five times the height;
- banks holding back water should have a gradient no steeper than 1 in 3;
- earth structures should be constructed to compensate for settlement (height can reduce by as much as one third); and
- provision should be made for the introduction of water control structures to allow for drainage of surface water from the land to the sea.

**Figure 3.10. Managed realignment at Nigg Bay on the Cromarty Firth, Ross and Cromarty. Two 20m wide breaches in existing sea defences were made to allow sea water to flood a 25ha field thus reducing the maintenance requirements of the existing failing defences and creating important habiat (© N. Russell, RSPB).**

**Table 3.3. Favourable and unfavourable factors when considering managed realignment.**

| Favourable factors | Unfavourable factors |
|---|---|
| • Naturally occuring higher ground (negating the need to build flood protection structures further inland) | • Presence of contaminated land such as landfill sites or refuse-filled seawalls |
| • Existing flood or coast protection structures have a low cost-benefit ratio | • Presence of infrastructure not designed for saline conditions that is very costly to move (e.g. electric or gas cables) |
| • Existing flood or coast protection structures are in poor condition and/or reaching the end of design life | • Presence of scheduled monuments or sites of historic importance |
| • Existing structures were built for land reclamation purposes (e.g. agricultural embankment) and structural integrity, design life or levels of protection provided are unknown | • Presence of protected areas that would not benefit from managed realignment |
| • Landowners are willing to lose some land to the sea | • Poor site access |

## Box 3.1. Tidal prism

The tidal prism is the volume of water that enters and leaves an area over a single tidal period. This could be an entire estuary or a managed realignment site.

The tidal prism can be calculated by subtracting the volume of water over an area at mean low water from the volume of water at mean high water. This largely determines the velocities that may occur and helps inform whether erosion, deposition or sediment transport is likely. In an estuary, the effects of NFM measures on the tidal prism are larger due to the smaller volume of water in an estuary compared with the sea.

Creating new intertidal areas increases the tidal prism of an estuary, causing more water to enter and leave the estuary within the tidal cycle. This can result in increased erosion in lower reaches of the estuary as tidal velocities are increased due to the greater overall volume of water entering and leaving the estuary. This could affect coast protection structures or habitats located elsewhere in the estuary. Potential effects are very site specific but will depend largely on the shape of the estuary, the size and location of the site within the estuary, tidal range and levels and sediment budget. Hydraulic modelling can assist in identification of the most appropriate realignment options to ensure changes to hydrodynamics and water levels do not result in increased flood risk elsewhere.

### Regulated tidal exchange

Regulated tidal exchange is when the inundation of land (behind existing structures) is artificially controlled by sluices, tide gates, spillways or pipes that are built into the existing structures (Figure 3.11). This can be used as an interim step in areas where the tidal velocities created by a breach or removal of the existing structures would likely result in erosion. In these areas regulated tidal exchange can help to build up sediment, raising land levels and establishing vegetation that will be stable or accreting when part or all of the existing structures is removed. However, regulated tidal exchange is generally more appropriate where the primary objective is habitat creation, rather than reducing flood risk. If regulated tidal exchange is considered as an interim option a number of fundamental requirements should be identified including[88]:

Figure 3.11. Regulated tidal exchange at Skinflats, Firth of Forth estuary: a pipe and sluice (pictured) mechanism was installed to regulate the inflow of sea water onto a grass field, providing a new line of defence and creating new habitat.

- tidal range is at least 3m;
- underlying geology is not prone to erosion or contamination of aquifers (not appropriate on peat or chalk but is appropriate on clays or silts);
- sufficient suspended sediment in the sea water to allow accretion within the site; and
- land behind the existing structures is 10cm lower than high spring water tides (a hydraulic head of less than 10cm is insufficient to ensure adeqaute flows onto and off the site).

### 3.4.1.2. Cost

The costs of managed realignment are extremely variable and will largely depend on:

- whether part or whole of the existing structure is removed;
- whether a secondary flood protection structure is required further inland;
- whether it is necessary to purchase land or provide compensation payments;
- whether recharge, re-profiling and/ or restoration of habitats is required; and
- the baseline and ongoing monitoring required (see Chapter 9).

Payments are available (in target areas) in the Scottish Rural Development Programme for coastal embankment, breaching, lowering or removal.

## Further reading and guidance

BROOKS, W. and SHARPE, J. (2003). Regulated Tidal Exchange: An Inter-tidal Habitat Creation Technique. Peterborough: Environment Agency.

LEGGETT, D. J, COOPER, N. and HARVEY, R. (2004). Coastal and estuarine managed realignment – design issues: CIRIA C628. London: CIRIA.

NOTTAGE, A. S. and ROBERSTON, P. A. (2005). The saltmarsh creation handbook: a project manager's guide to the creation of saltmarsh and intertidal mudflat. London: RSPB.

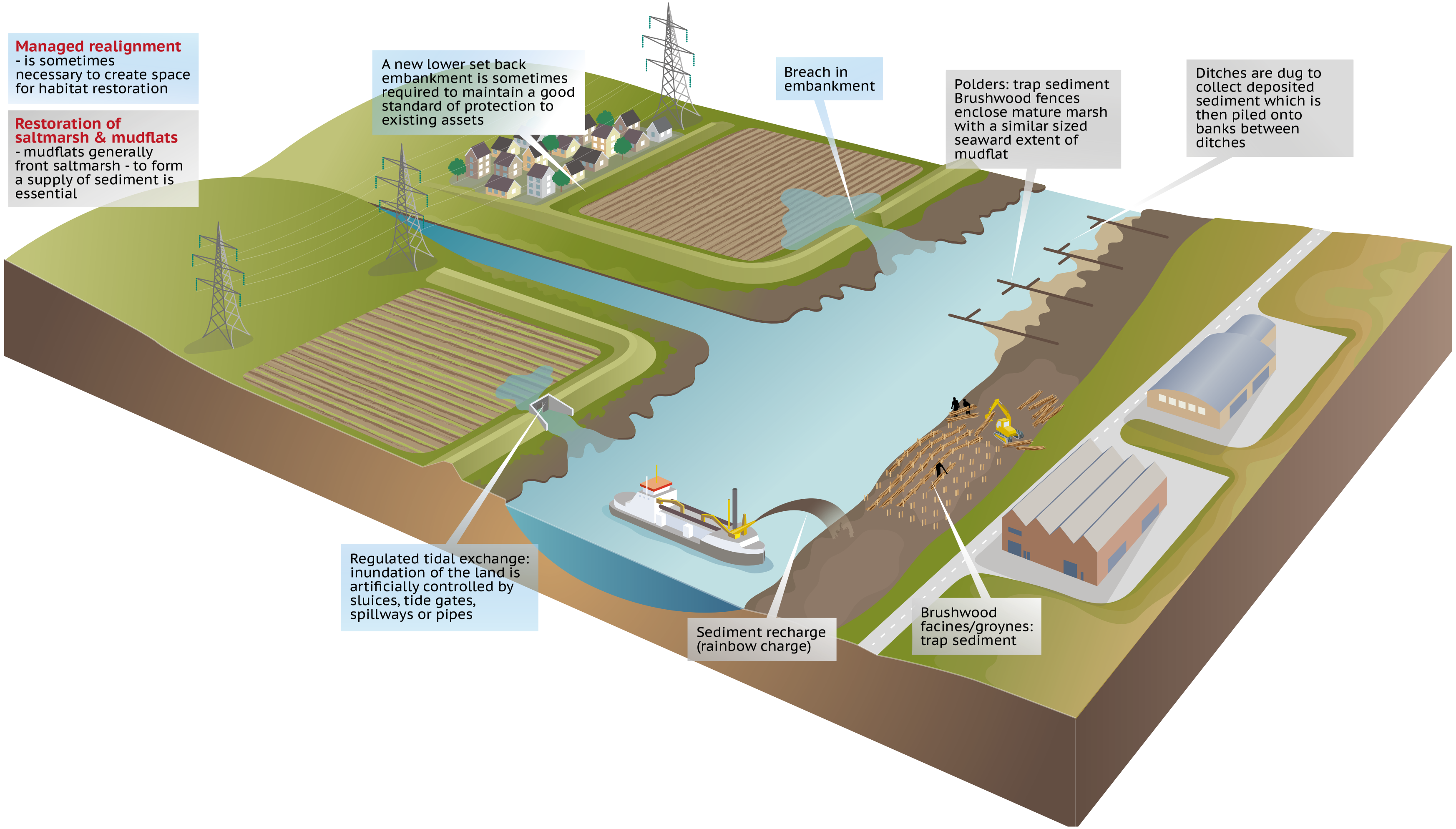


Figure 3.12. Natural flood management techiques in an estuary: managed realignment and inter-tidal habitat restoration.

## 3.4.2. Saltmarsh and mudflat restoration

**WHAT IS IT?**

The restoration of intertidal habitats such as mudflats and saltmarsh to create space to dissipate wave and tidal energy.

Saltmarsh vegetation consists of a limited number of salt tolerant species that are adapted to regular immersion by the tides. A natural saltmarsh system shows clear zonation according to the frequency of inundation (Table 3.4). There are approximately 40 species of higher plants found in British saltmarshes, but individual marshes generally have between 10 to 20 species[89].

**Figure 3.13. Saltmarsh at Bonar Bridge on the Dornoch Firth estuary, Sutherland: The saltmarsh provides space for wave and tidal energy to dissipate.**

**Table 3.4. Zonation of intertidal habitats and types of species found in each type of habitat (adapted from Boorman et al.[94] and Nottage and Robertson[87]).**

| Inundations (per year) | Habitat zones | Tidal zone | Plant community composition |
|---|---|---|---|
| 450 | Mudflat | Up to mean high water neap tides | None |
| 300-450 | Pioneer marsh | Centred around mean high water neap tides; above lowest neap tides | Open communities with one or more of Spartina spp., *Salicornia* spp. or *Aster tripolium* |
| Less than 300 | Low marsh | Centred around mean high water; inundated by most tides | Generally closed communities with *Puccinellia maritima* and *Atriplex portulacoides* (and previous species) |
| | Middle marsh | Only inundated by spring tides | Generally closed communities with *Limonium* spp. and/or *Plantago* (and previous species) |
| | High/ Upper marsh | Only inundated by the highest spring tides | Generally closed communities with one or more of *Festuca rubra, Armeria maritima* or *Elytrigia* spp. (and previous species) |
| | Transitional marsh | Inundated occasionally by tidal surges during extreme storm events | Vegetation intermediate between high marsh and non salt-tolerant species |

Saltmarsh and saltmarsh creeks can contribute to flood risk management by dissipating wave and tidal energy (Figures 3.12 and 3.13). A study of wave attenuation over a 180m wide salt marsh in Norfolk compared to a 197m wide sand flat, for example, found that the saltmarsh dissipated total wave energy by an average of 82%, while the un-vegetated sand flat only dissipated an average of 29% of total wave energy[90,91]. A recent controlled experiment in a wave flume estimated that up to 60% of observed wave reduction was due to the presence of saltmarsh vegetation. Although waves progressively flatten and break vegetation stems, reducing dissipation, the marsh substrate remains stable and resistant to surface erosion, creating a sustainable defence[92]. Even a small width of fronting saltmarsh can significantly reduce the height of sea walls required to achieve the same level of protection and thus initial construction costs (Table 3.5). It will also significantly reduce maintenance costs due to the reduced exposure to wave and tidal energy.

## 3.4.2.1. Technical considerations

### Where is restoration of saltmarsh appropriate?

Saltmarsh and mudflats are generally located together; with mudflats fronting saltmarsh. To form these habitats, fine grained sediments (silts and clays) need to settle out of the water column, which will only occur at very low water speeds (less than 0.0002cm/s$^{-1}$). As such saltmarsh will generally only form in areas with a wind fetch distance of less than 2,000m[93]. Therefore, saltmarsh is usually found in estuaries or sheltered areas such as bays or at the head of sea lochs. The overall shape of the estuary or bay determines the location and extent of saltmarsh versus mudflat. The four elements to allow colonisation of a mudflat and growth of saltmarsh are[94]:

- relatively stable (slowly accreting) area of sediment exposed to the air for more time than it is inundated by the tide;
- suitable suspended sediments present in the water during the inundation period;
- sufficiently low water speeds to allow some of this sediment to settle out; and
- a supply of appropriate seeds or propagules to establish vegetation cover.

For initial colonisation of mudflat, it is important that pioneer species seeds are present. It has been shown that there should be sufficient suspended sediment in the water to allow an accretion rate of 3-10mm per year, but an accretion rate greater than 150mm per year can smother new vegetation[93]. Development of mature saltmarsh typically takes between 40 to 80 years[94]. However, this will not be possible in all locations, particularly where existing protection structures restrict the establishment of higher zones.

It can be difficult to determine if conditions are favourable for the establishment of saltmarsh. In addition to favourable physical processes, the presence of nutrients and/or chemical pollutants can also affect whether saltmarsh can colonise mudflat. Therefore, it is generally better to increase the extent or facilitate the relative stability of existing saltmarsh, rather than attempt to establish this habitat in new areas where it has not been present historically. In Scotland, there are a large number of areas with relatively small areas of saltmarsh (75% of sites have an area of less than 10ha)[94]. Where new structures are being installed as part of port activities or flood or coastal protection schemes, this may create new areas where saltmarsh can be established.

**Table 3.5. The value of fronting saltmarsh in reducing the cost of seawall construction (adapted from Nottage and Robertson[87]).**

| Width of saltmarsh fronting seawall | Height of seawall required | Cost (£ c. 1994) per metre of seawall |
|---|---|---|
| 0 | 12 | 5,000 |
| 6 | 6 | 1,500 |
| 30 | 5 | 800 |
| 60 | 4 | 500 |
| 80 | 3 | 400 |

### Restoring saltmarsh

The tidal range will largely determine the extent of saltmarsh habitat that can be established. To increase the space available for saltmarsh, mudflat can be extended seawards or a managed realignment approach can be taken, moving existing coastal structures landwards (see Section 3.4.1). To extend mudflat seawards, it may be necessary to undertake trickle or rainbow charging (see Section 3.4.5). Mudflats, because they are cohesive and composed of fine sediments, take longer to dewater, consolidate and develop an infauna of microorganisms. Therefore recharged sediment will need some protection from the waves and tides to allow it to settle[95].

Sediment can be placed at various levels in the morphological profile:

- a thin layer of sediment can be sprayed over existing habitat to increase existing intertidal elevation; or
- sediment can be placed in the intertidal zone to artificially increase the intertidal area; or
- sediment can be placed in the sub-tidal zone to reduce erosion from intertidal margins.

To encourage sediment to settle and saltmarsh to establish the following techniques can be used:

- **Brushwood fascines/groynes:** Small wooden posts erected in parallel rows and in-filled with brushwood to create a small fence. Other materials can be used but brushwood has been found to be the most durable. The best orientation is generally at right angles to the foreshore[96].

- **Polders:** Brushwood fences or fascines are erected that enclose a width of mature marsh with a similar sized seaward extent of mudflat. Ditches are dug to collect deposited sediment, which is then piled onto banks between the ditches[96].

Saltmarsh can be left to naturally colonise the mudflats. However, unless there are good natural sources of local seeds, planting or sowing will be needed (Figure 3.14). Planting has generally been shown to be more effective than sowing[94]. Other key influences to saltmarsh successfully establishing are outlined in Table 3.6.

**Table 3.6. Influences on the successful establishment of saltmarsh.**

| Negative Influences | Positive Influences |
|---|---|
| • Trampling<br>• Invasive species<br>• Unsuitable soils e.g. non-saline arable soils (if managed realignment)<br>• Waves generated by ferry or boat wash<br>• Pollution or disease | • Cutting or grazing of vegetation to encourage growth |

**Figure 3.14. Saltmarsh restoration on the Eden estuary, Fife: This project was undertaken to help protect the coastline from erosion and benefit wildlife (© C. Maynard).**

### 3.4.2.2. Cost

The majority of the costs associated with establishing saltmarsh will be the associated costs of recharge (Section 3.4.5) or managed realignment (Section 3.4.1) required. If polders are used, the costs of establishing and maintaining these can also be significant. A number of options are available in the Scottish Rural Development Programme to assist with the restoration of intertidal habitats.

## Further reading and guidance

ADNITT, C., BREW, D., COTTLE, R., HARDWICK, M., JOHN, S., LEGGETT, D., MCNULTY, S., MEAKINS, N., and STANILAND, R. (2007). Saltmarsh management manual: R and D Technical Report SC030220. Bristol: Environment Agency.

LEGGETT, D. J, COOPER, N. and HARVEY, R. (2004). Coastal and estuarine managed realignment – design issues: CIRIA C628. London: CIRIA.

NOTTAGE, A. S. and ROBERSTON, P. A. (2005). The saltmarsh creation handbook: a project manager's guide to the creation of saltmarsh and intertidal mudflat. London: RSPB.

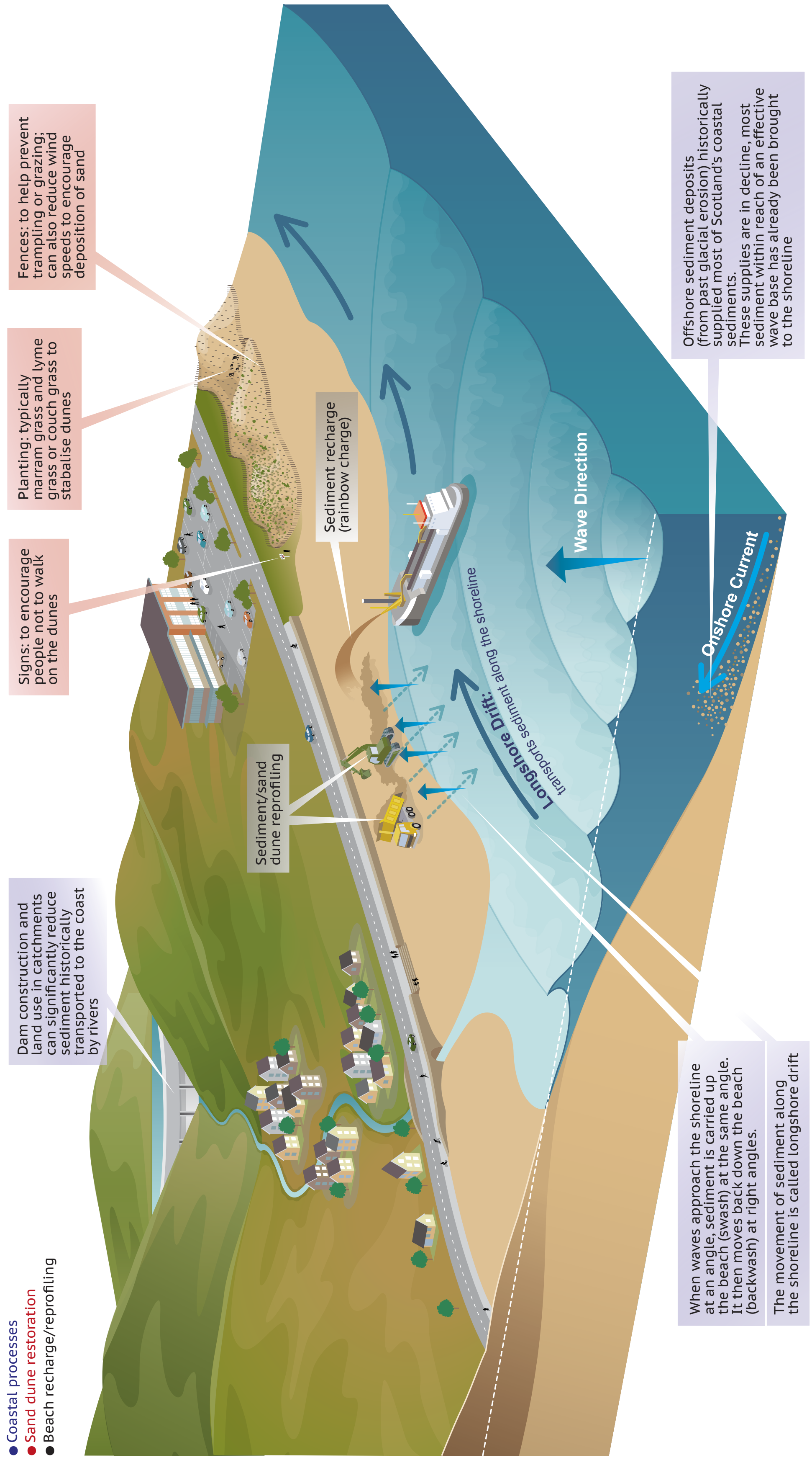


Figure 3.15. Natural flood management techniques along the shoreline: Beach management.

## 3.4.3. Sand dune restoration

**WHAT IS IT?**

The planting, thatching and fencing of a sand dune subject to erosion for the purpose of restoring stability to the sand dune and increasing its ability to dissipate wave energy.

Dune systems occur in a variety of different coastal settings e.g. estuaries or open coast, and have different morphological forms and levels of stability. Foredunes generally front the dune system located adjacent to the shoreline, with older lower dunes extending further inland. Where the beach and frontal dune sediment budget are positive, embryo dunes can form seawards of the existing frontal dunes, eventually forming new frontal dunes that extend the whole dune system seawards[99]. A total of 50,000 hectares (71% of the UK total) of sand dune habitat is located in Scotland. Coastal dunes in the UK can grow to maximum height of 50m above sea level and extend up to 10km inland, although most dune systems are more modest[97].

Unlike other coastal habitats, aeolian (wind driven) transport of unconsolidated sediments is particularly important in forming dune systems. The relative balance of wind energy from different directions, particularly onshore versus offshore, has a profound effect on the overall sand drift potential, dune mobility and dune morphology[98]. Where the natural mobility of a sand dune system is restricted by artificial structures and infrastructure, sediments blown inland beyond the dune system can be lost from the system and cause problems for roads, transport or properties located there. The Resultant Drift Direction can be calculated to determine the net sand transport potential. The amount and frequency of rainfall is also important. Rainfall directly increases the wind velocities required to move sand and indirectly increases vegetation growth, which helps stabilise dunes. The balance between the beach sediment budget and foredune sediment budget is critical to determining whether a dune frontage will experience erosion, accretion, or remain in equilibrium but with changes in dune height [98].

### 3.4.3.1. Technical considerations

The importance of sand dunes in flood protection depends on the height and width of the dunes relative to the assets located inland. Dunes can act as a natural dynamic coastal defence, absorbing wave energy and releasing sediment to the beach during storms and rebuilding by wind action during periods of fair weather. Continuous dune ridges provide the best flood protection value, with blow outs and/or low or narrow points creating areas more vulnerable to flooding. Dune systems less than 5m wide and/or less than 2m high can be considered to have little flood protection value as it is easily possible for such dunes to be eroded or severely overtopped in a single storm[99]. Vegetated dunes are more stable, effectively trapping sand and binding it together with root systems, creating a more effective flood protection structure.

#### Where is sand dune restoration appropriate?

Where space exists, frontal dunes should be allowed to roll inland and establish a new equilibrium. In areas of low wind energy or a negative beach sediment budget this is not likely to be possible and artificial dune profiling and restoration may be required[99]. Generally to reduce the risk of flooding, restoring sand dunes is primarily about stabilising or increasing the height, width or accretion rate of eroding dunes. Where current rates of erosion are between 1m-10m per year or dunes have been badly trampled it is likely that immediate action is required. Where erosion is less than this, action may not be required as dunes could be in dynamic equilibrium (cyclically eroding and accreting), or the erosion could be insignificant [97].

Under extreme storm conditions or a series of smaller events that occur close together in time, a dune system may be eroded altogether, overtopped or flattened. Wind scour of newly exposed sand can accentuate this. In these cases, restoration may be appropriate to accelerate natural recovery processes and maintain levels of flood protection [99].

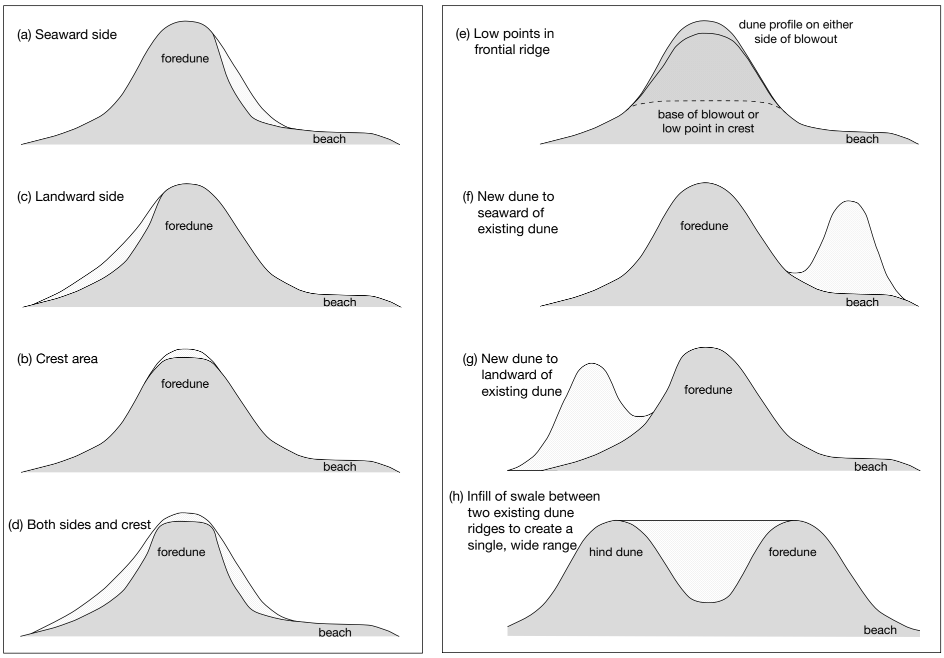


**Figure 3.16: Alternative sand dune deposition strategies for dune enhancements (adapted from Pye et al.[100]).**

### Restoring sand dunes

Restoration of sand dunes is achieved by reducing the erosion of sand. Unlike other coastal habitats this also includes reducing wind erosion. It is likely to be necessary to reprofile or recharge dunes prior to undertaking measures to stabilise dunes (Figure 3.15). Figure 3.16 gives an overview of the different sand deposition strategies to enhance dune systems.

The following measures can be undertaken to help stabilise dunes[97]:

- **Fencing:** Fencing should be parallel to the dune face with short spurs running perpendicular to the dune. This should be slightly forward of the toe of the dune. A void-to-solid ratio of 30-50% is recommended. Fencing helps prevent trampling or grazing and can also reduce wind speeds to encourage deposition of sand.
- **Thatching:** This is the placement of timber or brushwood cuttings on the exposed dune surface to reduce wind speed and increase deposition of sand. It is particularly effective where the amount of wind-blown sand is considerable. It is recommended that thatch should cover 20-30% of the exposed sand surface and should not be carried out on slopes with a gradient greater than 1:2. Beach users often remove thatching to make bonfires so ongoing maintenance is required.
- **Planting vegetation (Figure 3.17):** Typically marram grass (*Ammophilia arenaria*), lyme grass (*Leymus arenarius*) or couch grass (*Elymus farctus*) are used. It is best to transplant established dune grasses from a nearby site and is likely to take two to three years before transplants begin to thrive and spread. The vegetation and root network physically trap and hold sand in place, with organic matter and microorganisms also crucial to binding sand grains together. It is recommended vegetation should be planted at least 30m or greater landward of mean high water.

### Machair

Machair is a form of dune grassland that is almost unique to the British Isles, with 60% occurring in Scotland. However, it is a habitat largely created by human interventions including grazing, cultivation, addition of seaweed fertiliser and artificial drainage[75]. Machair is usually fronted by a dune system and often has lochs or wetlands landward of these. It is likely the existing habitat will be part of a protected area. If there are high value receptors at risk of flooding, and restoration of sand dunes is favoured, the techniques are likely to be similar.

**Figure 3.17. Sand dune restoration at St Andrews West Sands, Fife: Beach recharge, sand dune reprofiling and restoration was undertaken to improve the resilience of the dunes to manage flood and erosion risk (© R. Strachan/Fife Coast and Countryside Trust).**

## 3.4.3.2. Cost

The majority of costs will comprise any recharge or re-profiling works required. Fencing or thatching is likely to have moderate costs but will require ongoing maintenance. Planting is likely to have low to moderate costs as conservation groups can often help with planting. Ongoing monitoring is also required (see Chapter 9).

## Further reading and guidance


BRAMPTON, A., MOTYKA, G. and COSTES, T. (2000). A Guide to Managing Coastal Erosion in Beach/Dune Systems. Perth: Scottish Natural Heritage.

BROOKS, A. (2001). Sand Dunes: A Practical Handbook (second edition). British Trust for Conservation Volunteers. [Online]. http://store.tcv.org.uk/product/sand-dunes-a-practical-handbook. [Accessed: April 2015].

LIVERPOOL HOPE UNIVERSITY (*no date*). The Sand Dune and Shingle Network [Online]. www.coast.hope.ac.uk. [Accessed: April 2015].

PYE, K., SAYE, S. and BLOTT, S. (2007). Sand dune processes and management for flood and coastal defence, Part 1: Project overview and recommendations, R&D Technical Report FD1302/TR. London: Defra.

ROGERS, J., HAMER, B., BRAMPTON, A., CHALLINOR, S., GLENNERSTER, M., BRENTON, P. and BRADBURY, A. (2002). Beach Management Manual (second edition), CIRIA 685. London: CIRIA.

## 3.4.4. Shingle restoration

**WHAT IS IT?**

The movement of existing or new sediments placed on the foreshore to create a more desirable morphological profile that is better able to dissipate wave energy and attenuate storm surge.

Shingle beaches are mobile structures developed in high-energy environments that are very efficient at absorbing and dissipating wave energy. The height of shingle beaches and ridges is also often above astronomical tidal levels, providing an effective barrier against storm surge.

The term shingle is an imprecise term that can be used to describe a beach with significant proportions of gravel or cobbles (sediment with a grain size of between 2mm and 200mm). Most shingle beaches contain a significant proportion of sand or smaller sediment particles below the surface that influence the permeability of the shingle and mobility of the larger gravels or cobbles[102]. This, along with wave action will influence the beach profile and whether vegetated shingle can form. Restoration of shingle involves re-profiling to create a more desirable profile or planting of vegetation to stabilise shingle habitats.

### 3.4.4.1 Technical considerations

#### Restoring a shingle ridge

Re-profiling (Figures 3.18 and 3.19) is appropriate where previous management practices have created a very high, narrow shingle ridge for flood protection or where a recharge scheme is being undertaken and it has not been deemed appropriate to allow the shingle ridge to form naturally. In some cases, it may also be undertaken to repair a breach following a storm. However, care should be taken that re-profiling does not reduce the availability of sediment downdrift, potentially increasing flood or erosion risk there. In more stable beaches it can be more damaging to try to repair a shingle breach due to the impacts on vegetation and invertebrates associated with these structures.

When realigning or restoring a shingle ridge, a naturally wide profile should be aimed for in order to maximise the absorption of energy, although storm surges may still overtop the ridge. Historically managed shingle profiles have often been much steeper as a result of moving sediment upwards to create a higher crest levels or seawards to maintain the existing defence alignment. This puts the shingle ridge into contact with greater wave energy rather than allowing natural shoreline migration (with rising sea levels). Although this decreases the risk of overtopping, it increases the risk of a catastrophic breach and is unlikely to be sustainable[86].

**Table 3.7. Types of shingle beach and vegetation found (adapted from Doody and Randell[101])**

| Type of shingle beach | Common vegetation |
|---|---|
| Unstable beaches (common in high energy situations) | None |
| Beaches stable between spring and autumn | Summer annuals (e.g. *Galium aparine* and *Atriplex* spp.) |
| Beaches stable over 3-4 year periods | Short-lived perennials (e.g. *Sedum acre, Desmazeria marina*) |
| Beaches stable over 5-10 year periods | Long-lived perennials (e.g. *Cramble maritime, Suade vera, Silene vulgaris*) |
| Beaches stable over very long periods | Heath or heath grass vegetation (e.g. *Arrhenatherum elatius, Festuca rubra*) |

**Figure 3.18. Replenishment and reprofiling on the shingle at Chesil beach, Dorset: This work was undertaken in order to increase protection to the community of Chiswell following significant storms (© Environment Agency).**

**Figure 3.19. Shingle restoration at Spey Bay, Moray – Scotland's largest shingle beach (© Sally Gemmell).**

### Restoring vegetated shingle

The vegetation found on shingle beaches is largely determined by the stability of the beach[101] (see Table 3.7). However, sediment composition is also important, for example whether sand, silt, clay or organic matter dominate the finer sediment particles present. Restoration of vegetation is appropriate where a more stable shingle beach profile is desirable. For flood protection purposes, it is only appropriate as an additional measure where recharge and or re-profiling have been undertaken.

Vegetated shingle habitats are rare in part due to a lack of nutrient rich beds. Some fine material in shingle substrates improves plant germination and survival but excessive quantities can encourage weeds or invasive species. Possible approaches to the restoration of vegetated shingle include:

- allowing natural regeneration;
- using the natural seed bank;
- sowing seeds; and
- planting container-grown plants.

It is unclear which methods are most effective. However, it is important to wait until beaches have been reshaped by winter storms before attempting to plant vegetation.

### 3.4.4.2. Cost

The costs will be largely dependent on whether recharge is also required. Re-profiling costs will be determined by the size of the scheme. The costs of planting are likely to be minimal, although storms can undo this work. It may be appropriate to let nature take its course rather than try to restore vegetation (providing there is a natural supply of seeds). Baseline and ongoing monitoring is key to track success.

## Further reading and guidance

DOODY and RANDALL (2003). A guide to the management and restoration of coastal vegetated shingle. English Nature.

LIVERPOOL HOPE UNIVERSITY (*no date*). The Sand Dune and Shingle Network [Online]. www.coast.hope.ac.uk. [Accessed: April 2015].

## 3.4.5. Recharge (beach or intertidal)

**WHAT IS IT?**

The placement of sediment (mud, sand or shingle) usually on the intertidal foreshore for the purpose of dissipating wave energy. It can also be called beach nourishment or beach feeding.

Beach recharge involves the importing of mud, sand or shingle to replenish that lost to erosion and is appropriate where loss of sediments, sea level rise or reclaimed land is the underlying cause of a coastal flood risk (Figures 3.15 and 3.20). It typically requires dredging of the seabed to obtain the new material, although alternative sources such as inland sand and gravel pits may be able to provide sufficient material if the project is small in scale. The new material is placed anywhere from the upper beach to the nearshore, depending on the features of the site and the material used.

Where the source of sediment (Figure 3.7)is obtained within the same coastal cell, this is known as recycling. Recycling means there is no net loss or gain of sediment to the system. This is only appropriate if there is an area downdrift that is significantly accreting. If sediment is imported from outside the coastal cell there is a net gain to coastal system that can also benefit areas downdrift (Figure 3.15).

**Table 3.8. BS material size classification (adapted from Rogers et al.[102]).**

| Type | Material | Material size (mm) |
|---|---|---|
| **Sand** | Fine | 0.06-0.2 |
| | Medium | 0.2-0.6 |
| | Coarse | 0.6-2.0 |
| **Gravel** | Fine | 2.0-6.0 |
| | Medium | 6.0-20.0 |
| | Coarse | 20.0-60.0 |
| **Cobble** | Cobble | >60.0 |

### 3.4.5.1. Technical considerations

#### Where is recharge appropriate?

The most important consideration for recharge schemes is the composition of sediment particles and quantity of sediment required (Table 3.8). This will determine appropriate sources of sediment. Particle size and composition should be similar to that of the existing intertidal area to facilitate natural sediment sorting and a natural morphological profile. The existing sediment composition of a site acts as a good guide to sediments that are likely to be stable and not lost offshore. Coastal morphological profiles must be considered as whole units; changing the upper part of the profile and neglecting the inter and subtidal zones will not promote natural processes and enhance coastal stability[95]. It is also essential to understand the likely downdrift sediment movement (see Section 3.2.5). Where there is minimal or slow downdrift sediment movement, recharge will be effective over longer timescales.

#### Sources of sediment (mud, sand or shingle)

The main sources of sediment recharge material are[102]:

- existing licenced offshore aggregate dredging areas;
- offshore seabed deposits, where a specific dredging licence would need to be obtained;
- port and harbour maintenance and capital dredging operations;
- natural inland sand and gravel deposits and quarried rock; and
- secondary aggregates (by products from industrial processes) or recycled aggregates (materials from demolition or evacuation).

Most of the material used for recharge in the UK comes from marine-dredged sediments. In Scotland there are currently no offshore aggregate dredging licences, with most of the areas located in the south west or east of England. The distance from a sediment source to the beach may make transport costs prohibitively expensive for many areas in Scotland. Similarly the exploration costs, environmental statement, permissions and lead times required could make locating a suitable offshore seabed deposit near to the beach difficult. However, the British Geological Survey has identified several potential sources of aggregate deposits that could be exploited in the future[103].

Major navigation dredging and port improvement schemes can often create an incentive for beach recharge schemes due to the requirement to find a beneficial use for dredged material. This is better than disposing of the dredged material offshore, with reduced environmental effects and potentially reduced transport costs and disruption to local fisheries. In Scotland, 70,000m$^3$ of coarse sand material removed from Montrose Harbour was successfully used to recharge Aberdeen beach in 2006.

Where beaches are accreting, sediment can be moved from accreting areas updrift to eroding areas to help recharge and re-profile the beach. In Scotland, this has been successfully used to recharge and re-profile St Andrews West Sands beach (see Chapter 10). If recharging with non-marine sediments it may also be important to consider the mineralogy and shape of the sediment used. Softer materials may have a higher abrasion rate, so the sediment particle size decreases over much shorter timescales than those naturally found (which are often very hard materials that have been present for thousands of years[102]).

### Sediment recharge techniques

There are a number of techniques available to recharge sediment. These are similar regardless of the particle size i.e. whether the habitat is mudflat, sandy beach or shingle beach. The three main techniques are:

- Rainbow charge: sediment is sprayed onshore from a dredger creating a rainbow effect. This is usually done at slack low water to maximise onshore sediment transport. This allows sediment to be placed high on the foreshore. Nearshore bathymetry restricting vessel access can exclude this option.
- Pipeline Discharge: direct placement of material via a pipeline from an offshore location/location of sediment source. Pumping distances or potential disruptions to navigation can restrict this option. Sediment can also be pumped onshore via a pipeline from a dredger.
- Trickle charge: strategic placement of sediment in mounds in intertidal zone or directly into the water column, allowing waves and tides to rework sediment to settle on the foreshore. This will only be effective if the coastal processes favour accretion of sediment.

**Figure 3.20. Recharge underway at Aberdeen beach to protect sea defences and dissipate wave energy.**

## 3.4.5.2. Cost

Costs for recharge and re-profiling schemes are extremely variable. These will depend on:

- size of scheme;
- source of material;
- method of recharge;
- method and extent of re-profiling (if any);
- frequency of replenishment; and
- baseline and ongoing monitoring required.

In most cases it is likely that restoration measures will need to be undertaken to complement the sediment recharge and re-profiling (Sections 3.4.2 to 3.4.4). Recharge is often used in combination with other engineered structures such as offshore breakwaters, groynes or polders to restrict the movement of sediment away from the area that has been recharged and encourage further accretion.

## Further reading and guidance

ROGERS, J., HAMER, B., BRAMPTON, A., CHALLINOR, S., GLENNERSTER, M., BRENTON, P. and BRADBURY, A. (2002). Beach Management Manual (second edition), CIRIA 685. London: CIRIA.

# CHAPTER 4:
# The multiple benefits of natural flood management

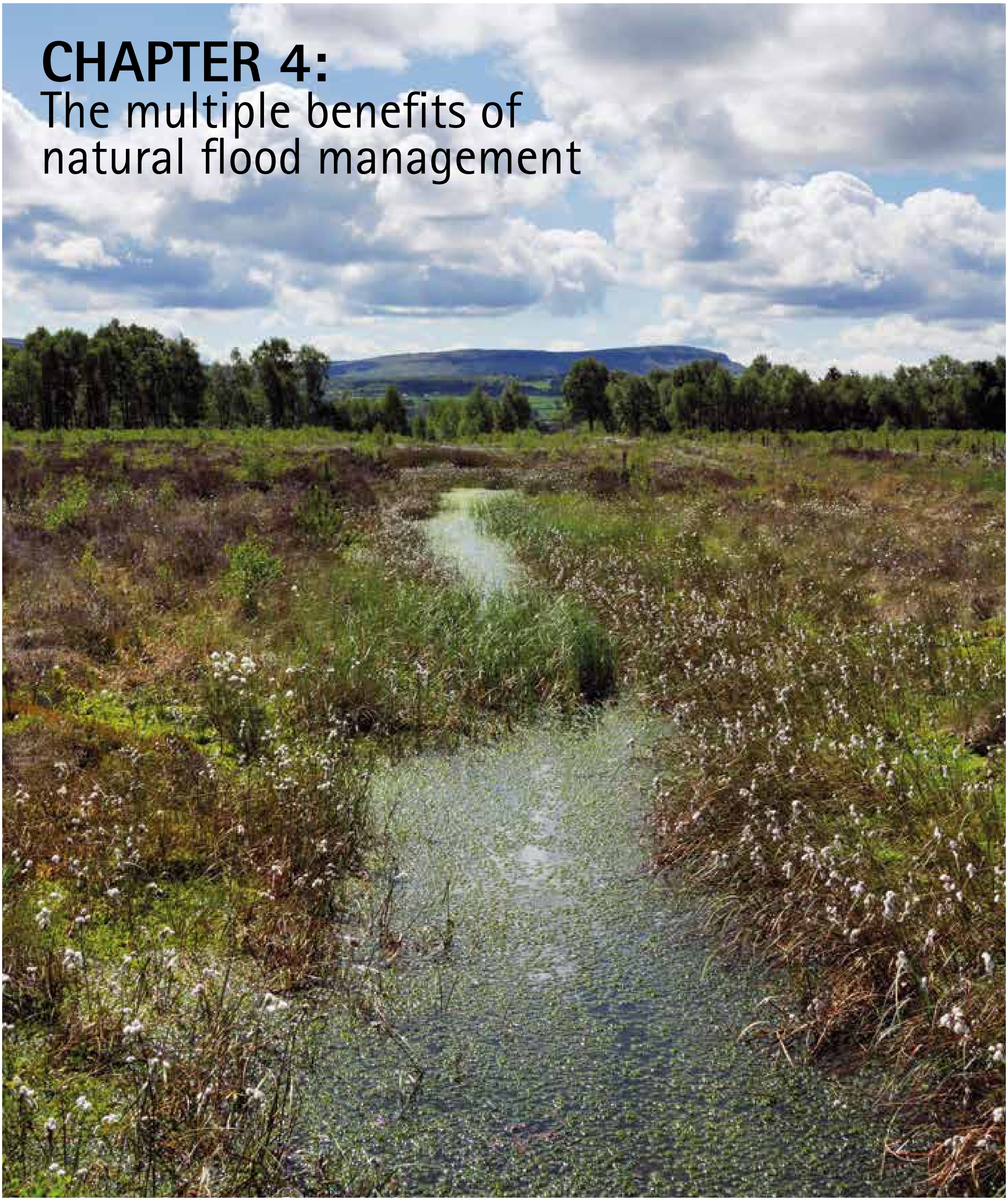

Figure 4.1. The 1.8 million hectares of blanket bog in Scotland is estimated to hold 1.6 million tonnes of carbon (© Lorne Gill/Scottish National Heritage).

Natural flood management rarely delivers benefits to flooding alone. When well-designed and delivered effectively, NFM measures can provide additional benefits for both people and nature. Quantifying the benefits of NFM to flooding can be challenging but, when considered together with these additional benefits, NFM can compare favourably against other traditional flood risk management measures and can provide a cost-effective opportunity to deliver other statutory targets and requirements.

Any improvement to the environment has with it the potential to bring a benefit to society, or what is commonly referred to as an 'ecosystem service' (e.g. Figure 4.1). For this reason there is increasing interest in assessing the benefits of NFM measures based on the services they provide to society (e.g. Iacob et al., 2012[104]) and current Scottish Government guidance specifically encourages this approach when making decisions relating to land management[105]. By assessing the effects of NFM in this way, it is possible to consider the many positive effects of NFM alongside any negative effects, such as loss of food production due to loss of fertile land, and in so doing assign an economic value to that measure (Figure 4.2).

Ecosystem services are broadly differentiated into four categories:

- provisioning (it delivers a product, such as drinking water, timber or food);
- regulating (it moderates natural processes, such as water quality or carbon sequestration);
- cultural (it delivers non material benefits, such as recreational experiences); or
- supporting (it contributes to the delivery of other services, such as nutrient recycling).

Some of the main ecosystem services that can be delivered by NFM measures, as well as the statutory drivers that they contribute to, are outlined further below.

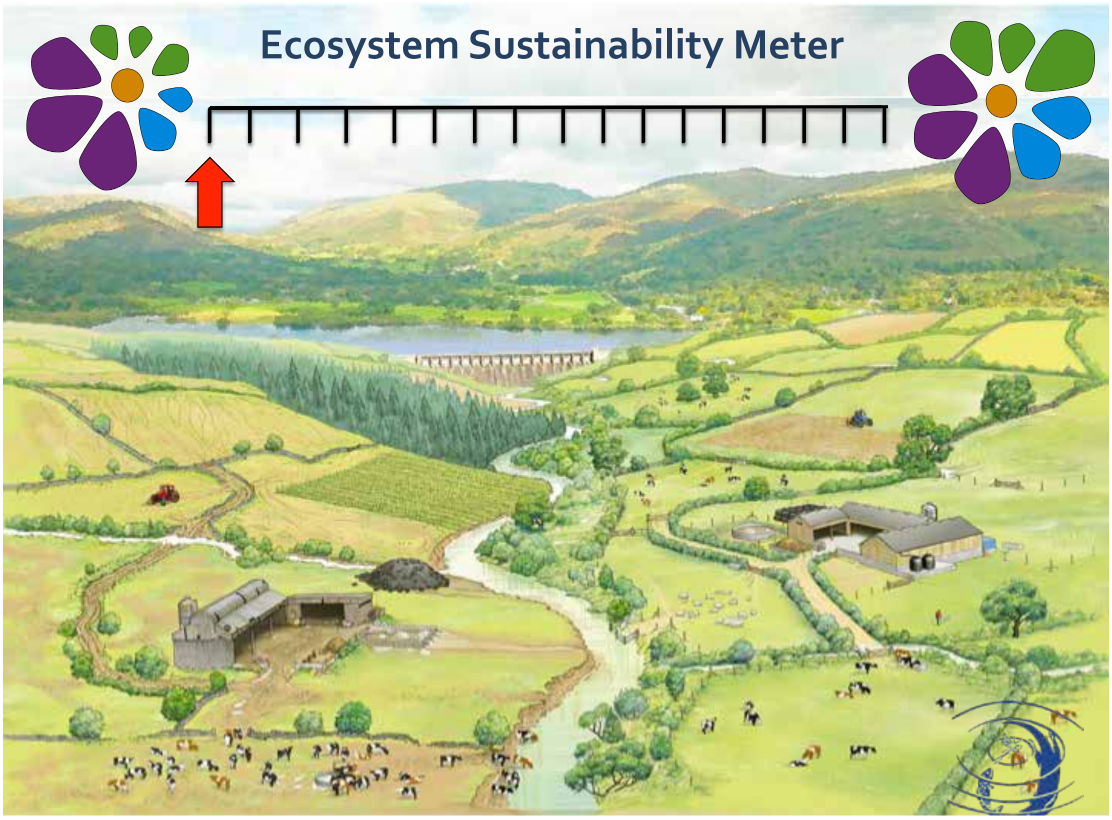


**Figure 4.2. Ecosystem services delivered by different land management practices: The more intensive land management on the left delivers more provisioning services such as food, while the less intensive land management on the right delivers greater regulating and cultural services such as better water quality and recreational opportunities (© Westcountry Rivers Trust).**

# 4.1. EXAMPLES OF THE MULTIPLE BENEFITS THAT NFM CAN DELIVER

## 4.1.1. Biodiversity

Many NFM measures seek to directly restore or strengthen an ecosystem which in turn supports a wider range of habitats and species. Wetlands (including intertidal habitat such as saltmarsh), for example, are considered to be one of the most biologically diverse of all ecosystems due to variations in nutrient levels and high primary productivity (Figure 4.3). Creating wetlands not only improves biodiversity at the site but potentially improves the connectivity between individual wetlands, in effect improving the ability of plants and animals to move between these habitats[106]. Works to restore rivers, such as where meanders are reinstated, can be particularly successful in increasing the diversity of instream habitat available for species such as salmon while woodland creation, where delivered appropriately, encourages development of a wide range of species beneath the tree canopy. Any NFM measure that improves water quality has the potential to improve instream habitat for fish and other wildlife.

## 4.1.2. Water Framework Directive

### 4.1.2.1. Water quality and sediment management

Many of the mechanisms by which NFM measures help reduce flooding also work to restore natural sediment processes and improve water quality. Improvement of soil structure where woodland is planted, or where land is managed less intensively, increases the rate of infiltration, reduces runoff and reduces topsoil (sediment) erosion. Reconnection of wetlands (including peatlands, floodplains and intertidal habitats) can be effective in managing high nutrient loads as the wetland vegetation uses these nutrients

**Figure 4.3. Saltmarsh is a highly specialised and productive habitat that supports many nationally scarce species.**

to grow. Other measures can improve the quality of water once it reaches the drainage network. Reconnection of floodplains, for example, increases the amount of instream sediment deposited on the land, thus reducing siltation further downstream, while upland drain blocking can reduce excessive loss of sediment high up the catchment[107]. All of these benefits to water quality can contribute to improvements in the status of water bodies under the Water Framework Directive (WFD)[108].

### 4.1.2.2. Channel and coastal morphology

Natural flood management measures in the river or on its banks typically seek to restore the watercourse to a more natural state. In addition to benefits to water storage and conveyance, these measures restore the natural functioning of the watercourse, improve instream ecology and make the watercourse more resilient to subsequent pressures. In recognition of the many benefits that can result from the restoration of channel morphology, the WFD includes channel morphology as a classification criterion in the assessment of the condition of water courses. Natural flood management measures to improve channel morphology can therefore lead to classification status upgrades under WFD (Figure 4.4). Coastal NFM measures can also bring about improvements in WFD classification by restoring coastal sediment processes and morphology. SEPA's pilot catchment project is a current example of the joint delivery of measures that benefit both flooding and channel morphology.

## 4.1.3. Climate change adaptation

### 4.1.3.1. Resilient ecosystems

Many NFM measures can deliver more resilient ecosystems in that they increase the capacity of the ecosystem to respond to disturbance and damage, including that brought about by climate change. Any works to restore wetlands or rivers, such as restoration of the natural functioning of these systems, can help safeguard the many services they provide to society. Measures that improve infiltration of surface runoff can increase the resilience of aquifers to the effects of drought, which in turn helps preserve drinking water supplies.

### 4.1.3.2. Carbon storage

Wetlands (including floodplains, peatlands and intertidal habitats) and woodlands (e.g. in leaf litter) are particularly efficient at accumulating and storing carbon-containing chemical compounds and in doing so removing carbon dioxide from the atmosphere (carbon sequestration). The 1.8 million hectares of blanket bog in Scotland is estimated to hold 1.6 million tonnes of carbon (Figure 4.1)[109]. Measures that reduce surface runoff and soil erosion such as ploughing along the contours of the land can also reduce carbon loss from soils.

## 4.1.4. Society and economy

Improvements to the environment can improve quality of life. This is particularly the case where measures are located in urban environments due to the increase in what is frequently limited green space. River restoration in public spaces, for example, can increase the number of visitors to that space by offering improved access to a safer, more attractive experience (Figure 4.5)[110]. Woodlands can also support many recreational activities such as walking, orienteering and mountain biking while at the same time improving health and mental well-being. Some NFM measures such as wetland and river restoration can be used as education tools or to provide links to our cultural past. All of these benefits can in turn increase the availability of jobs.

## 4.1.5. Agricultural production

Natural flood management measures that improve soil structure reduce the loss of valuable topsoil and can increase productivity (e.g. by increasing the amount of oxygen reaching crop roots). Measures that reduce runoff and raise the water table, such as drainage blocking, can also lessen the impact of droughts and reduce the amount of agricultural chemicals reaching the watercourse (thus lessening waste). Preventing livestock accessing watercourses reduces the risk of them acquiring waterborne diseases. While river restoration can result in the loss of productive land, setting back embankments can improve protection to land while simultaneously reconnecting the floodplain. Restoration of intertidal habitat, such a saltmarsh or mudflats, can also protect low-lying agricultural land.

**Figure 4.4. Straightened section of the Eddleston Water, Scottish Borders, prior to restoration: Remeandering of this watercourse (see front cover) has resulted in a WFD classification change for morphology from poor to moderate (© Tweed Forum).**

**Figure 4.5. Ninety per cent of visitors to the River Skerne in Darlington reported being satisfied with the restoration of the river, 15 years after completion of the work[110] (© Ulrika Åberg).**

## Further reading and guidance

JACOB, O., ROWAN, J., BROWN, I., and ELLIS, C. (2012). Natural flood management as a climate change adaptation option assessed using an ecosystem services approach. BHS Eleventh National Symposium, Hydrology for a changing world, Dundee 2012.

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# CHAPTER 5:
# Natural flood management assessment tools

Figure 5.1. Example of a 2D hydraulic model output.

A number of assessment tools can be used to identify or assess opportunities for NFM, including opportunity mapping, conceptual tools and hydrological/hydraulic models. Implementing an NFM measure will likely require the use of a number of these tools to address different questions at different stages of the implementation process. This chapter provides an overview of these tools, where they may be used in the course of an NFM project, and the varying levels of certainty associated with their outputs.

The availability of tools that can be used to assess NFM measures has increased significantly in the last ten years. Some of these tools have been developed specifically to identify or assess opportunities for NFM, while others are existing models that have been adapted to incorporate the effects of land and river management. Four broad classes of tools are available, i) opportunity mapping and conceptual tools, ii) hydrological models iii) fluvial hydraulic models (Figure 5.1), and iv) coastal assessment tools (Figure 5.2).

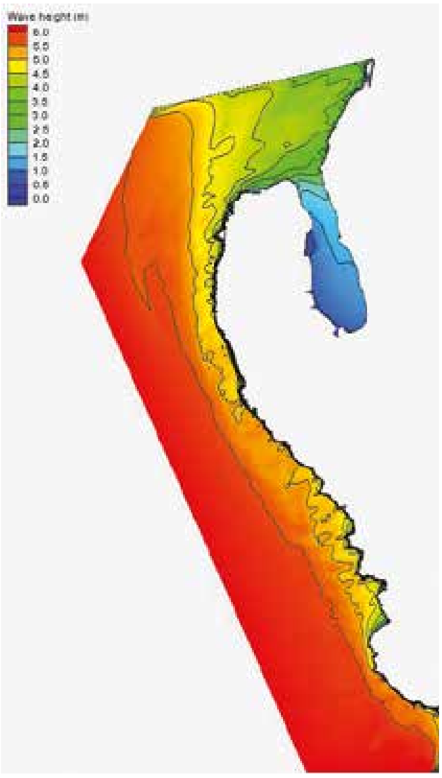



**Figure 5.2. Example of wave transformation model output for the Rhins of Galloway showing how wave heights change as they move inshore from a south-westerly direction (from the Solway Firth Flood Forecasting System Report, JBA Consulting, 2015).**

Implementing an NFM measure (Chapter 6) will likely require the use of a number of tools to address different questions at different stages of the process (such as scoping, options appraisal or design). At all stages it is important to ensure that the scale and complexity of the assessment is appropriate to the size of the project, potential impacts and achievable level of confidence. Further guidance on the application of hydraulic and hydrological modelling techniques for flood risk management will be provided in SEPA's Modelling Guidance for Flood Risk Management due for publication in 2015[111].

Deciding which type of tool is needed will depend on the question that is being asked such as:

- **Where within a catchment or coastline would NFM have the greatest effect?**
  This question can be addressed using opportunity mapping (for catchments and coastlines) and conceptual tools (for site specific assessments). Distributed hydrological models may also be useful. Limitations in the available tools and datasets mean that there is a significant degree of uncertainty associated with these assessments.
- **How much change would an NFM measure have to deliver to achieve a given reduction in flood risk?**
  This question can normally be answered using modelling techniques and the flood risk assessment techniques used for traditional engineering measures.
- **What would be the impact on flooding of an NFM measure?**
  For surface water and river flooding this question can either be addressed using hydraulic and/or hydrological modelling. Hydraulic models are typically used to look at the local effect of NFM measures in or adjacent to a particular watercourse while hydrological models are typically used to look at the effect of land use changes in the wider catchment. The types of assessment tool which may be applied to different NFM measures are indicated in Table 5.1. Limitations in the available tools mean that hydrological models can only provide an indication of the sensitivity to any proposed change, and formal cost-benefit analysis will not be possible. However, quantitative assessments may be possible with hydraulic and coastal models.

**Table 5.1. Assessment tools used to assess individual NFM measures**

| Measure group | Measure | Assessment tool | Indicative confidence in assessment* |
|---|---|---|---|
| Woodland creation and management | Catchment woodlands | Distributed hydrological models or opportunity mapping can be used to identify target areas.<br><br>Sensitivity testing hydrograph shapes in lumped hydrological models.<br><br>Scenario testing in hydraulic models. | Low |
| | Floodplain and riparian woodlands | Local effects can be estimated using hydraulic models and standard hydrological techniques.<br><br>Sensitivity testing hydrograph shapes in lumped hydrological models for catchment effects. | Medium for local effects using hydraulic models.<br><br>Low for catchment effects using hydrological models. |
| Land management | Land and soil management practices | Distributed hydrological models or opportunity mapping can be used to identify target areas.<br><br>Sensitivity testing hydrograph shapes in lumped hydrological models.<br><br>Scenario testing in hydraulic models. | Low |
| | Agricultural and upland drainage modifications | | |
| | Non-floodplain wetlands | | |
| | Overland sediment traps | Some hydrological modelling approaches may be used but these are subject to large uncertainty. | Low |
| River and floodplain restoration | River bank restoration | Some hydraulic approaches may be used but these are subject to large uncertainty. | Low |
| | River morphology and floodplain restoration | Localised effects can be estimated using hydrological and/or hydraulic models.<br><br>Sensitivity testing hydrograph shapes in lumped hydrological models for catchment effects. | High for local effects using hydraulic models, provided validation data is available to support the assessment.<br><br>Low for catchment effects. |
| | Washlands and offline storage ponds | Localised effects can be estimated using hydrological and/or hydraulic models.<br><br>Sensitivity testing hydrograph shapes in lumped hydrological models for catchment effects. | |
| | Instream structures | Localised effects can be estimated using hydrological and/or hydraulic models.<br><br>Sensitivity testing hydrograph shapes in lumped hydrological models for catchment effects. | Medium for local effects using hydraulic models (assuming no migration of structure).<br><br>Low for catchment effects. |
| Coastal measures | Managed realignment | Coastal assessment tools such as:<br>• hydrodynamic model: physical, numerical or composite<br>• geomorphological extrapolation<br>• extrapolation of historic data<br>• parametric equilibrium models | Variable depending on shoreline complexity and available data. |
| | Saltmarsh and mudflat restoration | | |
| | Sand dune restoration | | |
| | Shingle restoration | | |
| | Recharge (beach and intertidal) | | |

*based on literature available.

# 5.1. OPPORTUNITY MAPPING AND CONCEPTUAL TOOLS

Identifying where within a catchment or coastline measures should be targeted for the greatest effect is typically undertaken using opportunity maps. These maps are high level maps largely used in the early stages of identifying where to focus more detailed assessments. Opportunity mapping involves the use of GIS datasets to identify areas where measures could be most effective in altering hydrological processes, such as runoff, or coastal processes such as wave attenuation. They often do not consider areas of flooding and therefore further investigation is required to identify where these opportunities may benefit flood risk. The principal use of opportunity maps is to determine where further, more detailed assessment should be considered in scoping studies.

Conceptual tools are structured, model based approaches aimed at informing decisions around appropriate management. Users are taken through a series of steps in which they answer questions about their site and management of that site and are then presented with information on the effects of this on relevant processes such as runoff. Conceptual tools require some level of local knowledge of a site and, while involving a number of assumptions and simplifications, they can be useful in raising awareness of the potential benefits of different management approaches. Conceptual tools can be used during landowner engagement and for identifying measures in small sites (e.g. at the field scale).

## 5.1.1 Examples of opportunity mapping and conceptual tools

**Newcastle University, Floods and Agricultural Risk Matrix (FARM)[112]**

| Type of tool | Conceptual |
|---|---|
| Likely point of use | Identifying opportunities/land manager engagement |
| Licence | No |
| Access / further information | http://research.ncl.ac.uk/thefarm |

FARM is a decision support matrix designed to allow farmers and land managers to investigate the effect of land use interventions on runoff at a field scale. The tool, which is written in Excel, is aimed at farmers and land managers who have a high level of local knowledge of the land but less awareness of what constitutes a high or low runoff risk. The tool functions by asking the user a series of questions to identify the soil infiltration, storage and tillage regime and flow connectivity at their site (Figure 5.3). The user then views the results and the effect of any reduction measures through a runoff impact matrix.

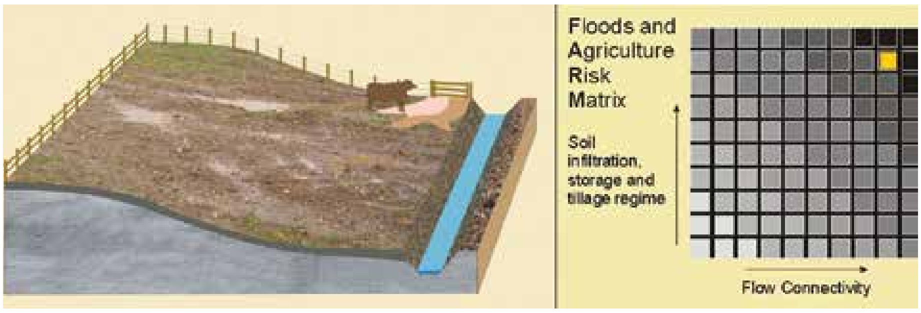



**Figure 5.3. Example of output from the Floods and Agricultural Risk Matrix (FARM) (© from Wilkinson et al.[112]).**

**University of Bangor, Polyscape and Land Utilisation and Capability Indicator (LUCI)[113]**

| Type of tool | Conceptual/opportunity mapping |
|---|---|
| Likely point of use | Identifying opportunities/land manager engagement |
| Licence | Open source |
| Access/further information | www.polyscape.org/ www.lucitools.org/ |

POLYSCAPE is a multiple criteria GIS toolbox designed to assist decisions around where to locate interventions that support NFM and more general landscape scale ecosystem services. The toolbox contains tools for assessing habitat augmentation/protection, flood mitigation, erosion/sediment delivery, carbon sequestration and agricultural valuations, and can be used to produce maps showing the trade-offs between competing land uses. The University of Bangor in partnership with the World Agroforestry Centre (ICRAF) is currently redeveloping the tool in the open source GIS package QGIS with the plan of making the tool freely available and open source.

**SEPA, Natural flood management maps[13]**

| Type of tool | Opportunity mapping |
|---|---|
| Likely point of use | Identifying opportunities/scoping |
| Licence | Publically available through SEPA's map viewer. Use of data for flood risk management included in SEPA flood map licence. |
| Access/further information | Maps: www.sepa.org.uk/environment/water/flooding/flood-maps/ <br> Guidance: www.sepa.org.uk/media/33480/natural_flood_management_2013.pdf |

SEPA's NFM maps were produced in 2012 as part of a high level strategic analysis of areas within Scotland where the implementation of NFM measures could be most effective (Figure 5.4). The outputs were primarily intended to assist SEPA and local authorities in identifying opportunities for NFM to take forward through the FRM Strategies and Local FRM Plans (as required by section 20 of the FRM Act). The approach to developing the maps was based on a methodology outlined by Halcrow[37].

The maps do not consider flood risk or directly recommend which specific NFM measures should be implemented. The outputs instead provide an indication of where more detailed assessment of opportunities for NFM should be focused. Five maps are available which show areas of potential for:

- runoff reduction;
- floodplain storage;
- sediment management;
- estuarine surge attenuation; and
- wave energy dissipation.

The maps have been produced for all of Scotland, with the exception of the map showing opportunities for river sediment management which has been produced for catchments greater than 10 km$^2$ containing a Potentially Vulnerable Area only. The river and catchment based NFM measures which may be appropriate in the opportunity areas identified by the first three maps are detailed in Table 2.1 of Chapter 2, while the coastal measures that may be applicable in the opportunity areas identified by the two coastal maps are described in Chapter 3.

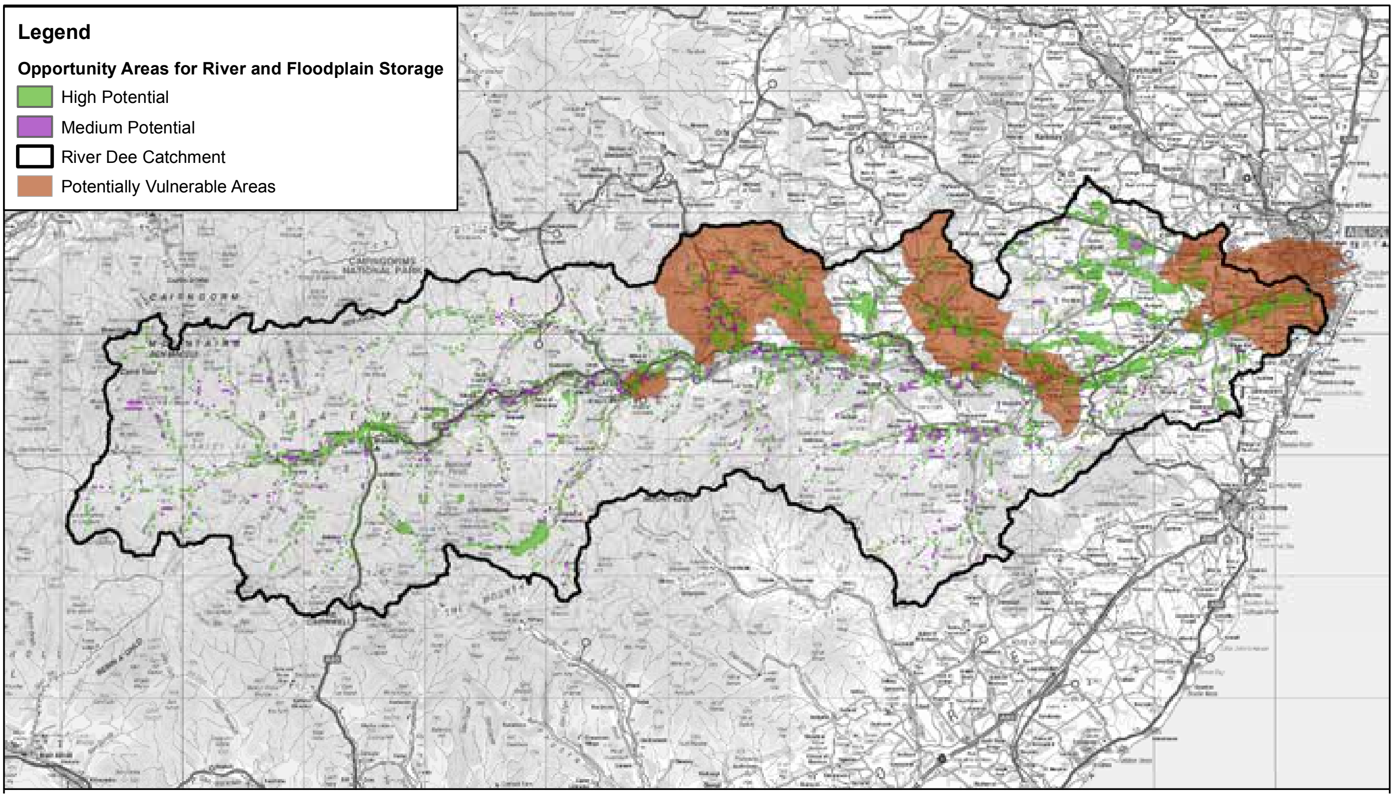



**Figure 5.4. Example of output from SEPA's NFM maps: Opportunity areas for floodplain storage in the River Dee catchment (some features of this map are based on digital spatial data licenced from the Centre for Ecology and Hydrology, © CEH, and include material based upon Ordnance Survey mapping with permission of H.M. Stationery Office, © Crown Copyright, licence number 100016991).**

**Forestry Commission Scotland/Forest Research, opportunity mapping: Woodland for water**[114]

| Type of tool | Conceptual/opportunity mapping |
|---|---|
| Likely point of use | Identifying opportunities/scoping |
| Licence | No |
| Access/further information | Maps available on request from Forest Research, see [www.forestry.gov.uk/fr/infd-97xgxx/](www.forestry.gov.uk/fr/infd-97xgxx/) |

Forestry Commission Scotland's opportunity mapping identifies areas where woodland creation would be most effective at reducing diffuse pollution and flooding (Figure 5.5). The method can be applied across a range of scales, from assessing opportunities for planting at a strategic regional or river basin level down to the practical farm/field scale. Catchments are divided into three zones (floodplain, riparian and wider catchment planting) and opportunities for planting mapped within each zone.

The approach (developed by Forest Research) consists of identifying constraints (e.g. deep peat >50 cm) and sensitivities to woodland creation (e.g. designated sites and land protected by flood defences), followed by an assessment of the scope for woodland planting to reduce runoff. Priority areas are mapped as those draining to a Potentially Vulnerable Area and comprise:

- soils with a high propensity to generate rapid surface runoff and medium or high potential for runoff reduction ('priority wider woodland');
- riparian land within 30m of either bank of the river network with a high risk of bank erosion or low structural diversity ('priority riparian woodland'); and
- floodplain land with a 0.1% probability of flooding and medium or high potential for floodwater storage ('priority floodplain woodland').

These areas are favoured either in view of their proximity to sources of flood generation or their ability to reduce the conveyance of flood flows downstream. Maps are available showing the distribution of the priority areas for planting floodplain, riparian and wider woodland within SEPA's top fourteen diffuse pollution priority catchments in Scotland.

The approach has also been used to identify opportunities for woodland creation to address diffuse pollution pressures affecting surface water bodies and groundwater resources within these catchments. Maps identify potential win-wins by comparing the distribution of the priority areas for woodland creation for flood risk management in relation to those for reducing one or more diffuse pollutant pressures. Account is also taken of the potential water trade-offs, as well as opportunities for changes to the design and management of existing woodland to benefit water.

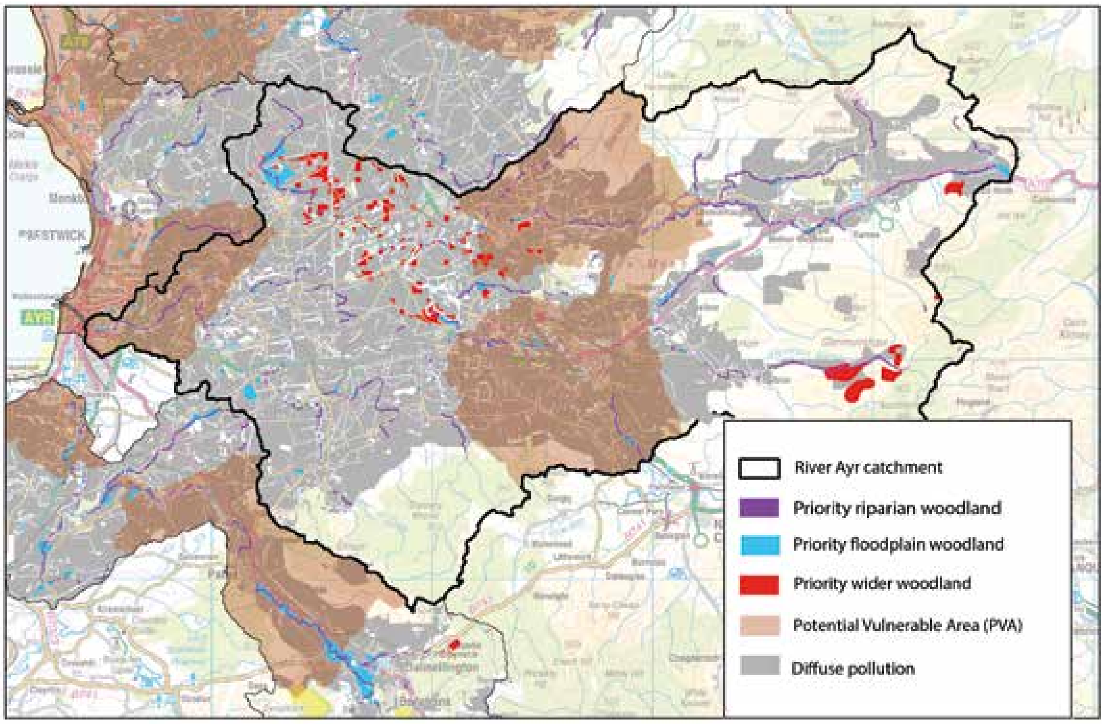



**Figure 5.5: Example of output from Forestry Commission Scotland's Woodland for Water maps: Opportunity areas for woodland creation to benefit flooding and water quality in the River Ayr catchment (© Crown copyright and database right 2014, Ordnance Survey licence number 1000025498).**

# 5.2. HYDROLOGICAL MODELLING

Hydrological models are simplified representations of the land part of the hydrological cycle. They cover the processes which influence the amount of rainfall that enters rivers, such as runoff and soil storage. By making assumptions about how land use change affects these processes, hydrological models can be used to look at the effect of changes in the wider catchment on flows. Typical NFM measures which might be investigated using hydrological models include upland blocking and woodland creation. Hydrological models cannot be used to provide direct flood levels or flood extents. Instead, they are used to provide inflow hydrographs for hydraulic models which in turn calculate the water levels and flood extents resulting from that inflow hydrograph.

Hydrological models can be classified in a number of ways. Models can either be:

- **Physically based or empirical:** Physically based models represent processes in a physically realistic manner, while empirical models are based on equations which fit the data but have no direct physical basis. It is also possible for a model to be semi-physically based where some processes are represented in a physically realistic manner, but others are partially represented using empirical equations.
- **Distributed or lumped (Figure 5.6):** Distributed models allow factors such as soil type or rainfall to vary across a catchment. Lumped models use a single unit to represent an entire catchment by using values of inputs averaged across a catchment. Distributed models are needed to investigate which areas within a catchment are likely to be most sensitive to NFM. However, lumped models can be used to investigate the likely sensitivity of peak flows and hydrograph shape to NFM.
- **Continuous or event based:** Event based models represent what happens during an individual storm or flood event, whereas continuous models are run for a much longer period and cover what happens between flood events.

Recommendations in the 2004 Defra study[36] on the impacts of rural land use and management on flood generation concluded that *"modelling* (of the impacts of land use change and land management) *should be distributed and be capable of running continuous simulations. It should also be partially or wholly physically based so that the physical properties of local landscapes, soils and vegetation can be represented, and it should include detailed modelling of surface water flow so that the effects of changes can be tracked downstream."*

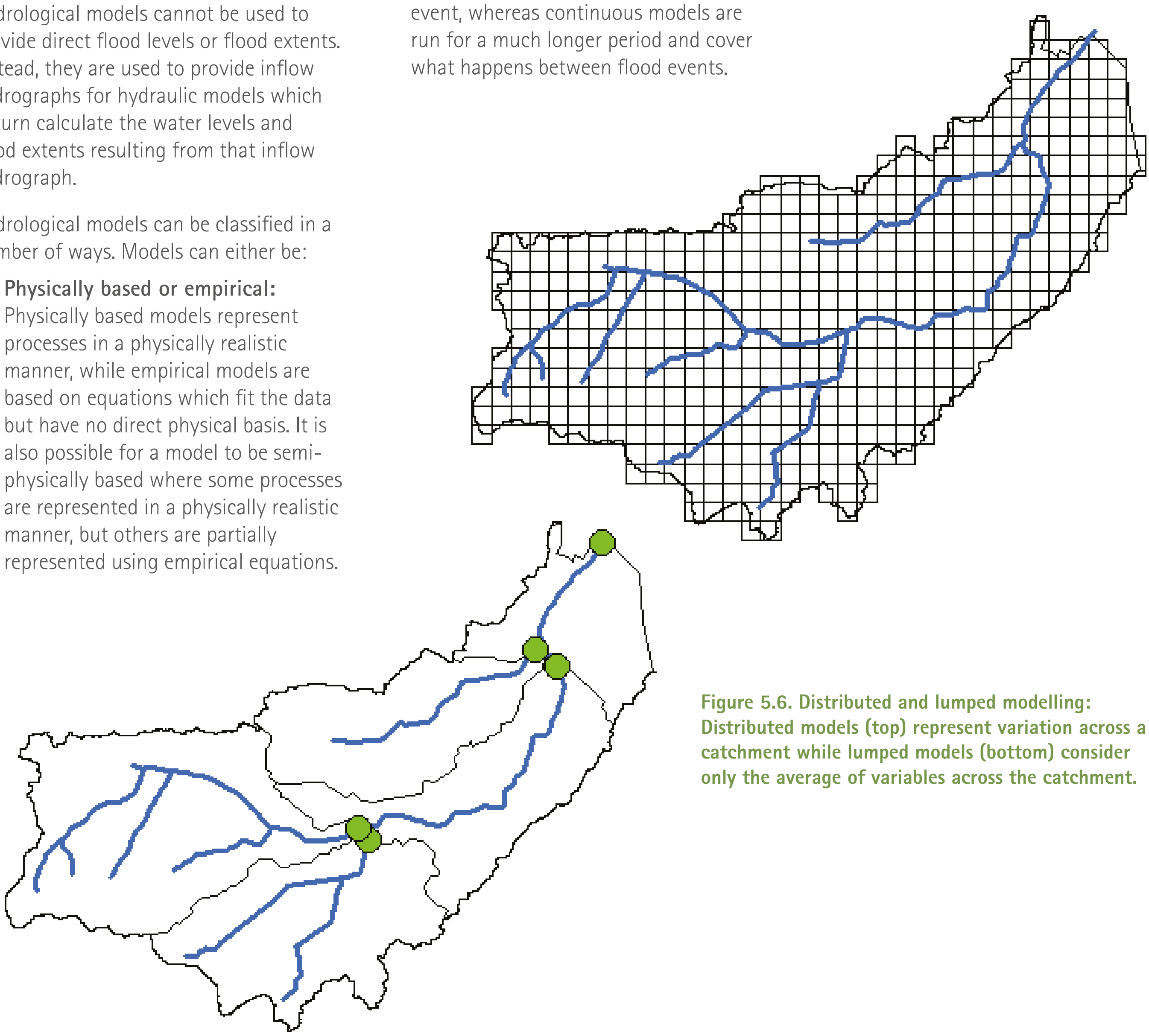


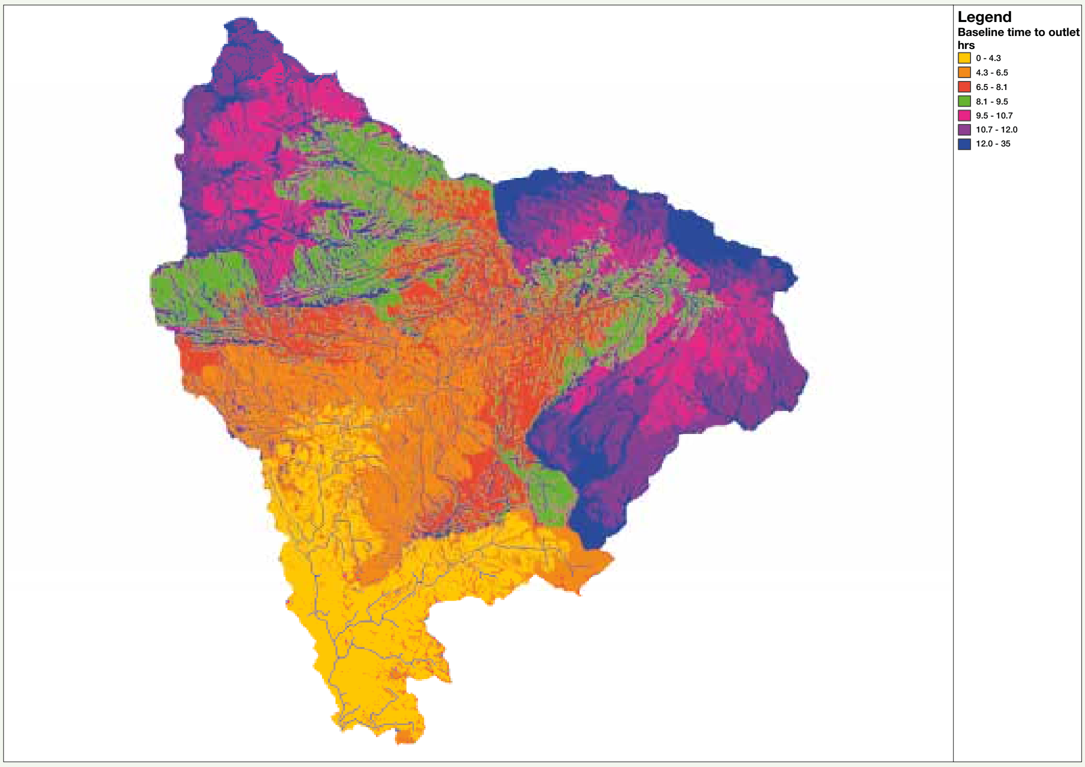
**Figure 5.6. Distributed and lumped modelling: Distributed models (top) represent variation across a catchment while lumped models (bottom) consider only the average of variables across the catchment.**

Since 2004, many spatially distributed and physically and semi-physically based hydrological models have been developed. These models include equations that can simulate some or all the major processes in the land phase of the hydrological cycle, including evapo-transpiration, overland flow, unsaturated soil water, and groundwater movement. The distributed nature of the models means that spatial variations in factors such as land use, topography and vegetation cover across a catchment can be accounted for and the models can be used to give an indication of the sensitivity to NFM measures at different locations within a catchment. However, there are a number of issues and uncertainties associated with the application of these models at the catchment scale (see Box 5.1) and careful experimental design and robust sensitivity testing is needed to understand the uncertainty in any assessment (see Box 5.3). O'Connell et al.[8] provide further discussion on the limitations of, and the difficulty in calibrating, hydrological models.

Due to the computing power required and the need for large and complex input datasets, distributed physical or semi-physical models have largely been limited to use by the research community. Some physical and semi-physical distributed models are freely available for use (e.g. SWAT[115] and TOPMODEL[116]), although setting up the models and interpreting the results requires significant user knowledge.

## Box 5.1. Natural flood management and desynchronisation of flood peaks

The amount of water reaching the outlet of a river system (and hence the potential for flooding) is in part determined by the extent to which the flood peaks from individual sub catchments coincide (synchronise) at that outlet. In the following figure, for example, the estimated time it takes for precipitation to travel to the catchment outlet from the point where it lands within the catchment is shown for the Allan Water (Forth catchment), Stirlingshire. This analysis indicates that the part of the catchment to the north-west and east all have a time to peak that is longer than the catchment average. Hydrological principles tell us that delaying the progression of floodwater from these areas may assist in further desynchronising the contributing sub catchment flood peaks (with a net effect of reducing flood risk at the catchment outlet).




**Summary of the estimated time that flows take to reach the outlet for the Allan Water, Stirlingshire: Areas to the north-west and east take longer than the catchment average (from CRESS and Halcrow[122]).**

While current evidence suggests that NFM measures can affect the time to peak of local flows (with the scale of the effect being dependent on the location of the measures within the catchment and the spatio-temporal variations in rainfall and runoff) there is currently little compelling evidence that NFM measures can desynchronise flood peaks at the catchment scale. Modelling of the effects of NFM on desynchronisation/ synchronisation of flood peaks is therefore associated with high levels of uncertainty. A CREW publication provides further discussion and review of the evidence relating the effects of NFM on desynchronisation of flood peaks at the catchment scale[117].

## 5.2.1. Recommended approach to the use of hydrological models

With all types of hydrological models there is uncertainty regarding the application to NFM and little guidance on how model parameters should be modified to represent proposed catchment changes. At present, the use of hydrological models is restricted to providing an indication of the sensitivity to any proposed change and where in the catchment changes are likely to have most effect. There is insufficient confidence in the application of hydrological models to provide predictions in the change in flow due to the implementation of NFM measures for a particular rainfall event. To manage this uncertainty a combination of the following assessment approaches can be used:

- use of historic flooding information, river gauge data and local knowledge to develop an understanding of the catchment and flooding mechanisms. Understanding key processes will inform the choice of hydrological model and identify the factors which may need to be considered, such as the phasing of flood peaks from tributaries and the role of sedimentation and blockages;
- use of opportunity mapping, conceptual tools (see Section 5.1), and expert judgement to complement hydrological modelling to identify the areas within a catchment which are likely to respond most to NFM measures;
- sensitivity testing (see Box 5.2) using either lumped or distributed hydrological models to determine the possible range of changes to peak flows and hydrograph shape resulting from the implementation of NFM measures. The outcome of opportunity mapping can also be used to inform sensitivity testing; and
- scenario testing (see Section 5.3.2 and Figure 5.10) to determine the impact of possible changes in flow hydrographs on receptors, using hydraulic models. This should consider changes in hydrograph shape and phasing as well as changes in the peak flow. The changes necessary to have an impact on receptors can be compared with the possible range of hydrograph changes identified from sensitivity testing, or with the size and type of areas identified through opportunity mapping using expert judgement.

## 5.2.2. Examples of hydrological models

The choice of hydrological model used for sensitivity testing will depend on the available data, the size of the project, and the potential impacts. Examples of different types of hydrological model which may be applied to NFM measures are discussed below. It should be noted that more complex approaches may not necessarily lead to a significant reduction in uncertainty.

For flood mapping and engineering scheme design the most commonly used hydrological models are the Flood Estimation Handbook rainfall runoff model (FEH) and the Revitalised Flood Estimation Handbook rainfall runoff model (ReFH). Key model parameters are estimated from physical and climatic descriptions of the catchment, such as the average slope, and annual averaged rainfall using empirical equations based on relationships between these variables and observed data. These physical and climatic descriptions are termed catchment descriptors and obtained from national datasets, usually through the FEH CD ROM.

**Centre for Ecology and Hydrology, FEH and ReFH rainfall runoff methods[118, 119]**

| Type of tool | Hydrological model |
|---|---|
| Likely point of use | Identifying opportunities/scoping |
| Licence | License required for FEH CDROM. Model incorporated in some hydraulic modelling software. |
| Access / further information | http://www.hydrosolutions.co.uk |

A number of factors limit the application of the FEH and ReFH rainfall runoff models to NFM assessment. The models are based on catchment average properties, with a minimum catchment size of 0.5 $km^2$, and calculate flows at the catchment outlet only, so the models cannot be used to identify where within a catchment NFM measures will have the greatest effect. There is currently no agreed method for altering catchment descriptors to account for land use change, although Packman et al.[120] propose a method for adjusting the soil type to account for degradation, and testing the sensitivity to the speed of runoff by altering the hydrograph time to peak. Confidence in the models is generally lower for small catchments as few small catchments were included in derivation of the empirical equations from data. However, an ongoing Environment Agency research project[121] is attempting to address this issue.

Despite their limitations, FEH or ReFH models could be used for sensitivity testing of NFM measures, particularly where the potential impacts and available data does not justify a more complex approach. In this case any analysis should consider the full range of plausible parameter values, and uncertainty in the results should be made clear.

## Halcrow and Centre for River EcoSystem Science (CRESS), Allan Water Method[122]

| Type of tool | Hydrological model (distributed, semiphysical, event based) |
|---|---|
| Likely point of use | Scoping |
| Licence | Further testing and development of the user interface and method would be required before application of the tool box to other products. |
| Access / further information | www.cress.stir.ac.uk/allanwater/ |

GIS platforms have been used to develop various conceptual distributed models which use readily available national datasets as inputs (Figure 5.7). The method used for scoping NFM opportunities in the Allan Water catchment by CRESS and Halcrow is an example of this approach. It employs a single event distributed hydrological model to estimate runoff rates using the American Soil Conservation Service's runoff curve number methodology[123].

### Box 5.2. Sensitivity testing

Sensitivity testing is undertaken to determine the amount and kind of change produced in a model output by a change in a model parameter. It is used to understand where changes to model inputs will have the greatest impact on the model results, and where uncertainty in parameter values may contribute most to uncertainty in the model results. Sensitivity testing can be used to provide an indication of those NFM measures that will achieve the greatest effect, compared with other measures.

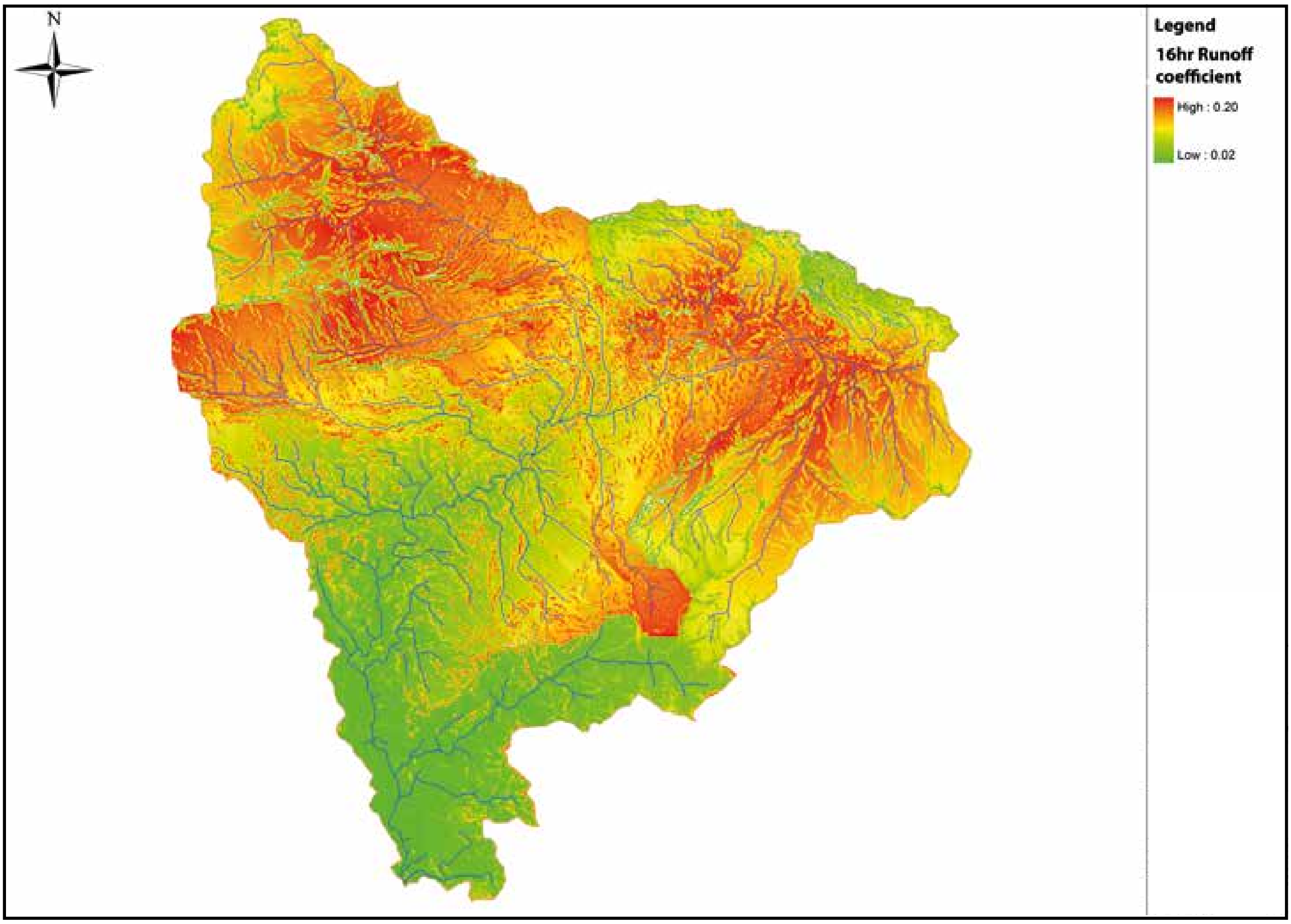



Figure 5.7. Generation of runoff that contributes to the flood peak in the Allan Water catchment, Stirlingshire: This figure shows that the majority of runoff contributing to downstream flooding is generated in the north-west of the catchment and hence where runoff reduction measures would have most effect (from CRESS and Halcrow[122]).

### U.S. Department of Agriculture Agricultural Research Service (USDA-ARS), Soil and Water Assessment Tool (SWAT)[124]

| Type of tool | Hydrological model (semi-distributed, semi-physical) |
|---|---|
| Likely point of use | Scoping/options appraisal |
| Licence | No |
| Access/further information | http://swat.tamu.edu |

The Soil and Water Assessment Tool (SWAT) is a public domain model jointly developed by the U.S. Department of Agriculture (USDA) Agricultural Research Service (USDA-ARS) and Texas A&M AgriLife Research, part of The Texas A&M University System. SWAT is a semi physically-based hydrological model developed to quantify the impact of land management practices on water, sediment, and agricultural chemical yields in large catchments with varying soils, land use, and land management conditions. A catchment is divided into sub-catchments and hydrologic response units (HRUs), each having unique soil and land use characteristics. Hydrology components of SWAT include canopy storage, infiltration, redistribution, evapotranspiration, lateral subsurface flow, surface runoff, ponds, tributary channels, and return flow. Based on daily precipitation, runoff, evapotranspiration, percolation, subsurface return flow, groundwater flow, and changes in water storage, a daily water budget in each HRU is calculated. The model is widely used and cited in in research literature for catchment management studies. However, there are few NFM specific applications to date.

### Danish Hydraulic Institute, MIKE-SHE[125] and Newcastle University, SHETRAN[126]

| Type of tool | Hydrological model (physical) |
|---|---|
| Likely point of use | Scoping/options appraisal |
| Licence | MIKE-SHE – Yes<br>SHETRAN – 50x50m grid free to download. |
| Access/further information | MIKE-SHE - www.mikebydhi.com<br>SHETRAN – http://research.ncl.ac.uk/shetran/ |

MIKE-SHE (Figure 5.8) and SHETRAN are both distributed physical models based on the Système Hydrologique Européen (SHE) model. The models contain representations of all the major processes in the land phase of the hydrologic cycle, including evapotranspiration, overland flow, unsaturated soil water, and groundwater movements. The models are modular, and the user has the option to choose between different physical or conceptual modules for particular processes. SHETRAN, developed by Newcastle University, has been used primarily in academic studies, several of which have looked at the impact on land use on flooding. MIKE-SHE, developed by the Danish Hydraulic Institute, is a commercially available package integrated within the MIKE software suite and has a full user interface and documentation. MIKE-SHE has been used to investigate the effect on flood risk of land use changes in the Parrett catchment in England.

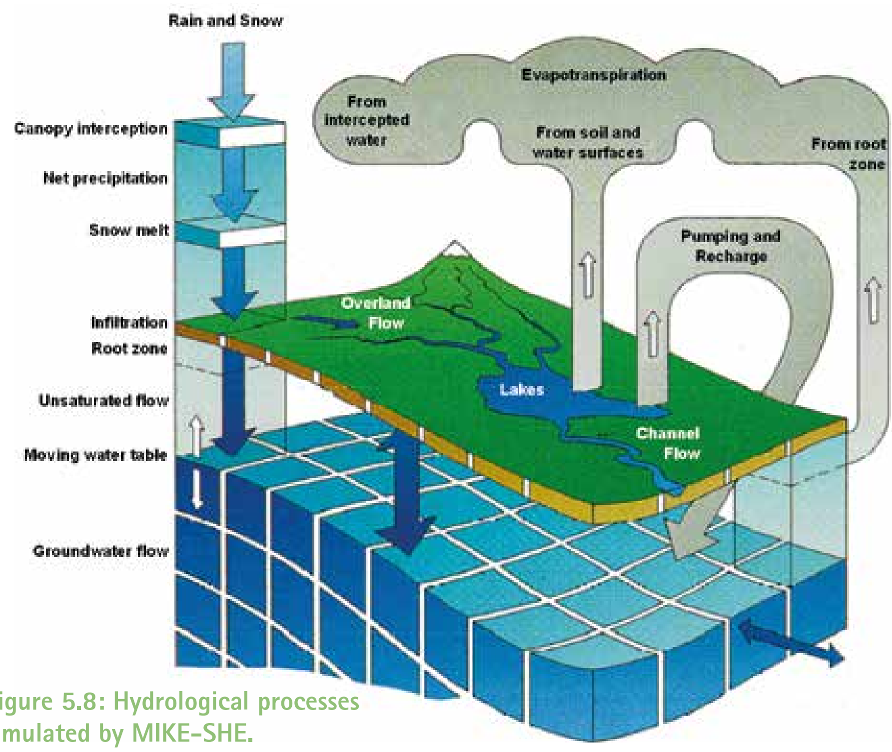



Figure 5.8: Hydrological processes simulated by MIKE-SHE. (© Mike Powered by DHI).

# 5.3. FLUVIAL HYDRAULIC MODELLING

| Type of tool | Hydraulic model |
|---|---|
| Likely point of use | Scoping/options appraisal/design |
| Licence | Depends on software |
| Access/further information<br><br>(software commonly used in the UK, other software is available) | Flood Modeller Pro (formerly called ISIS):<br><br>www.floodmodeller.com/<br><br>HECRAS: www.hec.usace.army.mil/software/hec-ras/<br><br>Infoworks: www.innovyze.com/<br><br>MIKE Flood: www.mikebydhi.com/products/mike-flood<br><br>SOBEK: www.deltaressystems.com<br><br>TUFLOW: www.tuflow.com |

There are two principal uses of hydraulic models in NFM assessment:

- they can be used to investigate the effects of physical changes such as increased roughness or changes to hydraulic structures within the model area; and
- they can be used for scenario testing of the effect of changes in flows and phasing resulting from NFM in the wider catchment.

Hydraulic models cannot be used to directly investigate changes in erosion and deposition or changes in infiltration and interception due to vegetation. However, it is possible to apply 1D and 2D hydraulic modelling techniques to specific NFM assessments at a range of scales.

Hydraulic models use physical equations to represent real world processes governing fluid flow (Figure 5.9). They are typically classified by their dimension (either 1D or 2D) and by whether they are steady or unsteady. In steady modelling it is assumed that flow does not vary with time at a given location. This assumption can be made for many applications where floodplain flow is limited. Unsteady models allow flow to change with time. Unsteady models are required for problems where flood wave propagation or flood storage or attenuation within the system is of interest.

1D models generally provide a better representation of in-channel flow, whereas 2D models provide a better representation of floodplain flow and storage. Where both channel and floodplain flow need to be represented in detail, coupled 1D-2D models are preferred. Unsteady models are used where there is a requirement to model flow attenuation. Flow hydrographs from hydrological models or gauge data are used as inputs for hydraulic models.

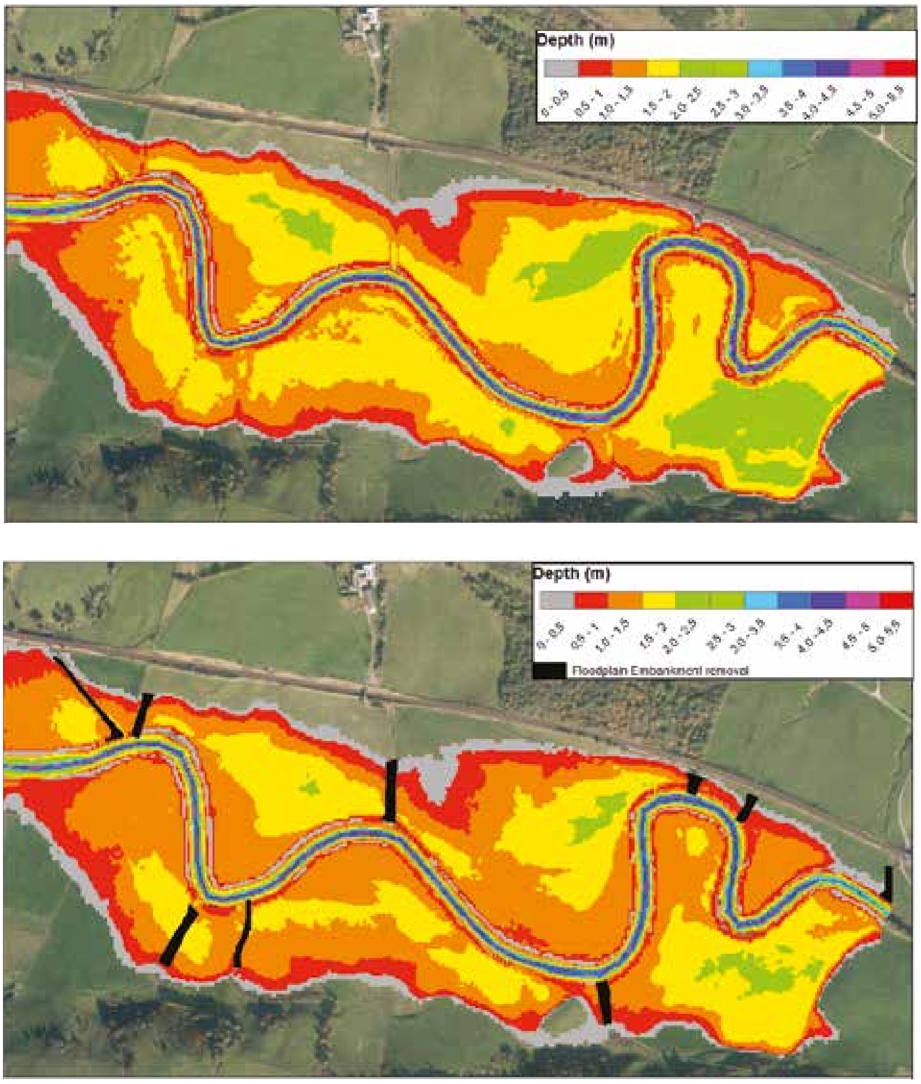



**Figure 5.9. Example of hydraulic modelling output: Floodplain flood depths before and after river embankment removal during a 1 in 10 year flood (some features are based on digital spatial data licenced from the Centre for Ecology and Hydrology, © CEH, and includes material based upon Ordnance Survey mapping with permission of H.M. Stationery Office © Crown Copyright, licence number 100016991).**

## 5.3.1. Physical changes

Two-dimensional surface water flood modelling techniques have been used to investigate overland flow pathways, as a consequence of the generation of surface runoff on hill slopes, over a detailed Digital Terrain Model (DTM). The natural flow pathways and flood accumulation areas identified by the modelling can then be targeted and assessed for the implementation of suitable NFM measures. Elements of the models (such as the underlying DTM, channel characteristics and the surface roughness) can be modified to represent NFM measures.

Linked 1D-2D hydraulic modelling has been used to assess out of bank flooding on floodplains and explore the impacts of river and floodplain NFM interventions, such as instream structures, remeandering, and riparian and floodplain planting. One example of a linked 1D-2D model is the ISIS-TUFLOW model. The ISIS 1D component of the model simulates the in-channel flows whereas the TUFLOW 2D component simulates the flow on the floodplain. There are a number of other 1D and 2D modelling packages on the market, including some that are free to use.

## 5.3.2. Scenario testing

Scenario testing with hydraulic models is a method for assessing the impact of possible changes in flow hydrographs. By varying the size and timing of tributary inflows the size of changes necessary to have an impact on flood risk at key receptors can be determined and compared with the possible range of hydrograph changes identified from sensitivity testing, or with the size and type of areas identified through opportunity mapping using expert judgement (Figure 5.10). This approach has been used for the Eden catchment in England[127].

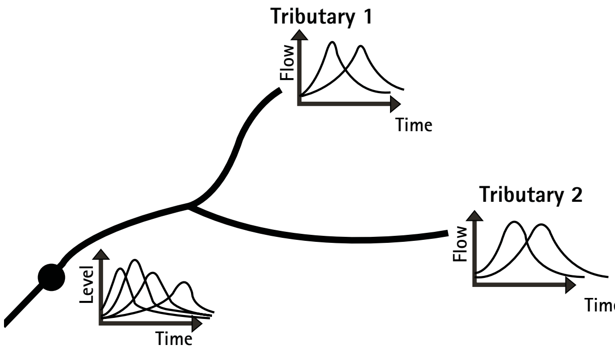



**Figure 5.10. Scenario testing using a hydraulic model which has inflows at tributaries 1 and 2: In this example a series of model runs are carried out shifting design hydrographs for tributary hydrographs earlier and later in time and the impact on peak stage at a receptor further downstream is investigated. Other scenarios could involve changing the relative magnitude of the tributary hydrographs or changing the hydrograph shape.**

Table 5.2 provides guidance on the type of NFM measures which may be incorporated into different types of hydraulic model. This is a guide only, and the suitability of a particular approach will depend on the characteristics of the catchment being modelled. It is established practice within the UK to use hydraulic models in the design of flood defences. This is directly applicable to some NFM measures, such as floodplain reconnection. However, for other measures there is a great deal of subjectivity in how they may be incorporated into hydraulic models, and robust sensitivity testing is necessary to ensure that uncertainty in the modelling results is fully understood.

Where other engineering solutions to flood risk management are being considered a hydraulic model for the area may already have been developed. For new hydraulic modelling studies the possibility of testing NFM measures should be considered when developing the modelling scope. In some instances this may involve an extension of the study area, collection of more data, or running the model for smaller more frequent events. Where possible, models used for NFM assessment should be calibrated and verified using data from past events. For more frequent events, model outputs should be compared with local knowledge.

**Table 5.2. NFM measures which can be incorporated into different types of hydraulic models.**

| Model type | Model software | Measure |
|---|---|---|
| 1D | ISIS 1D HECRAS, Infoworks RS 1D, Mike11 | Any measure involving channel geometry and roughness modifications including:<br>• instream structures;<br>• riparian/ floodplain planting; and<br>• river morphology restoration (remeandering). |
| 2D | TuFLOW, ISIS 2D, Infoworks RS 2D. | Any measure involving changes to geometry or roughness outwith the channel including:<br>• changes to roughness associated with land use change (but note will not consider infiltration). |
| 1D-2D | ISIS-TUFLOW, ISIS 1D-2D, MIKE Flood, Infoworks ICM. | Any measure involving channel and floodplain modifications including:<br>• instream structures;<br>• riparian/ floodplain planting; and<br>• river morphology and floodplain restoration (remeandering, embankment removal). |

## 5.4. COASTAL ASSESSMENT TOOLS

This edition of the NFM handbook does not cover coastal NFM assessment and modelling tools in the same detail as river tools. Current coastal tools and models have generally been developed to assess and inform the design of engineered structures in estuaries and along the coastline, rather than NFM measures. The modelling software used for rivers can often also model waves and surge at the coast or in estuaries (e.g. TUFLOW, MIKE 21 and DELFT 3D/SWAN) (Figure 5.11). Some of these packages also have modules which can be used to model sediment transport or morphology.

Coastal systems are complex and correspondingly difficult to model. A behavioural systems approach is recommended to ensure all the issues that could affect coastal processes are recognised even if they are not well understood. This approach focuses on understanding the interactions and linkages within a system; also ensuring the uncertainties with any modelling undertaken is recognised. The different modelling techniques available include:

- geomorphological extrapolation (based on morphological behaviour);
- numerical modelling (based on physical processes);
- extrapolation of historical data; and
- parametric equilibrium models.

For coastal NFM measures an understanding of sediment dynamics is essential[128]. Sediment movement may occur due to both tides and waves. The source of sediment present may also have been exhausted, for example if this was a glacial offshore deposit. Therefore, present day currents could be sufficient to move more than the measured load of sediment if more sediment was to become available. More information on the relevant coastal processes that can be modelled to help

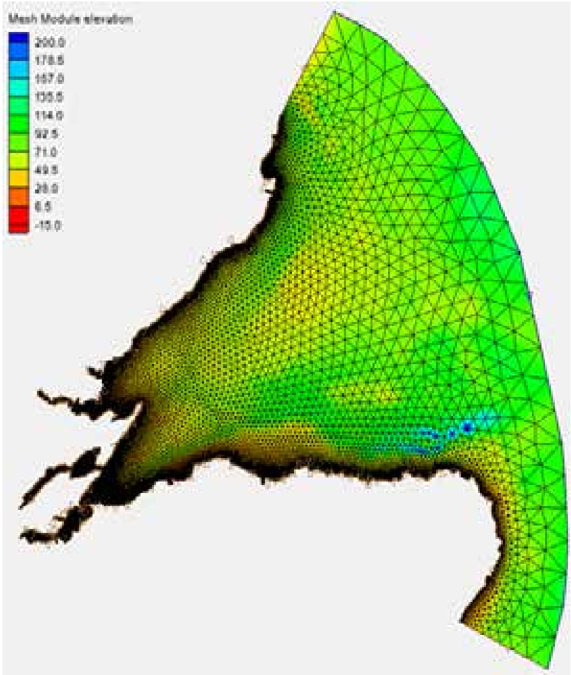



**Figure 5.11. Example of a wave transformation model grid such as might be used to look at the effect of wave dissipation measures.**

inform the potential effectiveness of coastal NFM measures is in Chapter 3. Variables important for sediment movement include:

- sediment size, shape, density and mineralogy of grains;
- sediment settling velocity;
- sediment availability;
- flow depth;
- water density and viscosity;
- bed shear stress;
- bed-form wavelength, height and steepness;
- maximal tidal velocity;
- residual tidal velocity;
- wave period and amplitude; and
- vegetation.

Advice should be sought from specialist coastal consultants as to what type of modelling may be appropriate according to the nature of the coastline or estuary and the data available. Coastal sediment transport processes are a consideration for many major coastal developments around the world, and there is a considerable body of expertise in this area.

### Further reading and guidance

BURGESS, K.A., FRAMPTON, A.P.R. and BRADBURY, A.P. (2014). Beach modelling: lessons learnt from past scheme performance. Project: SC110004/R1. Bristol: Environment Agency.

DEFRA (2006). Shoreline Management Plan Guidance Volume 2: Procedures. London: DEFRA.

HALCROW (2012). Methods to screen and quantify natural flood management effects. Report by Nutt, N. to the Scottish Environment Protection Agency and Forestry Commission Scotland. Edinburgh: SEPA.

LEGGETT, D. J, COOPER, N. and HARVEY, R. (2004). Coastal and Estuarine Managed Realignment – Design Issues: CIRIA C628. London: CIRIA.

ROGERS, J., HAMER, B., BRAMPTON, A., CHALLINOR, S., GLENNERSTER, M., BRENTON, P. and BRADBURY, A. (2010). Beach Management Manual (second edition), CIRIA 685. London: CIRIA.

SEPA (in draft). Modelling Guidance for Flood Risk Management. Stirling: SEPA.

# CHAPTER 6:
## Implementing a natural flood management project

Figure 6.1. Remendering works taking place on the Eddleston Water, Scottish Borders (© Tweed Forum).

The process by which NFM measures are identified, assessed, reviewed and finally implemented on the ground (hereafter referred to as an NFM project) varies from site to site. However, successful implementation of NFM typically involves a number of key stages informed by catchment studies, modelling, surveying and engagement. This chapter outlines these stages, including identification and prioritisation of measures, land manager engagement and delivery of works on the ground (Figure 6.1).

The following describes the key steps which are common to most NFM projects and in some cases mandatory, for example, obtaining permissions (Figure 6.2). None of these steps have fixed durations and some can be undertaken concurrently, most notably land manager engagement which will likely take place throughout the process.

| | |
|---|---|
| **Step 1. Need/aspiration** | Identification of NFM need or aspiration by local authority in FRM Strategies and Local FRM Plans or by land manager, non-governmental organisation or local stakeholders. |
| **Step 2. Engagement** | Land manager engagement to assess level of interest and obtain buy in, plus wider stakeholder engagement and awareness raising – will continue throughout process. |
| **Step 3. Identification of opportunity areas** | High level assessment of opportunity areas for NFM, including a desk based study of GIS maps (e.g. SEPA's NFM maps). |
| **Step 4. Scoping study** | Identification and prioritisation of NFM measures within a catchment or coastline, informed by catchment characterisation, a high level appraisal of the effects of the measures identified and feasibility/land manager considerations. |
| **Step 5. Options appraisal** | Assessment of the various options to implement the prioritised measures and the relative advantages and disadvantages of each option to deliver, informed by surveys and modelling as required. |
| **Step 6. Design** | Production and agreement of design (including permissions) including the undertaking of surveys and modelling and production of engineering drawings, as required. |
| **Step 7. Implementation of works** | Implementation of measures on the ground (ground works). |
| **Step 8. Management and monitoring** | Ongoing management and maintenance of measures, including monitoring of effect to inform adaptive management. |

**Figure 6.2 The key steps involved in implementing an NFM project.**

## 6.1. NEED/ ASPIRATION

All NFM projects begin when a need or aspiration to deliver NFM within a catchment or coastal area is recognised. At a strategic level this will be initiated by a local authority as part of their work to deliver actions set out in the FRM Strategies and Local FRM Plans (see Box 6.1). Alternatively, it may be initiated locally, by a rivers trust, landowner, land manager or local stakeholder group in order to help reduce local flood risk not identified in the FRM Strategies. In some cases, such as with the delivery of the FRM Strategies and Local FRM Plans, the main driver will be flood risk management, while in other cases there will be multiple drivers of which flooding is one component.

## 6.2. ENGAGEMENT

Any initiative to deliver NFM requires the setting up and management of active stakeholder and landowner/land manager engagement to promote and raise the awareness of NFM. This permits the level of interest and acceptance of NFM by stakeholders within particular catchments or areas to be explored. This active and open engagement activity should continue throughout the process and may help to facilitate future NFM projects.

The extent and focus of engagement will be dependent on the nature and scale of the project. For example, where NFM is proposed in close proximity to settlements, then the community will need to be engaged. Where the work proposed to take place is in a remote location or is very small in scale, then engagement may only need to take place with the relevant landowners/managers. The development of a communications plan, particularly for larger scale projects, will help guide effective engagement.

### Box 6.1. Delivery of NFM actions identified in the Flood Risk Management Strategies

As required by the FRM Act, SEPA has been working with local authorities and Scottish Water to identify the most sustainable actions to manage flood risk within flood risk areas (called Potentially Vulnerable Areas or PVAs) and detail this in Flood Risk Management Strategies. Local authorities are responsible for determining how these actions will be implemented and financed and outlining this in a Local Flood Risk Management Plan. NFM actions that a local authority may be tasked with progressing are:

- runoff reduction;
- river or floodplain restoration;
- sediment management;
- surge attenuation; and/or
- wave energy dissipation.

Table 2.1 in Chapter 2 describes the river and catchment based NFM measures that relate to the first three of these actions. Chapter 3 describes the measures that relate to the latter two coastal actions. Where one or more of the above actions have been identified, a local authority will be required to examine in greater detail the potential for the action to benefit flood risk, and its cost/feasibility (including landowner/land manager buy in) and what measures may be merited. The nature of the assessment will vary depending on the nature of the action (e.g. runoff reduction which are typically non engineered measures versus river or floodplain restoration which can be highly engineered), its spatial scale (e.g. consideration of multiple measures within a catchment versus a study of options on a single river reach) and the wider suite of actions under consideration. Very generally studies will involve one of two approaches, both of which will be informed by land manager engagement:

- Scoping study: where one or more of the above actions have been identified and there is a need to better understand where opportunities should be targeted and the benefits they may provide within a catchment or coastline then a scoping study should be undertaken (see Section 6.4 for further details); or
- Options appraisal: where the location of measures to deliver a given action (e.g. river restoration of a defined reach) is already known then it may be possible to proceed direct to an appraisal of the options for delivery of that action at that location (see Section 6.5 for further details).

Where these studies conclude that the action is feasible and merited, the local authority will be expected to progress to the next phase of assessment or design and, where deemed appropriate, implement measures.

**Figure 6.3. Tweed Forum interactive natural flood management model in action (© Tweed Forum).**

### 6.2.1. Awareness raising and community engagement

Where wider awareness raising is deemed necessary, a number of different engagement mechanisms can be employed. Promotional leaflets can be useful as they summarise in layman's terms what is being proposed and can be distributed to the community via a mail shot. Community council or other community group meetings can be successful in identifying the aspirations of the community and any potential concerns. The websites of the project partners can include landing pages promoting the project, together with contact details for further information. Exhibitions and displays at agricultural or other rural shows can be very effective in reaching a wide audience, particularly if they involve the use of interactive demonstration models. These models, such as the one developed by Tweed Forum, can also be used in schools and colleges if they are mobile (Figure 6.3).

### 6.2.2. Landowner/land manager engagement

It is imperative that the lead organisation (or appointed agent) makes contact with all the relevant landowners and land managers at an early stage in the process. Unfortunately, landownership and land manager contact information is rarely readily accessible (due to data protection law). This can frequently be overcome by working with an organisation that has existing relationships with relevant landowners/land managers in the local area.

One-to-one meetings with landowners/land managers are frequently the most effective method of engagement (Figure 6.4). This may be initiated by a personalised letter or email and subsequent phone call where relevant. Where possible, group meetings with landowners and managers in the catchment may also help to identify opportunities and constraints and build consensus on action at the catchment scale. Some of the above techniques used in community engagement, such as the use of visualisation tools, may also be useful. Engagement with landowners/land managers is usually best undertaken in the evening and outwith periods of major faming activity (e.g. harvest or lambing).

### 6.2.3. Barriers to participation and engagement

In order to engage effectively it is fundamental for the agent or intermediary to understand the main barriers to implementation from the landowner/land manager's point of view. A range of questions that may be asked by landowners/land managers is provided in Box 6.2. The following summarises some of the most frequently raised concerns that may influence delivery of NFM.

- **Loss of income and/or capital value of land** – Any loss of productive land or decrease in capital value of the land may affect the commercial success of the farming business. It is therefore important to source or provide payments which cover not only the capital works but compensate the landowner/land manager for the change in land use (see Chapter 8). This may mean being able to assess the value of piece of land and the income foregone from changing management. It is also beneficial to communicate any opportunities for NFM to increase revenue, such as through the provision of wood fuel, improved game habitat or improved fish habitat.
- **Loss of control of land management** – Implementation of some NFM measures will require land management agreements with, or driven by, third parties and hence a perceived loss of control of that land. It is therefore necessary to make the landowner/land manager aware of their commitments such as the term of the agreement, whether it can be reversed, or whether it is on marginal ground with little impact on the working viability of the farm unit.
- **Contrary to preferred approach to river management/maintenance** – Historic policies and incentives encouraged maintenance activities that removed water from the land quickly, such as dredging, and some of these approaches are the preference of land managers today. However, while such maintenance activities may be justified in certain situations they are not long term sustainable solutions and may exacerbate flooding and increase costs. Communicating the advantages and disadvantages of different approaches, including NFM, is therefore important.
- **Bureaucracy** – Many funding mechanisms are complex and require time and effort to progress applications. Provision of simple funding schemes (e.g. by a local authority) or pursuit of applications on the applicant's behalf, either directly or through the appointment of an agent or intermediary, will help reduce this burden.

### 6.2.4. The trusted intermediary

While the statutory responsibility for delivery of the Local FRM Plans lies with the local authorities, it may be beneficial to employ the services of an impartial party to carry out engagement and deliver works on the ground. This party is normally a local non-governmental organisation such as a local river or fisheries trust. Such organisations have the advantage of being independent and trusted. They also have extensive local knowledge and, in most cases, established relationships with the land managers within the catchment. Ideally they will also have good knowledge of farming systems so as to be able to offer sound practical advice in a way that fits in with farming operations and the farming calendar.

**Figure 6.4. One-to-one engagement on the Bowmont Water catchment, Scottish Borders (© Tweed Forum).**

## Box 6.2. Frequently asked questions

The following highlights some of the questions that are most frequently asked about NFM, particularly by landowners and land managers prior to committing to a contractual agreement to implement works. The answers provided incorporate the most up-to-date information and advice available.

### Does NFM work – what evidence is there?

The concept of NFM has been around for many years but it is true that scientific evidence, particularly of the effects of some measures at a larger catchment scale, is limited. While NFM measures alone are not likely to protect communities during a major flood event, evidence from projects in the UK and internationally indicate that NFM can work at a local scale and reduce the flood risk to communities during smaller more prevalent flood events. NFM measures can also be used alongside more traditional hard engineering methods to increase their resilience and help buffer the effects of climate change.

### Is NFM ever likely to increase flood risk?

NFM are generally no regret measures, and with careful assessment and design should not increase flood risk. Some NFM measures (e.g. instream structures) are associated with a greater level of uncertainty than other measures (e.g. non-floodplain wetland restoration) and consequently require a greater level of assessment and design. Considerable work, including improvements to modelling, is being undertaken to review and evaluate NFM techniques to increase our knowledge about which NFM measures will work and where. Sharing knowledge and further investment into NFM research and demonstration will prevent measures being used where they could increase flood risk.

### How long do NFM measures take to provide benefits?

This depends on the measure. Structural measures, like large woody debris or remeandering of a straightened river, will have an immediate effect on local flows. Conversely, there is a significant lag time associated with non-structural measures, such as the planting of trees, which will take years to establish.

### Why should land managers flood their land to benefit those who have built on a floodplain further downstream?

Everyone can benefit from NFM measures. While people downstream may have their flood risk lowered, the land manager delivering the measure can benefit from a payment to provide that service. It is also possible that NFM measures may benefit the land on which they are sited, for example, by improving soil structure and improving yield. Funding for NFM may also incorporate elements to incentivise uptake by land managers such as the provision of fencing.

### Are landowners and land managers obliged to undertake NFM measures?

Section 56 of the FRM Act enables a local authority to do anything which it considers will contribute to the implementation of measures described in the Local Flood Risk Management Plan. This includes entering into agreements or arrangements with individuals for the purpose of carrying out work (by either the local authority or individual) or for the purpose of managing land (by that individual) to slow or retain flood water. Local authorities will liaise with landowners and land managers to reach agreements to implement any measures identified on their land.

### Can councils purchase land to implement NFM?

Local authorities will work with landowners and land managers to agree appropriate measures and will work through options for implementation. This could include land purchase if both sides are in agreement that this is the best way forward. In the future it may be that community or private funded NFM schemes include land purchase elements.

### Will implementing NFM increase the risk of disease transfer from standing waters?

There are always risks from standing water and these will need to be identified and addressed appropriately. However, NFM measures generally do not involve the creation of permanent standing water. Any flood water stored on land will be temporary and infrequent in nature. It may be possible to provide capital payments for fencing to prevent livestock entering wetland areas.

**Will implementing NFM affect the capital value of land?**

This will depend upon the land use change resulting from the implementation of the NFM measure. For example, if low quality grazing land was used for amenity tree planting or wetland creation, it may increase the capital value of the land.

**Will implementing NFM affect Single Farm Payment?**

Most often, land that is not 'agriculturally productive' can be categorised as 'providing environmental benefit' and, in these circumstances, payments are generally not affected. However, where woodlands have been created payments could be affected. Land managers should contact their local area RPID (Rural Payments and Inspection Division) office for more specific advice.

**Could implementing NFM affect farm rent (i.e. through loss of agricultural land leading to reduction in agricultural output)?**

Both tenant and landlord will be required to agree to any proposed works. This agreement should cover any adjustments to farm rent where there is demonstrable loss of production.

**What happens to the contractual arrangement if the tenant leaves?**

As stated above, both tenant and landlord will be required to agree to the proposed works. Where works and/or maintenance are the responsibility of the tenant, this agreement should identify arrangements for transfer of this responsibility, in the event the tenant leaves, to the succeeding tenant.

**Can implementing NFM impact land ownership boundaries (e.g. remeandering where a watercourse represents the holding/ property boundary)?**

No general rules can be given here, as it would depend on scale and individual land ownership circumstances. However, there may be a requirement to adjust the title deeds of the properties in question. In practice, this is likely to be a small area of land.

**How will land managers water their stock if watercourse access is removed?**

If access to a watercourse is removed, off-stream watering for stock may be required using either mains supplies or by diverting or pumping water into drinking troughs from the watercourse. Where the work is local authority led, this can be accommodated within a project cost/compensation package. Where the work is funded through the Scottish Rural Development Programme, an element of the alternative/replacement drinking water facility is usually fundable.

**Are there any penalties associated with contractual arrangements?**

Once a contract is signed, the contract should be adhered to as it is a legally binding contract. If, for example, an area of woodland was due to be planted as an NFM measure under a Scottish Rural Development Programme agreement and the landowner/land manager backs out, a monetary fine might be imposed on the agreement holder by the government, if an acceptable reason for not planting it is not provided (and accepted).

**Will land managers still be able to fell/coppice/manage trees?**

This will be possible but permission from Forestry Commission may be required along with a felling licence. Conifers or beech trees generally do not coppice but native species, such as ash, hazel, willow and oak, will coppice. Re-growth shoots may need to be protected from deer and domestic livestock. Coppicing riparian woodland is a good way of managing woodlands, and it can also provide fuel wood for the farm, while benefiting wildlife and the rural landscape.

**What happens if the land manager wants to revert the land back to agricultural production?**

Some NFM measures may exist alongside current agricultural production. However, where they do not, this will depend on the agreement into which the land manager entered. For example, if an area of woodland was due to be planted under a Scottish Rural Development Programme contract and the farmer backs out, then unless good reasons can be given for this, and a contract waiver is not possible, a monetary fine may be imposed. If a land manager wishes to terminate a contract then they would be obliged to discuss this with the appropriate authorities to determine the consequences and then work together to identify and implement the most appropriate course of action to manage any negative impacts.

## 6.3. IDENTIFICATION OF OPPORTUNITY AREAS FOR NFM

The FRM Strategies and Local FRM Plans prioritised opportunities to deliver NFM within Scotland and therefore this step does not apply to those actions. However, it may be that a stakeholder, landowner, land manager or non-governmental organisation such as a river trust wishes to identify additional opportunities to help manage local flood risk in a catchment or coastline. In such cases the process may benefit from a high level of assessment of target areas within that catchment or coastal area prior to undertaking a more detailed scoping assessment. This is particularly the case for large catchments where scoping of the potential for NFM in the entire catchment is not feasible.

Identification of opportunity areas should involve a short desk based study of GIS maps, including:

- SEPA's NFM and flood risk maps[13];
- Forestry Commission/Forest Research woodland for water maps (where available)[28];
- land cover maps (e.g. Land Cover Map 2007[129]); and
- historical maps/aerial images (where available).

Existing plans and studies may also provide useful information such as:

- local authority flood studies;
- strategic flood risk appraisals;
- National Coastal Change Assessment;
- National Marine Plan;
- Marine Spatial Plans (where available);
- River Basin Management Plans;
- Catchment Management Plans (where available);
- Shoreline Management Plans (where available); and
- the Online Marine Registry.

SEPA's NFM maps (see Chapter 5 and Figure 6.5) and flood risk maps[13] should be consulted to identify where there are opportunities for NFM that may benefit flood risk. For example, extensive opportunities for floodplain storage immediately upstream of a PVA will likely merit progression to a more detailed scoping study. Where available, additional information on the extent of modification of a watercourse (such as whether embankments are present or the watercourse has been channelised), should also be used to inform target areas. This information may be obtained from site walkovers, historical or aerial maps or any catchment surveys that have been carried out.

Further guidance on the identification of opportunity areas and the use of the NFM maps is available on the SEPA website[130].

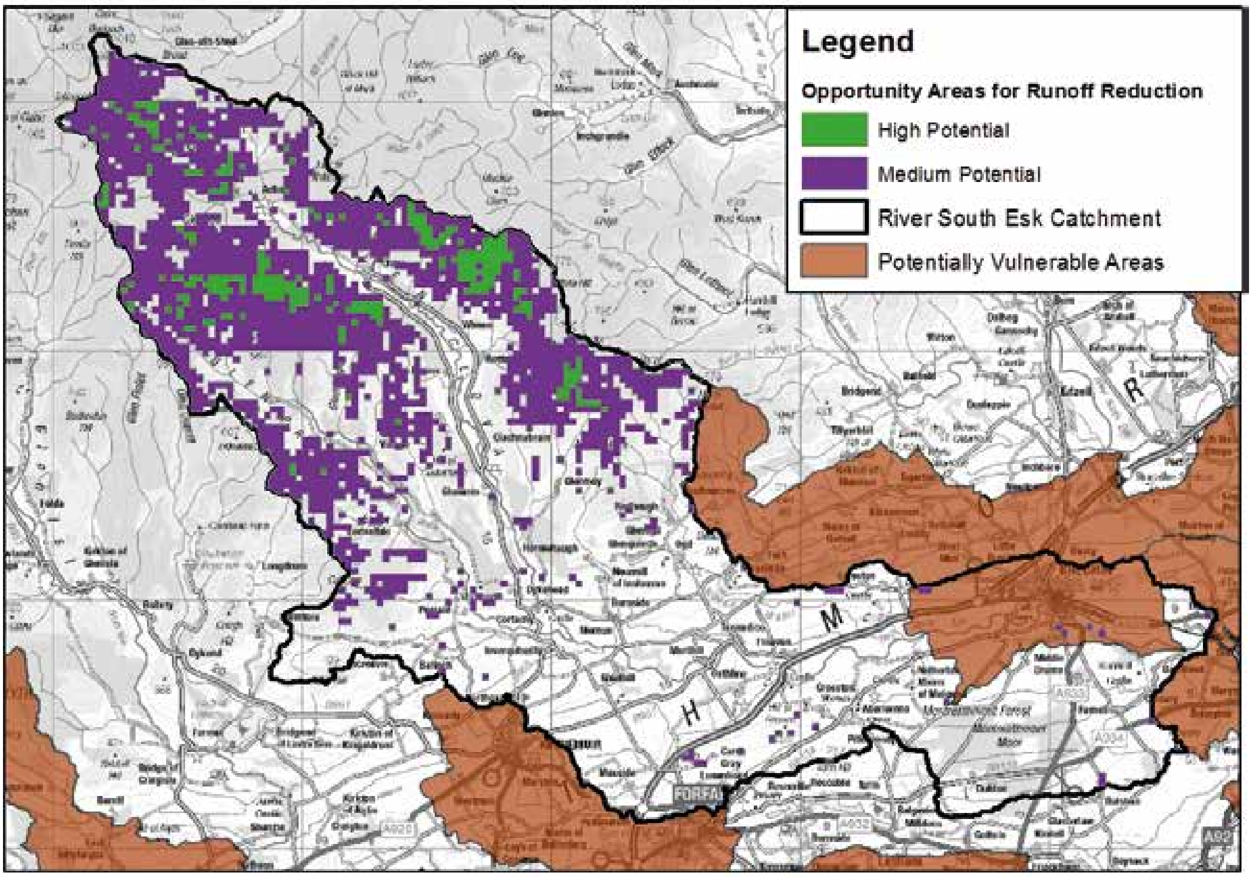



**Figure 6.5. Example of output from SEPA's NFM maps showing areas with potential for runoff reduction in the River South Esk (Angus) catchment.**

# 6.4. SCOPING STUDY

Identification and prioritisation of NFM measures within a particular catchment or coastal area requires a suitable scoping assessment to be undertaken. This assessment should include characterisation of the catchment or coastal area, appraisal of the flooding and potential wider benefits of different measures, together with consideration of landowner and land manager interests and constraints. The final output is a short list of measures that represent those measures most likely to deliver flooding and additional benefits.

## 6.4.1 Catchment/coastal characterisation

Using existing spatial data sets within GIS and information from SEPA's baseline studies undertaken during the development of the FRM Strategies, an initial assessment of the study area (which may include a coastline, hereafter referred to as a 'catchment') characteristics should be provided. This should enable the formulation of a detailed understanding of how the catchment currently operates under flood conditions and the areas of the catchment which contribute most to flooding.

Catchment characterisation should include information on:

- environmental context (such as topography, precipitation, soil type, land cover and land use, WFD status);
- hydrology and flood risk (such as an overview of the response of the catchment to flood flows, e.g. analysis of median annual maximum flow and time to peak); and
- opportunity areas for NFM as identified in SEPA's NFM maps.

GIS data should be complemented by walk-over surveys of the areas identified to be of significance to NFM (Figure 6.6) and should include elements such as:

- confirmation of land-use;
- identification of infrastructure such as new buildings or utilities;

**Figure 6.6. Hydromorphological surveying on the Invergowrie Burn, Perth and Kinross.**

- evidence of restoration potential;
- morphological pressures and assessment of hydromorphic/coastal/ sediment processes;
- identification of biodiversity features (and designated sites); and
- identification of hydraulic structures.

At the end of this phase of the study, catchment maps (e.g. Figure 6.7) should be produced showing the findings of the above assessment, including information that can be used to determine opportunities to deliver additional benefits, such as improvements in ecology and Water Framework Directive status.

## 6.4.2. Long listing of measures

A long list of potential NFM options should be identified using expert judgement and referencing the catchment characterisation.

The focus of the long listing will depend on the actions under consideration, namely runoff reduction, floodplain and river restoration, sediment management, surge attenuation or wave dissipation.

In addition to information from existing projects and studies, the following datasets should be used to further inform the selection of measures for inclusion in the long list. These include:

- survey data where available (e.g. fluvial audit data);
- land cover data (e.g. Land Cover Map 2007[129], Native Woodland Survey of Scotland[131], National Forest Inventory[132]);
- aerial photography where available;
- historic maps where available (e.g. old toll road maps, Figure 6.8); and
- Land Capability for Forestry Map[133].

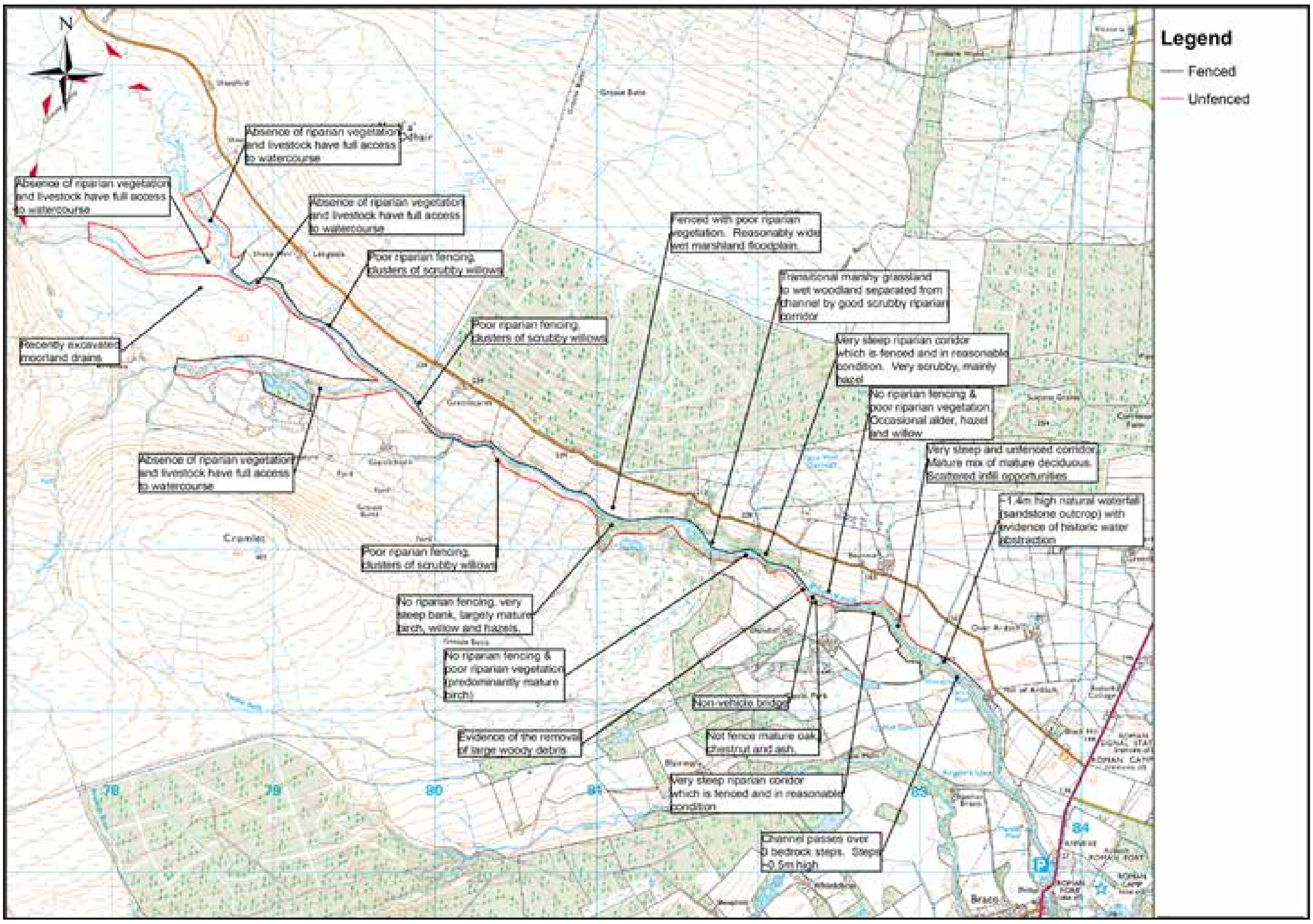



**Figure 6.7. Catchment reconnaissance observations used to inform an NFM scoping study of the Allan Water, Stirlingshire (©CRESS and Halcrow).**

### 6.4.2.1. River and floodplain restoration

Consideration of opportunities for river and floodplain restoration should take account of the extent of the floodplain, the presence or absence of river embankments, i.e. whether the floodplain is connected to the watercourse, and whether there is the potential for reconnection if not. Reference should also be made to land cover, and measures only targeted in areas that are suitable for wetland. Where artificially channelised sections of river exist, reach restoration such as remeandering should be considered. It's important to note that the above measures will frequently achieve the greatest benefit in conjunction with other measures, for example, reach restoration in conjunction with floodplain planting.

### 6.4.2.2. Sediment management

Sediment management measures will generally fall in to two categories,

- those that manage sediment at source; and
- river restoration.

Where there is sufficient information on the source of an artificial supply of sediment then measures to address that supply should be considered (e.g. improved land management practices or sediment traps). Alternatively, where alterations to the river channel or its banks have generated excessive amounts of in channel sediment, river bank restoration or river morphology restoration may be appropriate. Chapter 2 provides further information on sediment dynamics and management (Box 2.3). Sediment management studies should always consider whether the source of sediment is naturally occurring (and thus unlikely to merit intervention) or artificial, as well as the river's potential for natural recovery.

### 6.4.2.3. Runoff reduction

Information on the current land cover, including the presence of existing forest/woodland, should be used to inform the selection of runoff reduction measures. The identification of where planting may be pursued for the purpose of reducing runoff should also be informed by reference to the land capability for forestry map. Planting is not recommended above the natural treeline but upland drain blocking may be suited to these areas. The identification of opportunities for upland drain blocking should be informed by aerial photography (or other remote

**Figure 6.8. Historic map showing original meandering course of the Eddleston Water prior to channelisation, Scottish Borders: This map was used to inform works to restore the river to a more natural planform (front cover) (sourced by Harrison[134] from National Records of Scotland archives).**

sensing information) where available as this may provide information on existing drains.

#### 6.4.2.4. Estuarine surge attenuation and wave energy dissipation

Selection of coastal measures for progression to long listing will be largely determined by the findings of the characterisation assessment outlined in Section 6.4.1, such as the nature of the coastal processes at the site, the condition of the site, and the flooding and flood risk for that PVA (e.g. whether the flooding is a result of direct inundation, or breach or overtopping of existing structures). Strategic flood risk appraisals and any other projects or studies on coastal flooding or restoration within that PVA, including information in Shoreline Management Plans or equivalent should be considered.

The Coastal Erosion Susceptibility Model and associated outputs and documents commissioned via the Centre of Expertise for Waters (CREW) should also be referenced[135,136]. Chapter 3 should be referred to for more information on the considerations and datasets that should inform the selection of coastal measures.

### 6.4.3. Short listing of measures

#### 6.4.3.1. Effect on flood risk

The options long listed in section 6.4.2 should be assessed to estimate the potential effect of each measure on flood risk. This should include elements of qualitative and quantitative assessment (modelling). The extent to which an NFM measure will have an impact on flood risk will be partly influenced by how close it is to the area of flood risk. Consequently, consideration should be given to the proximity of the potential measure to the area of flood risk. Since NFM actions will have the greatest effect on flows during more frequent flood events, potential measures should be prioritised where there is local, more frequent flooding.

The type of assessments required will depend on the NFM measures in question – Chapter 5 should be referred to for further discussion of the tools and assessment methods that may be applicable. Where resources permit, modelling should be undertaken at this stage to determine how much change in flood flows or levels NFM would have to deliver to achieve a given reduction in flood risk. This can be used to inform expert judgement in determining whether long listed measures are likely to have sufficient impact on flood risk to be progressed to the short list. Modelling can also be undertaken at this stage to refine identification of areas within a catchment where NFM may have the greatest effect on flood risk (see Section 6.5 for further discussion of modelling).

#### 6.4.3.2. Additional benefits (and disbenefits)

Information on the potential for additional benefits or disbenefits to the wider economy, environment and society should also be used to identify those measures for shortlisting. Understanding these wider impacts is important to finding sustainable solutions and achieving multiple benefits. Impacts in this category will be best described in a non-monetised manner and in a short descriptive form, rather than being quantified in detail.

The following questions should be considered when determining the significance of a range of additional benefits and disbenefits:

- What are the likely key positive and negative impacts on the economy, society and environment?
- How important is the part of the environment and society that is likely to be affected?
- What is the scale of the impact and how long will it last?
- Are the impacts important enough to affect the final selection of measures to progress to implementation? and
- Are the key impacts likely to be important to local stakeholders and communities?

The assessment of wider impacts may not be limited to these impacts, especially if additional impacts are important to key stakeholders and communities. A clear record of how these impacts were considered should be provided.

#### 6.4.3.3. Feasibility issues

Where information is available, the impact of proposed measures on existing services, utilities and other infrastructure should be considered. This should include reference to major infrastructure such as sewers, gas and electricity supply, roads and rail networks. Where the costs involved in relocating or disrupting such infrastructure are significant, it may be unfeasible to progress an NFM measure. Consideration should also be given to any potential for increased flood risk, such as the placement of instream structures immediately upstream of bridges or culverts.

This assessment should be carried out against a range of potential economic, social and environmental impacts, such as those described in Table 6.1.

**Table 6.1. Examples of criteria for inclusion in assessment of wider benefits and disbenefits**

| Criteria | Description |
|---|---|
| Morphology (including WFD objectives) | Assess impacts (positive and negative) on coastal or channel morphology, including the potential for achievement of WFD objectives. Information on the current morphological status and objectives for water bodies is available on the SEPA website[137]. SEPA should be contacted for further information on whether a proposed NFM project could achieve a classification status change. |
| Water quality (including WFD objectives) | Assess impacts (positive and negative) on water quality, including the potential for achievement of WFD objectives. Information on the current chemical status and objectives for water bodies are available on the SEPA website[135]. |
| Natural processes | Assess impacts (positive and negative) on other natural processes not captured under WFD objectives (e.g. soils, geology, and aspects of geomorphology) or for those parts of the water environment not defined as a water body under the WFD (e.g. small watercourses). |
| Climate change impact | Assess impacts (positive and negative) on adaptability to climate change, for example, whether a measure enables natural systems to better adapt to a future changing climate, e.g. sea level rise. |
| Habitats and species | Assess impacts (positive and negative) on designated sites, including European designations and sites of national importance. Identify opportunities for the measure to help meet site conservation objectives. Potential impacts on protected species known to be located in the areas affected by measures should also be considered. Further information on designated sites is available on the SNH Site Link website[138].<br>Also assess impacts (positive and negative) on any local and non-designated sites, such as degradation in the habitat quality and reduction in species, or an opportunity for the creation/enhancement of other non-designated habitats and species. |
| Recreation and tourism | Assess impacts (positive and negative) relating to tourism and recreation (e.g. impacts on water sports, wildlife watching opportunities, fisheries, walking, visitor numbers). |
| Landscape | Assess visual impacts on the landscape (positive and negative) associated with proposed measures. Landscape includes all external environments, including; cities, villages, rural landscapes and the elements that comprise them. |

### 6.4.3.4. Land manager considerations

Areas of high grade agriculture, as detailed in the land capability for agriculture map[133], should be considered as measures may impact food production and it may be difficult to gain land owner agreement for such measures (Figure 6.9). However, caution should be applied when using this criterion to screen out measures, as impacts on productivity may not be significant when judged over the long-term, and agreements can be reached with land manager on suitable levels of compensation. Impacts on other farm activities, such as game shooting, should also be considered. Benefits to the land manager of undertaking a measure, such as improved drought resistance, reduced river maintenance commitments, and reduced flooding of downstream stakeholder land should also be considered.

### 6.4.3.5. Summary of short listing assessment

For each measure the following should be presented in tabular form together with the following details:

- estimated impact on flood risk (and levels where allowed by assessment method) at each return period;
- known feasibility issues;
- land manager benefits and disbenefits;
- land owner buy in if known;
- additional benefits and disbenefits; and
- based on the above, whether the measure should be progressed to the short list and more detailed assessment (options appraisal and design).

**Figure 6.9. Arable field in the highly productive region of Fife: Short listing of measures should consider feasibility including loss of high grade agricultural land.**

## 6.5. OPTIONS APPRAISAL

While a scoping study identifies the type and location of NFM measures that may be implemented in a catchment or coastline, an options appraisal identifies and reviews the various options to implement the prioritised measures and their relative advantages and disadvantages (Figure 6.10). Its main objective is to provide sufficient information to reach agreement on a preferred option or options (in consultation with the landowner/land manager and other stakeholders) and to outline additional assessments/surveys required to progress the preferred options. Most projects that require a considerable level of engineering such as river realignment and embankment removal will require an appraisal of options, although the level of appraisal will vary depending on the breadth of options.

Most options appraisals first consider whether the overarching objective is to assist restoration of, for example, a river reach, or to undertake full restoration.

Based on the overarching objective, options for the site are then developed. Typical factors considered in an options appraisal include the potential effect (both positive and negative) of each option on:

- flood risk;
- hydromorphology (including status changes under WFD);
- infrastructure, services/utilities;
- land ownership;
- water quality;
- archaeology;
- landscape;
- amenity;
- carbon emissions; and
- costs.

Where risks are identified, approaches to mitigation of these options should also be outlined. The outputs of this options appraisal are then used to decide on a preferred option with the landowner/ land manager and other stakeholders. The preferred option is then taken forward to outline design.

Scoping studies should be referred to for baseline information on the characteristics of the catchment or coastline. However, more detailed surveys of the site in question should also be carried out as required to inform options appraisal, such as a topographic survey, hydromorphology survey or ground investigations.

Modelling should be undertaken to inform options appraisal (see Chapter 5). The degree of benefit gained from each potential measure (e.g. embankment removal, channel realignment) should be assessed relative to the baseline scenario. The assessment should consider the potential change to peak flood flows, hydrograph timing and, where the method of assessment allows, flood levels. Uncertainty analysis should be undertaken to determine the level of confidence in the assessment.

The final outputs of an options appraisal should include:

- short options appraisal paper/report detailing each option considered and associated costs and benefits;
- specification for the preferred option; and
- estimated costs.

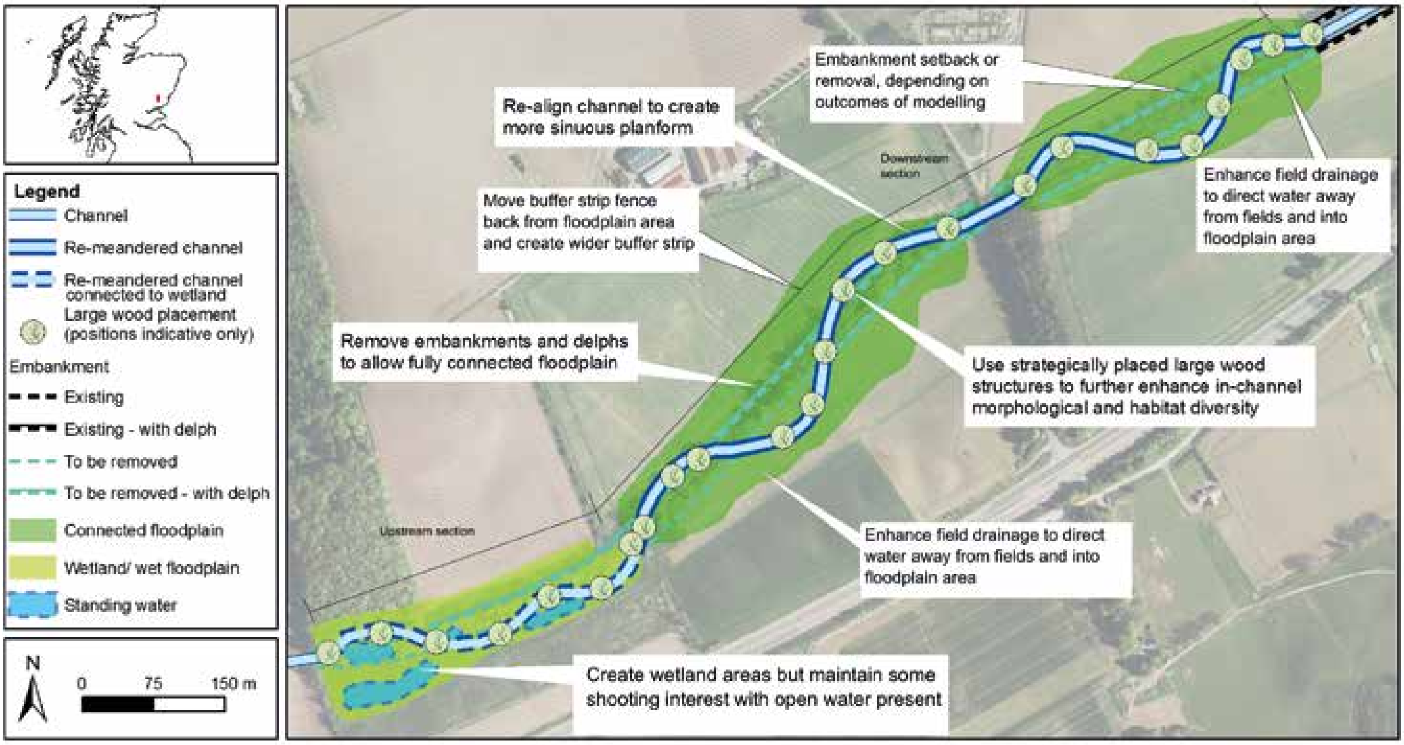



**Figure 6.10. Options appraisal for restoration of a reach in the South Esk catchment, Angus (©cbec eco-engineering UK Ltd.)**

## Box 6.3. Consenting requirements for NFM measures


The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended)

A Practical Guide

A practical guide to the regulations, including:

- An overview
- Definitions of the regimes
- Levels of authorisation
- The General Binding Rules

Version 7.2 March 2015

A number of different consents, licences and other permissions may be required when implementing a NFM measure. Any activity which may affect inland water must be authorised under the Water Environment (Controlled Activities) (Scotland) Regulations 2011 (CAR). Where activities are classed as providing an environmental service then no fee will be charged for these authorisations. While many NFM measures will not require formal authorisation (i.e. a registration or licence) they will need to comply with CAR general binding rules. Further information on CAR and the charging scheme is available on the SEPA website[140,141].

In Scotland, the Crown Estate manages about half of the coastal foreshore and almost the entire seabed. Consent for the use of the foreshore and seabed within Crown Estate ownership must be sought from the Crown Estate Commissioners and a lease may be required. Coastal NFM measures may also require authorisation from Marine Scotland Licensing Operations team under the Marine (Scotland) Act 2010. Licensable activities include many of the measures required for flood protection or coast protection schemes[142], such as:

- deposit of a substance or object in the sea or on or under the seabed;
- construction, alteration or improvement of works in the sea or on or under the seabed;
- removal of substances or objects from the seabed; and
- dredging (including water injection, agitation, plough and side-casting).

CAR applies to engineering works above the Normal Tidal Limit (NTL). CAR does not apply to works below Mean High Water Springs (MHWS). If works are below NTL but above MHWS advice should be sought from SEPA as to whether CAR applies. In such cases, where the location of works exhibits river/fluvial morphology characteristics rather than estuarine/marine characteristics CAR will normally apply. Further information on marine licensing and associated charges is available on the Scottish Government website[142].

Movement of waste, such as may be required when removing embankments, may require a waste management license or exemption from SEPA[143] while large scale works such as river realignment may require local authority planning permission[144] and/or an Environmental Impact Assessment (and associated fees)[145]. Where works are taking place in a designated site or where there is the potential to impact a protected habitat or species, approval from Scottish Natural Heritage will need to be sought.


**Implementing realignment works on the Balmaleedy Burn (North Esk), Aberdeenshire: River reach realignment works will require the appropriate CAR authorisation and may require planning permission (© K. MacDougall/EnviroCentre).**

**Box 6.3. (Contd.)**

Likely consents required for individual NFM measures

| Measure group | Measure type | Likely consents required for individual NFM measures* |
|---|---|---|
| Woodland creation. | Catchment woodlands. | Forestry Commission Scotland consent sometimes required. Local authority planning permission may also be required for large scale planting. |
| | Floodplain woodlands. | Unlikely to require consent. |
| | Riparian woodlands. | Unlikely to require consent. |
| Land management. | Land and soil management practices. | Unlikely to require consent. |
| | Agricultural and rural drainage modifications. | Unlikely to require consent. |
| | Non-floodplain wetlands. | May require a CAR authorisation if it involves engineering works, or works in or in the vicinity of existing wetlands. |
| | Overland sediment traps. | May require a CAR authorisation if it involves engineering works, or works in or in the vicinity of existing wetlands. |
| River and floodplain restoration. | River bank restoration. | May require a CAR authorisation from SEPA depending on technique adopted. |
| | River morphology and floodplain restoration. | Requires a CAR authorisation from SEPA. Local authority planning permission may also be required for major river works such as realignment. |
| | Instream structures. | Requires a CAR authorisation from SEPA. |
| | Washlands and offline storage ponds. | Requires a CAR authorisation from SEPA. Local authority planning permission may also be required. |
| Coastal measures. | Managed realignment. | May require a marine licence from Marine Scotland or a CAR authorisation from SEPA depending on type and location of works. Local authority planning permission may also be required. |
| | Saltmarsh and mudflats restoration. | May require a marine licence from Marine Scotland. Local authority planning permission may also be required. |
| | Sand dune restoration. | May require a marine license from Marine Scotland. Local authority planning permission may also be required. |
| | Shingle restoration. | Requires a marine licence from Marine Scotland. Local authority planning permission may also be required. |
| | Recharge (beach or intertidal). | Requires a marine licence from Marine Scotland. Local authority planning permission may also be required. |

* in addition to landowner

## 6.6. DESIGN AND CONSENTS

The nature and complexity of the NFM measure under consideration will determine the level of detail needed for the final design. Detailed engineering drawings will be required for the construction of more engineered NFM measures (e.g. channel realignment, removal of embankments, soft engineered river bank restoration, instream structures and most coastal NFM works). Other less engineered NFM measures (e.g. small offline storage ponds) may be implemented from outline drawings, instructions and face-to-face discussions between an experienced individual and the contractor or landowner/land manager carrying out the works.

### 6.6.1. Outline design

Once a preferred option has been selected, it is often useful to produce an outline of the design that can be discussed between all the relevant parties, prior to committing to detailed design. An outline design should include technical drawings showing the scope and extent of the works, materials to be used, and reinstatement procedures. It should also include non-technical drawings, sketches or visualisations to indicate clearly what the site will look like once measures are in place in order facilitate discussions. The outline design should be gradually amended until the landowner/land manager, funder and the regulatory/planning authorities agree the design.

### 6.6.2. Detailed design

A detailed design plan should contain all the information required to obtain the necessary consents (see Box 6.3) and to guide construction of works on the ground. It should be informed by a number of surveys and assessments which will typically include:

- flood risk assessment informed by appropriate modelling (further information on undertaking a flood risk assessment is provided in SEPA guidance[139]);
- hydromorphological assessment (e.g. to inform analysis of river dynamics in a river channel prior to, and after, restoration); and/or
- for coastal measures, a detailed understanding of coastal processes (which may require pre works monitoring).

All assessments should be informed by the necessary surveys, including topographic, channel (e.g. cross sections), and hydromorphological surveys. Information should also be gathered on potential ecological interests which could be impacted by the proposed measures (e.g. salmonids, freshwater pearl mussels) or whose presence could impact the timing of groundworks (e.g. otter holts). Where deemed necessary, species and/or habitat surveys should be commissioned to inform this process. Depending on the features of the site, archaeological, contaminated land and ground surveys may also be required.

The final outputs of the detailed design process should include:

- engineering drawings (including the location of the site and the water environment in the vicinity of the proposed works; the affected part of the water environment, site establishment details, and materials that will be used in relation to any temporary and permanent structures) (Figure 6.11);
- non-technical drawings, sketches or visualisations;
- details of all the surveys and assessments undertaken;
- information on approach to modelling and modelling outputs;
- details of all consents (see Box 6.3);
- build feasibility statement and construction method statements; and
- recommendations for maintenance and management.

Where design is contracted to a consultant, it may also be prudent to ask the consultant to include their costs for providing input to onsite works, as this helps ensure that the design is implemented as intended.

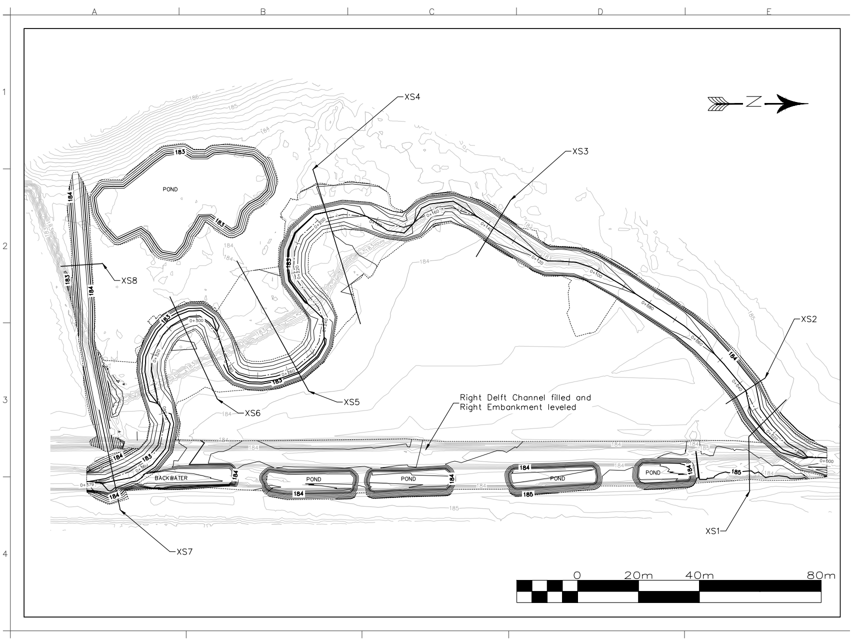



**Figure 6.11. A design drawing used to inform realignment and granting of permissions on the Eddleston Water, Scottish Borders (©cbec eco-engineering UK Ltd./Tweed Forum).**

# 6.7. IMPLEMENTATION OF WORKS

The implementation of NFM measures on the ground will need careful planning before works commence (Figure 6.12). The following describes some of the broad considerations that are important in planning works in most NFM projects. Specific considerations regarding the implementation of individual measures are described in more detail in Chapters 4 and 5.

## 6.7.1. Timing of works

An important consideration is determining when best to undertake works within the calendar year. This will need to take account of:

- potential for impacts on the environment, e.g. it is not advisable to undertake works in rivers in the winter or following significant rainfall when water levels will tend to be higher and ground conditions are usually more saturated meaning heavy machinery could more easily damage the ground and release sediments;
- the farming calendar, e.g. most land managers will be reluctant to give up their time to assist with works during lambing time (spring) or in the lead up to and during harvest time;
- conservation interests, e.g. bird breeding and nesting season; and
- project interests, e.g. timing preferences in terms of sowing grasses, planting trees/hedgerows, etc.

## 6.7.2 Personnel

The implementation of NFM measures involving a considerable amount of engineering on the ground (e.g. realignment or embankment works) will normally require the use of specialist works contractors, supervised by an appropriately experienced works manager. For other less engineered NFM measures it may be possible for a land manager to use their own machinery and personnel to implement NFM measures, again under the supervision of an appropriately experienced individual.

## 6.7.3. Legal considerations

A contractual agreement will need be drawn up and signed between the funding providers and landowners/land managers on whose land the NFM measure is to be implemented. Where land is tenanted, permission must be sought from the landowner and agreement reached between the landowner and tenant on any adjustments to farm rent as a result of loss of agricultural production.

The ultimate goal must always be to implement and maintain NFM measures such that liability is not an issue. Liability for measures will need to be agreed and included in the formal contract between the funder and the landowner/land manager. The contract should also outline commitments relating to maintenance and management of the NFM measure (see Section 6.8) including transfer of responsibilities to succeeding landowners or tenants.

**Figure 6.12. Implementing realignment works on the South Esk, Angus (© M. Halliday).**

# 6.8. LONG-TERM MANAGEMENT

The long-term management and maintenance of the site will need to be agreed with the landowner/land manager on whose land the NFM measure has been implemented. Ideally, this agreement should commit the landowner/land manager to maintain and manage the site for as long as is possible in order to retain the operational effectiveness of the measure. The nature of the management agreement will be dependent on the financial mechanisms being used to deliver the measure (e.g. a five year agreement under SRDP versus an in perpetuity commitment through a land covenant – see Chapter 8). Most larger scale NFM projects will require monitoring (such as site visits) at intervals after completion of the works in order to assess the effects of the measure and inform adaptive management (see Chapter 9).

## Further reading and guidance


HOLSTEAD, K., KENYON, W. and ROUILLARD, J. (2012). Factors that affect uptake of natural flood management features by farmers in Scotland: A Review. CREW: Edinburgh.

SCOTTISH GOVERNMENT (2010). Marine Scotland: Marine (Scotland) Act 2010, Part 4 Marine Licensing: General Guidance for Applicants. Edinburgh: Scottish Government.

SEPA (2013). Identifying opportunities for natural flood management. Stirling: SEPA.

SEPA (2015). The Water Environment (Controlled Activities) (Scotland) Regulations 2011 (as amended): A Practical Guide. Version 7.2. Stirling: SEPA.

# CHAPTER 7:
## Managing a natural flood management project

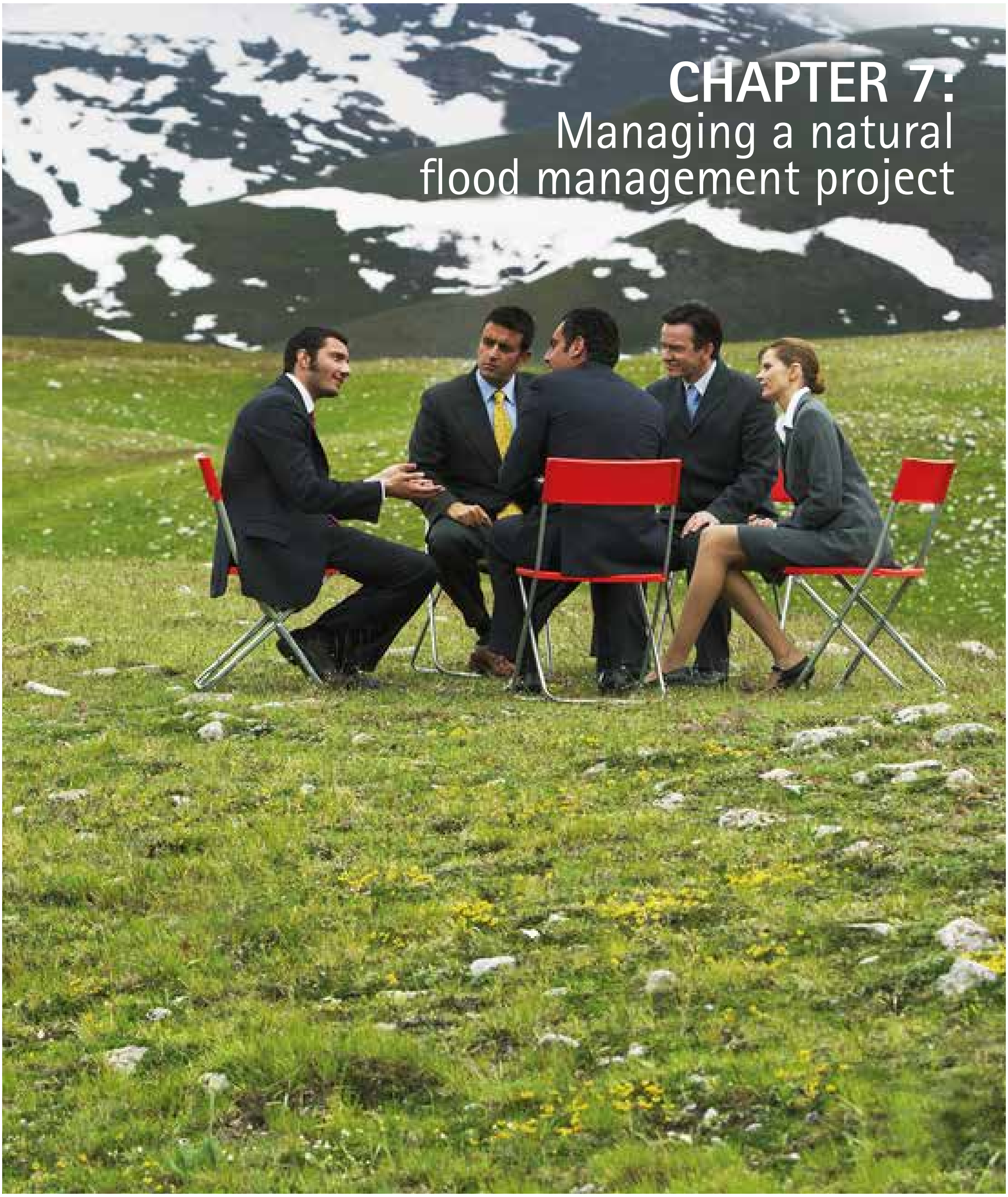


Figure 7.1. NFM projects will typically require a number of individuals and organisation to works together in partnership to deliver a joint vision (© Shutterstock).

Most NFM projects, particularly those that are large in scale, are delivered by a number of individuals and organisations working together in partnership to deliver a joint vision (Figures 7.1 and 7.2). Working together in this way brings flexibility that is less constrained by organisational structures and allows a pooling of capital and shared responsibility. It provides the range of expertise that is necessary in the decision-making process and in guiding the project to its successful completion. This chapter outlines the project management structure that helps facilitate effective delivery of an NFM project and maximises the benefits of partnership working.

For partnerships to be effective in delivering NFM, it is important that there is both a clear shared vision for the project and a robust project governance structure established at the outset in which roles and responsibilities are clearly defined and in which decisions can be made. This framework should specify the relationships between all groups and individuals and the route through which information is disseminated to other non-partner stakeholders. Most importantly it will ensure that reviews and approvals take place at appropriate stages of the project.

There are various project management methods that can be useful in guiding a project to delivery within budget, on time and to the appropriate quality. But as a guide, a successful project requires, as a minimum:

- a clear project governance structure that includes a decision-making authority with representation from relevant partners (e.g. project steering group);
- clear aims, objectives and defined deliverables that are agreed by all partners at the outset for working together to reach a common goal;
- a clear understanding of each member's roles, responsibilities and accountability for all aspects of the project;
- a process for recording, dealing with and communicating changes in a timely and transparent way;
- a process for the recording, communication and escalation of risks and issues in a timely and transparent way;
- a plan that sets out each partner's roles and responsibilities, as well as actions and timescales for delivery;
- commitment from partners that they will invest the necessary effort and resource (both time and/or finances);
- a communication plan, including internal project reporting requirements and the identification of external stakeholders with agreed routes to engage with these stakeholders; and
- a mechanism to review the original project objectives against current activities and ultimately against what is delivered to gauge success.


**Figure 7.2. Meeting of project partners on the Eddleston Water, Scottish Borders to launch realignment works. The Eddleston Water Project is managed by Tweed Forum and funded by multiple public and private organisations (© C. Spray).**

# 7.1. PROJECT STRUCTURE

The complexity of individual project structures will vary depending on the nature of the work, its scale, and the level of risk. However, there are certain elements that are typical to most NFM projects and these are described below in a generic framework that can be adapted to suit each project (Figure 7.3).

## 7.1.1. Project steering group

The project steering group should be made up of both the supplier (the delivery body or project delivery group and the user (e.g. local authority or land manager) at a minimum with other sponsors as appropriate, such as government agency, water supply company or rivers trust. This group should have decision-making powers for the project including the capability to make financial decisions. The size of the group depends on the scale of the project, for example, whether it is part of a strategic plan or more complex with many interests, but should remain as focused as possible otherwise it can become difficult to coordinate and the decision-making process is slowed. The group has responsibility for monitoring the progress of the project against its goals and keeping these goals and the project plan under review. It is also responsible for discussing and resolving any issues that arise during the course of the project. The Chair of the steering group is often known as the project executive and should be someone with executive decision making authority and overall accountability for the project.

## 7.1.2. Project manager

The project manager has the authority and responsibility for day-to-day management of the project, to deliver the required outcomes within the constraints agreed by the project steering group. The main responsibilities of the project manager are:

- to prepare and track progress against the project plan;
- to coordinate and manage the project delivery team;
- to report to the project steering group and advise them of any deviations to the agreed plan, as well as potential risks and current issues;
- to liaise with regulatory authorities and landowners/land managers as appropriate; and
- to ensure good communication is maintained between everyone involved in the project.

Where a project is being led by a local authority, the project manager may be an individual from that authority. However, where resources permit, it can be beneficial to employ a locally-based independent third party to undertake project management, such as a rivers trust or non-government organisation, who have well-established relationships with local landowners and land managers.

## 7.1.3. Project delivery group

The project delivery group, coordinated by the project manager, is made up of the people that will implement delivery of the measures on the ground. Usually, this is a mixture of technical experts such as specialist consultants, non-governmental organisations (e.g. river trusts), and regulators. This group identifies options for delivery of each element of the project and then ensures delivery of that element under the direction of the project manager. This group will work closely with the landowner/land manager and may, in some cases, include that individual in the group. Smaller projects may integrate the role of the project delivery group into the project steering group. However, if this occurs there must be a clear understanding of roles and decision making responsibilities.

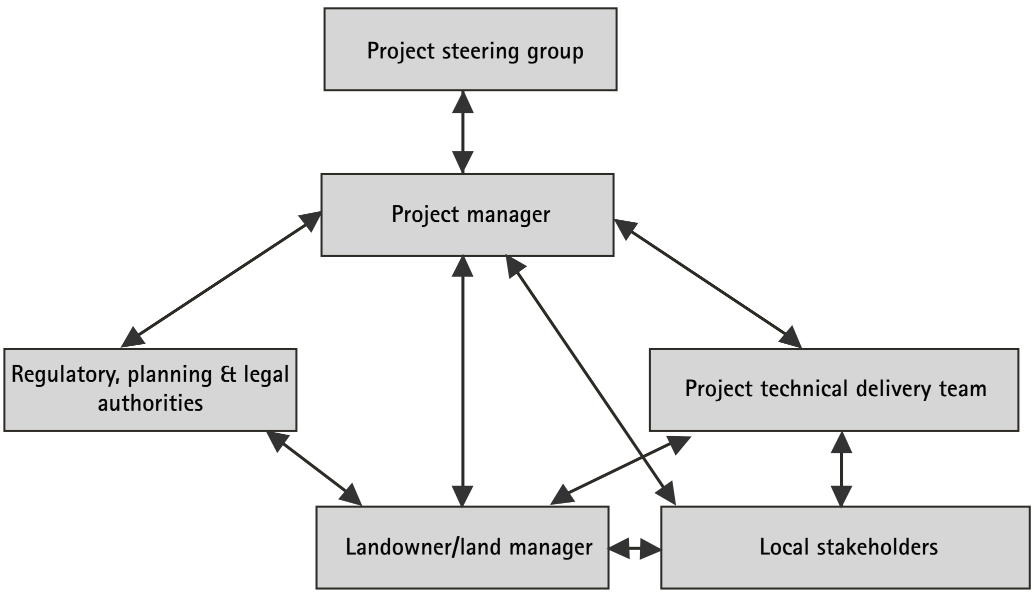



**Figure 7.3. An example of a typical project structure for managing an NFM project.**

Figure 7.4. Landowner workshop in the Bowmont Water catchment, Scottish Borders (© Tweed Forum).

Figure 7.5. The project manager for the Allan Water Project discussing proposals with the local community (© Communities Along the Carron).

## 7.1.4. Regulatory, planning and legal authorities

This is the group of relevant authorities that reviews applications for specific NFM measures. For larger projects it includes planning authorities and the regulators for environmental licences (e.g. for working in or near the river environment). In Scotland, the 32 local authorities and two national parks are our planning authorities, while SEPA is the regulator for environmental licences. Additional permissions may also be required from Scottish Natural Heritage for nature conservation permissions, particularly where works are being undertaken in a designated site and/or Historic Environment Scotland for permissions relating to the historic environment.

## 7.1.5. Landowners/land managers

Successful delivery of a project will require the involvement of all relevant landowners and/or land managers of the land where works are being implemented (Figure 7.4). In most cases land managers will be responsible for the management and maintenance of the measure, although there are exceptions to this such as where forestry management is contracted to a forestry contractor.

## 7.1.6. Local stakeholders

Local stakeholder engagement refers to the community and local interest groups (Figure 7.5). The mechanisms through which proactive engagement takes place will be influenced by the communication plan developed at the outset of the project. This group should include local interest groups such as rivers trusts, local farmer/landowner groups, local flood action groups, National Farmers Union Scotland, local communities, local councils, local interest groups (e.g. wildlife, environment, conservation, recreation), and charities.

## Further reading and guidance

HM Treasury (2007). Project governance: a guidance note for public sector projects. Norwich: HMSO.


Figure 8.1. Most NFM projects will require funding for material and labour and, in some cases, a payment to the land manager for costs incurred (© Shutterstock).

There are a number of potential sources of funding for the various components required to deliver NFM, including preworks assessment and capital works. This chapter provides an overview of these sources and outlines the approach to identifying the payment mechanisms to use when paying landowners/land managers for the provision of, and costs incurred in delivering, a flood risk management service.

Most NFM projects will require funding for the material and labour required to implement works on the ground (Figures 8.1 and 8.2). Large-scale projects such as river, floodplain or coastal restoration will also require funding for the necessary scoping, preworks assessments and design and in some cases, a payment to the landowner/land manager for the services they have provided (and costs incurred) in implementing works. The sources and the mechanisms through which funding is applied to an NFM project will need to be confirmed by the relevant parties and may require a formal agreement and funding application.

There are a number of potential public and private funding streams available for NFM projects which can fund some or all of the phases of implementation. Table 8.1 highlights some of the funds most suited to funding NFM although other funds exist, such as those provided by charities. The most commonly accessed of these is the Scottish Rural Development Programme (SRDP) funding for agri-environment and forestry/woodland works. Funding can also be sought from locally-based funding streams such as wind farm biodiversity offsetting initiatives, voluntary carbon schemes, landfill tax projects or local charities. Government bodies such as Scottish Natural Heritage and SEPA also offer funding packages for projects where there is delivery of other benefits (such as improvements in Water Framework Directive classification or improvements to biodiversity). The funding for each project will be dependent on the nature of the project and what it is delivering as well as the body that is promoting it. Some of these sources will require match funding, usually from a different source so, for example, an EU fund could not be matched against another EU fund.

**Figure 8.2. Realignment works on the Long Philip Burn, Ettrick Water (Tweed): These works form part of a wider suite of NFM and flood protection scheme measures implemented to help protect the town of Selkirk. The work and compensation to land managers was funded by the local authority's capital grant, Scottish Government and the Scottish Rural Development Programme (© Selkirk Flood Protection Scheme).**

**Table 8.1. Primary funding sources for delivering NFM measures**

| Fund | Eligibility | Nature of projects | Payments/duration |
|---|---|---|---|
| **Public sector** | | | |
| Scottish Rural Development Programme<br><br>Agri-environment Climate Scheme (www.ruralpayments.org/publicsite/futures/topics/all-schemes/agri-environment-climate-scheme/ ) | Land managers with land in Scotland (including public sector, voluntary sector and charities). | Support in targeted areas for land managers to undertake capital works and land management for environmental purposes, including NFM. | Payments are either:<br><br>– a one-off payment for capital works (e.g. peat dams for ditch blocking, river embankment removal); or<br><br>– annual payments for a specific land management option (e.g. floodplain management).<br><br>Contracts usually cover five years. |
| Scottish Rural Development Programme<br><br>Forestry Grant Scheme (www.ruralpayments.org/publicsite/futures/topics/all-schemes/forestry-grant-scheme/) | Land managers with land in Scotland (including public sector, voluntary sector and charities). | Supports the creation of new woodlands and the sustainable management of woodlands. Eight categories of grants – two for the creation of new woodlands and six for managing existing woodland. | Woodland creation options provide an initial payment for planting with an annual maintenance payment provided thereafter for five years. The contract to maintain works associated with the woodland creation covers 20 years.<br><br>A range of capital grants are also available (e.g. fencing and tree protection).<br><br>Higher payment rates are available for woodland creation (except conifer and native broadleaves) identified as benefiting water quality and/or flooding ('woodlands for water'). |
| Scottish Rural Development Programme<br><br>Environmental Co-operation Action Fund (www.ruralpayments.org/publicsite/futures/topics/all-schemes/environmental-co-operation-action-fund/) | Individuals, facilitators, private, public or constituted not-for-profit organisations or constituted groups. | Payment for facilitation of environmental landscape scale environment projects (including NFM) including two or more land holdings.<br><br>Projects must be new, demonstrate additionality and occur in rural areas of Scotland. | Facilitators can claim up to £300 per day deemed necessary to deliver the environmental project such as identifying and securing participants, evidence gathering, producing the necessary plans, consulting agencies and overseeing project delivery. The scheme can also fund elements that support delivery such as options appraisal and design studies. Contracts must be for between two and five years in length. |
| SEPA Water Environment Fund (www.sepa.org.uk/environment/water/water-environment-fund/) | Anyone, including individuals, charities, non-governmental organisations, local authorities, companies (unless the works form part of a statutory duty). | Supports river restoration that improves waterbody status under the Water Framework Directive (morphological restoration or river barrier removal). | Can fund most types of costs relating to delivery of a project, including feasibility studies and capital costs of works.<br><br>Funding is approved for one year at a time, although funding in principle can be provided for multi-year projects. |
| Scottish Natural Heritage grants (www.snh.gov.uk/funding/our-grants/) | Community groups, voluntary groups, non-governmental organisations, private individuals. | Supports projects that get more people and communities actively involved in caring for Scotland's nature and landscapes, such as peatland restoration. | Varies depending on nature of project. |

Table 8.1. (contd.)

| Fund | Eligibility | Nature of projects | Payments/duration |
|---|---|---|---|
| **Public sector** | | | |
| Heritage Lottery Fund (HLF) (includes a number of grants such as HLF Heritage Grants and HLF Landscape Partnership (www.hlf.org.uk) | Community groups, voluntary groups, community interest companies, charities or trusts, social enterprises, local authorities, other public sector organisations. | Supports projects that enhance the natural heritage of an area.<br><br>Habitat works can be funded where part of a suite of measures that include the likes of access, education, training and interpretation. | Various depending on the nature of project. |
| EU LIFE+ (www.snh.gov.uk/funding/life+-nature-and-biodiversity/) | Government bodies, non-governmental organisations. | Supports projects that help implement European policies and Directives including nature, biodiversity and climate change mitigation/adaptation. | Various depending on the nature of project. |
| Local authority capital grants (contact relevant local authority) | Local authority projects. | Specific capital grants may only be used to fund the expenditure for which they have been set, e.g. flood risk management works.<br><br>General capital grants must contribute to delivery of the Single Outcome Agreement and the National Strategic Objectives and Purpose. | At the discretion of the local authority. |
| **Private sector** | | | |
| Carbon Offset Schemes (contact relevant facilitator or buyer) | Will depend on scheme. | Support projects that can help offset carbon emissions. Some companies, e.g. Forest Carbon, can help source commercial buyers of carbon offsets. | Various depending on scheme and nature of project. |
| Biodiversity Offset Schemes (contact relevant buyer of offset, e.g. developer) | Will depend on scheme. | Support projects that involve conservation activities that can deliver biodiversity in one place that compensates for losses in another (e.g. as a result of a housing or windfarm development). | Various depending on scheme and nature of project. |
| Landfill Tax Credit Scheme (www.entrust.org.uk) | Any environmental organisation registered with ENTRUST. | Supports projects delivered by environmental organisations that that help landfill operators offset their landfill tax liability.<br><br>Projects delivered must meet one of six objectives which include the conservation of a natural habitat. | Various depending on nature of project. |

# 8.1. COMPENSATION MECHANISMS

Where changes in rural land management help to reduce flooding, payment for the provision of those services by the landowner/land manager may be needed (Figure 8.3). In this context, payment is usually made to cover costs incurred in the provision of that service (such as loss of productive land where an embankment has been removed) although rewards are also possible (such as where a landowner/land manager manages his land in a way to benefit runoff that exceeds basic compliance).

A range of different compensation mechanisms can be adopted and some of these are described below. The actual payment made will form part of a transaction between the buyer (those responsible for progressing the works, normally a public body) and the seller (the landowner/land manager) but will typically lie somewhere between the maximum amount that the buyer is willing to pay and the minimum amount that the seller is willing to accept[146].

Mechanisms which have traditionally been used to pay landowners/land managers for works that deliver flood risk management services include annual payments and land purchase. However, a number of other mechanisms exist, many of which are now being used in the rest of the UK and abroad. Tables 8.2 and 8.3 provide an overview of these mechanisms and the scenarios in which they may be appropriate while Chapter 10 provides some examples of where these different mechanisms have been used.

The information and recommendations provided here are all informed by work carried out in a Scottish Government commissioned study[147]. This report should be referred to for a comprehensive set of case studies covering the different types of mechanisms, the scenarios in which these payments may be appropriate, and how payments should be calculated.

## 8.1.1. Negotiating a compensation agreement

Compensation agreements are normally established between a public body and the landowner/land manager, although an independent broker may also be involved. Obtaining an agreement broadly involves five steps:

- Step 1: identification of key skills needed (by public body);
- Step 2: background research (by public body OR public body and broker);
- Step 3: discussions (between landowner/land manager and public body OR landowner/land manager and broker);
- Step 4: identification of mechanisms which are likely to be most appropriate; and
- Step 5: agreement on mechanism and payment rate (all parties).

Figure 8.4 shows how the steps involved link up to form an iterative process. It may be necessary to repeat Steps 3, 4 and 5 several times to enable agreement between all parties.

**Figure 8.3. Creation of an offline storage pond in the Belford Catchment, Northumberland: Payments were made to land managers to compensate for disruption and loss of agricultural land (© Mark Wilkinson).**

**Table 8.2. Types of payment mechanisms that can be used to fund and compensate NFM**

| Mechanism type | Description |
| --- | --- |
| Advice and technical support | Advice: A landowner/land manager is provided with advice on how to implement practices that help increase infiltration of water and sediment into soils and reduce runoff. This advice could form part of a negotiated agreement on land management. |
| | Technical support: A landowner/land manager is provided with support to enable them to continue their business operations which may otherwise be affected by an NFM measure. Support may be provided as a one-off or on an incident basis. For example, if a land manager allows part of their field to be used as flood storage, they can be provided with replacement feed or crop following a flood event. Alternatively, if a particular field cannot be used during wet periods, a land manager could be provided with a barn to house animals. |
| Capital and annual payments (including grants) with funding sourced from public bodies, e.g. EU, government, lottery | Capital payment: A public body provides funds for the purchase of equipment, materials and/or labour required to deliver a NFM measure. Funding could be sourced from a grant (from a governmental source) or the public body's own budget. |
| | Annual payment: A public body makes an annual payment to a landowner/land manager to manage their land in a particular way. The payment could make up for loss of income, or encourage a particular land use. Funding could be sourced from a grant (from a governmental source) or the public body's own budget. |
| Capital and annual payments (including grants) with funding from non-government sources | Capital payment: A public body provides funds for the purchase of equipment, materials and/or labour required to deliver a NFM measure. Funding needs to be sourced from a non-governmental body or grant fund (potentially via a broker). |
| | Annual payment: A public body makes an annual payment to a landowner/land manager to manage their land in a particular way. The payment could make up for loss of income, or encourage a particular land use. Funds for payment need to be sourced from a non-governmental body or grant fund (potentially via a broker). |
| Economic instruments (fiscal, permits, service payments, auctions) | Fiscal: Tax breaks/credits can be used to encourage a particular type of land management, although this is likely to require action at a government rather than local authority level. |
| | Permits: This could involve a system of tradable flood permits, where a public body buys permits from land managers to allow flooding of particular areas. Land managers are able to buy and sell their permits to each other. |
| | Service payments: A land manager sells a particular service (e.g. floodplain storage) to the public body or an insurance company. |
| | Auctions: Reverse auctions require land managers to identify the payment they would accept to implement a particular land use (e.g. floodplain storage). The public body selects the most cost effective options to achieve their NFM objectives. |
| Land lease to public body | The landowner/land manager leases land to the public body to implement an NFM measure (the public body may then choose to sublease the land). |
| Land purchase/sale | The public body buys land from the landowner/land manager and implements an NFM measure on that land. |
| Land purchase/sale and leaseback | The public body buys land from land manager and implements an NFM measure on that land. Land is leased back to the original land manager. |
| Servitudes and wayleaves | Servitude: Servitudes can be attached to a land title to benefit another property and enable rights of access, or rights to construct and maintain an NFM structure. The public body pays a one-off payment for the servitude. |
| | Wayleave: A public body makes wayleave payments to a landowner/land manager. An annual wayleave payment could allow a public body to implement and maintain an NFM measure. Alternatively, the payment could be event-based so that it is paid when the land is flooded. |

### 8.1.1.1. Step 1: Identification of key skills needed

In Step 1, the public body identifies the skills and resources it has which will be useful when developing an agreement with a landowner/land manager. Points to consider include:

- what processes the public body is familiar with (e.g. buying and selling, leasing);
- the resources likely to be available for management of an agreement or mechanism over time;
- the level of agricultural knowledge held by the public body;
- the level of understanding held by the public body of NFM measures and their impacts on land; and
- whether the public body knows any broker organisations which are active in the area.

Considering the above will help the public body decide whether it can negotiate the agreement itself, or whether it would be better to involve a broker.

### 8.1.1.2. Step 2: Background research

Step 2 involves gathering the information required to inform the selection of an appropriate compensation mechanism. Information to be gathered will include:

- the type of flooding including frequency and severity;
- details of the proposed measures, including their scale, effect on land use and long-term management and maintenance requirements;

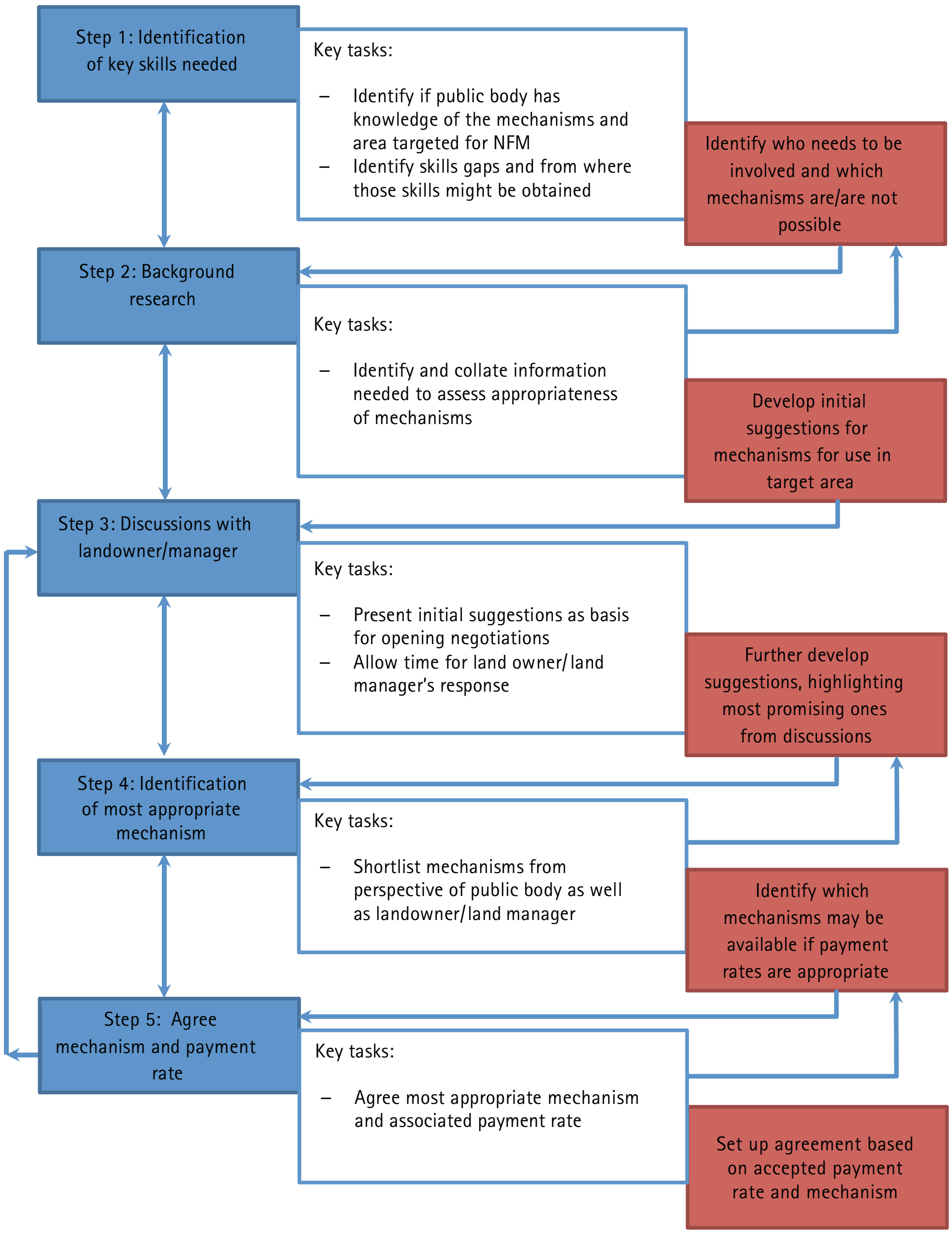



Figure 8.4. Steps involved in establishing a compensation agreement

- information on the land holding and landowners/land managers such as the area of land holding, the land use type, type of farming system, the type of recipients (landowner, tenant) and the number of recipients; and
- farm business considerations such as changes to productivity, farm rent, singe farm payment or capital value of land (see Box 6.2 of Chapter 6).

Bringing everyone together in a partnership may save time and resources. This could be possible with economic instruments or advice and technical support. For the other types of mechanism, individual agreements are generally needed, although several individual agreements could be negotiated with a number of land managers, owners and tenants to bring overall catchment benefits.

### 8.1.1.3. Step 3: Discussions with landowner/land manager

Step 3 involves discussing the options for compensation with the landowner/land manager. These discussions will be informed by the information obtained in Step 2 and provide the public body (or broker) with the opportunity to discuss initial ideas about the mechanisms which may be appropriate. This will likely include discussions relating to the administrative burden, the payment frequency, and the flexibility of each mechanism over time. Landowner/land managers are likely to require time to consider the ideas presented and determine how they may affect their business.

### 8.1.1.4. Step 4: Identification of most appropriate mechanism

Step 4 involves producing a short list of potential mechanisms. While each situation should be considered on its own merits, there are some mechanisms which are likely to be more appropriated in certain situations. Table 8.3 considers five key features of compensation mechanisms and identifies how each mechanism type performs against these features. These features are:

- public body responsibility for land management – where a mechanism requires a public body to take on land management responsibilities, this will require time, resources and equipment (or money to subcontract the land management);
- upfront financial commitment by public body – where money is available for capital expenditure, mechanisms such as land purchase/sale may be more viable than those where ongoing payments are required;
- ongoing financial commitment by public body – where a mechanism requires an ongoing financial commitment (whether this is regular or incident based) funding will need to be secured for the period in question;
- effectiveness of the measure over time – some mechanisms provide the public body with more control than others to ensure that the NFM measure is implemented as desired; and
- flexibility of the mechanism over time – both the public body and the landowner/land manager may want flexibility in case their circumstances change.

The public body (or broker) will need to consider which of the short listed mechanisms is likely to be most appropriate given the requirements and also the outcomes from the landowner/land manager discussions. There may need to be further discussions. Trade-offs may have to be made to ensure that both parties are happy, before moving to Step 5.

### 8.1.1.5. Step 5: Agree mechanism and payment rate

The final step in the process involves the public body (or broker) and landowner/land manager agreeing a mechanism and negotiating the payment rate. A formal meeting will be needed to enable the most appropriate mechanism to be agreed, and the payment rate to be negotiated. There may be a need to return to Step 4 (or to repeat Step 3) should the public body's ideal option not be acceptable to the landowner/land manager.

The payment rate is dependent on a range of variables which are specific to each type of mechanism. For some mechanisms, there are few variables (e.g. land purchase/sale) whereas for other mechanisms (e.g. capital or annual payment) there are many variables which need to be taken into account.

The District Valuer Services (DVS) has indicated a preference for a before and after approach to calculating any payment (with this generally accepted by the Lands Tribunal). This method generally results in a one-off capital payment to the landowner/land manager. This payment can be referenced to market value using direct comparisons. However, flexibility is required in all negotiations and each case needs to be treated on its own merits. There is no 'one size fits all', so determination of the payment rate should occur as part of the five step process described above.

Figures 8.5 to 8.8 provide examples of the recommended approaches to calculating some types of payment rate. In Figure 8.5, the payment rate is the amount the public body should pay the land manager as compensation and does not take into account other costs which the public body may incur (e.g. legal fees, valuation fees). The variables have been identified by analysing the legal and financial implications of the different mechanisms. Where possible, to fit with the before and after approach favoured by the DVS, determination of the payment rate has been based on market value. This is only an example and the circumstances of each individual case must be taken into account when negotiating payment rates.

Further recommendations on the calculation of payment rates for other types of compensation mechanisms, including further information on the types of NFM measure with which the mechanism could be used, is provided in RPA, RHDHV and Allathan Associates[147].

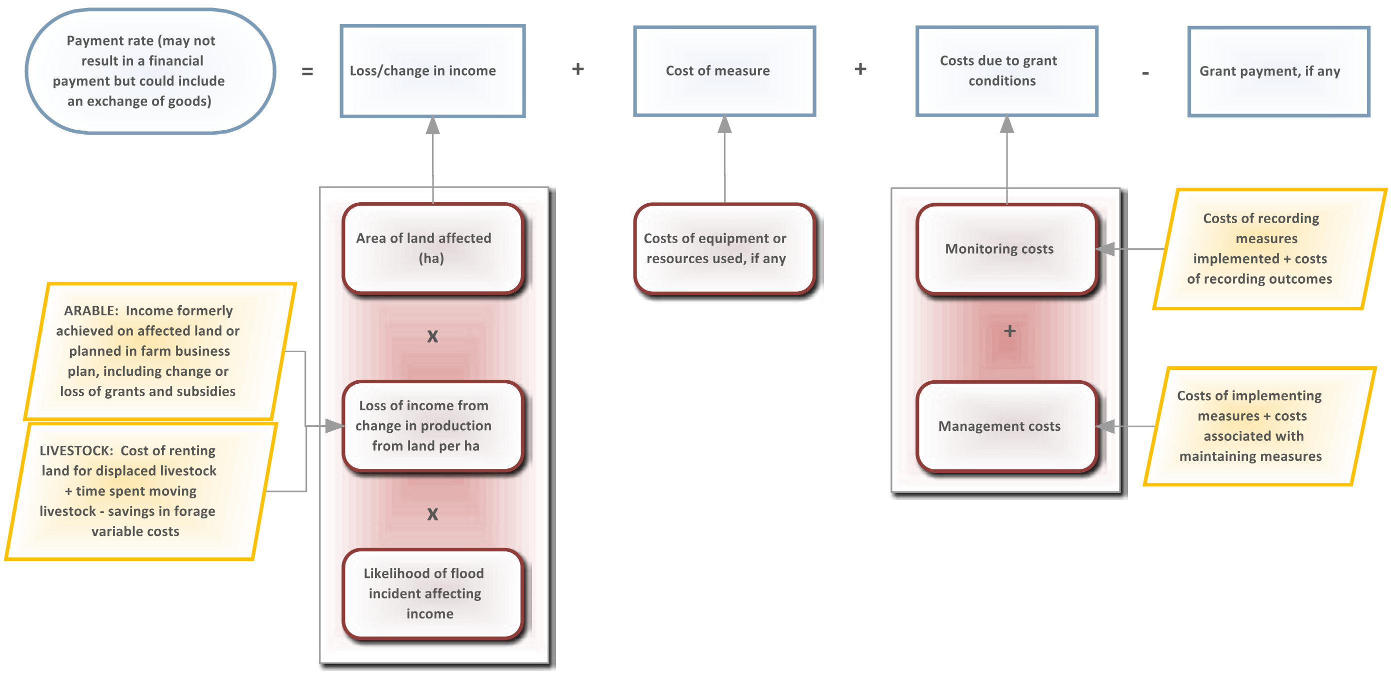



Figure 8.5. Determination of the payment rate when using capital and annual payments (including grants) with funding sourced from public bodies.

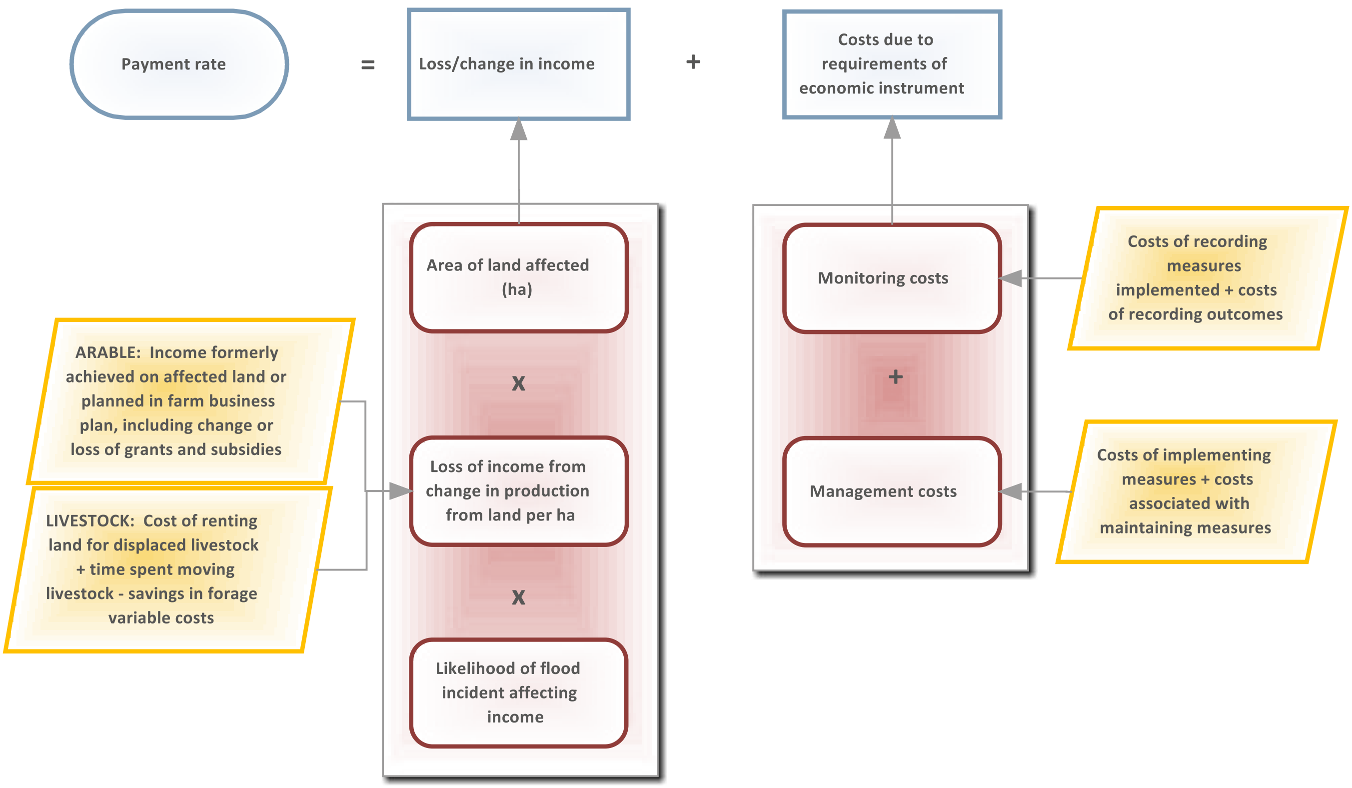



Figure 8.6. Determination of the payment rate when using economic instruments.

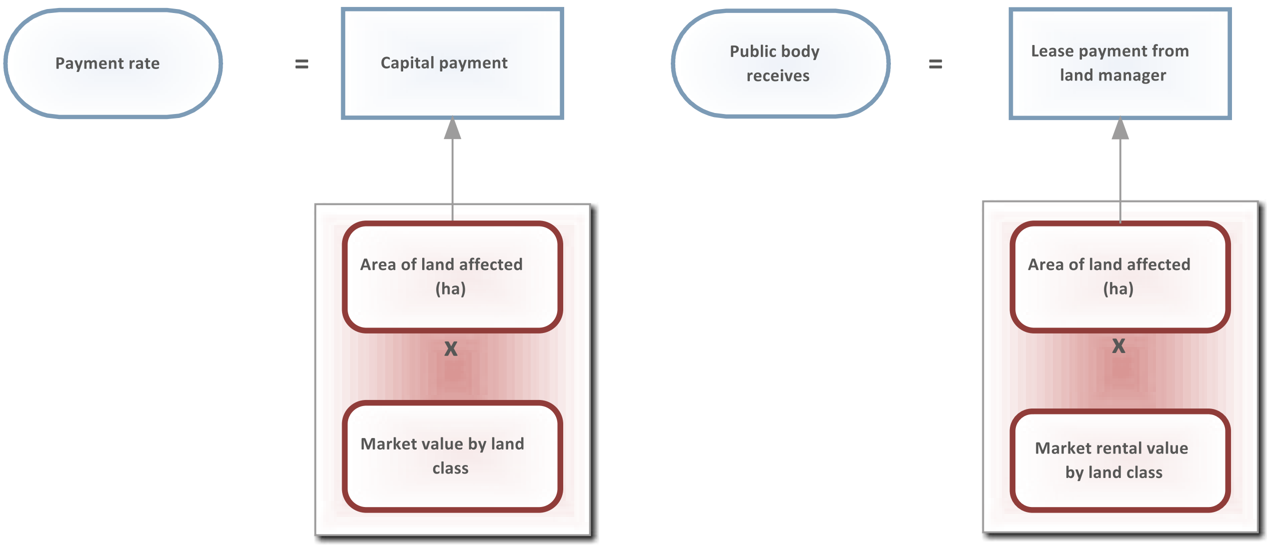



Figure 8.7. Determination of the payment rate when using land purchases and leaseback.

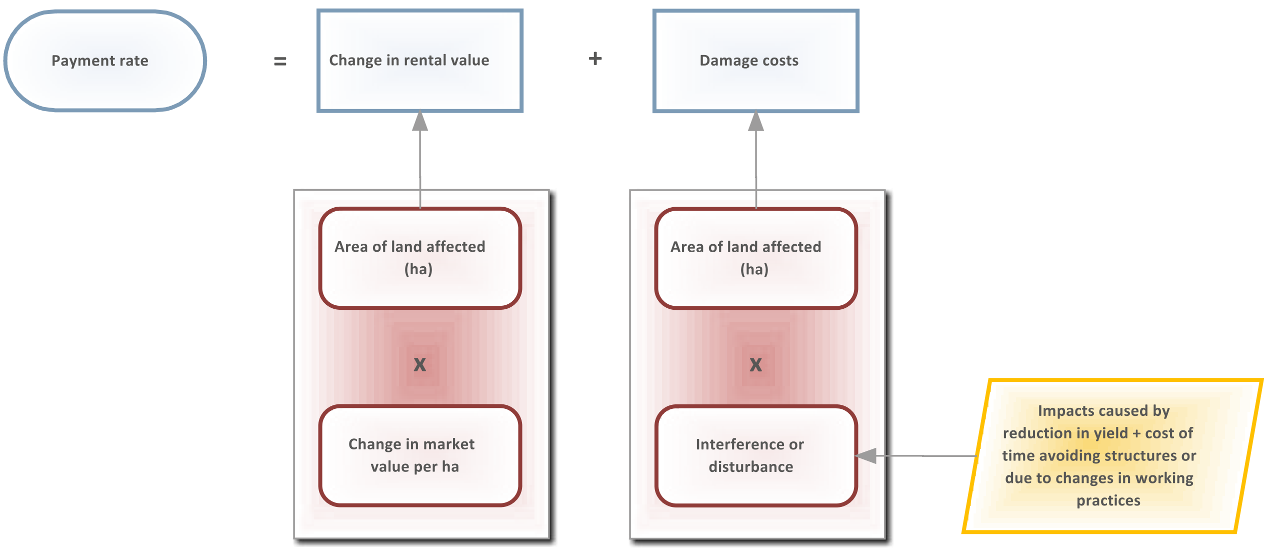



Figure 8.8. Determination of the payment rate when using wayleaves.

Table 8.3. Performance of different types of compensation mechanisms

| Feature | Low level | Moderate level | High level |
|---|---|---|---|
| Public body responsibility for land management | **Low level of public responsibility for land management:**<br>Servitude, wayleaves<br>Capital and annual payments (including grants) – government source<br>Capital and annual payments (including grants) – non-government source<br>Economic instruments<br>Advice and technical support<br>**May be appropriate where:**<br>Limited resources to undertake land management; many land managers involved | **Moderate level of public responsibility for land management:**<br>Land purchase/sale and leaseback<br>**May be appropriate where:**<br>Funding for initial purchase can be borrowed and paid back over time; public body does not want (or need) to have to manage land (e.g. White Cart Water, Glasgow); land manager is happy to continue managing the land following the implementation of the NFM measure | **High level of public responsibility for land management:**<br>Land purchase/ sale<br>Land lease to public body<br>**May be appropriate where:**<br>Public body has the resources to undertake ongoing land management; area of land acquired is limited and expected to result in considerable flood risk reduction benefits (e.g. Upper Garnock flood prevention scheme); loss of land does not detrimentally impact land manager's business |
| Upfront financial commitment by public body | **Low level of financial commitment by public body:**<br>Capital and annual payments (including grants) – non-government source<br>Advice and technical support<br>**May be appropriate where:**<br>Limited capital available for upfront funding; independent third party organisations are already active and engaged with land managers | **Moderate level of financial commitment by public body:**<br>Land lease to public body<br>Servitude, wayleaves (dependent on whether servitude or wayleave is used)<br>Capital and annual payments (including grants) – government source<br>Economic instruments<br>**May be appropriate where:**<br>Some funding is available to start NFM implementation, but there is uncertainty over how long the funding may last | **High level of financial commitment by public body:**<br>Land purchase/sale<br>Land purchase/sale and leaseback<br>**May be appropriate where:**<br>Capital sums are available for purchasing land and land managers can be readily identified (case studies have determined that this process can be time consuming) |
| Ongoing financial commitment by public body | **Low level of ongoing financial commitment:**<br>Land purchase/sale<br>Land purchase/sale and leaseback<br>Capital and annual payments (including grants) – non-government source<br>Economic instruments<br>Advice and technical support<br>**May be appropriate where:**<br>Limited funds are available to maintain mechanism | **Moderate level of ongoing financial commitment:**<br>Servitude, wayleaves (dependent on whether servitude or wayleave is used)<br>Capital and annual payments (including grants) – government source<br>**May be appropriate where:**<br>Some funding is available to maintain mechanism, but this is not unlimited; land managers agree to maintaining land use in line with agreement (and implementation of NFM measure) | **High level of ongoing financial commitment:**<br>Land lease to public body<br>**May be appropriate where:**<br>Funding can be secured for a set amount of time (to enable the lease to be paid for its term and thus provide security to the land manager) |

Table 8.3. Performance of different types of compensation mechanisms (contd.)

| Feature | Low level | Moderate level | High level |
|---|---|---|---|
| Effectiveness over time | **Low level of effectiveness over time:**<br>Advice and technical support<br>**May be appropriate where:**<br>Amount of buy-in and commitment from land managers, as well as the effectiveness of NFM measures, are uncertain | **Moderate level of effectiveness over time:**<br>Land lease to public body<br>Servitude, wayleaves<br>Capital and annual payments (including grants) – government source<br>Capital and annual payments (including grants) – non-government source<br>Economic instruments<br>**May be appropriate where:**<br>Land managers are interested in NFM and likely to be engaged | **High level of effectiveness over time:**<br>Land purchase/sale<br>Land purchase/sale and leaseback<br>**May be appropriate where:**<br>There is a degree of certainty with regard to the likely effectiveness of the NFM measure being implemented on the land |
| Flexibility over time | **Low level of flexibility over time:**<br>Land purchase/sale<br>Land purchase/sale and leaseback<br>**May be appropriate where:**<br>There is a degree of certainty with regard to the likely effectiveness of the NFM measure being implemented on the land. The case studies have shown that land purchase negotiations may be complicated and time consuming, so the public body needs to be clear that these mechanisms are appropriate | **Moderate level of flexibility over time:**<br>Land lease to public body<br>Servitude, wayleaves<br>Capital and annual payments (including grants) – non-government source (dependent on funding and conditions from third parties)<br>Economic instruments<br>**May be appropriate where:**<br>The land manager and public body agree to implement an NFM measure, but they want to use a mechanism which has some flexibility so that changes to the agreement can be made over time if necessary | **High level of flexibility over time:**<br>Capital and annual payments (including grants) - government source<br>Advice and technical support<br>**May be appropriate where:**<br>Land managers do not want to commit to long-term changes without seeing how the mechanism/ measure combination affects their business; there is uncertainty with regard to the effectiveness of the NFM measure being implemented, thus there may be a need to adapt the mechanism used |

## Further reading and guidance

BEEDELL, J., MORRIS, J. and HESS, T.M. (2012). Mobilising the contribution of rural land management to flood risk management in Scotland: Land owner compensation and approaches for flood protection work. Report to Scottish Government: Ref CR/2010/14. Peterborough: Smiths Gore.

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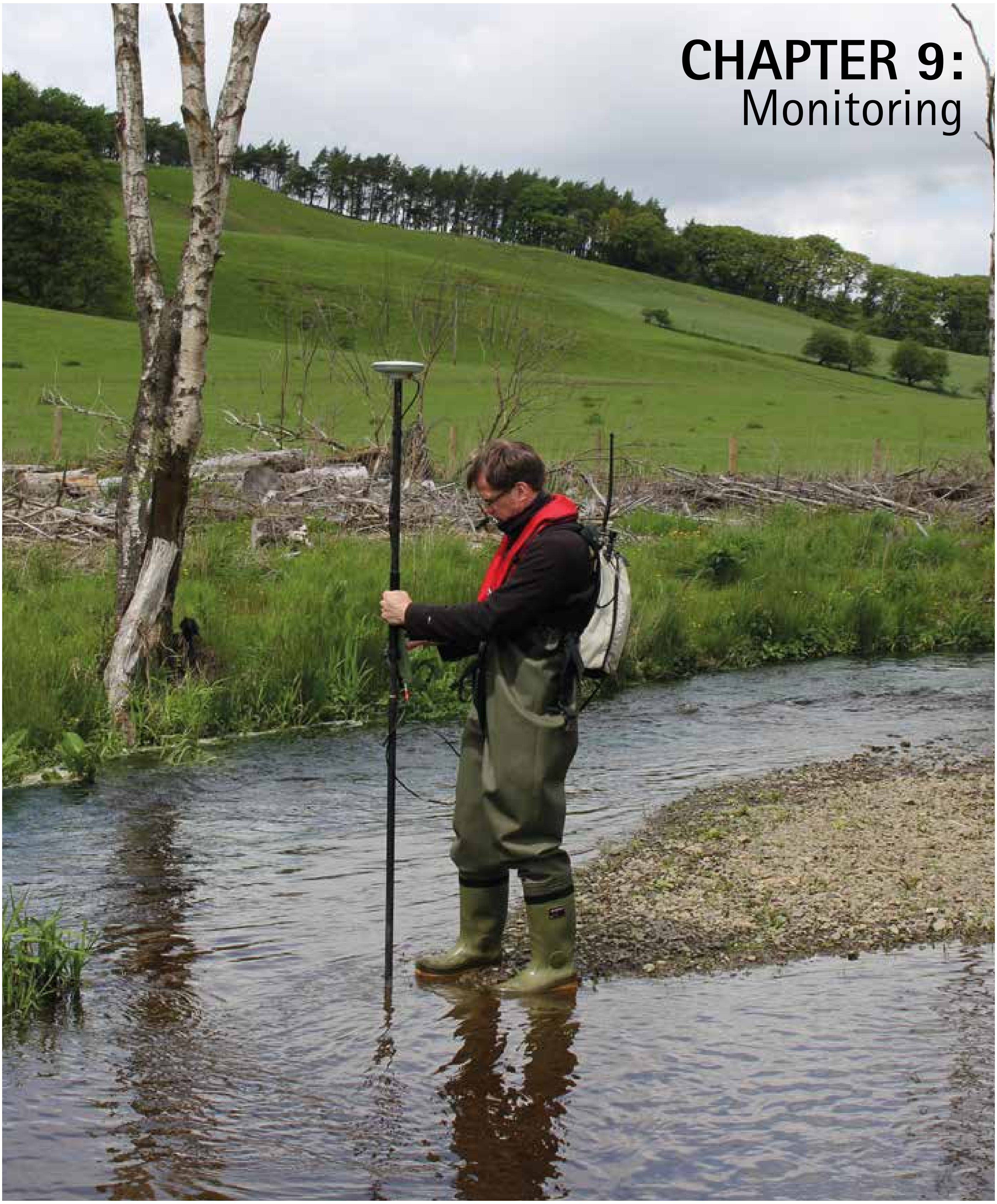


Figure 9.1. Cross section surveying on the Eddleston Water, Scottish Borders (© C. Spray).

Successful delivery and management of NFM projects requires an understanding of the site and its processes, management of risk and adherence to permissions, as well as a means of evaluating fulfilment of objectives and demonstrating success, all of which will require the implementation of an appropriate monitoring programme. This chapter provides an overview of some of the considerations when putting together a monitoring programme as well as links to further more detailed guidance.

Proposals for monitoring (Figures 9.1 and 9.2) will be influenced by funds, timing (e.g. time available for collection of baseline data) and the nature of the works. Larger scale projects associated with greater levels of risk will tend to require more comprehensive monitoring programmes.

The objectives of monitoring will vary between projects but in most cases should seek to:

- appraise project objectives, e.g. reduction in flood peak, provision of public space, improved habitats;
- manage risk, e.g. by identifying adverse impacts on infrastructure or ecosystems;
- guide adaptive management of the site, i.e. to inform amendments to management over time; and
- ensure compliance with consenting conditions, e.g. planning consents or habitats regulations.

Where evidence gathering is an objective of the project then monitoring should also seek to provide data to increase the evidence base, for example on the effects of measures on flood flows and on the ecosystem. Monitoring can also improve the evidence base by providing data that permits calibration and validation of physical and numerical models. Coastal projects typically require extensive pre-works monitoring data on the condition of, and coastal processes at, the site in order to inform the selection of measures.

**Figure 9.2. Topographic surveying at Culbin Sands, Moray (© A. Rennie/Scottish Natural Heritage).**

## 9.1. DESIGNING A MONITORING PROGRAMME

Detailed guidance on the development of monitoring programmes as well as survey methods and costs is provided in the guidance documents detailed at the end this chapter. The following provides an overview of some key considerations.

### 9.1.1. Structure and level of detail

The extent and complexity of monitoring will primarily depend on:

- the project scale; and
- the level of risk (which will be a function of both the level of certainty in the outputs and the potential for failure of measures).

The level of monitoring required for large scale projects and/or projects with high levels of uncertainty, for example, will require greater levels of monitoring (e.g. Figure 9.3). The selected approach should allow for adaptive assessment, e.g. modification of monitoring as a site establishes following restoration.

More complex monitoring of river or catchment based NFM measures should be delivered within a nested design that reflects the hierarchical nature of river ecosystems (Figure 9.4). In this approach, monitoring across the catchment or sub catchment is complimented by more detailed reach or site based monitoring. This approach permits analysis of the effects of measures at different scales. Given that most information on NFM measures is at the local scale only, such an approach has the potential to substantially improve the evidence base, particularly if the outputs can be compared with the monitoring outputs from a similar, 'control' catchment.

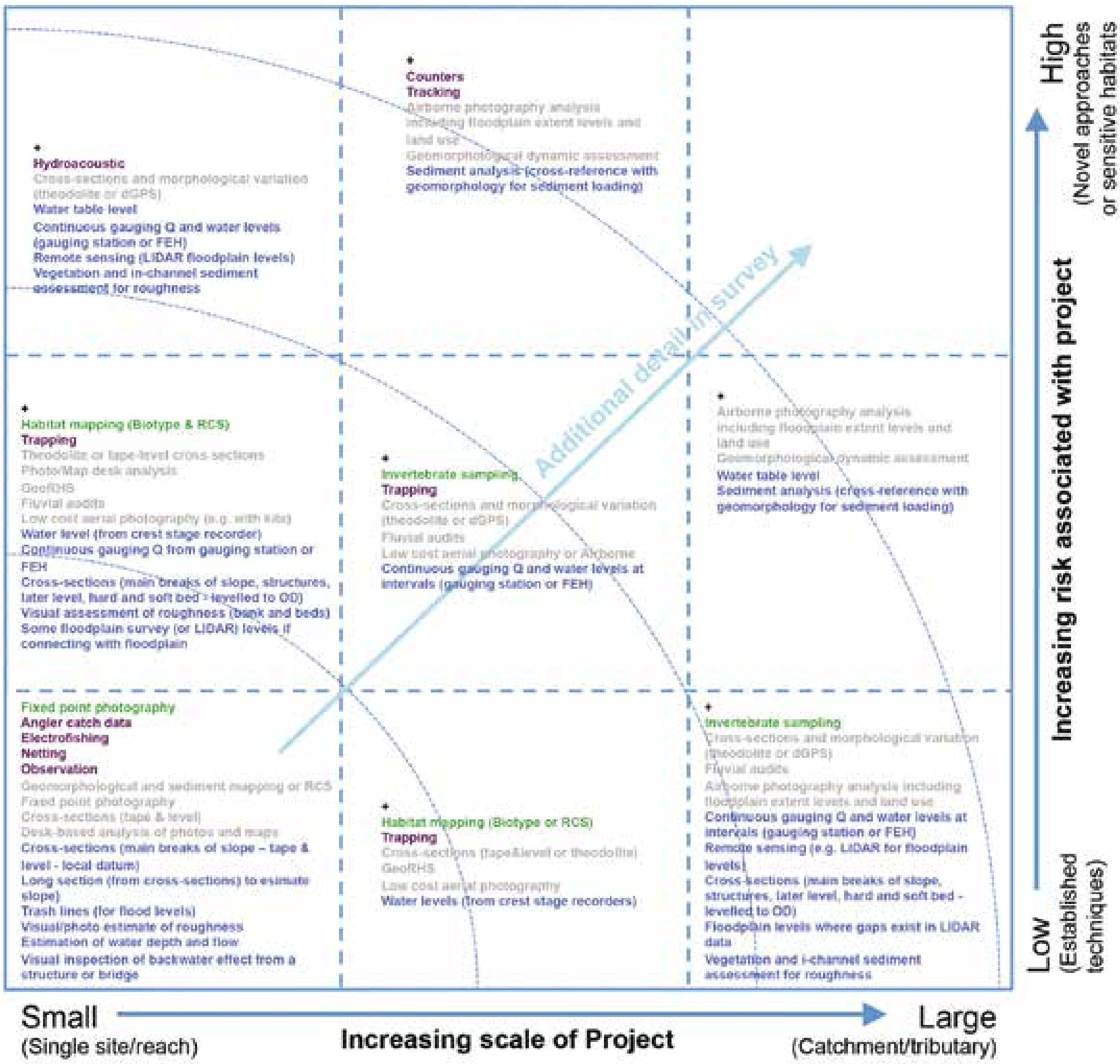


**Figure 9.3. Recommended levels of sampling for river and floodplain restoration projects across scientific disciplines (from CRESS and Halcrow[122], based on work undertaken by the River Restoration Centre[149]).**

## 9.1.2. Monitoring parameters

### 9.1.2.1. Fluvial monitoring parameters

River and catchment based NFM projects, given their nature, will normally need to prioritise hydrological monitoring above other disciplines. However, given that most NFM projects will seek to deliver multiple benefits and that risks to the environment may need to be examined, monitoring of a wider suite of parameters is preferable. A typical comprehensive monitoring programme will include monitoring of:

- hydrology (e.g. rainfall, river velocity, water level) (Figures 9.5, 9.6 and 9.8);
- hydromorphology (e.g. erosion/ deposition of sediments); and
- ecology (e.g. fish, invertebrates, plants).

Some of these parameters may already be monitored in the catchment in question by SEPA, the local authority or local organisations such as rivers trusts. The nature of the survey technique used will be dependent on the scale and risk associated with the project, as discussed earlier. So, for example, a project that is large scale and high risk (e.g. the realignment of a long section of river near an urban area) will be best monitored using a suite of qualitative techniques that record empirical data (e.g. flow gauging, invertebrate sampling, fluvial audit). A smaller, lower risk project (e.g. riparian planting in a rural area) may only require the use of quantitative techniques such as fixed point photography.

### 9.1.2.2. Coastal monitoring parameters

There are five main parameters that can be monitored at coastal site[86]:

- morphology (e.g. elevation, topography, bathymetry, area, beach profile, any creek systems in saltmarsh or blowouts in sand dunes (Figure 9.7));
- hydraulic conditions (e.g. tidal range, current velocities, wave action);
- water quality (e.g. salinity, dissolved oxygen, turbidity, contaminants);
- sediments (e.g. sedimentation rates, contaminants, salinity, water content, pH, organic matter, redox potential, surface cohesive strength, particle size); and
- ecology (e.g. vegetation, benthos, invertebrates, birds, fish, mammals, lizards).

For coastal NFM projects, it is also important to record wave and water level conditions during significant storm events and assess post-storm changes to the beach or estuary. SEPA provides a coastal flood warning service in partnership with the Met Office and can provide information on when water levels higher than astronomical tides are expected.

Appropriate information can be collected by a variety of organisations and brought together. For coastal projects, a partnership approach between local authorities, SEPA, local conservation groups, ports and harbour authorities, Marine Scotland, the Crown Estate, local businesses and universities is often necessary to achieve the required level of monitoring and inspection.

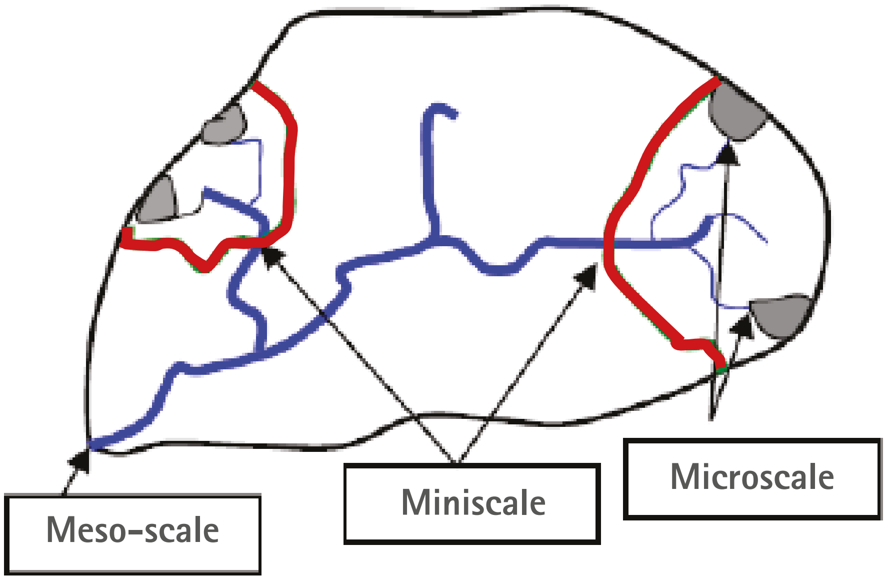


Figure 9.4. An example of a multi-scale nested catchment monitoring platform (adapted from O'Connell et al.[148]).

Figure 9.5. Gauging station level recorder on the Eddleston Water, Scottish Borders (© C. Spray).

## 9.1.3. Monitoring timescales

Any monitoring plan will need to consider both the period over which monitoring takes place (e.g. 15 years), the season in which to monitor, and the monitoring frequency (e.g. once a month). The approach selected will be very much determined by the original project objectives and funding. Where empirical data is being collected to evaluate the effects of measures then a period of monitoring prior to implementation of works will be needed (baseline monitoring) followed by monitoring that is long enough to pick up change. Hydrological monitoring is further complicated by the need to monitor the effect of measures during large flood events which will necessitate as long a period of monitoring as funds permit. Long term monitoring (>15 years) is particularly important at coastal sites due to the dynamic nature of the coast.

The River Restoration Centre Guide[149] provides further information on identifying suitable timescales for river and catchment based monitoring as well as recommendations on the seasons in which to undertake different types of monitoring. The Marine Monitoring Handbook provides more information on considerations when planning monitoring programmes at coastal sites[150]:

**Figure 9.6. Installing a telemetered water level monitoring station in the Allan Water catchment (Forth), Stirlingshire: This station was installed to collect baseline data prior to woodland planting (© L. Bellini).**

**Figure 9.7. Topographic monitoring at St Cyrus, Montrose, Angus (© A.Rennie/Scottish Natural Heritage).**

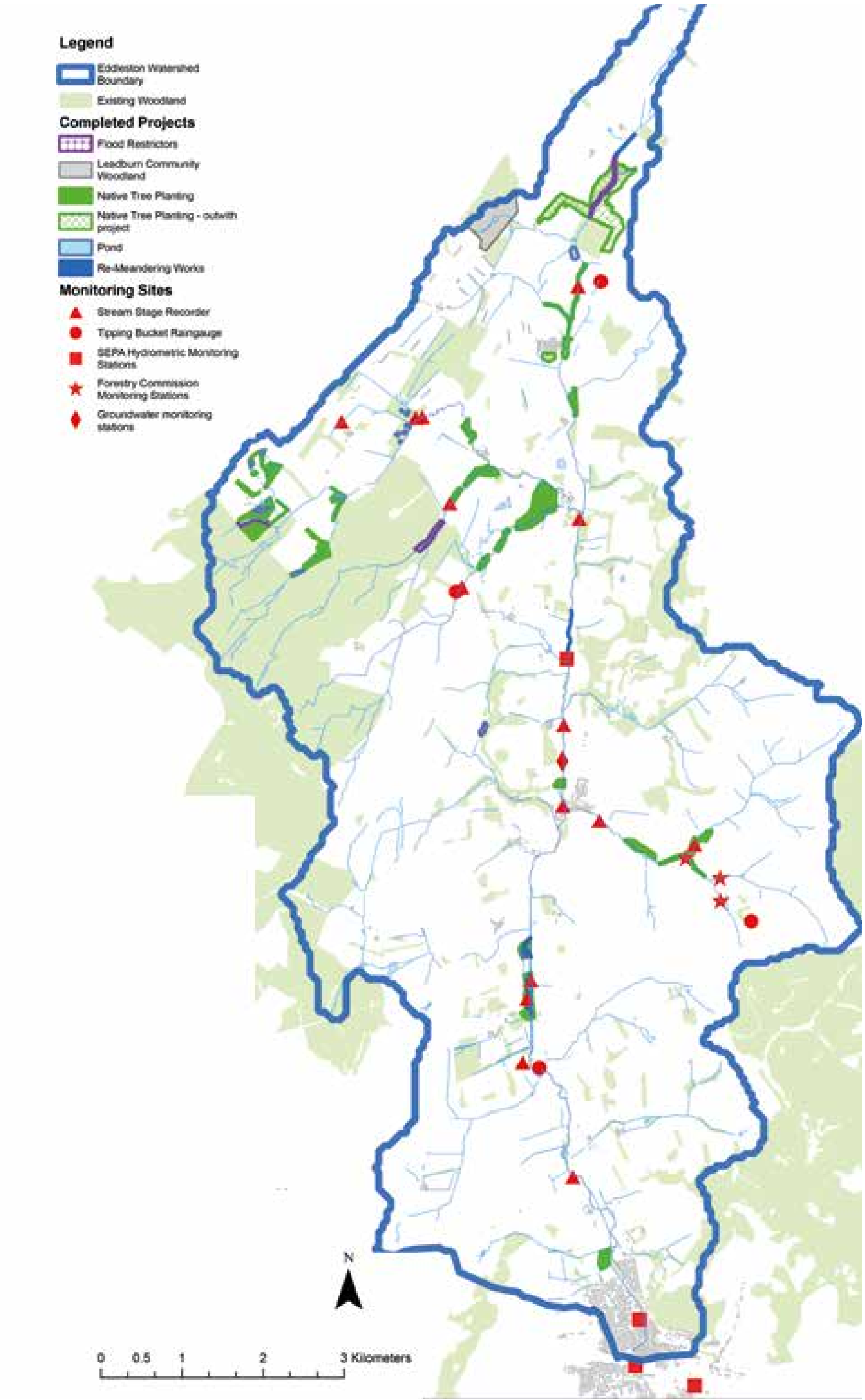


**Figure 9.8. Hydrological monitoring sites on the Eddleston Water, Scottish Borders (© Tweed Forum).**

## Further reading and guidance


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O'CONNELL, P. E., QUINN, P. F., BATHURST, J. C., PARKIN, G., KILSBY, C., BEBEN, K. J., BURT, T. P., KIRKBY, M. J., PICKERING, A., ROBINSON, M., SOULSBY, C., WERRITTY, A. and WILCOCK, D. (2007). Catchment Hydrology And Sustainable Management (Chasm): An Integrating Methodological Framework For Prediction. International Association of Hydrological Sciences. Predictions In Ungauged Basins: PUB Kick-Off, 20-22 November 2007 Brasilia. International Associiation of Hydrological Sciences.

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WATER FRAMEWORK DIRECTIVE UK TAG (2014). TAG Monitoring Guidance for Transitional and Coastal Waters (v1_33.PR6-12-06). [Online]. http://www.wfduk.org/resources/category/biological-standard-methods-201/tags/transitional-coastal-water-159?page=1 [Accessed: April 2015].

# CHAPTER 10: Case studies

## Case study 1

### Eddleston Water Project
### Peeblesshire, Scottish Borders

#### Description

The Eddleston Water Project is a partnership project led by Tweed Forum which aims to restore the Eddleston Water (tributary of Tweed, catchment area 69km$^2$) for the benefit of flood attenuation, the local community, and river habitat. An important component of the project involves working with landowners to maximise the benefit they derive from the works while maintaining profitability. A series of measures are currently being implemented throughout the catchment, with the effects of these works being closely monitored.

Over the last few centuries, the course of the Eddleston Water has been extensively altered and long sections straightened in order to increase the land available for roads and agriculture. Other changes in land management, both in the river valley and on the surrounding hill slopes, also altered how the land drained. Together, these changes have resulted in an increased risk of flooding to Eddleston and Peebles while also damaging the river environment itself and leading to the loss of over a quarter of the river's original length. Plant and animal habitats have been lost, such as those supporting salmon and trout as well as rare and protected species, such as otters and lamprey. As a result, the Eddleston Water was classed as 'bad' under the EC Water Framework Directive (WFD) on account of its altered course and river banks.

Figure 10.1. Woodland creation in the upper catchment (© Tweed Forum).

#### Types of measures

- **Riparian woodland:** A total of 70ha of native woodland has been planted along approximately 6km of watercourse in order to reduce runoff and erosion, improve bank stability, and increase instream organic matter thus benefiting ecology (approx. £3,000-10,000 per hectare, depending on the design and length of fence required) (Figure 10.1).
- **River and floodplain restoration:** A total of 1.2km of straightened river has been realigned, creating 1.5km of meandering river form and increasing the river length by 20% (see front cover for realignment at Cringletie which cost approximately £70,000, excluding preworks assessments and design, and Figure 10.2 showing realignment works at Lake Wood). The new channel and removal of the flood embankments were designed to permit flood waters to spread over the floodplain thus increasing storage capacity during small to medium rainfall events.
- **Non-floodplain wetlands and offline storage ponds:** Fifteen wetlands have been created in the headwaters which are designed to retain water during high rainfall and so slow down the rate of runoff into streams.
- **Instream structures:** A total of 79 woody debris structures have been installed in the upper catchment to slow flows (approx. £200 per feature) (Figure 10.3).

Figure 10.2. Realignment works (© Tweed Forum).

## Benefits

Monitoring the effects of measures is an important part of the project. Consequently, an extensive network of rain gauges, groundwater and river level gauges have been installed throughout the valley to collect data on how the changes affect river flows and flood frequencies. Other monitoring programmes will reveal what changes occur to the river's habitats and wildlife. Detailed monitoring and modelling of the groundwater has also been undertaken at a site close to Eddleston village. In addition to benefits to flooding and habitat restoration, the project has also sought to improve carbon sequestration, soil conservation, and water quality, while also enhancing the landscape. The watercourse has improved by two classifications for morphology under the Water Framework Directive (going from 'bad' to 'moderate').

## Funding mechanism: Capital grants and annual payments

A total of £400k was obtained from a variety of sources including:

- **Public sector** – Scottish Government, Water Environment Fund, Scottish Rural Development Programme, Scottish Borders Council.
- **Private (and charitable) sector** – Forest Carbon, CEMEX, Woodland Trust, Scottish Power and landowner contributions.

## Impacts for landowner/land manager

There have been minimal impacts on farming operations as works have primarily been undertaken on marginal land so that they are cost neutral to the landowner/land manager. The implementation of certain measures has brought about additional benefits for landowners/land managers, such as improved sporting opportunities (shooting/fishing) and increased resilience of the farm business to more extreme climatic events. Maintenance is shared by landowners/land managers and Tweed Forum.

**Figure 10.3. Instream structures (© Tweed Forum).**

## Impacts for delivery partners

The partnership approach and using an experienced intermediary body such as Tweed Forum has enabled the delivery partners to achieve a huge amount with relatively little outlay of funds or resource (e.g. staff time).

## Lessons learnt

The robustness of the monitoring has been greatly helped by early setup of baseline monitoring (two years in advance of any works). Using a trusted, knowledgeable intermediary such as Tweed Forum has had significant benefits in terms of engaging landowners/land managers and reducing the burden of paperwork and delivery of measures. Multiple funding streams are often required to incentivise land managers. Work in the upper catchment is often cheaper and easier to realise (due to land value and size of channel).

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RESTORE (*no date*). RiverWiki. [Online] www.restorerivers.eu [Accessed: March 2015].

Partners: Tweed Forum, Scottish Government, SEPA, Dundee University, Scottish Borders Council, British Geological Survey, Forestry Commission, Tweed Foundation, cbec eco-engineering UK Ltd., local landowners/land managers

Eddleston Water catchment, Peeblesshire, Scottish Borders

2009 – present

Capital and annual payments funded by multiple organisations and individuals.

£400k spent on multiple measures on 12 farms.

# Case study 2

## Belford Proactive Flood Solutions
## Northumberland, England

### Description

The Belford Proactive Flood Solutions project has involved catchment scale natural flood management in the Belford Burn catchment (6km$^2$), with the overarching aim of reducing flooding to the small town of Belford in North East England.

Initially the Environment Agency looked at the feasibility of a traditional flood defence scheme with the construction of a flood storage reservoir to capture a 150 year flood event (estimated cost of £2.5m) initially proposed. However, this failed to receive Grant-In-Aid funding due to the low benefit-cost ratio resulting from the low number of properties at risk (30). This, and a lack of space at the site for traditional means of flood defence, led to the proposition of an alternative approach which involved the design and construction of over 40 'Runoff Attenuation Features' (RAFs).

Figure 10.4. Offline storage ponds (© Mark Wilkinson).

### Types of measures

- **Offline storage ponds and overland flow interception features:** To disconnect overland flow, wooden barriers and soil bunds (50m long and 1m high) were installed (approx. £1000 per feature) (Figures 10.4 and 10.6). Sediment captured was either removed or ploughed back into the field.
- **Instream structures:** Large woody debris was placed in streams to slow the flow and create new ecological habitat (approx. £200 per feature) (Figure 10.7).
- **In-ditch structures:** Wooden dams were installed to slow in ditch flow in the top of the catchment (approx. £500 per feature (Figure 10.5)).
- **River bank protection:** Sections of willow were planted along the stream network to improve bank stability and reduce erosion.
- **Sediment traps:** Sediment traps were installed to reduce both coarse and fine sediments input to offline and wetland features.
- **Wetland creation:** Wetlands were created at two points in the catchment to temporarily store runoff and increase biodiversity.
- **Floodplain and riparian woodlands:** Willow planting on the riparian zone was undertaken in sections while hazel and holly were planted on the floodplain.

### Benefits

Newcastle University continue to study the scheme using a detailed network of scientific instrumentation. Data shows evidence of local scale flood peak reductions along with the collection of large amounts of sediment which can be ploughed back into the field. The instream woody debris and riparian planting has improved the ecological diversity of the woodland that was once dominated by sycamore trees (which blocked low canopy sunlight). Many of the other features, such as the wetland, offline storage ponds, and sediment traps have been found to provide diffuse pollution benefits – initial findings from monitoring have shown reductions in phosphorus, nitrate and suspended sediment losses during storm events.

### Funding mechanism: Capital grant

The scheme was funded by a £200k payment through the Environment Agency's North East Local Levy, raised by the Northumbria Regional Flood Defence

Figure 10.5. In-ditch structure (© Mark Wilkinson).

Figure 10.6. Offline storage pond (© Mark Wilkinson).

Figure 10.7. Instream structures (© Mark Wilkinson).

Committee through local authorities. Compensation of around £1000 was paid to farmers at points during the project to cover disruption and the loss of land for farming. The project manager closely liaised with farmers to establish a process both parties could agree to (Newcastle University for phase 1, Environment Agency for phase 2). The Environment Agency mechanism involved a simple letter signed by both parties followed by the provision of a cheque to the farmers.

## Impacts for landowner/land manager

The impacts for landowners/land managers have been minimal. There is only one feature which has been recognised as needing ongoing maintenance and a five-year de-silt agreement is in place with the farmer. Sediment capture permits valuable topsoil to be retained and ploughed back into fields.

## Impacts for delivery partners

The five-year de-silt agreement was negotiated as part of a discussion for new features on the farmer's land with no additional cost to the project partners. There are no significant ongoing responsibilities for the project partners. The Environment Agency Estates and Procurement teams were involved in phase 2 agreements but there are no ongoing legal obligations.

## Lessons learnt

It took a significant amount of time to arrange meetings with busy farmers. Tact and patience was required and it was important to avoid being too focused on early delivery. Agreement was aided by the fact that these were simple features, most of which do not need formal maintenance plans. It was possible to modify some measures in order to maximise benefits to diffuse pollution.

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Newcastle University, Environment Agency, Royal HaskoningDHV, James Hutton Institute, Northumberland Rivers Trust, Northumbria Water, Northumberland County Council, AMCO Civil Engineering, local landowners/ land managers

Belford Burn catchment, Northumberland, England

2007 – 2013

Capital grant from the Environment Agency's North East Local Levy, raised by the Northumbria Regional Flood Defence Committee through local authorities

£200k one-off payment for scheme.

# Case study 3

## Holnicote
## Somerset, England

### Description

The National Trust owned Holnicote Estate (40km$^2$) is situated in Exmoor National Park and stretches from the moors down to the coastline; the estate covers 90% of the catchments of the River Aller and Horner Water. The project is led by the National Trust and is one of three Defra funded multi-objective flood management demonstration projects. The primary aim of the project has been to implement a range of NFM measures across the estate to provide flood attenuation functions and deliver other multiple benefits. The estate contains 14 tenant farms and 170 tenant cottages so community buy-in to the scheme has been essential for implementing the measures successfully.

**Figure 10.8. Flooded Helnicote fields behind the bunds (© Penny Anderson Associates).**

### Types of measures

To date the following measures have been implemented on the ground:

- **Offline storage ponds and wetlands:** Five shallow bunded flood meadow areas (Figure 10.8) and some surface water scrapes have been created on the middle Aller floodplain to increase floodplain storage capacity.
- **Instream structures:** Instream woody debris dams and accumulations have been installed to slow flows; the development of natural instream debris has also been encouraged in the existing historic woodland (Figure 10.9).
- **Land and soil management practices:** Tenant farmers have been advised on best in-field management practices in managed grassland and arable fields, including the use of a soil aerator in fields experiencing soil compaction. Surface drainage has also been slowed and connectivity with the river network reduced through the construction of around 800 shallow earthen cross bunds along 20km of footpaths and tracks on the moorland (Figure 10.10).

The project commissioned individual soil condition/management surveys for each of the 14 tenant farms. The resultant reports were sent out to each farm with suggestions on how soil management could be improved. Overall, the reports and free advice received a positive response with one tenant farmer subsequently purchasing specialist soil remediation equipment to help implement the recommendations.

To demonstrate to the local community and tenant farmers how NFM measures changes could help reduce flooding, a range of modelling approaches was employed. These showed the current catchment flooding during observed and design rainfall/runoff events and how this would change with the implementation of different measures. This enabled the farmers to see exactly what actions could be achieved on their land and helped to remove some of the uncertainty and provide reassurance.

**Figure 10.9. Instream structures (© Penny Anderson Associates).**

Figure 10.10. Ditch blocking (© Penny Anderson Associates).

## Benefits

A sophisticated hydrological monitoring network and associated data telemetry system was established across the Aller and Horner Water catchments in order to quantify the effects of the measures on runoff response and flooding. Water quality and ecological studies are also being undertaken to explore other benefits, together with an ecosystem services assessment. Outcomes from the project are providing a wide range of additional benefits to the environment and society, including improvements to biodiversity, landscape quality, carbon stewardship, water quality, and amenity and recreation.

## Funding mechanism: Advice and support, indirect payments and compensation payments

One-off payments were made as compensation for loss of productive land and/or investment in farm buildings. The National Trust renegotiated the farm rent on one farm in order to compensate for income foregone as a result of a reduction in subsidy resulting from the works.

## Impacts for landowners/land managers

The measures currently implemented will require a range of ongoing, low cost management and maintenance activities. These include:

- periodic repair of shallow earthen bunds on moorland paths and tracks that have been damaged by walkers, mountain bikers and livestock;
- periodic clearing of accumulated woody material from bridges located downstream of Horner Wood; and
- periodic cleaning and adjustment of piped outflow control devices through earthen bunds on the flood meadow areas following flood events.

None of the compensation mechanisms used is thought to have caused any long term impacts to the landowners/land managers.

## Impacts for delivery partners

Direct annual payments were unnecessary, so there are no ongoing financial commitments for the National Trust. While the decrease in rental income is a cost, this is thought to be small impact compared to the benefits resulting from the change from arable to grassland.

## Lessons learnt

The key to implementing changes to land management and agreeing on suitable compensation mechanisms was establishing a good relationship between all parties based on open and transparent discussion. Sufficient time had to be allocated to fully explore NFM aspirations and possibilities with all stakeholders and obtain formal consents and approvals from regulatory and planning authorities (where necessary) prior to any implementation on the ground. The process was significantly aided by the work of a specially appointed National Trust project manager who maintained regular, active and open dialogue with landowners/land managers and the local community. The provision of local awareness raising and demonstration events, including contributions from influential local land managers, also greatly helped to promote the potential benefits of the works.

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National Trust, Environment Agency, JBA Consulting, Penny Anderson Associates, Exeter University, Wessex Water, local landowners/land managers

Exmoor, England

Current phase: 2009 – 2015

Advice and support, indirect and compensation payments

Funding from Defra, Environment Agency and National Trust

# Case study 4

## Bowmont Glen FRM Project
## Roxburghshire, Scottish Borders

### Description

The Bowmont Water (catchment area 100 $km^2$), a tributary of the River Till (Tweed), flooded most recently in 2008 and 2009 resulting in major damage to roads, bridges, fences, and power lines, and stranded families. Large areas of valuable haugh land, where silage is grown, were lost due to erosion, channel switching, and large gravel deposits (Figure 10.11).

Much of the damage that was repaired by landowners in 2008 was undone by the 2009 event resulting in a great deal of frustration as to what should be done and what could be authorised on a designated site (the whole of the Tweed being a Special Area of Conservation). To address the issues a Bowmont Water Management Group, made up of land managers, landowners representatives and statutory bodies and chaired by Tweed Forum, was set up with the aim of building a consensus on the best way to integrate the needs of residents and statutory bodies and to help build long term resilience to extreme events in the future.

Tweed Forum, with support from SEPA and Natural England, commissioned a fluvial audit to identify problem areas and possible solutions. This found that the erosion of excessive glacial and fluvial material present in the valley was being exacerbated by the sustained removal of vegetation through grazing. The project also took evidence from land managers on how the floods had affected them. Individuals reported that the river had lost much of its stability, habitat and charm, and been replaced by a more unpredictable and raw landscape of gravel and new channels.

### Types of measures

- **Riparian planting:** To date a total of 52ha of native woodland has been planted on three farms, in addition to 100ha which were planted as part of a farm restructuring to increase habitat for game (approx. £4000/ha). Further planting is planned in the next few years.
- **River bank protection:** A series of different styles of bank protection techniques have been installed on the edge of an arable field in the lower part of the catchment to reduce the release of gravel and protect the public road from scouring. These methods included a two-tier willow spiling bank (Figure 10.12), compost filled nylon 'socks' anchored to the bank (Filtrexx), larch log lattice with willow planting (Figure 10.12), and a traditional wooden palisade (approx. £100 and £200 per metre length).
- **Instream structures:** A number of different types of instream structures have been installed to manage river gravel. Engineered log jams have been used to act like windblown trees washed into the channel and capture sediment (approx. £200 per feature). Instream woody debris has also been installed on a first order tributary, Elm Sike, to slow down the flow of floodwaters into the main stem of the river (approx. £150 per feature).
- **Erodible river corridor:** Part of the river, which had no artificial banks to breach, was given space to flood along a 2km wide corridor. The land manager cannot alter the floodplain in any way but can still use the area for grazing. The farm entered into a five year agreement with the Scottish Rural Development Programme.

**Figure 10.11. Inundation of agricultural land with sediment laden floodwater (© Tweed Forum).**

In order to address immediate needs, a sediment management licence was also developed in conjunction with SEPA that enabled land managers to remove sediment within agreed limits and that did not affect the status of the designated site.

### Benefits

The James Hutton Institute is monitoring the effects of the measures with a comprehensive network of water level gauging (nine sites), rain gauges (three sites) and a weather station, in addition to sediment surveys. The network has been running for nearly three and a half years and data is currently being analysed. The project has sought to increase farm resilience to flooding, reduce the amount and effects of gravel deposition, create connected riparian woodland habitat, and demonstrate the effect of land use upstream on flood flows downstream.

### Funding mechanism: capital and annual payments

Capital and annual payments were funded by the Scottish Rural Development Programme, SEPA's Water Environment Fund, Forest Carbon, Woodland Trust, Natural England, Environment Agency and individual landowners.

Figure 10.12. Willow spiling bank protection (© Tweed Forum).

## Impacts for landowner/land manager

The works have helped to protect business assets. The measures currently implemented will require a range of ongoing, low cost management and maintenance activities.

## Impacts for delivery partners

Tweed Forum oversees the project on behalf of the project members and has instigated some repairs of undermined bank protection. Individual land managers are responsible for SRDP compliance regarding planting, fencing and other measures.

Figure 10.13. Set-back log bank protection (© Tweed Forum).

## Lessons learnt

It took time and extensive discussions to arrive at a consensus, with both sides (the agencies and the land managers) needing to be flexible. Agreements had to be reached between landowners and tenants regarding changes to farm rent resulting from some of the works. Many of the measures were experimental and their performance will be monitored to inform future works.

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Partners: Tweed Forum, Scottish Government, Scottish Borders Council, Natural England, James Hutton Institute, SEPA, Scottish Natural Heritage, Northumberland National Park, local landowners/land managers

Bowmont Water catchment, Roxburghshire, Scottish Borders

2009 - present

Capital and annual payments funded by multiple organisations and individuals.

£230k planting, fencing, bank protection and instream structures.

# Case study 5

## West Sands Beach Recharge and Dune Restoration St Andrews, Fife

### Description

Coastal managers at St Andrews West Sands identified assets at risk from coastal erosion and flooding. While much of the dunes along St Andrews West Sands were thought to be relatively robust there was concern that some of the low lying dunes, on locally erosional sections, would act as flood routes into the dune interior and threaten infrastructure. In addition, numerous informal public access routes were responsible for creating multiple weak points through the dunes and onto the dune face. In 2010 a storm surge breached parts of the dune system and flooded farmland adjacent to A91 and parts of the golf courses. The West Sands Partnership (made up of relevant organisations and interest groups) provided a forum for discussions to take forward more sympathetic NFM approaches to improve resilience of the dunes to manage flood and erosion risk. This approach was particularly important given the broader context of the Firth of Tay and Eden Estuary Natura 2000 site and adjacent areas. Sand collected from an accreting area in the intertidal zone has been used to repair low points in the dunes together with the introduction of chestnut pale fencing and marram grass planting.

**Figure 10.14. Sediment pathways at West Sands: Areas of erosion are marked in red, sediment pathways in blue and areas of accretion in green – sediment was 'borrowed' and returned to areas of erosion.**

### Types of measures

Informed by the natural sediment patterns and grain size distributions of dunes and the intertidal area, a donor site was identified that could accommodate modest, periodic sediment extraction without compromising the Natura site's conservation objectives. This allowed coarse sands to be extracted and taken to reinstate erosional sections of the dunes (Figure 10.14).

The weak points within the dunes were re-profiled, access routes re-laid and sand fencing installed along with marram grass planting. The sediment used to recharge the beach will gradually drift back towards the location where the sediment was removed, allowing the process to be repeated. The cost for this initial dune rebuild was approximately £80,000. This approach has been undertaken along the West Sands (protecting roads and car parks) with a similar approach on the Eden Estuary coast (protecting parts of the Jubilee Golf Course).

In each case the dune corridor is wider, higher and more robust reducing erosion and flood risk, while not compromising habitats, access or aesthetic aspects. Figure 10.15 show the sand dunes before and after works respectively.


**Figure 10.15. Sand dunes before, during and after restoration (©John Inglis/West Sands Partnership).**

## Benefits

The choice of an NFM approach here ensures the dunes remain attractive and accessible to users, while offering improved resilience for erosion and flood risk. The benefits to recreation and tourism derive from both enhancing the landscape and biodiversity and protecting infrastructure.

Much of this coast is natural (un-defended) and repairing weak points with sand addresses the underlying cause of the problem, rather than hard engineering structures that attempt to deal with the consequences. The approach fits within a holistic strategy of flood and erosion risk management within the dunes which protects important recreational areas that generate millions of pounds to the Scottish economy.

## Funding mechanism: capital payments

The main capital works were funded by the INTERREG's Sustainable Coastal Development in Practise (SUSCOD) fund. Ongoing funding is provided by Fife Council local community budget grants, augmented by an annual contribution from Fife Council Transportation. Labour has, and continues to be, provided by St Andrews Links Trust.

## Impacts for landowner

The work has helped to protect valuable assets. Maintenance responsibilities have been shared with delivery partners and volunteers, thus easing burden on the landowner (St Andrews Links Trust).

## Impacts for delivery partners

All project partners sit on both the Sands Liaison Group and the West Sands Partnership group. This enables a positive and pro-active approach to defining responsibility for future management or restoration works. Maintenance includes re-instatements of chestnut pale fencing due to sand accretion and fencing repairs (approx. £3000-£5000 per year). In addition volunteers spend time that approximates to 12 days per year primarily transplanting lyme and marram grass and removing invasive species such as lupin and violet willow (Figure 10.16). The dune restoration is outlined as a long term project (2010-2025) in the management plan, all partners are aware of the need to work closely and all understand the commitment required to maintain the dune system. The dune system will always require management and restoration in varying measures.

## Lessons learnt

While sands from the Tay have, over millennia, collected and created the dunes at St Andrews, augmenting the upper beach and dunes will help these world-renowned dunes remain robust as sea levels rise.

- Partnership working between landowners, interested groups and statutory advisors ensures a coordinated approach that doesn't compromise the Natura site.
- Good technical knowledge of coastal processes is essential to identify an appropriate sediment donor site.
- Ongoing monitoring and maintenance is key to ensure success; volunteer groups can play a vital role in delivering this.
- EU initiatives such as SUSCOD can provide important sources of funding for NFM measures and provide valuable support in facilitating meetings, workshops and information gathering.

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**Figure 10.16. Planting marram grass (© R. Strachan/Fife Coast and Countryside Trust).**

The West Sands Partnership, Fife Coast and Countryside Trust, St Andrews Links Trust, Scottish Natural Heritage, Fife Council, local landowners.

West Sands, St Andrews, Fife

2010 – present

Capital payments funded by INTERREG SUSCOD (initial rebuild) and Fife Council thereafter.

£80k for initial rebuild, maintenance (primarily fending repairs), £3–5k per year thereafter.

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