The natural flood management manual

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CIRIA C802 London, 2022

The natural flood management manual

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CIRIA C802 RP1094 © CIRIA 2022 ISBN: 978-0-86017-945-0

British Library Cataloguing in Publication Data

A catalogue record is available for this book from the British Library

Keywords

Natural flood management (NFM), surface water drainage and flooding, sustainability, natural processes, civil and ground engineering, construction process and management, environmental management, flood risk management and surface water drainage, infrastructure asset management, sustainable water management

Reader interest

Planning, design, construction and management of drainage works, including civil engineering, hydrology and environment, highways, waterways and railway infrastructure, land drainage, and flood risk management, catchment management

Classification

Availability	Unrestricted
Content	Advice, information, original research
Status	Committee-guided
User	Lead local flood authorities, Environment Agency, Internal Drainage Boards, water and sewerage companies, National Highways, Forestry Commission, landowners and land managers, Rivers Trusts and other relevant NGOs, relevant local community groups, catchment partnerships, occupiers and tenants, universities and research organisations

This manual should be cited as:

WREN, E, BARNES, M, JANES, M, KITCHEN, A, NUTT, N, PATTERSON, C, PIGGOTT, M, ROBINS, J, ROSS, M, SIMONS, C, TAYLOR, M, TIMBRELL, S, TURNER, D and DOWN, P (2022) *The natural flood management manual*, C802, CIRIA, London, UK (ISBN: 978-0-86017-945-0)

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Executive summary

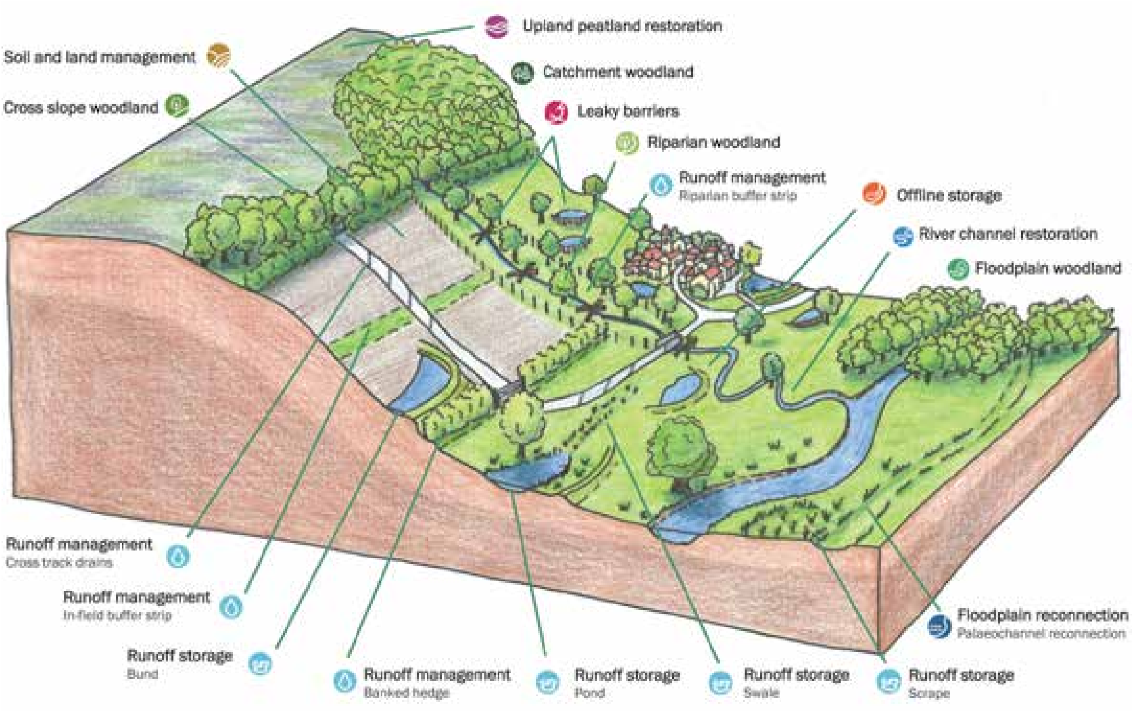
WHAT IS NATURAL FLOOD MANAGEMENT?

Natural flood management (NFM) is a tool to help reduce flood risk. It complements other flood risk management approaches and involves working across the landscape to protect, restore or mimic the natural hydrological processes that occur. These include increasing infiltration of water, slowing the flow of water across the landscape, storing water and holding back sediment. Importantly, natural flood management can have a range of complementary, co-benefits such as habitat creation, carbon storage, water quality improvement and recreational and wellbeing benefits if delivered effectively and considered from the outset. These co-benefits can be maximised by working with others.

Part A provides an overview of natural flood management and a high-level checklist of the steps to deliver it.

WHERE DOES IT WORK AND WHAT ARE THE DIFFERENT MEASURES?

NFM can be applied across the landscape, in rural and urban locations, tailored to the given location. There are a range of inland NFM measures described in this manual. These complement and overlap each other – there may be a number of measures suitable for a given catchment and it is preferable to use a broad range of measures rather than relying on one or two.



NFM measures across a river catchment (courtesy Emma Wren)

NFM projects should consider three main aspects, in the following order:

A leaky woody feature that has naturally formed across a watercourse

1 **Protect** – take steps to retain things in the current landscape that are functioning well in terms of natural processes – it is best to start by looking after what is working if possible

A watercourse that could be restored by adding meanders and being reconnected to its floodplain

2 **Restore** – work at the source of the problem and reinstate natural hydrological processes across the landscape, by taking steps to restore or enhance hydrological processes. Making many positive changes across the landscape, such as soil or land management interventions, adds up to a bigger impact.

A scrape added to the landscape to store overland runoff before it reaches the watercourse

3 **Mimic** – it is unrealistic to restore the landscape everywhere. However, NFM features can be added to mimic natural hydrological processes or to give enhanced flood risk benefits. An example would be runoff storage features in an agricultural landscape. These mimic the way that runoff across the land would be expected to be slower in more natural settings.

Part B describes the philosophy of NFM and the first part of the delivery process - how to set up a project for success and choose appropriate NFM sites and measures.

Part C gives more detailed information on a range of inland NFM measures. There are 12 measures covered in the manual and of these four are covered in a greater depth – these priority measures are shown in bold. The others are given a short overview with signposts to further detail.

Upland peatland management	Riparian woodland
Soil and land management	Floodplain woodland
Runoff management	**Leaky barriers**
Runoff storage	**Floodplain reconnection**
Catchment woodland	River channel restoration
Cross slope woodland	Offline storage


Runoff management (courtesy West Country Rivers Trust)

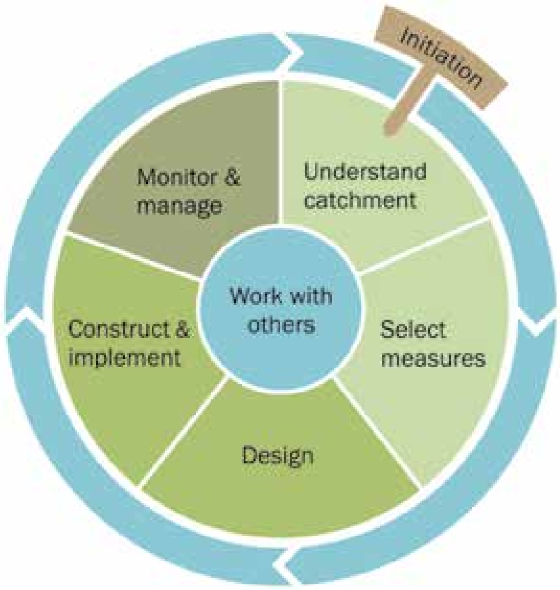

Leaky barriers (courtesy Mike Norbury)


Runoff storage (courtesy Yorkshire Dales Rivers Trust)


Floodplain reconnection (courtesy Atkins)

HOW SHOULD NFM BE DELIVERED?

NFM is most effective when delivered in a location over a longer time period with time to re-visit earlier project steps and evolve as understanding and momentum increases. This circular process allows more informed decisions over time and increases the likelihood of a successful project. It is also important that the level of effort is proportionate to the overall intended outcome. It is often preferable to deliver something on the ground and build learning and momentum from making a tangible start.



NFM delivery process

There are five key steps to consider, which are presented as a linear process. However, there may be a need to go back and refine some multiple times or to consider earlier in the process, for example some baseline monitoring may be needed at the start to help understand the catchment.

Understand the catchment	Engage with catchment stakeholders and gather data to understand the geography of the catchment and the interests of everyone. Identify partners and funding
Select measures	Choose the sites and NFM measures that can achieve the desired outcomes, including maximising co-benefits
Design	This should be tailored to the project aims and the site. Health and safety risks must be considered
Construct and implement	This is dependent on the design of the NFM measures. Consider the timing, safety, liability, access and environmental impacts
Monitor and manage	Develop a site management plan dependent on the aims and objectives of the project

Part D provides detailed information on the NFM delivery process, and supporting information, including case studies and worked examples, are in the **Appendices**.

WHY WORK WITH OTHERS?

The ability to deliver co-benefits and seek to dexliver on multiple aims is one of the key outcomes of NFM. It is important to work with other interested groups at every step of the NFM delivery process to maximise these benefits – to seek alignment in what each are trying to achieve and to pool expertise and resources. This is outlined in **Part B**.

Acknowledgements

This manual is the result of CIRIA Research Project (RP)1094. It has been written under contract to CIRIA by an author team led by Emma Wren of Mott MacDonald.

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Marie specialises in the freshwater environment, particularly fisheries science, river restoration and ecological monitoring. She has practical experience of delivering and overseeing several NFM projects in her role at the Yorkshire Dales Rivers Trust. Her passion is working together with local communities, farmers and landowners to achieve and deliver environmental improvement projects for the benefit of people and wildlife.

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Dan is a project manager at The Rivers Trust with a specific interest in NFM, agricultural and green investment. He leads the Wyre NFM Investment Readiness project, which is a first of its kind project, looking at how private investment capital can be blended with public sector funding to finance natural landscape restoration through development of monetisable ecosystem services such as NFM. In previous roles, Dan has led several NFM projects delivering physical interventions and he recently completed a PGcert in flood risk and coastal management. Brought up on a large commercial farm, Dan has extensive experience of the agricultural sector.

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Project steering group

Following CIRIA's usual practice, the research project was guided by a project steering group (PSG) which comprised:

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Paul Quinn	Tyndall Centre for Climate Change Research
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Barry Spiers	Department for Infrastructure Northern Ireland
Bruno Venturini	WSP
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Project funders

Anglian Water
Department for Environment Food and Rural Affairs
Department for Infrastructure (Northern Ireland)
Environment Agency
Hertfordshire County Council
JBA Trust
National Highways
Natural Resources Wales
Network Rail
Scottish Environment Protection Agency
Severn Trent Water
United Utilities
Welsh Government (Llywodraeth Cymru)

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Joanne Barlow	Mott MacDonald
Colin Brown	University of York (iCASP)
David Brown	Environment Agency
Alexandra Bryden	River Restoration Centre
Robin Chase	Atkins
Victoria Coates	Mott MacDonald
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CIRIA would also like to thank Mott MacDonald for their substantial in-kind contribution in the production and dissemination of this manual.

We also acknowledge the support of the Rivers Trust via the Interreg Atlantic Area project AA-Floods EAPA_45/2018, and the Yorkshire integrated Catchment Solutions Project (iCASP) funded by the Natural Environment Research Council (NERC).

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A Natural flood management and the manual

Image courtesy Victoria Coates

Courtesy River Restoration Centre

1 INTRODUCTION

Contents

Chapter 01

Introduction

This chapter provides an overview of natural flood management and a high-level checklist of the steps to deliver it.

- ▶ *Summary drawings are provided of four NFM measures covered in detail in this manual:*
- ▶ *Runoff management: Chapter 7 provides more detail on this measure*
- ▶ *Runoff storage: Chapter 8 provides more detail on this measure*
- ▶ *Leaky barriers: Chapter 10 provides more detail on this measure*
- ▶ *Floodplain reconnection: Chapter 12 provides more detail on this measure*

1.1 WHAT IS NATURAL FLOOD MANAGEMENT?

NFM is used across the landscape to protect, restore or mimic the natural functions of catchments, floodplains, rivers and the coast. It is a potential approach to help reduce the risk of flooding from all sources such as rivers, the sea and surface water runoff. It should be considered alongside a range of other options to reduce both the likelihood of flooding (eg flood walls, embankments, storage reservoirs) and the impacts of flooding (eg improved flood warning and recovery).

The starting point for any NFM work is a desire to reduce flood risk, and a recognition that NFM may be a viable option to do this, by working with natural processes across the landscape. NFM can perform one or more primary functions relating to flood risk management:

- increase infiltration
- slow the flow of water
- store water
- hold back sediment.

It can also perform secondary functions to provide co-benefits, such as habitat creation and biodiversity enhancement, soil improvement and retention, water quality improvement and carbon storage, and can create more valuable landscapes leading to recreation or tourism opportunities for the local and wider community. Equally, other initiatives, which have their primary objectives outside of flood risk management, can also provide a secondary flood risk co-benefit (eg biodiversity-driven projects can help reduce flood risk).

NFM can take many different forms and can be applied at different scales, in urban and rural areas, by altering the way habitats, land, rivers, estuaries and the coast, are managed (**Figure 1.1**).

1.2 RIVER AND CATCHMENT-BASED NFM MEASURES

NFM, to reduce the risk of surface water and river flooding, can be applied in different ways. The NFM measures included in this manual are detailed in **Table 1.1** and those given more focus are shown in bold.

There is considerable overlap between some measures. This is because some can be used in different ways in different places in the landscape. For example, leaky barriers can be used to both manage overland runoff and stream or river flows, and bunds can be used to intercept flow pathways and store runoff. It is also important to consider a range of measures in a range of locations to reduce the risk of relying on a single solution or a particular location.

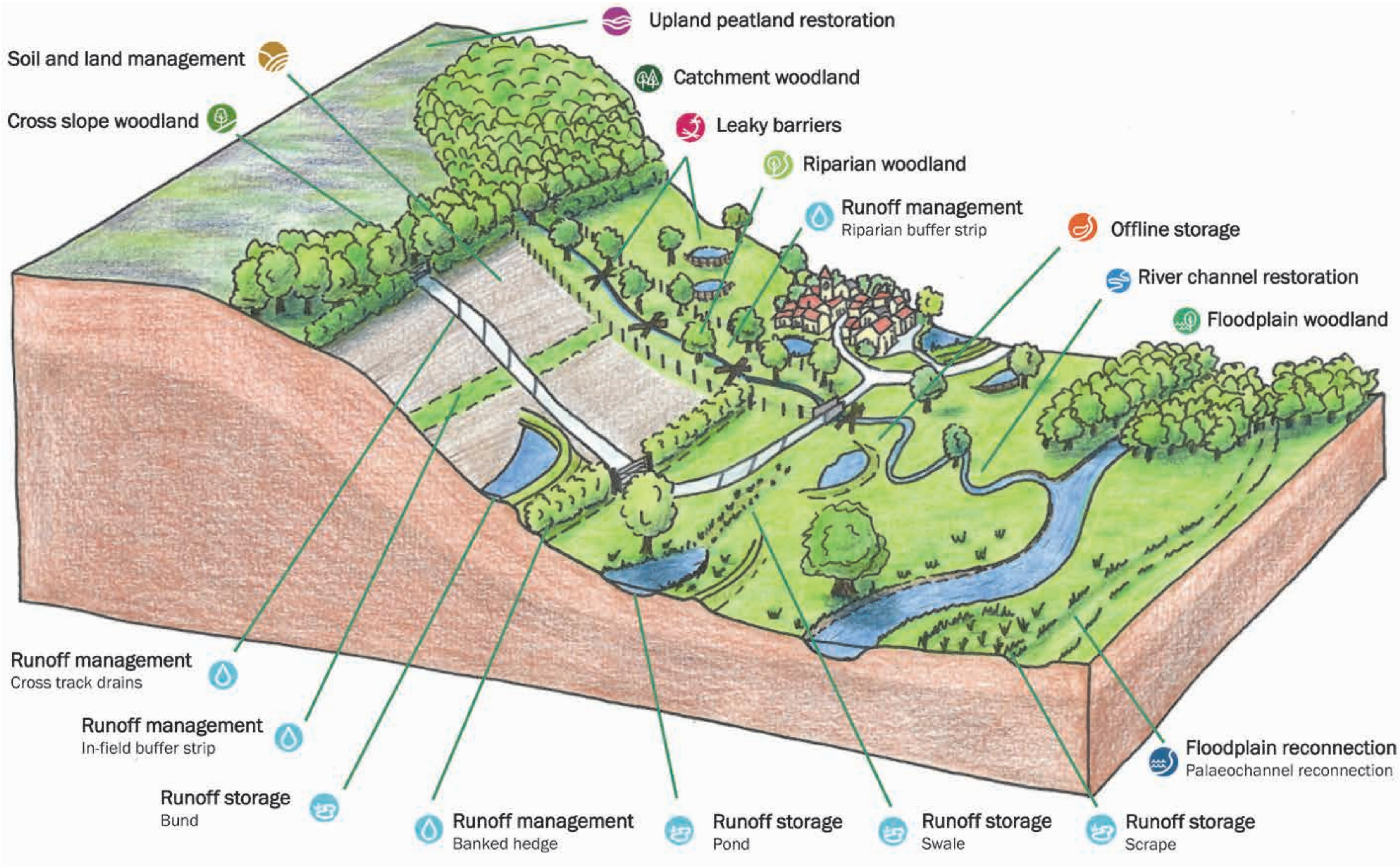


Figure 1.1 NFM across a river catchment

TABLE 1.1 Types of NFM in a river catchment

Measure	Measure types	How it works	Consider alongside
Upland peatland management	Revegetation and habitat management Gully blocking using leaky barriers for peatlands Ditch blocking Hillslope pool creation	Manage upland peatland and enhance ability to store and slow the flow of water from headwaters. Revegetate and roughen bare areas and encourage dense peat-forming vegetation. Block artificial drainage channels (grips) to support vegetation change. Stabilise eroded gullies. Install leaky barriers that are appropriate for peatland to provide enhanced flood storage. Create pools to buffer the rainfall response.	Upland peatland management typically takes place in the headwaters of a catchment and so can be adopted upstream of all other NFM measures. They need to be designed to suit the upland peatland environment.
Soil and land management	Changes to farm management practices Reduce soil compaction Encourage more natural habitats	Restore or enhance the ability of soil to infiltrate and store water.	Runoff management Runoff storage Woodland (all types)
Runoff management	Cross track drains and diverters Cross slope hedgerows (including banked hedges) Buffer strips	Interrupt or divert overland flow pathways across the landscape, encourage infiltration into the ground, slow the flow and divert water away from problematic locations.	Soil and land management Leaky barriers across overland flow pathways Cross slope or catchment woodland Riparian or floodplain woodland in riparian buffer strips Runoff storage to store diverted water
Runoff storage	Ponds Scrapes Bunds Swales	Store water on overland flow pathways to reduce the flow towards a watercourse and encourage infiltration.	Soil and land management Runoff management Cross slope or catchment woodland Leaky barriers across overland flow pathways Offline storage adjacent to runoff pathways
Cross slope woodland		Plant woodland belts across slopes to slow the flow down slopes, intercept rainfall, increase evaporation and uptake by vegetation and infiltration.	Runoff management and storage Soil and land management
Riparian woodland		Plant trees in the river corridor to slow the flow in channels, intercept rainfall, increase evaporation and uptake by vegetation and infiltration.	River channel restoration and floodplain reconnection Leaky barriers on watercourses Buffer strips along watercourse Floodplain woodland

continued...

TABLE 1.1 Types of NFM in a river catchment (contd)

Measure	Measure types	How it works	Consider alongside
Floodplain woodland		Plant trees in the floodplain to slow the flow across it. Intercept rainfall, increase evaporation and uptake by vegetation and infiltration.	River channel restoration and floodplain reconnection Leaky barriers on watercourses Riparian woodland Soil and land management Buffer strips along watercourses Offline storage in/adjacent to floodplains
Catchment woodland		Increase woodland cover across the landscape to intercept rainfall, increase evaporation and uptake by vegetation and infiltration.	Soil and land management Runoff management and storage Other woodland measures Leaky barriers and offline storage on runoff pathways and watercourses within woodland
Leaky barriers	Leaky barriers on watercourses Leaky barriers on runoff pathways	A flow obstacle to slow down and store water in small streams and their immediate floodplain. Or a barrier across overland flow pathways to store and slow water.	Riparian or floodplain woodland to supply woody material in the future Soil and land management Runoff management and storage eg buffer strips along watercourse River channel restoration and floodplain reconnection Catchment, floodplain and riparian woodland
Offline storage	Next to watercourses Adjacent to runoff pathways	Divert water from an overland flow pathway or stream to be temporarily stored nearby.	Leaky barriers to divert water into storage areas Runoff management to divert water from flow pathways Runoff storage Could locate within floodplain or catchment woodland
Floodplain reconnection	Lower, remove or set back existing embankments Reconnect palaeochannels In-channel features to push flow into floodplain Floodplain wetland restoration	Restore or enhance the natural function of the floodplain to store water.	River channel restoration Floodplain and riparian woodland Leaky barriers to push flow into floodplain Offline storage
River channel restoration	Restore channel planform Restore longitudinal connectivity Restore lateral river movement	Restore modified river channels due to artificial changes (direct or indirect).	Floodplain reconnection Floodplain and riparian woodland Leaky barriers Buffer strips along watercourse

Figure 1.2 Example NFM measures

1.3 WORKING WITH NATURE

The philosophy of NFM centres on working with nature where possible to reduce flood risk close to the origin of flooding. **Figure 1.3** explains this approach, showing that the focus should be to work with nature to protect, then restore and mimic hydrological processes.

Figure 1.3 The NFM continuum of protect, restore and mimic hydrological processes

An NFM project should seek to retain features in the landscape that are naturally functioning well. It should then seek to restore natural hydrological processes across the landscape, by enhancing or adding to what is present across the catchment. Finally, if the entire landscape cannot be restored, an NFM approach can be adopted to mimic hydrological processes or to give greater flood risk benefit. This could mean adding more engineered storage features to the landscape rather than, or as well as, working at source to improve the ability of soil to store water. Alongside this hierarchy there are five key principles to adopt when working with nature (**Figure 1.4**).

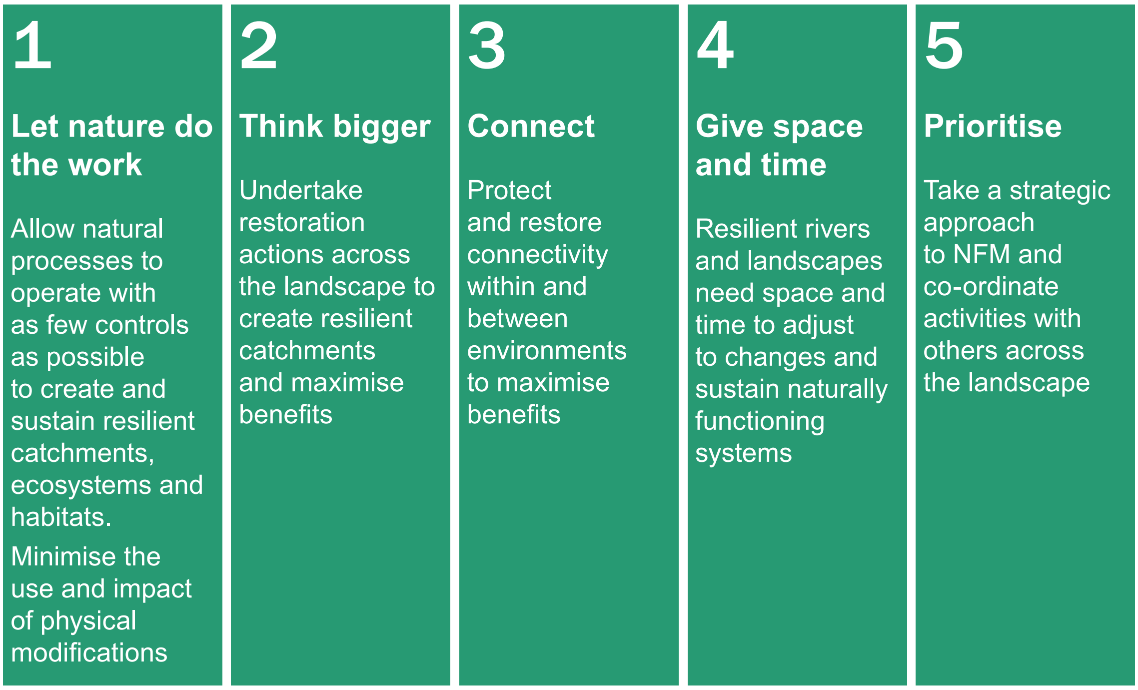


Figure 1.4 Five key principles for working with nature

1.4 HOW TO USE THE MANUAL

This manual is divided into four parts (**A to D**) plus appendices and is colour coded based on those sections (**Figure 1.5**). It starts with a high-level overview and progresses into more detailed information.

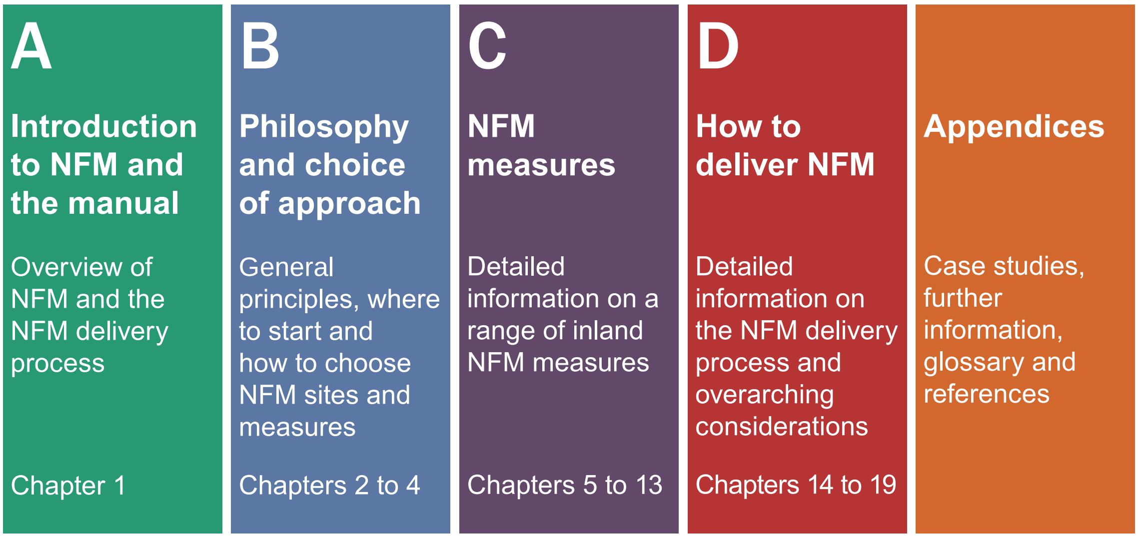


Figure 1.5 Structure of this manual

1.5 THE NFM DELIVERY PROCESS

The delivery process is the starting point in this manual to appreciate the process to implement NFM. There are five key steps to the process, shown in **Figure 1.6**. It is important to work with other interested groups to maximise the outcomes of NFM at every stage.

The delivery of NFM combines methods used in flood risk management (eg assessment of risk and hydrological modelling) and environmental management (eg understanding natural processes and ecological impacts).

NFM is most effective when delivered as a long-term, circular process. This enables increased understanding to improve design and delivery as the project progresses. This will result in more informed decisions over time and the increased likelihood of a successful project. The level of detail needed at any given step is highly project specific and should be proportionate to the overall intended outcome. It is also important to recognise that there may be several full or part iterations around the delivery process – NFM projects tend to be more organic in their nature than engineering projects – NFM measures can be incrementally added over time as more partners become involved and support for this way of working builds momentum in a place.

The following sections explain the key steps in the delivery process and provides high-level checklists to ensure that all aspects are considered. **Figure 1.7** signposts where more information is found in later sections of this manual.

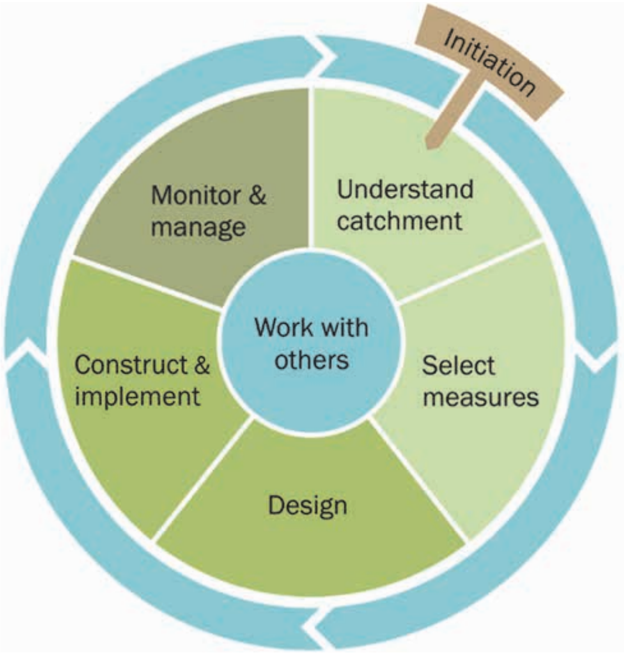


Figure 1.6 The NFM delivery process

Progress through a project

Delivery stage	What is needed?	Key information	Further detail
Initiation	Understand the NFM delivery process, agree project aims, raise support and understand wider aspirations	1 Introduction 2 Aims and success factors 3 Top tips for successful NFM	
Understand catchment	Gather information to understand issues and opportunities in the catchment	4 Select sites and measures	
Select measures	Select sites and measures to target the catchment issues and maximise outcomes	4 Select sites and measures Part C NFM measures	14 Hydrology and hydraulics 15 Costs and benefits 16 Environmental considerations
Design	Develop appropriate NFM designs	Part C NFM measures	17 Design and materials
Construct and implement	Deliver the NFM	Part C NFM measures	18 Construction and implementation
Monitor and manage	Aftercare for the NFM delivered	Part C NFM measures	19 Monitor and manage
Work with others	Integral to maximise outcomes and co-benefits	3 Top tips for successful NFM	

Figure 1.7 How to use the manual to deliver an NFM project

1.5.1 Understand the catchment

To start, an NFM project requires a broad understanding of the catchment and the interests of the people within it. This understanding is an iterative process and, due to the complex and dynamic nature of river systems, it is never complete.

There can be a number of starting points dependent on the nature of a catchment and the people involved. Projects range from small-scale interventions to multi-catchment strategies, and can be initiated and led by a variety of organisations, stakeholders and partnerships.

The success of NFM projects rests on early engagement, to gather support from the community and landowners as well as flood risk authorities. Support from these stakeholders will provide a platform to deliver NFM and inspire confidence in the project.

Understanding the catchment is critical to understand the source of catchment impacts and the factors contributing to these issues and also identify opportunities to address these. This understanding means that NFM measures can be targeted to both reduce flood risk and deliver co-benefits.

Checklist	✓
Understand flood risk (where and what floods; sources, pathways and receptors)	
Understand the interests, aims and aspirations of everyone involved in the catchment	
Find others to work with to achieve more together	
Define the project aims and success factors; review them as understanding increases	
Identify potential funding sources	
Understand the physical nature of the catchment and catchment pressures	
Understand current and future strategies, plans or developments	
Identify opportunities to reduce flood risk, address impacts and maximise co-benefits	
Understand risks and barriers to implementation (eg land ownership, infrastructure)	
Put in place any monitoring needed to gather missing data or understand project success	

1.5.2 Select measures

Select NFM sites and measures that will achieve the project objectives and address the causes of flood risk in a catchment. The NFM measures chosen should aim to address the issues identified during the 'understand the catchment' step and maximise opportunities for co-benefits.

Checklist	✓
Identify priorities for NFM locations and measures	
Protect and restore what is there before seeking add more engineered measures	
Combine a range of NFM measures and types	
Seek to address flood risk issues at source and align to the catchment hydrology and hydraulics	
Take opportunities to address wider catchment issues and deliver co-benefits	
Select measures to align with project aims – funding requirements, landowner or community preference, and the people involved and expertise available	
Select measures to maximise environmental benefits and minimise detrimental impacts	
Consider how measure choice will affect the overall costs and benefits	
Understand if specific consents or permissions may be needed	
Consider if design, construction and future management requirements affect the choice (eg expertise available, health and safety, land access)	

1.5.3 Design

Design is a vital part of the process as it is required to obtain permission to construct or implement NFM measures. The main benefits of a good design are:

- it enables NFM principles to be embedded
- good project performance
- reduction of risk
- positive communication and engagement
- allows the monitoring of project success.

The level of detail required in design depends on the type, scale and location of the NFM measure. The optimal design of an NFM measure depends on the unique conditions of the site and the aims of the project. Safety needs to be considered in design (see **Section 17.5**) to reduce health and safety risks during construction and throughout the lifespan of measures.

Checklist	✓
Work with the community to improve designs or overcome implementation barriers	
Specify the NFM measures to be constructed	
Align the level of design to the NFM measure, scale and location and the performance aims	
Optimise the hydrological and hydraulic design of individual measures	
Refine understanding of the costs and benefits of the project	
Maximise environmental opportunities and minimise harmful environmental effects	
Understand and eliminate or reduce safety risks	
Consult with the relevant consenting authorities to understand if the design meets their needs	

1.5.4 Construct and implement

The approach to construction and implementation is dependent on the type of measure and the outputs of the design process.

The aspects to be considered are unique to a site and include the timing of works, safety, liability, access, environmental designations and more.

Some measures can be implemented in a day with a group of volunteers, while others require a civil engineering approach, which can take longer.

Checklist	✓
Make the most of collective working to construct NFM measures effectively	
Plan how to construct or implement the measures as they are specified in the design	
Ensure that health and safety risks are considered and minimised	
Confirm site access and understand any constraints (eg services, timing)	
Plan how to minimise and manage any harmful environmental impacts	
Ensure all necessary consents and permissions are in place	
Keep appropriate records of the completed measures and their future management	

1.5.5 Monitor and manage

The specific approach to monitoring will depend on the aims and objectives of the project. Successful monitoring should:

- establish the strengths and weaknesses of both the individual measures and the wider NFM project
- target the key indicators of success, at the scale at which they are expected to change
- inform the catchment understanding, measure selection, design and construction to improve the current and subsequent projects.

By working with natural processes, NFM measures may require little or no ongoing management. In some cases, NFM measures require maintenance (periodic or based on flood events, eg woodland management, repairs) or adaptive management (changes and alterations). This is informed by monitoring and inspection findings.

Checklist	✓
Develop and implement a site management plan	
Assign responsibility for inspection and management or maintenance	
Monitor the overall flood risk benefits and co-benefits to demonstrate project success	
Monitor whether individual measures are working as planned	
Consider mechanisms to incorporate adaptive management (changes and alterations)	

1.6 AIM AND SCOPE OF THE MANUAL

The manual covers the delivery of NFM from start to finish: problem identification, conception, funding, design, construction, inspection, maintenance, adaptive management and end-of-life considerations. It is primarily concerned with the ‘where' and ‘how' of NFM delivery, rather than ‘why', and aims to provide confidence in NFM and ensure the best outcomes are delivered. The manual is not intended to be exhaustive and innovation in this area is constantly emerging.

It is intended for use in the UK and is tailored to the geographical settings and conditions of the country. It does not cover the legal context for countries outside the UK although it draws on advice and case studies from elsewhere and could be of assistance for overseas projects.

The manual covers NFM measures to reduce the risk of flooding from surface water and rivers. It does not include coastal NFM to reduce the risk of tidal or coastal flooding by techniques including restoration or creation of salt marshes, mudflats, dunes and beaches. Further guidance on coastal NFM is given in Forbes *et al* (2015) and Burgess-Gamble *et al* (2018).

Detailed technical advice is given on four measures (shown in bold in **Table 1.1**). These are considered more challenging to deliver and with less detailed information available. The remaining measures are each given a one-page summary with signposts to other publications. The manual is structured so that more information can be added on the other measures.

The primary audience is those implementing NFM in their local river catchment. This may be individual or groups of landowners or managers, a community group or an environmental non-governmental organisation (NGO), such as a Rivers Trust or Wildlife Trust. It may also be used by the full range of authorities, organisations and professionals working on NFM projects (**Section A3.2**). It is aimed at groups implementing projects to reduce flood risk, although it can also be used to help design other nature-based solutions that may provide flood risk benefits alongside other aspirations.

BOX 1.1 Definitions of NFM and similar approaches

Name	Definition
NFM	An approach to reduce flood risk by working with natural processes across the landscape.
Nature-based solutions (NbS)	An approach that adopts natural processes to overcome or offset environmental issues. NFM is a type of NbS, focusing on flood risk, and achieving co-benefits. Other nature-based solutions may focus on different outcomes, for example biodiversity improvements, water quality improvements or climate resilience, and could also provide a flood risk benefit. Similar techniques may be used to achieve these outcomes.
Natural water retention measures	Term used across Europe with a similar meaning to NFM. Natural water retention measures aim to retain and enhance the natural water storage capabilities of the landscape, soil and aquifers using natural processes.
Sustainable drainage systems (SuDS)	Ways to manage surface water runoff (the flow of rainwater across the surface) by capturing, using, absorbing, storing and transporting rainfall in a way that mimics nature. They also reduce pollutants as well as provide other amenity and biodiversity benefits. Some overlap with NFM. Described in detail in Woods Ballard *et al* (2015).
Blue-green infrastructure	Uses the landscape and NbS to provide multi-functional spaces that are strategically planned and managed. The green refers to elements such as parks, gardens, playing fields trees and woods; the blue refers to watercourses, canals, ponds, lakes and wetlands.

TABLE 1.2 Key introductory references to NFM

Common name	Description	Reference
Natural mitigation of flood risk	A short summary of evidence for the effectiveness of NFM and successful governance approaches to implementation	UK Parliament POST (2020)
SEPA NFM handbook	A guide for Scotland, giving a good overview to NFM techniques	Forbes *et al* (2015)
WWNP Evidence base	A guide for England and Wales, brings NFM research and evidence together	Burgess-Gamble *et al* (2018)
NFM – A farmer's guide	Aimed at landowners and farmers. Focuses on benefits to the farm	SRUC (2019)
FWAG information sheets	Information sheets for landowners on a range of measures	FWAG South West: **https://www.fwagsw.org.uk/natural-flood-**management-information-sheets

Further reading

UK Parliament POST (2020) *Natural mitigation of flood risk*, Postnote number 623, Parliamentary Office of Science and Technology, London, UK

⇨ A short summary of evidence for the effectiveness of NFM and successful governance approaches to implementation

https://researchbriefings.files.parliament.uk/documents/POST-PN-0623/POST-PN-0623.pdf

Forbes, H, Ball, K and McLay, F (2015) *Natural flood management handbook*, Scottish Environment Protection Agency, Stirling, Scotland (ISBN: 978-0-85759-024-4)

⇨ A guide for Scotland, giving a good overview to NFM techniques

https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf

Burgess-Gamble, L, Ngai, R, Wilkinson, M, Nisbet, T, Pontee, N, Harvey, R, Kipling, K, Addy, S, Rose, S, Maslen, S, Jay, H, Nicholson, A, Page, T, Jonczyk, J and Quinn, P (2018) *Working with natural processes – the evidence directory*, SC150005, Environment Agency, Bristol, UK

⇨ A guide for England and Wales, brings NFM research and evidence together

https://assets.publishing.service.gov.uk/media/6036c5468fa8f5480a5386e9/Working_with_natural_processes_evidence_directory.pdf

SRUC (2019) *Natural flood management – a farmer's guide*, SAC Consulting and the Tweed Forum, Scotland

⇨ Aimed at landowners and farmers. Focuses on benefits to the farm

https://www.farmingandwaterscotland.org/downloads/natural-flood-management-a-farmers-guide/

FWAG South West *FWAG information sheets*

⇨ Information sheets for landowners on a range of measures

https://www.fwagsw.org.uk/natural-flood-management-information-sheets

Floodplain reconnection

Chapter 12 provides more detail

What is floodplain reconnection?

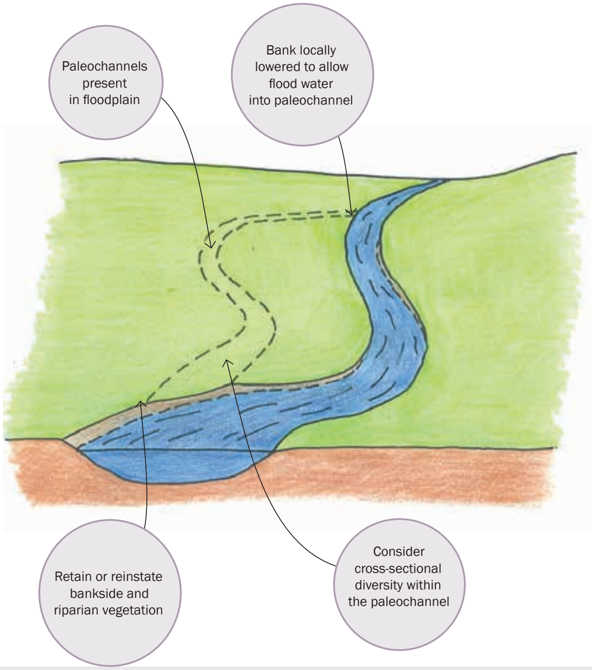
- 'Reactivation' of floodplains to reverse previously reduced connection between the river and its floodplain
- Increases the frequency and/or spatial extent of floodplain inundation
- Allows water to be stored outside the main channel in times of flood
- Deliver adjacent to the river channel, usually in the middle to lower reaches of a river catchment

Key metrics

- Moderate to high cost
- Moderate build complexity
- Low maintenance requirements
- Indefinite design life

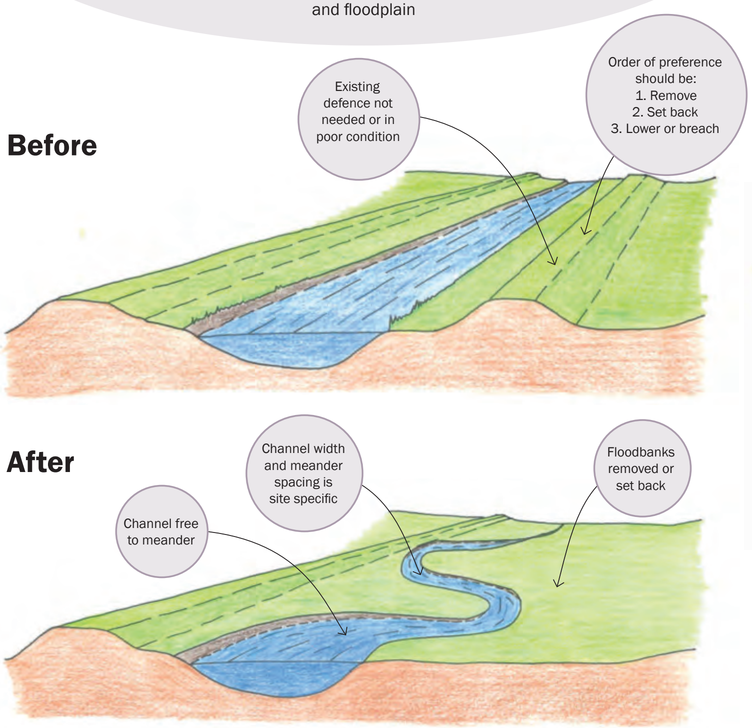
Paleochannel reconnection

Allows former river channels (in the floodplain) to become inundated in times of higher flows/flood



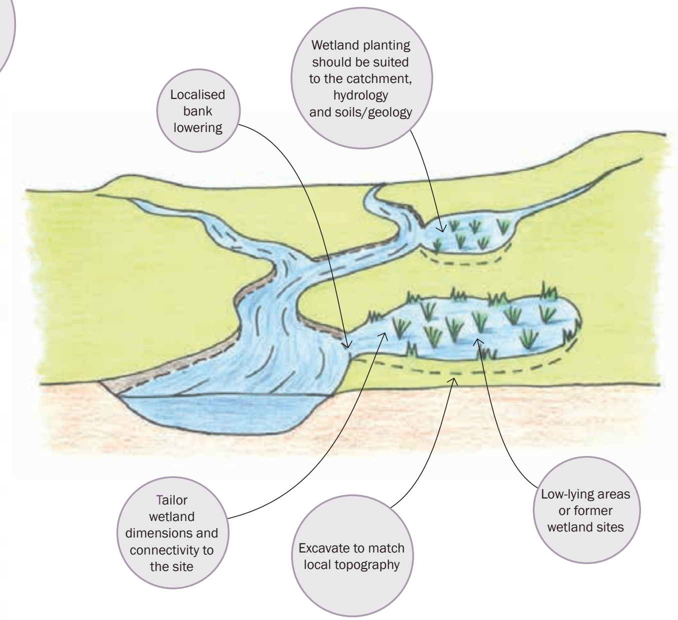
Remove, set back or lower flood banks

Allows the physical transfer of water between a river and floodplain



Floodplain wetland restoration

Create or restore wetland areas within the floodplain



Key benefits:

- **Flood risk reduction:** reduction in flood risk elsewhere by directing flow onto the floodplain
- **Restored natural geomorphological processes and ecosystem services:** transfer of water, sediment and organic matter from channel to floodplain creates more room for the river
- **Drought resilience:** slow release of stored water from the floodplain
- **Climate regulation:** increased resilience by making space for flood waters. Carbon capture and storage by wetlands

Work well with:

- **Riparian or floodplain woodland** to further slow the river flow
- **Leaky barriers** to elevate water into a reconnected floodplain or wetland
- **River channel restoration** alongside floodplain reconnection
- **Offline storage** incorporated into the same location
- **Riparian buffer strips** to maximise the impact in a river corridor

Design notes common to all floodplain reconnection measures:

- The size of the measure is site specific and hydraulic modelling may be needed to design it
- Impacts on flood risk, erosion and deposition, and environmental receptors need to be considered
- Excavation may be needed – the amount is site and design specific
- Minimise loss of mature trees
- Consents may be required for these measures. Refer to the manual for further detail

Leaky barriers

Chapter 10 provides more detail

What are leaky barriers?

- They obstruct flows within watercourses or along runoff pathways
- They raise the water level, slow the flow and increase channel roughness, which spreads out water over a wider area and reconnects the channel and floodplain
- Most effective when several leaky barriers are built in series along the same flow path or watercourse
- Constructed using live materials, wood or stone

Key metrics

- Low cost
- Easy to build
- Low maintenance requirements
- 5–10 years design life

Woodland watercourse

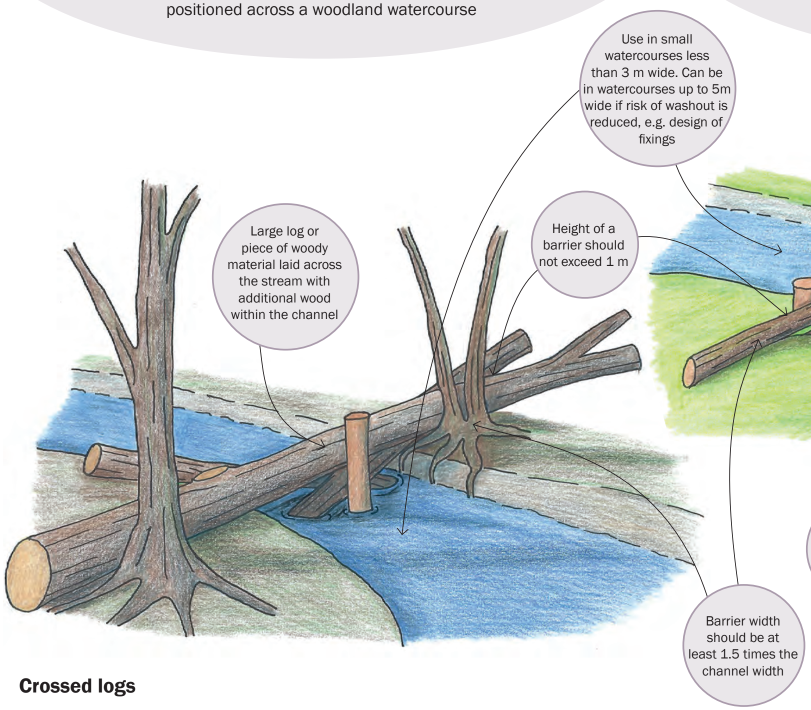
Live materials or wood sourced from site that is hinged or positioned across a woodland watercourse

Non-woodland watercourse

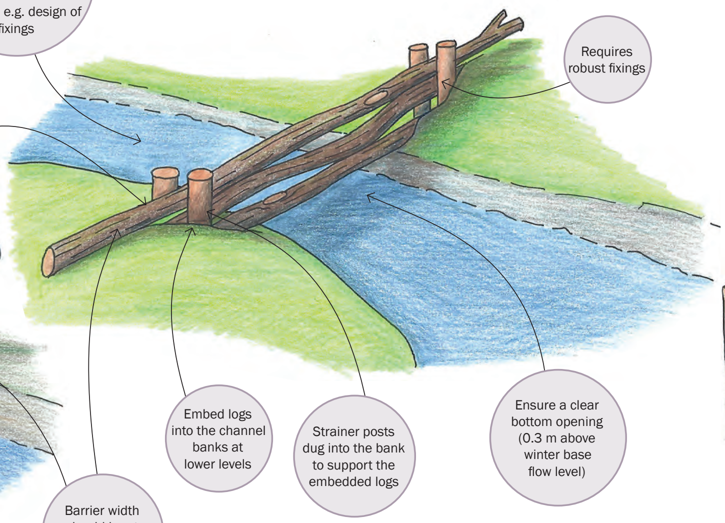
Non-living, but preferably locally sourced wood positioned across the watercourse

Runoff pathway

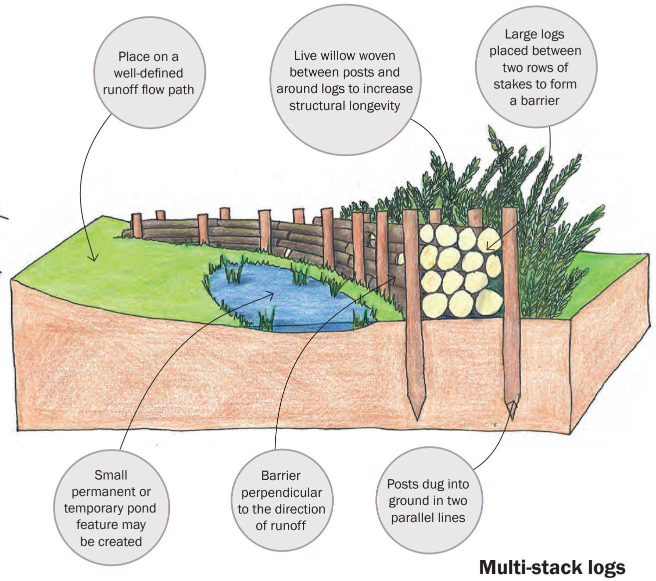
Constructed perpendicular to surface water runoff pathways to slow the surface runoff feeding into watercourses from the surrounding landscape



Crossed logs



Stakes and wedged logs/wall of logs



Multi-stack logs

Key benefits:

- **Flood risk reduction:** leaky barriers slow in channel flows and direct flow onto the floodplain. This helps to store water, increase infiltration, increase root uptake and evaporation and reduce flood flows downstream
- **Environmental improvement:** leaky barriers can improve sediment dynamics and flow diversity and also stabilise the riverbank and floodplain
- **Habitat creation:** leaky barriers can provide food sources, shelter and perches for wildlife. They can trap floating debris and sediment, to help regenerate habitat
- **Drought resilience:** leaky barriers on runoff pathways can retain water during dry periods and increase soil moisture

Work well with:

- **Woodland** to provide a source of material. This can be used to restrain leaky barriers and help promote the natural formation of barriers on watercourses over time
- Leaky barriers can be used to raise water out of the channel to enable **floodplain reconnection** and the diversion of flow into **offline storage** areas
- **Riparian buffer strips** can exclude stock from accessing leaky barriers and also improve the surrounding riparian habitat
- Leaky barriers positioned on runoff pathways interrupt flows and can act as a **runoff storage** feature

Design notes common to all types of leaky barrier:

- Heavy lifting or machinery may be needed to position logs and drive in stakes
- Design and locate to take advantage of local materials
- Locate so that floodwater remains within the landowner boundary or obtain agreement from the neighbouring landowners
- Ideally build several structures in series along the sameflow path or watercourse. The most downslope structure should be most robust to catch debris if upslope structures were to fail
- Consents may be required for these measures. Refer to the manual for further detail
- Do not locate in the area of water ponded upstream of another barrier
- Minimise use of artificial materials

Runoff management

Chapter 7 provides more detail

What is runoff management?

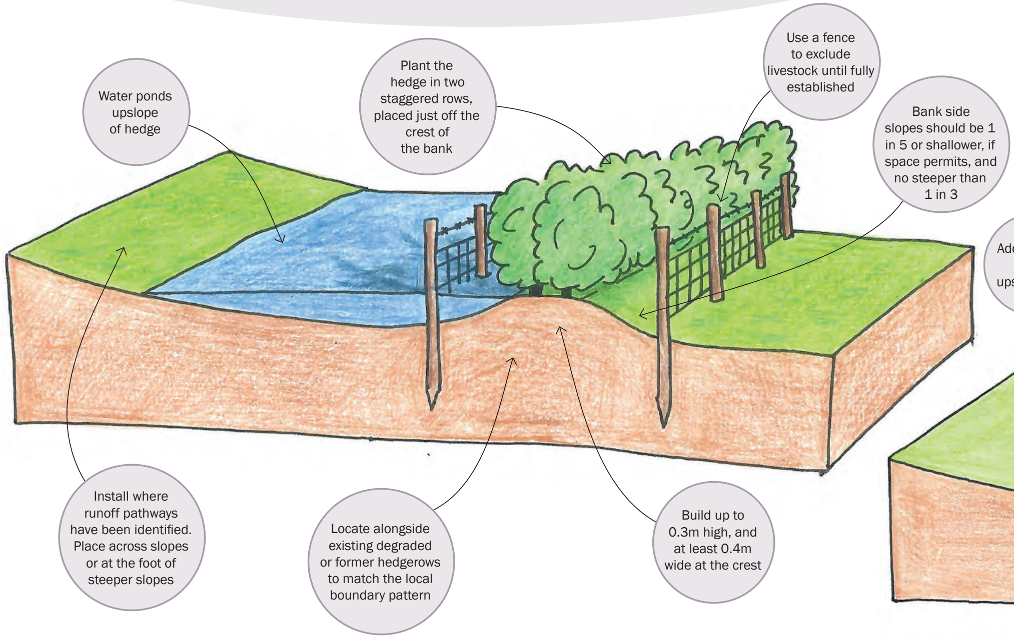
- Aims to interrupt, slow or divert overland flow pathways across the landscape
- Encourages infiltration into the ground and diverts water away from challenging locations
- Includes cross drains and deflectors; cross slope hedges and buffer strips

Key metrics

- Low cost
- Easy to build
- Moderate maintenance requirements
- Indefinite design life if maintained

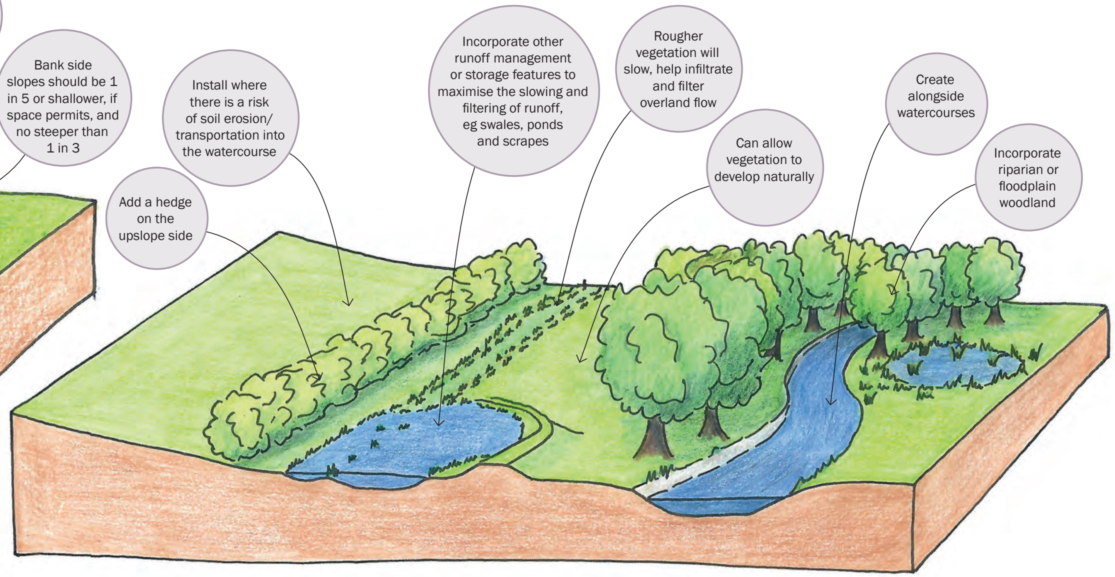
Banked hedge

Hedges planted cross slope on a raised bed or bank, to intercept flow pathways and store water, to increase infiltration and transpiration



Enhanced riparian buffer strip

Linear features strategically placed across a slope alongside a watercourse to allow the establishment of rougher vegetation to slow, and help infiltrate and filter overland flow



Key benefits:

- **Flood risk reduction:** measures divert, infiltrate and store runoff, to reduce downstream flood risk and divert water away from challenging areas such as highways and infrastructure
- **Water quality:** measures can be designed to trap and filter contaminated runoff
- **Climate regulation:** hedgerows and buffer strips can capture and store carbon
- **Habitat creation:** hedgerows and buffer strips create habitat which can be used as wildlife corridors to link existing habitats
- **Soil health:** help retain soil on the land rather than it being washed into watercourses
- **Farm operation:** hedgerows can be a long-term field boundary and are beneficial to livestock health

Work well with:

- **Soil and land management** to reduce runoff and soil loss at source
- **Runoff storage** to store water alongside measures to slow runoff
- **Woodland** across the landscape to reduce the rate of runoff
- **Leaky barriers** to slow the flows in watercourses or on runoff pathways
- **River channel restoration and floodplain reconnection** to provide further benefit in the river corridor

Design notes common to all runoff management measures:

- The appropriate runoff management measure is dependant on location, purpose and construction method
- Living and natural materials should be used where possible
- Consider access requirements for maintenance and livestock access for grazing or water needs
- Bunds, swales, ponds or scrapes require earthworks. Bunds need compaction in layers
- Protect new trees from pests for the first two years
- Consider adding hedgerow trees to increase biodiversity, variation and structure
- Plant hedges or trees between October and March
- Use native trees similar to species present in the local landscape
- Connect existing habitats and/or create wildlife corridors
- Avoid sites where invasive species are a known issue
- Consents may be required for these measures. Refer to the manual for further detail

Runoff storage

Chapter 8 provides more detail

What is runoff storage?

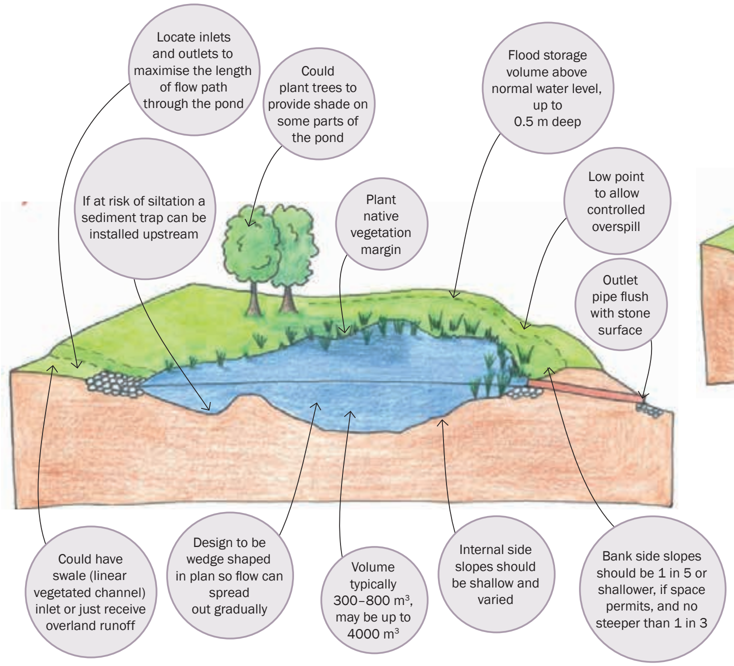
- Measures that temporarily store water
- They fill during rainfall events and empty slowly
- Increase water storage across a catchment which reduces flood risk downstream
- Best in locations with sloping topography where runoff flows in defined pathways
- Include ponds, scrapes, swales and bunds

Key metrics

- Moderate cost
- Moderate build complexity
- Moderate maintenance requirements
- Indefinite design life if maintained

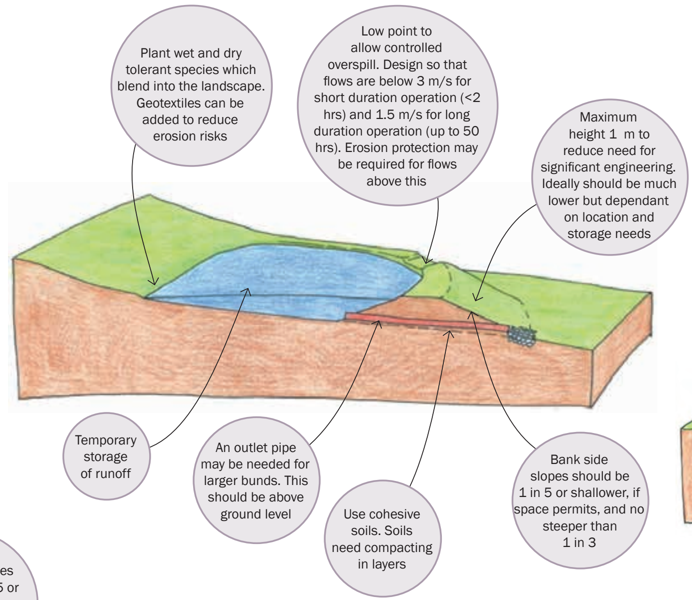
Pond

Depression that holds water permanently with additional capacity for storm events



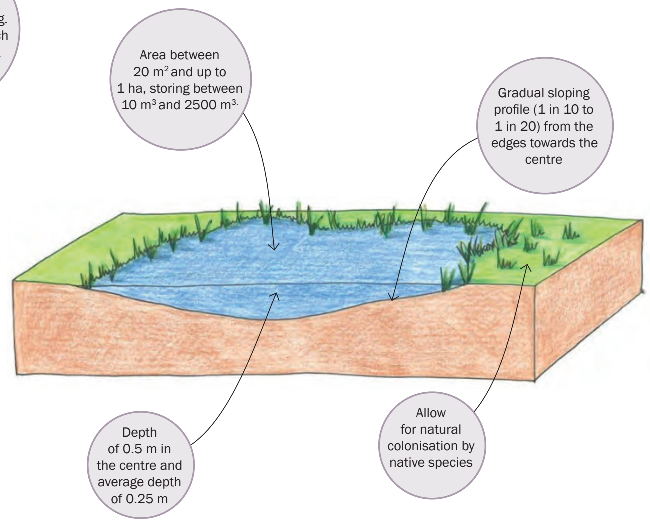
Earth bund

A bank created to provide flood storage or to help divert runoff



Scrape

Depressions that fill with water in the winter and gradually dry out in the spring and summer



Key benefits:

- **Flood risk reduction:** measures are effective as soon as they are installed. Runoff rates are reduced by water retention and controlled flow release which slows the rate of rise of a flood peak. Water storage increases the opportunity for infiltration and evaporation
- **Water quality:** measures allow sediment to settle out from the flow. This has a positive impact on water quality and improves the functioning of downstream watercourses
- **Habitat creation:** these measures, particularly ponds and scrapes, provide new wildlife habitats and increase biodiversity
- **Climate regulation:** wetland habitats, like ponds and scrapes, capture and store carbon
- **Soil retention:** storing runoff close to source allows soil to be trapped in storage features, rather than entering watercourses. Soil can then be returned back to farmland

Work well with:

- **Soil and land management** to reduce runoff at source across the landscape
- **Runoff management or cross slope woodland** alongside measures to interrupt, slow or divert runoff and to store it
- **Catchment woodland** to reduce runoff at source
- **Leaky barriers** to slow and store water on runoff pathways
- **Offline storage** to hold water adjacent to runoff pathways and to slow the flow

Design notes common to all runoff storage measures:

- Avoid volumes over 10000 m^3 as can lead to additional duties under reservoir safety legislation
- Design to release water so that storage can be used again in the next storm
- Likely to require earthworks
- Ponds and earth bunds may require an outlet to provide additional capacity during storm events. Outlets may need a headwall to support earhworks above and prevent material falling down into the flow. Erosion protection may be needed
- Size of the measure based on its catchment area and target rainfall event
- Consents may be required for these measures. Refer to the manual for further detail

Part A : Natural flood management and the manual

Part B : Philosophy and approach

Part C : Technical detail

Part D : How to deliver NFM

Appendices

B

Part B describes the philosophy of NFM and the first part of the delivery process – how to set up a project for success and choose appropriate NFM sites and measures.

Philosophy and approach

Image courtesy Summit Fever Media

Courtesy Emma Wren

2 AIMS AND SUCCESSES

Contents

Chapter
02

Aims and successes

This chapter describes the aims of NFM and what can be achieved. It introduces hydrological processes and the wider co-benefits of NFM.

▶ *More detailed information on hydrological processes is given in Chapter 14.*
▶ *Case studies and worked examples of successful NFM are provided in the appendices.*

2.1 AIMS OF NFM

The overall aims of NFM are to:

- reduce flood risk (**Section 2.1.1**)
- protect, restore or mimic natural hydrological processes (**Section 2.1.2**)
- deliver wider co-benefits (**Section 2.1.3**)
- maximise outcomes by working with others (**Section 2.1.4**).

2.1.1 Reduce flood risk

Improved flood risk management is the primary outcome of any NFM project. As with any flood risk project this needs to be considered in an integrated way across the catchment and, ideally, as part of a wider strategy to manage flood risk in the area. All catchments are different, and so different solutions to manage flood risk are appropriate in each.

Flooding is a natural part of the hydrological cycle and floodplains are part of the river system and naturally flood on a seasonal basis. Flooding can occur in a number of interlinked ways and understanding how each contributes to catchment flooding and the sources, pathways and receptors of flood risk is important in considering NFM approaches (**Figure 2.1**).

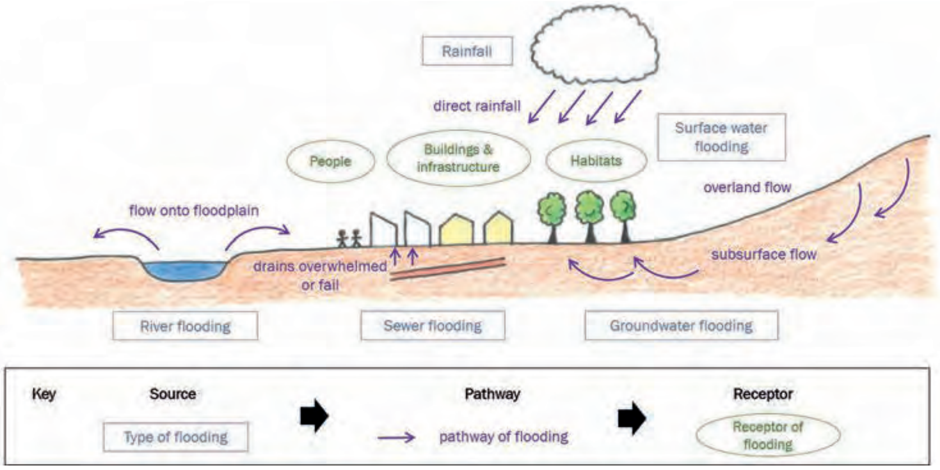


Figure 2.1 Types of flooding and the source-pathway-receptor model (courtesy Emma Wren)

Issues arise when people, communities and infrastructure are located in areas where flooding naturally occurs and subsequently affects society. Flood risk is a combination of the probability (likelihood or chance) of a flood event and the damage and disruption it causes. Understanding flood risk and its potential impacts is the first step towards creating communities that are better prepared to manage flooding. This requires a combination of local knowledge, technical data and expertise, analysis using maps and river data, an understanding of catchment processes, and an appreciation of climate change.

Traditional flood management solutions focus on the people and places that have issues with flooding and often work by separating people and property from water in, or close to, the location affected by flooding. They encourage large volumes of water to travel downstream faster (flood walls) or store water just upstream of people and property (flood storage areas). NFM provides a different, catchment-based approach that tries to reduce flood risk at the source, close to where rain falls, so that it is less of a problem in the places downstream. The two approaches are compatible and should be considered in combination, working to reduce flood risk across the catchment close to the source while supplementing with traditional flood risk solutions for some receptors. Equally, NFM can be used to further reduce the flood risk in places that already have traditional solutions and also provide resilience to climate change, which will increase the risks associated with flooding in the future. NFM can also be an effective tool to improve community engagement around local flood risk issues.

The flood risk issue, including location, severity and contributing factors, need to be understood to reduce flood risk. This means that to successfully implement NFM there needs to be an understanding of the study areas and the wider catchment context (**Chapter 3**) as well as the hydrological processes that can occur (**Chapter 4**). The level of flood risk reduction that can be achieved depends on a combination of the prior catchment condition, the project scale and the measures installed. This includes their location, size, type and the number/density of measures.

2.1.2 Protect, restore or mimic natural hydrological processes

For NFM projects, there is a need to understand how water currently flows through and is stored in the landscape and what previously might have occurred, perhaps when the catchment was considered to be functioning more 'naturally'. A range of nature-based methods can be used to restore or mimic the natural hydrological characteristics of the landscape, while protecting those locations that already perform good hydrological functions. There are many ways to accommodate constraints and maximise co-benefits.

The hydrological or water cycle includes the processes described in **Box 2.1** and presented in **Figure 2.2**.

NFM measures are used across one or more of these processes. They help reduce flood risk by protecting, restoring or mimicking natural hydrological processes, ideally working in that order and seeking to maximise co-benefits, but without necessarily reverting the landscape to a completely natural or wild condition. A range of changes have taken place over many decades across the UK landscape, linked to river use, farming practices, management of flood risk, climate change and wider development. These have altered the way water travels through and is stored in a catchment, often with other unintended consequences.

Table 2.1 details simple natural processes and indicates ways that NFM can be designed to restore or mimic these. This is a high-level summary by process, similar information is given by NFM measure in **Table 3.8**. Measures work in combination across the hydrological cycle – ideally NFM projects will encourage more interception, evapotranspiration and infiltration close to where rain occurs, then consider the resulting runoff and finally consider slowing the flow in watercourses.

BOX 2.1 Hydrological processes

Precipitation can take several forms, with rainfall and snow being the most common. For simplicity, the term rainfall is used in this manual to encompass all forms of precipitation.

Interception is the process by which rainfall is prevented from directly falling on the ground. This may be because it falls onto the leaves of trees (the canopy), other vegetation or buildings.

Evapotranspiration is the loss of water from the ground and vegetation back to the atmosphere. This is either due to evaporation from the surface of vegetation, the ground (including urban and rural areas), the near-surface soil or waterbodies such as ponds and lakes, or the uptake and loss of water by plants (transpiration).

Infiltration is the process by which water soaks into the ground. It may soak into the soils or travel deeper into the groundwater stored in the rocks beneath the ground. In principle each catchment has a set amount of rainfall that can be absorbed into the ground (the 'storage capacity'). The storage capacity remains the same, however if soil and groundwater are already wet, then less infiltration will take place and water may runoff the land surface instead. An impermeable surface is one where water cannot infiltrate (eg hardstanding) and a permeable surface is one that can absorb water (eg soil). The soil type and condition also influence how easily water can be absorbed into the ground.

Runoff is water flowing across the ground down a slope. It occurs when the soil is waterlogged and at full capacity, rainfall arrives more quickly than the soil can absorb it, or across impermeable areas (eg hardstanding or compacted ground). There are many factors which influence the rate and type of runoff, for example, the intensity, duration and amount of rainfall. Where the runoff might occur is generally defined by the physical characteristics, such as land use, degree of urbanisation, vegetation, soil types and steepness. Soil compaction (by grazing or machinery) can often lead to increased runoff.

Groundwater flow is the flow of water beneath the ground surface that has entered the ground due to infiltration.

Streamflow is water that has entered the streams and rivers of the catchment through either runoff or groundwater flow.

In addition, **sediment erosion, transport and deposition** are important fluvial geomorphological processes (ie the processes related to rivers or streams) (**Section 17.4**). Hydrological and geomorphological processes are highly interconnected as the volume/rate of water determines sediment erosion, transport and deposition.

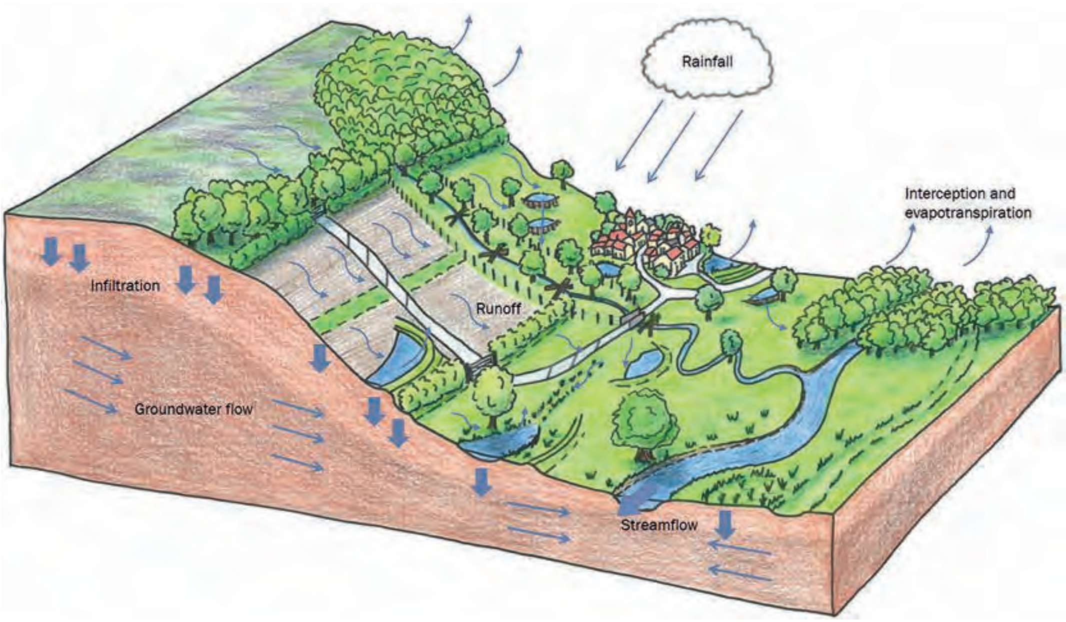


Figure 2.2 The hydrological cycle and NFM (courtesy Emma Wren)

TABLE 2.1 Ways to work with hydrological processes

Process	Reasons to modify this	Design aspects to encourage	*Soil and land management*	*Woodland*	*Runoff management*	*Runoff storage*	*Upland peatland management*	*Offline storage*	*Floodplain reconnection*	*River channel restoration*
Interception	Additional interception, by trees, new/enhanced habitats, or a rougher vegetation creates extra opportunity for subsequent evapotranspiration and infiltration of rainfall.	Increase vegetation cover, change to a denser or leafier habitat/vegetation type or change farming practices (eg plant cover crops to reduce bare earth).	✓	✓						
Evapotranspiration	Additional interception also increases evaporation from plants and the near-surface soil. Additional vegetation leads to more water uptake by roots and hence increased transpiration.	As above, plus: Improve soil structure. Add more topography (small depressions or raised features) to the land surface to increase water storage in the near surface for longer, eg cross slope ploughing, banked hedges.	✓	✓	✓	✓				
Infiltration	Infiltration into soil or underlying rock stores water and can delay and reduce runoff. Relies on soil and groundwater flow pathways generally being slower than surface water. Dependent on soil type, condition and geology.	As above, plus: Encourage water to enter slower, subsurface flow paths by redirection of runoff towards more permeable areas to encourage infiltration.	✓	✓	✓	✓				
Runoff	Reducing the rate and volume of overland runoff could reduce flood risk downstream.	As above, plus: Slow down runoff routes by lengthening flow pathways by diversion or adding obstructions to increase flow diversity. Install measures as close to the source of the runoff as possible. Temporarily store water either where it falls as rain or on/close to runoff pathways. Encourage storage features to empty before the next rainstorm arrives to maximise the store available when it next rains.	✓	✓	✓	✓	✓	✓		

continued...

TABLE 2.1 Ways to work with hydrological processes (contd)

Process	Reasons to modify this	Design aspects to encourage	*Soil and land management*	*Woodland*	*Runoff management*	*Runoff storage*	*Upland peatland management*	*Offline storage*	*Floodplain reconnection*	*River channel restoration*
Streamflow	Reducing the rate and volume of streamflow could reduce flood risk downstream.	Lengthen flow pathways by restoring the channel or connecting the floodplain. Slow down runoff routes by lengthening flow pathways by diversion or adding obstructions to increase flow diversity. Consider which part of the flood hydrograph is targeted. Storing water to reduce the flood peak is likely to maximise flow reduction. Encourage storage features to empty before the next rainstorm arrives to maximise the store available when it next rains.					✓	✓	✓	✓
Fluvial geomorphological processes (soil erosion, transport and deposition)	Soil is a valuable resource to retain at source. If washed from fields it can damage river environments and cause flood risk, erosion and deposition issues.	Increase vegetation cover. Install measures as close to the source of the runoff as possible. Identify problematic sources and pathways of sediment and address alongside flooding issues. Protect, restore or enhance natural sediment transport processes.	✓	✓	✓	✓	✓			

2.1.3 Deliver wider co-benefits

NFM presents an opportunity to deliver a range of benefits alongside a reduction in flood risk. This manual uses the following terminology to define benefits:

- the primary benefit of NFM is flood risk management
- the co-benefits associated with delivering NFM schemes besides flood risk management, eg improved biodiversity and increased carbon storage
- the multiple benefits associated with NFM, including flood risk management and the co-benefits.

A high-level description of the types of benefits that can be achieved by NFM is provided in **Table 2.2**. Further information on the types of benefits and how they can be calculated is in **Section 15.3** and the key benefits of each NFM measure are provided in **Part C**.

TABLE 2.2 Benefits of NFM

Benefit category	Description
Flood risk	Reduce both direct and indirect flood damage (eg property, infrastructure, agriculture, vehicles, health, risk to life) from all sources (eg rivers, surface water, groundwater).
Climate resilience	Resilience (eg ecosystem or flood) to climate change. Capture and storage of carbon through maintaining or creating healthy soils, vegetation and wetland/peatland.
Soil health	Healthy soil can store more water. It can capture and store carbon, and retain soil (reduce erosion) to ensure more sustainable farming.
Fluvial geomorphology	Working with natural processes, for example, restoration to a more natural river shape or flow, functioning floodplains, reduced erosion or siltation risks.
Biodiversity and ecology	Healthy habitats are likely to provide more infiltration and storage of rain. Protect, restore, create or connect habitats to enhance biodiversity and ecology and create resilient ecosystems.
Health and wellbeing	Improve mental and physical wellbeing by providing access to better quality nature and green space and recreational opportunities.
Landscape, amenity and recreation	Improvements in the attractiveness and desirability of an area. Restoration of a more natural and varied landscape. Opportunities for/increase in recreation and tourism.
Water quality	Improve the chemical, biological or ecological status of a water body, eg sediment, nutrients, pollution.
Water quantity	NFM can help infiltrate and store water closer to source. This increases soil and groundwater storage (which could be used for water supply) and will help restore the contribution of groundwater to streamflow. This helps reduce the likelihood of low stream flows or drought like conditions and their associated impacts (on ecology in particular).
Air quality	Trees can reduce particulates and pollutants in the air, reducing the impact on health.
Education	Enhanced educational opportunities for local communities, schools, visitors and other groups. Help create a nation of climate champions.
Farm operation	NFM can be a way to diversify the farm business and certain measures can help sustain the business, eg soil management, cross track drains, buffer strips. Hedgerows can reduce the spread of disease between livestock.
Reduced reliance on traditional flood defences	In some locations there may be an opportunity to create a more natural and sustainable solution, eg floodplain reconnection or river channel restoration. Reduction of carbon footprint of flood management and less use of non-renewable natural resources.

2.1.4 Maximise outcomes by working with others

A successful NFM project works with a range of people and organisations to maximise the benefits for everyone, both in terms of the reduction in flood risk and the associated co-benefits. An NFM project is an opportunity to work together and achieve multiple outcomes to deliver the aspirations of a wide range of interested parties who are keen to improve a local environment for nature and people. **Section 2.2** gives more detail on how to work together to achieve this. **Section 3.2.5** provides some wider environmental considerations that NFM projects could align with to maximise outcomes and achieve more together.

2.2 SUCCESS FACTORS

The success of a project will depend on how well its aims are met and desired outcomes achieved. Success factors, which are measurable targets to monitor project success, should be determined at the project outset. Critical success factors can also be key factors on which success depends. These can be monitored, to establish if or when the project has had the desired outcome. They may need to be flexible to reflect the current uncertainty around some NFM outcomes or be adapted as the project progresses. **Table 2.3** gives a list of potential success factors to adopt for an NFM project, which generally link to the benefits in **Table 2.2**. In each case consider what the project is trying to achieve and what success might look like.

Chapter 7 provides further information on how to monitor the success of an NFM project.

TABLE 2.3 Potential success factors

Benefit area	Example success factor(s)	What success might look like
Flooding	Reduce risk in a certain place (and by a certain amount)	The definition of success using NFM needs to be considered along with the flood risk issue and any other actions being taken to address it. The timeframe needs to be considered, as well as climate change or other changes that could affect flood risk in the same period (eg development, tree felling). Calculate a reduction in the flood risk to quantify this (**Chapter 14**).
Climate resilience	Enhance climate resilience. Capture and store carbon. Minimise whole-life carbon footprint. Use sustainable materials	Reduce flood risk linked to climate change (see *Flooding*). Use carbon accounting to measure carbon stored or use a proxy (eg trees planted, area of peatland restored). Work with landowners to protect the current hydrological function of those parts of the landscape which perform well at present, as this is the most sustainable approach.
Soil health	Reduce soil loss or sediment in runoff. Improve soil health	Soil erosion, or pollution linked to this, may be a particular issue the project can address. Success may also be reduced flooding due to siltation.
Geomorphological processes	Restoration of sustainable functioning natural river system	Sediment erosion, transport and deposition is in balance. Limited requirement for ongoing routine maintenance.
Biodiversity and ecology	Retain habitats and landscapes that currently provide flood risk benefit. Create/restore/link certain types of habitats	The starting point should always be to retain the beneficial function that the habitat already performs, for example riparian (wet) woodland may already be supplying large woody debris to streams that slows down the flow. It is important to encourage the retention of this habitat so it can continue to perform flood risk benefits alongside others. Success may be measured by the area/type or biodiversity of the habitat created/restored.
Water quality	Improve water quality (chemical, biological or ecological)	Success may be improvement in water body status (a measure of river quality), or a more local improvement. Local flood interest groups or community groups could monitor water quality (citizen science).
Education	Engage with the community on flood risk	Encourage the involvement of the local community; set a target number of people to be engaged with in different ways.
Health and wellbeing	Improve quality of the local environment	Access to a varied, interesting and engaging landscape. Creation of new places to enjoy for physical exercise and mental wellbeing.
Project success	To demonstrate the viability of an NFM approach	For example, provide value for money, implement work safely, install effective NFM across the landscape, involve a range of partners, and complete work on time and within budget.

Courtesy Jennifer Armstrong, University of Leeds

3 TOP TIPS FOR SUCCESSFUL NFM

Contents

Chapter 03

Top tips for successful NFM

This chapter discusses successful project delivery through working with others, how to maximise funding opportunities and main issues to consider at the start of a project.

▶ *Further information on the proportionate and adaptive approach introduced in this chapter can be found in Part D.*

3.1 INTRODUCTION

This chapter presents some of the wider, less technical, considerations that are needed to deliver NFM and gives ideas of how to approach these and achieve successful project delivery. The topics covered are:

- Working together (**Section 3.2**).
- Being proportionate and adaptive (**Section 3.3**).
- Maximising funding opportunities (**Section 3.4**).
- Managing legal issues (**Section 3.5**).
- Getting permission (**Section 3.6**).
- Working safely (**Section 3.7**).

The themes detailed in the chapter should all be considered at the project outset and reviewed throughout the process.

3.2 WORKING TOGETHER

3.2.1 Why work together?

By working together, the knowledge of individuals is shared, and a collective understanding can be developed. Projects delivered by a collaborative approach are more successful in meeting the objectives of all involved.

NFM projects often involve multiple partners, landowners and stakeholders to work together to use a wide range of measures and to make the most of the opportunities available. Working together will result in a collaborative design that combines local knowledge, data and technical expertise. It brings many positive aspects to a project:

- a wider base of knowledge and experience of the catchment, eg sources and experiences of flooding, knowledge of existing activities that may increase the risk of flooding, the specific issues of the area, what is feasible and what is needed
- everyone working together to find the best solution (co-design), makes the project fit for purpose and more likely to go ahead
- ensures potential issues are considered early and managed
- opens up opportunities for further development/delivery of NFM
- widens the funding sources available
- raises the profile and understanding of NFM, the role it can play, as well as its limitations.

Figure 3.1 shows what can be gained from working with others at each project stage.

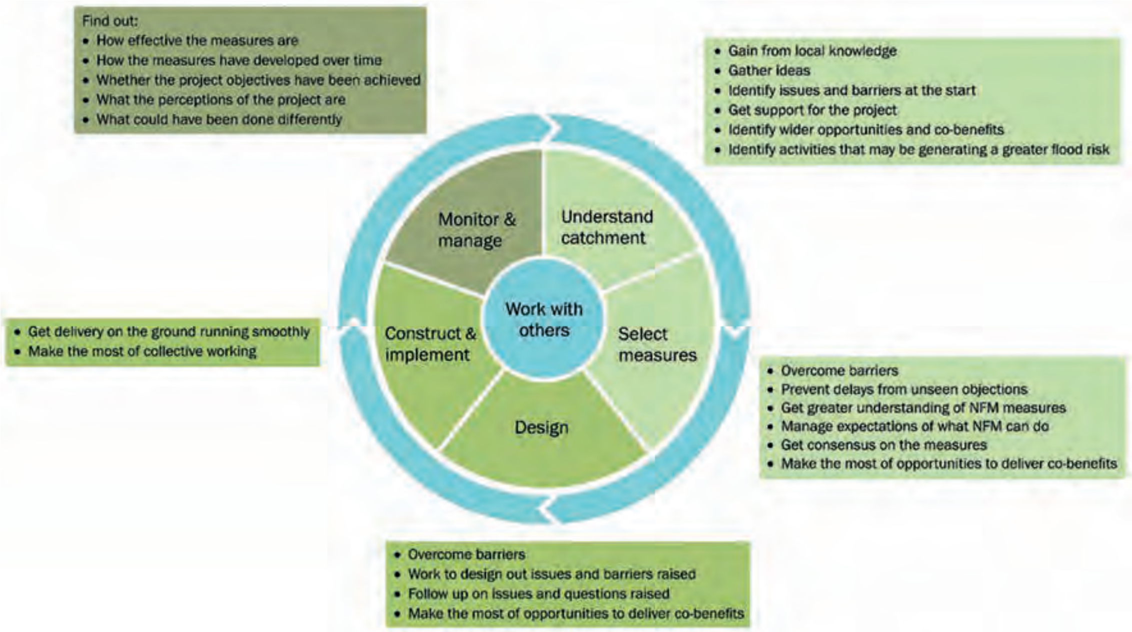


Figure 3.1 The benefits of working together

Table 3.1 outlines the challenges associated with working together, which can be overcome with planning and constant communication.

TABLE 3.1 Challenges associated with working together and ways to overcome them

Challenge	Solutions
Working across several organisations	• Build on existing partnerships. • Agree how to work together – prepare a memorandum of understanding to set out who is responsible for each aspect (planning, design, construction, management, communication, and approaches to investors/funders). • Use the wider pool of knowledge and experience to find the best person for each task.
Conflict of priorities and poorly matched objectives	• Work out the areas of overlap and shared interests. • Discuss issues and opportunities as they arise and recognise where compromise will be needed. • Consider use of a trusted intermediary to act as broker. • Early and regular discussions can reduce later conflicts.
Managing the expectations around NFM compared to traditional flood risk management and management of expectations	• Early engagement with communities to share knowledge of NFM and the co-benefits. • Use a range of communication methods. • As the project progresses, provide updates, especially if there is no visible progress.
Additional time and costs	• Building relationships takes time and effort yet it is beneficial for NFM. • Upfront and continuous engagement, across the whole process, allows questions to be answered and issues resolved before they become barriers. • It may take longer to build relationships than it does to deliver the work.
Challenges	• Use the broad range of experience and knowledge available to identify potential obstacles early on and to develop solutions

There is upfront work and associated costs with working together, however the benefits outweigh the time and thought required. It should ideally start as the first ideas of a project come together and continue throughout all the stages to implementation, monitoring and managing the results of the project. Working together is based on relationships; it is important that the right people get together at the right time. Box 3.1 provides some top tips.

BOX 3.1 Top tips for working together

- It is never too late to engage people.
- It can take time – everyone needs to consider new ideas and develop new working relationships.
- Spend time identifying who needs to be engaged.
- Successful projects tend to have a central contact who is a trusted by all, a good communicator, is good at asking questions and listening, is easy to contact and work with.
- A project supported by all involved is often more successful.

3.2.2 Planning a collaborative approach

There are various stages to working together. Figure 3.2 is a suggested plan for who to involve and how.

Gather information

Who would be interested in or relevant to the project?

- Who will the work affect?
- Who may think the work affects them?
- Who may support/ object?
- What knowledge do you need?
- Who could influence the project?
- Who can help deliver the project?
- Who can help with funding?

Refine the partners

Gather more information to target the key partners

- What are their main interests?
- What common ground is there?
- Which stages of the project are most relevant to them?
- Where can you get together and how?
- What do they each bring?
- Who are the leaders or influencers?

Link to project stages

Link the list to the stages of the project

- What outcome is needed from engagement?
- What is the type of engagement?
- Tailor the style to match the type.
- When will it happen?
- Who will it involve?

Follow plan

Check on progress and amend the plan if circumstances change

Figure 3.2 Suggested stages of working together: gather information, refine partners, link to project stages and follow the plan

Things to consider:

- Relationships are built between people – develop a relationship before use of technology, eg make individual or group contact before using web pages.
- There are often natural groupings of people/organisations that can be brought together – they may have similar interests, areas of work, or a desired common outcome.
- Working together may provide different routes for engagement, the project can link to these and use existing networks, rather than building new ones.
- Use consistent messaging.
- Start with an open dialogue and approach to the project that can be narrowed down to specific ideas/ options and take into account the perspectives of the wider group.
- Ensure that everyone can express their opinion, eg through a mix of individual and group discussions.
- Engage those that are against the project; overcoming their challenges can improve the overall outcome.
- Empathy is important – understanding each person's viewpoint and the validity of their comments/thoughts.
- An engagement plan should be prepared that sets out how the project will bring people together. It

should be tailored to match the size and complexity of the project. The plan will set out who is involved, why the engagement is happening, what the planned outcome is, and when and how it will happen.

- Use professional engagement specialists if circumstances dictate it.

At the start of the project, it is important to think as widely as possible about interested parties who might help to achieve the project aims and who else might be wanting to achieve similar things. Consider contacting people/groups/organisations who:

- will benefit from the project
- may be negatively affected or will not benefit from the project
- can deliver aspects of the project, including helping get it off the ground
- know, live or work in the area or know about NFM and can build knowledge into the project – in particular anyone with knowledge of flood risk in the area
- are interested in potential co-benefits of the project that could be maximised alongside flood risk benefits, for example biodiversity, water quality or recreation
- have a statutory role in flood risk management or any co-benefits the project is trying to achieve.

It is important to be aware of who is involved as the project progresses. As a project develops and changes, so too will the partners who need/want to be involved. There may be policy changes, new funding sources or project momentum may enable others to understand the benefits and want to get involved.

There is no standard list to follow for who to involve, but **Table 3.2** gives a list of groups and organisations to consider along with why they are of interest or the role they may have in an NFM project. **Section A3.3** provides detail of specific UK organisations within the categories listed. **Section 3.2.5** also gives some other wider environmental considerations that may help introduce others.

TABLE 3.2 Potential groups, organisations and individuals to work with on NFM projects (after Ngai *et al*, 2020)

Who?	Why work together?
Local communities	• They are likely to have been affected by flooding and want to reduce the problem. They provide local knowledge, resources and skills and can be a driving force for action. • They often have ideas that complement flood risk reduction such as access to green spaces or creation of wildlife habitat. They can be directly affected by any work. • It helps educate them around flood risk and NFM, including the benefits and limitations. • It may provide access to funding sources for community led projects.
Landowners and managers	• Play a vital role in NFM – often provide knowledge and access to local resources and skills. • Knowledge of the landscape enables understanding of where and which NFM measures can be used. They can identify potential conflicts and provide sites for NFM measures. If they provide sites, then they have a personal stake in project success and can become a driving force for action. • NFM can be beneficial to the farm operation and diversify income streams. It is important to ensure that 'double funding' does not occur, ie NFM has not been claimed for via a subsidised scheme, and also funded via a different mechanism. • They may bring access to funding sources such as agri-environment schemes.
Flood interest groups	• Grassroots organisations made up of the local community who are motivated to reduce flood risk. • May already have links with the flood risk authority. • May open up different funding sources.

TABLE 3.2 Potential groups, organisations and individuals to work with on NFM projects (contd)

Who?	Why work together?
Flood risk authorities	• Responsible for flood management work – important to contact at the start of an NFM project. Consult on the need for planning permissions or consents. • Provide knowledge of flood regulation, funding for flood risk management and others involved.
Water environment regulatory authority	• Responsible for regulating the health of rivers and other waterbodies. Provide knowledge on regulation requirements, consents or others involved. • May have access to relevant funding streams or schemes.
Infrastructure owners and managers	• Interested in the resilience of their assets to flood risk and associated hazards including landslides or debris entrained by water. These have potential to cause catastrophic failure of infrastructure. • Includes authorities or companies that own or operate infrastructure such as roads, railways, water and sewage, power, and telecommunications. • Some are substantial landowners and can plan, develop, and implement NFM measures/projects on their land. Water utility companies in particular may fund environmental projects with benefits to the water industry that may also provide flood risk management benefits.
Local authority	• Integral to the flood risk management planning process and should be consulted regarding the need for planning permission or consents. They also have responsibility for Areas of Outstanding Natural Beauty (AONB) in their areas and there may be an AONB officer.
National Park authorities	• Have a variety of roles, often including a knowledge of NFM, land management, facilitation, working with others, implementation, and funding – both as applicants and fund holders. • They have the role of the local authority for planning in National Parks.
Nature conservation organisations	• Often involved in NFM or similar work. They can bring knowledge and experience of NFM projects, potential partners and facilitation. • Knowledge of potential funding sources and development of funding applications. • Can act as trusted intermediaries, to bring groups with differing opinions together.
National Farmers Union (NFU)/ Country Landowners Association (CLA)/ Tenant Farmers Association (TFA)	• Organisations that represent farmers on both a national and local level and can provide advice and guidance.
Land agents and farm advisers	• Provide an understanding of farming systems and agri-environment work. • Provide support and advice to the farmers and landowners they work with
Statutory historic and natural environment organisations	• Provide advice and manage consents for statutory heritage and environmental designations
Catchment partnership groups (eg catchment based approach, CaBA)	• Often involved in NFM work and provide partnership approach to integrated catchment management, bringing together local knowledge and expertise of issues and interests. • CaBA groups are active in each of the 100+ Water Framework Directive (Directive 2000/60/EC) (WFD) catchments across England, including those cross-border with Wales. They undertake integrated management of land and water, address each catchment as a whole and deliver cross-cutting practical interventions.

3.2.3 Ways to work with others

There is a diverse range of engagement tools. The ones to use should be based on what is being done, the outcomes needed and the group or individuals working together. This should help to build open and trusted relationships. Professional engagement specialists can be brought in if needed. **Table 3.3** lists some common engagement methods for NFM and the situations they are best used for.

TABLE 3.3 Engagement types

Type	*Engagement*	*Raising awareness*	*Communications*	Good for	Challenges
Meetings	✓	✓	✓	• Bringing an audience together to gather thoughts and opinions on a topic. A good experience of a public meeting can encourage involvement and project support • Consultations – focused on a series of topics that are inter-related or one specific issue • Gathering information – interactive with elements for all to get involved in • Informing – can address many people at once but may not allow for much discussion • Consistent messaging • Raising awareness of NFM and project progression	• Not everyone will speak at a meeting – include ways to allow individuals to voice their opinions • Reluctance to share. Say how the information will be used and use updates to show the input has helped the project
Workshops	✓			• Consultations • Gathering information • Raising awareness	• Allow each participant to contribute. Consider how questions can be answered by individuals and then as a group
Task focused working groups	✓	✓	✓	• Working together on specific issues, with people involved to represent wider groups and their interests • Getting a greater understanding of an issue • Working together to find a solution • Moving work forward	
Surveys/ questionnaires	✓		✓	• Collecting qualitative data • Gauging reactions to ideas • Gaining opinion on the proposals • Setting baselines for information and measure project success	• Design with care. The questions need to give answers that can analysed but should not lead the responders

TABLE 3.3 Engagement types (contd)

Type	*Engagement*	*Raising awareness*	*Communications*	Good for	Challenges
Drop-in sessions	✓	✓	✓	• Sharing findings • Providing updates • Discussing ideas in an informal way • Personal contact and to answer individual questions	
Volunteer working groups	✓			• Getting specific tasks done – especially practical tasks	
Newsletters			✓	• One-way communications • Keeping everyone informed • Signposting meetings/workshops/ drop-in sessions etc	• Producing another newsletter that is not read, consider adding articles to existing newsletters rather than having one specific to the project
Social media			✓	• Highlighting successes and issues • Easy to follow	
Web pages		✓	✓	• Making information available and link to other areas of work	

Further reading

CIRIA (2014) *Communication and engagement techniques in local flood risk management*, C752F, CIRIA, London, UK (ISBN: 978-0-86017-758-6)

⇨ Practical support and ideas.

www.ciria.org

Elwin, A, Clark, J M, Short, C, Garwood, J E and Birdi, K (2020) *Natural flood management scenario workshop methods*, Presentation from NERC Landwise project, 29 May 2020, University of Reading, UK

⇨ An example of how to get everyone involved in a consultation meeting.

https://vimeo.com/428447013

Environment Agency (2019) *Working with others. Stakeholder analysis*, Environment Agency, Bristol, UK

⇨ A good overview of stakeholder analysis.

https://catchmentbasedapproach.org/learn/guidance-on-stakeholder-analysis

GCS (2020) *Ensuring effective stakeholder engagement*, Government Communication Service, London, UK

⇨ Guidance on effective stakeholder engagement giving an overview of all the key stages.

https://gcs.civilservice.gov.uk/publications/ensuring-effective-stakeholder-engagement/

RICS (2014) *Professional Guidance UK. Stakeholder engagement 1st Edition*, Royal Institution of Chartered Surveyors, London, UK

⇨ A good overview of the stages in stakeholder engagement

https://www.rics.org/globalassets/rics-website/media/upholding-professional-standards/sector-standards/construction/stakeholder-engagement-1st-edition.pdf

3.3 BEING PROPORTIONATE AND ADAPTIVE

When developing a NFM scheme it is important to adopt both a proportionate and adaptive approach. This is particularly important given the uncertainty associated with working with and adapting natural processes.

The level of information and confidence in the design should be proportionate to the degree of flood risk and the overall investment in the project; compromise may be needed to maximise overall project outcomes. This manual provides a range of approaches and methods and these should be tailored to the project needs. This may depend on the geographical scale, the level of investment, the certainty needed in the outcome, or the requirements of project partners or funders.

Approaches should also be adaptive, so that they can react to ongoing catchment or climate changes, unforeseen issues, or local variations. This applies across the entire delivery process (see **Sections 14.1, 15.2.3, 16.2.2 and 19.3.2**). Further information is provided in **Part D**.

Being adaptive and proportionate includes appreciation that many NFM projects will build momentum over time – and are less likely to go through a single iteration of the delivery process than more traditional engineering solutions. For example, a good way to build support is to implement some measures on the ground, which can then lead to buy-in for a more widespread adoption of NFM measures to achieve more beneficial outcomes for a community.

3.4 MAXIMISING FUNDING OPPORTUNITIES

3.4.1 Find out about funding opportunities

There are several ways to find out what funding opportunities are available and most involve networks. For example:

- consider the funding opportunities available and design the scheme to match them
- understand the benefits and co-benefits that the scheme could deliver and align these with potential beneficiaries
- talk to the people involved, in particular, ask any funding organisations about potential funds
- make links with local networks, such as catchment partnerships, local nature partnerships and UK community foundations.
- check websites – the UK Government includes a page for community project funding (gov.uk)
- subscribe to funding sites such as FundsOnline.org.uk, Funding Central (from the National Council for Voluntary Organisations), MyCommunity.org.uk

3.4.2 Considerations for funding applications

Table 3.4 outlines what to consider in relation to a funding application, for example, design can maximise the funding opportunities available. This includes working with others to broaden the funding opportunities and the co-benefits that could be achieved in addition to flood risk management (**Section 15.3**).

TABLE 3.4 Key considerations of funding applications

Before applying	What needs funding and the costs involved	• The funding landscape. • The terminology used (eg in-kind contributions, match funding). • Know what the project aims and objectives are. • The risks if the project costs increase. • The risks to delivery and have a contingency for additional costs that may be incurred. • Consider dividing the project into sections to match with funding opportunities.
	Work with others	• Broaden the base of funds that can be applied for; one partner may be eligible for funding that others are not and could make that application. • Build on the strengths of the team – who has experience of making applications? Who can work together to make an application?
	Find the right funds to match the project	• Check which parts of the project match the funding offered. • Know the limitations/restrictions on funding – some funding streams can be contradictory. • Check the funders' requirements – if there is more than one funder, are their needs and timeframes compatible? • Check when payments are made, if payments are made in arrears (after the work is done) how will the costs of the work be covered?
	Know the funders	• Who are they? • What are their motivations – what will they fund and why? • What are their application criteria? • What else have they funded? • Make contact with them and discuss the project – does it have potential? Which areas are they interested in?
	Be aware of deadlines	• Allow time to do a good job.
Making an application	Read the form	• Think about what each question asks and what the funders want to see. • Work out what information is needed and gather it all before completing the form.
	Tell them	• What the project is aiming to achieve. • What the issue is, how the project will address it, and what the expected results are. • How the results will be measured. • How this project matches with their interests. • The benefits to the funder and the project of them being involved.
	Be	• Clear, concise and realistic • Accurate in costing the project • Aware that funders deal with applications all the time and have experience of what is achievable and the cost
	Cross check the application	• Consistency across an application is important.
	Do	• Submit the application on time.

continued...

TABLE 3.4 Key considerations of funding applications (contd)

After applying	The bid is successful	• Ensure the terms of the grant are understood before signing the agreement. • Thank the funders for their support. • Keep the funders up-to-date with progress. • Recognise the funders' involvement.
	The bid is unsuccessful	• Make the most of the optimum window to ask questions about the application. • Be proactive – say thank you for being considered. • Ask for feedback and ask how the project can be improved. • Ask if they have any future funding opportunities.

3.5 MANAGING LEGAL ISSUES

Table 3.5 gives an overview of the legal aspects that need to be considered to undertake NFM. Legal requirements and responsibilities are highly site specific and subject to change. Where needed seek specialist advice from a legal professional (**Section A3.2**) or the relevant regulatory authorities in relation to consents and permissions for NFM.

TABLE 3.5 Management of potential legal issues

Issue	How to manage this
Land access and ownership	Establish who owns or manages the land as early as possible and involve them in discussions, including design. Record land ownership/access agreements and discussions with the landowner. Remember to discuss ongoing access for monitoring or maintenance. Consider whether new land rights will need to be created in respect of the works. Work with others involved to reach a compromise that works for everyone. Never approach a landowner with fixed ideas.
Long-term management	Explain how any NFM measures should perform to others involved and how they can help inspect and monitor them. Consider and understand the risks of not specifying management or maintenance (including legal and reputational risks) for everyone involved. If it would have been reasonable for a landowner to undertake management/maintenance, and failure to do so caused damage to a third party, they may be liable as a result. Liability in respect of maintenance can also fall to other parties in certain circumstances. Provide simple advice on future inspection and maintenance. In some cases, a maintenance schedule may be needed.
Assessment of liability	Be open. Discuss the concept of liability early with everyone involved. Funding or co-operation agreements could be used to assign any liability for damage that occurs as a result of the NFM project.
Increased water levels and flood risk	Explain that NFM could result in increased water levels and flooding in some locations to those involved. For example, floodplain restoration will increase flood levels in the immediate area. Explore whether permission is needed to undertake the planned NFM (Section 3.5). Recognise that NFM works can affect flood levels beyond the immediate vicinity of the intervention (eg neighbouring landowners or infrastructure asset owners). Talk to all stakeholders that may be affected by this and seek buy-in and permission. Then work together to deliver the NFM.

continued...

TABLE 3.5 Management of potential legal issues (contd)

Failure of asset (eg leaky barrier, embankment storing water)	Work with the community or landowners to identify any concerns or risks around failure and how to manage these risks – these may be as a direct result of failure or associated flood risks. Choose NFM measures, their location, size and material, to avoid or reduce these risks to satisfy the various needs/concerns of landowners, potentially affected communities or asset owners and any authorities involved. Consult early with any authority that would need to provide permission (Section 3.5). Consult early with any infrastructure asset owner located nearby that could be affected. They will also be interested to understand how the planned NFM may affect their assets. In certain circumstances, there is a risk of liability for asset failure. This could fall on the landowners or organisations closely involved in the management of those assets.
Environmental risks	Identify any potential environmental risks as early as possible (Chapter 16)
Data protection	Consider this at the project outset; understand and meet all data protection requirements.
Insurance	Relevant insurance should be in place – it is often a requirement of funders.
Protection of intellectual property	Ensure that permission is sought to use any third party intellectual property such as data, reports or photographs.
Confidentiality	If a public body is involved it is important to set out the expectation that information shared will not be confidential unless necessary. Public bodies are required to act transparently.

3.6 OBTAINING PERMISSION

Anyone delivering NFM needs to find out which specific permissions and licences are required from the relevant consenting authorities (**Table 3.5**). These must be in place before work can begin, otherwise a project may be breaking the law. It is important to plan, and leave plenty of time, for this – some applications take a long time and require supporting specialist assessments and there is a risk of missing funding opportunities or the correct season to work. To avoid any surprise costs or delays, engage consenting authorities early in the project planning phase. They will be able to advise what is required and may be able to suggest designs/changes to gain approval more easily.

There are national variations in the consents, permissions and licences needed and the related charging structures across authorities for NFM works. Early consultation with all potential authorities is recommended – keep any advice or reference later in the project.

The type and location of the NFM works will influence the authorities that need to be consulted and the types of consents, permits or licences that may need to be in place. **Table 3.5** gives a prompt list of potential aspects of NFM work, the type of authority that may need to be consulted and links it to inland NFM measures. It should be used for advice, the specific circumstances of the project will influence exactly what permissions are needed. Further detail is provided in **Chapter 16**.

TABLE 3.6 Prompt list of NFM activities that may need permission by NFM measure

Prompt	Authority type to consult	*Upland peatland management*	*Soil and land management*	*Runoff management*	*Runoff storage*	*Catchment woodland*	*Cross slope woodland*	*Riparian woodland*	*Floodplain woodland*	*Leaky barriers*	*Offline storage*	*Floodplain reconnection*	*River restoration*
Woodland creation	Forestry authority					✓	✓	✓	✓				
Work in or near a watercourse, floodplain or existing flood defence	Flood risk authority							✓	✓	✓	✓	✓	✓
Creating or changing a discharge into a watercourse, eg outlet from a storage area	Water environment regulatory authorities				✓						✓	✓	
Protected species or site designated for nature conservation on site/nearby	Statutory nature conservation organisation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Historic environment designated site, and known or unknown buried archaeology on site/nearby	Statutory historic environment organisation	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Generation of waste, eg due to earthworks	Statutory waste regulatory organisation			✓	✓						✓	✓	✓
Tree works such as felling, removing branches, or working in tree root zone	Local authority (ask if trees are in a conservation area, are protected, or support protected species) Forestry authority (felling)			✓	✓					✓	✓	✓	✓
Work on or near a public right of way (PRoW)	Local authority	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Planning permission	Discuss with local planning authority if they consider NFM to be development			✓	✓						✓	✓	✓

3.7 WORKING SAFELY

Health and safety law applies to all aspects of NFM delivery, including design, construction, monitoring, maintenance and removal. It places a duty of care on everyone involved to consider the health and safety of themselves, others involved and anyone that could later be affected. This could either by undertaking NFM work, or indirectly by, for example, a member of the public climbing onto an NFM measure resulting in injury. The Construction (Design and Management) (CDM) Regulations 2015 (CDM 2015) apply to some NFM measures (**Section 17.5.1**).

The person who owns or has control over an NFM measure has a duty of care to safeguard the public and those working on the asset. Employers have a duty of care to ensure the safety, health and welfare of workers, including volunteers.

Risk assessment should consider all groups who may be affected by the work. The process is summarised in **Box 3.2** with further information given in **Section 17.5.2**.

- A risk assessment is the process of identifying possible hazards and the likelihood and consequences of the hazards occurring or being encountered.
- A hazard is a feature (eg a river) an event (eg a tree falling) or an action (eg using a saw) that could lead to someone or something being harmed or damaged.
- Risk is a combination of both the probability (chance) of harm and the severity of harm.
- Mitigation measures are ways to avoid or reduce the impact of a risk.

BOX 3.2 Risk assessment

A risk assessment should consider all groups at risk – the public and people installing or maintaining NFM. It should follow these five steps:

1 Identify the hazards.
2 Determine who may be harmed and how.
3 Evaluate the risks and select mitigation measures to reduce these risks.
4 Record the findings and proposed actions, and implement these.
5 Review the assessment and update if necessary.

A risk assessment for NFM should consider (not an exhaustive list):

- the hazards in Section A3.1
- any safety risk to the public – where it is situated to residential areas, public open spaces or PRoW
- the full range of water levels or flows that may occur, including due to climate change
- the risk of any NFM measure failing
- if the risk would change by season, time of day or weather conditions
- ease of access (for rescue or influence work practices)
- the methods of installation and the competence of the workforce
- any maintenance needed and how this will be done
- how the risk might change if land use changes, eg new housing; different farming practices.

Take a broad view, considering the locality rather than just a specific NFM measure.

A risk assessment and any mitigation measures should be kept on file (eg health and safety file for the CDM 2015) and reviewed:

- periodically, as determined when the risk assessment was completed
- if there is an accident or near miss

- if the site changes
- before starting work to modify or remove an NFM measure.

A prompt list of hazards and control measures associated with NFM projects is given in **Section A3.1**. This is not comprehensive and should be tailored to the activities being undertaken, location, likely weather conditions, equipment, training and competence of the people involved.

Measures to eliminate or reduce risk are preferable to isolating or controlling residual risks, as they are passive and protect all user groups – including members of the public who do not always appreciate the risk associated with an NFM measure. Risks are most easily reduced in the early stages of design. The residual risk should be as low as reasonably practicable. This implies a proportionate approach, although it does not require risks to be mitigated regardless of cost, time or effort.

Information on the health and safety requirements of the design phase is given in **Section 17.5** and the construction phase is in **Section 18.3**. Specific safety considerations for the design and construction of each NFM measure are in **Part C**.

Further reading

Birdwatch Ireland (2016) *General health and safety information for volunteer fieldworkers*, British Trust for Ornithology

⇨ Focused guidance for use of volunteers.

https://www.bto.org/sites/default/files/u36/downloads/admin_H%26Sinfo_for_volunteers.pdf

Gotch, P, Hind, M and Russell, G (2009) *Guide to public safety on flood and coastal risk management sites*, SC060076/SR1, Environment Agency, Bristol, UK (ISBN: 978-1-84911-086-0)

⇨ Public safety risk assessment: generic hazards list and measures to protect the public.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/291178/scho0809bqvs-e-e.pdf

HSE (2006) *Health and safety in construction, third edition*, HSG150, Health and Safety Executive, London, UK (ISBN: 978-0-71766-182-2)

⇨ Advice on the causes of accidents and how to eliminate hazards and control risks

https://www.hse.gov.uk/pubns/priced/hsg150.pdf

HSE (2014) *Risk assessment: A brief guide to controlling risks in the workplace*, INDG163(rev4), Health and Safety Executive, London, UK

⇨ Guidance on controlling risks

https://www.hse.gov.uk/pubns/indg163.pdf

HSE (2015) *Managing health and safety in construction. Construction (Design and Management) Regulations 2015. Guidance on regulations*, L153, Health and Safety Executive, London (ISBN: 978-0-71766-626-3)

⇨ CDM regulations including client and designer duties

https://www.hse.gov.uk/pubns/books/l153.htm

Courtesy Emma Wren

4 SELECT SITES AND MEASURES

Contents

Chapter 04

Select sites and measures

This chapter summarises how to select sites for NFM and measures to include.

▶ *Further information on NFM measures is given in Part D.*

4.1 INTRODUCTION

The choice of where to implement NFM measures and which ones to use is important to NFM success. It is important to understand the catchment context, link this to the project aims, identify what the successful outcome of the project is and then choose sites and which NFM measures to adopt. This is an iterative process, and the exact starting point will vary depending on who initiates the project, who they are working with, the initial level of funding and the initial thoughts on project scale and desired outcomes. Creative and holistic thinking should be used when embarking on an NFM project due to its complex nature and the wider opportunities it provides. **Figure 4.1** provides an overview of the key steps needed to select NFM measures. **Chapter 2** provides information on choice of project aims and success factors and **Chapter 4** expands on community engagement.

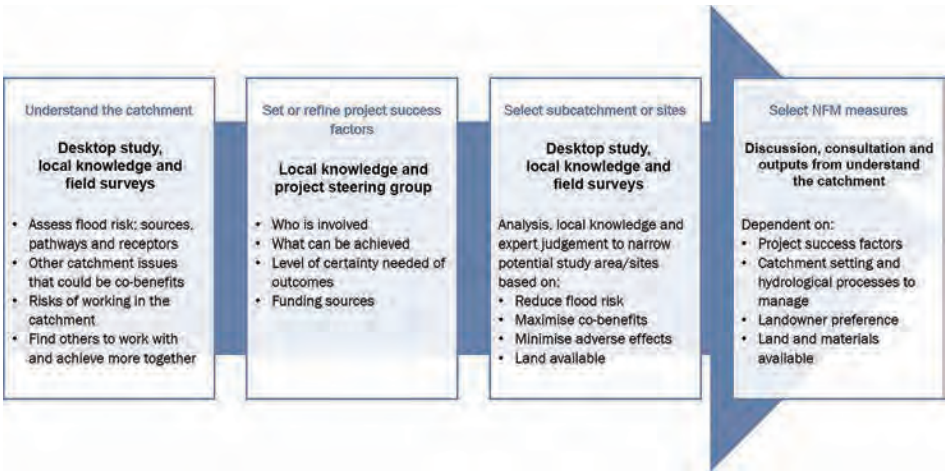


Figure 4.1 The iterative process to select NFM sites and measures

This manual uses the terms catchments, subcatchments and sites to describe different geographical scales of NFM. The larger the NFM project area and number of measures installed, the greater influence the project is likely to have in terms of reducing flood risk at receptors. These nested scales are broadly defined in **Figure 4.2**.

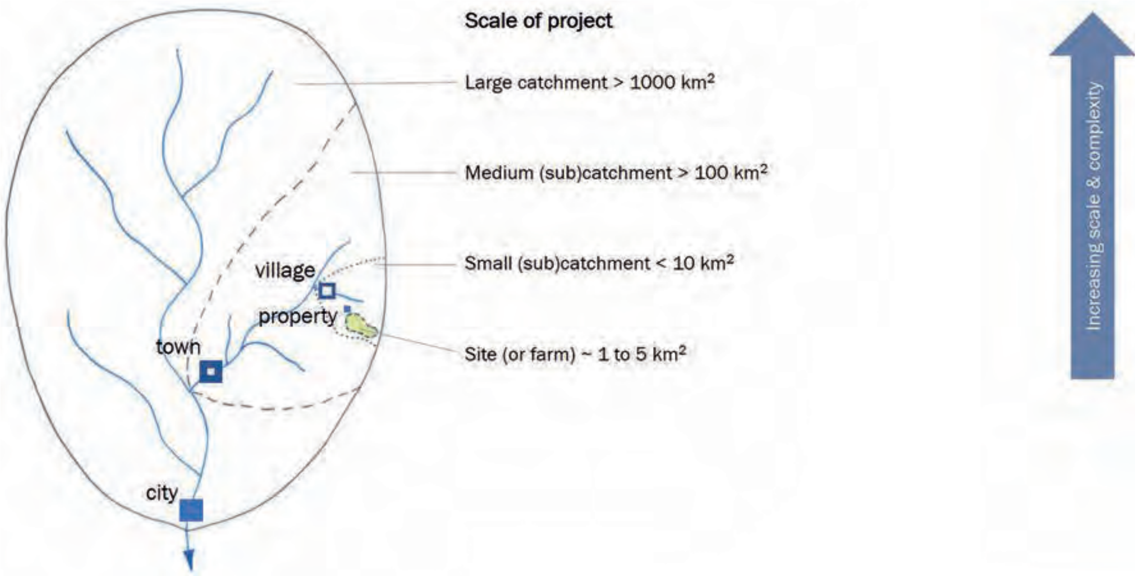


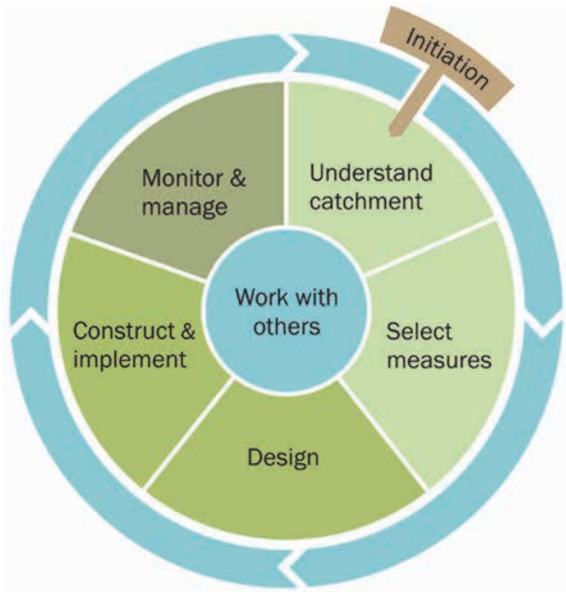
Figure 4.2 Geographical scales of NFM

4.2 UNDERSTAND THE CATCHMENT

To achieve a successful outcome, the people involved need to understand the catchment context. This will help to consider questions such as:

- how to reduce flood risk (sources, pathways and receptors)
- how to think about the other co-benefits and constraints
- who else to work with to maximise outcomes.

This requires a combination of appreciating local knowledge, desk studies and field surveys, which should be undertaken in parallel. These three building blocks of understanding the catchment will support the decision making to select sites and measures (**Figure 4.3**). This is an ongoing iterative process, and the level of effort needs to be proportionate to the overall investment. Records of information, data and experiences need to be kept to maintain and improve catchment understanding, and these should be updated as the project progresses.



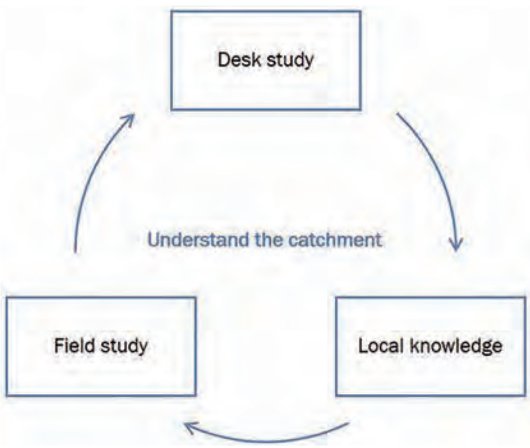


Figure 4.3 The process of understanding the catchment

4.2.1 Desk study

The desk study is the process of gathering and collating all the relevant data and information available for the catchment.

Keys areas to understand, the importance of that information and how it can be gathered can be found in **Table 4.1** and links to example data sources or methods are in **Section A3.4**. A wealth of information is freely available and it is recommended to work closely with relevant authorities and other stakeholders to obtain datasets that are not open source or freely available. Working together may enable more data to be shared.

TABLE 4.1 Potential sources of catchment data for the desk study

Type	Importance	Example datasets or methods
Hydrology and flood risk	• See Section 4.2.4. • Understand where flooding comes from. • Understand how water flows or where the runoff pathways are. • Understand who or what is at risk of flooding.	• See Table 4.4.
Geomorphology (see also Chapter 16 and Section 17.3)	• Work with geomorphological processes to reduce soil loss/erosion. • Design NFM measures to work alongside current processes. • Are there issues of erosion or sediment deposition of relevance for the project (site, reach or catchment scale)?	• Geology. • Permeability. • Historical trend analysis. • Expert geomorphological assessments.
Environment (also see Section 4.2.5, Chapters 16 and 17)	• Understand current setting to design appropriate NFM measures. • Understand environmental constraints and opportunities.	• Aerial photograph or satellite imagery.
Topography	• Understand where runoff pathways might be present within the catchment. • Allows specific areas to be targeted to improve project outcome.	• Ordnance Survey (OS) maps. • Digital elevation data (eg LiDAR).
Soil	• What is the condition of the soils? • Do the soils/ground have capacity to store more water?	• National soil map (NATMAP). • Topsoil data (eg available water capacity) erosion risk assessment. • Hydrology of soil types (HOST).
Land cover, land use and management	• What are current farming practices? • What has changed over time? • How drainage has been modified to support agricultural activities? • Are land managers open to changes?	• Aerial photograph or satellite imagery. • Remote sensing – Landsat and Sentinel satellites. • Land cover maps. • CORINE.
Land ownership	• Understand who needs to be involved in the NFM project and who might need to give permission for the work to go ahead.	• Customer land database (CLAD). • HM Land Registry. • Infrastructure owners and operators.
Local strategies	• Understand if there are co-benefits or constraints. • Could there be funding opportunities. • Catchment actions.	• Surface water management plans. • Critical drainage areas. • Flood risk management plans. • WFD datasets. • River basin management plans.

4.2.2 Local knowledge

Knowledge gathered from the local community should be used to confirm or improve the desk study findings. Local knowledge is important at all stages of the NFM delivery process and involving local communities will likely increase the overall success of the project (Chapter 4). The community can provide a range of information to increase catchment understanding. Table 4.2 provides a guide to what local knowledge can be gathered and who to involve to increase catchment understanding.

TABLE 4.2 Types and sources of local knowledge to help develop catchment understanding

Source of knowledge	How they can help			
	Flood risk and water	*Land management*	*Geology and soils*	*Working with others*
Local residents and flood interest groups	Hydrology: • Where and what floods? • Where does the water come from and go to? • When has it flooded? • Where does it collect? Photographs Soil erosion issues	What has changed? (eg recent development built in an area that was frequently wet)	Observations	Who else (ie grounds, people) is doing similar things in the catchment, eg wildlife group, tree planting group, footpath group?
Farmers and land managers	As above.	Current and previous management practices. How drainage has been modified to support agricultural activities. Current stewardship plans (not yet registered online).	Geographic extents of soil types/geology (especially if they manage/farm at multiple locations).	Farmers generally form a community, so can help forge links across the catchment.
Catchment Partnerships and non-statutory environmental organisations (eg NGOs)	Knowledge of the catchment and have access to data to increase knowledge and understanding of flood risk.	Could be working with local landowners and farmers in catchment and hold data on current land management practices.	Could have access to useful datasets to increase understanding, eg geology and soils.	Could be working with other key organisations that could help with knowledge and or have access to funding.
Flood risk management authorities	Historic flood records. Planned/previous actions to reduce flood risk. Formal data eg maps, models, hydrological records.			Who else to involve.
Infrastructure asset owners	Issues with assets being flooded. Water quality issues. Water and sewerage companies may have hydraulic models of the surrounding networks and information on flood risk or drainage.	Could own or manage land, key contact for future delivery.		

4.2.3 Field survey

Following the desktop study and collating local knowledge, field surveys can be used to fill knowledge gaps. Findings from these can then be incorporated into the overall catchment understanding. Field surveys are important to:

- cross check the desk study results with the situation on the ground
- collect additional information or data that could not be gathered during the desk study.

Some typical field surveys that may be needed at this stage are given in Table 4.3.

TABLE 4.3 Field surveys to increase catchment understanding

Survey type	Purpose	Who	Cost	Technical ability
Walkover surveys and site visits	To confirm or develop understanding of sources, flow paths, opportunities for NFM, soil and land management practices	Trained volunteers, environmental organisations (eg NGOs), consultants	Volunteers suitable for straightforward activities. Costs for materials only. However, higher risk of error and liability sits with the lead organisation. Commercial organisations will provide technical expertise with insurance cover but there are costs for staff time as well as materials.	Simple/ intermediate
Time lapse cameras	Provide site-specific, real time information that cannot be captured on a single site visit	Trained volunteers, environmental organisations, consultants	Cost of cameras can vary. Night vision cameras are more expensive but provide more data to increase confidence	Simple/ intermediate
Drone footage	Provide more up-to-date aerial photography than other datasets and help visualise the study area for engagement	Licensed individuals and companies	Dependent on the experience of the individual or company providing the service. The area covered will also influence the cost (size and location)	Intermediate/ detailed

Monitoring is also an important tool to gather missing data, and a way to measure the effectiveness of any project (see Chapter 7). Understanding hydrology and geomorphology may require specialist skills, consider working with a professional hydrologist and/or geomorphologist at the stage of catchment understanding (Section A3.2).

4.2.4 Understand catchment hydrology

As reducing flood risk is the key component of NFM outcomes, it is important to understand hydrology from the project outset, ie where water comes from in the catchment, what paths it takes, and who or what is affected. The flowchart in Figure 4.4 describes these key questions in the context of the source-pathway-receptor model (Figure 2.1). A good understanding of the hydrology in the early stages of a NFM project can help identify which part of the hydrological cycle to protect, restore or mimic (or manage) to make the final NFM measures more effective.

The level of detail and effort put in to understanding the hydrology should be proportionate to:

- the complexity or the number of sources of flooding
- the vulnerability of receptors to flood risk
- the availability of money, time and expertise.

The flowchart helps identify the appropriate approach to investigate the hydrology during the desktop study. It is recommended that there is a review of the approach taken at each stage of the NFM delivery process, as a project gathers more data and understanding of hydrology and the flooding issues. NFM is unlikely to be the main tool used to reduce flood risk if there is a risk to people's lives and critical infrastructure, due to the size of flows that the NFM measures generally seek to manage. However, is still important to consider such a rare case to quickly identify when the consequences of flooding are so great that it requires expert support from the outset. **Table 4.4** sets out the key considerations for simple, intermediate and detailed approaches to help ask the right questions to understand hydrology in the study area, with websites giving links to relevant information provided in **Appendix A3**.

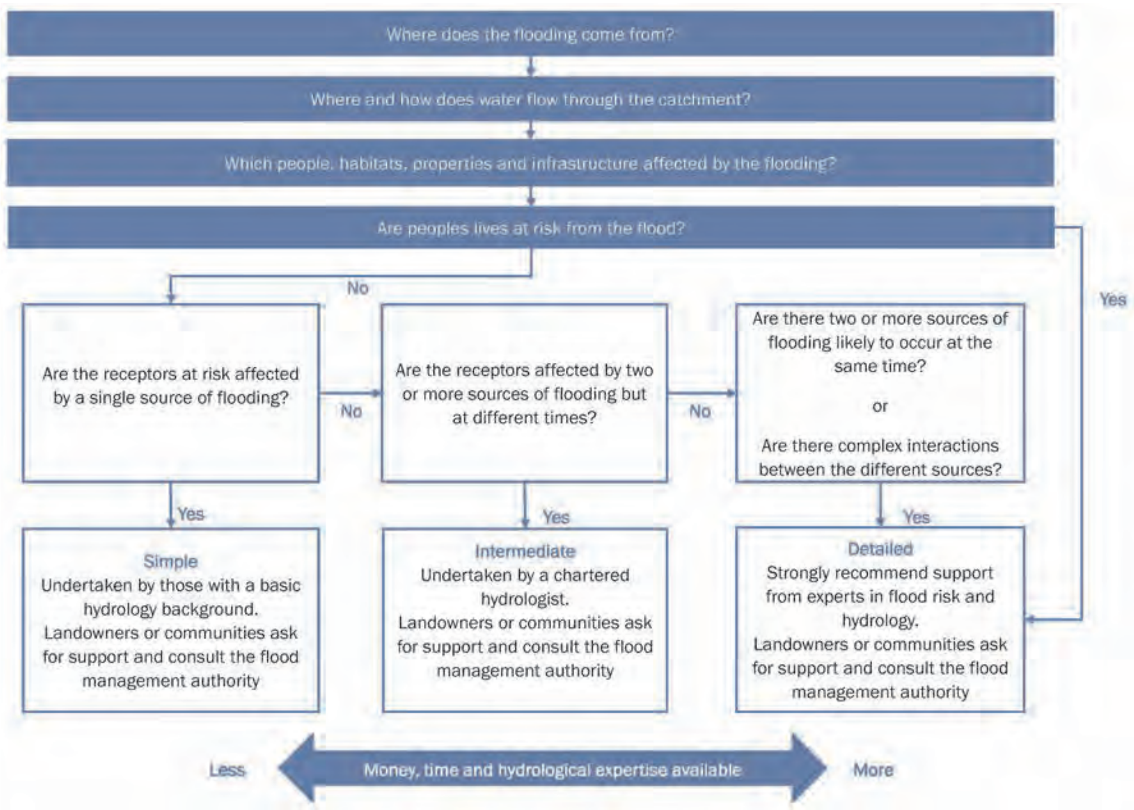


Figure 4.4 Selecting the appropriate level of detail to understand hydrology of the catchment

4.2.5 Overarching environmental issues

When developing catchment understanding NFM projects should consider the wider environmental context at an early stage to maximise co-benefits. This may enable projects to focus on subcatchments or sites where more can be collectively achieved and could:

- provide significant opportunities for additional flood risk and co-benefits
- enable additional project aims and/or success factors to be considered
- engage a wider audience about the project and the environmental issues
- identify other people (and their expertise) to work with
- create additional funding opportunities.

It is important to take a holistic approach – consider what could be achieved by an NFM project, the potential benefits and what others may be trying to achieve in the same location or within the catchment, authority area or community. For example, an NFM project may be being considered in a village that is also keen to improve their local park or develop a new cycle route into the nearby town. Working together and demonstrating a project that meets multiple criteria will bring together more expertise and potentially more funding. It could also reduce overall carbon costs, disruption by construction traffic and reduce mobilisation and consenting costs. **Table 4.5** provides examples of what to consider and their possible application.

TABLE 4.4 Potential methods to identify sources, pathways and receptors of flooding

	Level of detail	Key considerations	Example datasets or methods
Source Where water comes from in the catchment (see also **Chapter 14, 19 and Appendix A5**)	Simple	• Does flooding occur from surface water flows over the land? • Does flooding occur from rivers or more defined channels? • Does flooding occurs from springs or rising groundwater? • How much rainfall is there in the catchment? • How much water flows through the catchment? • Does groundwater influence the catchment?	• Local knowledge • Historic flood reports • Gauged rain and flow records • Groundwater vulnerability maps • Hydrological summaries • Hydrology data explorer • National river flow archive (includes average annual rainfall data)
	Intermediate to detailed	• How frequent are the rainfall storms? • What types of rainfall storms cause the floods? • How frequent and how big are the floods? • How frequent and what are the low flow conditions? • How much does groundwater influence flows in the catchment? • Are different types of flooding likely to happen at the same time?	• Climate records • Gauged flow, level and rainfall records • Hydrological summaries • Groundwater level records • Monitoring • Design flood hydrology methods • Joint probability methods
Pathway Where does it flow or where are the runoff pathways? (see also **Chapter 14 and Appendix A5**)	Simple	• Where does water flow over the land? • Where are the rivers or more defined channels? • Where is water stored? • How do these flow pathways cause the flood?	• Local knowledge • OS or national topographic mapping • Detailed River Network • NFM opportunity mapping
	Intermediate to detailed	• How quickly does the catchment respond to rainfall? • How quickly does the water drain away? • How much water fits in the river channels? • What points along the pathways restrict flows?	• Gauged flow, level and rainfall records • Groundwater levels • Channel survey • Infiltration tests • (Hydraulic) asset information database for rivers • Design flood hydrograph methods • Rainfall-runoff methods • Hydraulic methods

continued...

TABLE 4.4 Potential methods to identify sources, pathways and receptors of flooding (contd)

	Level of detail	Key considerations	Example datasets or methods
Receptor Who or what is at risk of flooding? (see also **Chapters 14, 15 and Appendix A5**)	Simple	• Where does it flood? • Who or what is affected by the flood water? • Are people's lives at risk during the flood?	• Local knowledge • Flood risk extent maps (river or surface water flooding) • Flood hazard maps (river or surface water flooding) • Flood risk studies or management plans for a catchment or local authority area
	Intermediate to detailed	• How deep is the floodwater? • How fast is the floodwater? • How many people, habitats, properties and infrastructure are affected? • How severe is risk to life? • Is there risk of damage to sensitive habitats, buildings, or infrastructure?	• Flood risk extent maps (river or surface water flooding) • Flood risk studies or management plans for a catchment or local authority area • GIS methods • Hydraulic methods • Hydraulic modelling methods • Detailed flood hazard maps • OS mapping • National receptors database • Environmental designated sites database

continued...

TABLE 4.5 The application of wider environmental issues

Issue	Description	Relevance	Ways to bring into NFM projects
Sustainability	Consider environmental, social and economic issues in decision making, to meet the needs of the present without compromising the ability of future generations to meet their needs. Every government, organisation and project should contribute to the United Nations Sustainable Development Goals (UN SDGs) – 17 interconnected goals to be achieved globally by 2030.	Optional, yet good practice	Provides common themes to compare to other NFM and non-NFM projects. Could use UN SDGs as a metric.
Mitigation of climate change	The UK is to reduce carbon emissions to net zero by 2050, relative to 1990 emissions to contribute to mitigation of the climate crisis/ climate emergency. Net zero means all direct and indirect carbon emissions are reduced as a priority. Carbon emissions that cannot be reduced are offset, which results in a reduction in carbon emissions over time. Carbon neutral (an interim step to net zero) involves direct and (some or all) indirect carbon emissions being reduced or offset, but there does not have to be a reduction in carbon emissions over time.	Optional, yet good practice	Many UK councils have declared climate emergencies, and many organisations and businesses have made pledges to be net zero by 2050 or before, NFM could align with or contribute to these aims for partners or other organisations. Some NFM measures can contribute to reduce the effects of climate change (mitigation), such as upland peatland restoration or tree planting.
Environmental and biodiversity degradation	Recognised need to reverse the overall trend of degradation and loss of environment (particularly biodiversity). Environmental net gain is a proposed approach where development projects are required to leave the environment in a better state than before the development.	Optional, yet good practice Environmental net gain approach may be required. More relevant for large catchment scale projects.	Seek to develop wildlife/habitat corridors to increase the resilience of existing habitats and species to further environmental biodiversity degradation. Remove invasive and/or non-native species to increase ecological resilience.
Biodiversity net gain (BNG)	A strategy for conservation of biodiversity to reverse continued loss within the UK. Certain projects will have to provide a certain proportion of BNG, as opposed to achieving 'no net loss' or focusing on achieving statutory obligations. Biodiversity will be in a better state after the project. A sub-set of environmental net gain.	Will become mandatory in England for projects requiring planning permission. May be mandatory elsewhere in future. Optional for all other projects.	Well-planned NFM projects are likely to achieve BNG and so could offer partnering or funding opportunities for others seeking to achieve BNG.

continued...

TABLE 4.5 The application of wider environmental issues (contd)

Issue	Description	Relevance	Ways to bring into NFM projects
Access to nature	Reduce inequality and improve long-term access to nature for all people and communities. Enable increased connections to nature, improve mental and physical wellbeing, and increase the value communities place on local natural outdoor spaces.	Optional	Develop NFM sites with public access in mind, especially in locations where access to nature is currently limited. Seek to provide and encourage long-term public access to as part of NFM projects.
Water resources management	Consider all water resources aspects at the same time and across the catchment with an aim to improve water management, land and related resources without compromising the environment.	Mandatory if relevant to any statutory role of organisations involved. Optional for all other projects. More appropriate for catchment scale proposals, or NFM projects with multiple locations.	Consider how NFM can also contribute towards addressing other catchment issues (eg low flows; water quality)
Place making	Review existing national, regional and local plans and strategies. These can be topic and/or geographically based. May focus on management of flood risk, the water environment, biodiversity and nature conservation, landscape, transport planning, parks and gardens, or be local planning documents.	Mandatory to consider where relevant to any statutory role of organisations involved, or for certain proposals (eg planning permission needed). Optional for all other projects. More appropriate for larger-scale projects.	Consider how the aims and objectives align and how the NFM project could help achieve these overall visions for a place. Think widely and holistically about all the potential co-benefits.

4.3 SELECT SUBCATCHMENT OR SITES

The requirement for this step will depend on the geographical scale of the project study area and the level of investment. If the NFM project is already focused at a site scale or a relatively small subcatchment, then this step may not be needed to the same extent and it can go straight to the choice of measures (**Section 4.4**).

If the NFM project is at a catchment scale, then effort is needed to refine the areas of focus and select sites to install NFM measures. There may be a number of subcatchments or sites within the larger catchment that can be of focus. A degree of prioritisation is needed to maximise the outcome. This prioritisation should consider how to work effectively across the catchment to:

- reduce flood risk
- maximise co-benefits
- minimise adverse effects and mitigate risks.

These can be considered 'top-down' approaches. The choice of sites is optimised based on beneficial outcomes. In addition, bottom-up approaches may also be considered. These may be based on factors such as:

- land availability
- enthusiasm of the community to get involved
- willingness of partners.

In reality, the selection of subcatchments or sites may be a combination of these 'bottom-up' and 'top-down approaches'. This reflects that although NFM projects aim to reduce flood risk and maximise co-benefits, there are many other wider factors that affect the choice of location. Table 4.6 signposts examples of opportunity mapping. For the majority of NFM projects, the delivery areas should primarily be based on the locations that provide most flood risk benefit, however the degree to which other co-benefits are considered will depend on what the project seeks to achieve.

Depending on the starting point, there may need to be a further iteration. For example, if a project initially starts at a large catchment scale and narrows down the focus to a subcatchment, then there may need for further assessment to establish the best sites. This needs to be proportionate and to have due consideration of the key risks at each project stage. This is so that informed decisions can be made to reduce project risks and any knock-on effects to project costs or programme.

Project tools such as risk registers and options appraisal tools can be used to compare opportunities and constraints, and these can be revisited as the project progresses and the level of catchment understanding increases. GIS is an excellent tool to manage location specific opportunities and constraints, it can combine the two sets of information and facilitate decision making on NFM locations.

There are a range of NFM opportunity mapping tools available that can be used to help understand the high-level potential for NFM measures across a catchment. Opportunity mapping provides a good starting point to identify feasible sites however, their use alone can be too coarse or identify too many sites to be practically implemented at catchment scale. Collaborative stakeholder and/or community engagement can be useful to refine feasible sites from a long list of possible sites. **Box 4.1** provides an example of how local knowledge is essential for selecting the most effective sites for a successful NFM project. More information about the importance of local knowledge and community engagement can be found in **Section 4.2.1 and Chapter 4**, respectively.

TABLE 4.6 Examples of NFM opportunity mapping

Name	Inland measures included	Coverage
Natural processes mapping	Tree planting, floodplain reconnection, runoff management and storage and leaky barriers	England and Wales
https://naturalprocesses.jbahosting.com/Map		
SEPA flood maps	Runoff reduction, floodplain storage, sediment management	Scotland
https://map.sepa.org.uk/floodmap/map.htm		
Thames Regional Flood and Coastal Committee (RFCC) NFM opportunity and priority map	Gully blocking, bunds, ponds, riparian buffer strips, floodplain reconnection, catchment woodland	Thames catchment
https://geography.blog.gov.uk/2020/09/30/thames-rfcc-natural-flood-management-opportunity-and-priority-map/		
Forestry Research opportunity mapping	Woodland creation for water objectives	England and Wales
https://www.forestresearch.gov.uk/research/opportunity-mapping-woodland-for-water/		

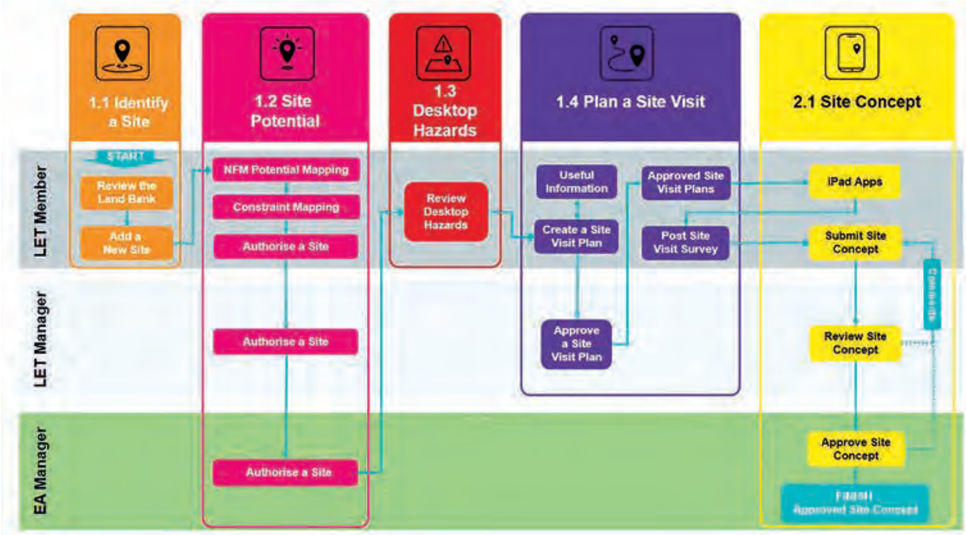
BOX 4.1 Leeds NFM project – working in partnership with landowners to select suitable sites

Project lead: Environment Agency and Leeds City Council

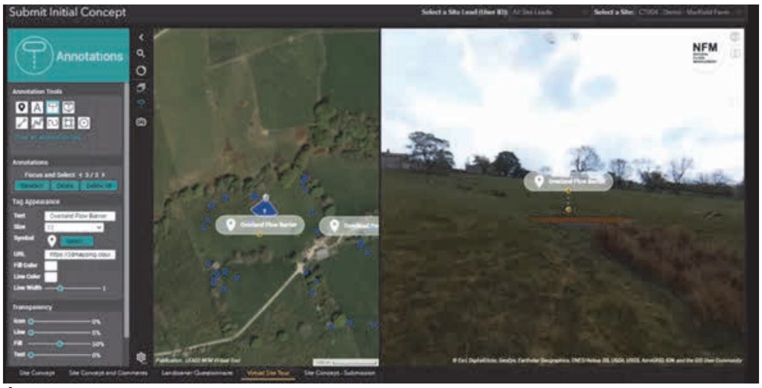
Working in partnership: Mott MacDonald, Thomas McKay, the Forestry Commission and White Rose Forest

Location: Leeds, England

Reason for NFM: The project aim is to use catchment scale NFM to offset the projected increase in flood risk in Leeds due to climate change between 2039 and 2069. It was instigated by Leeds City Council as part of a wider Leeds Flood Alleviation Scheme.



a



b

c

The process of site selection involved a landowner engagement team (LET) (see (a)). The LET identified potential sites in the catchment and then used the bespoke project GIS tool to complete an early screening process to review the potential opportunities and constraints of each site (see (b)). Opportunities included all applicable NFM measures, and constraints, as well as utilities and environmental considerations. The LET visit the site and work with the landowner to agree a 'site concept' showing where NFM could be located (see (c)).

4.3.1 Selecting hydrologically-effective sites

When working at subcatchment and catchment scale, it can be useful to consider which locations are the most hydrologically effective and which NFM measures to implement to strategically target those sites that reduce and delay flows the most. This top-down approach relies on hydrological expertise or tools so may be more suitable for larger or more complex catchments rather than sites identified as simple (**Figure 4.3**).

Figure 4.5 outlines the general steps to help narrow down potential hydrologically effective sites using intermediate and detailed hydrological and hydraulic methods suggested in **Table 4.4**. The main flow paths within the subcatchments can be identified from the desktop study approaches (**Table 4.4**) or local knowledge. This ensures that the proposed measures are sited to intercept or encourage infiltration in the most appropriate locations to protect and restore existing hydrological processes or mimic them by creating new pathways and storage features in the catchment.

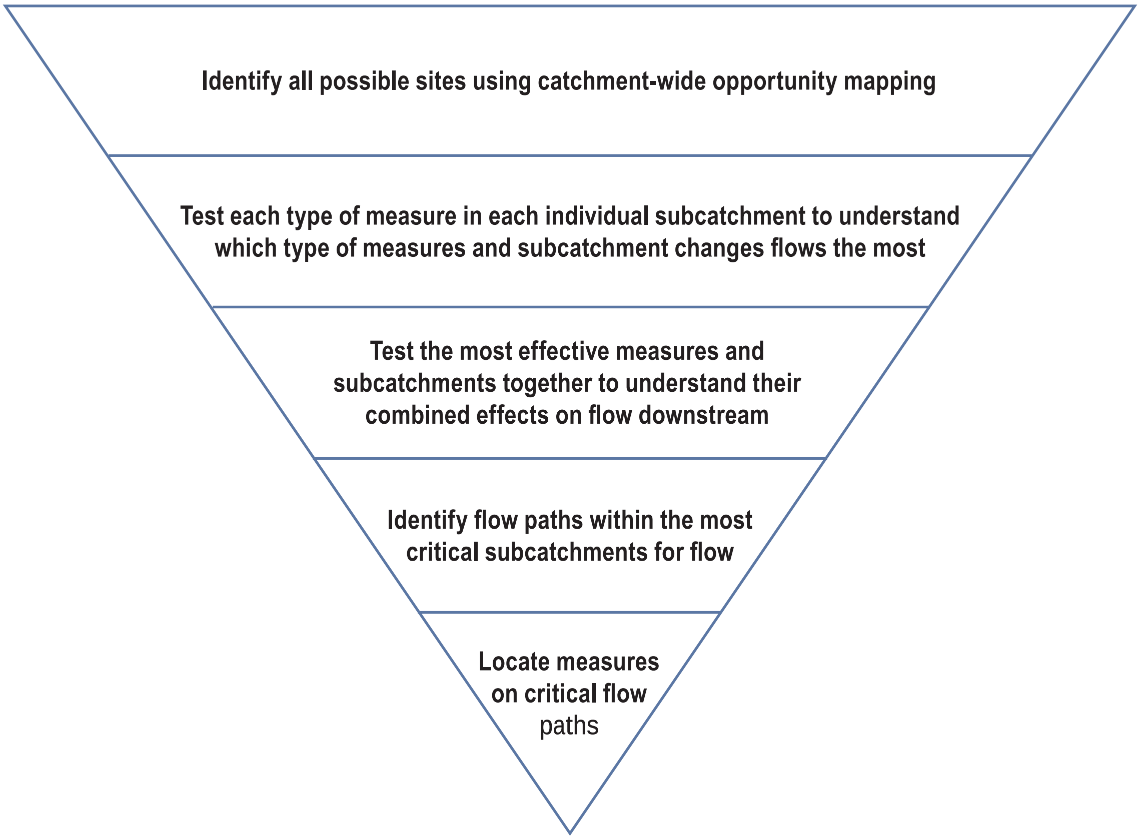


Figure 4.5 Steps to narrow down hydrologically effective sites from catchment to site scale

Narrowing down effective sites at subcatchment to catchment scale requires greater analysis and hydrological expertise. **Figure 4.6** sets out some examples of different locations within a catchment and the hydrological impacts and potential risks. Measures located upstream of a constriction, such as bridge, culvert or road, may limit the hydraulic impact downstream of this feature. Locating measures close to the receptors can provide localised benefits but increases the risk that the peak flows might coincide at the confluence depending on the relative time it takes the flood to travel from point a to c see **Section 4.3.2** for assessing synchronicity). Measures located in the upper to mid reaches can have help desynchronise peak flows from multiple flow paths if planned carefully but the storage capacity is important to reduce flood volumes to reduce flood risk. Locating measures on main flows paths to store, divert or increase infiltration at a site or farm scale is relatively straightforward once construction constraints are understood (**Chapter 17**). Selection of appropriate measures is covered in more detail in **Section 4.4**.

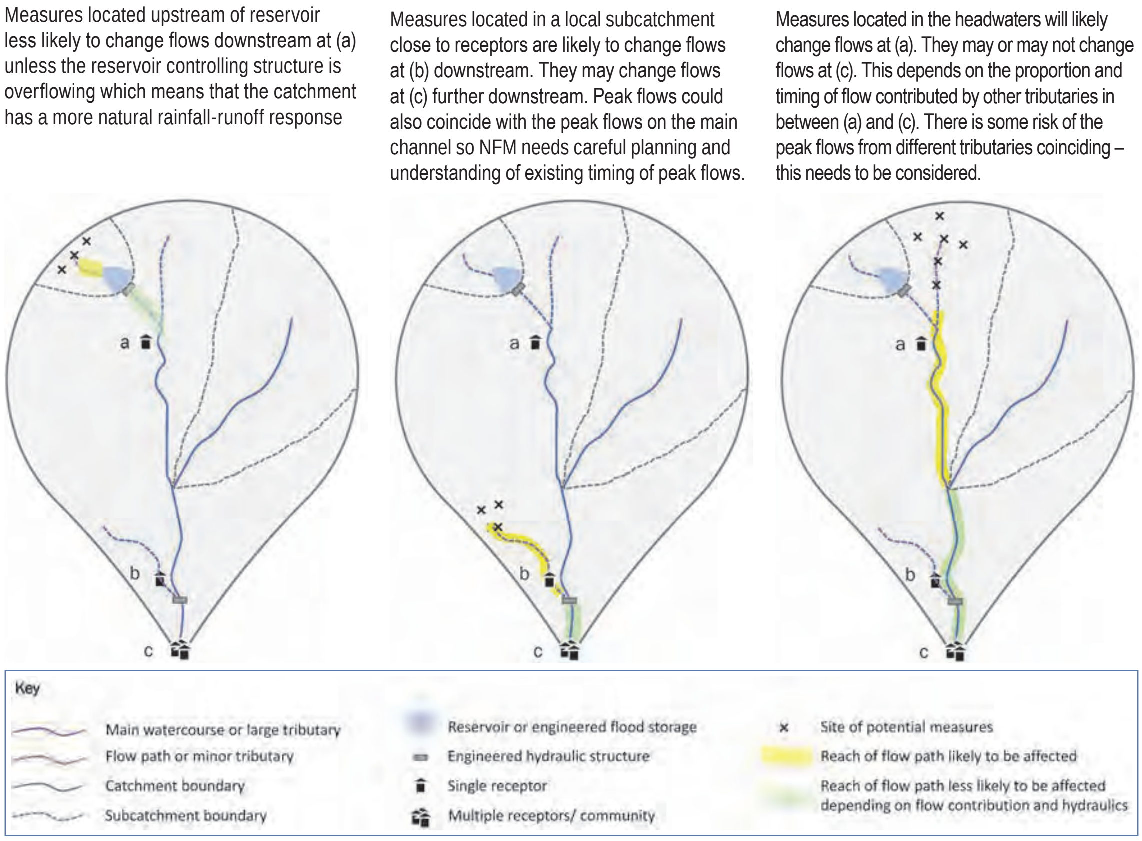


Figure 4.6 Considerations when selecting hydrologically effective sites within a catchment

4.3.2 Check timing of flood peaks

It is important to consider the impact of NFM measures on timing of the peak of the flood in catchments with multiple tributaries. When the flood peaks meet at the confluence of two channels or flow paths at the same time, downstream flows are greater and flood levels rise higher – this is known as synchronisation. When flood peaks happen at different times along channels or flow paths that meet at a confluence, downstream flows are reduced and flood levels can be lower – this is known as desynchronisation (**Figure 4.7**).

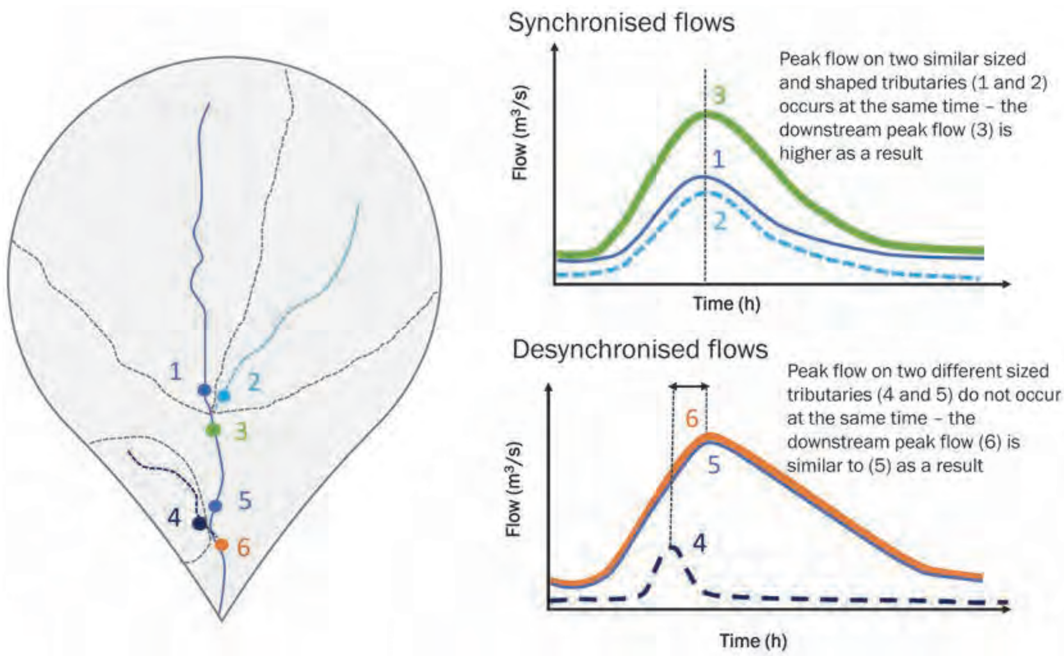


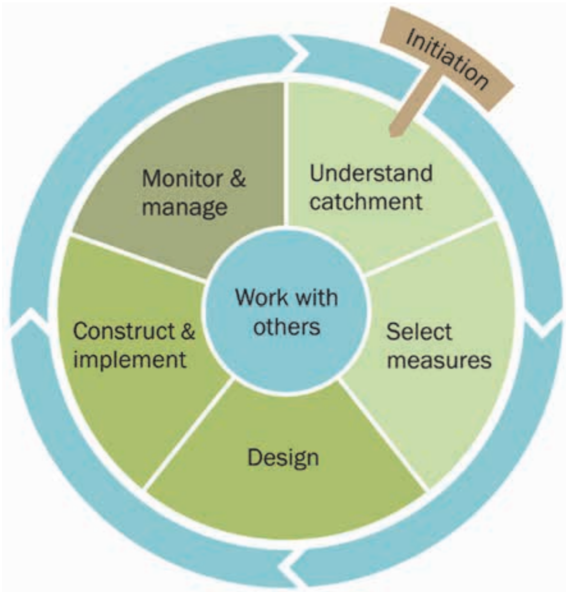
Figure 4.7 Timing of flood peaks and potential issues within a catchment

Careful site selection and design of NFM measures can help desynchronise tributaries or flow paths from one another to help manage flood risk downstream. Inappropriate selection of site and design of measures can increase flood risk downstream in certain circumstances by synchronising tributaries or flow paths. However, it is also important to realise that the timing of runoff in a given rainfall event will depend on a range of factors such as the way the storm passes across the catchment and the wetness of the ground at the start of the rainfall event. There will not be exactly the same runoff response in a river each time it rains.

It is the responsibility of the designer in the NFM delivery process to review whether that the planned sites and design of measures will increase flood risk by causing a synchronised system. Local knowledge combined with hydrological expertise in the early stages can help assess this risk and avoid synchronisation issues later in detailed design. It is recommended that an intermediate or detailed approach from **Table 4.4** is considered when delivering NFM measures at more than one site across multiple tributaries, or in combination with traditional flood risk management solutions downstream. Further details on how to change the time to peak and the synchronisation of the system into the NFM measures can be found in **Chapters 14 and 17**.

4.4 SELECT MEASURES

NFM aims to work across the landscape and with natural processes to reduce flood risk. In any given location, a range of interlinked natural processes are occurring. To obtain maximum benefit, a range of NFM measures and types of each measure should be used in combination across a catchment and multiple smaller measures should be used in preference to a few larger measures.



This helps to:

- target the sources and pathways of flooding
- avoid over reliance on a single solution or location
- tailor measures to meet the needs of individual landowners
- overcome uncertainty in the knowledge of catchment understanding and hydrology
- spread the risk of failure or reduced performance across the landscape
- understand which measures are most successful in the catchment, meaning future measures can be designed with increased success.

The various NFM measures, and the NFM measure types, are described in **Part C** and further information on the design and construction of NFM is given in given in **Chapters 17 and 18** respectively.

If the starting point of a project is an individual site and a desire to implement NFM, then the site ideally needs to be placed into a wider context (**Sections 4.2 and 4.3**) to ensure that the consequences of any actions are understood and to maximise what can be achieved. **Figure 4.8** shows the steps to follow if the starting point is an individual site or farm.

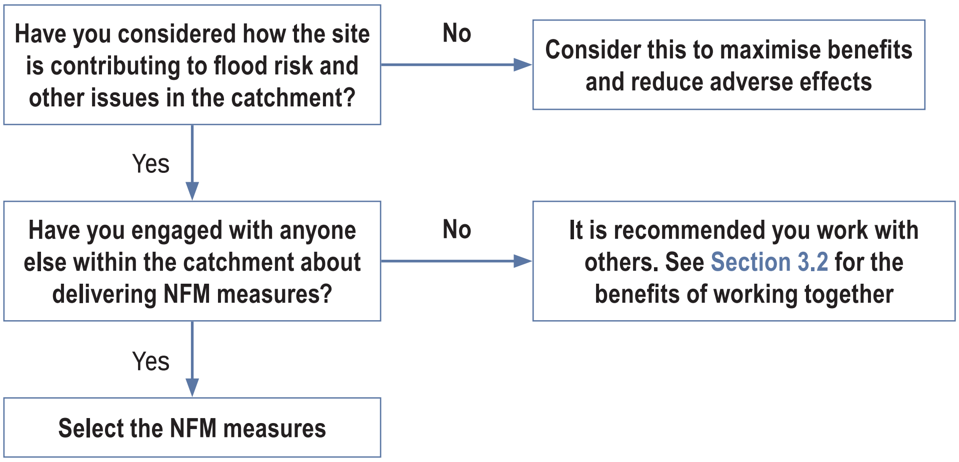


Figure 4.8 Key steps to select NFM measures on a site

Once subcatchments or sites have been prioritised and established, the choice of NFM measures needs to be considered. The choice of measure is highly dependent on a wide range of, potentially conflicting, factors. In addition, there are many ways to implement each measure or measure type, and knowledge about how effective each of these is in any given situation is constantly evolving. This means that there is not always a 'right' or 'wrong' choice, and more likely a range of solutions could be effective. It is important to use the NFM continuum (**Figure A1.3**) to protect, restore, mimic or manage hydrological processes, and choose measures that work with nature (**Figure A1.4**).

Two flow charts help select measures to address runoff management issues (working at source or on overland flow pathways) (**Figure 4.9**) and to help slow the flow in rivers and their floodplains (**Figure 4.10**). **Table 4.7** summarises the range of factors to be considered to determine exactly which measures might be delivered and in which locations and where further detail can be found in this manual to support the choice.

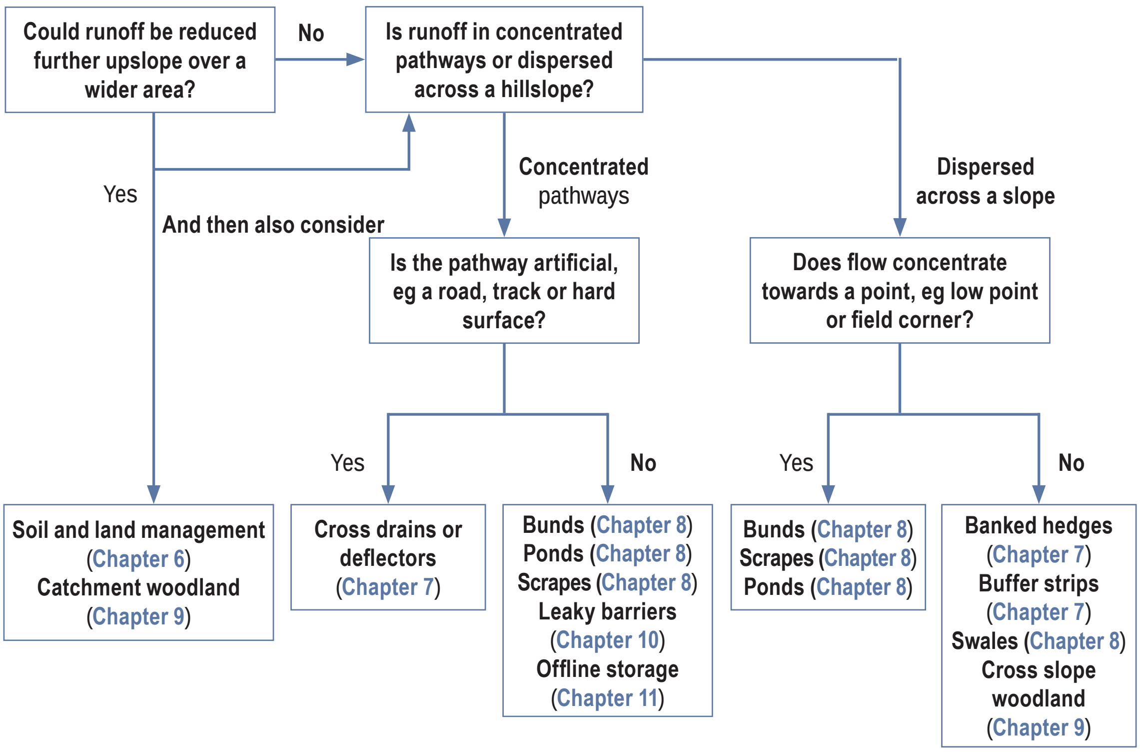


Figure 4.9 Decision tool for runoff management measures (working at source or on overland flow pathways)

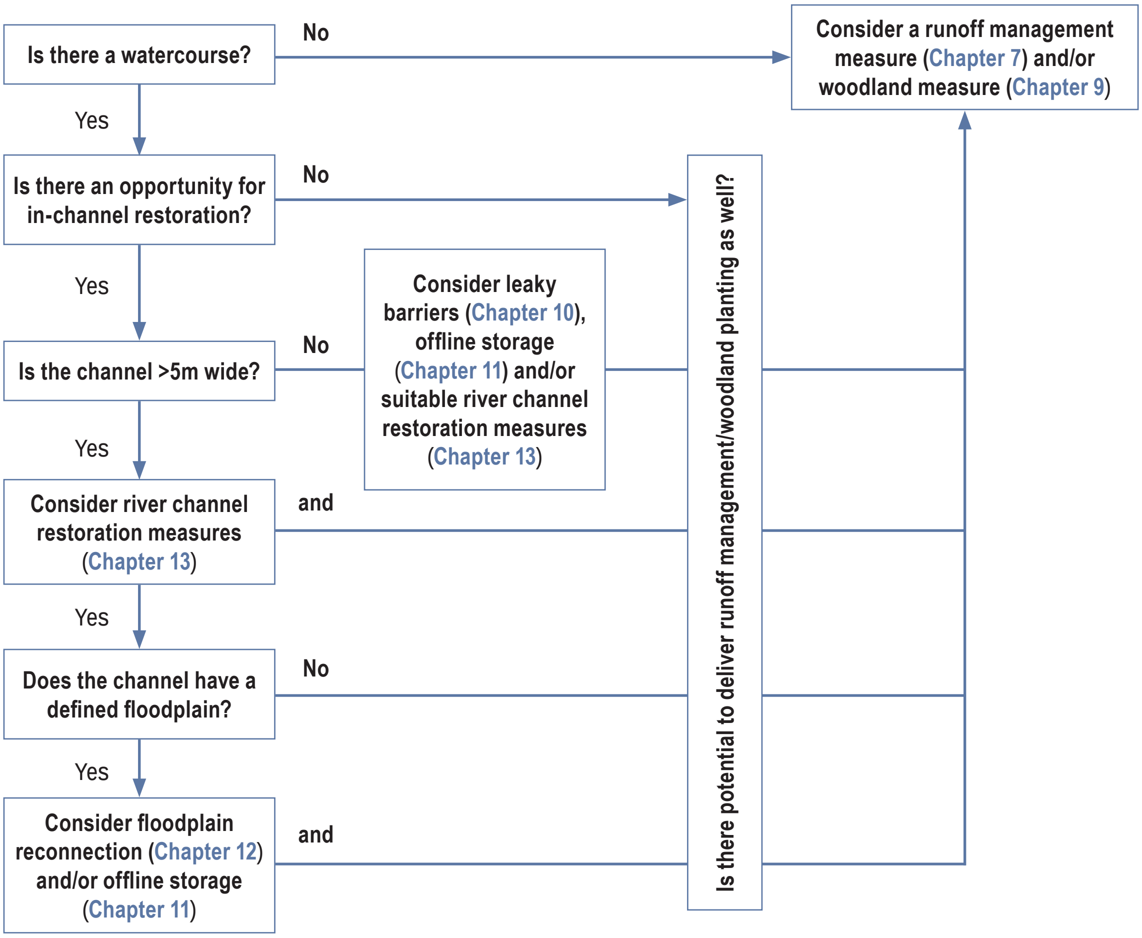


Figure 4.10 Decision tool for river and floodplain management measures

TABLE 4.7 Factors to consider when choosing NFM measures on a site

Factor	Considerations	Further detail
Project factors		
People or partners involved	The resources and expertise available to help will affect the type of NFM measures delivered, both in terms of skills needed and the outcomes that are important to project success.	**Section 4.2**
Project success factors	These factors should steer measure choice, for example if a target is to reduce flood risk in a particular location, then there may need to be more certainty of NFM performance, or if a key target is carbon storage, soil retention and tree planting may be more of a focus.	**Section 2.2**
Funding	Certain funding streams may only be available for some measures.	**Section 4.3**
Site factors		
Preference	The landowner or community may prefer a certain location, measure, measure type or material to be used.	**Section 4.2**
Land use	May affect the choice of measure, measure type or design details. For example, livestock may need to be excluded from an earth bund.	
Utilities	These can be above and below ground and overhead, including easements (eg electricity, gas, water). They can restrict location of measures, overhead working, excavation or methods of working.	**Chapters 16, 17, 18**
Access	Safe transport of labour and materials for site walkovers, construction, monitoring and maintenance.	**Section 18.5**
Consents and permissions	Certain measures/locations may require specific permission.	**Section 4.5**
Ownership and liability	The requirement to take on liability and maintenance/management may mean that a landowner prefers a certain approach.	**Section 4.4**
Hydrological or hydraulic factors		***Chapter 14***
Catchment area	The volume of runoff available to store, slow down or infiltrate will affect which hydrological process is targeted. For example, it may be inappropriate to construct a large storage area near the top of a slope if there is not enough runoff to use it.	
Geology	The effectiveness of measures that encourage infiltration will be dictated by this.	
Soil type and condition	The effectiveness of measures that encourage infiltration depends on this. The risk of storage areas being quickly filled with sediment.	
Topography	The gradient of the land or watercourse affects the choice of several measures. The presence of depressions or runoff pathways may present opportunities to store runoff.	
Location/presence and scale of sources, pathways and receptors of flooding	Affects the choice of measure and the location to use them. For example, certain measures are more suitable on overland runoff pathways, others on ditches or gullies, or on watercourses.	
Flood hydrograph – flow, volume and velocity.	Affects the choice and sizing of a measure and potential volume of water that can be stored. Deep, fast flow increases risk of erosion and mobilisation of materials. Consider low flow routes and exceedance routes as well as the design flood.	
Existing structures or pinch points	Risk of blockage of a structure (eg bridge) and flooding if a measure breaks up, breaches or fails. This risk needs to be accounted for in the choice of measure or measure type.	

continued...

TABLE 4.7 Factors to consider when choosing NFM measures on a site (contd)

Factor	Considerations	Further detail
Environmental factors		**Chapter 16**
Habitats and species	These may be protected or require particular specialist surveys and consents. Also provide an opportunity to enhance/extend or connect habitats.	**Section 16.5**
Invasive non-native species	Risk of spreading species if not treated effectively – treatment can increase cost.	**Section 16.5**
Landscape setting	Measures types and materials to complement the setting and to provide interconnecting landscape features, eg woodland, hedgerows.	**Section 16.6**
Design and materials		**Chapter 17**
Availability and type of local materials	Local materials have lower biosecurity risk and carbon footprint and fit in with the local landscape more readily.	**Section 17.4**
Duration and intensity of sunlight	Woodland and measures incorporating living vegetation require sufficient sunlight for growth (eg swales, living leaky barriers).	
Construction and implementation		**Chapter 18**
Timing	Timing of the NFM construction could affect what can be delivered.	**Section 18.5**
Skills	The skills and expertise of the people involved, and the equipment available/can be used on site, may affect measure choice.	
Health and safety	The choice of measures on a site may affect health and safety risks.	**Sections 4.6, 17.5, 18.3**
Monitoring and management		**Chapter 19**
Long-term commitment	Select measures that can be effectively managed in the future. Ensure that arrangements are in place for appropriate monitoring or management for the measures chosen.	

Hydrological analysis (**Chapter 14**) may mean that a project seeks to focus on a particular part of the hydrological cycle. For example, it may be that in a less permeable catchment it is more appropriate to focus on slowing runoff and streamflow rather than measures to encourage infiltration. Table 4.8 shows how the NFM measures can restore or mimic hydrological processes, with the main process for each NFM measure, in terms of flood risk reduction in blue text.

The best results will generally be obtained by utilising a combination of several NFM measures. This means that different processes, co-benefits and locations can be realised within the target area. It also means that different timescales can be targeted. For example, leaky barriers could be installed relatively quickly and be effective immediately, but floodplain woodland will take several years to be fully effective. In that time the effectiveness of the leaky barriers may have diminished, or some may have been washed away, however the woodland will start to supply large woody debris to perform a similar function. Some measures may need a certain management regime in place to remain effective, for example, the use of cover crops or lower stocking densities. Based on experience, **Figure 4.11** shows which NFM measures work well together at the site or farm scale. At a larger catchment scale, there is generally more variation in the landscape, leading to more opportunity to consider the full range of NFM measures.

TABLE 4.8 Choice of NFM measures to protect, restore or mimic hydrological processes

Measure	Ways to improve hydrological processes to reduce flood risk		
	Increase interception and evapotranspiration	***Increase infiltration***	***Store and slow runoff and streamflow***
Upland peatland management	Revegetate bare peat and re-wet all peat.		Roughen landscape and block gullies to slow overland runoff
Soil and land management	Additional vegetation will increase interception and evapotranspiration. An improved soil structure can increase evaporation from the near-surface soil.	Use management techniques such as cover crops, reduced till techniques, change species composition and reduce stocking densities to increase vegetation cover and improve soil structure and increase the organic matter content.	Cross slope ploughing to slow the runoff rate across a field by increasing storage and lengthening flow pathways.
Runoff management	Additional vegetation (hedgerows and buffer strips) will increase interception and evapotranspiration. Storing water close to the land surface will increase evaporation.	Encourage areas temporary standing water and waterlogged ground, such as behind banked hedgerows. Cross drains can be designed to encourage infiltration.	These measures slow flow pathways, especially if they are also lengthened.
Runoff storage	Areas of open water and wetland encourage evaporation.	Areas of temporary standing water and waterlogged ground encourage this.	Slow down the progress of runoff across the landscape, especially if flow pathways are also lengthened, eg using swales. This effect only lasts until the NFM measures reach capacity or are bypassed.

TABLE 4.8 Choice of NFM measures to protect, restore or mimic hydrological processes (contd)

Measure	Ways to improve hydrological processes to reduce flood risk		
	Increase interception and evapotranspiration	***Increase infiltration***	***Store and slow runoff and streamflow***
Catchment woodland	Woodland can increase interception of rainfall and evapotranspiration from the trees, understorey and the near-surface soil (depending on woodland type/ season/maturity).	An improved soil structure in woodland and promoting understorey growth (depending on woodland type/maturity) can encourage infiltration.	Promoting understorey growth (depending on woodland type/maturity) can slow the flow of runoff across the surface.
Cross slope woodland			
Riparian woodland			Trees and branches along/in the river channel
Floodplain woodland			Trees in the floodplain
Leaky barrier	Increased areas of open water may encourage more evaporation.	If water is temporarily pushed out of bank or stored on runoff pathways then infiltration may increase as water is present for longer to allow this.	Leaky barriers can slow and lengthen runoff pathways, in channels and across land. This effect only lasts until the barriers reach capacity or are bypassed.
Offline storage	Increased areas of open water may encourage more evapotranspiration.	If water is pushed out of bank and stored then infiltration may increase.	Offline storage can lengthen runoff pathways and slow and store water to reduce the downstream flood peak. This effect only lasts until the features reach capacity.
River channel restoration	–	–	Restoration will change the form of the river channel, often storing and slowing the flow to reduce the downstream flood peak.
Floodplain reconnection	Increased wetland area or out of bank flow may increase evaporation.	If water comes out of bank and is stored then infiltration may increase.	Lengthening runoff pathways and storing water on floodplains will store and slow the flow to reduce the downstream flood peak. The features may also delay overland flow reaching the river channel.

NFM measure												
Upland peatland management												
Soil and land management												
Runoff management	*	✓										
Runoff storage	*	✓	✓									
Catchment woodland		✓	✓	✓								
Cross slope woodland		✓	✓	✓	✓							
Riparian woodland			✓		✓							
Floodplain woodland		✓	✓		✓		✓					
Leaky barriers	*	✓	✓	✓	✓		✓	✓				
Floodplain reconnection							✓	✓	✓			
River channel restoration			✓				✓	✓	✓	✓		
Offline storage				✓	✓			✓	✓	✓		

Note

* Leaky barriers, runoff management and runoff storage approaches can be used for upland peatland management. They need to be designed specifically for that environment (**Chapter 6**) to both support peatland function and achieve NFM outcomes.

Figure 4.11 Potential combinations of measures for an NFM site

C Technical detail

Part C gives information on a range of inland NFM measures for those involved in delivery and management. There are 12 measures covered in the manual and of these four are covered in a greater depth.

Courtesy Marcus Huband

Courtesy West Country RIvers Trust

TECHNICAL DETAIL

Contents

Chapter 05 Upland peatland management

Upland peat management aims to enhance peatland in order that it can slow and store the runoff of water from the headwater areas of catchments. The measure types included are:

- Revegetation of bare areas – to improve the surface roughness of the peat.
- Gully blocking using leaky barriers design for a peatland environment. These are wooden, stone or peat barriers, each with a small slot or pipe to store and slowly release water and reduce runoff.
- Ditch blocking – installation of dams, formed from peat extracted adjacent to the ditch to create a widened pool and raise the water table across the site.
- Hillslope pool creation – creation of shallow open water pools on peat hillslopes to retain water.

Upland peatland

Revegetation and habitat management

Courtesy Joseph Holden, University of Leeds

Description: conversion of bare peat or sparse vegetation to a well-vegetated condition, or from uncharacteristic vegetation to peat-forming vegetation, often with a dense surface cover including Sphagnum moss. Habitat interventions or improvements may need to be ongoing. Plug planting and peatland re-wetting may need to be undertaken to initiate good conditions and enable ongoing improvement to the density of peat-forming vegetation on the surface.

Function: enhances surface roughness. This slows overland flow, reduces streamflow peaks and slows streamflow.

Good locations: 10 m either side of any watercourse, gentle gradient slopes within the catchment, areas where there is limited dense vegetation cover directly over the peat surface at depths relevant to overland flow.

Locations to avoid: none, but flood attenuation effects are smaller when implemented only on steeper areas.

Gully blocking using leaky barriers designed for peatland environments

Courtesy PROTECT-NFM

Description: installation of leaky barriers, formed from wooden piling, stone or peat, each with a small slot or pipe to slowly release water. They should be installed in a series of cross-channel barriers repeated at intervals along the length of erosion gullies.

Function: they provide temporary water storage during storm events. This will reduce flow peaks and increase channel roughness. Will also reduce sediment-bound carbon loss from peatlands.

Good locations: long gullies (>50 m) that have developed in the last 200 years, which are <10 m wide.

Locations to avoid: very steep gully sections (>0.35 m per m).

Ditch blocking

Description: installation of dams, formed from peat extracted adjacent to the ditch to create a widened pool. This is repeated at intervals along the length of open ditches. Occasionally other materials (eg plastic piling, wood) can be used to form peat dams, especially if the ditch has been deeply eroded.

Function: to raise the water table across the site. This provides better conditions for peat-forming mosses and promotes original hilltop to hilltoe water flows. Note that there is limited evidence that ditch blocking directly provides flood benefits, but the secondary benefits, by creation of a landscape with dense peat-forming ground cover (eg Sphagnum), are important to help slow flows.

continued...

Upland peatland (contd)

Courtesy Joseph Holden, University of Leeds

Good locations: data, based on topographic index approaches, are required to show which ditches have the greatest effect on redirecting flow away from the peat mass and can be targeted for blocking to aid peat mass re-wetting.

Locations to avoid: modelling is generally required to predict whether ditch blocking could increase or decrease downstream flood peaks. Such effects will depend on ditch orientation in relation to the slope direction and the drainage network. Current evidence suggests that any immediate reduction in flood peak due to ditch blocking are likely to be outweighed by the longer-term benefits of peat-forming vegetation regrowth aided by ditch blocking which will have a larger impact on slowing flows.

Hillslope pool creation

Courtesy Moors for the Future Partnership

Description: development of shallow (30 cm to 50 cm) open water pools on peat hillslopes (not channels) formed by scraping out peat hollows or forming semi-circular raised peat bunds on the peat surface to retain water.

Function: enables additional site-scale temporary water storage during storms, which increases landscape roughness and evaporation loss. This allows additional rainfall storage otherwise not possible within the peat mass, thereby attenuating peak flows. Additional benefits include aquatic biodiversity and improved peatland condition.

Good locations: gentle gradient slopes (0.09 m per m)

Locations to avoid: slopes >0.09 m per m, shallow peat (<75 cm deep).

Where to find out more

See **Chapter 10** for guidance on leaky barriers not located in upland peat habitats – in watercourses, on runoff pathways and in gullies and ditches.

Further reading

Allott *et al* (2019)

Baird *et al* (2020)

Gao *et al* (2016)

Moors for the Future restoration factsheets: **www.moorsforthefuture.org.uk/our-resources**

Yorkshire Peat Partnership (2018a) and (2018b)

NatureScot (2020)

IUCN UK Peatland Programme: **https://www.iucn-uk-peatlandprogramme.org**

Yorkshire Peat Partnership: **https://www.yppartnership.org.uk**

Southwest Peatland Partnership: **https://www.southwestwater.co.uk/environment/working-in-the-environment/south-west-peatland-partnership**

Legal consultees for consent

- Statutory nature conservation organisation for designated conservation sites.

Case studies

Revegetation and gully blocking

Protect-NFM, South Pennines: **https://protectnfm.com**

See **Chapter 10** for guidance on leaky barriers not located in upland peat habitats – in watercourses, on runoff pathways and in gullies and ditches.

Pool creation

National Trust Holcombe Moor trial:
https://www.nationaltrust.org.uk/projects/restoring-holcombe-moor

Chapter 06 Soil and land management

Soil and land management aims to restore or enhance the ability of the wider catchment landscape to intercept, evaporate, infiltrate and store water. The measure types included are:

- Changes to farm management practices – to sustain good soil health so that soils store more water, for example by changing the crop types or use of vehicles.
- Reduce soil compaction – to improve soil structure to increase infiltration and reduce runoff, for example through mechanical aeration.
- Encourage more natural habitats - look for opportunities to protect, enhance, restore, and create more natural habitats to restore hydrological processes.

Changes to farm management practices


Courtesy Victoria Coates, Mott MacDonald

Description: farm management practices to sustain good soil health and reduce soil compaction which can reduce flood risk locally, for small events.

Arable: sow cover crops (eg ryegrass, barley, clover, mustard) to increase organic matter content and increase surface roughness which maintains soil structure and slows runoff in winter. Contour ploughing, across the slope, increases the volume of water held in the soil. Avoid double trafficking and minimise overlap when spraying by using GPS. Minimum or no tillage is becoming mainstream. This can improve soil structure and increase infiltration and water retention.

Grassland: reduce stock density, encourage wintering of stock inside, regularly move feeders and shelter areas to prevent localised soil compaction.

Set aside land: sow with fallow crops, leave to regenerate naturally, or sow with mixed species herbal leys with diverse and deep rooting species. This will increase soil organic matter, improve soil structure, and increase infiltration.

Farm vehicles: improve operational efficiency of tractors by using larger/more tyres with lower inflation pressures and avoiding/reducing activity on land in wet spring conditions (eg by early sowing of winter crops) to prevent soil compaction. Consider moving gates to the driest areas of fields.

Function: good land management reduces soil compaction, increases infiltration, and reduces surface water runoff rates.

Good locations: arable fields, extensively grazed grasslands adjacent to watercourses and used for winter grazing.

Locations to avoid: soils in good condition.

Issues: site specific (dependent on land use and soil characteristics). Set aside land takes time to naturally regenerate. Herbal leys have an optimum period of four years before rotations are needed.

Additional benefits: reduction in soil erosion, reduced fertiliser use, expenditure on feed and veterinary bills, increase in local biodiversity, habitats, water quality and soil carbon storage.

Reduce soil compaction


Courtesy Victoria Coates, Mott MacDonald

Description: direct interventions to improve soil structure and alleviate soil compaction which reduces runoff. The intervention needed will depend on the depth/cause of compaction. These include:

Aeration: mechanical spiking of the topsoil (<10 cm depth) to allow good drainage and aeration for plant respiration in arable and pastoral fields.

Sward lifting: breaks up the topsoil (at 20 cm to 35 cm depth) to improve drainage

continued...

Soil and land management (contd)

and aeration in grasslands, but without damaging the productive sward.

Deep cultivation and subsoiling: break up the soil at depth (>35 cm) to disrupt the plough pan in arable fields which can improve soil structure and also drainage.

Re-seeding or overseeding: use deep rooting plant species to improve soil structure by increasing macropores.

Function: healthy soils with a good soil structure encourage more infiltration in the subsurface and store surface water runoff.

Good locations: heavily compacted topsoil, field gateways, vehicle wheelings, shelter, and feeding areas.

Locations to avoid: these techniques should not be implemented in soils in good condition, in extremely wet, or extremely dry soils.

Issues: site specific, should be implemented at the correct depth and in appropriate conditions, otherwise compaction can be exacerbated rather than improved. Cannot alleviate deeper compaction (>45 cm). Mechanical techniques are restricted by the presence of shallow field drains, or bedrock. Only effective in the short-term, may only partially solve the problem and additional methods may be required.

Additional benefits: increase in local biodiversity (earthworms, microbes, and plant roots) and increase in nutrient availability and more efficient crop growth.

Encourage more natural habitats

Courtesy Victoria Coates, Mott MacDonald

Description: look for opportunities to protect, enhance, restore, and create more natural habitats.

Wetlands: protect and restore nature rich habitats such as wet grassland, woodland, meadows, peatbogs and fens to soak up excess water and release it slowly into river systems. They also act as a natural energy dissipater along river banks.

Native vegetation: protect, restore and create areas of woodland, shrubs, and grasses to increase the amount of interception and evapotranspiration and reduce surface runoff.

Arable reversion: convert arable fields to create species-rich grassland fields to improve soil structure and increase infiltration.

Diverse crop rotations and reduced tillage: diversify organic matter types and increase earthworm populations which increase the macro-porosity of the soil and infiltration.

Function: healthy, well-functioning habitats are species rich and have good soil health so can temporarily store water and release it slowly.

Good locations: degraded arable and pastoral fields close to watercourses, ie locations which help link/expand other good habitats.

Locations to avoid: areas with existing rich habitats, archaeological sites.

Issues: reversion is a long-term commitment: all habitats need to be managed.

Additional benefits: more diverse and new habitats for wildlife, more landscape connectivity, increase in soil carbon storage.

Where to find out more

Environment Agency (2007)

AHDB (2019)

Barlow *et al* (2014)

Dales to Vale Rivers Network (2019)

Forbes *et al* (2015)

Who to consult

- Local catchment advisor.
- Soil scientist.
- Farm advisory services – for advice on policies and grants.

Case studies

Pontbren, Wales: Wheater and Evans (2008), Keenleyside (2013), Marshall *et al* (2014)

Parrett catchment, UK (Godwin and Dresser, 2003): **https://iagre.org/downloads/347casestudy6_improvedsoilmanagementtoreducerunoffandfloodflows-347.pdf**

Soil structural degradation in south west England and its impact on surface water runoff generation: **http://eureferendum.com/documents/sum12068.pdf**

Hodder catchment, UK (Ewen *et al*, 2013)

Skell catchment, UK (Coates, 2018): **https://repository.lboro.ac.uk/articles/thesis/Quantifying_the_impact_of_rural_land_management_on_soil_hydrology_and_catchment_response/9456176**

National Research Centres

Department of Farming and Rural Affairs – Rothamsted Research, Sustainable Soils and Grassland Systems Department, UK: **https://www.rothamsted.ac.uk/sustainable-agriculture-sciences**

Agriculture and Biotechnology Sector – AgResearch, New Zealand: **https://www.agresearch.co.nz/**

United States Department of Agriculture (USDA): **https://www.ars.usda.gov/**

Department of Natural Resources Canada – Agriculture and Agri-Food scientific research centres, Canada: **https://www.agr.gc.ca/eng/agriculture-and-agri-food-canada/?id=1395690825741**

Commonwealth Scientific Industrial Research Organisation – Division of Land and Water, Australia: **https://www.csiro.au/**

Chapter 07 Runoff management

7.1 INTRODUCTION

7.1.1 Overview

This chapter provides information for projects and sites where runoff management has been identified as a viable option. The principle of runoff management is to interrupt, slow, or divert overland flow pathways across the landscape, to encourage infiltration into the ground and divert water away from challenging locations. All measures that manage runoff have multiple functions and co-benefits such as improving water quality and increasing biodiversity (**Table 7.2**).

Figure 7.1 shows that runoff management measures that can be delivered across the landscape, usually in locations with sloping topography. They can be used with runoff storage measures to provide additional flood risk benefits (**Chapter 8**).

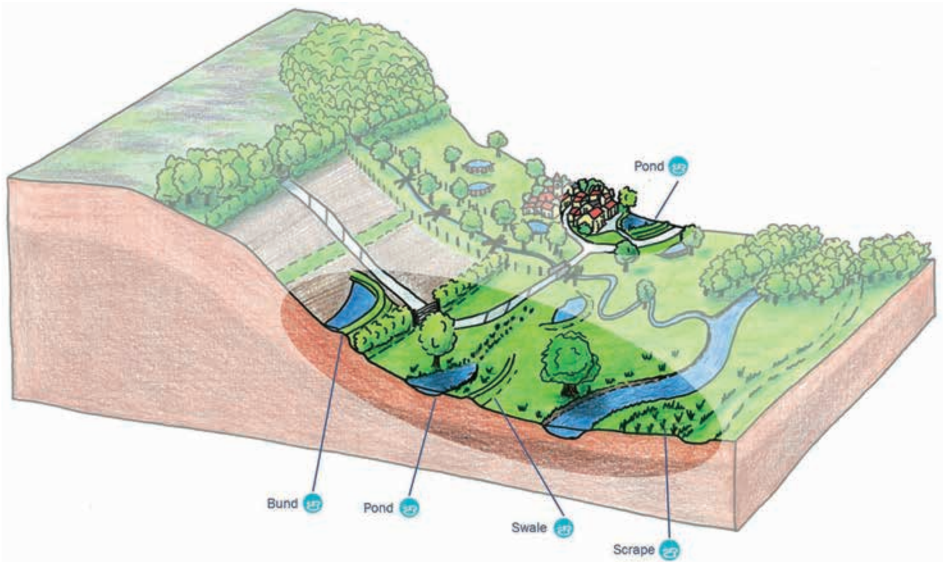


Figure 7.1 Location of runoff management measures within a river catchment (courtesy Emma Wren)

TABLE 7.1 Types of runoff management measures

Challenge	Solutions
Cross drains and deflectors	
Tracks and roads are impermeable surfaces which often cut across natural flow paths meaning that they accumulate and accelerate flow. As a result, water travels more quickly into downstream watercourses. Retrofitting cross drains and deflectors on existing tracks can mitigate for these accelerated runoff pathways by diverting water into areas of higher permeability such as fields and verges or into runoff storage areas (see **Chapter 8**). Cross drains typically sit below the surface of the road whereas deflectors sit above the surface.	 Cross drain installed on a farm track (courtesy West Cumbria Rivers Trust)
Cross slope hedgerows (including banked hedges)	
Hedgerows are an intrinsic part of landscapes and part of the cultural heritage. Traditionally used as a long-term field boundary, hedgerows provide important habitat and wildlife corridors. Hedges can increase interception and infiltration of rain and uptake of water. Banked hedges can further enhance the ability of a hedgerow to intercept and store water as the bank at the base of hedge traps runoff. Hedges can be planted across a slope, including on existing boundaries, where runoff pathways have been identified.	 Banked hedge (courtesy West Cumbria Rivers Trust)
Buffer strips	
Linear features strategically placed across a slope to allow the establishment of rougher vegetation to slow, and help infiltrate and filter overland flow. Riparian buffer strips run alongside watercourses. In-field buffer strips can be found across fields or along field boundaries. They can be used in a range of situations within agricultural land or amenity grassland and alongside woodland, hedgerows/field boundaries or watercourses. Land removed from management can be left to allow natural vegetation to develop.	 Riparian buffer strip (courtesy James Turner)

continued...

7.1.2 BENEFITS AND RISKS

Table 7.2 highlights the benefits and risk of runoff management measures. It is important to consider these to ensure the benefits are realised and the risks are mitigated.

TABLE 7.2 Benefits and risks of runoff management measures

Benefits	Risks
• **Flood risk reduction:** measures can divert, infiltrate and store runoff, helping to reduce downstream flood risk and divert water away from challenging areas such as highways and infrastructure. Features with vegetation elements will take longer to become effective. • **Water quality:** measures can be designed to trap and filter contaminated runoff. • **Climate regulation:** hedgerows and buffer strips can capture and store carbon. • **Habitat creation:** hedgerows and buffers create habitat which can be used as wildlife corridors to link existing habitats. • **Soil health:** help retain soil on the land rather than it being washed into watercourses. • **Farm operation:** hedgerows can be a long-term field boundary. Installation of cross drains on tracks can reduce track scour and erosion and therefore maintenance costs. • **Livestock health:** hedgerows provide a barrier to the spread of disease, especially from animal to animal contact.	• **Flood risk increase:** increased flood risk through incorrect siting of measures, concentrating flow and causing damage. Do not direct runoff straight into watercourses or other runoff pathways. • **Ineffective design:** incorrect location, materials or spacing of cross drains could result in washout and erosion of tracks and roads. Ensure appropriate care is taken during the design phase. • **Blocking field drains:** certain tree species can penetrate drains and cause blockages. Identify drains and avoid certain species like willow and birch. • **Soil loss:** when creating banked hedges, earth moving could lead to excess sediment runoff. Avoid wet periods when constructing bunds. • **Failure to establish a hedge:** inadequate planting and after care could result in young plants not getting established. Ensure a management plan is developed. • **Weed encroachment:** buffer strips could enable unwanted weeds to spread into productive fields. • **Invasive non-native species:** when fencing off areas, there is potential for invasive species to colonise due to reduced livestock grazing. Develop a management plan that could include a small amount of grazing.

7.2 SELECT MEASURES

7.2.1 Location

There are good and bad locations for runoff management measures, **Table 7.3** identifies both good and poor locations for runoff management measures.

TABLE 7.3 Good and poor locations for runoff management measures

Measure type	Good locations	Poor locations
Cross drains and deflectors	• Hydrologically connected farm tracks where runoff can be diverted away from the track. • Where contaminated water can be diverted to areas, or storage features, which can trap and remove sediment and/or pollutants. • Entrances to fields from highways to prevent runoff onto highways which could be a hazard for traffic.	• Extremely steep farm tracks. • Where there is no ground adjacent suitable to buffer or store runoff. • Heavily used roads that are in frequent use by heavy machinery.
Cross slope hedgerows	• Across slopes or at the foot of steeper slopes. • To fit with the local field boundary type and pattern • Along the path of lost (or degraded) hedgerows • Along existing field boundaries or where there is already a fence installed to protect against livestock. • Where hedgerows can be used to connect existing woodlands or habitats.	• Waterlogged areas where plants are unlikely to become established. • Where hedges are not present in the local landscape.
Buffer strips	• Adjacent to watercourses. • Where there is a high risk of soil erosion. • Where there are opportunities to link up existing habitats to create wildlife corridors. • Where they can be at least 5 m wide to align with Defra (2018).	• Where weeds or invasive non-native species (INNS) are a known issue and cannot be managed.

7.2.2 Selecting the measure type

There are several different types of runoff management measures. Selection of the appropriate measure depends on the location, the purpose of the runoff management measure and the knowledge and experience of both the designer and the construction method. **Figure 4.8** provides a flowchart to select measures to manage runoff at source or on overland pathways. **Section 14.3.1** provides some hydrological and hydraulic considerations for the design of runoff management measures.

Figure 7.2 outlines the decision process for installing cross drains and deflectors, cross slope hedgerows and buffers strips based on good locations and poor locations (**Table 7.3**).

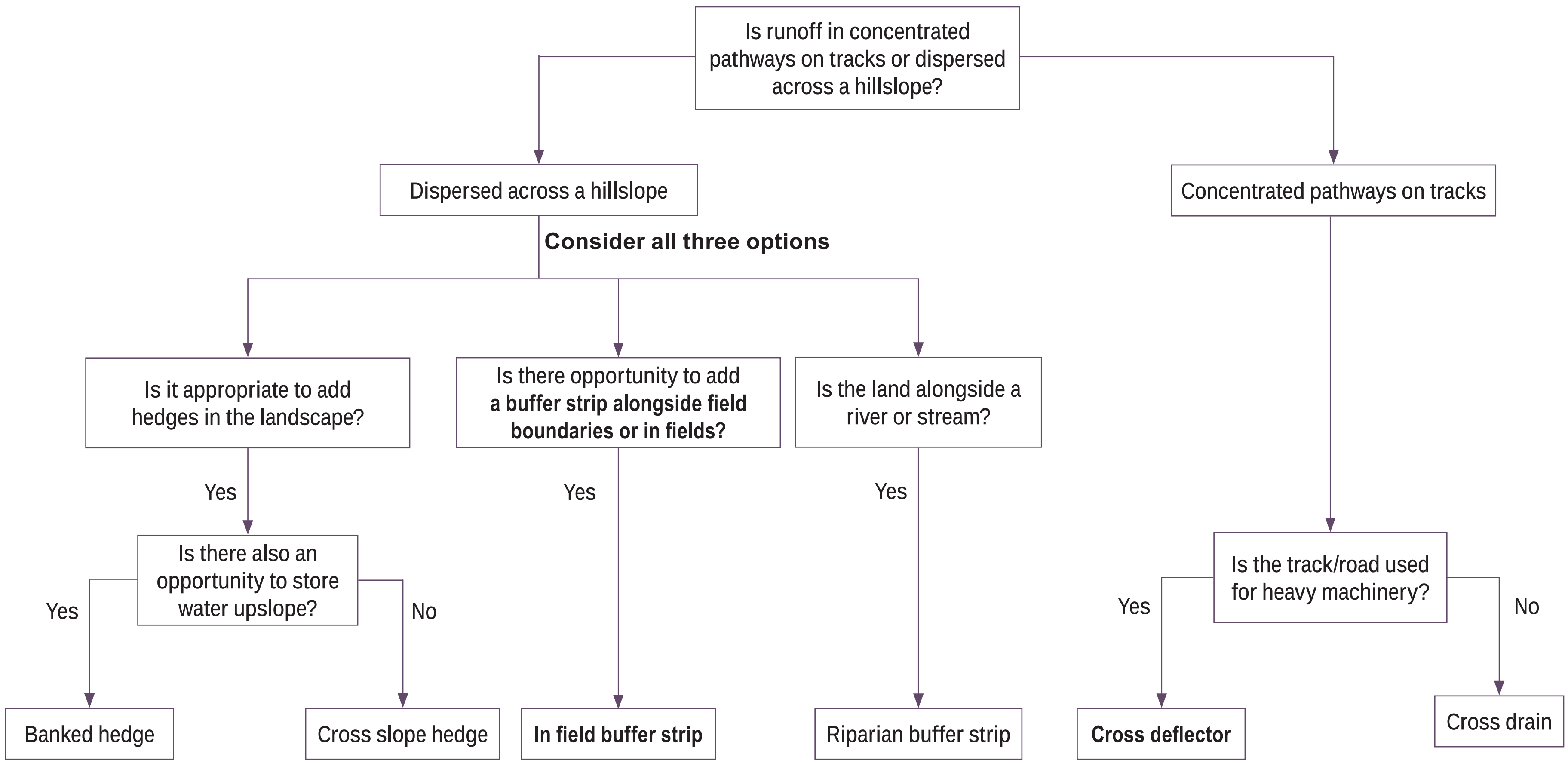


Figure 7.2 Decision flow chart for selection of runoff management measures

BOX 7.1 Banked hedgerows to intercept runoff

Banked hedge storing water deliver as part of the Flimby project (courtesy West Cumbria Rivers Trust)

Location	Flimby, Allerdale, Cumbria, England
Techniques used	Bank created out of excavated soil, hedge planted in two staggered rows, livestock exclusion fencing on both sides of the hedge, 2 m apart
Delivery	The banked hedge was created by West Cumbria Rivers Trust as part of the Flimby NFM project funded by the £15M Defra NFM Project and delivered in partnership with the Environment Agency. The project identified high risk runoff areas in the catchment by assessment of surface runoff mapping, wet weather walkovers and farm visits. Banked hedges were targeted to intercept overland surface runoff from fields grazed by livestock. The landowner was approached, a basic concept design developed, and the storage calculated using simple approaches. It was completed in 2019 and a long-term maintenance agreement is in place with the landowner.
Outcomes	The bank successfully stores and intercepts overland runoff, while the hedge helps to infiltrate water into the ground. This hedge connects existing hedgerows, creating an improved network of wildlife corridors, increasing habitat and food availability for farmland birds and pollinators. The hedge provides a valuable asset and a long-term field boundary and shelter for livestock. As part of the wider project a simple monitoring programme of wet weather observations was implemented to assess the benefits. The findings are fed into The Rivers Trust monitoring and evaluation tool.

https://www.westcumbriariverstrust.org/projects/flimby-flood-alleviation

7.2.3 Health and safety

It is important to consider the specific implications of implementing runoff management measures alongside the wider issues (**Section 4.6**). Specific details around design are in **Section 17.5** and construction in **Section 18.3**.

Understanding the likely route of diverted runoff and whether there is a risk of flooding to people, livestock, property or infrastructure, or a risk of scour and erosion damage should be considered when siting cross drains and deflectors. They should be designed with a safe route to areas of higher permeability such as fields and verges or into runoff storage areas. Regular monitoring and maintenance of cross drains and deflectors should be carried out to assess washout or erosion.

Hedges and buffer strips pose less of a risk. If fencing is required, gates or stiles should be carefully positioned to ensure safe access. Where there is public access, barbed wire should be avoided to minimise the risk of injury.

7.3 DESIGN AND MATERIALS

7.3.1 Design process

General advice on design is given in **Chapter 17**. Runoff management measures aim to reduce or divert runoff occurring in the catchment, delaying the conveyance of water through a catchment. The design and location of these measures will determine their overall effectiveness. The design process typically involves two stages:

- Outline design is essential for cross drains, deflectors and banked hedges and involves selecting suitable locations (**Section 7.2**) and primary materials. With cross drains and deflectors it is important to define spacing, angle and gradient.
- Detailed design is required for tracks which experience heavy traffic and ensures a buildable design that performs the desired function and remains safe throughout its design life.

Health and safety must be considered throughout the design process.

7.3.2 Design components

The design life of runoff management measures is dependent on appropriate monitoring and management (**Section 7.4**). These features have multiple benefits to the landowner and efforts should be made to demonstrate their value and agree how they will be managed.

Table 7.4 provides an overview of design components and typical features for runoff management measures. Where possible living and natural materials should be used.

TABLE 7.4 Design components and typical materials for runoff management measures

Measure type	Design components	Typical materials
Cross drains and deflectors	Earthworks (to set cross drains below the track surface) Fixing structures or earthworks to create a raised mound	**Cross drain:** Pre-cast concrete drains, lined concrete drains, wood, plastic or existing road/track material **Deflectors:** Concrete, stone, wood or existing road/track material such as hardcore
Cross slope hedgerows	Earthworks (for banked hedges)	Trees. Tree guards; spiral and canes or tree shelters and stakes Excavated material Fencing (if livestock present)
Buffer strips	Ground preparation might be required	Fencing (if livestock present)

7.3.3 Cross drains and deflectors

When constructing cross drains and deflectors, it is important to consider the materials used. There should be a balance between product sustainability and longevity. For example, concrete and stone (see **Table 3.5**) will have a longer life span than wood. They should be designed to be easily maintained and replaced as required. The appropriate siting and location of the measures will dictate the longevity. High risk runoff areas are likely to experience greater washout and sediment and debris build-up. In these situations, debris grids or traps should be considered to reduce the maintenance burden (FWAG, 2017).

The design of cross drains and diverters will depend upon the slope of the track, track construction, rainfall and the flow of water along the track. They should be positioned to capture water on the upside of the track and transfer it to the downside outlet such as a field edge. Runoff can then infiltrate into the ground, reducing pollution, soil or track erosion and/or sedimentation of downstream waterbodies. The outfalls should be carefully positioned to not cause erosion.

Cross drains and deflectors should be installed in intervals. The number will be dictated by the length and steepness of the track but should be sited close enough together to capture most of the water during high-flow events. A simple rule can be found in **Section 14.3.1**. **Table 7.5** highlights design considerations for cross drains and deflectors.

Figure 7.3 outlines a typical plan and cross-section for cross drains and deflectors.

TABLE 7.5 Design considerations for cross drains and deflectors

Design aspect	Cross drains	Cross deflectors
Type	Constructed below the surface on tracks for light traffic of domestic and light machinery.	Constructed above the surface on tracks with heavier traffic flow or heavy machinery use.
Where	In a range of situations, including agricultural land, amenity grassland, woodland or on lightly used infrastructure such as farm tracks.	
Dimensions and construction	At a minimum, they should be constructed to 100 mm depth and 100 mm to 250 mm wide. Where high sediment load and debris build-up is likely, the channel should be at least 150 mm wide with a galvanised grating installed (Rural Payments Agency, 2020).	When constructing a raised hump to act as deflector, a foundation trench should be excavated across the track to a depth of at least 300 mm. Kerbstones should be keyed into the trench, so they protrude 60mm to 100 mm above the surrounding area.
Materials	They can be either excavated channels or pre-fabricated concrete, metal or made out of stone or wood to create drainage channels.	A range of material can be used as kerbstones: wood, concrete or existing road material (FWAG, 2017a).

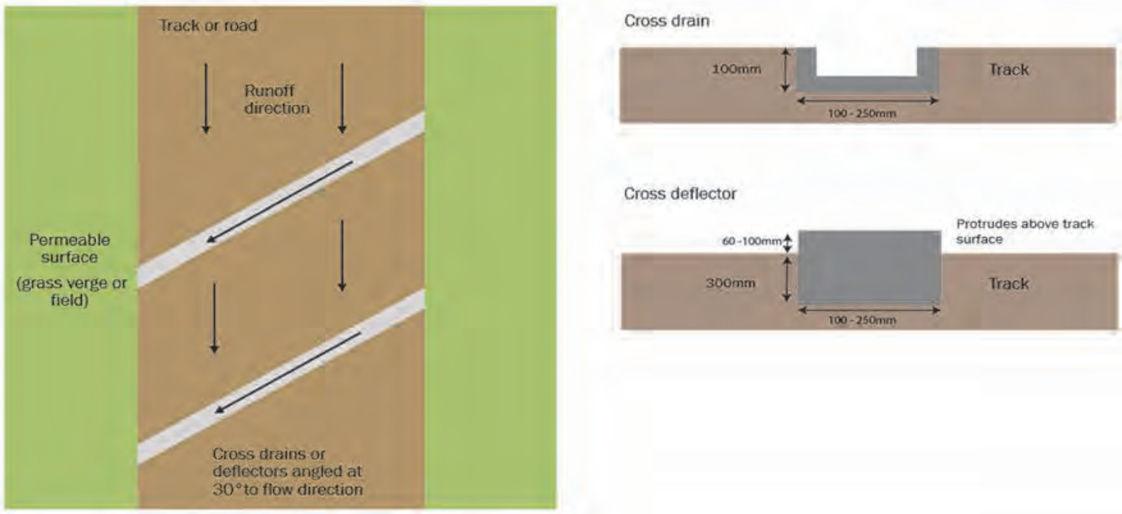


Figure 7.3 Cross drains and deflectors design considerations

7.3.4 CROSS SLOPE HEDGES

Table 7.6 highlights some of the design considerations for cross slope hedges. Cross slope hedges are an effective runoff management technique but can also deliver several additional benefits. When considering cross slope hedges it is important to note their locations and which hedge species are planted to ensure wider benefits such as drought protection, habitat connectivity and shelter are realised. More details on how to consider tree species and planting can be found in **Chapter 9** on woodland management.

TABLE 7.6 Design considerations for cross slope hedgerows

Design aspect	Cross slope hedgerows
Dimensions	The wider a hedge is, the greater the surface roughness and the ability to intercept water. This is particularly important where there are no existing buffer strips or field boundary. Ideally a minimum of 1.5 m width should be allowed for planting. Any fences should be at least 0.5 m away from plants to avoid livestock grazing the young hedge.
Hedge planting (**Figure 8.4**)	Hedgerows designed to intercept overland flow will ideally be planted at a higher density, creating a bushy solid boundary edge. While this can be achieved by early maintenance, initial planting spacing is crucial. Plant two or three staggered rows of trees with between five and nine trees per metre respectively. Plant with a minimum distance of 20 cm to 30 cm between each plant.
Plants	Plant native trees and similar to existing species present in the local landscape (**Chapter 9**). Consider the benefits certain species might bring. Some species have greater ability to slow subsurface flow, whereas others have better wet canopy evaporation properties. Thorny species such as blackthorn and dogwood are good for creating protection, whereas fruit producing species like hazel and hawthorn have high wildlife value (Woodland Trust, 2014). Hedgerows trees are also a good way to increase biodiversity, variation, and structure to the hedge. Placing trees to grow into standards at regular intervals is advised. It is important to mark them to help prevent the trees being trimmed with the rest of the hedge.
Ground preparation	Before planting, clear any existing vegetation which could compete with the new plants.
Establishment	The early establishment of plants is critical to the success of the hedgerow. Plant between October and March. Adequately protected against pests. The level of protection will depend on the location. At a minimum, spiral tree guards and canes should be used to protect the plants in the first two years of growth. Rabbit or deer fencing might be considered in some places. Where hedges are vulnerable to wind exposure or inundation, mesh or tree shelters with solid wood posts should be considered. Use a fence on both sides of the hedge to exclude livestock until the hedge is fully established.

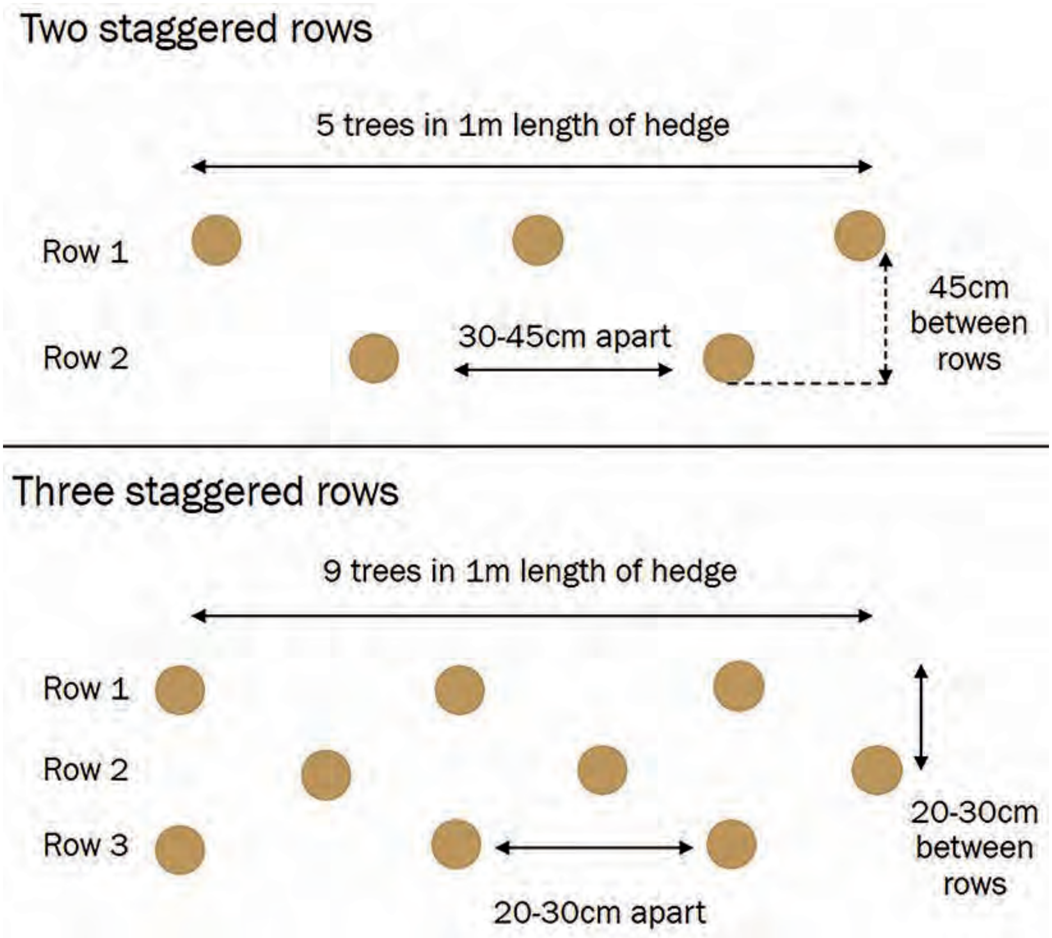


Figure 7.4 Hedge planting density and structure

Hedges planted on a bank are commonly referred to as banked or kested hedges. Devon bank hedges, another local term, are typically a linear earth bank, faced with either stone or turf, but can perform a similar function. Incorporating banks has the added benefit of intercepting and temporally holding greater volumes of water. **Table 7.7** highlights additional design considerations for banked hedges.

When creating banked hedges it is important to consider local approaches such as Devon hedges (Devon Hedges group, n.d.)

TABLE 7.7 Additional design considerations for banked hedges

Design aspect	Banked hedgerows
Dimensions	The height of the bank will depend on the location and desired outcome. The bank should be roughly 0.3 m high and 0.4m wide at the crest. The bank side slope gradient should be as shallow as possible to fit into the landscape especially on the downslope side which could be eroded if it overtops. The side slope should ideally be around 1 in 5, if space permits, and be no steeper than a 1 in 3 gradient to avoid collapse.
Ground preparation	Remove topsoil from an area wider than the intended width of the bund, scraping some of the subsoil either side of the bund line to form the bund.
Bank/bund creation	Allow an extra 25% extra material for settlement of soil. Ensure suitable compaction during the formation of the bund. Replace sods back on top of the bund, making sure they are place upside down to reduce competition.
Planting	Planting structures and density should be two staggered rows (see Figure 3.4). The hedge should be positioned just off the crest of the bank to prevent trees drying out.

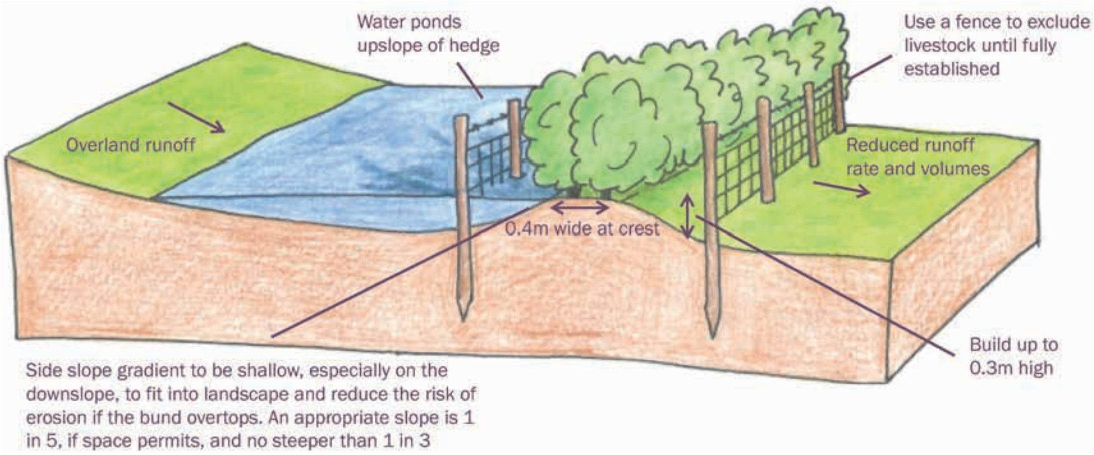


Figure 7.5 Design considerations for banked hedgerows (courtesy Emma Wren)

7.3.5 Buffer strips

Table 7.8 highlights some of the design considerations when considering buffers strip. There are two main types of buffer strips. In-field margins which run alongside field boundaries or within field and riparian buffer strips which run adjacent to watercourses. 'Enhanced' buffer strips (see *Runoff managment summary*, **Chapter 1**) are wide buffer strips that have had other measures, such as runoff storage measures or woodland incorporated into them to maximise outcomes.

TABLE 7.8 Design considerations for buffer strips

Design aspect	In-field margins	Riparian buffer strips
Where	Alongside field boundaries or across fields.	Near to watercourses.
Longevity	Temporary in arable settings (minimum 12 months) or permanent.	Permanent.
Width	At least 6 m.	At least 5 m measured from the watercourse bank top.
Establishment	Livestock should be excluded where stocking rates cannot be kept low. Establish in-field margins in the autumn. Establish through natural regeneration if possible. If there is no natural seed bank, sow seeds that create greater diversity and wildlife benefit. Consult with local seed merchants and wildlife experts to ensure appropriate seed mixtures.	Livestock should be excluded where stocking rates cannot be kept low Permanent fencing should be designed to consider the needs of: • access to water for livestock • access for maintenance of the buffer strip and riparian zone.
Management	Cut annually, after 15 July to allow natural seeding. Fertilisers, manures and pesticides should not be used. Weeds such as nettles, bracken or INNS can be controlled using herbicides through weed wiping or spot treatment.	If livestock exclusion fencing is required, consider a management plan to allow a small amount of grazing. This will help manage the development of unwanted species and encourage a more diverse riparian habitat resilient to extreme flows.
Enhance by providing sites for other NFM or making more diverse habitats	Create a small mound down the centre of the margin to help intercept runoff pathways and create beetle banks. These increase wildlife and encourage natural predators of crop-eating insects (RSPB, n.d.). Incorporating earth bunds or scrapes can optimise the NFM and biodiversity benefits.	Include additional features such as cross slope or riparian woodland, cross slope hedges, sediment traps, swales, ponds and scrapes to enhance their natural ability to reduce runoff and hold water. See *Runoff managment summary* (**Chapter 1**)

7.4 CONSTRUCTION AND IMPLEMENTATION

General advice on construction and implementation is given in **Chapter 19**. Runoff management measures require low impact construction and some aspects can be volunteer led. For example, for cross slope hedgerows, consider using contractors to install the fences (and bank if required) and volunteers to plant the hedge. **Table 7.9** provides an overview of construction methods for runoff management measures.

TABLE 7.9 Construction methods for runoff management measures

Task	Volunteer	Contractor	Landowner	Mechanical plant
Excavation		✓		✓
Installation of cross drains and deflectors		✓		✓
Fence construction		✓	✓	✓
Ground preparation for buffer strips			✓	
Tree planting	✓			

7.5 MONITORING AND MANAGEMENT

There are several different approaches to monitoring NFM measures which are covered in **Chapter 19**. For runoff management measures, regular inspection, fixed point photography and time lapse cameras are a relatively cheap way to analyse how the measures are developing and functioning (Environment Agency, 2018d). Regular review can help identify issues early such as erosion or build-up of sediment in cross drains, helping to reduce maintenance costs. **Table 7.10** provides an overview of maintenance considerations for runoff management measures.

TABLE 7.10 Maintenance considerations

Measure	Maintenance considerations	Frequency
Cross drains and deflectors	Removal of gravel, sediment and debris build-up within drains or behind deflectors. If a channel has been eroded, reshaping the drain might be required after large storm events.	After each flood event
Cross slope hedgerows	Tree aftercare. All trees will require annual maintenance until 1.5 m tall. This will involve weed control, straightening, and tightening tree guards. Removal of tree protection once plants have been established. Once the hedges have been established, the hedge should be trimmed every two years to encourage bushy growth, allowing it to be more effective at intercepting water and creating a long-term barrier. Hedge trimming should take place in the autumn or winter. Hedges must not be trimmed from the start of March to the end of August to avoid disturbing nesting birds. Lay established hedges every 12 to 15 years. This should take place in March or April and avoid disturbing any nesting birds.	Annually
Buffer strips	Check for invasive species colonisation and treat accordingly. Check for weed encroachment into agriculturally productive land.	Annually

Chapter 08 Runoff storage

8.1 INTRODUCTION

8.1.1 Overview

This chapter provides information for projects and sites where runoff storage has been identified as a viable option. Runoff storage involves measures that create and maintain capacity on runoff pathways across the landscape to reduce overland flow. The general principle is that they fill during rainfall events and empty slowly to slow down runoff. This chapter focuses on runoff storage in ponds, scrapes, swales and bunds (**Table 8.1**). These measures increase water storage, and a range of these measures within a catchment can have a cumulative effect by reducing flood risk to communities downstream, along with co-benefits such as habitat creation for wildlife and water quality improvements (**Table 8.2**).

Figure 8.1 identifies that runoff storage measures can be delivered across the landscape, usually in locations with sloping topography where runoff flows in defined pathways. They can be used with runoff management measures to provide additional flood risk benefits (**Chapter 7**). Other NFM measures can also deliver flood storage such as leaky barriers on runoff pathways (**Chapter 6**), offline storage areas (**Chapter 11**) and floodplain reconnection (**Chapter 12**).

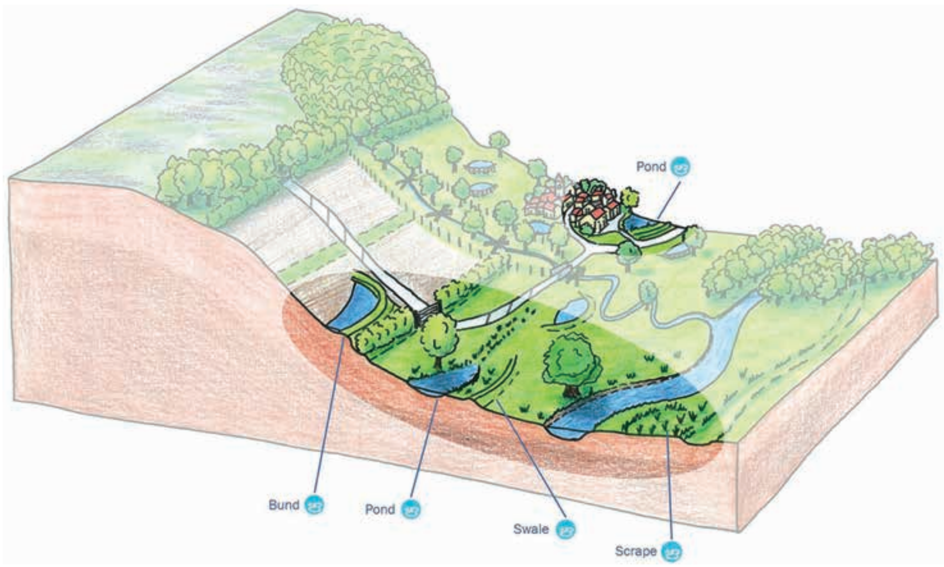


Figure 8.1 Location of runoff storage measures within a river catchment (courtesy Emma Wren)

TABLE 8.1 Types of runoff storage measures

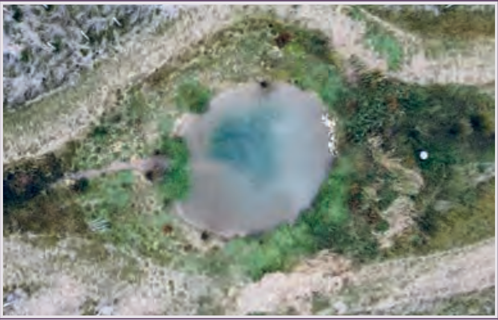
Type	Photograph
Ponds Features that hold water permanently, but with additional capacity to hold more water during storm events. Flood water is then stored temporarily and released in a controlled manner. Ponds described in this chapter are designed and located to store water from runoff pathways.	 Courtesy Evenlode Catchment Partnership
Scrapes Natural or excavated depressions that fill with water in the winter and gradually dry out in the spring and summer. They are designed to have additional capacity to hold more water during storm events. Scrapes discussed within this chapter are designed and located to store water from runoff pathways. Scrapes can be referred to as temporary ponds (Natural England, 2010).	 Courtesy Yorkshire Dales Rivers Trust
Swales Broad, shallow, linear vegetated channels which can store or convey surface water (reducing runoff rates and volumes) and remove pollutants following rainfall (YDNPA, 2017). They can be used in combination with other measures to transfer water from a runoff pathway to another storage measure (eg a pond or disconnected part of floodplain). In addition, they could receive runoff from cross drains. A number of small check dams may be constructed across a swale to slow the flow, reduce erosion and encourage the settlement of sediments.	 Courtesy Atkins
Bunds A bank created to provide flood storage or to help divert runoff. Commonly made from earth but other materials such as timber can be used. For the benefit of flood storage, bunds are constructed along the contour to slow and hold back field runoff. A bund can form a basin where water is held behind it. Bunds can also be constructed at an angle to the contour to slow and divert runoff away from areas at high flood risk. This chapter will focus on the storage element.	 Courtesy Yorkshire Dales Rivers Trust

TABLE 8.2 Benefits and risks of runoff storage

Benefits	Risks
• **Flood risk reduction:** measures are effective as soon as they are installed. Runoff rates are reduced by water retention and controlled flow release which slows the rate of rise of a flood peak. Water storage increases the opportunity for infiltration and evaporation. • **Water quality:** measures allow sediment to settle out from the flow. This has a positive impact on water quality and improves the functioning of downstream watercourses. • **Habitat creation:** these measures, particularly ponds and scrapes, provide new wildlife habitats and increase biodiversity. • **Climate regulation:** wetland habitats, like ponds and scrapes, capture and store carbon. • **Soil retention:** storing runoff close to source allows soil to be trapped in storage features, rather than entering watercourses. Soil can then be returned back to farmland. • **Farm operation:** constructing a raised access track to function as a bund can provide land access benefits, by raising access tracks out of wet areas of fields.	• **Failure:** sudden failure of one or more features could result in a rapid release of water causing flooding of downstream property or infrastructure. • **Erosion:** risk of erosion to a structure, which could cause it to fail, become less effective or increases runoff and sediment transport within the catchment. • **Ineffective design:** if more than one storm event occurs in quick succession these measures could be ineffective following the first storm event because they already contain water. Blockage of inlets and outlets could reduce the effectiveness of structures. Excessive vegetation growth within the measures may reduce the capacity and effectiveness. • **Livestock health:** livestock standing in water and deep mud can increase risk of infections and diseases. The severity of this can vary, for example foot rot is a bacterial infection that can be treated with antibiotics whereas parasitic infections, such as liver fluke, can be fatal.

8.2 SELECTION

8.2.1 Location

These measures are best located on or near runoff pathways, this information can be gathered by local knowledge, field surveys and desktop studies. More information on selecting focus areas or sites for runoff storage measures can be found in **Chapter 4**. Good and bad locations for runoff storage measures can be found in **Table 8.3**.

TABLE 8.3 Good and poor locations for runoff storage measures

Measure type	Good locations	Poor locations
Ponds and scrapes	• On, or near a runoff pathway. • Low point in a field or catchment that receives runoff. • Areas with a safe route for exceedance flows and low consequences of any pond embankment failure. • Non-intensively managed landscapes where native vegetation is already established and/or will flourish (eg field corners or buffer zones). • Agricultural areas, woodland and semi-natural areas. • Locate runoff storage ponds on land that is on slightly higher ground than the floodplain.	• Floodplains may already become inundated during a flood event so the feature will not provide additional flood storage. • Steeply sloping land. • Unstable ground. • Made ground or areas of waste fill, uncontrolled fill or non-engineered fill. • Sensitive areas (eg rare non-wetland habitats and archaeological value). • Areas with highly permeable soils.
Swales	• In areas where it can be used in combination with other measures, for example to receive runoff from cross drains to convey flood water to a pond. • Areas targeted for the reduction of water pollution from agriculture where contaminated water can be diverted to areas that can trap and remove pollutants. • Sunlit areas to encourage vegetation growth – a key requirement for effective functioning – with easy access for regular maintenance of the vegetation.	• Cuttings or embankments where slopes may become unstable. • Brownfield sites, pollution hotspots or other areas where there is a risk of leaching contaminants into underlying groundwater (unless lined to prevent infiltration).
Bunds	• Where runoff can be intercepted. • Close to tracks to divert runoff away from hard surfaces, which act as preferential pathways. • In-field corners and margins to minimise loss of productive land. • Sloping fields where the runoff tends to exit the field at a point, such as a valley bottom, where slopes converge on a low point in the field.	

8.2.3 Selecting the measure type

Figure 8.2 provides a flowchart to select between runoff management and storage measures. Using a range of measures on site is recommended. Consider if the area can accommodate a combination of measures that can work together to complement each other and increase the NFM potential/benefit.

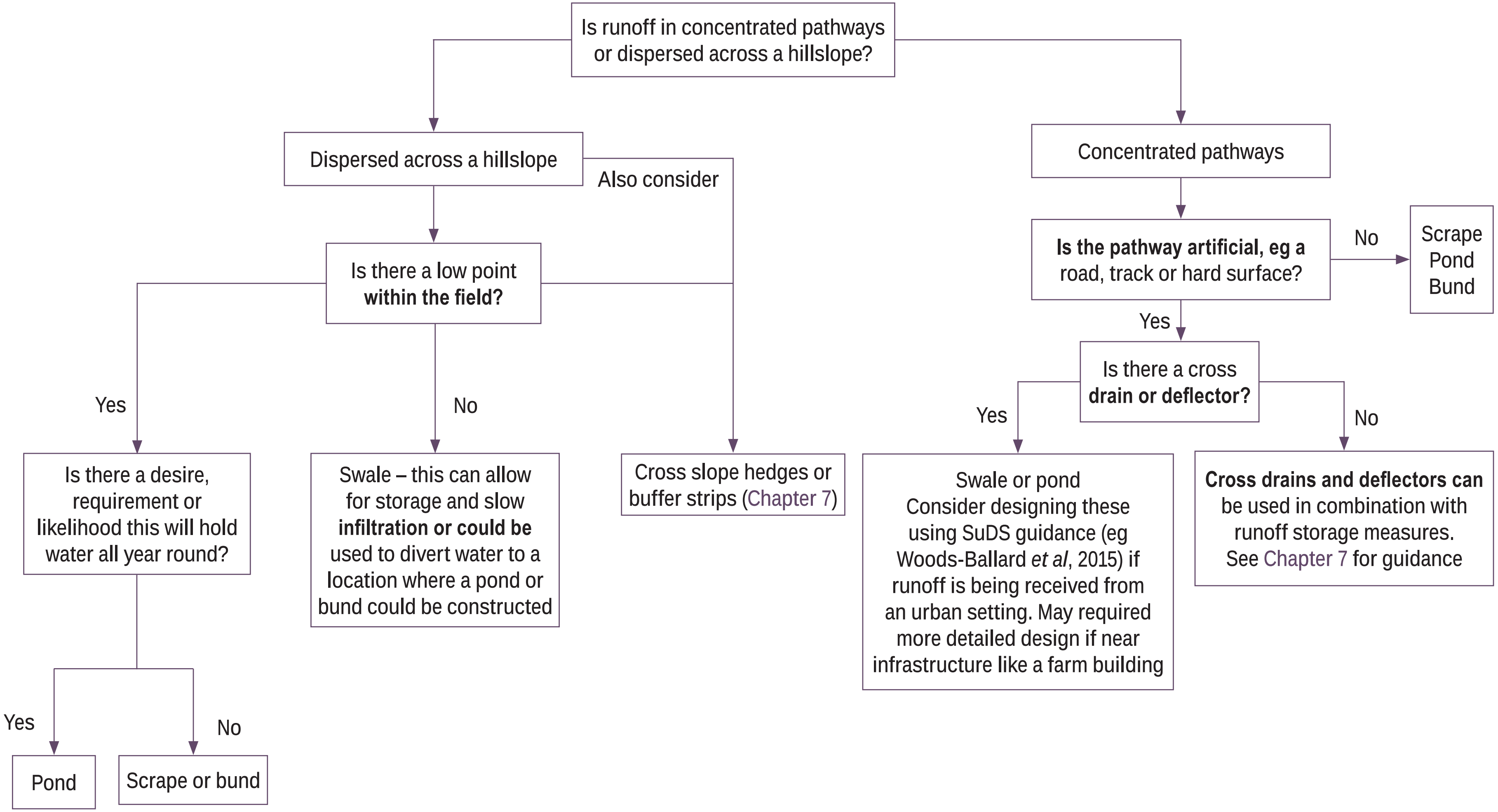


Figure 8.2 Decision flow chart for selection of runoff storage

8.2.4 Health and safety

It is important to consider the specific implications of implementing runoff storage measures alongside the wider issues (**Section 4.6**). Key details on design and safety can be found in **Chapter 17.5** and construction in **Chapter 18**.

Runoff storage measures should be designed to store water in a predictable manner, without increasing risk to third parties. Measures should be designed with a safe route for flows that exceed or overtop the feature. Outlets can help to reduce this risk, allowing water to drain away more quickly than it can naturally through the soil. Consider the exceedance level, the level at which water will start to overflow, the likely route of any overflow and whether there is a risk of flooding to people, property or infrastructure, or a risk of scour damage, where the water erodes the feature as it flows over the top or through the outlet. If measures are constructed in publicly accessible areas, signs are recommended to inform members of the public about the measures and their function and the design should consider safe access and egress.

8.3 DESIGN AND MATERIALS

8.3.1 Design process

Measures to store runoff aim to increase storage within a catchment during periods of prolonged rainfall and storm events. The design and location of these measures will dictate the capacity and frequency in which they are active and remain effective. All runoff storage measures should be designed to look natural, while providing storage during rainfall events. It is also important to consider a proportionate approach when designing measures. **Section 17.2.3** provides details on complexity of designs and **Section 17.3** highlights design considerations. **Section 14.3.1** also provides some hydrological and hydraulic considerations for the design of runoff storage measures.

The design process typically involves two stages (**Chapter 17**):

- **Outline** design is essential for storing runoff and involves selecting suitable locations (**Section 8.2**), and defining the combination of measures, dimensions and primary materials required (**Section 8.3.2**). See **Figure 17.3** for the design process for runoff storage methods.
- **Detailed** design is important to ensure strength and durability, this involves selecting materials, fixings and detailing specified. **Section 17.3** provides a design toolbox.

Health and safety must be considered throughout the design process (**Section 8.2.4**).

8.3.2 Design components

Table 8.4 provides an overview of design components and typical features for runoff storage measures. Further details about design and materials can be found in **Sections 17.3 and 17.4** respectively.

When carrying out earthworks it is good practice to strip the topsoil and set aside. Replace the stripped topsoil over the side slopes and/or base of runoff storage features at a maximum depth of 150 mm to increase the success of vegetation becoming established. If required, fencing should be erected at least 600 mm away from the base of side slopes.

TABLE 8.4 Design components and typical materials for runoff storage measures

Measure type	Design components	Typical materials
Ponds and scrapes	• Earthworks. • May include low point for flow exceedance. • Locate inlets and outlets to maximise the flow path length through a pond. Consider the effects of temporary blockage by sediment or debris. • May require outlet, set at a level on the embankment to provide additional capacity to hold more water during storm events. • Outlets may need a headwall to support the earthworks above and prevent material falling down into the flow. • Provide erosion protection where flow is fast or very turbulent (eg at outlet or inlet pipes).	• Excavated material. • Granular fill (eg sand or gravel) may need an impermeable clay core or waterproof membrane on the upstream face. • Pipe materials, consider using stone or clad to reduce use of plastic. • Stone or biodegradable geotextiles (eg coir matting) at the base of the outflow pipe to reduce the risk of scour/erosion.
Swales	• Earthworks. • Check dams may be needed if swale is located on steep slope and used to transfer water. Check dams can reduce flow velocities and increase storage.	• Stone or timber for check dams.
Bund	• Earthworks. • May include low point for flow exceedance. • May require outflow pipe. To enable bunds to drain down completely, outlet should be set near to the base to allow most flow out and to reduce the risk of blockage. • Provide erosion protection where flow is fast or very turbulent (eg at outlet or inlet pipes).	• Excavated material, timber or stone. • Granular fill (eg sand or gravel) may need an impermeable clay core or waterproof membrane on the upstream face. • Pipe materials, consider using stone or clad to reduce use of plastic. • Stone or biodegradable geotextiles (eg coir matting) at the base of the outflow pipe to reduce the risk of scour/erosion.

Further reading

Benn, J, Kitchen, A, Kirby, A, Fosbeary, C, Faulkner, D, Latham, D and Hemsworth, M (2019b) *Culvert, screen and outfall manual*, C786F, CIRIA, London, UK (ISBN: 978-0-86017-891-0)
www.ciria.org

8.3.3 Ponds

Ponds for flood management consist of a permanent pool with flood storage provided above the normal water level. This should be designed to store runoff and release it in a controlled manner to reduce the peak runoff. They should be sized based on the targeted rainfall event and the area draining to it and designed to release water so that water levels return to normal within 24 to 72 hours. A typical plan and cross-sections are shown in **Figure 8.5** along with simple rules for a typical pond design. Small ponds may dry out during prolonged dry weather. Temporary ponds are such as scrapes are covered in **Section 8.3.4**. Pools more than two metres deep may be subject to stratification and anoxic conditions. Shallower pools may be prone to algal blooms and high biological activity during summer months. Pond designs may vary depending on where the runoff is coming from, for example for runoff from farm tracks or buildings, consider designing measures using principles relating to rural SuDS measures. Consider designing a pond to also provide wildlife requirements (see *Further reading*).

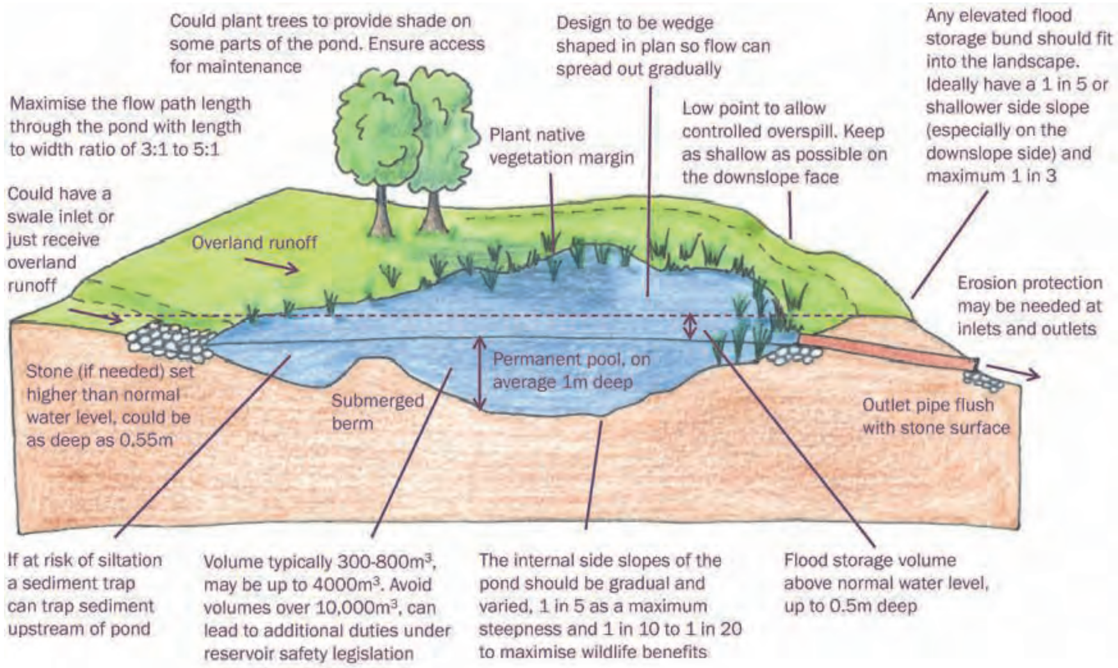


Figure 8.3 Design consideration for ponds (courtesy Emma Wren)

8.3.4 Scrapes

Scrapes do not permanently hold standing water (ie in dry periods) and are generally shallower than ponds. Because they dry out, they provide valuable water storage within the catchment during storm events. Information on the design of scrapes is given in **Figure 8.4**. For projects with a relatively low budget, consider constructing many small scrapes, these collectively can provide as much storage benefit as one large, more engineered pond.

Further reading

Biggs, J, Williams, P, Whitfield, M, FOX, G, Nicolet, P (2020) *Ponds, pools and Lochans, Guidance on good practice in the management and creation of small waterbodies in Scotland*, Scottish Environment Protection Agency, Stirling, Scotland

⇨ Advice on the management of ponds and scrapes.

https://www.sepa.org.uk/media/151336/ponds_pools_lochans.pdf

Duffy, A, Moir, S, Berwick, N, Shabashow, J, D'Arcy, B D and Wade, R (2016) *Rural sustainable drainage systems: a practical design and build guide for Scotland's farmers and landowners*, CREW2015/2.2, Abertay University and Moir Environmental, Scotland

⇨ Guidance on design and construction of runoff storage measures aimed at landowners.

https://www.crew.ac.uk/publications

Freshwater Habitats Trust (2013) *Million ponds project. Designing wildlife ponds in the river floodplain*, supplementary habitat factsheet, Freshwater Habitats Trust, Oxford, UK

⇨ Factsheet on design of ponds.

https://freshwaterhabitats.org.uk/wp-content/uploads/2013/09/FLOODPLAIN.pdf

NFWAG (2016) *Norfolk Ponds Project*, Norfolk Wildlife Trust, Norfolk, UK

⇨ Guidance on managing Britain's ponds and conservation lessons from a Norfolk farm case study.

http://www.norfolkfwag.co.uk/norfolk-ponds-project

Quinn, P F, Hewett, C J M, Jonczyk, J, and Glenis, V (2007) *The PROACTIVE approach to Farm Integrated Runoff Management (FIRM) plans: flood storage on farms*, Newcastle upon Tyne: Newcastle University, UK

⇨ Case study and details around integrated runoff management within a farm setting.

https://research.ncl.ac.uk/proactive/ms4w/PROACTIVEReportPQ.pdf

Woods Ballard, B, Wilson, S, Udale-Clarke, H, Illman, S, Scott, T, Ashley, R, Kellagher, R (2019) *The SuDS manual*, C753, CIRIA, London, UK (ISBN: 978-0-86017-760-9)

⇨ Includes information on the design and management of ponds.

https://www.ciria.org

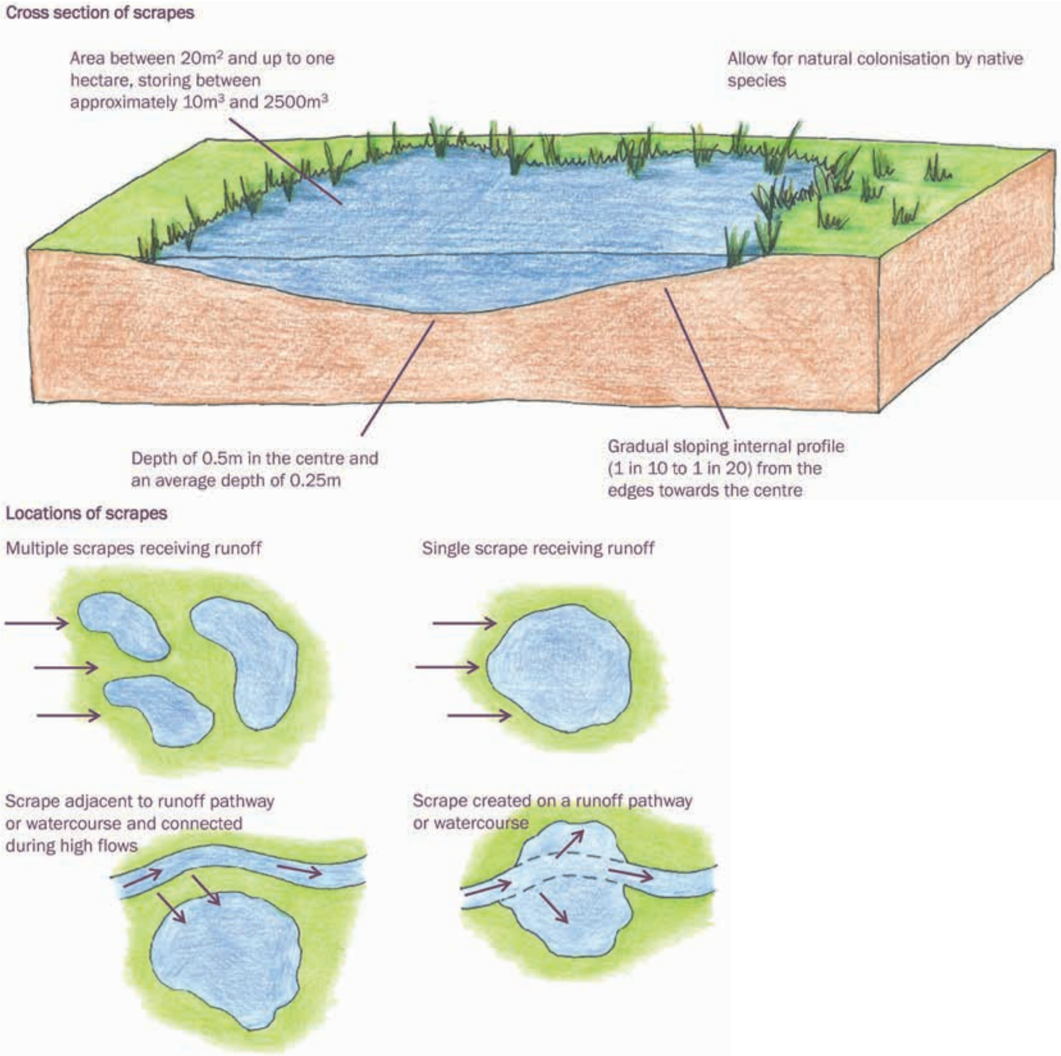


Figure 8.4 Design considerations for scrapes (after Natural England, 2010)

8.3.5 Swales

There are two types of swale:

- **Conveyance swales:** for NFM these are typically unlined and free draining. They can be used to transfer water from a runoff pathway into a storage feature nearby such as a pond or bund.
- **Storage swales:** these are situated to receive runoff and are typically free draining

Swales are often designed to allow infiltration, unless this is prohibited by local conditions such as high groundwater, poor water quality or land contamination, in which case the base of the swale may be lined.

Infiltration increases with residence time, infiltration surface area and soil permeability. Storage swales may have greater infiltration potential due to increased permeability of the subsurface medium and increased residence time, compared to a conveyance swale. Soil permeability in a swale tends to decrease due to clogging over time (depending on maximum water levels and sediment load), although this can be allowed for in the design. The design event runoff volume should half empty within 24 hours.

Check dams may be also incorporated into the design of swales. This consists of small dam constructed across a swale to slow the flow, reduce erosion and encourage the settlement of sediments. As a result, swales are effective in improving water quality of runoff, by removing sediment and particulate pollutants. In wet swales, the effectiveness is further improved by providing permanent wetland conditions on the base of the swale. Check dams can be used on steeper slope swales (longitudinal slopes greater than 3%). They are often adopted to enhance infiltration capacity, decrease runoff volume, rate, and velocity, and promote additional filtering and settling of nutrients and other pollutants. So, check dams create a series of small, temporary pools along the length of the swale, which drain down within a maximum of 72 hours. Swales with check dams are more effective at mitigating runoff quantity and quality than those without. The frequency and design of check dams in a swale will depend on the swale length and slope, as well as the desired amount of storage/treatment volume. Care should be taken to avoid erosion around the ends of the check dams.

Information on the design of swales is given in **Figure 8.5**.

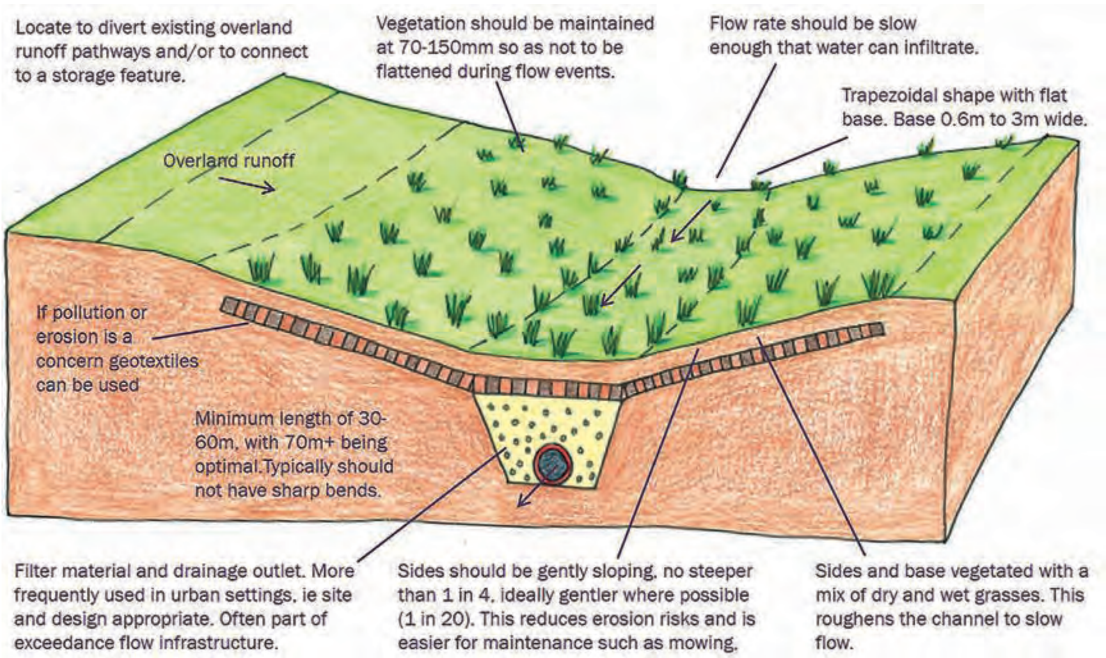


Figure 8.5 Design considerations for swales (courtesy Emma Wren)

Further reading

European Commission (2013) *Individual NWRM swales*, Natural Water Retention Measures project, Office International de l'Eau consortium, European Commission

⇨ General overview of the benefits of swales including, scale, impact, design and costs.

http://nwrm.eu/measure/swales

Kirby, A M, Roca, M, Kitchen, A, Escarameia, M and Chesterton, O J (2015) *Manual on scour at bridges and other hydraulic structures, second edition*, C742, CIRIA, London, UK (ISBN: 978-0-86017-747-0)

⇨ Guidance on scour assessment and detailed design of scour protection.

www.ciria.org

Pennsylvania Department of Environmental Protection (2006) *Pennsylvania Stormwater Best management practices manual*, Vol 34, Tab 20, Department of Environmental Protection, Bureau of Watershed Management, Pennsylvania, USA

⇨ American example of swales being used in more urban setting and provides design considerations.

https://pecpa.org/wp-content/uploads/Stormwater-BMP-Manual.pdf

Woods Ballard, B, Wilson, S, Udale-Clarke, H, Illman, S, Scott, T, Ashley, R and Kellagher, R (2019) *The SuDS manual*, C753, CIRIA, London, UK (ISBN: 978-0-86017-760-9)

⇨ Advice on planning, design, construction, management and maintenance of SuDS, which include swales.

https://www.ciria.org

8.3.6 Bunds

Bunds can be constructed from different materials including earth, stone and timber (see **Chapter 10**). It is important to design bunds for each specific location. The location of a bund is determined by where the water is coming from. Information on the design of earth bunds is given in **Figure 8.6**. **Case study 8.1** provides details of how bunds were delivered within the Holnicote project and the key outcomes.

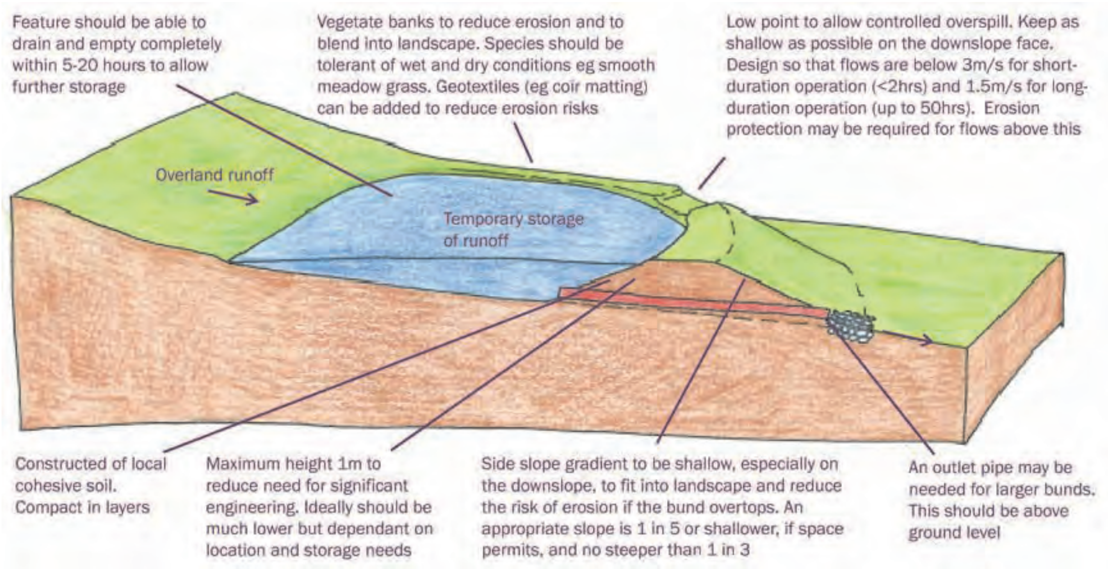


Figure 8.6 Design considerations for earth bunds (courtesy Emma Wren)

CASE STUDY 8.1

Holnicote, from source to sea, creating earth flood bunds

Creation of flood storage and bund at Holnicote (courtesy Peter Worrall, Penny Anderson Associates)

Location	Aller and Horner catchment, Holnicote Estate, West Somerset, England
Delivery	Baseline flow monitoring on the Holnicote Estate began in 2010, with the plan to create a series of offline flood storage areas, using floodplain lowering and the creation of earth storage bunds focused on the Aller and Horner catchment. Sites for earth bunds were initially identified using a 2D flood model. This highlighted areas where surface runoff naturally collected and flow pathways that ran between these collection areas and the stream network. Constraints such as archaeology, heritage, ecology, environmental designations, and landownership were considered. A detailed digital terrain model (DTM) was used to design storage by both putting earth bunds on flow pathways and maximising the areas where surface runoff already collected. A 1D to 2D model was then used to refine the bund design and to consider how water travelled through each bund in detail. This detailed modelling enabled regulation requirements to be understood and to ensure compliance (eg flood risk assessment, land drainage consent and liability under the Reservoirs Act 1975). The design of the bunds was integrated with in-stream structures, including the re-instatement of drop board weirs and floodplain reconnection. Over 200 low level earth bunds were installed in 2013 across both upland and floodplain areas.
Outcomes	During the winter following the installation of the bunds there was a significant flood event. This occurred across the 23 and 24 December 2013, following 50 mm of rainfall over 24 hours, on already saturated soil. The peak flow was estimated to be 10% lower at the gauging station, when compared to similar previous flood events.

8.4 CONSTRUCTION AND IMPLEMENTATION

Overarching principles and issues in the construction and implementation of NFM measures are set out in **Chapter 18**. To construct runoff storage measures from earth a mechanical excavator will be needed along with a contractor or experienced operator. Volunteer-led activities might only be associated with bunds constructed from wood or stone (see **Chapter 10**).

Vegetation planting can be carried out by volunteers or contractors. Simple rules for planting of runoff storage measures can be found in **Table 8.6**. Other information can be found in **Chapter 7** for hedge planting and **Chapter 9** for woodland planting.

TABLE 8.5 Vegetation planting considerations for runoff storage measures

Measure	Considerations
Ponds	Ponds do not need to be planted. Once they have been excavated a simple and cheaper method is to allow for natural colonisation by native species. If planting ponds, it is important to: • use native plant species (research where plants are sourced from to reduce the risk of spreading INNS) • plant a variety of different plants (eg submerged, floating and emergent plants) • check with relevant environmental regulator before translocating plants.
Scrapes	Planting of scrapes is not needed, allow for natural colonisation by native species.
Swale	Grass seed mixture at a rate of 24g/m^2. Grass seed mixture to include grass, legumes, and wildflowers, eg creeping red fescue (70%), smooth meadow-grass (20%), and creeping bent (10%). Sowing should typically be between April and early October.
Bunds	As swale.

Further reading

Illman, S and Wilson, S (2017) *Guidance on the construction of SuDS*, C768, CIRIA, London, UK (ISBN: 978-0-86017-783-8)

⇨ Construction of runoff storage measures.

www.ciria.org

8.5 MONITORING AND MANAGEMENT

Understanding how measures function *in situ* is important. The main consideration for runoff storage measures is sediment build-up, which will have an impact on effectiveness and capacity. The lifespan of all runoff storage measures is indefinite if they are well maintained, ie any sediment deposited is removed. The frequency of sediment removal will be dictated by the location. If there is a high input of sediment from the surrounding landscape, more frequent sediment removal may be required.

The general principles for monitoring and management are set out in **Chapter 19**. Specific recommendations for maintenance requirements are listed in **Table 8.7**.

TABLE 8.6 Maintenance considerations for runoff storage measures

Issue	Maintenance considerations
Sediment accumulation that reduces capacity or function of measure	Remove sediment from measures as required. Landowners should be encouraged to return trapped sediment to their fields. Consider timing of the year to minimise wildlife disturbance.
Blockage	Inlets, outlets and pipes should be checked twice a year and following storm events to remove any build-up of vegetation or blockages to ensure they function as planned.
Overgrown vegetation	Long grass (max 100 mm) should be cut regularly in the growing season, either by strimming or mowing.
Pond plant management	Maintenance activities are recommended to take place in autumn and winter. This reduces the risk of disturbance to breeding birds, amphibians and fish. When emergent plants cover more than 50% of the pond surface, consider removal. When removing plants leave about 20% of the emergent vegetation and do not remove more than 10% of a pond's marginal plants in any one year.
Structural damage and deterioration	Repair eroded or damaged areas as required to ensure design performance is maintained.
Colonisation by INNS	Check measures have not been colonised by unwanted plant species, this risk can be reduced if planting and seeding take place upon completion of the measure construction.

Further reading

Neale, J and Gasca, D (2019) *Catchment science field-scale monitoring handbook*, Atkins, UK

⇨ Guidance on monitoring of runoff storage measures.

https://catchmentbasedapproach.org/wp-content/uploads/2019/08/Atkins-Catchment-Science_Fieldscale-Monitoring-Handbook-2019.pdf

Chapter 09 Woodland management

Woodland helps to intercept rainfall, increase evaporation and uptake by vegetation and infiltration into the soil. It also helps reduce the runoff down slopes and along river corridors. Woodland creation is described and then the four woodland NFM measures:

- Cross slope woodland – belts of woodland planted across slopes with the aim to reduce runoff.
- Riparian woodland – woodland created along river banks to slow the flow in the watercourse.
- Floodplain woodland – trees planted in the floodplain of a river to slow the flow and water.
- Catchment woodland – woodland creation to increase the overall woodland cover across a catchment, where it does not fit into one of the above three categories.

Woodland management

Woodland creation

Courtesy Dominick Spracklen, University of Leeds

Description: increase woodland cover through tree planting or natural regeneration, where trees seed naturally.

Function: woodlands increase the use and interception of water, reduce the volume of water runoff, increase surface roughness, soil infiltration and water storage, reduce the rate of runoff and flood peaks, particularly for smaller flood events.

Good locations: woodland can be created in different locations, namely catchment woodland, cross slope woodland, riparian woodland and floodplain woodland described in this section.

Issues: planning, design, permissions and grant applications take considerable time (typically one year) and need to be completed before tree planting can begin. Tree planting needs to occur in autumn and winter. Design needs to account for the local landscape and existing biodiversity. Planting patterns, species selection and the formation of new topographic features can increase water storage. Site drainage during woodland creation, either as a preparation for tree planting or during construction of forest roads, can increase flood risk and should be avoided. Priority should be given to native tree species to match the soil and climate, and fencing may be needed to exclude livestock. Natural regeneration can create woodlands without the need for tree planting, but only where there are nearby mature trees to provide a seed source. Ongoing maintenance of stock fences and aftercare of planted trees is crucial for successful woodland creation.

Additional benefits: woodlands provide habitat for wildlife, capture and store carbon to help mitigate climate change, shelter for livestock, increase land value and additional options for revenue through wood products.

Cross slope woodland

Courtesy Dominick Spracklen, University of Leeds

Description: tree planting to create narrow belts and blocks of woodland across a slope.

Function: interrupts surface flow of water and increases infiltration and storage of water into soil, reducing rapid runoff. Inclusion of holding features can enhance function.

Good locations: cross slope above a watercourse particularly where overland flow is known to occur, and downhill from arable fields.

Issues: loss of agricultural land may be a concern to some land managers.

Additional benefits: benefits water quality through reduced sediment and nutrient loads; woodland can provide shelter for livestock and create links between existing areas of woodland providing habitat connectivity.

continued...

Woodland management (contd)

Riparian woodland


Courtesy Dominick Spracklen, University of Leeds

Description: woodland creation along watercourses, usually a narrow strip either side of the watercourse often accompanied with exclusion of livestock. Over time, fallen trees will naturally create large woody debris dams, which can also be artificially installed (**Chapter 10**).

Function: increases channel roughness and water storage, slows the flow of water and reduces downstream flood risk.

Good locations: middle and upper catchments are best, with wider and longer riparian woodlands resulting in greater benefits; regions with high risk of sediment delivery where riparian woodland can also reduce diffuse pollution.

Locations to avoid: upstream of culverts or bridges where large woody debris from fallen trees could cause flooding through blockage.

Issues: riparian woodland can reduce access for livestock to drinking water, increased capture of rubbish and debris by the woodland, fencing damage due to increased large woody debris, risk of flood damage to newly planted trees.

Additional benefits: stabilises banks and reduces erosion, reduces sediment and agricultural pollutants entering watercourses, shading of river channels reduces water heating and benefits aquatic biodiversity, habitat connectivity along a river corridor.

Floodplain woodland


Courtesy Dominick Spracklen, University of Leeds

Description: increased woodland cover within the fluvial floodplain.

Function: to increase the roughness of the floodplain, slow the flow of water, increase water storage, delay the time of peak flooding and reduce downstream flood risk. Leaky barriers (**Chapter 10**) can be used to divert flows onto the floodplain.

Good locations: greatest benefit in middle and lower parts of medium to large catchments. Benefits increase with width and length of woodland across the floodplain.

Locations to avoid: immediately upstream or downstream of roads or built environment where increased flood water depth could cause local flooding issues.

Additional benefits: reduced diffuse pollution, improved wildlife habitat, shading of river reduces water temperatures and benefits fish and aquatic life, increased low river flow.

Issues: potential loss of high quality agricultural land.

continued...

Woodland management (contd)

Catchment woodland

Courtesy Dominick Spracklen, University of Leeds

Description: tree planting and woodland creation to increase the overall woodland cover across a catchment, where it does not fit into one of the previous three categories.

Function: increased interception and use of water and increased soil infiltration and water storage reduces flood peaks, flood flows and flood frequency.

Good locations: regions with seasonally waterlogged and flashy soils which generate rapid runoff and regions with soils that are sensitive to degradation. Locations on slopes are preferable to enable runoff from upslope to infiltrate and be slowed by the woodland.

Locations to avoid: no tree planting should occur on deep peat or open habitats with high conservation value, such as species-rich grasslands.

Issues: existing woodlands should be managed through continuous cover forestry (where only selected trees are cut in any year); clear-fell harvesting (where all the trees in one area are cut in the same year) should be minimised, particularly above streams, and should be limited to <20% of a catchment within a three year period.

Additional benefits: carbon storage and climate mitigation, wildlife habitat, and recreation.

Where to find out more

Further reading

Q-NFM project: **https://www.lancaster.ac.uk/lec/sites/qnfm/default.htm**

Barlow *et al* (2014)

Who to consult

- Forestry authority regarding licences, permissions, advice and grant aid, and to determine if EIA regulations apply.
- Woodland Trust can provide free advice to landowners on woodland design, planning and permissions, including information on the range of grant schemes available for woodland creation: **https://www.woodlandtrust.org.uk/plant-trees/large-scale-planting/**
- River Trusts.
- Nearby residents potentially affected.
- Flood risk authority if working in or close to the river.

Case studies

Forest Research (2021)

Keenleyside (2013)

McEwan (2020)

Sussex Flow Initiative: **http://www.sussexflowinitiative.org/**

Sussex Flow Initiative: **https://www.woodlandtrust.org.uk/media/4908/natural-flood-management-planting-trees.pdf**

Tree planting and woodland creation in Calderdale: **http://www.treesponsibility.com/**

Wilkinson and Addy (2019)

Chapter 10 Leaky barriers

10.1 INTRODUCTION

10.1.1 Overview

This chapter provides information for projects and sites where leaky barriers have been identified as a potential intervention to implement. Leaky barriers may form naturally or be constructed across watercourses, temporary (ephemeral) streams, surface water runoff pathways and floodplains using live materials, natural wood, timber or stone. See **Chapter 5** for guidance on leaky dams located in upland peat habitats.

Leaky barriers slow the flow and increase channel roughness, direct water onto the floodplain during higher flows and store water, to be released as the watercourse flow subsides. This can increase water storage, soil infiltration, root uptake and evaporation, and reduce the likelihood of the flood peak occurring simultaneously in tributaries of a larger watercourse. This can reduce flood risk to downstream communities. Leaky barriers provide flood benefits immediately, but geomorphological and ecological co-benefits may take longer to develop. **Figure 10.1** identifies that leaky barriers can be delivered in woodland and can also be installed in non-woodland watercourse, gullies and ditches, and in locations with sloping topography where runoff flows in defined pathways. See **Table 10.1** and **Figure 10.2** for further detail.

Leaky barriers are most effective if they are formed naturally and are placed or built in series. A single leaky barrier stores a small volume of water with little impact on flood risk but the cumulative effect of a series of leaky barriers can reduce flood risk downstream.

Figure 10.1 Location of leaky barriers within a river catchment (courtesy Emma Wren)

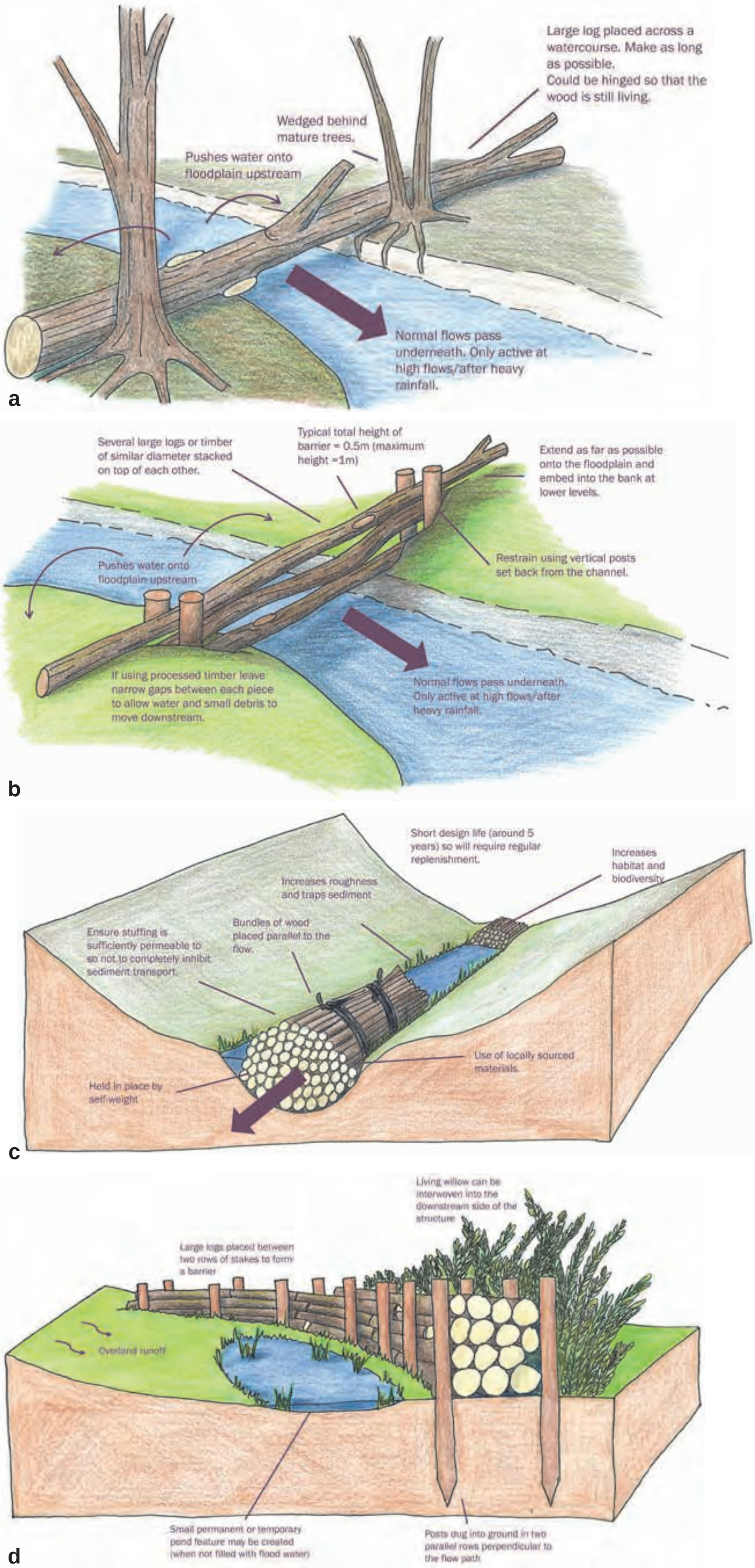


Figure 10.2 Types of leaky barriers: woodland watercourse (a), non-woodland watercourse (b), in ditch (c), runoff pathway (d)

10.1.2 Benefits and risks

TABLE 10.1 Benefits and risks of leaky barriers

Benefits	Risks
• **Flood risk reduction:** leaky barriers increase channel roughness, slow the flow, and encourage it to spread onto the floodplain. This helps to store water, increase infiltration, increase root uptake and evaporation, and reduce flood flows downstream. • **Environmental improvement:** leaky barriers can improve sediment dynamics, flow diversity and water quality, They can also stabilise the riverbank and floodplain. • **Habitat creation:** leaky barriers can provide food sources, shelter and perches for wildlife. They can trap floating debris and sediment, to help regenerate habitat. • **Drought resilience:** leaky barriers on runoff pathways can retain water during dry periods and increase soil moisture.	• **Upstream effects (backwater):** leaky barriers can increase upstream water levels, causing flooding of property, infrastructure, third party land or PRoW, or increasing risk to people, livestock or wildlife. This risk can be reduced by careful positioning. • **Downstream washout and blockage:** leaky barrier material can become detached and wash downstream (potentially at high velocity), blocking structures such as culverts or bridges, and increasing flood risk. Simultaneous failure of a series of leaky barriers may release a surge of water, causing flooding of downstream property and infrastructure. This risk can be reduced by careful positioning (ie sufficiently upstream of downstream structures) and design. • **Public safety:** members of the public may access leaky barriers located in frequently or easily accessible locations. Signage could reduce the risk of injury. • **Fish passage:** a leaky barrier with insufficient opening below water level or a poorly maintained barrier with siltation or other debris may obstruct fish or eel passage. There is potential for fish to become stranded on the floodplain as flood water subsides. Designing structures with a sufficient gap beneath can reduce the risk of obstruction.

10.2 SELECTION

10.2.1 Location

Leaky barriers are best located where there are available living materials or where materials can be locally sourced. Good and poor locations for leaky barriers can be found in **Table 10.2**. **Figure 10.3** presents a decision process based on location characteristics to determine whether leaky barriers should be installed on a watercourse and the mitigation strategies which will need to be implemented to reduce the risk of woody material washout. This is a high-level diagram which provides examples of factors that should be considered and is not a definitive workflow.

TABLE 10.2 Good and poor locations for leaky barriers

Measure type	Good locations	Poor locations
Watercourses	• Position less than 3 m wide, or less than 5 m wide where risk of washout is reduced through design, eg fixings. This allows materials to span the watercourse and reduces risk of material washout, downstream flooding and blockage. • Locate such that floodwater remains within the landowner boundary or obtain agreement from the neighbouring landowner/s likely to be affected. This avoids an increase in flood risk to other landowners without agreement. • Ideally position in woodland areas or grassland with trees or where trees are planned to be planted. This allows use of local woody materials, to reduce biosecurity risk and provide compatible habitat. • Ideally position where there is a not a barrier to receding water carrying fish back to the channel. This avoids fish being stranded on the floodplain as flood water subsides. • Ideally where there is sufficient space for structures to be positioned in series. 7-10 channel widths spacing is advised to encourage channel stabilisation.	• More than 5 m wide. This prevents materials spanning the watercourse and increases risk of material washout, downstream flooding and blockage. • Steeply sloping channels where fast or turbulent flow would cause material washout. • With a sandy bed and/or banks. This would increase risk of flow around and under the barrier causing erosion which can migrate upstream. • In rocky channels. This would prevent effective embedment or anchoring of materials. • Downstream of property or infrastructure that could be affected by upstream water levels. This would increase the impacts on flood risk of increased water levels upstream of the barrier. • Upstream of structures (eg bridges, culverts) which in the event of blockage would cause flooding. This would risk damage to infrastructure and properties.
Gullies and ditches	• Ideally position in woodland areas or grassland with trees or where trees are planned to be planted. This allows use of local woody materials, to reduce biosecurity risk and provide compatible habitat.	• On steep gullies where self-weight (the weight of the woody material) would not prevent materials from moving downslope.
Runoff pathways	• Locate where there is a clear and well-defined runoff flow path to ensure the structure efficiently intercepts flows and its benefit is maximised. • Locate perpendicular to the direction of runoff. • Ideally where there is sufficient space for structures to be positioned in series.	• On steep gradients with limited storage capacity or where, if self-weight (ie the weight of the woody material) is used, this would not prevent materials from moving downslope.

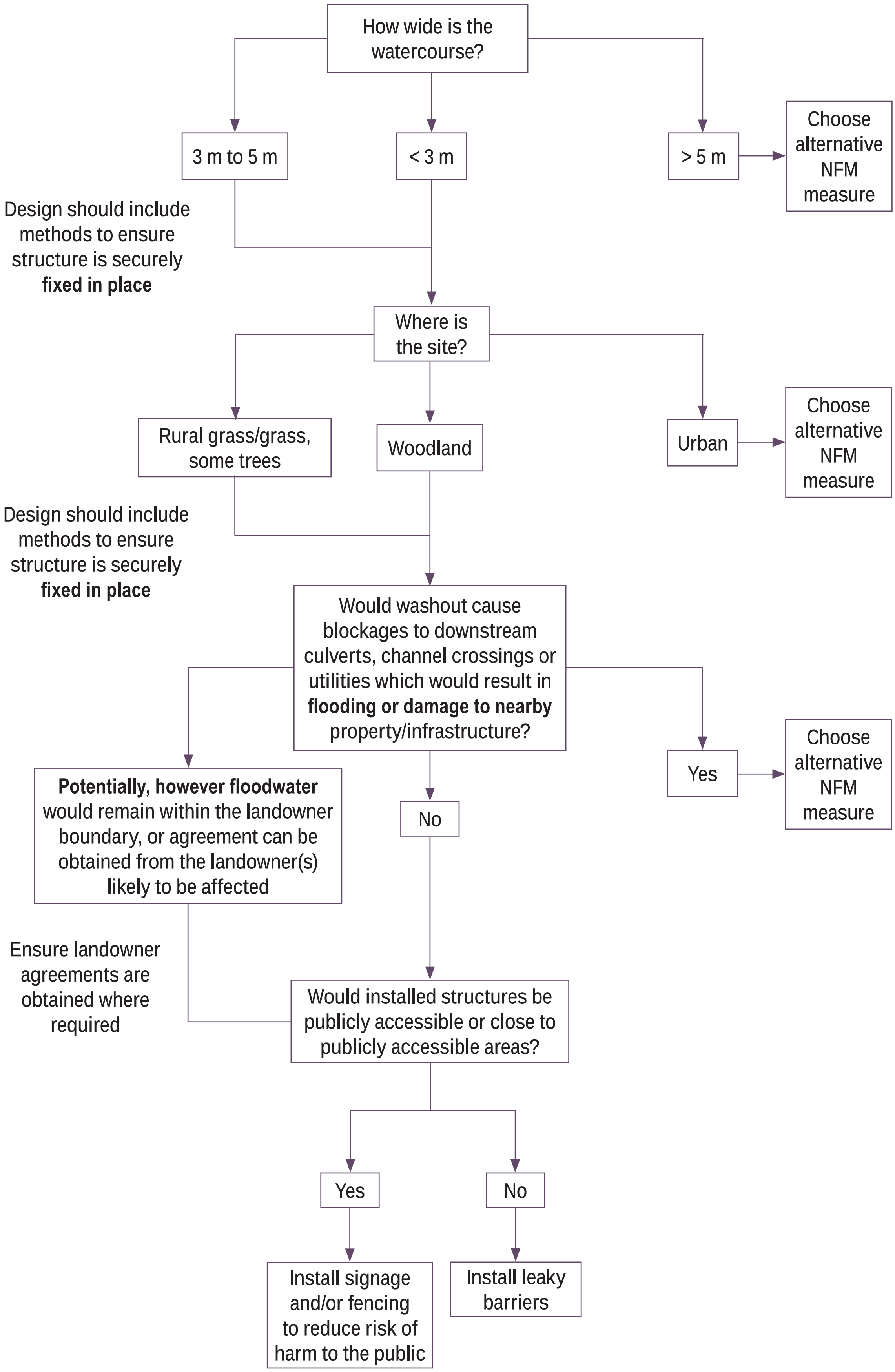


Figure 10.3 Location-based decision flow chart for installation of leaky barriers on watercourses

10.2.2 Selecting the measure type

Knowledge and experience in the design, construction and function of leaky barriers is evolving and there are numerous variations. **Figure 10.4** outlines the decision process for deciding on the type of leaky barriers to install based on location characteristics, aims and available materials.

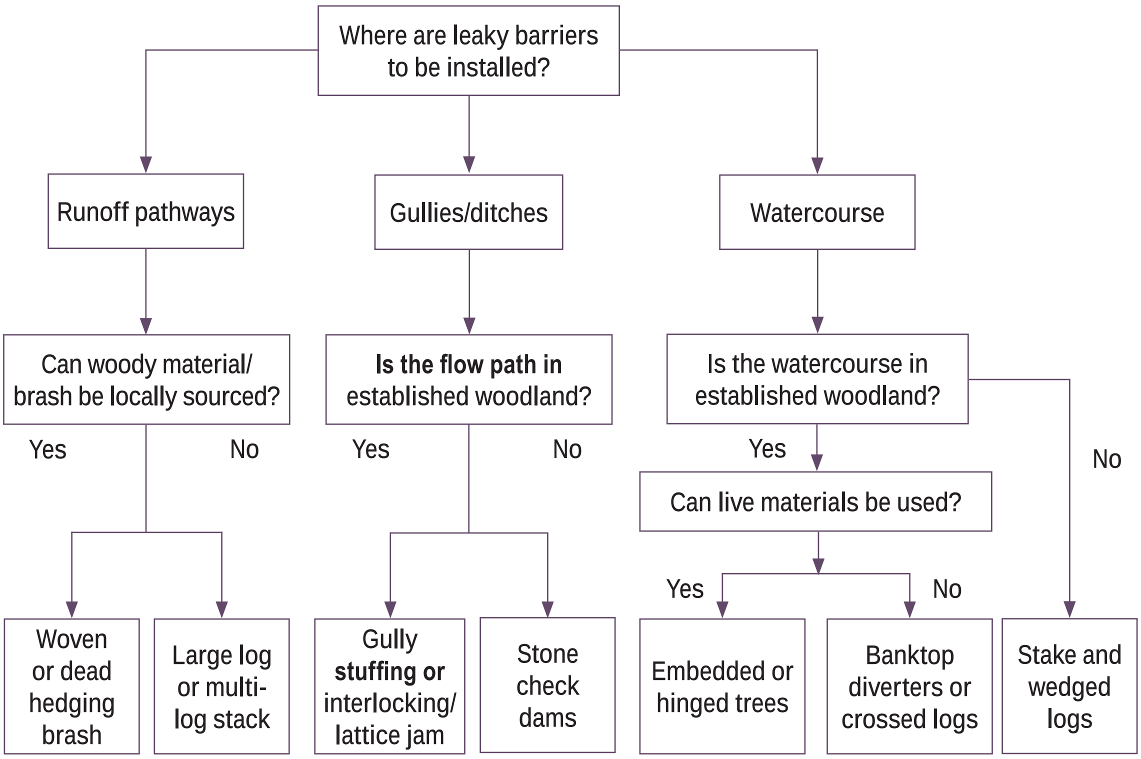


Figure 10.4 Decision flow chart for types of leaky barriers

10.2.3 Health and safety

It is important to consider the specific implications of implementing leaky barriers alongside the wider issues (**Section 4.6**). Specific details on design are in **Chapter 17** and construction in **Chapter 18**.

The likely route of overbank flows and whether there is a risk of flooding to people, livestock, property or infrastructure, or a risk of scour damage, should be considered when siting leaky barriers. They should be designed with a safe route for overbank flow onto the nearby floodplain.

The most downstream leaky barrier in a series should catch debris from any washout of structures further upstream. The design, monitoring and maintenance of the downstream barriers in a series should be prioritised and be more robust than for barriers further upstream.

It is important to be proportionate in considering risks to public safety:

- In high traffic areas such as country parks and nature sites, signage could be used to warn of the risks and raise awareness by explaining the function of measures.
- In medium traffic areas such as popular walking routes and tourist areas, natural deterrents could be used (eg shrubs).
- In low traffic areas such as moorlands/valleys with low traffic walking routes little exclusion would be required.

If restraints and fixings are used (**Table 10.7**), precautions should be taken to reduce the risk of injury. For example, materials used to secure the structure should have no sharp exposed ends. For example, they could be embedded/recessed into the structure and concealed (see Uttley, 2017).

10.3 DESIGN AND MATERIALS

10.3.1 Design process

Multiple designs and types should be built at a single site to provide a wider variety of environmental benefits. The design process for leaky barriers should be iterative, with lessons learnt throughout a project lifespan (**Figure 10.5**). **Section 14.3.2** provides some hydrological and hydraulic considerations for the design of leaky barriers.

The design process typically involves two stages (**Figure 10.4, and Chapter 17**):

- **Outline** design is essential for all leaky barriers and involves selecting suitable locations (**Section 10.2**), defining spacing, alignment, levels and dimensions (**Section 10.3.2**), and selecting primary materials, and type of restraint or fixings (**Section 10.3.3**).
- **Detailed design** is needed for high risk leaky barriers and develops a buildable design that performs the required functions and remains safe throughout its design life. The detailed design of leaky barriers is similar to water-retaining structures and the detailed design methods in **Section 18.3.5** apply.

Health and safety must be considered throughout the design process (**Section 10.2.2**).

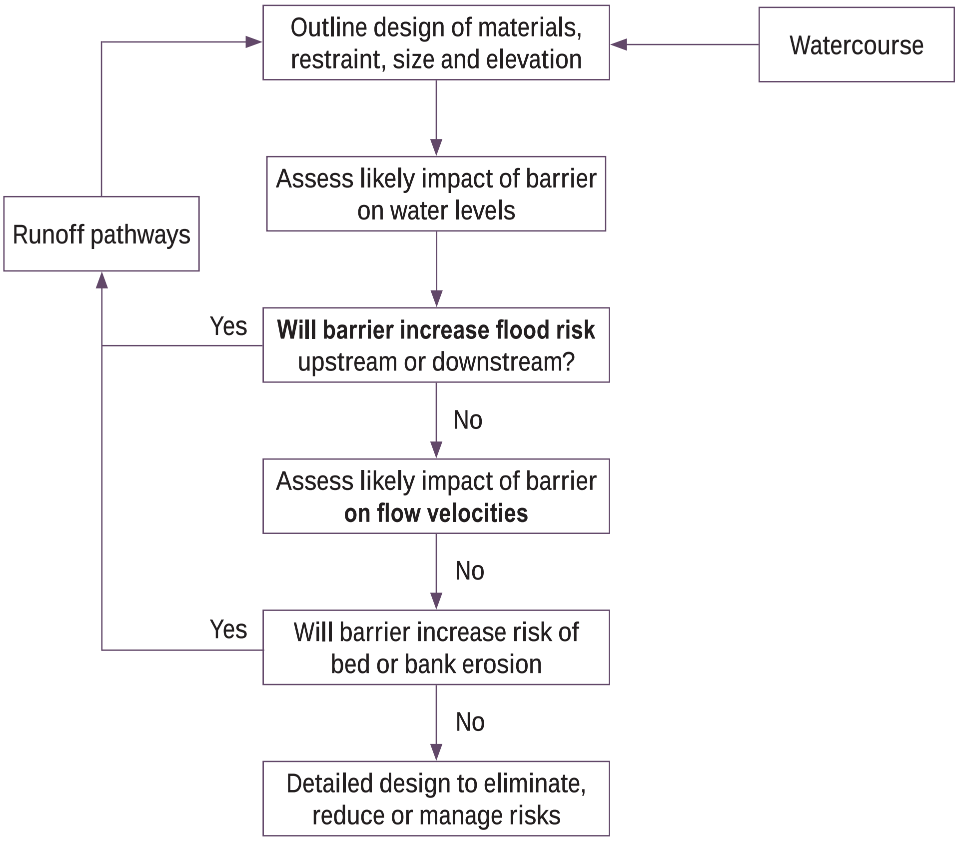


Figure 10.5 Design process for leaky barriers

BOX 10.1 **Learning through implementation – water friendly farming**

a b

Figure 10.6 Barrier designs in 2016 (a) compared to 2020 (b) (courtesy Water Friendly Farming)

Location	River Soar and Welland: Water Friendly Farming (the Allerton project), Leicestershire
Delivery	Water Friendly Farming is a long-term catchment scale research demonstration project aiming to explore the multiple benefits of nature-based measures in three headwater subcatchments across the upper Welland and Soar river basins in Leicestershire. The first leaky barriers were installed in 2016.
Design approach	Intervention design and implementation was an iterative process. Measures were adopted over time so that lessons could be learnt and applied to the design of future measures to improve their stability and function. • Materials were initially a combination of locally sourced and brought-in timber. Monitoring over five years led to a greater understanding of erosion and instability issues around the barriers and to longer lengths of timber being used in newer dams. Consequently, the project used brought-in rather than local timber to increase the structures' longevity. • The study found that a larger flow gap beneath the barrier increased barrier stability and flood storage. By allowing average high flows to pass unimpeded (rather than backing-up behind the dams) there was greater storage capacity available during larger flood events. Barriers constructed in 2020 have a larger bottom flow gap and greater spacing between horizontal logs than those constructed earlier in the project.

10.3.2 DESIGN COMPONENTS

The design life of leaky barriers is dependent on appropriate monitoring and management (**Section 10.4**). These features have multiple benefits to the landowner and efforts should be made to demonstrate their value and agree how they will be looked after and be maintained.

Table 10.4 provides an overview of design components and typical features for leaky barriers.

TABLE 10.3 Design aspects for leaky barriers

Design aspect	On watercourses	On runoff pathways
Series	Ideally installed in series. Smaller structures are preferable to a few larger structures (see **Figure 10.7**) to increase storage volume and distribute storage over a longer reach.	
Height	The height of leaky barriers should not exceed one metre to avoid excessive forces on the structure and reduce the risk of structural failure and sudden release of stored water.	
Spacing	Installed sufficiently far apart such that no barrier is located in the impoundment zone upstream of another (see **Box 10.2** for equation) to avoid causing flotation or failure of the upstream leaky barrier.	
Restraint/fixing	**Table 10.5** provides details of restraints and fixings. The level of restraint and fixing will be dependent on the type of leaky barrier delivered (see **Tables 10.6 to 10.10**).	
Width	Leaky barriers should be as wide as possible to ensure they are well anchored and to reduce their mobility. This also improves hydraulic connection between the channel and floodplain and ensures they are not outflanked/scoured at their edges. This also maximises storage.	Not applicable
Gap	There should be a clear bottom opening (sufficiently above winter base flow level) so as not to impede flow in normal conditions and to avoid obstruction to fish and eel passage (if applicable) under normal flows.	Not applicable
Permeability	They should be sufficiently permeable (leaky) to allow the passage of leaves and small branches. This prevents the build-up of debris, clogging up of the barrier and reduction of storage capacity over time.	Not applicable
Longitudinal spacing (**Figure 10.7**)	The minimum spacing for leaky barriers is: Minimum spacing (m) = height of barrier (m) x watercourse slope (m/m) The height of a barrier should not exceed 1 m. Watercourse slope can be estimated using OS mapping, during site walkover or using topographic survey.	Not applicable

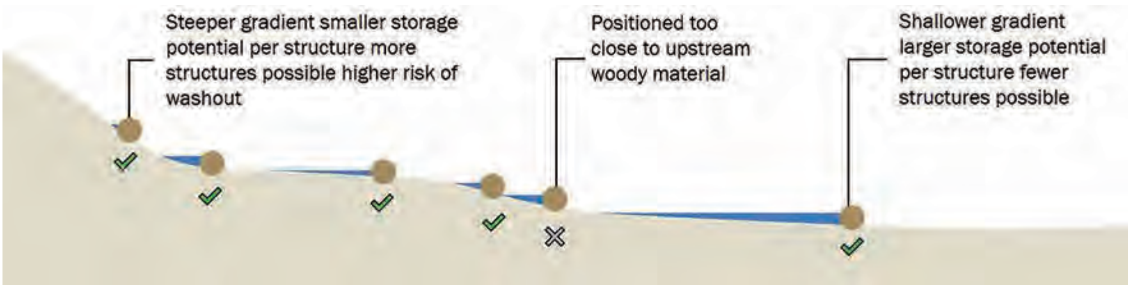


Figure 10.7 Longitudinal spacing of leaky barriers (after Sussex Flow Initiative, 2020)

10.3.3 MATERIALS

Leaky barriers can be constructed using live materials, natural wood, timber and stone (**Table 10.4**). Leaky barriers and their components should be capable of withstanding the mobilising actions during high or flood flow conditions over its design life, and restraint or fixings may be needed (**Table 10.5**).

The choice of materials, restraint or fixings depends on project budget, funding and availability of materials, design life, channel dimensions, flow velocity, proximity to woodland, geology and depth to bedrock, ease of excavating or driving into the ground, risk of erosion around embedded materials, ease of installation, and overall environmental aspirations. The barrier furthest downstream in a series should be the most robust to catch any materials washed out from other barriers upstream and avoid unwanted failure. Consider flow velocities with the leaky barrier in place over a range of flows and water levels.

Chapter 18 provides further information on design and materials.

TABLE 10.4 Materials for leaky barriers

Material	Advantages and disadvantages
Living materials (felled, partially felled or woven)	Renewable, sustainable, low carbon, suited to installation by volunteers, grow and evolve over design life (eg timber woven with willow may mature into a willow thicket).
Natural wood (cut or felled woody material such as logs, branches or trees)	Natural appearance, limited design life.
Timber (wood that has been processed for building or carpentry purposes)	More artificial appearance, limited design life (softwood – 5 to 10 years, hardwood – up to 25 years).
Stone	Indefinite design life provided stones have been designed to withstand flow conditions.

TABLE 10.5 Methods of restraint or fixing for leaky barriers (in order of decreasing preference)

Method	Advantages and disadvantages
Living materials: fell a riverside tree partially or entirely into watercourse, or use living materials (eg willow) to anchor leaky barriers to the banks. Felling with a hinge allows a tree to continue living naturally and secures it to the bank, felling without a hinge detaches the tree from the stump and requires staking of the trunk.	Most secure method of restraint. Good for woodland or watercourses with bankside trees.
Restraint using natural features: position logs to bridge a gap between standing trees, tree stumps, bed rock, boulders or other natural features capable of providing lateral restraint.	A reliable method of restraint. Good for woodland or watercourses with bankside trees, rocky outcrops or boulders.
Self-embedding: logs with root wads self-anchor into stream bed due to sediment deposition, and vegetation, which tends to colonise the whole structure.	Good for woodland or watercourses with bankside trees.
Partial embedment: excavate and bury part of structure in bed or banks. Avoid burying the structure too deeply such that only a small portion of the wood comes into contact with the channel flow.	Good for gravel bed channels and floodplains. Sand may be eroded but may also silt up. Unsuited to bedrock channels or channels with fast flow velocities and erodible bed or bank material where erosion may outflank the leaky barrier during high-flow conditions.
Self-weight: large or heavy material is more resistant to flotation and sliding.	Large logs, dense wood and wood placed in deep water that remains saturated may be more resistant to decay.
Self-restraint: fix several units together so that all the components act as one unified structure. **Rope or wire lashing:** tie logs tightly to one another so that all the components act as one unified structure, or tie logs to driven stakes or rock ballast.	Good for natural wood (eg logs) – tie together into a bundle. Can create a hazard over time as wood or timber decays.
Driven stakes: secure logs between stakes driven into the stream bed. For long elements, provide restraint or mechanical fixings at each end as a minimum. Stakes should ideally be set back from the full channel conditions channel edge and driven deeper than channel bed level to remain stable even when scour has occurred.	Good for silt, sand, gully stuffing. Unsuited to shallow bedrock, very stony or stiff bed material. Wooden stakes preferred, stainless steel rods may be used.

10.3.4 Leaky barriers on woodland watercourses

There are two designs for leaky barriers on woodland watercourses – either using living materials or logs (**Table 10.7**). Living trees can be used to restrain leaky barriers, reducing the likelihood of washout or blockage of downstream water infrastructure such as culverts. The aim of the structure should be considered when choosing a barrier type (see **Figure 10.2a and 10.3**).

TABLE 10.6 Design considerations for leaky barriers on woodland watercourses

Type	Material	Restraint	Advantages and disadvantages
Embedded tree Fell entire trees into the watercourse. Root ball is excavated and buried in the stream bank.	Living material	Live materials	Interacts with all flows. Slows flow by increasing in-channel roughness. Increases habitat diversity. Makes use of locally-sourced materials. Can be self-sustaining. Minimal artificial materials are required. Ensure that branches are removed to make gaps to allow fish passage and sediment transport to downstream habitats. Requires bank excavation.
Hinged tree Fell entire trees into the watercourse. Trees are 'live-hinged'. (**Figure 10.8**)	Live materials	Live materials	Interacts with all flows. Slows flow by increasing in-channel roughness. Increases habitat diversity. Makes use of locally-sourced materials. Can be self-sustaining. Does not require bank excavation. Minimal artificial materials are required. Ensure that branches are removed to allow gaps for fish passage and for sediment transport to downstream habitats.
Banktop diverter or flow spreader/large log Large log of piece of woody material laid across the stream or ditch. (**Figure 10.9**)	Living material	Natural features	Pushes water out onto floodplains. Allow normal and low flows to pass under them. Only active under heavy rainfall/high flows. Reconnects watercourses with floodplain. Makes use of locally-sourced materials. Minimal artificial materials are required. Should be designed to leave a gap to allow fish passage in normal flows.
Crossed logs Similar to bank top diverters but with additional wood within the channel.	Living material	Natural features and self-weight	Makes use of locally-sourced materials. Minimal artificial materials are required. Some (minimal) interaction with base-flow. Requires more securing to reduce likelihood of washout. Should be designed so as not to damage sensitive floral communities such as ghyll streams. Should be designed to leave a gap to allow fish passage in normal flows.

Figure 10.8 Hinged tree living leaky barriers (courtesy Marc Huband, Atkins)

Figure 10.9 Banktop diverter or flow spreader/large log leaky barriers (courtesy Marc Huband, Atkins)

10.3.5 Leaky barriers on non-woodland watercourses

Leaky barriers on non-woodland watercourses (**Figure 10.2b**) will most likely be constructed using non-living material sourced from locations off-site, preferably locally, such as from a nearby woodland. Consider using local non-native tree species of low ecological value. Leaky barriers on non-woodland watercourses may require more robust fixings because riparian trees cannot be used to secure the structures or capture material washed downstream in the event of structural failure. **Table 10.7** outlines the design considerations for leaky barriers on non-woodland watercourses.

TABLE 10.7 Design considerations for leaky barriers on non-woodland watercourses

Type	Material	Restraint	Advantages and disadvantages
Stakes and wedged logs/wall of logs Logs embedded into the banks adjacent to the channel. Strainer posts dug into the bank to support the embedded logs.	Logs	Stakes, posts and artificial fixings	Makes use of locally-sourced materials where possible. Pushes water onto floodplain in high-flow events. Gap beneath barrier should be raised to reduce interaction with normal flows. Requires bank excavation, and robust, artificial fixings. Heavy lifting required in construction, which may require heavy horses or mechanical plant.

Figure 10.10 Stake and wedge leaky barrier (courtesy Yorkshire Dales Rivers Trust)

10.3.6 Leaky barriers in ditches and gullies

Ditches and gullies can act as flow pathways during high rainfall events, where they may become temporary tributaries of watercourses. Leaky barriers installed in gullies and ditches (**Figure 10.2c**) may become 'online' less frequently than those installed in more-permanent watercourses (**Table 10.8**). There are two key types of leaky barriers that can be built in these locations. In woodland settings or locations where woody material can be easily sourced, bundles of wood (gully stuffing) can be placed parallel to the direction of flow. Alternatively, in locations where woody material cannot be locally sourced, stone check dams or timber boards can be constructed perpendicular to the direction of flow.

See **Chapter 5** for guidance on upland peatland management.

TABLE 10.8 Design considerations for leaky barriers in ditches and gullies

Type	Material	Restraint	Advantages and disadvantages
Gully stuffing Bundles of wood placed in the channel parallel to the flow. Best in grips and small ditches (**Figure 10.11**)	Non-living natural wood	Self-weight	Makes use of locally-sourced materials. Interacts with all flows. Increases roughness and traps sediment, and habitat diversity. Construction does not require heavy lifting. Avoid placing where weight is not sufficient to prevent the bundle moving downstream. May inhibit fish passage or sediment transport to downstream habitats if placed in flowing streams. May damage sensitive floral communities such as ghyll streams if not sufficiently permeable. Short design life (about five years) so will require more regular replenishment.
Interlocking/lattice jam Logs arranged in interlocking pattern. Rounded logs with branches removed (**Figure 10.12**)	Logs	Stakes, posts and artificial fixings	Makes use of locally-sourced materials. Increases channel roughness. Encourages the accumulation of sediment and woody material. Interacts with all flows. May inhibit fish passage or sediment transport to downstream habitats. Heavy lifting required in construction – may require heavy horses or mechanical plant.
Timber boards Two posts dug into the toe of the bank. Boards embedded into the bank. Boards secured upstream of the posts with nails or staples (**Figure 10.13**)	Processed wood	Stakes, posts and artificial fixings	Gap beneath barrier can be raised to reduce interaction with normal flows. Requires bank excavation.
Stone check dams Piles of stone profiled by hand to create localised bed riffle features. For information specific to stone barriers, see Moors for the Future (2020b). Advice on the design of stone riffle in-channel features is available in RRC (2020).	Stone	Self-weight	Interacts with all flows, can trap sediment to become vegetated overtime. They can be easily constructed/reprofiled by hand. They do not make use of locally-sourced living materials, although local stone may be readily available.

Figure 10.11 Gully stuffing (courtesy Marc Huband, Atkins)

Figure 10.12 Interlocking/lattice jam leaky barriers (courtesy West Cumbria Rivers Trust)

Figure 10.13 Timber boards (courtesy Yorkshire Dales Rivers Trust)

10.3.7 Leaky barriers on runoff pathways

Leaky barriers can be constructed perpendicular to surface water runoff pathways (**Figure 10.2d**) to slow the surface runoff feeding into watercourses from the surrounding landscape. These designs intercept water closer to the source of runoff and traps sediment before it reaches watercourses. **Chapters 7 and 8** give further information on measures to manage runoff. **Table 10.9** presents design specifications for leaky barriers on runoff pathways.

BOX 10.2 Design principles for leaky barriers on temporary watercourses or runoff pathways

- Such structures can be designed following the same principles as those outlined in **Table 10.3** and **Chapter 18**.
- Structures should be sited according to overland flow pathways to maximise their benefit.
- If sited in series, the most downslope structure should be prioritised in its robustness of design, monitoring, and maintenance so that, if appropriate, it can act as a debris catcher if upstream structures were to fail.

TABLE 10.9 Design considerations for leaky barriers on runoff pathways

Type	Material	Restraint	Advantages and disadvantages
Woven barrier Posts dug into the ground (single row) perpendicular to the flow path Long branches woven between the posts (eg willow or hazel)	Living and non-living material	Natural material posts, willow thicket to improve stability	Increases habitat diversity. Makes use of locally-sourced materials. Can be self-sustaining if combined with living materials such as willow. Minimal artificial materials are required. Can act as a green corridor. Requires regular replenishment if not combined with living materials.
Dead hedging brash barrier Posts dug into the ground in two parallel rows perpendicular to the flow path. Bundles of dead hedging and brash material piled between the two rows. This technique should not act as a barrier to fish passage (**Figure 10.14**)	Living and non-living material (eg posts)	Natural material posts, willow thicket to improve stability	Can be self-sustaining if combined with living materials such as willow. Minimal artificial materials are required. Can act as a green corridor. Requires regular replenishment if not combined with living materials.
Large log Large log placed perpendicular to the flow path (**Figure 10.15**)	Non-living material	Self-weight	Makes use of locally-sourced materials. Minimal artificial materials are required.
Multi-stack log Posts dug into the ground in two parallel rows perpendicular to the flow path. Large logs piled between the two rows (**Figure 10.16**)	Non-living material	Self-weight and wooden posts	

Figure 10.14 Living leaky barrier (courtesy Michael Norbury, Mersey Forest)

Figure 10.15 Multi-stack living log leaky barrier (courtesy Michael Norbury, Mersey Forest)

Figure 10.16 Large log (courtesy Stroud District Council)

BOX 10.3 Using volunteers for runoff pathway leaky barriers, Smithills Estate

Figure 10.17 Leaky barriers (courtesy Mike Norbury, Mersey Forest)

Location	Working in partnership the Environment Agency, Mersey Forest, University of Liverpool and the Woodland Trust developed a NFM programme to decrease downstream flood risk, increase climate resilience, create storage volume and maximise habitat creation. The Smithills community has a history of flooding. Dean Brook, flowing from the West Pennine Moor SSSI downstream into Smithills, carries 12 282 m^3 of water in a 1% annual exceedance probability (AEP) event, which impacts over 50 downstream properties. Smithills Estate is about 900 ha and was acquired by the Woodland Trust in 2015.
Design and delivery approach	Leaky barriers were delivered through a collaborative effort between the contractor and volunteers. To ensure stability, fence posts were installed by contractor plant. Timber from areas of woodland cleared by the Woodland Trust to promote understorey species growth were then carried to site by volunteers and fixed in place. The design ethos meant that all structures have a living component such as willow woven into leaky barrier structures so that a willow thicket will develop over time as non-living woody material decays, reducing future maintenance liability and providing habitat.

10.4 CONSTRUCTION AND IMPLEMENTATION

Some leaky barrier designs require low impact construction and can be volunteer led (**Table 10.10**). However, some designs may require more heavy lifting and require contractors and heavy machinery to move materials into position. For example, consider using a contractor to install vertical timber posts, and volunteers to weave brash material/willow between posts. **Section 3.2** gives information on working safely with volunteer groups.

TABLE 10.10 Construction methods for leaky barriers

Task	Volunteer	Contractor or landowner	Mechanical plant	Heavy horses
Hauling small or lightweight materials	✓	✓		
Hauling large or heavy materials			✓	✓
Driving stakes or posts into the ground		✓	✓	
Rope or wire lashing		✓		
Manual weaving (eg willow)	✓			
Log piling and gully stuffing	✓	✓	✓	

10.5 MONITORING AND MANAGEMENT

The need for maintenance should be reduced by design where possible. However leaky barriers will decay and deteriorate over time. It is good practice to carry out condition assessments twice a year, although inspection may also be needed following high-flow events. **Table 10.11** provides a prompt list of maintenance considerations for leaky barriers.

TABLE 10.11 Maintenance considerations for leaky barriers

Issue	Maintenance considerations
Blockage/ reduced structural permeability	Barriers may require de-silting to avoid stagnant pool formation and enable fish passage. The design may need adjusting to reduce this. Stability and function should be checked regularly (at least annually, depending on design and location). Inspections should happen at different times of the year to ensure assessments under varying environmental/flow conditions. Unless necessary, and a risk assessment determines that it is safe to do so, maintenance checks should not be undertaken from within the stream channel.
Structural damage and deterioration	The use of soft woods, degradable fixings or exposure to high-flow events may result in structural instability or deterioration, for example, softwood leaky barriers have a lifespan of about 5 to 10 years, and more regular maintenance may be required than for hardwood structures. Pins used to fix structures to the bank may rise slightly. In such circumstances the pins should be hammered back into place, so they sit flush with the wood. Natural replenishment is preferred, however reconstruction may be required, particularly in the case of stone dams which may lose mass over time. Additional trees may need to be felled to supplement the original structure over time. Washed out woody material deposited within the channel does not require removal if there is no risk of downstream structural blockage and no risk of impeding fish passage. If downstream structures become blocked, removal of woody debris as required.
End-of-life hazards	Local environmental conditions such as temperature, sunlight exposure and frequency of wetting affect structural longevity. De-silt before barrier removal to avoid releasing silt and reducing downstream water quality. Assess the leaky barrier's habitat functionality prior to removal. Remove non-biodegradable materials from the watercourse during barrier removal.

Ideally, baseline monitoring should be conducted several years before leaky barrier construction. Where this is not possible, the river reach upstream of a series of leaky barriers could be used as a control reach to compare to the river reach downstream of the series. See **Chapter 19** for further information.

Further reading

Adept, Environment Agency, Forestry Commission and Forestry Research (2019) *Assessing the potential hazards of using leaky woody structures for natural flood management*

⇨ Guidance on locating leaky barriers and ways to reduce the risk of material washout.

https://catchmentbasedapproach.org/learn/natural-flood-management-programme-assessing-the-risk

FWAG South West (2018) *Flood Management Information Sheet 11: Leaky woody dams*, Farming and Wildlife Advisory Group South West, Somerset, UK

⇨ Fact sheet to explain the purpose and management of leaky woody dams and outline suitable locations.

https://www.fwagsw.org.uk/Handlers/Download.ashx?IDMF=dd979e4e-fcfe-4567-ad35-30c449a12a1c

Sussex Flow Initiative (2020) *Restoring wood in watercourses for natural flood management*, Sussex Flow Initiative, Sussex, UK

⇨ Provides specifications for types of leaky barrier and general guidelines for positioning them.

http://www.sussexflowinitiative.org/uploads/1/6/3/1/16313516/sfi_lwd_guidance_booklet_nfm.pdf

Utterley, C (2017) *High Water Film: Chris on debris dam construction*, Stroud District Council, UK

⇨ Features leaky barriers delivered by Stroud District Council.

https://www.youtube.com/watch?v=6RZ7TzSWYV4

Yorkshire Dales Rivers Trust (2018) *Naturally resilient. Natural flood management techniques – Level 2. Leaky dams*, Yorkshire Dales River Trust, North Yorkshire, UK

⇨ General design and maintenance guidelines for leaky barriers and and consenting guidance.

https://www.ydrt.org.uk/wp-content/uploads/2021/04/NFM-Leaky-Dams-guide.pdf

Chapter 11 Offline storage

Offline storage measures aim to store water temporarily to reduce the flood peak further downstream. The measure types included are:

- Offline storage areas next to watercourses – to temporarily store additional water in the floodplain.
- Offline storage adjacent to runoff pathways – these are typically a pond or earth bund with runoff diverted into them.

Offline storage

Offline storage next to watercourses

Courtesy Evenlode Catchment Partnership

Description: areas of the floodplain that have been adapted, with a containment, to divert water from the main river channel, temporarily store it, and then slowly release water back to a watercourse after flood levels have receded. The containment may also require an inlet, outlet, and an overflow. An example would be a bund of earth or timber barrier that is built to follow the contour of the slope. They are gravity drained and are usually dry for periods of the year. Design of earth bunds is covered in Chapter 8.

Function: to attenuate and/or delay the in-channel flood peak and overall volume that is passed downstream. There may need to be a leaky barrier (Chapter 10), or other flow control structure on the channel to elevate water levels onto the floodplain and divert water into the storage area.

Good locations: in the floodplain next to a watercourse, on shallow slopes and in fields draining to a single corner, which are naturally wet. These may be unproductive areas, or slopes that are prone to runoff during flood events.

In areas where the outlet would be above normal water level of the river. Where the soil texture is appropriate for founding the bund (ie relatively impermeable).

Locations to avoid: on steep slopes and highly productive areas.

Away from historical, or archaeological features and areas of wildlife value. Away from public access routes, publicly accessible open/green spaces, and roads and not near to INNS, protected habitats and species, utilities assets or trees.

The areas cannot be used to collect dirty water, effluents, or slurries.

Issues: the creation of large structures should be designed by a civil engineer (Section A3.2) and may need planning permission (Section 3.5). Large structures also require regular inspection to ensure they are still intact and working as expected. They may also need to be cleaned and maintained. Consider the potential need to comply with the Reservoirs Act 1975 if designing larger structures.

The design should consider exceedance of the feature, to understand the probable flow paths of water if the feature is overtopped or if it fails.

The creation of structures can have an environmental impact, lead to loss of crop production, and make cutting and mowing practices more complex.

Additional benefits: offline storage areas can encourage the settlement of sediment and reduce soil loss into rivers if created on a large enough scale. The retention of water can be beneficial in drought periods. They can also filter diffuse pollutants and improve water quality.

continued...

Offline storage (contd)

Offline storage adjacent to runoff pathways

Courtesy Evenlode Catchment Partnership

Description: areas that have been adapted to store water by diverting it from a runoff pathway, temporarily store it, and then slowly release water or allow it to infiltrate or evaporate after flood levels have receded.

This will likely consist of a pond or earth bund that has runoff diverted into it using either a low/ extended earth bund (that could also be a banked hedge, a swale or cross drains or diverters to divert water from tracks. Chapters 8 and 9 give more information on the design of these measures.

Where to find out more

Further reading

Ackers and Bartlett (2009)

Newcastle University and Environment Agency (2011)

Yorkshire Dales National Park Authority, Yorkshire Dales Rivers Trust and North Yorkshire County Council (2017)

Who to consult?

- local authority
- flood risk authority
- non-statutory water organisation, eg local rivers trust

Case studies

Belford Burn: **https://www.therrc.co.uk/sites/default/files/projects/16_belford.pdf**

Holnicote Estate: **https://www.therrc.co.uk/sites/default/files/projects/20_holnicote.pdf**

Lustrum Beck: **https://www.therrc.co.uk/sites/default/files/projects/21_lustrum.pdf**

Burn of Mosset:
https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/6.4_Burn_of_Mosset_Forres.pdf

Chapter 12 Floodplain reconnection

12.1 INTRODUCTION

12.1.1 Overview

This chapter provides information for projects and sites where floodplain reconnection has been identified. The principle of floodplain reconnection is to 'reactivate' floodplains to allow permanent reconnection between the river and its floodplain (ie laterally) where this has previously been reduced, or to increase the frequency and/or spatial extent of inundation by floodwater. This reconnection allows water to be stored outside the main channel in times of flood. Floodplain reconnection can also include creation of 'washlands', flood storage areas that are designed to reduce flooding downstream (English Nature, 2001).

Figure 12.1 identifies that floodplain reconnection measures need to be delivered near to the river channel, usually in the middle to lower reaches of a river catchment.

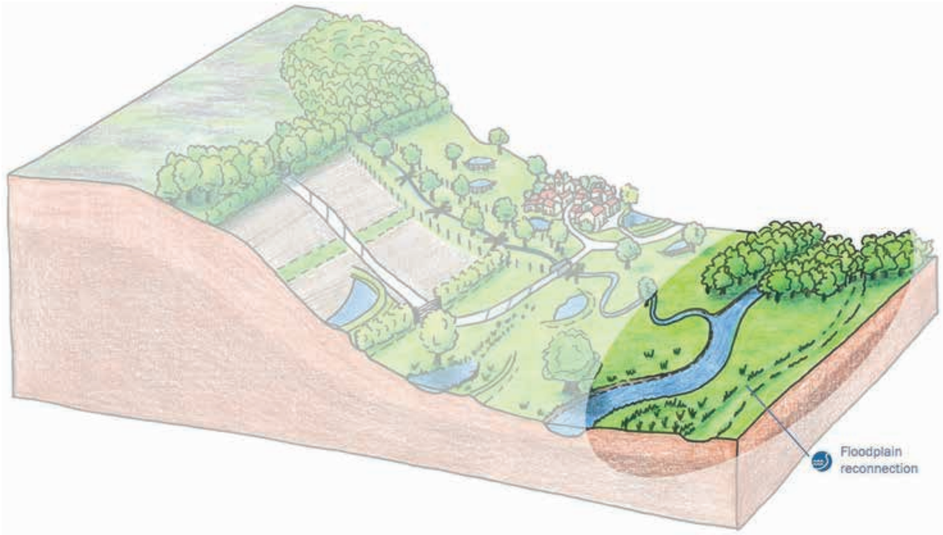


Figure 12.1 Location of floodplain reconnection within a river catchment (courtesy Emma Wren)

Figure 12.2 provides illustration and descriptions of the four types of floodplain reconnection measures that are covered in this chapter, they include:

- remove, set back or lower existing embankments that physically prevent water transfer from river to floodplain
- palaeochannel reconnection – implementing measures to allow former river channels (in the floodplain) to become inundated, in times of higher flows/flood
- in-channel features to elevate flow into the floodplain – natural materials placed in the channel to push water onto the floodplain
- floodplain wetland restoration – creation or restoration of wetland areas within a river's floodplain.

Swindale Beck: remove, set back or lower existing embankments (courtesy Summit Fever Media)

River Evenlode at Pudlicote Farm: palaeochannel reconnection (courtesy Evenlode Catchment Partnership)

River Churnet: in-channel features to elevate flow into the floodplain (courtesy Nick Mott, Staffordshire Wildlife Trust)

Figure 12.2 Types of floodplain reconnection measures

Depending on site-specific conditions (**Chapter 17**), no interventions may be necessary allowing the river to undergo 'natural recovery'. Many rivers will naturally recover and reconnect with their floodplains if allowed to do so. Natural recovery is most typically suitable in rural settings.

Another emerging approach to floodplain reconnection is 'stage zero' river restoration (Bryden, 2020). Stage zero involves regrading and in-filling the existing course of a river to allow it to redevelop, based on stage zero natural reference conditions that pre-date human modification. This approach is not covered in detail here, however a list of further readings is provided at the end of this chapter.

12.1.2 Benefits and risks

In general terms, river floodplain reconnection will encourage interchange of water, sediment and nutrients between the channel and its floodplain. This delivers benefits in terms of flood risk, climate regulation, habitat provision and support to wider ecosystem services. Wetlands can also create benefits in the form of amenity and cultural activities. The specific benefits for a given project will be dependent on site-specific opportunities and constraints.

Floodplain reconnection measures are often delivered in combination with other measures, such as riparian and floodplain woodland, offline storage areas and/or full-scale river restoration (which involves more significant changes to the channel planform, as opposed to focusing solely on lateral connectivity).

Table 12.1 identifies the key risks to be considered in the design of floodplain reconnection measures. Many of the opportunities and risks can be initially reviewed through use of publicly available datasets (see **Chapter 16**).

Table 12.2 describes typically good and poor locations for floodplain reconnection with specific advice for individual measure types (where needed).

TABLE 12.1 Benefits and risks for floodplain reconnection measures

Key benefits	Key risks
• **Flood risk reduction:** reduction in flood risk elsewhere by directing flow onto the floodplain. • **Removal of traditional flood defences:** replacement of traditional flood defences with a more natural and sustainable solution. • **Drought resilience/groundwater recharge:** reduced risk of drought (surface water and groundwater) due to slow release of stored water from the floodplain. • **Restored natural geomorphological processes and ecosystem services:** transfer of water, sediment and organic matter from channel to floodplain (and back again) and creating more room for the river. • **Reduced risk of erosion:** due to dispersal of flood waters across the floodplain, instead of containment in the river channel. • **Soil health:** improved soil retention due to modification of overland flow/land drainage. • **Habitats:** restoration and/or creation of habitat for aquatic and/or terrestrial wildlife (including birds). • **Climate regulation:** potential for greater river and floodplain resilience to future climate change by making space for flood waters. Carbon capture and storage by wetlands to help offset climate change. • **Landscape restoration:** contributes to restoration of a more natural and varied landscape. • **Amenity and cultural services:** aesthetic and cultural benefits for catchment stakeholders and/or local communities.	• **Ineffective design:** measure does not perform as intended due to poor understanding of channel-floodplain hydraulics. This could mean that floodplain connectivity is not restored fully, or that the floodplain wetland habitat cannot be sustained. • **Flood risk increase:** increased velocity, depth and/or frequency of flooding to third party assets and infrastructure (including buildings, utilities etc) and sensitive or protected habitat, upstream and/or downstream, compared to before the measure was implemented. • **Erosion and/or deposition:** increased risk of scour and/or sediment deposition compared to before the measure was implemented. This can affect the location and performance of the measure itself, in the wider channel and/or floodplain. • **Embankment failure:** increased potential for remaining sections of embankment to be undermined/breached (if embankments are lowered, removed or breached to reconnect floodplain). • **Failure of structure:** risk of in-channel measures being undermined and materials (eg timber/stone) being entrained in flow, posing a flood hazard (if in-channel structures are used to reconnect floodplain). • **Fish stranding:** potential for fish to be unable to return to the main river channel, due to topographic depressions in the floodplain. • **Invasive species:** potential for invasive species to colonise the floodplain or wetland (or in reverse into river) due to improved connectivity.

Box 12.1 provides an example of lowering, removing or 'setting back' existing embankments.

TABLE 12.2 Good and poor locations for floodplain reconnection measures

Measure type	Good locations	Poor locations
Advice applicable to all floodplain reconnection measures	• Areas identified with potential for floodplain reconnection in existing datasets (eg Environment Agency WWNP, 2020 and EEA, 2020). • Areas where increased lateral connectivity could improve and/or restore hydrologically dependent riparian and floodplain habitat, including where Identified in existing river restoration plans or flood risk management plans.	• Urban environments (where flood defences are maintained and reduce flood risk to the community). • Areas with river crossings (eg bridges, culverts, buried pipelines or other utilities). • River reaches with high stream power (typically steep, narrow watercourses). • Areas with known issues of erosion (where erosion risk cannot be readily managed as part of the design). • Areas of high-grade agricultural land (where increased flood risk may be less acceptable). • Areas with high-quality habitat, which could be adversely affected by increased frequency and/or magnitude (velocity and/or depth) of inundation. • Areas of contaminated land.
Remove, set back or lower existing embankments	• Areas where existing defences are informal, obsolete, in poor state of repair, provide limited benefit or can otherwise be set back.	
Palaeochannel reconnection	• Areas identified to have palaeochannels, associated with a previous course of a river (based on appraisal of aerial imagery, historical mapping and/or LiDAR). • Areas with limited elevation difference between channel and floodplain.	
In-channel features to elevate flow into the floodplain	• Typically, implemented in the middle and lower reaches of a river catchment. • Areas with existing lowered banks or some degree of existing floodplain connectivity.	
Floodplain wetland restoration	• Land next to existing wetlands (to expand total area of wetland). • Areas identified to have historically sustained wetlands and sites that have a watercourse running through them (based on contemporary and historical OS maps, flood risk maps, topographic survey and/or hydraulic modelling). • Former wetlands that have been drained or are otherwise degraded. • Areas identified to be low-lying and periodically inundated by fluvial flood waters. • Poorly drained soils or land with a high water table, including areas with redundant land drainage channels in the floodplain (which could be infilled). • Low-lying areas, typically in the middle and lower reaches of a river catchment.	• Sloped land (that will generate high rates and/or volumes of surface water runoff). • Areas with free-draining soils.

BOX 12.1 **Swindale Beck floodplain reconnection**

Swindale Beck floodplain reconnection under construction (courtesy Summit Fever Media)

Location	Swindale Beck, Lake District National Park, Cumbria, England
Techniques used	Removal of engineered bank protection, palaeochannel reconnection and river restoration.
Delivery	Swindale Beck is one of the largest and most ambitious upland river and floodplain naturalisation projects in the UK. AECOM provided geomorphological designs to breach historic channel realignments and predict channel self-restoration back to a more natural, meandered form. Site supervision was undertaken during channel construction works, to guide creation of habitat forms that 'work with' the river and the floodplain, and 'slow the flows' for NFM and habitat restoration. Restoration options were identified by a fluvial audit (geomorphology assessment). The fluvial audit reviewed the baseline conditions and characteristics of the channel, describing the historic interventions that had been made. The river had been placed into a stone-lined, straightened course before the earliest available maps (1859) were produced. Raised embankments (from generations of dredging) had cut-off the channel from its floodplain and prevented flow back into the channel after the levees were overtopped. The fluvial audit identified reconnection options and desired outcomes: to restore sinuosity, to reconnect the channel to its floodplain, attenuate flow in the floodplain, restore in-channel and floodplain habitat quality and contribute to reducing downstream flood risk. The design proposed excavating a meandering channel, in part following palaeochannels that were identified with a drone survey (to produce a digital elevation model). Hydraulic modelling, to understand frequency of floodplain inundation and preferential flow pathways provided increased confidence in the design. No sensitive floodplain receptors were identified that would be at risk of flooding or scour. Part of the restored reach passed through a hay meadow SSSI, which required careful planning for construction activities, to manage plant movement and soil storage. A geomorphological clerk of works was required for construction supervision. The project was delivered in partnership by the RSPB, United Utilities (landowner), the Environment Agency and Natural England. The total cost of the project was £209 000.

continued...

BOX 12.1 Swindale Beck floodplain reconnection (contd)

Outcomes	The project was completed in 2016 and restored one kilometre of dynamic, meandering river system, reconnected with its floodplain, improving both in-channel and floodplain habitats. Salmon spawning was recorded shortly following construction. Other complementary projects, including the restoration of over 1000 ha of blanket bog, 15 ha species-rich hay meadow and woodland (40 000 trees planted) have been carried out, which collectively contribute to a whole catchment restoration. The project is a good example of NFM used to provide multiple environmental benefits at the river valley scale.

12.2 SELECTION

12.2.1 Location

Selecting the floodplain reconnection measure type and identifying the location for delivery and implementation is an integral step and is covered in **Chapters 2, 17 and 18**. This section provides specific advice to identify the best location for floodplain reconnection and how to select the most appropriate measure type.

12.2.2 Selecting the measure type

Figure 12.3 outlines the selection process to determine appropriate floodplain reconnection measures for a given site, based on likely good and poor locations (see **Table 12.2**).

12.2.3 Health and safety

It is important to consider the specific implications of implementing runoff storage measures alongside the wider issues (**Section 4.6**). Specific details on design are in **Section 17.5** and construction in **Section 18.3**.

As floodplain reconnection involves deliberately increasing the frequency, spatial extent and/or depth of flooding, health and safety should be factored into the design. The measures should be designed so that they increase flooding in a relatively controlled and predictable manner, without increasing risk to third parties up or downstream. Consider the likely route of overbank flows and whether there is a risk of flooding to people, livestock, property or infrastructure, or a risk of erosion and scour damage.

As the reconnected floodplain will likely involve new or altered flood regimes, installation of temporary flood warning signs should be considered to alert members of the public that there is a new or increased risk of flooding. This should be assessed on a site-specific basis, for example, public footpaths or frequently used routes through floodplains. If required, signs should ideally include a short explanation of the purpose and benefits delivered by the floodplain reconnection. If in-channel structures are required to elevate flow into the floodplain, these measures would ideally be located in less publicly accessible areas. However, if the measure is installed where the public can access river bank, consideration should be made to install a fence along the bank top to limit access.

Box 12.2 provides an example of floodplain reconnection on the River Wensum.

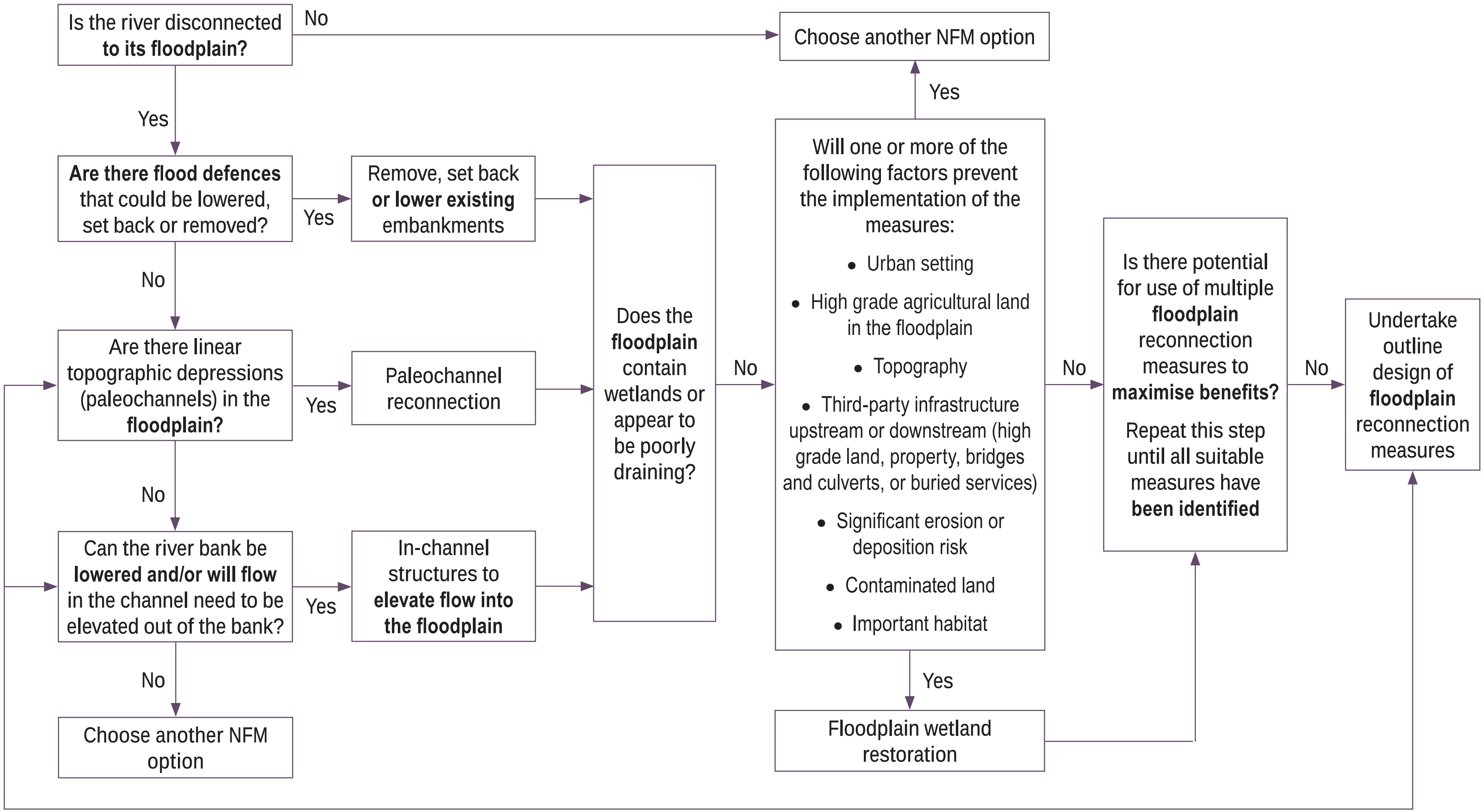


Figure 12.3 Decision flow chart for selection of floodplain reconnection measures

BOX 12.2 **River Wensum floodplain reconnection**

River Wensum case study (courtesy Rob Dryden, Environment Agency)

Location	River Wensum, Swanton Morley, Norfolk, England
Techniques used	Lowering and removal of spoil embankment, palaeochannel reconnection, in-channel structures such as lateral shelves, gravel glides and woody material, improved connectivity between river and floodplain, tree planting.
Delivery	The River Wensum is a chalk river, 70 km of which is designated as a SSSI and a Special Area of Conservation (SAC), providing nationally and internationally important habitat. Like many rivers in the UK, the channel has been modified (overly widened and deepened) by historical dredging and was disconnected from its floodplain by large spoil embankments, on both sides of the river. The channel lacked tree cover and woody material. Drivers for the project included addressing physical modifications to the channel (to meet WFD targets), restoring the Wensum SAC and contributing to the chalk rivers Biodiversity Action Plan. Feasibility studies identified the need for improvements to the main river channel and for reconnection of existing palaeochannels. The project was delivered by the Environment Agency working in partnership with Natural England, riparian landowners and the Water Management Alliance (group of Internal Drainage Boards, IDBs). The project focused on 0.88 km of the River Wensum, downstream of Swanton Morley weirs. The designer, Atkins, identified a suite of techniques to re-establish natural forms and processes, involving removal of spoil embankments, gravel bed raising and meander reconnection to restore floodplain connectivity. In-channel features and habitats were also restored, through installation of gravel glides, flow deflectors and berms, along with woody material and riparian tree planting. As a result of past drainage activities large spoil embankments existed either side of the river. These prevented the majority of high flows from inundating the floodplain, as would naturally occur, and forced flow downstream carrying with it large amounts of sediment. As part of the scheme sections of embankment were removed to encourage floodplain wetting during periods of high flow. This should have the combined benefits of increasing floodplain biodiversity and providing a sink for suspended sediment, as well as reducing flood risk to people and property

continued...

BOX 12.2 River Wensum floodplain reconnection (contd)

Delivery	in the downstream catchment. The level at which water will spill on to the floodplain has been set so that there is a low probability of summer flooding and minimal impact on the agricultural use of grazing marshes. Presence of a flow gauging station upstream of the project provided valuable data to inform the design but also posed a constraint; physical modification to the river had to be designed to avoid impact on the accuracy of the gauge. Similarly, the floodplain connection works had to ensure the floodplain drainage network did not become surcharged with flood water and that there was a clear route for water to drain back to the River Wensum, once flood levels recede. These challenges were overcome by working with the existing topography, and using spoil to locally raise sections of the floodplain to manage flood flow pathways. Another important element of the floodplain connection was to provide a route for water to drain back into the channel once river levels had receded. The project was designed to avoid use of synthetic materials. Sourcing gravels from a local quarry also minimised local effects on traffic and reduced the project's carbon footprint. The project was delivered between June and September 2012. Traditional river restoration schemes take place between late August to March (to avoid the main fish spawning and bird breeding seasons); the timing of project implementation required a carefully planned programme of ecological mitigation measures. The cost of the project was £187 593.
Outcomes	The key NFM outcome of the project was restored floodplain connectivity. This included increased floodplain biodiversity (Winter waders and wildfowl), flood storage, water quality improvements (deposition of silt on the floodplain) and creation of backwater habitats in the floodplain. In addition, the project improved hydromorphological conditions in the River Wensum, contributing to its WFD targets to achieve good ecological potential, improved ecology of the channel, delivered Biodiversity Action Plan objectives and provided improved angling opportunities. A pre-works baseline fish survey carried out in 2012 recorded a total of 45 fish, representative of seven species. The post-works repeat surveys recorded 143 fish of 11 species in 2013, 549 fish of nine species in 2015, and 107 fish of 10 species in 2019. Kick sampling of invertebrates has shown a post-restoration increase in the diversity of taxa in all but one of the sample locations within the restored reach. Of particular note were two species of stoneflies, which require a pebbly substrate with plenty of interstices and high dissolved oxygen levels. Caseless caddis flies were absent from the pre-works survey, but were recorded along the whole reach in the post-works survey. These species require larger stable substrates and will have benefited from the installation of the gravel glides. Mayfly species diversity has increased in the post-restoration survey samples. Despite these encouraging signs the numbers of invertebrates found was quite low. This might indicate high predation pressure from the invasive signal crayfish which are abundant in this section of the Wensum. Aquatic plant populations remain poor on the restoration reach. Again, this may relate to the large population of signal crayfish.

12.3 DESIGN AND MATERIALS

12.3.1 Design process

The following steps should be followed for design of floodplain reconnection measures:

1. Determine the most effective location and minimise risk (**Table 10.2**). Make use of information from available datasets (eg WWNP datasets, publicly available flood mapping, aerial imagery, LiDAR, historical and contemporary OS mapping, see **Chapter 16**).
2. The size (length, width and configuration) of the measure will be determined by site-specific conditions. For larger rivers or for complex sites, review should be made of existing hydraulic modelling (or by undertaking bespoke modelling, see Chapter 14) and elevation data (eg topographic survey and LiDAR). On medium to larger rivers (>10 m in width), hydraulic modelling will typically be required due to the higher flows expected in watercourses of this size. Typically, 2D only modelling is sufficient for floodplain flow, however, dependent on existing model availability, or site complexity a 1D/2D model may be required. **Section 14.3.3** gives hydrological and hydraulic considerations for the design of floodplain reconnection.
3. Consider changes to baseline hydraulics under a range of flow conditions. Determine the likelihood for erosion and deposition because of the proposed measure (**Chapters 14 and 16**) and the impacts on upstream and downstream flood risk or environmental receptors. Soft-engineered erosion protection may be required along riverbanks if there is a need to maintain a defined bank boundary. Minimise risk of erosion by tying in any bank lowering and/or reprofiling with the bed and banks upstream and downstream of the reconnected floodplain. This will reduce any sudden changes in bed or bank profile that could cause erosion and/or deposition.
4. Aim to minimise loss of trees in the riparian zone (as mature trees provide long-term bank stability). Assess the tolerance of riparian vegetation to more frequent/deeper inundation. Consider the potential to include a vegetated riparian buffer strip, such as the opportunity or the need to replant the riparian zone or within the wider floodplain (**Chapter 7**).

Following initial assessment of feasibility, the design process typically involves two stages:

- **Outline** design is essential for all floodplain reconnection measures and involves selecting suitable locations (**Section 12.2**), defining the area to be reconnected (**Chapter 6**), and selecting the required design components (**Section 12.3.2**). It is recommended that any required walkover surveys are undertaken at this stage (eg ecology, geomorphology), to help identify opportunities and constraints. Proof of design could be demonstrated by hand calculations or simple hydraulic modelling (if needed). Outline design should establish that the proposed floodplain reconnection measure would work in principle at the identified location. Concept design drawings/sketches may be produced at this stage.
- **Detailed** design is needed to develop a buildable design that performs the required functions and remains safe throughout its design life. Detailed hydraulic modelling would be undertaken at this stage (if required), along with further site-specific investigation, such as ground investigation. The outline design is refined to propose lengths and heights of bank or floodplain modifications, along with any features (in-channel or on the floodplain) that are to be created. Detailed design drawings and/or construction drawings are produced and relevant consents and environmental permits obtained.

Health and safety must be considered throughout the design process (**Section 12.2.3 and Chapter 17**).

12.3.2 Design components

Table 12.4 provides an overview of design components and typical features for floodplain reconnection measures.

TABLE 12.3 Design components and typical materials for floodplain reconnection measures

Measure type	Design components	Typical materials
Remove, set back or lower embankments	• Earthworks (may include lowering/removal/breach of sections of embankment or the embankment as a whole). • Replacement, set back embankments (if applicable).	Excavated material, stone/earth bunds
Palaeochannel reconnection	• Earthworks (palaeochannel excavation and/or bank lowering). • Lowering or reprofiling of riverbanks. • Reprofiling of palaeochannel (where required).	Excavated material
In-channel features to elevate flow into the floodplain	• Earthworks (to secure in-channel structures in the bank and/or bank lowering). • In-channel structures (eg timber, woody material or stone boulders).	Excavated material, timber, stone
Floodplain wetland restoration	• Earthworks (lowering or reprofiling of banks and/or the floodplain). • In-filling of redundant land drainage channels in the floodplain (if applicable). • Vegetation planting in the floodplain.	Excavated material, vegetation

12.3.3 Remove, set back or lower existing embankments

For removing, setting back or lowering existing embankments, preference should be to remove the embankments if possible (subject to infrastructure at risk), then for setting back and finally for lowering or breaching (see **Figure 12.4**). With any of these approaches, a proportionate assessment should be undertaken to inform:

- design flows under which floodplain connectivity currently occurs or will occur
- location and size of bank lowering or breaches. Breaches may be new removal of embankment that is entirely engineered, or formalisation of existing breaches that have occurred by natural processes (eg flooding and erosion)
- flow routes and drainage from the breached area
- frequency and duration of floodplain inundation
- scour risk to banks nearby.

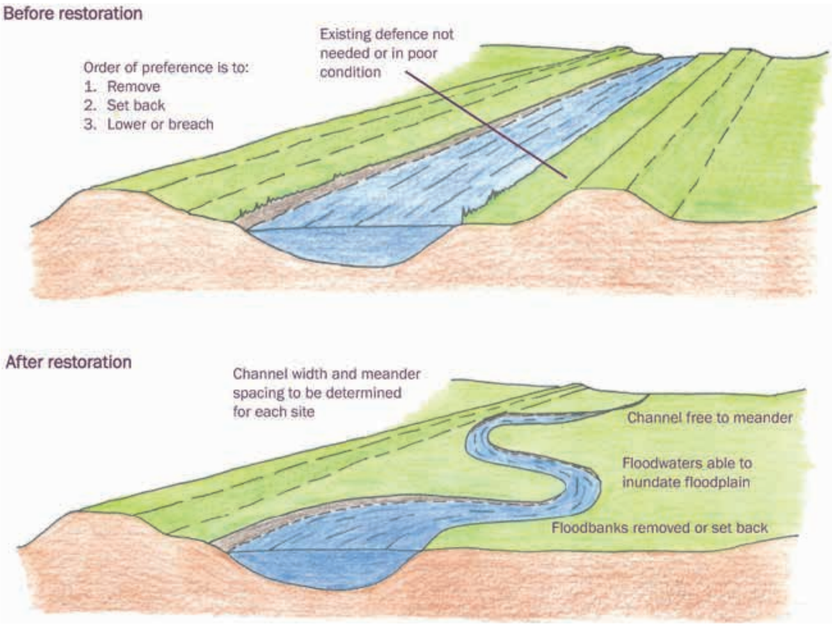


Figure 12.4 Key principles for removing, setting back or lowering existing embankments (courtesy Emma Wren)

12.3.4 Palaeochannel reconnection

For palaeochannel reconnection, the size (length, width and configuration) and extent of excavation required for the palaeochannel will be determined by site-specific conditions (see **Figure 12.5**). It may also be appropriate to include cross-sectional diversity within the palaeochannel (ie through use of alternating berms or roughening the channel cross-section). Finally, it is generally preferred to retain or reinstate bankside and riparian vegetation. This could be achieved by turf stripping and replacing, or by seeding the banks of the channel with appropriate vegetation, native to the catchment and able to survive periodic inundation.

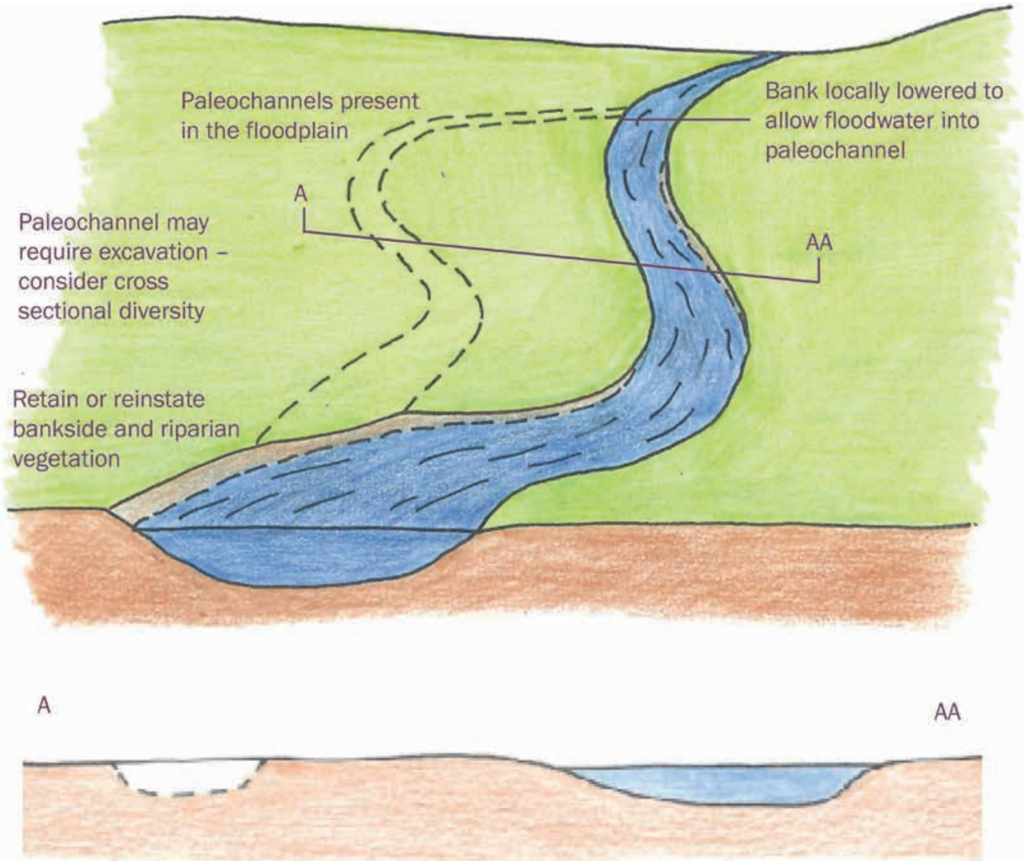


Figure 12.5 Key principles for palaeochannel reconnection (courtesy Emma Wren)

12.3.5 In-channel features to elevate flow into the floodplain

In-channel features may involve localised bed raising to create riffle features, or use of large wood and stone. **Chapter 10** discusses using wood or stone.

12.3.6 Floodplain wetland restoration

For floodplain wetland restoration (**Figure 12.6**), Roberts *et al* (2000) advise the following:

- An understanding of the relationship between plant communities and water regimes on the floodplain should provide the baseline against which the design will be made.
- Generally, the more data that can be compiled on hydrology, soils and groundwater, the better the basis for design. At a minimum the design should account for groundwater depth, salinity and flood frequency/extent, as this can affect the success of a floodplain wetland.
- Consideration of plant species, size and growth in response to catchment and site-specific environmental conditions is key. For example, submerged species are generally more sensitive to changes in water quality and light than other floodplain wetland species.
- Dimensions are entirely site specific.

Specific advice on the creation and restoration of floodplain meadows is also given in Rothero *et al* (2016).

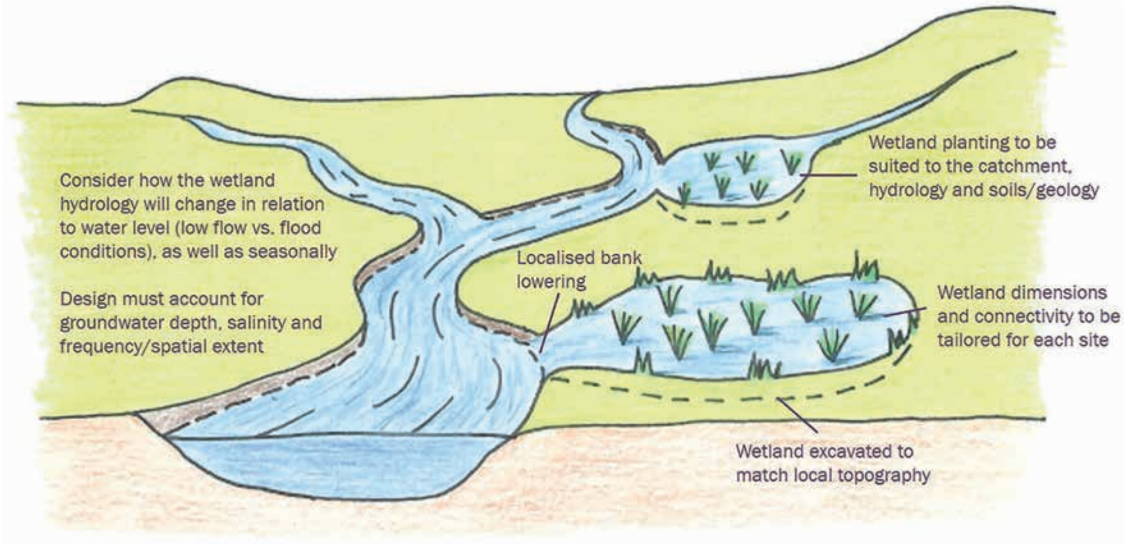


Figure 12.6 Schematic for floodplain wetland restoration (courtesy Emma Wren)

12.4 CONSTRUCTION AND IMPLEMENTATION

Overarching principles and issues in the construction and implementation of NFM measures (applicable to floodplain reconnection) are set out in **Chapter 18**.

In general terms, floodplain reconnection measures require excavation and removal of materials from the bank top and/or floodplain (**Table 12.4**). In-channel features to elevate flow into the floodplain will also require the addition of material into the channel, to modify flow hydraulics.

Box 12.3 is an example of floodplain reconnection by elevating flow into the floodplain and by reconnecting palaeochannels.

BOX 12.3 **Afon Merin floodplain reconnection**

Afon Merin case study (courtesy Mike Jenkins/Nick Young, Natural Resources Wales)

Location	Afon Merin, Ceridigion, Wales
Techniques used	In-channel features to elevate flow into the floodplain, palaeochannel reconnection, river restoration and leaky barriers.
Delivery	Pre-work aerial studies, ground survey and fixed point photography were used to determine geomorphological changes within the system. This work identified that the course and planform of the Afon Merin had been severely modified by agriculture, forest plantation and land drainage. The river had incised into its bed and was disconnected from its floodplain under all but extreme flood events. Fine gravels were flushed through the system leaving an even-sized cobble bed. The project aimed to restore a more natural and dynamic river system. It also intended to create/restore habitat and biodiversity, improve land use management and water quality, provide carbon storage, and reduce flood risk. The project was undertaken on a three kilometre section of channel within a Welsh Government Woodland Estate. Delivery involved selected tree felling, ditch blocking and 15 leaky barriers to attenuate flow and elevate water to reconnect palaeochannels in the floodplain. This focused on using low ground pressure tracked excavators to key trunks into the bank at meander bends, with the dam's backfilled with forestry brash. Notches were made in the riverbank at some locations to assist overspill. This design ensures minimal disruption to low flows but slows flood flows. It creates more dynamic flow patterns, permanent and temporary in-channel and floodplain features and retains gravel (for habitat). Ongoing monitoring is being undertaken by NRW staff (photo monitoring, drone surveys), and Aberystwyth University (flow and ecology) to monitor long-term success of the project. The project has been well received internally and externally, and secured additional funding for phase two works in winter 2020–2021. The second phase reinforced some of the phase one dams, added deadwood buffers into the relict channels using whole tree lengths and forestry brash piles, added additional dams into the phase one area, and new dams/deadwood in the river further downstream. The project was delivered by NRW and the Welsh Government in 2018 to 2019, with a total cost of £30 000 for phase one, and £25 000 for phase two (including tree felling, installation of leaky barriers and creation of floodplain scrapes).
Outcomes	The project has demonstrated that low-cost, NbS can deliver multiple benefits (river floodplain reconnection, flood risk reduction and habitat creation).

12.5 MONITORING AND MANAGEMENT

Well-designed floodplain reconnection measures should be self-sustaining, with minimal maintenance requirements. However, monitoring and maintenance is recommended to ensure the measure is operating as designed, to allow for adaptive management and demonstration of the NFM benefits.

The general principles for monitoring and management are set out in **Chapter 19**. Specific recommendations for floodplain reconnection measures are as follows:

- Floodplain reconnection involves reinstating 'natural processes' of water, sediment and organic matter transfer between river and floodplain, increasing dynamism and potential for geomorphic change. For this reason, at a minimum, it is recommended that visual inspection of a given measure is undertaken up to twice per year (by a qualified geomorphologist). Additional survey (eg visual) should also be undertaken following individual flood events.
- Monitoring specification should be made on a site-specific basis. Dependant on the complexity of a given project and its specific requirements, data collection may include visual inspection, photographs, fixed point photography, topographic survey, velocity and/or water level monitoring.
- For rivers with a mobile bed, erosion and/or deposition of sediment can be monitored visually, using fixed erosion posts, or more detailed techniques such as drone survey or repeat cross-section bed elevation surveys.

Monitoring is essential for adaptive management of floodplain reconnection measures.

Box 12.4 is an example of floodplain restoration used to rejuvenate floodplain grassland.

BOX 12.4 **Portholme Meadow floodplain grassland restoration**

Portholme Meadow case study (courtesy Emma Rothero, Floodplain Meadows Partnership)

Location	Portholme Meadow SAC, River Great Ouse, Cambridgeshire
Techniques used	Reconnected a meadow by breaching a bund to facilitate effective hydrological connection between the river and its floodplain.
Delivery	FMP has been advising on the hydrological management of Portholme Meadow SSSI/SAC since 2008, based on evidence collected through regular botanical surveys and retrieval of hydrological data from automatic dataloggers installed on the site. These data are fed into a hydrological model that the FMP hold for the site, which predicts the plant community changes based on development at groundwater level. It is a site designated for its rare plant communities, which depend on a particular water regime and good connectivity between the river and its floodplain. The botanical data collected indicated that the plant community was changing at the site due to increased flood duration and decreased drainage capacity, leaving particular areas of the site waterlogged. These conditions do not suit the very diverse plant community at Portholme, and resulted in an increase of opportunistic, waterlogging-tolerant species, such as curled dock and coarse sedges. The FMP were invited by the Environment Agency and Natural England to make some recommendations based on the model and the data available. One recommendation was to reinstate the surface drainage system in the northern part of the site, where the traditional network of grips had ceased to function due to a bund of sediment having built up along the riverbank. In the affected area, the plant communities were indicating that the soil remained waterlogged for prolonged periods in spring, and deposition of sediment had increased the soil fertility there. In 2011, the ditch recommended by FMP was constructed by the Environment Agency. FMP have monitored the site subsequently and demonstrated that the species diversity in the affected area increased, but in a control area, beyond the new ditch's zone of influence, little change occurred.
Outcomes	Increased extent of species-rich plant community at the site.

Further reading

Floodplain reconnection

Acreman, M C, Riddington, R and Booker, D J (2003) "Hydrological impacts of floodplain restoration: a case study of the River Cherwell, UK", *Hydrology and Earth System Sciences*, vol 7, 1, European Geosciences Union, Copernicus Publications, UK, pp 75–85

⇨ Academic study into the effects of embankment construction and removal, on floodplain reconnection.

Brooks, A (1989) *Channelized rivers: perspectives for environmental management*, first edition, John Wiley & Sons, Chichester, UK (ISBN: 978-0-47191-979-7)

⇨ Guidance on how to integrate fluvial geomorphology and floodplain connectivity, into river management.

Clivered, H M, Thompson, J R, Heppell, C M, Sayer, C D and Axmacher, J C (2016) "Coupled hydrological/hydraulic modelling of river restoration impacts and floodplain dynamics", *River Research and Applications*, vol 32, 9, Wiley Online, UK, pp 1927–1948

⇨ Study of river floodplain hydrology, pre- and post- embankment removal.

English Nature (2001) *Sustainable flood defence. The case for washlands*, No. 406 English Nature Research Reports, English Nature, Peterborough, UK (ISSN 0967-876X)

⇨ Guidance on the benefits of washlands for floodplain reconnection and flood risk management.

http://publications.naturalengland.org.uk/publication/60035

Heritage, G, Large, A and Milan, D (2021) *A field guide to British rivers*, John Wiley & Sons Inc, UK (ISBN: 9781118487983)

⇨ Guide on UK river types, their restoration and management.

Newson, M D (1997) *Land, water and development: sustainable and adaptive management of rivers*, second edition, Routledge, London, UK (ISBN: 978-0-41541-946-8))

⇨ Primer on the sustainable management of rivers and their catchments, including floodplain reconnection.

Remove, set back or lower existing embankments

Nichols, A L and Viers, J H (2017) "Not all breaks are equal: Variable hydrologic and geomorphic responses to intentional levee breaches along the lower Cosumnes River, California", *River Research and Applications*, vol 33, 7, Wiley Online, UK, pp 1143–1155

⇨ Case study of embankment breach/removal to provide floodplain reconnection (USA).

Palaeochannel reconnection

JBA Consulting (2012) *Long Preston Deeps SSSI restoration: Phase II works description*, unpublished, Environment Agency, Bristol, UK

⇨ Case study of palaeochaennel reconnection in the UK.

https://restorerivers.eu/wiki/images/7/72/Long_Preston_Phase_2_works_report_FINAL.pdf

Floodplain wetland restoration

Craft, C (2016) *Creating and restoring wetlands: from theory to practice*, Elsevier, Oxford, UK (ISBN 978-0-12407-232-9)

⇨ Guidance on floodplain wetland restoration.

Galat, D L, Frederickson, L H, Humburg, D D, Bataille, K J, Bodie, J R, Dohrenwend, J, Gelwicks, G T, Havel, J E, Helmers, D L, Hooker, J B, Jones, J R, Knowlton, M F, Kubisiak, J, Mazourek, J, Mccolpin, A C, Renken, R B and Semlitsch, R D (1998) "Flooding to restore connectivity of regulated, large-river wetlands: natural and controlled flooding as complementary processes along the lower Missouri River", *BioSCience*, vol 48, 9, Oxford University Press, UK, pp 721–733

⇨ Case study on floodplain wetland restoration in the USA.

continued...

Further reading

Rothero, E, Lake, S, and Gowing, D (eds) (2016) *Floodplain meadows – beauty and utility. a technical handbook*, Floodplain Meadows Partnership, Milton Keynes, UK (ISBN: 978-1-47302-067-2)

⇨ Guidance and examples of floodplain meadow restoration in the UK.

https://www.floodplainmeadows.org.uk/sites/www.floodplainmeadows.org.uk/files/Floodplain%20Meadows%20-%20Beauty%20and%20Utility%20A%20Technical%20Handbook.pdf

Stage zero river restoration

Bryden, A (2020) *What is the stage zero approach to river restoration?* River Restoration Centre, Bedfordshire, UK

⇨ Overview and guidance on stage zero river restoration.

https://www.therrc.co.uk/blog/what-stage-zero-approach-river-restoration

Cluer, B and Thorne, C (2013) "A stream evolution model integrating habitat and ecosystem benefits", *River Research and Applications*, vol 30, 2, Wiley Online, UK, pp 135–154

⇨ Academic article on stage zero river restoration.

Powers, P D, Helstab, M and Niezgoda, S L (2018) "A process-based approach to restoring depositional river valleys to Stage 0, an anastomosing channel network", *River Research and Applications,* vol 35, 1, John Wiley & Sons, UK, pp 3–13

⇨ Academic article on stage zero river restoration

Ecosystem services and biodiversity benefits of floodplain reconnection

Beastegen, K R, Poff, N L, Baker, D W, Bledsoe, B P, Merritt, D M, Lorie, M, Auble, G T, Sanderson, J S and Kondratieff, B C (2019) "Designing flows to enhance ecosystem functioning in heavily altered rivers", *Ecological Applications*, vol 30, 1, e02005, Ecological Society of America, Wiley Periodicals, USA

⇨ Guidance on how to deliver functional ecosystems as part of floodplain reconnection and river restoration.

Junk, W J, Bayley, P B and Sparks, R E (1989) "The flood pulse concept in river floodplain systems". In: Dodge D P (ed) *Proceedings of the international large river symposium fisheries and oceans*, Ottawa, Canada (ISBN: 0-66013-259-1) pp 110–127

⇨ Academic article that explains the importance of river-floodplain connectivity in natural and restored river systems.

Opperman, J J, Luster, R, Mckenney, B A, Roberts, M, and Meadows, A W (2010) "Ecologically functional floodplains: connectivity, flow regime and scale", *Journal of the American Water Resources Association*, vol 46, 2, American Water Resources Association, John Wiley and Sons, USA, pp 1–16

⇨ Academic article that explains how to deliver ecologically functional floodplains (for floodplain reconnection), including case studies.

Tockner, M (2000) "An extension of the flood pulse concept", *Hydrological Processes*, vol 14, 16–17, Wiley, UK, pp 2861–2883

⇨ Explanation of how the 'flood pulse' concept for river-floodplain connectivity can be applied more widely.

Chapter 13

River channel restoration

This chapter provides a high-level overview of river channel restoration measures, including a summary of their function as well as good locations for their implementation and locations to avoid.

River channel restoration

Restore channel shape (planform)

A river returned to its former sweeping meandering course, River Blackwater, New Forest (courtesy River Restoration Centre)

Description: re-establishment of ‘reference state’ channel planform, eg reconnection of artificially-isolated side channels, re-meandering of straightened channels.

Function: allows natural channel evolution and the development of geomorphological features and habitats. Slows the flow by adding a more complex and longer flow path. Improves channel-floodplain connectivity by replacing artificial or oversized managed channels, raising the water table and reinstating wet/wetter floodplain habitat.

Good locations: the wider rural landscape and urban parkland with room for the river to adjust.

Locations to avoid: close to infrastructure or where there may need to protect the restored bed and banks, which minimises the benefits of this approach.

Issues: requires corridor/floodplain width to allow sinuosity and movement.

Additional benefits: habitat diversity, climate resilience, aesthetic and landscape improvements, reduced maintenance costs, increased biodiversity.

Restore longitudinal connectivity

Description: removal of artificial barriers or impediments to the free movement of water, sediment, organic material and biota, and to increase habitat diversity, eg complete or partial removal of weirs, dams and culverts.

Function: restores natural self-regulation of the river, allows sediment transport and deposition.

Good locations: all modified rivers, where risk is low.

Locations to avoid: where barriers are part of a national flow gauging network, structurally linked to buildings or roads, are listed or protected, could destabilise/undermine the upstream banks and bed leading to building/road/bridge failures or are used for hydropower. In particular, urban centre locations.

Removal of a failed weir structure (before and after) on the River Great Ouse, Buckingham (courtesy River Restoration Centre)

continued...

River channel restoration (contd)

Issues: barriers also act to hold back water; they can increase upstream storage, so removal could also increase flood risk. Culverts can be extensive in urban centres and require significant redevelopment to allow the river to be 'daylighted'.

Additional benefits: free passage for fish and invertebrates, free sediment movement and habitat creation – addressing impoundment, fine silt deposition and water quality (nutrient build-up) behind barriers. Reduced physical modification of the river, removes liability for engineered structures and safety risks.

Restore lateral river movement

Description: remove constraining structures, eg culverts, bank protection, artificial bed and banks, and other in-channel structures. Also avoid new bank protection works where overall risk is low.

Function: allows rivers to adjust freely and to accommodate changes in hydrology and sediment supply. Maintains or raises bed levels and water table, slowing flows. Promotes better connection to the floodplain to re-wet and store floodwater.

River and floodplain in continuous connection displaying multi-thread mobile gravel bed channels, Llandovery Bran, Dyfed (courtesy River Restoration Centre)

Good locations: all modified rivers where risk is low. Improvements to in-channel sinuosity may be possible when constraints do not allow lateral movement.

Locations to avoid: close to infrastructure or where there may be a need to protect the restored bed and banks, which minimises the benefits of this approach.

Issues: the need to convey awareness of future erosion, and scale. Nearby landowners' acceptance. Perception of all erosion being 'bad'.

Additional benefits: habitat diversity, climate resilience, aesthetic and landscape improvements, reduced maintenance costs, increased biodiversity.

Where to find out more

Further reading

RRC (2020b)

RRC (n.d.)

Addy et al (2016)

Who to consult

- Statutory environment agencies or local authority depending on watercourse type.
- Nature conservation organisations for designated sites.
- Professional river restoration specialist or a fluvial geomorphologist.

Case studies

RRC (2021)

Channel shape:

Highland Water at Warwickslade cutting: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/1.11_Highland_Water.pdf**

River Ravensbourne: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/1.6_Ravensbourne.pdf**

Longitudinal connectivity:

Babingley Brook: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/12.1_Babingley_Brook.pdf**

River Great Ouse: **https://www.therrc.co.uk/sites/default/files/general/MOT/final/12.6_great_ouse.pdf**

River Monnow: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/12.3_Monnow.pdf**

Lateral movement:

Braid Burn: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/1.10_Braid_Burn.pdf**

River Alt: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/3.4_Alt.pdf**

Yardley Brook: **https://www.therrc.co.uk/MOT/Final_Versions_%28Secure%29/3.7_Yardley_Brook.pdf**

D

Part D provides detailed information on the NFM delivery process.

How to deliver NFM

Courtesy Tweed Forum

Courtesy Nick Mott, Staffordshire Wildlife Trust

14 HYDROLOGY AND HYDRAULICS

Contents

Chapter
14

Hydrology and hydraulics

This chapter shows how a good understanding of the hydrological processes and hydraulics of a catchment can help select the most effective NFM measures and evaluate their success after implementation.

▶ *Understanding the hydrology and hydraulics are part of understanding the catchment (Chapters 2 and 4) and work together with environmental processes (Chapter 16). They should be considered throughout design stages (Chapter 17)*

14.1 INTRODUCTION

Hydrology considers how much water is available at a given location and how quickly or slowly the catchment responds to rainfall. Hydraulics considers where that water will flow, how deep, how fast, and how long water remains in any one location. Hydraulic processes can then determine how much water arrives downstream to sustain habitats, provide amenity, or cause flooding. These are natural processes governed by the climate, topography and geology of the catchment, and summarised in **Section 2.1.2**. These processes can be affected by the land use, farming practices, roads, bridges, urban areas, and other human interactions.

14.1.1 Why consider hydrology and hydraulics?

A good understanding of the hydrological processes and hydraulics of a catchment can help select the most effective NFM measures and evaluate the relative success of the measures after construction.

Understanding how much flow arrives at the selected site and from which sources can help to design NFM measures to maximise the potential of the site to store or slow down flows. Understanding the capacity of the existing flow path to contain flood water without flooding a community or other receptors can help set a target flow reduction for the whole NFM scheme to reduce flood risk.

An understanding of the existing hydrological and hydraulic processes in the catchment is required from the outset of all NFM projects (see **Chapter 4**). This understanding should be refined throughout the project to ensure that the chosen solutions are effective at reducing flood risk. Larger-scale NFM schemes or NFM measures that are located close to a main river or ordinary watercourse often need hydrology and hydraulic assessments to demonstrate that:

- it will be effective at reducing flood risk, perhaps to approve funding from flood risk authorities (**Chapter 15**)
- it will not increase flood risk to others, located upstream or downstream which is often needed to obtain permission from the flood risk authority (**Section 3.5**).

Hydrology and hydraulic assessments have a degree of uncertainty depending on the quality and coverage of input data available and the detail of assumptions taken. The estimate flood risk reductions are estimates of relative change only and the uncertainty in these values should be carefully considered in the proposed performance when seeking funding for any NFM measure or scheme as set out in **Chapter 15**.

14.1.2 How and when should assessments be carried out?

Table 14.2 outlines the key hydrological and hydraulic considerations at each stage of the NFM delivery process and how improving the understanding of hydrology enables more effective design of NFM measures.

TABLE 14.1 The NFM delivery process – hydrological and hydraulic considerations

Stage	Hydrological and hydraulic considerations
Initiation (**Chapters 2 and 4**)	• Determine the project aims (**Section 2.1**) and consider the receptors at risk whether that is a community, property, road, rail, infrastructure or a sensitive habitat. • Identify project success factors (**Section 2.2**) in terms of changing flood risk or flows available in low flow conditions at those receptors. • Define the catchment area as the area contributing water to the receptors. Hydrological information may need to be collected over the catchment to understand the site context. It can be useful to look over a wider area for nearby rainfall and river gauges to help with this assessment. Tools to support this can be found in **Appendix A4**. • Hydrological considerations should be integrated as early as possible and at every stage to maximise the effectiveness of the NFM design and potential benefits from reducing flood risk.
Understand the catchment (**Chapters 2 and 4**)	• Gather local hydrological knowledge and past flood experiences, consult with local communities, flood action groups, landowners or the local flood risk authority. • A desktop study will identify the sources that bring water to the site, the pathways of how that water reaches the site and any flood receptors downstream. • Understand the source-pathway-receptor model (**Figure 2.1**) specific to the catchment to help select the most appropriate sites and types of measures to effectively reduce flood risk downstream. • Understand the timing of the peak flow from each flow path to help understand where flows currently coincide to excerbate flooding downstream and where this could potentially become an issue for NFM measures • Hydrological processes do not operate in isolation, so consider the interactions between sediment and environmental processes as well (**Chapter 16**). • There can be significant uncertainty in flow estimation or the assessment of impacts to receptors without local gauge data available. Set in place monitoring plans to complete data gaps at this stage. Local knowledge and observation of past flooding issues can help to qualitatively verify and engage the local communities and stakeholders in understanding the hydrological processes.
Select measures (**Chapter 4**)	• Ensure understanding of hydrological processes is applied when selecting NFM sites and measures (**Chapter 4**) and when siting those measures to protect, restore or mimic the hydrological processes across the whole catchment. • Monitoring schemes and field surveys may be ongoing at this stage. • Consider the how wet the catchment is likely to be before the flood and how full storage features are likely to be before when selecting storage or infiltration type measures. • Consider the potential to desynchronise the tributaries in the catchment so that the time of the peak flow from each flow path does not coincide (**Chapter 4**). • If multiple sites are being considered, there is potential for a combination (or cumulative) of effects to occur due to the amount of measures acting to slow or change the pathways made to the environment. This should be considered for all projects but will require more detail if there are vulnerable receptors at risk downstream, such as a community, or if an environmental impact assessment (EIA) is required. • Select NFM measures to maximise potential changes in flood risk and maximise co-benefits (**Chapters 15 and 16**) taking full account of construction and safety (**Chapter 18**).

continued...

TABLE 14.1 The NFM delivery process – hydrological and hydraulic considerations (contd)

Stage	Hydrological and hydraulic considerations
Design and materials (**Chapter 17**)	• Hydrological and hydraulic processes should be considered throughout the design stages to size and optimise the operation of each measure. • The optimisation of the hydrological and hydraulic design can be done iteratively to achieve the project aims of reducing flood risk downstream at the receptors using flood routing methods. • Hydrological and hydraulic methods can help identify the channel capacity, flood level and velocities that define the size of the measures and type of materials required to withstand the expected flows. Consider when the measures are activated during a flood as well as when measures become overwhelmed in exceedance events (**Chapter 17**). • Ensure the design, the construction/implementation and monitoring or maintenance required for the measures do not cause any unwanted increase in flood risk in any given event.
Construction and implementation (**Chapter 18**)	• Hydrological and hydraulic inputs in the construction and implementation phases are likely to be minimal if the above stages have been followed. Inputs are only likely to be required if there is signifncant change to the design during construction. • Follow good practice to undertake as-built survey of the final implemented NFM measures to ensure their performance meets the specification of the design phases. Highlight any change in flood risk impacts from the plan to allow for sign off of the measures.
Monitor and manage (**Chapter 19**)	• Hydrological monitoring can determine the effectiveness of NFM measures and demonstrate the achievement of flood risk benefits, compared to the information gathered about the site before construction/implementation began. • Monitoring can also identify unexpected negative flood risk effects; in these cases, action should be taken to limit these in future.

14.1.3 Proportionate approach

The scale and complexity of hydrological and hydraulic assessment should be proportionate to the project. The aim is to maximise understanding of the source and pathways of flooding early on, while being aware of the number or vulnerability of receptors at risk of flooding. The selection of the most appropriate and proportionate method for each stage of the NFM delivery process is set out in **Figure 4.3** and is influenced by:

- the size or complexity of the catchment
- how many different flood sources interact and how complex the interactions are
- how many receptors at risk of flooding and to what degree of risk
- the data available to support the assessment
- the budget and/or time available
- the level of hydrological and hydraulic expertise available
- the level of detail the funders require.

Additional effort should only be invested to improve the accuracy of hydrological and hydraulic processes if there is significant uncertainty on the potential impacts, the data is available to support more detailed methods and there is a project need to do so.

14.2 KEY CONCEPTS

The following sections explain the key hydrological and hydraulic concepts related to the delivery of NFM.

14.2.1 Typical flood hydrograph

The variation of rainfall during a storm is known as rainfall profile. This rainfall profile can vary greatly depending on the type of weather system, spatial variation across the catchment, storm tracking direction, speed that the storm passes over the catchment and how saturated the catchment was before the storm.

At the understand the catchment stage, effort should been undertaken by an experienced hydrologist and stakeholders to understand what rainfall profile caused past floods based on observation and rainfall gauge or radar data. Where observations or gauge information is not available, the FEH webservice can provide rainfall totals which can be used to estimate a typical rainfall profile in rainfall-runoff software (**See Appendix A2**). From this assessment, a typical rainfall profile can be developed for a range of flood probabilities to support NFM measure development.

The typical flood hydrograph describes how water will runoff from a catchment during the typical rainfall profile adopted as the basis for the design of NFM. The key parameters describe the shape of the flood hydrograph (**Figure 14.1**) are:

- **Peak flow** – the maximum flow that passes through a point in the channel or defined flow path (in m^3/s).
- **Storm duration** – the duration of rainfall that causes the flood flows (in hours).
- **Time to peak** – the time from the start of rainfall to the peak flow at that point in the channel or defined flow path (in hours).
- **Volume of the flood** – the total volume of flow that passes through that point in the channel or defined flow path over the duration of the flood (in m^3).

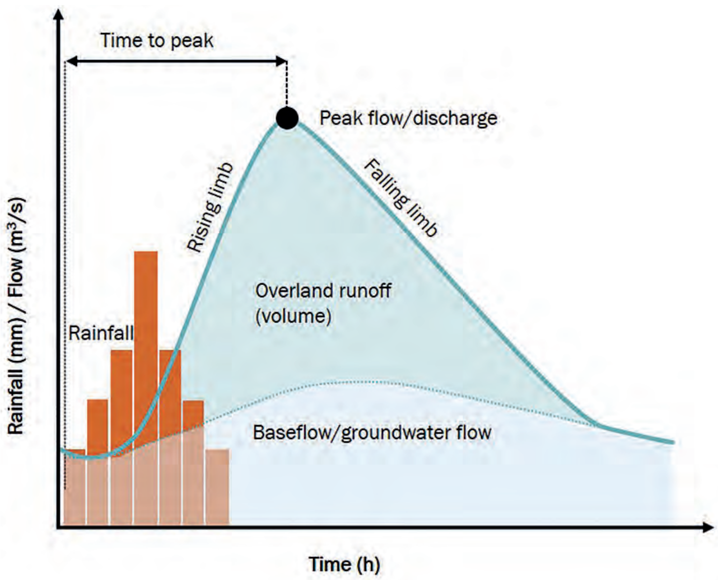


Figure 14.1 Flood hydrograph

NFM measures are often optimised to the manage design flood in a top-down approach to achieve the project success factors. In a bottom-up approach , the target design flood may not be known in advance so multiple different storms and corresponding hydrograph may need to be assessed to maximise flood risk benefits and co-benefits.

NFM measures are often located and designed to store some of the volume of the flood to be released later and/or slow the rising limb by encouraging greater infiltration into the soil. This storage and slowing means that the peak flow is both delayed and smaller as runoff arriving at the point of interest is spread out over a longer time.

There are a range of methods to calculate the design hydrograph (see *Further reading*). An understanding of the hydrological processes and response to rainfall of a catchment is required by anyone planning

NFM as set out in **Chapter 14**. However the calculation of simple, intermediate or detailed hydrology for understanding the catchment and design of measures should be undertaken with the support of those with hydrological expertise (**Appendix A4**).

Further reading

England

Environment Agency (2016) *Flood risk assessments: climate change allowances*, Environment Agency, Bristol, UK

⇨ Sets out the climate change allowances to consider in flood risk assessments for sites in England.

https://www.gov.uk/guidance/flood-risk-assessments-climate-change-allowances

Environment Agency (2020) *Flood Estimation Guidelines. R&D Technical Report 197-08,* , Environment Agency, Bristol, UK

⇨ Guidance for methods to calculate peak flows and hydrographs for England.

Northern Ireland

DfI (2019) *Technical flood risk guidance in relation to allowances for climate change in Northern Ireland*, Water and Drainage Policy Division, Department for Infrastructure, Belfast

⇨ Approach to allow for climate change in the design of road drainage, storm drainage and river infrastructure in Northern Ireland.

https://www.infrastructure-ni.gov.uk/publications/technical-flood-risk-guidance-relation-allowances-climate-change-northern-ireland

Scotland

SEPA (2015) *Flood modelling guidance for responsible authorities*, version 1.1, Scottish Environment Protection Agency, Scotland

⇨ Best practice for flood modelling to support flood risk management decisions in Scotland.

https://www.sepa.org.uk/media/219653/flood_model_guidance_v2.pdf

SEPA (2019) *Climate change allowances for flood risk assessment in land use planning*, version 1, Scottish Environment Protection Agency, Scotland

⇨ Climate change allowances to consider in flood risk assessments for sites in Scotland.

https://research.fit.edu/media/site-specific/researchfitedu/coast-climate-adaptation-library/europe/united-kingdom-amp-ireland/SEPA.--2019.--CC-allowances-for-flood-risk-assessment-in-land-use-planning.pdf

Wales

NRW (2017) *Flood estimation: technical guidance*, GN008, Natural Resources Wales, Wales, UK

⇨ Guidance for estimating flows for flood risk assessment for sites in Wales.

NRW (2017) *Adapting to climate change: guidance for flood and coastal erosion risk management authorities in Wales*, Welsh Government, Cardiff, Wales

⇨ Guidance on climate change allowances to consider in flood risk assessments for sites in Wales.

https://gov.wales/flood-and-coastal-erosion-risk-management-adapting-climate-change

Climate change allowance note

The national guidance documents sets out the climate change allowances under the National Planning Policy Framework (NPPF) (MHCLG, 2021b). Climate change projects are continually evolving so the latest climate change allowance should be checked at every stage of the NFM process to ensure the measures can be effective for the duration of their design life.

14.2.2 Flood probability and frequency

Flood risk is often expressed in terms of flood probability and frequency to help understand how likely and often flooding might occur before and after the implementation of NFM.

Flood probability and frequency are often used interchangeably but they do not have exactly the same meaning:

- **Flood probability** defines the chance of occurrence of one flood event compared to the population of all the flood events.
- **Flood frequency** defines the expected number of occurrences of a particular flood within a given period.

NFM measures are small-scale and typically aim to modify flows during flood events that have a 50% to 2% chance of being equalled or exceeded during any given year (known as the AEP). These events are likely to happen more frequently. This can also be expressed as return period of 1 in 2 year to 1 in 50 year flood event as outlined in **Table 14.2**.

In rarer, less frequent events, the NFM measures are more likely to be overwhelmed and the relative effects on flood flows reduced. This includes extreme floods with a 1% and 0.1% AEP that are often used in larger flood alleviation schemes or flood risk assessments.

TABLE 14.2 Common terms for probability of a design flood

Size of flood	Rarity of flood or storm	Probability of a flow or rainfall amount being exceeded in any given year commonly considered for NFM		
		%AEP	*Chance (ratio)*	*Return period (expressed as 1 in x year)*
Small	Frequent	50%	1:2	1 in 2 year
↓	↓	20%	1:5	1 in 5 year
		10%	1:10	1 in 10 year
		5%	1:20	1 in 20 year
		4%	1:25	1 in 25 year
		3.3%	1:30	1 in 30 year
Large	Rare	2%	1:50	1 in 50 year

There are several common misunderstandings that originate from this terminology, which are addressed in **Table 14.3** using the example of the 2% AEP flood.

The standard methods of flood probability and frequency applicable to the UK and allowance of climate change are provided in **Appendix A4**.

14.2.3 Mean and low flows

For NFM the probability of mean or low flows may also need to be understood to assess environmental criteria, for example to allow a nominal flow rate through leaky barriers in non-flood conditions to allow for ecological connection. In the UK, low flows are typically estimated using the following methods:

- **Simple.** Observations of typical flows and levels on non-flood days throughout the year can be used to inform useful parameters for design. Hydrologically similar gauges nearby may provide additional information if the catchment areas at the NFM site is no smaller than 10% of the catchment area at the gauge. Flow statistics may need to be adjusted to account for the difference in catchment area draining to the site and the gauging station – it is common practice to use the ratio of catchment areas to make this adjustment. Be aware of the significant effect that artificial influences (abstractions and discharges) can have on low flows. Flow statistics can be corrected for these effects using summaries of abstraction and discharge available in catchment abstraction management strategies (see *Further reading*).

TABLE 14.3 Common misunderstandings in flood probability

Common misunderstanding	Response
"The probability of the rainfall storm is the same as the river or surface water flood"	The probability of a rainfall storm event may be different to the river or surface water flood because the antecedent condition of the catchment (condition of the catchment before the flood) and human interventions may modify how quickly it runs off. For example, a 10% AEP rainfall event could result in a 2% AEP river flood if the catchment was already saturated before the rainfall storm causing more water to runoff overland and peak quicker.
"We have just a 2% AEP flood (also known as a 1 in 50 year flood) so it won't happen again for another 50 years"	The chance of experiencing a 2% AEP flood remains the same in any given year. This means a single location could experience a 2% AEP flood in consecutive years. There is a 64% chance that a 2% AEP flood will occur 'once' in the next 50 years. Be aware that the peak flow associated with a 2% AEP flood may alter over time. Rainfall and runoff processes will change as a result of climate and land use management changes.
"In the next 50 years, we will definitely see the a 2% AEP flood (also known as a 1 in 50 year flood)"	This fails to recognise the random nature of rainfall and floods. In fact, 230 years would be needed to ensure a 99% or greater chance of a 2% AEP flood occurring.
"Across the UK, the 2% AEP flood (also known as a 1 in 50 year flood) is expected to happen only once every 50 years"	Catchments across the UK act independently to each other so the chance of a 2% AEP flood somewhere in the UK increases with the catchment area and the number of independent catchments considered. In larger catchments, the same storm does not necessarily result in a 2% AEP flood across the entire catchment because the time to peak varies by subcatchments and antecedent ground conditions can vary significantly.
"The frequency of the flood will stay the same over time"	The UK climate is changing over time so the frequency or the number of floods within a given period will also change. Flood probability in terms of %AEP is more robust to express the chance in any given year that can change with the climate rather than an expected number of floods within a time period of interest.

- Intermediate. Estimation of typical low flow statistics using generalised models that relate catchment and climatic conditions to estimate the flow-duration curve, for example LowFlows2 software (see *Further reading*). These can be refined by using nearby hydrologically-similar gauges.
- Detailed. Long-term flow records for low flows, or a synthetic series extracted using continuous simulation rainfall-runoff techniques (see *Further reading*).

In low flow conditions, evapotranspiration rates may impact losses from any standing water such as floodplain restoration or runoff storage features and how quickly they drawdown. As water evaporates, the soil dries out affecting its capacity to store water and this influences overland runoff. Soil moisture deficit is the amount of rain needed to bring the soil moisture content back to the maximum capacity the soil can hold against gravity. Evapotranspiration and soil moisture deficit for the UK can be assessed using the following methods:

- **Simple.** A typical upper rate of 3 mm evaporation per day per 1 m^2 of vegetative surface can be used for mid-summer rates.
- **Intermediate to detailed.** Meteorological observations modelled using MORECS v2 software. The output can be provided averaged over a 40 km x 40 km grid. **https://catalogue.ceh.ac.uk/documents/b9155463-ac86-4e19-a24f-57cef6b79505**

Further reading

NRW (2021) *Catchment abstraction management strategies. Various in Wales*, Natural Resources Wales, Cardiff, Wales

⇨ Sets out how water resources should be managed across a specific catchment in Wales or along the Welsh-English border. It provides information about where water is available for abstraction and where there is a need to reduce current rates of abstraction.

https://naturalresources.wales/about-us/what-we-do/water/water-available-in-our-catchments/?lang=en

Shaw, E M, Beven, K, Chappell, N A and Lamb, R (2011) *Hydrology in practice*, fourth edition, CRC Press, Oxon UK (ISBN: 978-0-41537-042-4)

⇨ An introductory textbook for hydrology in engineering design and practice. Provides hydrological principles and methods to estimate rainfall, low flows, high flows and various other hydrological parameters frequently used to assess and design hydraulic measures.

UKCEH (2021) *National river flows search data*, UK Centre of Ecology and Hydrology, UK

⇨ Archive of daily and peak river flows for the United Kingdom from over 1500 gauging stations.

https://nrfa.ceh.ac.uk/data/search

UK Government (2021) *Catchment abstraction management strategies. Various in England*, UK Government, London, UK

⇨ Sets out the how water resources should be managed across a specific catchment in England or along the English-Welsh Border. Provides information about where water is available for abstraction and outlines where there is a need to reduce current rates of abstraction.

https://www.gov.uk/government/collections/water-abstraction-licensing-strategies-cams-process

Young, A R, Grew, R, and Holmes, M G R (2003) "Low Flows 2000: A national water resources assessment and decisions support tool", *Water Science and Technology*, vol 48, 10, IWA Publishing, London, UK, pp 199–126

⇨ Summarises a range of modelling techniques to assist in the estimate of natural and artificially influenced low flow in rivers where there limited or no recorded data.

14.2.4 CHANNEL CAPACITY, FLOOD LEVEL AND VELOCITY

The channel capacity is the maximum flow a defined channel or flow path can pass before it spills over its river banks to inundate the floodplain. The capacity is principally governed by the cross-sectional flow area of the flow path and how quickly the water flows (the velocity) based on the channel bed slope and roughness.

Flood level is the maximum water level in metres above Ordnance Datum (or local datum). Flood depth is the relative depth of water between the flood level and channel bed or floodplain ground level. Flow velocity refers to the speed of flowing water.

Calculating the flood depth and velocity for a given flow based on the geometry of a channel, flow path or floodplain helps to quantify the overall risk to receptors. It also enables an understanding of how that might change when NFM is implemented and the relative flood risk benefits if appraisal is required (**Chapter 15**). The flood level and velocity is also required to design several NFM measures (**Chapter 17**).

The open channel flow equation (**Box 14.1**) is a simple way to estimate channel capacity and the corresponding velocity in engineered or non-engineered channels. The channel area and slope should be obtained by observation, topographic survey or DTMs. The relative roughness (or Manning's n value) can be obtained from site observations or a land use approximation from national background mapping datasets (**Table 14.4**). Consideration should be made where downstream constrictions in the channel or structures slow the flow down and cause water to raise upstream (known as backwater) as this can limit free flow in open channels.

These hydraulic parameters can be calculated manually at a single site or channel reach for a single flow or level per calculation for the main flow path. The hydraulic equations in **Box 14.1** and flow routing tools such as the Conveyance and Afflux Estimation System (CES/AES) can be used. See **Appendix A4** and *Further reading*).

Initial flow across the floodplain can be much slower as vegetation and complex topography can obstruct and slow down flows as the water spreads out in multiple directions. As the floodplain starts to fill, it acts a store to attenuate flows. Once the floodplain becomes full, water can find shorter routes to bypass features like meander bends and can speed up the travel times of the flood water in extreme cases. Calculation of floodplain flow requires professional hydraulic expertise to interpret the varying flood mechanisms at different stages during a flood event.

BOX 14.1 Simple approach to calculate free flow in open channels

$$\text{Flow }(Q) = \text{Area }(A)\ .\ \text{Velocity }(V) \qquad (14.1)$$

Where

$$\text{Velocity }(V) = \frac{1}{n}\ .\ \text{Hydraulic radius }(R)^{\frac{2}{3}}\ .\ \text{Slope }(S)^{\frac{1}{2}} \qquad (14.2)$$

and

$$\text{Hydraulic radius }(R) = \frac{\text{Area }(A)}{\text{Wetted perimeter }(P)} \qquad (14.3)$$

Where ‘n’ is the Manning’s n value from **Table 14.4**.

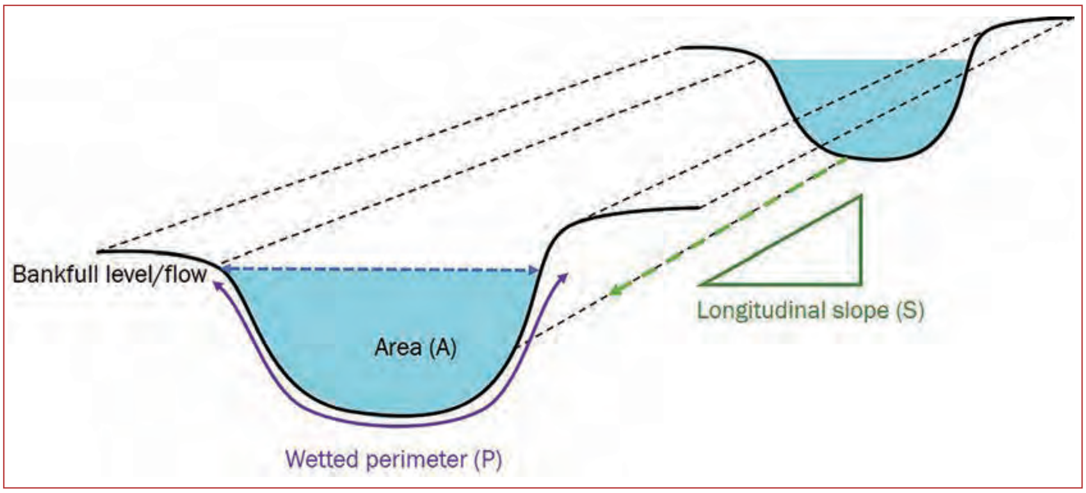


Diagram of cross-sectional parameters

TABLE 14.4 Manning's n value ranges for typical channel and floodplain types (after Chow 1959)

Channel type/floodplain vegetation cover	Indicative range
Clean straight channels no riffles or pools	0.025–0.033
Clean, meandering channels, some riffles, and pools	0.033–0.045
Meandering channel, some weeds, and stones with ineffective flow areas at low depths	0.040–0.055
Very weedy channel reach, deep pools, or trees within flood channels	0.075–0.150
Pasture	0.030–0.050
Cultivated fields fallow/no crop	0.020–0.040
Cultivated fields mature crops	0.030–0.050
Light scrub vegetation	0.040–0.080
Dense trees or woodland on the floodplain eg willow or heavy stand of timber	0.080–0.150

The threshold of flooding refers to the flow and/or level that first causes flooding to receptors such as properties, roads, critical infrastructure or sensitive habitats. Using the hydraulic calculations in **Box 14.1**, the flow can be predicted, in order to set a limit that can be safely passed through the area of interest before flooding becomes a problem. This threshold of flooding can be useful to set flood risk reduction targets to help with NFM measure design. For example, the target flow may be used to size NFM measures in the catchment so that flow remains in the channel as it passes through a community to help reduce flooding.

There are a number of national flood estimation guidance documents that detail the standard approaches and extensive reports on models suitable for catchment scale assessment; see further reading below. Further discussion of the appropriate hydraulic method for different catchments and NFM types is discussed in **Appendix A4**. The hydraulic design considerations for NFM are summarised in **Section 14.3**.

Further reading

England

Environment Agency (2010) *Computational modelling to a assess flood and coastal risk, version 2*, Operational Instruction 379_05, Environment Agency, Bristol, UK

⇨ Flood modelling standards for hydraulic modelling in flood risk assessment and appraisal studies in England.

Northern Ireland

⇨ At the time of writing, no modelling standard or guidance was available for DfI Rivers Northern Ireland. Standard practice is to follow similar methods as the rest of the UK.

Wales

NRW (2015) *Producing flood risk hydraulic models and flood consequence assessments for development planning purposes*, Natural Resources Wales, Cardiff, Wales

⇨ Flood modelling standards for hydraulic modelling in flood risk assessment and appraisal studies in Wales.

https://naturalresources.wales/media/5568/gpg-101-producing-flood-risk-hydraulic-models-and-flood-consequence-assessments-for-development-planning-purpose-english.pdf

continued...

Further reading (contd)

Scotland

SEPA (2015) *Flood modelling guidance for responsible authorities, version 1.1*, Scottish Environmental Protection Agency, Scotland

⇨ Flood modelling standards for hydraulic modelling in flood risk assessment and appraisal studies in Scotland.

https://www.sepa.org.uk/media/219653/flood_model_guidance_v2.pdf

General

Benn, J, Kitchen, A, Kirby, A, Fosbeary, C, Faulkner, D, Latham, D and Hemsworth, M (2019) Culvert, screen and outfall manual, C786F, CIRIA, London, UK (ISBN 978-0-86017-891-0)

⇨ A practical manual that assists in the key design considerations for these structures.

www.ciria.org

Bradley, J (1978) *Hydraulic design series 1. Hydraulics of bridge waterways*, Department of Transportation, Federal Highway Administration, Office of Engineering, Bridge Division, Hydraulics Branch, Washington DC, USA

⇨ A manual on the calculation of hydraulic losses through bridges.

CES/AES tool: **http://www.river-conveyance.net/**

Chow, V T (1959) *Open channel hydraulics*, McGraw-Hill, New York, USA (ISBN: 978-1-93284-618-8)

⇨ A textbook on open channel flow hydraulics including the estimation of conveyance and guidance on Manning's n roughness values.

Hankin, B, Burgess-Gamble, L, Bentley, S and Rose, S (2016) *How to model and map catchment process when flood risk management planning*, R&D Technical Report SC120015/R1, Environment Agency, Bristol, UK (ISBN: 978-1-84911-377-9)

⇨ A technical report that reviews existing modelling software, mapping to help develop flood management projects.

https://assets.publishing.service.gov.uk/media/60352aece90e0740b50cac34/How_to_model_and_map_catchment_processes_-_report.pdf

HR Wallingford (1988) Afflux at arch bridges, Technical Report SR 182, HR Wallingford, Wallingford, UK

⇨ Report on the calculation of afflux and hydraulic losses through arched bridges typically found around the UK.

https://eprints.hrwallingford.com/219/

Wynn, P (2014) Hydraulics for civil engineers, ICE Publishing, Institute of Civil Engineers, London, UK (ISBN: 978-0-72775-845-3)

⇨ A textbook open channel flow hydraulics and assessment of hydraulics through various hydraulic structures such as bridges, culverts, orifices, and sluice gates.

14.3 HYDROLOGICAL AND HYDRAULIC CONSIDERATIONS TO DESIGN MEASURES

14.3.1 Runoff management and runoff storage

Runoff management measures (**Chapter 7**) such as cross slope hedgerows (unbanked) and buffer strips seek to capture the overland flow, slow it down and encourage more to infiltrate through the locally improved soil structure. Runoff management measures such as cross drains and banked hedges act to divert flow paths into areas of greater permeability or storage areas and slow down the time to peak flow in river channels downslope. It is good practice to consider the following in the hydrological design of cross drains and banked hedges:

- Aim to locate the drains and/or bunds where overland runoff is concentrated, based on flow path mapping using desktop studies (**Chapter 4**).
- Calculate the flow arriving to the measure for the typical flood hydrograph or range of flood hydrographs.
- Calculate the required size and slope (in the direction of diverted flow) of cross slope measures to contain the required design flow. This can be calculated using the open channel flow equation (**Box 14.1**) and engineering principles in **Chapter 17**.
- Design the route and length of cross slope diversion-type features to delay the time of the peak and desynchronise flooding between subcatchments based on the residence time estimate as follows:

$$R = \frac{L}{V} \tag{14.4}$$

Where:

R is the residence time for water along a flow path (seconds)

L is the length along the flow diversion route (m)

V is the velocity which can be obtained using **Box 14.1** (m/s)

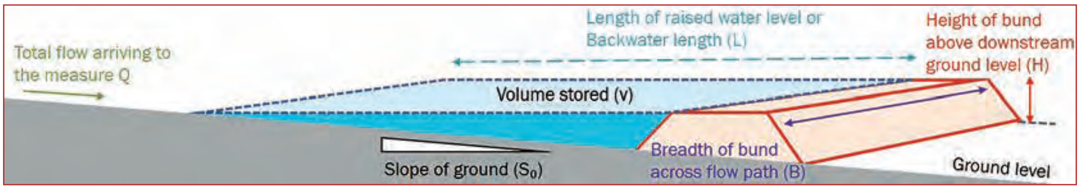
- Changes to frictional roughness due to hedgerows and buffer strips can be represented by varying roughness within the recommended range for proposed vegetation (see **Table 14.4**). The chosen roughness values should be calibrated against observed water levels and flows if data permits.
- Changes to infiltration from hedgerows and buffer strips can be estimated by varying infiltration rates within the recommended range for proposed vegetation (see **Table 17.6**). The rate of infiltration should be monitored and calibrated if data permits.

Runoff storage measures (**Chapter 8**) such as ponds, scrapes, swales and bunds can be designed and assessed using one of the following two concepts:

- Bottom-up hydrological design, where a nominal or the maximum acceptable bund height at each site is used to assess the volume that can be stored and then that volume is removed from the hydrograph using hydraulic/flood routing methods set out in **Appendix A4**.
- Top-down hydrological design, where the volume required to keep flood waters below the threshold of flooding is calculated.

The bottom-up approach is most used in landowner-based schemes, where the potential sites limit how much volume can be stored behind a given bund or barrier feature, as set out in **Figure 14.2**. If a scheme requires more accurate estimates, GIS contour or 2D hydraulic direct rainfall methods can be used to calculate the volume stored from the terrain and modelled flood depths (**Appendix A4**).

BOX 14.2 **Calculation of volume stored behind an NFM storage measure (after Samuels, 1989)**



$$L = a\frac{H}{S_0}$$

Where

L is the backwater length from the downstream bund

a is a coefficient. A value of 0.5 should be considered for on runoff pathways and a value of 0.7 for in-channel backwater

H is the height of the bund above ground level at the downstream toe of the proposed bund (m)

S_0 is the longitudinal slope of the flow path in (m/m)

$$V = \frac{L \times H \times B}{2}$$

Where

V is the approximate volume stored behind the bund (m^3)

H is the height of the bund above ground level at the downstream toe of the proposed bund (m)

B is the breadth of the bund across the flow path, perpendicular to the flow (m)

The top-down approach is more useful in subcatchment or catchment scale strategic studies where the scheme aims to reduce risk to a community or receptor downstream. The capacity of the channel at the receptor can be quickly estimated using **Box 14.1** by anyone with a basic hydrology or environmental science background, or more detailed hydraulic modelling methods by hydraulic specialists where budget and time permits.

Any flow in the design hydrograph above the threshold of flooding (or target flow to safely convey flows through the receptor without flooding) should aim to be stored by the runoff attenuation measures.

The efficiency of how water is stored and attenuated is key to the reduction in flood risk. How effective any storage or runoff management features are, will depend on the:

- threshold at which the measure starts to activate
- volume available to store the water before it becomes full
- capacity of that storage before the flood or antecedent conditions.

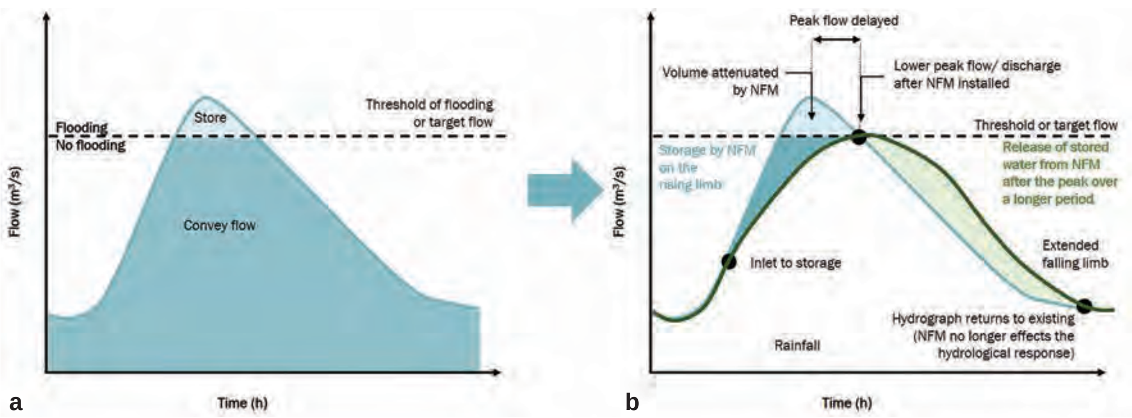


Figure 14.3 Modification of the design flood hydrograph with runoff storage-type NFM measures

If the NFM measures are designed to only activate above the threshold and contain all flood waters (as shown in **Figure 14.3a**), the flood can be managed. This design would represent 100% efficiency but would likely require a more offline pond engineered approach or an active flow control structure to only activate at the given threshold that may not be compatible with some types of runoff attenuation measures. Calculating the volume in the design hydrograph above the threshold can be used to develop an initial estimate of the volume required to be attenuated by the NFM measures upstream.

Instead, NFM measures often aim to intercept the flow on the rising limb to delay the peak flow and release the stored water after the peak, as shown in **Figure 14.3b**. The measures are set to activate such that they fill at various times during the flood to store or slow flow during the rising limb. This results in a slow rate of rise in the early part of the flood as water is stored, a delay to the peak and an attenuated or reduced peak flow, changing it from the shorter, peaky blue hydrograph to the longer, flatter green hydrograph. So, more measures may be required to achieve the same effect as a single measure with 100% efficiency to capture and contain all flows.

The capacity of a storage measure to reduce runoff will be affected by the antecedent conditions and whether the storage is already full or partly full before a flood. Once runoff attenuation features are overwhelmed, they have little impact on the existing runoff rates and flooding mechanisms. At the simplest level of detail, it can be assumed that there is little to negligible impact on flows once the storage has been exceeded and flows return unmitigated to the existing runoff hydrograph. The intermediate and detailed methods listed in **Table 14.5**, can investigate the design flood hydrograph changes in more detail if the project warrants this level of hydrological assessment identified in **Figure 4.4**.

Section 4.3.2 outlines the need to check the timing of flood peaks between the hydrograph of multiple flow paths to understand flows that currently combine to increase flood risk downstream. The design of any attenuation features or network of features should seek to delay the time of the peak not only to store the water but also to desynchronise the timing of the flood peaks to help reduce flows below channel capacity downstream.

Table 14.5 summarises the key hydrological and hydraulic considerations for design of runoff management and storage measures using simple, intermediate, and detailed approaches. See *Further reading* for supporting information.

TABLE 14.5 Hydrological and hydraulic considerations for design of runoff storage measures

Level of detail	Volume stored	Threshold of activation and assessment of impact on peak flow
Simple	Potential volume stored by each individual feature using the simplified geometry approach set out in **Figure 14.2**. Compare to approximate volume required using the flow capping methods set out in **Figure 14.3**.	Iteratively set the threshold to store the required volume across the NFM measures during the rising limb such that the target peak flow is achieved. This simple approach assumes the flows are actively controlled (which is not necessarily the case with NFM). However, it can be useful to provide an initial understanding of scale and feasibility of NFM to manage runoff during the early stages of the NFM process (Norbury *et al*, 2019).
Intermediate	GIS techniques to map the DTM contour at the top elevation of the bund and calculate the volume of the sink in the DTM. This assumes a flat water surface across the storage features. Likely to be representative on small, short features.	Flow routing using spreadsheet methods (such as Nicholson *et al*, 2019) or lumped rainfall-runoff methods (such as PDM) to iteratively alter the threshold of activation until the attenuated peak achieves the flow reduction required at the catchment outlet. Placement of multiple storage features in sequence and on multiple tributaries can be tested to work cumulatively in reducing flow (Quinn *et al*, 2013). Residence times and synchronisation issues can be investigated at a catchment scale (Metcalfe *et al*, 2017a).
Detailed	2D hydraulic modelling of the full storage feature and any associated elements that act like a weir or orifice opening to control flow in or out of the storage area such as a leaky barrier or flow over the bund. Volume stored can then be extracted from the final modelled flood depths.	Semi- or fully-distributed hydrology modelling or 2D hydraulic modelling of the full storage feature and any associated elements that act like a weir or orifice opening to control flow in or out of the storage area. The threshold of activation of multiple features can be simulated to understand cumulative storage through a cascade. Residence times and synchronisation issues can be investigated at a catchment scale (Metcalfe *et al*, 2017a).

14.3.2 Leaky barriers

The design of leaky barriers (see **Chapters 12 and 17**) aims to slow flow and store water upstream in the channel or on runoff pathways. At a local scale, they store water, cause backwater, reduce velocities and increase floodplain connection. This has the effect of slowing flood flows for a short reach downstream. How hydrologically effective any single leaky barrier is on a local scale depends on the design assumptions taken, such as the:

- threshold at which the leaky barrier starts to obstruct and slow flows
- threshold at which the leaky barrier is overtopped or bypassed on the floodplain
- relative blockage that leaky barrier forms to flood flows.

How effective a leaky barrier or series of leaky barriers are at wider subcatchment or catchment scale will depend on the location of measures relative to the receptors at flood risk, as detailed in **Figure 4.6**.

While there are various case studies that support a range of percentage flow reductions specific to each catchment assessed, there is limited evidence available to support typical reductions nationally, in larger flood events or a standard range of impacts for catchments greater than 100 km^2.

Care should be taken when selecting a modelling technique to ensure that it is an appropriate representation of hydraulic processes to reflect the blockage either horizontally or vertically across the channel or runoff pathway. Static designs that do not rely on trapping debris during the event can be assessed using hydraulic structures calculations most similar to their design type such as weir or orifice. More complex or evolving barriers, for example living hinged trees that might rely on trapping more debris and logs during a flood, are less easy to standardise. Ultimately, the modelling technaique will need to provide evidence of the change in conveyance at sufficient detail to achieve the funding requirements. The level of detail used to represent the leaky barriers may start with simple approach and be adpted to more intermediate and detailed approachs to support mutliple design phases, eg from concept to outline to detailed design.

TABLE 14.6 Hydrological and hydraulic methods to assess leaky barriers

<table>
<tr><th>Level of detail</th><th>Volume stored/water levels upstream</th><th>Flow passed through structure/attenuation downstream</th><th>Flow passed over structure</th></tr>
<tr><td>Simple
Individual site assessment (where living materials, logs or timbers are placed horizontally across the channel or runoff pathway)</td><td>Potential storage volume can be calculated based on geometry in a similar way to the bund in Figure 14.2.</td><td>Orifice flow from hydraulic structure equations set out in Appendix A4.</td><td>Weir equations from hydraulic structure equations set out in Appendix A4.</td></tr>
<tr><td>Intermediate
Strategic scale assessment where specific sites are unknown (multiple leaky barriers of any design)</td><td>Not applicable to strategic scale studies to assess benefits in attenuation flows downstream.</td><td colspan="2">1D hydraulic modelling with adjusted roughness up to the top of the proposed leaky barriers. Flow around the structure can be considered as floodplain flow.
Any roughness change should be limited to bank full height to allow for water bypassing the barrier over the riverbank.
As a starting point, consider varying the Manning's n values using Table 2 from Addy and Wilkinson (2019) and summarised in Appendix A4.</td></tr>
<tr><td>Intermediate to detailed
Individual site (or strategic scale assessment where all sites are known) (multiple leaky barriers of any design)</td><td colspan="3">Explicit structure, geometry, or porosity changes in 1D or 2D hydraulic modelling to represent each individual leaky barrier.
Full shallow water models are able to assess orifice flow, weir flow and backwater effects to extract additional volume stored, flow through the barrier and flow over the barrier in larger floods.
In complex or research studies explicit 3D modelling may be appropriate.
See Appendix A4.</td></tr>
</table>

Table 14.6 summarises approaches to consider when assessing the hydrological and hydraulic impact of leaky barriers where the shape of the barrier can be standardised and design does not rely on trapping debris over time to form a blockage.

14.3.3 Floodplain reconnection

Reconnecting the floodplain to the river channel allows more space for flood flows to spread out on the floodplain. The floodplain is naturally rougher and less efficient than the channel as it does not continually convey flow. When the floodplain is not entirely full, this encourages floodwater to slow down and be stored on the floodplain, rather than being funnelled by the channel to the next channel constriction downstream (**Chapter 12**). Like storage features, the hydraulic effectiveness of floodplain restoration depends on the design of the restoration, the point at which it activates and the volume of the floodplain available to store water. The addition of barrier features on the floodplain can help slow that flow down even more when located perpendicular to flood flows, such as hedgerows, tree planting, leaky barriers or bunds.

The effectiveness of flood attenuation by floodplain reconnection depends on the current characteristics of the site and the magnitude of the flood event. In smaller flood events where flood waters do not completely fill the reconnected floodplain the impact can be significant, such as the 25% reduction in peak flows found in the more frequent floods after floodplain restoration measures at Selworthy and Holnicote (National Trust, 2016 and Burnham, 2019). However, these benefits reduce to negligible levels in rarer and more extreme flood flows, as the floodplain completely fills in these events with, or without, the floodplain reconnection measures.

The reconnection of a floodplain at specific channel water levels can help optimise the attenuation of flow, specific to the needs of the catchment, by altering the location and level at which the riverbanks overtop. Leaky dams can become more efficient to store flows where they are used to increase water levels in order to elevate or divert water into offline storage areas that would not previously have been connected to the floodplain (see **Section 14.3.3**).

Care should be taken not to increase the speed at which the flood wave passes down the catchment in larger floods by providing a short cut.

Table 14.7 summarises key considerations and methods available for the hydrological and hydraulic design and assessment of floodplain reconnection measures.

14.4 MONITORING AND CALIBRATING HYDROLOGICAL AND HYDRAULIC PERFORMANCE OF MEASURES

The nature of NFM means that schemes are often small-scale and community led and do not always have monitoring in place to check a detailed catchment model against observed data. While there is an extensive library of methodologies used in past case studies, there are still very few examples of studies that are able to verify the effectiveness of NFM by analysis data pre-installation and post-installation.

Monitoring good practice (**Chapter 19**) should be followed to observe the hydrological processes before NFM is adopted, ideally over several flood seasons. Early monitoring provides evidence to understand the existing hydrological processes and informs parameter selection for the hydrological and hydraulic design of measures. Post-implementation monitoring is strongly recommended to verify the measure is performing as expected and to refine the assumed hydraulic parameters (ie roughness) to better reflect reality.

Monitoring also helps increase the evidence to inform the hydraulic and hydrological assumptions needed to simulate NFM measures for future designs.

TABLE 14.7 Hydrological and hydraulic considerations for design floodplain reconnection

Level of detail	Key consideration	Suggested approach
Simple	Can the floodplain attenuate/store enough water to reduce flow downstream?	Estimate volume of floodplain storage behind flood defence/riverbank/raised embankment using the volume estimation method set out in **Figure 16.6**. This can include the capacity of restored palaeochannels where the DTM has been changed to represent these. The volume could be estimated based on the approximate area and average depth from in-field measurements and then refined by topographical survey, contours on paper or digital topographic maps and/or DTMs. Survey, contour and/or DTM assessment are likely to require some topographic understanding to collect and interpret the data using specialist surveyors or GIS experts. Estimate the volume required to be stored/attenuated to reduce flows below the required threshold at the receptor (**Figure 14.3**). An effective measure will be where floodplain volume exceeds volume storage required Note this method is likely to lead to overestimation of floodplain volume storage where the raised embankment is removed, as storage and attenuation will be dynamic between the channel and floodplain.
Intermediate – detailed		Use flood routing, hydraulic modelling or any hydrological modelling with reservoir/storage functionally. See **Appendix A4**. Lower relevant section(s) of raised embankment and/or restore palaeochannels in present in topographical data. Represent this offline storage either as a volume-limited storage area in a flood routing model, or directly in the geometry of the hydraulic models. The threshold at which the offline storage in the floodplain is triggered will need to be iteratively developed to optimise attenuation downstream.
Simple	Does the floodplain delay/attenuate the peak flow?	When the floodplain is not full (ie flood volume arriving to the site < floodplain volume available) the delay to time to peak for can be calculated simply from the residence time equation (Equation 14.4). This can be calculated for each time step and flood depth during the event to understand the delay to flow on the rising limb, at the peak and falling limb. Velocity can be estimated from the Box 14.1 where backwater is negligible. When the floodplain is completely filled (ie flood volume arriving to the site > floodplain volume), the attenuation effects and any time delay can be assumed to be negligible.
Intermediate–detailed		Use flood routing, hydraulic modelling or any hydrological modelling with reservoir/storage functionally (Section 16.5) to simulate storage over the duration of the flood(s).

Courtesy Jo Old

15 COSTS AND BENEFITS

Contents

Chapter

15

Costs and benefits

This chapter gives key concepts in cost benefit analysis and discusses how their appraisal can help to deliver NFM.

▶ *Further information on funding is given in Chapter 3*

15.1 INTRODUCTION

This chapter provides an overview of the key concepts in estimating the costs and benefits of NFM, and provides signposts to relevant national guidance to compare and identify best value. The chapter can be used in combination with funding information in **Section 3.4** to evaluate the project's affordability.

15.1.1 Why assess costs and benefits?

It is important that the costs and benefits of projects are understood to aid good decision making as outlined in HM Treasury (2020a). This allows projects to budget for future expenditure and demonstrate 'best value'. This is of particular importance when public funds are concerned to provide appropriate assurance to funders and society. A good understanding of costs and benefits can help maximise the delivery of objectives and help motivate others to support the project.

Assessments should be tailored to evaluate costs and benefits to a level of accuracy and detail that the project requires, normally defined by funders, and a pragmatic approach is required for all project scales. Project teams should not set out to fully understand every potential cost and benefit without consideration of the significance to the project.

15.1.2 How and when should assessments be carried out?

Costs and benefits should be considered throughout the project life cycle. On small community projects it is anticipated that the primary interest will be to estimate the project's implementation cost. A high-level qualitative identification of benefits and maintenance costs will be adequate for smaller projects. On projects promoted by public bodies, specifically those using government flood risk management funding, it will be necessary to undertake more detailed appraisals in order to comply with the requirements of funders. National flood appraisal guidance documents (**Box 15.1**) detail the requirements to access government flood risk management funding in the UK (see also **Section 3.4**).

Further reading

National appraisal guidance in the UK

England

Environment Agency (2010a) Flood and coastal erosion risk management appraisal guidance, Environment Agency, Bristol, UK

https://www.gov.uk/government/publications/flood-and-coastal-erosion-risk-management-appraisal-guidance

Scotland

Scottish Government (2016) Flood protection appraisals: guidance for SEPA and responsibility authorities, Scottish Government, Edinburgh, Scotland (ISBN: 978-1-78652-221-4

https://www.gov.scot/publications/guidance-support-sepa-responsible-authorities/pages/6/

Wales

Welsh Government (2019) Flood and coastal erosion risk management: business case guidance, Welsh Government, Cardiff, UK

https://gov.wales/sites/default/files/publications/2019-06/flood-and-coastal-erosion-risk-management-fcerm-business-case-guidance_0.pdf

Northern Ireland

Department of Finance (2020) Northern Ireland guide to expenditure appraisal and evaluation, NI Direct, Belfast

https://www.finance-ni.gov.uk/topics/finance/step-by-step-economic-appraisal-guidance

During the selection of NFM for the catchment (**Chapter 4**) costs and benefits should be considered to ensure they are aligned with specific aims and investment objectives. An initial broad range of feasible options can be iteratively refined by the project team before the selection and delivery of the preferred option during the design (**Part C and Chapter 17**) and implementation (**Chapter 18**). It is important that consideration of costs and benefits continues post-construction to provide assurance that the project's objectives will be realised and to manage costs (**Chapter 19**). Consultation with partners, funders and stakeholders should continue throughout the project life cycle to ensure that the adopted assessment approach will provide evidence that the project achieves its objectives and is both good value for money and affordable.

There is a variety of methods that can be used to evaluate costs and benefits depending on the project scale, the types of measures being used, location and the needs of funders. Additional effort should only be invested to improve the accuracy of these methods if there is a project need to do so. **Figure 15.1** summarises the appropriate level of analysis for a range of project scales. It should be remembered that all cost and benefit estimates are approximations. The national appraisal guidance documents outline how iterative refinement, sensitivity testing and switching analysis can be used to efficiently identify best value. **Section 15.4.6** details how to use optimism bias and quantitative risk management to control costs. **Section 15.2.3** presents how sensitivity testing, switching and adaptive pathways can be used to manage uncertainty.

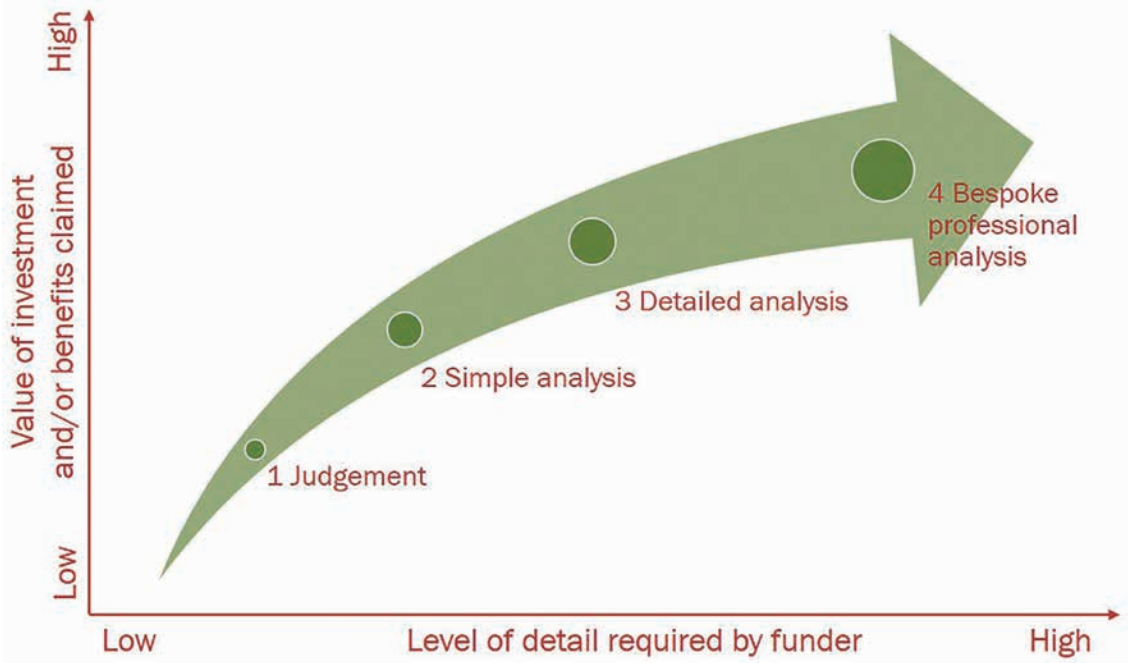


Figure 15.1 Increasing level of detail required by funders for the assessment of costs and benefits on NFM projects

15.1.3 Comparing costs and benefits

The comparison of costs and benefits via an economic analysis should form a key part of the process to select the most appropriate NFM measures for a specific project (**Chapter 4**). It may be necessary to compare costs and benefits as part of the economic analysis using a method prescribed by funders (**Section 15.1.2**) to demonstrate good value for money.

There is a range of approaches for appraising costs and benefits as part of an economic analysis.

- cost-benefit analysis
- cost-effect analysis
- multi-criteria analysis.

See **Box 15.1** for information on their suitability and application.

15.2 KEY CONCEPTS FOR ASSESSING COSTS AND BENEFITS

15.2.1 Whole-life valuation

To facilitate good decision making and the selection of economically sustainable options, costs and benefits should be evaluated and compared over the whole life of the proposed project. While the most significant costs typically occur in the capital delivery phase of an NFM project, the yearly management and maintenance costs can be a significant project consideration. Although it may seem difficult to estimate what maintenance work and repairs will be required many years from now, provided reasonable assumptions are made, then these will usually be acceptable to funders. Unlike costs, it may take a number of years for NFM measures to generate benefits, and they will accrue gradually over the lifespan of the project.

It is important that a consistent time period is selected for the evaluation of costs and benefits to allow a fair comparison of options. HM Treasury (2020a) and national flood risk management appraisal guidance documents provide direction on selecting an appropriate appraisal period – usually 40 to 100 years for environment and flood risk management projects.

15.2.2 Discounting

Depending on the requirements of funders it may be necessary to discount costs and benefits. Discounting is used to determine the present value (PV) of future costs and benefits to allow the full appraisal period to be systematically compared. HM Treasury (2020a) defines good practice for discounting in the UK, including defining set discount rates.

15.2.3 Uncertainty

Sensitivity testing and switching analysis may be undertaken to investigate uncertainties in the costs and benefits to demonstrate that the preferred option is robust. The national appraisal guidance documents provide details (**Box 15.1**).

Adaptive pathways (**Figure 15.2**) are routinely used to incorporate climate adaptability (Brisley *et al*, 2018), and to manage uncertainty associated with the scale of NFM implementation in a catchment and its hydrological impact on flood risk (Nutt *et al*, 2020a). Parallel horizontal lines (storylines) are interlinked by vertical lines (triggers) to show a range of scenarios for a flood risk management approach (Haasnoot *et al*, 2013) over future time periods. They help communicate the impact of decisions made today on the flood risk management approaches that will be available in the future.

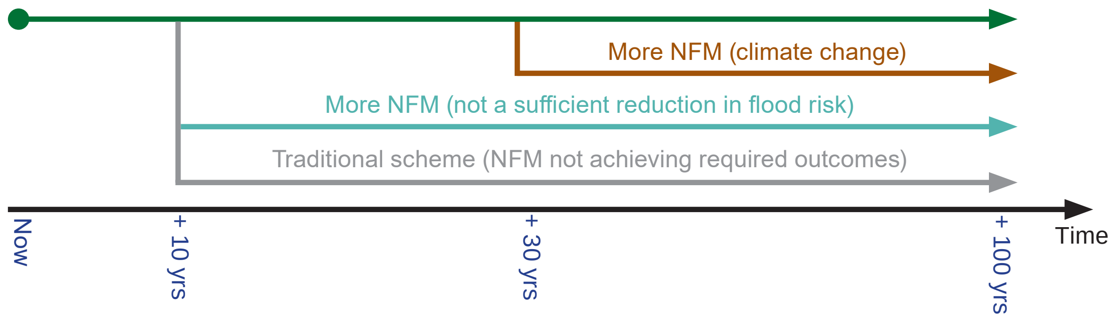


Figure 15.2 Example using adaptive pathways with NFM to map a range of future scenarios

15.3 BENEFITS

15.3.1 Types of benefits

NFM can generate two benefits:

- flood risk reduction benefits
- co-benefits.

The primary objective of an NFM project will be to reduce damage caused by flooding, however NFM can support the delivery of a broad spectrum of co-benefits. There is no unified categorisation or definition of benefits. **Table 15.1** presents a range of classifications. Project teams should select the classification system most suited to their project based on the anticipated benefits and the requirements of funders.

Advice on how to identify significant benefits is given in **Section 15.3.2**. Some benefits are quantifiable in monetary terms. However, it is not feasible or proportionate to quantify all benefits. The most appropriate approach will vary between projects. **Section 15.3.3** provides information on benefits appraisal.

TABLE 15.1 Potential benefits categorisations for NFM projects

The Multi-Coloured Handbook (MCH) (Penning-Rowsell *et al*, 2020)	Enabling a natural capital approach (Defra, 2021)	Working with natural processes (Burgess-Gamble *et al*, 2018)	B£ST guidance (Horton *et al*, 2019)	Six capitals approach (Integrated Reporting Council, 2021)
• flood – residential damages • flood – non-residential damages • flood – risk to life • flood – other losses (transport, community services and infrastructure) • emergency response • recreation • agriculture • environment	• provisioning/ abiotic – food, timber, minerals, peat, renewable energy, water. • regulating – air quality, carbon, water, noise, climate, waste • cultural – education, recreation, mental health, volunteering • bundled – biodiversity, amenity, landscape, soil, non-use • negative – air pollution, noise, flooding, waste, non-native invasive species	• air quality • aesthetic quality • habitat • climate regulation • low flows • flood (ground water or surface water) • flood (fluvial) • health access • cultural activity • water quality	• air quality • amenity • asset performance • biodiversity/ ecology • building temperature • carbon reduction and sequestration • education • enabling development • flooding • health and wellbeing • noise • recreation • traffic calming • water quality • water quantity	• financial • manufactured • intellectual • human • social and relationship • natural

15.3.2 Identifying significant benefits

It is important that projects identify and record significant benefits (and disbenefits) early on to facilitate good decision making and the efficient use of limited resources. Screening is typically undertaken as part of the long list process and using the suggested method within Table 7 of Defra (2021). The B£ST tool (Digman *et al*, 2019) also provides a systematic screening checklist suitable for use on NFM projects.

Significance is subjective and will vary between projects and individuals. It may also vary as aims, catchment understanding, and pressures change. A strong understanding of local issues is key to forming a robust understanding of local needs and a consensus on what is significant.

The benefits wheel (Burgess-Gamble *et al*, 2018) is a useful and readily accessible means to quickly identify the categories of potentially significant benefit. These can be used to develop a good understanding of the catchment (**Section 4.2**), including knowledge of the local issues and opportunities (**Chapter 16**). Early identification of significant benefits may help to involve additional partners, seek additional funding (**Section 4.3**), adapt project aims and achieve more together.

Appraisal summary tables (Environment Agency, 2010b) can be used to record the relative significance of benefit categories for a range of options and direct users to decide which, if any, benefits should be appraised further (see **Section 15.3.3**). The project objectives and the needs of funders should be considered when identifying which benefits are considered significant.

15.3.3 APPRAISING BENEFITS

Flood risk reduction will often be the primary aim for NFM projects, however co-benefits often exceed the flood risk reduction benefits. **Table 15.2** provides a summary of the scale of flood reduction benefits and co-benefits. The identified benefits associated with each project are specific to that project and the methods adopted by the appraisers. While the results cannot be directly transferred to other projects, they do illustrate the scale and pattern of benefits.

TABLE 15.2 Estimated flood risk reduction and co-benefits for a range of NFM projects

Project	Description of project	Monetised estimate of co-benefits	Monetised estimate of flood risk reduction benefits	Percentage reduction in flood damages
Clothworkers Wood, Royal Borough of Greenwich (Susdrain, 2019)	Various NFM measures including leaky dams, low berms and attenuation storage. Catchment area unknown.	£14 000 average annual benefit	£1 300 average annual benefit	(Insufficient information to calculate)
Eddleston Water, Scottish Borders (Nutt *et al*, 2020b)	Various NFM features over 70 km^2 catchment comprising: 207 ha hillslope tree planting, 33 ha riparian tree planting, 2.9 km river re-meandering, 116 'flow restrictors' and 29 runoff attenuation features.	£141 000 average annual benefit	£32 000 average annual benefit	3.4%
Pudlicote Farm, Oxfordshire (Winlow *et al*, 2019)	Various NFM features on a 20 ha area within the 430 km2 River Evenlode catchment. Measures comprised 550 m buffer strips, 4.9 ha conversion of arable to grassland, and 550 m river restoration, 0.2 ha wetlands and 1.7 ha woodland.	£22 000 average annual benefit	£930 average annual benefit	(Insufficient information to calculate)
Southwell, Nottinghamshire (Scott *et al*, 2017)	Creation of 1.5 km^2 conifer plantation in catchments of Halam Stream (2.8 km^2) and Potwell Stream (6.2 km^2).	£183 000 average annual benefit	£38 000 average annual benefit	6.8%

The generally accepted method for evaluating the flood risk reduction benefits is detailed within The MCH (Penning-Rowsell *et al*, 2020), which also provides an assessment method to compare the whole-life flood damages for a baseline case and an appraised option. To determine an appropriate appraisal baseline case, consult the relevant national appraisal guidance (**Box 15.1**). Flood risk reduction benefits can be difficult to quantify and even attempting to quantify them may be deemed inappropriate. Guidance from funders should be followed to determine an appropriate way to assess and report flood risk reduction benefits.

Table 15.3 presents a range of potential approaches dependent on the quality of flood risk information available. The approaches align with the levels of detail presented in **Figure 15.1**.

TABLE 15.3 Approaches for the quantification of flood risk reduction benefits

Approach	Description
Level 1 'judgement'	If there is very limited information, expert judgement from a hydrologist, hydraulic modeller or other flood risk specialist can be used to estimate the potential flood reduction benefit. There are no published simple rules on the flood risk reduction benefit arising from NFM. In the absence of better information, the case study information in **Table 15.3** could be used to estimate the range of potential benefits. Judgement-based approaches will commonly be used in the early stages of most projects, but are unlikely to be acceptable to funders where the cited flood risk reduction benefit is a significant percentage of the overall benefits.
Level 2 'simple analysis'	When there is modelling of the baseline (or existing) case, and flood hydrographs are available, techniques like the top-down approach can be used to calculate an appropriate shift in the probabilities of the modelled flood events. This approach requires estimation of the impact NFM measures will have on the flood hydrograph and so is an approximation. This approach is unlikely to be acceptable to funders where the cited flood risk reduction benefits are a significant percentage of the overall benefits, but may be acceptable for smaller investments when supported by robust sensitivity testing.
Level 3 'detailed analysis'	When robust flood modelling has been undertaken of both the baseline case and the 'with NFM investment' case using normally available techniques. Flood damages and flood risk reduction benefits can be calculated as for traditional flood risk management approaches using the methods detailed in the MCH.
Level 4 'bespoke/ academic' analysis	Similar to Level 3 'detailed analysis' but the calculation of flood risk reduction benefits incorporates detailed modelling, monitoring data and property surveys to reduce uncertainty. The cost and timescale will make this approach unsuitable for most projects.

Environment and social enhancements can generate significant co-benefits in the form of ecosystem services which accrue from natural capital (Defra, 2021). Where deemed significant and appropriate to do so, published analysis methods can be used to quantify ecosystem services. B£ST (Digman *et al*, 2019) is well suited for evaluating co-benefits on all types of flood risk management projects. There is a broad range of tools and methods available, each with strengths and weaknesses. The Ecosystems Knowledge Network Tool Assessor is a maintained searchable repository of ecosystems services assessment tools.

As outlined in **Section 15.1.2**, it should be recognised that benefits are estimated and rarely known. The refinement of benefits estimates can consume available funding and delay implementation. As a general principle, benefits should only be appraised in more detail where the additional invested effort could alter decision making or is necessary to secure funding. Iterative refinement should be used alongside sensitivity testing and probabilistic approaches. Following the principles of The MCH (Penning-Rowsell *et al*, 2020), should a benefit category generate less than 10% of the overall benefits, or if a refinement is not expected to change an estimate by more than 10%, then the additional appraisal effort is normally not deemed justifiable.

It should be noted that current government flood risk management funding across the UK nations is primarily intended to reduce flood damages and not to deliver co-benefits via environmental enhancement. While some ecosystem services may be deemed acceptable in funding applications, government flood defence funding may currently require that non-flooding benefits are capped to a proportion of the flood risk reduction benefits.

TABLE 15.4 Tools to evaluate ecosystem services and co-benefits

Tool	Qualitative or quantitative	Technical requirement	Description
Digman, C J, Horton, B, Ashley, R M and Mcmullan, J (2019) *B£ST: Benefit Estimation Tool – Valuing the benefits of blue-green infrastructure*	Quantitative	Medium	Provides guidance to practitioners on estimated benefits of blue-green infrastructure.
https://www.susdrain.org/resources/best.html			
Environment Agency (2020b) *Carbon calculator*	Quantitative	Medium	Tool to evaluate the carbon footprint of projects. Includes functionality to evaluate carbon storage.
Mersey Forest (2018) *Green Infrastructure Valuation Toolkit (GI-Val)*	Quantitative	Medium	Tools to assess the value of a green investment. Where possible, the benefits of green infrastructure are given an economic value. Other quantitative contributions (eg number of jobs) can also be provided to give a more complete view.
https://www.merseyforest.org.uk/services/gi-val/			
Sharp, R, Douglass, J and Wolny, S (eds) (2018) *InVEST 3.7.0. User's guide*	Quantitative	High	Uses open source software models to map and value ecosystem services. Explores how changes in ecosystems are likely to affect benefits.
https://naturalcapitalproject.stanford.edu/			
Binner, A, Bateman, I J and Day, B (2019) *Natural Environment Valuation Online tool (NEVO)*	Quantitative	Low	Help users explore the benefits derived from existing and altered land use across England and Wales. A free web tool designed to be easy to use.
https://www.leep.exeter.ac.uk/nevo/			
Day, B H and Smith, G (2018) *Outdoor recreation valuation (ORVal) user guide*	Quantitative	Low	Recreation and amenity focused. Predicts the number of visits to existing and new greenspaces and estimates the welfare value of those visits in monetary terms.
https://www.leep.exeter.ac.uk/orval/			
Environment Agency (2020d) *Partnership Funding Calculator 2020 for FCERM grant-in-aid*	Quantitative	Low	Used to evaluate flood defence grant-in-aid in England. It enables users to quickly quantify the monetary value of co-benefits (reported as qualifying benefit) for a range of habitat types.
https://www.gov.uk/government/publications/partnership-funding-calculator-2020-for-fcerm-grant-in-aid-gia			

15.4 COSTS

Cost information is required to identify the NFM option that provides best value and to define the budget required to deliver it. As with the appraisal of benefits, it is essential that a proportionate approach is adopted. When identifying the option that provides best value, costs should only be refined where the additional effort to improve cost estimates will enhance the quality of decision making. Once a preferred option is selected it is generally appropriate to further refine costs.

Costs of NFM projects are discussed in the following sections:

- feasibility, appraisal and design (**Section 15.4.1**)
- land (**Section 15.4.2**)
- construction and implementation (**Section 15.4.3**)
- post-implementation (**Section 15.4.4**)
- residual value and decommissioning (**Section 15.4.5**)
- optimism bias and risk (**Section 15.4.6**).

Table 15.5 summarises a range of resources that can be used to estimate costs.

Project teams should discount costs (**Section 15.2.2**) when undertaking economic appraisal and should follow guidance from funders to determine a proportionate level of detail.

Costs are not solely monetary and can extend to carbon, environmental and social costs (**Section 15.4.7**). Care should be taken to determine whether a cost should be considered a negative benefit to avoid double counting, for example the loss of a view.

15.4.1 Feasibility, appraisal and design

The percentage of total project costs attributed to feasibility, appraisal and design of NFM normally exceeds that for traditional flood risk management projects. Liaison with a wide range of stakeholders, including land managers, over a catchment can require considerable additional effort. This early investment can be fundamental to understand the pressures in the wider landscape, maximise benefits, secure stakeholder acceptance and avoid undesired environmental trade-offs.

The potential wide range of benefits, and the knowledge limitations regarding the effectiveness of NFM at reducing flood risk can result in expensive professional studies to provide satisfactory assurance to funders that the benefits are achievable. Careful consideration should be given to what feasibility and appraisal costs are appropriate. It may be appropriate to reconsider the proposed funding source if these costs are likely to represent a significant proportion of the overall project benefits.

Avoiding bespoke design for NFM can help to minimise design and implementation costs. The use of standardised designs and the rationalisation of NFM types to a small selection of low risk designs will typically serve to lower project complexity and costs (**Part C**). Where bespoke design is required the project team should be satisfied that good value for money can be achieved.

15.4.2 Land

The costs associated with securing and maintaining agreements for NFM can be very different to traditional engineered flood defences due to the significant area of land that can be affected. Early in the project, it is important to understand how land is currently used and how it could change as a result of population growth, economic development, environmental policy or an NFM project.

Landowner compensation can be divided into five categories:

- permanent loss of land, such as land being eroded or permanently flooded
- permanent change in flood risk, eg floodplain restoration leading to increased damage to crops

- temporary damages, eg due to construction affecting productivity
- change in land management, such as crops planted or harvested in an alternative way
- change in land cover leading to a change in land use, eg conversion of pasture to woodland.

NFM projects may impact the eligibility for subsidies or agri-environment payments. Consider this when assessing project land costs.

Appropriate budget should be allocated to cover the cost of negotiating agreements with landowners. The size of this budget should reflect the legal status of the prospective agreements in addition to the number of parties to the agreements. Great care may be needed to evaluate compensation payments; simple valuation approaches such as writing off agricultural land values, land reinstatement costs or the assessment of income forgone may not accurately reflect changes that could arise from NFM.

15.4.3 Construction and implementation

The costs associated with construction and implementation will vary depending on the type of NFM measure being delivered. Measures implemented by volunteers could have relatively low costs compared with those that require paid contractors.

Construction and implementation costs are typically broken down into labour, plant and materials. On NFM projects typical construction and implementation costs could relate to:

- supply of timber for the creation of NFM features (materials)
- operatives, diggers and other earth moving equipment to create NFM features (plant and labour)
- erosion and sediment control to mitigate environmental impacts (labour, plant and materials)
- planting and reinstatement (labour and materials)
- disposal of soil from excavation (materials).

These will be influenced by:

- scale of the interventions
- type of labour (eg volunteer or contractor led)
- type of organisation promoting the project and the form of contract used
- goodwill of landowners and the local community
- accessibility
- design standard (eg acceptance of risk of failure)
- specification of materials (eg local site won materials versus imported materials)
- location
- time of year.

Table 15.5 summarises a range of resources that can be used to estimate construction and implementation costs.

15.4.4 Post-implementation

15.4.4.1 Inspection and maintenance

Inspection and maintenance keeps measures fit for purpose and operating to the designed standard. Without appropriate maintenance the benefits may not be achieved. Typically, maintenance costs for NFM measures will be lower than for traditional flood risk management infrastructure. It is assumed that most NFM projects will not entail significant operation costs, such as the cost of pumping, but some operational costs may occur, such as grass cutting. Conversely, the maintenance cost associated with some NFM projects may be notable, for example the renewal or replacement of decayed timber structures.

Estimates of the whole-life cost for inspection and maintenance will be required when assigning budget for delivery and may be required for assessing best value for money. For economic appraisal, costs should be discounted (**Section 15.2.2**) to create PV.

Table 15.5 includes a range of tools to assess inspection and maintenance costs. The parties responsible for inspection and maintenance should lead on estimating the costs, but it may be appropriate to liaise with an organisation with more experience. Consideration should be given to how asset refurbishment or renewal will be funded. As identified in **Section 19.2**, it is important that the design phase seeks to minimise these costs through good access, a long design life and the avoidance of measures that require frequent inspection.

The uncertainty of the natural environment means an adaptive approach needs to be taken and measures might need to be adapted over time, making it hard to fully forecast costs. **Section 15.2.3** discusses managing uncertainty.

15.4.4.2 Monitoring

Section 19.3 outlines the types of monitoring activities which may be required to quantify benefits, understand uncertainties and demonstrate the achievement of objectives. Effective monitoring will help secure future funding, engage local communities, and enable a managed adaptive approach (**Section 15.2.3**).

The scale of monitoring should be proportionate to project needs and will often be defined by the project funder. For small-scale community NFM projects, a light touch could be adequate, whereas large catchment scale projects could require more complex approaches.

15.4.5 Residual value and decommissioning

In line with HM Treasury (2020a), residual values and the cost to decommission should be considered. It is anticipated that many NFM projects will have significant residual value at the end of the appraisal period and that few projects will entail decommissioning costs as NFM features will either continue in perpetuity or naturally decay, returning the site to its original condition. In most cases it is anticipated that residual values can be considered via a simple qualitative assessment.

15.4.6 Optimism bias and risk

Optimism bias should be added to correct for the proven tendency for appraisers to be too optimistic when estimating project costs and durations. HM Treasury (2020a) provides guidance on the selection of appropriate correction factors.

Risk management is the structured approach to managing risks and should be an ongoing process throughout the whole project life cycle. HM Treasury (2020a) and (2020b) provide detailed information on the management of risks that could affect cost or programme. A risk register should be maintained detailing the potential scale and likelihood of unmitigated risks, their ownership and how the risk is being managed. Workshops can be used to populate, update and discuss the most appropriate means of managing risks.

Risk contingencies should be used when budgets are being defined to provide assurance that adequate funding is available for the delivery of the project. The most appropriate approach will depend on project scale and the needs of funders. For simple low value community projects, it may be appropriate to assess the additional costs, if identified risks were to occur, and add the figure to the overall project cost. Risks that have been identified, and recognition of the risks that have not, can be used to form an estimate of the potential additional costs to deliver the project. On larger more complex projects, it may be appropriate to adopt a quantitative risk management technique such as mean expected value or Monte Carlo analysis. It should be noted that optimism bias is different to a risk contingency. Projects should adjust for optimism bias and allocate a suitable contingency for the management of risks.

15.4.7 Carbon and other non-monetary

NFM projects should give appropriate consideration to non-monetary costs, typically the project's impact on carbon emissions, but also social and environmental costs. The requirement to consider non-monetary costs will often be driven by the funders, but can also relate to statutory duties such as compliance with Climate Change Act 2008 and Equality Act 2010. It is anticipated that qualitative recording and consideration of non-monetary costs using appraisal summary tables (Environment Agency, 2010c) will be adequate for most small community-led NFM projects. Larger projects may need to assess the carbon impact of the project using carbon accounting. There is an array of publicly available tools to evaluate the emissions associated with engineering works. Equality impact assessment, distributional analysis and environmental impact assessment can also be used to highlight and identify mitigation for potential social and environmental impacts.

Table 15.5 includes a range of tools to assess the carbon, social and environmental cost of projects. As with all costs and benefits, it is essential that care is taken to avoid double counting (double reporting) of costs. For example, if the cost to fully mitigate an environmental loss is included in the appraisal, it should not also be cited as a disbenefit.

15.4.8 Resources

Table 15.5 provides a summary of key sources of cost information for NFM projects.

TABLE 15.5 Resources available for assessment of costs

Source	Available information	*Feasibility, appraisal and design*	*Construction*	*Post construction*	*Land*	*Carbon*
Long-term costing tool (Pettit and Keating, 2015) Cost estimation for habitat creation – summary evidence (Keating *et al*, 2015) Costs of flood risk management measures (Pettit and Bassett, 2013)	High-quality cost data for the construction of a range of NFM and other flood risk management assets based on outturn costs.	✓	✓	✓	✓	
Quotations from suppliers	Costs can be highly dependent on the scale and scope of work. Early supplier engagement can assist with allocation of appropriate budgets. Quotes should be secured from at least three suppliers. Supplier quotations may not be acceptable as estimates of costs for some funders.	✓	✓	✓	✓	
Outturn costs for similar contracts	Analysis of the outturn value of previous commissions can help determine appropriate budgets.	✓	✓	✓	✓	
Natural flood management handbook (Forbes *et al*, 2015)	A series of high-level cost estimates for the strategic assessment of NFM costs.	✓	✓	✓		

continued...

TABLE 15.5 Resources available for assessment of costs (contd)

Source	Available information	*Feasibility, appraisal and design*	*Construction*	*Post construction*	*Land*	*Carbon*
Bill of quantities and published unit price books (eg AECOM, 2019a, 2019b, Mott MacDonald, 2013)	Unit costs for a wide range of works which can be used with a bill of quantities to estimate construction cost. Some include rates for labour and plant to allow a labour, plant and materials approach.		✓	✓		
Monitoring and evaluating the Defra funded natural flood management projects (Arnott *et al*, 2018)	Indicative costs for a range of monitoring approaches			✓		
Assessing the mechanisms for compensating land managers (Fenn *et al*, 2015)	Guidance on the assessment of compensation for land managers affected by NFM projects.			✓		
Land value estimates (MHCLG, 2016)	Database of land value estimates in England.				✓	
Price paid data (HM Land Registry, 2021)	Database of actual land sales in England and Wales.				✓	
The MCH (Penning-Rowsell *et al*, 2020)	Provides tables of (a) financial and economic gross and net margins for selected land uses, and (b) estimated damage per flood event to a range of land uses.				✓	
Records of farm income in previous years	Analysis of past typical farm income to calculate income forgone.				✓	
Carbon Calculator (Environment Agency, 2020b) Carbon Modelling Tool (Environment Agency, 2020c)	Rapid top-down and bottom-up whole-life carbon assessment and optioneering tools. Use during the project appraisal phase to enable carbon assessment to inform the option selection process.					✓
Practical river restoration appraisal guidance for monitoring options (Hammond *et al*, 2011) Monitoring and evaluating your project (RRC, 2017)	Comprehensive guidance on the cost of undertaking monitoring.			✓		
Environmental Impact Assessment (MHCLG, 2020) Equality Impact Assessment (HM Government, 2010) The Green Book (HM Treasury, 2020a)	Guidance on the legislative environmental impact assessment, equality impact assessment and distributional impact assessment processes. Can be used to identify significant environmental and social costs.	✓	✓	✓	✓	✓

Courtesy Emma Rothero, Floodplain Meadows Partnership

16 ENVIRONMENTAL CONSIDERATIONS

Contents

Chapter 16 Environmental considerations

This chapter discusses the opportunities and constraints of NFM with regard to the water environment, the landscape and its ecology and the historic environment.

▶ *Potential groups to work with are given in Chapter 3*

16.1 INTRODUCTION

Providing multiple environmental co-benefits is one of the main advantages of an NFM approach. More can be achieved if an NFM project works with the natural environment to improve water quality, habitats and biodiversity quality and resilience, and strengthen the landscape character.

Environmental opportunities and constraints need to be considered at all delivery stages – in the immediate vicinity of the NFM measures, as well as upstream and downstream within the wider catchment. Early identification of opportunities is critical in order to work with (rather than against) the existing environment in order to maximise the environmental co-benefits to be achieved alongside flood benefits. Similarly, if constraints are identified early, then the scheme can be designed around these or avoid them. Early consideration also enables any associated cost, programme, legal and consent requirements to be defined and managed.

Environmental opportunities help maximise the effectiveness of NFM projects and could:

- improve the environment's capacity for hydrological processes to operate naturally and protect or restore these as part of a project (eg improve the quality of a peatland habitat to store more water)
- deliver NFM measures that improve the environment (eg creating a species-rich banked hedgerow)
- improve the environment more widely alongside or with NFM.

To identify opportunities, it is important to understand the study area or catchment, work with others, and encourage creative and holistic thinking within the project team. Consider opportunities to protect and restore existing habitats and features alongside the creation of new ones.

Environmental constraints are environmental factors that may influence the project, either in terms of how or where to implement NFM, the NFM measure or type to use, or the timing of works.

Many environmental topics may be relevant to individual NFM projects. Typical topics are considered to be the water environment, fluvial geomorphology, ecology, landscape, the historic environment, and waste and contamination, which are covered in this chapter. This chapter also provides a framework for considering environmental issues at each stage of the NFM delivery process and outlines potential opportunities and constraints for each (**Sections 16.3 to 16.8**).

Section A3.2 provides information on how and when to engage a range of environmental professionals in an NFM project.

Table 16.1 highlights specific environmental situations that may be encountered in NFM projects and signposts further information.

TABLE 16.1 Environmental consideration – where to find information

Does the project include or may affect	Section in this manual
Surface water (eg lakes or rivers) or groundwater	16.3
Works to a river channel and/or the floodplain	16.4
Site designated for nature conservation	16.5, 16.5.2.1 (for statutory and non-statutory designated sites)
Protected or priority plant or animal species or habitats	16.5, 16.5.2.2, 16.5.2.3
INNS	16.5, 16.5.2.4
Site designated for landscape qualities, recreation or amenity	16.6
Landscape-scale NFM	16.6, 16.7, 16.7.2.3
Designated or non-designated heritage asset	16.7, 16.7.2.1, 16.7.2.2
Excavation	16.6, 16.7.2.2 (information regarding non-designated heritage assets), 16.8
Consents, licences, permissions, permits, or assessments	Consult relevant statutory organisation (Section A3.3) to discuss requirements, the whole of this chapter, and 3.5.

16.2 ENVIRONMENTAL CONTEXT

16.2.1 Delivery process

Table 16.2 outlines the main environmental considerations at each NFM delivery process stage. It should be adapted to meet local and project conditions and be proportionate to the project scale and intended outcomes.

TABLE 16.2 Environmental considerations in the NFM delivery process

Stage	Environmental considerations
Initiation (**Chapters 2 and 3**) 	• Determine the project aims (**Section 2.1**) and consider how the environmental elements apply. • Identify project success factors (**Section 2.2**) related to the environment. • Define the area being considered for the NFM implementation. Environmental information may need to be collected over a wider area to understand the site context. Identify this additional buffer distance. • Environmental opportunities and constraints should be integrated as early as possible and at every stage to maximise co-benefits and minimise risks.

Understand catchment
(**Chapter 4**)

	• Activities required depend on factors such as the environmental sensitivities of the site, the scale of works proposed, and the potential need for consents, permissions or assessments. The overall process is given in **Section 4.2**.
	• To gather local environmental knowledge, consult with local nature conservation groups or heritage groups (**Section A3.3**).
	• A desktop study (**Section 4.2.1**) will identify key environmental sensitivities within the study area. This could include statutory or non-statutory designated sites, protected sites or areas, or protected features on or near the site being considered for NFM (**Sections 16.3 to 16.8**). Most information is available online (**Section A3.4** contains useful websites for viewing/obtaining environmental baseline data). Environmental topics do not operate in isolation – consider interactions between environmental topics.
	• The presence of environmental sensitivities can provide opportunities and/or constraints for NFM. Engage with the relevant statutory consultees (**Section A3.3**) as early as possible to develop a scheme compatible with these sensitivities and to maximise opportunities.
	• Review wider environmental considerations at this stage to enable any other aims to be integrated within the project (**Section 4.2.5**).
	• If environmental sensitivities are likely then consult a professional (**Section A3.2**) as to whether they are being considered as opportunities or constraints. Further desktop study may be required (eg to support a consent or manage a risk), and further topic-specific data may be needed. If relevant, contact environmental organisations (**Section A3.3**) for site-specific data.
	• Some environmental factors may mean a field survey is required, for example:
	  ○ presence of designated sites/features/assets
	  ○ the site's potential for further environmental sensitivities to be present
	  ○ the requirement for consents/assessments/permissions and statutory consultee requirements
	  ○ surveys can also identify any natural environmental processes present, what the functional site uses are, and local conditions. Use a professional (**Section A3.2**), where required, to scope and undertake environmental field surveys. Some surveys are seasonally dependent.

continued...

TABLE 16.2 Environmental considerations in the NFM delivery process (contd)

Stage	Environmental considerations
Select measures (**Chapter 4**)  	• Use environmental information to influence the selection of NFM sites and measures (**Chapter 4**) and sources of funding (**Section 3.3**). • Field surveys may be ongoing through this stage. Use the mitigation hierarchy to avoid or manage any harmful effects on the environment (**Figure 16.1**). • There is uncertainty and limited scientific evidence about the beneficial and adverse environmental effects of some NFM measures, especially in circumstances where they have not previously been used. When there is an uncertain risk of environmental degradation (especially in sensitive environments), consider a less sensitive location, a smaller scale, and monitoring to identify and address any signs of environmental degradation. Identify and implement good practice requirements (**Section 16.2.3**) from this stage until the project is complete. These can be identified by local key stakeholders and relevant environmental organisations (**Section A3.3**) and professionals (**Section A3.2**). • Identify any requirements for consents, assessments and/or permissions (**Section 3.5**). • If multiple sites are being considered, there is potential for a combination (or cumulative) of effects to occur due to the sum of changes made to the environment. These can be beneficial effects or adverse. This should be considered for all projects but will require more detail if an environmental impact assessment is required. NFM projects that are constructing or implementing multiple NFM measures across a catchment usually consider cumulative hydrological effects (**Chapter 14**), as they are seeking to reduce flood risk. However, cumulative effects can occur for other environmental topics. For example, multiple areas of new woodland could change the character of a landscape. • Select NFM measures that maximise potential co-benefits.
Design and materials (**Chapter 17**)  	• The environmental opportunities and constraints should be considered in an integrated way throughout the outline and detailed design stages. Findings from field surveys should be fed into the design before this stage is complete. This is the latest stage for assessments to be completed, and any consents or permits needed must be obtained before construction or implementation (**Section 3.5**). The timing of these activities is important, as enough information is needed on the proposals to undertake the work required, but any feedback from assessments, the consenting processes and statutory consultees, should also influence the design process, particularly for more complex schemes. • As designs develop, consider the proposals in the context of the environmental information gathered and use the mitigation hierarchy (**Figure 16.1**). Environmental information and consultees may influence, for example, the type and source of materials used or the height or scale of NFM measures. • The design stage should avoid the creation of a situation where, due to the design, the construction/implementation and monitoring or maintenance required might cause harmful environmental effects.
Construction and implementation (**Chapter 18**)  	• Adopt good environmental practice as a minimum (**Section 16.2.3**). • Avoid environmental damage (including pollution) to ensure legal compliance and avoid legal action. If environmental damage does occur during construction or implementation (eg pollution or other environmental incident), it should be reported immediately through the appropriate channels. Appropriate action should be taken as soon as possible to limit any environmental damage, and rectify any damage caused at the source.

continued...

TABLE 16.2 Environmental considerations in the NFM delivery process (contd)

Stage	Environmental considerations
Monitor and manage (**Chapter 19**) 	• Depending on the project requirements (including any requirements from consents/ permissions/licences), no or few environmental activities may be required at this stage. • Environmental monitoring can determine the effectiveness of NFM measures and demonstrate the achievement of environmental co-benefits, compared to the information gathered about the site before construction/implementation began. If remedial work (Figure 16.1) is required before construction begins, ongoing monitoring can be mandated via a consent/permission to ensure that, for example, replacement habitat is established as proposed. Monitoring can also identify unexpected negative environmental effects; in these cases, action should be taken to address these. • Management of NFM measures should be planned and undertaken in a way that ensures the management/maintenance activities align with the wider project objectives and do not cause harm to the environment or create any legal compliance issues. • Reporting to statutory authorities or publishing of results may be required at this stage, and this can be voluntary or required through a consent/permission.

16.2.2 Proportionate approach

Environmental opportunities and constraints should be considered in proportion to the project, with an aim to maximise co-benefits and reduce issues later on. Proportionality for environmental input in relation to other aspects of the project, such as design or construction, can affect both budget and programme. Where there are no organisational environmental requirements to follow, the requirements (and proportion of environmental input) are often influenced by:

- Following good environmental practice and legal compliance (the requirements may vary depending on location, sensitivities and NFM proposals) including any requirements for consents, permissions, assessments or licences.
- The desire and opportunity to achieve environmental co-benefits, and their type and scale.
- Type and scale of NFM measures to be constructed or implemented.
- Environmental sensitivity of the site (and associated requirements related to those sensitivities).

If the environmental considerations become disproportionate to manage, aspects of the project should be amended to reduce environmental risks.

16.2.3 Good environmental practice

Following good environmental practice helps to manage constraints and ensure the project is legally compliant. Projects should follow any specific environmental guidance required by the organisation undertaking the NFM project, or the funding organisation. This may include how and when environmental opportunities and constraints should be considered, specific processes to follow and/or documentation to be kept. If there is no specific guidance, t hen follow UK good environmental practice advice (see *Further reading*).

Mitigation is an activity undertaken to reduce the severity or seriousness of an action likely to have a negative effect, in this case on the environment. The mitigation hierarchy (**Figure 16.1**) provides a framework within which to consider NFM projects in the order of priority shown, adopting good practice. Negative effects should be avoided or minimised (reduced) where possible; where not, measures or actions to restore or compensate should be taken. Several levels of the mitigation hierarchy may be applied in one project, for example, effects may be minimised, but remaining effects should be remedied or compensated.

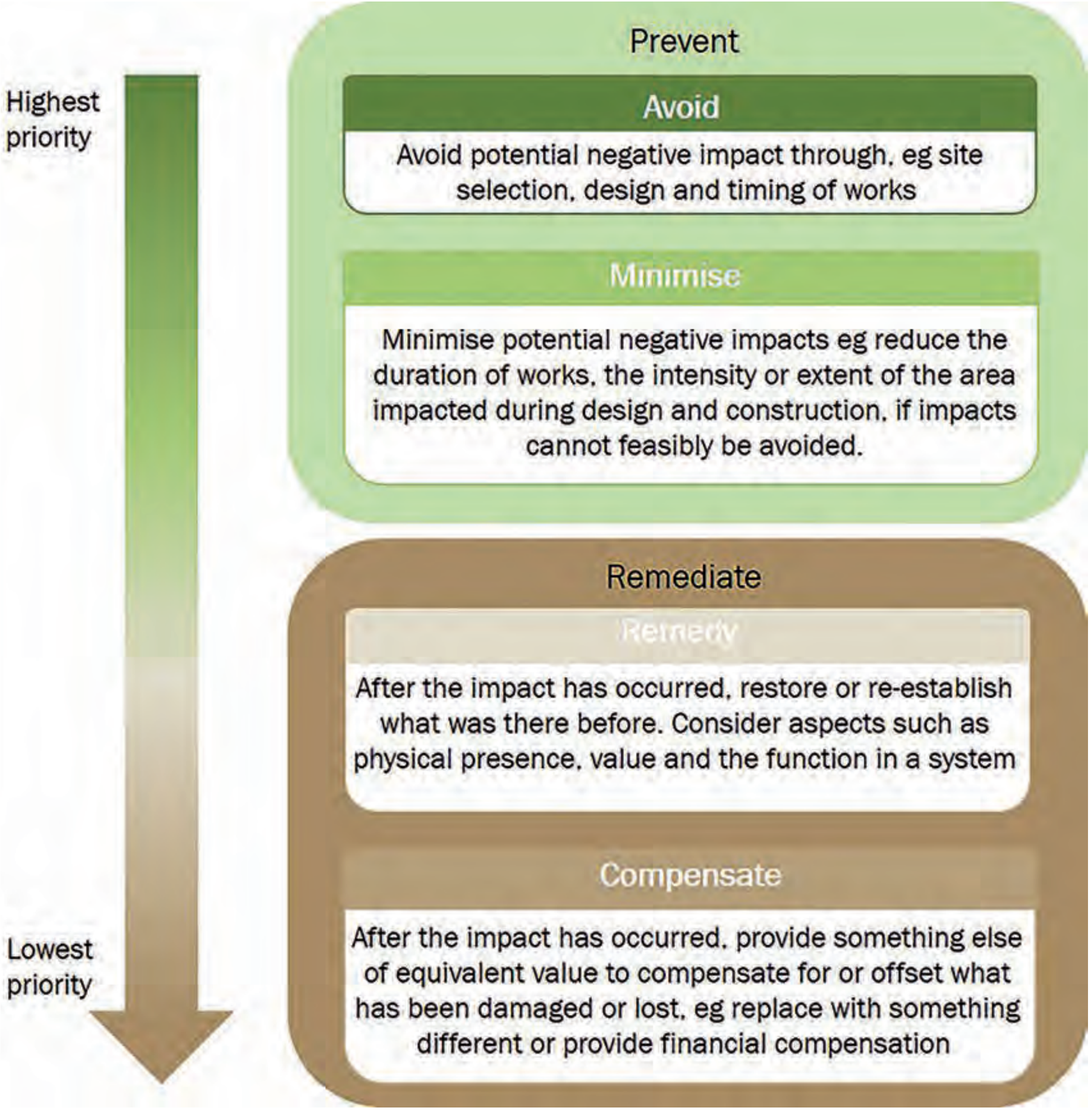


Figure 16.1 The mitigation hierarchy – mitigation of impacts on the environment

Further reading

Charles, P and Edwards, P (eds) (2015) *Environmental good practice on site*, fourth edition, C741, CIRIA, London, UK (ISBN: 978-0-86017-746-3)

⇨ Good environmental practice before and during site construction, irrespective of the location, size or nature of the development.

www.ciria.org

Environment Agency (2017) *Natural flood management toolbox: guidance for working with natural processes in flood management schemes*, cbec co-engineering UK, Ltd, Inverness, Scotland

⇨ Examples of approaches to considering the environment at various project stages.

https://catchmentbasedapproach.org/wp-content/uploads/2018/08/EA-NFM-Toolbox-Final-Draft.compressed.pdf

Law, C and D'Aleo, S (eds) (2016) *Environmental good practice on site pocketbook*, fourth edition, C762, CIRIA, London, UK (ISBN 978-0-86017-777-7)

⇨ Pocket-sized version of CIRIA C741 for good environmental practice before and during site construction, irrespective of the location, size or nature of the development.

www.ciria.org

RRC (2021) Manual of river restoration techniques, updated, The River Restoration Centre, Bedfordshire, UK

⇨ Examples of approaches for managing environmental considerations (Part 3 and case studies).

https://www.therrc.co.uk/manual-river-restoration-techniques

Websites

Considerate Constructors Scheme best practice hub: **www.ccscheme.org.uk/ccs-ltd/best-practice-hub**

SEPA and NIEA NetRegs: **https://www.netregs.org.uk/**

Environmental guidance for organisations in Northern Ireland and Scotland, including the construction, forestry and waste sectors which may be relevant to NFM. There is no direct equivalent available for England or Wales, relevant information can be found on the Environment Agency (England) and National Resources Wales (Wales) websites.

16.3 WATER ENVIRONMENT

16.3.1 Introduction

The water environment is defined here as freshwater (rivers and lakes), wetlands, transitional waters (estuaries), coastal waters and groundwater. The overall condition (or status) of the water environment is typically measured in terms of availability (quantity), water quality and, for surface waters, fluvial geomorphology and supporting aquatic habitat.

BOX 16.1 Good environmental practice for the water environment (Section 16.2.3)

- Aim to work with natural processes to deliver NFM as well as potential improvements to the water environment as co-benefits.
- Identify early the water environment baseline (and current condition of water bodies).
- Early engagement with the relevant regulatory authorities/statutory consultees is important to identify opportunities and constraints.
- Consider wider opportunities, for example water industry targets may provide additional opportunities to deliver and implement NFM with water companies.
- Consider how the project could benefit water quantity and/or quality, alongside NFM.

Table 16.3, alongside **Table 16.2**, identifies key considerations related to the water environment throughout the NFM delivery process.

TABLE 16.3 When to consider the water environment

Delivery stage	Considerations
Understand catchment	• What water features are present (rivers, lakes, groundwater), and what is their baseline condition/status (see **Section A3.4**) (quantity and quality)? • What are the main flow pathways (overland and in-channel) of relevance for the project (site, reach or catchment scale)? • What are the relevant flood extents, frequency and flow regimes (and how might this change between dry periods and times of flood)?
Select measures	• Which measures are appropriate for the catchment? How will they interact with the water environment? • Can they deliver wider water environment benefits (eg changes to water quantity and/or quality)?
Design	• How will the design be determined by flow hydraulics, water quantity and/or water quality? • How will the scheme change flow hydraulics and/or water quantity, including sediment transport (**Section 16.4**)? How would this affect water quality? • How would the identified changes affect locations downstream and upstream of where the NFM measures are being implemented?
Construct and implement	• Timing of construction activities in relation to seasonality (flooding is generally more frequent and/or severe in autumn/winter, but flash flooding may occur in spring/summer).
Monitor and manage	• Is there a need to monitor flow, velocity, water level and/or water quality? Is this needed for adaptive management, or is it important to demonstrate delivery of project outcomes?

16.3.2 What to consider

NFM projects usually provide significant opportunities to improve the water environment, however, inappropriate, or inadequate design could be detrimental to the water environment. For example, a poorly designed NFM measure could increase the risk of erosion, which would result in release of sediment into a watercourse; this increase in sediment could reduce water quality and damage river habitats downstream.

The main environmental opportunities and constraints to consider for NFM projects linked to the water environment are summarised in **Table 16.4**.

TABLE 16.4 Opportunities and constraints linked to the water environment

Consideration	Opportunities	Constraints
Water environment policy and legislation targets	• Reduce flood risk to third party receptors through standalone use of NFM, or NFM with traditional flood management techniques. • Locations where increased flooding would be beneficial due to restoration or creation of habitat, restoring hydrological connectivity to areas previously cut-off from flood interactions. • Locations where NFM can deliver, or contribute to the delivery of, water environment policy or legislation targets. • Aquatic/water environment protected sites or water-dependent habitat – potential to improve the water environment by creating or restoring in-channel and riparian habitat (**Section 16.5**).	• Locations where increased flooding would not be tolerated due to the presence of sensitive habitat or other flood risk receptors (eg buildings, infrastructure, utilities or high-grade agricultural land). • Aquatic/water environment protected sites or water-dependent habitat, which could be adversely affected by NFM (ie water availability and/or quality) (**Section 16.5**). • Locations with contaminated land issues, such as pollution from historical mining, industry, or dredging. • River reaches that are highly dynamic or have significant erosion/deposition (**Section 16.4**).
Water industry targets	• Locations where NFM can deliver, or contribute to, water resource targets for a given catchment. • Locations where NFM can help tackle water quality issues, such as pollution from sewage treatment, agriculture, historical mining or industry. • Restoration of river reaches that have been historically modified and have a straightened or artificial channel (**Section 16.4**). • Locations where NFM can deliver, or contribute to, non-statutory river restoration targets that benefit the river system and may deliver wider co-benefits.	• Locations where NFM can limit or prohibit water resource targets being met for a given catchment. • Locations where NFM could conflict with the operation and performance of water industry infrastructure, through changes in flow regime or sediment transport (**Section 16.4**).
Climate resilience	• Potential to contribute to mitigation of climate change, either by making the catchment more resilient to flooding or through carbon capture and storage.	

16.3.3 Methods

A range of baseline information (**Section A3.4**), can be used to understand the catchment. If the NFM measure involves working in or close to a river channel, then consult with a flood risk specialist or water environmental professional and the relevant regulatory bodies (**Appendices A3.2 and A3.3**).

Further reading

Barlow, J, Moore, F and Burgess-Gamble, L (2014) *Working with natural processes to reduce flood risk. R&D framework: initiation report*, SC130004/R1, Flood and Coastal Erosion Risk Management Research and Development Programme, Environment Agency, Bristol, UK (ISBN: 978-1-84911-330-4)

⇨ An integrated approach to working with natural processes to deliver shared outcomes at the catchment scale.

https://assets.publishing.service.gov.uk/media/6034dc27e90e07660881174f/SC130004_R1.pdf

Ferrier, R C and Jenkins, A (2009) *Handbook of catchment management,* Blackwell Publishing, Chichester, UK (ISBN 978-1-405-17122-9)

⇨ Explains an interdisciplinary catchment based approach to managing and protecting water resources, including land use management.

Newson, M D (1997) *Land, water and development: sustainable and adaptive management of rivers*, second edition, Routledge, London, UK (ISBN: 978-0-41541-946-8))

⇨ Covers the key principles of sustainable river management.

Purseglove, J (2017) Taming the flood: rivers, wetlands and the centuries-old battle against flooding, second edition, William Collins, London (ISBN: 978-0-00813-221-7)

⇨ Details traditional versus contemporary approaches toward river management, with a focus on flooding.

16.4 FLUVIAL GEOMORPHOLOGY

16.4.1 Introduction

Fluvial geomorphology (the form and function of rivers and their interaction with the wider landscape) is an important consideration for effective NFM delivery. In the UK, there are relatively few rivers that have not been modified by human activity. Often, historical modification of a river is evident, for example a straightened channel with raised flood walls or flood embankments. In some cases, modifications are less obvious, such as a rural river with an artificially drained floodplain; in most cases, the forms of channels and floodplains, the hydrological regime and sediment transport processes are likely to have been disrupted, compared to a natural catchment.

BOX 16.2 Good environmental practice for fluvial geomorphology (Section 16.2.3)

- Aim to work with river processes to deliver NFM and consider potential improvements to the water environment as co-benefits.
- Consider how an NFM measure could affect geomorphological processes from reach scale to catchment scale (hydrology and sediment transport processes).
- If implementing NFM measures in-channel, identify the characteristics of the river and sediment transport regime (eg erosion or deposition).
- Identify opportunities to improve connectivity between the river and its floodplain (**Chapter 12**).

The physical geomorphological condition of a watercourse is fundamentally linked to ecology as, along with hydrology and hydraulics, it provides the basis for habitats. Appreciation of natural fluvial processes and sediment transport can also help target measures in certain parts of the catchment, or to identify where measures might not be appropriate.

Table 16.5, alongside **Table 16.2**, identifies main considerations for fluvial geomorphology throughout the NFM delivery process.

TABLE 16.5 When to consider fluvial geomorphology

Delivery stage	Considerations
Understand catchment	• Which rivers could be affected by the project, and what is their baseline condition/status (water quantity and quality, **Sections 17.3 and A3.4**)? • What are the baseline river characteristics (eg gravel bed meandering channel, groundwater-fed chalk stream)? What is the channel gradient and how well connected is the channel to the floodplain (**Section A3.4**)? • What historical modifications have been made to the channel and its floodplain (eg straightened, widened or deepened)? Are there embankments between channel and floodplain? Does the floodplain have artificial land drainage? • Are there known issues of erosion or sediment deposition of relevance for the project (eg site, reach or catchment scale)?
Select measures	• Are NFM interventions required (**Chapters 12 and 13**)? For example, a meandering section of river in a rural setting may not pose a significant flood risk to people, property or the wider environment, so it may be appropriate to take no action and (ie allow natural processes to continue). However, where a river has been historically characterised by incision (ie eroding downwards into its bed), then it would be entrenched and cut-off from its floodplain, so floodplain storage techniques would be less effective without floodplain reconnection. • How could the selected NFM measures improve or restore natural geomorphological processes (flow and sediment transport between river and floodplain), and at what scale (reach scale to catchment scale) (**Chapters 12 and 13**)?
Design	• How will the NFM measures change flow hydraulics and geomorphological processes, compared with the baseline? How can the NFM measure improve or restore natural river processes (ie flow, water quantity, sediment transport, floodplain connectivity)? • How will the design be affected by flow hydraulics and geomorphological processes? Consider spatial flood extents, frequency and flow regime (and how this might change between dry periods and times of flood). • Could future changes in erosion or deposition influence the performance of the design of the NFM measure? Could changes in erosion or deposition affect third party receptors? If so, how can this risk be minimised?
Construct and implement	• How can construction impacts on flow and sediment transport be minimised? Note that responsibility for the management of erosion or siltation risk during construction stage (including release of sediment pollution) falls to the construction contractor or individuals delivering the works.
Monitor and manage	• Is there a need to monitor flow, velocity and/or water level? Is this needed for adaptive management, or is it important to demonstrate delivery of project outcomes? This may be most applicable in steep catchments with dynamic rivers or with known erosion/deposition issues.

16.4.2 What to consider

Appreciation of geomorphological processes provides useful insight into what the river 'wants to do' (either naturally or because of artificial change). This presents opportunities that can be delivered as part of the project, for example, to remediate a deposition problem that is increasing flood risk, or to create/restore ecological habitat. However, geomorphological assessment can highlight potential constraints or issues that need to be factored into the design, such as an erosion risk that could potentially undermine or jeopardise the performance of an NFM measure.

The main environmental opportunities and constraints to consider for NFM projects in relation to fluvial geomorphology, are summarised in **Table 16.6**.

TABLE 16.6 Main opportunities and constraints linked to fluvial geomorphology

Consideration	Opportunity	Constraint
Unsuitable river reaches or catchments		• Poor performance or failure of NFM measures due to poor understanding of geomorphological processes at the design stage. • Areas with third party flood risk receptors (eg urban environments, areas with river crossings or infrastructure in the floodplain, or high-grade agricultural land). • River reaches with high stream power (typically steep, narrow watercourses) are often 'less suitable' due to propensity for erosion. • Areas where permeable or resistant geology limits the range of NFM measures that can be used.
Water environment policy, legislation targets and river restoration	• Locations where NFM can deliver, or contribute to, statutory and non-statutory river restoration targets that benefit the river system, and may deliver wider co-benefits. • Removal of historical artificial modifications to a channel, such as straightened or lined channels, with limited morphological features (**Chapters 12 and 13**). • Reconnection of rivers with their floodplain through lowering, removal or setting back of existing embankments, reconnection of palaeochannels, use of in-channel structures to elevate flow onto the floodplain, or floodplain wetland restoration (**Chapter 12**). • Creation or restoration of the aquatic/water environment protected sites or water-dependent habitat – potential to create or restore in-channel and riparian habitat (**Sections 16.3 and 16.5**). • Management of sediment transport issues (eg erosion or deposition) from the reach to catchment scale (eg risk of erosion could be reduced due to dispersal of flood waters across the floodplain, as opposed to containment in the river channel).	• Potential for changes in geomorphological processes from the baseline, which could conflict with broader water environment policy and legislation targets or pose an increased flood or erosion risk. • Aquatic/water environment protected sites or water dependent habitat – could be adversely affected by NFM (ie water availability and/or quality) (**Section 16.5**). • Locations with contaminated land issues, such as pollution from historical mining, industry or dredging.

continued...

TABLE 16.6 Main opportunities and constraints linked to fluvial geomorphology (contd)

Consideration	Opportunity	Constraint
Natural recovery or 'stage zero river restoration'	• Depending on site-specific conditions (and constraints, **Table 16.5**) then no interventions may be necessary, allowing the river to undergo natural recovery. Many rivers will naturally recover and reconnect with their floodplains if allowed to do so. Most suitable in rural settings. • An alternative approach is 'stage zero' river restoration, which 'resets' a river to pre-modified conditions by regrading the channel and surrounding floodplain. Stage zero river restoration is discussed further in **Chapter 12**.	
Wider catchment management	• Changes to hydrology, flood risk and/or water quality issues (**Table 16.4, Section 16.3.2**).	
Climate change	• Potential to contribute to mitigation of climate change, either by making the catchment more resilient to flooding and erosion risk, or through carbon capture and storage.	Changes in future flow and/or sediment transport processes could increase risk of NFM measures being damaged by floods, or undermined by erosion or siltation; if not factored into the design.

16.4.3 Methods

Geomorphological assessment typically involves a combination of desk-based assessment and field walkover survey, which should be carried out by a professional geomorphologist (**Section A3.2**). Estimation of stream power (the amount of energy in a river) is a particularly useful tool for assessing erosion risk (see *Further reading*). Specific assessment requirements should be tailored to the scope of the project and be proportionate to the nature, aims and budget; this may require consultation with a professional geomorphologist and relevant regulatory bodies (**Appendices A3.2 and A3.3**).

Further reading

Brookes, A (2006) *Stream power: a practical tool for river restoration and management with specific examples from the UK*, Jacobs Babtie, UK (unpublished presentation)

⇨ Overview of stream power (important geomorphology technique for estimation of river energy).

https://www.therrc.co.uk/sites/default/files/files/Conference/2006/presentations/1._andrew_brookes_0.pdf

Lewin, J (2013) "Enlightenment and the GM floodplain", *Earth Surface Processes and Landforms*, vol 38, 1, Wiley Online, London, UK, pp 17–29

⇨ Key academic article on human floodplain modification in the UK.

RRC (2021) *Manual of river restoration techniques, updated*, The River Restoration Centre, Bedfordshire, UK

⇨ Case studies demonstrating a variety of river restoration techniques and mitigation measures when developing NFM projects.

https://www.therrc.co.uk/manual-river-restoration-techniques

Sear, D A, Newson, M D and Thorne, C (2003) *Guidebook of applied fluvial geomorphology*, R&D Technical Report FD1914, Defra/Environment Agency Flood and Coastal Defence R&D Programme, Bristol (ISBN 0-85521-053-2)

⇨ Key reference for applied fluvial geomorphology.

https://eprints.soton.ac.uk/15424/

Thorne, C R, Hey, R D and Newson, M D (1998) *Applied fluvial geomorphology for river engineering and management*, John Wiley & Sons, Chichester, UK (ISBN: 978-0-47196-968-6)

⇨ Overview of fluvial geomorphological principles and processes for non-experts (designed for engineers).

16.5 ECOLOGY

16.5.1 Introduction

Ecology is the distribution and abundance of organisms (flora and fauna) and how they interact within the system. All NFM projects should consider ecology because it is everywhere and is very likely to affect, or be affected by, NFM. In addition, certain ecology is legally protected or supported by nature conservation policies.

Table 16.7, alongside **Table 16.2**, sets out the main ecological considerations at each of the delivery stages.

BOX 16.3 Good environmental practice for ecology (Section 16.2.3)

- Work with nature to achieve NFM and consider biodiversity improvements as co-benefits.
- Identify the ecological baseline early (ie what is currently on site).
- Consider wider environmental considerations early, especially BNG when it is mandatory (**Section 4.2.5**).
- Avoid harm to, or disturbance of protected species and their habitats, and priority habitats and species.
- Avoid damage to statutory and non-statutory sites designated for nature conservation.

16.5.2 What to consider

NFM can be used to improve ecology and biodiversity as an integral part of its design. However, it also has the potential to harm ecology if not planned considerately, and ecology can cause constraints to NFM implementation. Examples of opportunities and constraints are provided in **Table 16.8**, and are discussed further in **Sections 16.5.2.1 to 16.5.2.4**.

Changes can occur on and off-site due to NFM projects, so consider:

- Effects that can occur downstream or upstream (eg material being washed downstream during construction, or where passage is blocked to fish migrating upstream).
- Changes that may occur due to the presence of NFM, for example changes in flood extent, frequency, and to the flow regime (ie land made wetter/drier) (**Section 16.4**) which may influence the habitats and species present.

TABLE 16.7 When to consider ecology

Delivery stage	Considerations
Understand catchment	• What ecological features are present (eg designated sites, protected species, invasive species), or expected but absent? • What condition is the site, or any designated sites, habitats or species populations, in? • Are ecological surveys required?
Design	• Complete any ecological assessments required, and update them to capture any design changes. Can the design/location be amended to reduce the impact on the environment, or demonstrate co-benefits? • Obtain any ecological consents required before construction/implementation.
Monitor and manage	• Is ecological monitoring and/or reporting required, for example, the success of ecological mitigation as part of a consent or species licence?

TABLE 16.8 Main opportunities and constraints linked to ecology

Consideration	Opportunity	Constraint
Improve or restore existing habitats	• If a habitat present is not as expected or optimal (eg it is degraded, does not function naturally and/or does not have the expected biodiversity) it could be restored to act as an NFM measure, for example peatland, floodplain grazing marsh, fish passage/habitat. Ensure alignment with the site's conservation objectives. This can also help the habitat be more resilient to climate change.	
Improve the hydrology for existing habitats	• If existing habitat is not in the condition expected and could benefit ecologically from changes to hydrology, for example, removing flood defences so that floodplain or wet woodland can benefit from more natural processes.	
Consider all site issues together	• Develop a restoration plan for a habitat or site and consider flood risk alongside any other issues so that the best group of measures can be introduced together. This is more efficient and benefits the habitat by restoring hydrology (potentially with recovery happening faster).	
INNS	• Manage or remove them for the benefit of the project and the environment.	• They can be expensive to manage or remove. Avoid work near them where there is a risk that they may be spread, or their disposed required (unless their removal is part of the project plan).
Protected habitat		• Could affect designated or protected habitat, or habitat used by protected species. A consent may be required.
Protected species – seasonality of surveys		• Protected species can be present with or without a designated site. If works may affect these species, then surveys will be needed. Some surveys are needed at certain times of the year. They need to be identified early and planned into the project programme. A consent may be required.
Presence of protected species to inform design		• An early understanding of the access and habitat requirements of protected species should inform design. For example, fish passage being possible underneath a leaky barrier as well as continuity of their habitat.
Presence of protected species to inform construction/ implementation		• An early understanding of any seasonal restrictions of potential protected species is needed, for example fish migration and fish spawning, or to disturbance during construction. This should be integrated into the project programme to avoid delays.

continued...

TABLE 16.8 Main opportunities and constraints linked to ecology (contd)

Use of local natural materials that may be habitat for protected species		• If local natural materials are being used to construct NFM, check that the habitat contains or is suitable to contain protected or priority species. For example, if local trees are being felled to construct leaky barriers, they should first be checked for the potential to support bats or nesting birds. If fallen trees are to be used, they should be checked for the potential to support protected species such as otter. It may be appropriate to select alternative trees or else further surveys may be required to determine if protected or priority species are present. Preferably consider local non-native tree species of low ecological value.

16.5.2.1 Sites designated for nature conservation

If statutory or non-statutory designated sites for nature conservation (**Table 16.9**) are present or nearby, they will require specific consideration to identify any opportunities or constraints.

TABLE 16.9 Sites designated for nature conservation

Sites designated for nature conservation	Examples*
Statutory designated sites for nature conservation	• SAC • Special Protection Area (SPA) • Ramsar site. • SSSI or area of special scientific interest (ASSI). • National nature reserves (NNRs). • Local nature reserve (LNR).
Non-statutory designated sites for nature conservation	• Local ecological sites and local geological sites. These can be named depending on the local authority, for example as sites of importance for nature conservation, sites of nature conservation importance, sites of biological importance, or an equivalent, and can be found within local plan documents. • Ancient woodland.

Note

* This is not an exhaustive list and other terms and designations may be used across the UK.

The difference between statutory and non-statutory designated sites for nature conservation is the way they are protected in UK law. Non-statutory designated sites only need consideration when other consents are required (such as planning permission). Some designated sites require their own consents or assessments for working within them or near them, causing harm to the features for which they are designated.

Some other types of designated or protected sites or features can include:

- Ecological criteria – a key part of the reason for designation, such as for protected hedgerows (**Section 16.6**).
- Ecology – partly informs the designation, such as a special quality in designating a national park (eg in respect of wildlife habitats present, **Section 16.6**) or as a criteria to designate a world heritage site (**Section 16.7**).

In addition, some of the nature conservation designations listed in **Table 16.12** include other considerations such as ancient woodland, which also has relevance to the historic environment (**Chapter 16.7**).

16.5.2.2 Protected species

If protected species are present on site or nearby, they will require specific consideration to identify whether they present opportunities or constraints.

It is important to be aware early on in the project if any protected species are present, or likely to be present, and to understand if they may be affected by the proposed NFM measures. It is a legal requirement to avoid harm to these species, even if other consent is needed. The mitigation hierarchy (**Figure 16.1**) assists with this.

Harm includes killing, injuring or disturbing the species (including their young), removing their resting, breeding and/or feeding places, and their food sources, depending on the species. The presence of certain species can depend on location, either in geographical parts of the UK, or in relation to their habitat requirements. Some species have very limited ranges or conditions they live in, and some are widespread.

Protected plant and animal species can move around and may be present even if a survey previously indicated that they were not. Ecological surveys may be required; some have to be undertaken at specific times of year (eg when the species is active or using a particular habitat).

Table 16.10 gives examples of some groups of species to consider in relation to NFM projects.

TABLE 16.10 Groups of species to consider

Species*	Considerations*
Birds	• All wild bird species, their nests and eggs (with exceptions). • Nesting birds – this is seasonal and can vary, but is considered as March to August inclusive. • Bird migration is also seasonal (occurs in about September/October and again in February/March). This can bring overwintering birds (ie migrate to spend the winter in the UK; usually October to February/March) and generally focused on wetland areas such as floodplains and wetlands.
Fish and shellfish	• If working in or near a body of water, for example rivers and streams and/or in the floodplain: • Breeding and spawning, and fish passage and migration requirements. • They have different seasonal/life cycle sensitivities to disturbance and it can be difficult to determine an overall less sensitive season for in-channel working if there are multiple species present. • Examples to consider include spined loach (found in English wetland habitats) as well as salmonids, eel and lamprey, which migrate seasonally, and white-clawed crayfish.
Mammals	• Water voles and otters (if working in or near watercourses). • Bats and badgers. • Red squirrels and pine martens (if working in woodland in certain parts of the UK). • Some mammals have additional seasonal constraints as to their sensitivity to disturbance, and appropriate survey times because they relocate or are less active during certain times of the year.
Reptiles	• Snakes and slow worm – surveys are seasonally dependent.
Amphibians	• Great crested newts (if working in or near ponds or other suitable static waterbodies, and associated terrestrial habitat) – surveys are seasonally dependent.
Certain plants	• Surveys are seasonally dependent and undertaken within the vegetative growth season (nominally March to September).

Note

* These are not exhaustive lists.

16.5.2.3 Priority habitats and species

If a consent such as planning permission is required, these habitats and species should be conserved and (where possible) enhanced. This approach is proposed to be reinforced by the requirement for BNG in England (see **Section 4.2.5**). It is also good practice even where a consent such as planning permission is not required. So, it is important to identify whether there are any priority habitats and species that are likely to be affected by the proposed NFM measures.

Each UK nation maintains a list of priority habitats and species. Some nations use local biodiversity action plans or biodiversity strategies to inform the list contents. Priority habitats and species are the highest priority for conservation action. Species that have been designated are those that are most threatened, in greatest decline, or where the UK holds a significant proportion of the world's total population.

Hundreds of species of principal importance are identified for each UK nation. Habitats of principal importance are identified within groups of habitat types such as arable, freshwater, grassland and woodland.

16.5.2.4 INNS

If INNS are present on site or nearby (particularly upstream), then they will require specific consideration to identify whether they present an opportunity or constraint.

Consideration should also be given to importing invasive and non-native species to site, for example through materials or machinery (see *Biosecurity risks* in **Table 16.25**). It is illegal to spread certain INNS, and a person that causes this to happen can, for example, be fined or sent to prison for up to two years.

Invasive and non-native species can be plants or animals and they can be found in a variety of habitats, but are particularly common along and in watercourses. These species compete with native species and can harm them directly, or change the environment they live in. They may be present now or later in the project, for example, if INNS are spreading downstream over time, they may be present on site when construction begins.

Plants which are either non-native, or invasive non-native must not be planted in the wild, or allowed to grow in the wild. This can include moving contaminated soil or plant cuttings. The requirements are strengthened in Scotland where, for example, a species can be considered as non-native within a particular part of the nation, where it may not be considered as non-native within the nation as a whole.

For animals, consideration of invasive and non-native species mainly relates to release/escape into the wild of any animal that is not ordinarily resident, is not a regular visitor in a wild state, or listed in legislation in the UK. As for plants, variations to this approach may apply to specific UK nations. Invasive and non-native animals may only be relevant to NFM projects in certain circumstances. For example, if surveying for crayfish and instead trapping a non-native crayfish, which cannot then be released back into the wild. An ecologist can provide advice where these situations may be relevant to the project (**Section A3.2**).

16.5.3 Methods

An appropriately qualified and competent ecologist (**Section A3.2**) will help determine what, if any, ecological methods to use and they should undertake the surveys. Surveys can include desk studies, field surveys, and/or assessments, and the requirements will depend on what is present on the site and what is required for any consents or by any statutory consultees.

Further reading

CIEEM (2017) *Guidelines for preliminary ecological appraisal*, second edition, Chartered Institute of Ecology and Environmental Management, Winchester, UK

⇨ Further guidance is also available on the CIEEM website.

https://cieem.net/wp-content/uploads/2019/02/Guidelines-for-Preliminary-Ecological-Appraisal-Jan2018-1.pdf

FWAG South West (nd) *Hills to levels information sheets*, Farming and Wildlife Advisory Group South West, Somerset, UK

⇨ Information sheets to inform and advise landowners, managers and contractors on how to implement NFM.

https://www.fwagsw.org.uk/hills-to-levels

FWAG South West (nd) *NaturEtrade NFM measure specification 6: Hedge planting on bunds*, Farming and Wildlife Advisory Group South West, Somerset, UK

⇨ Specification sheet about how to design, construct/plant and manage hedges on bunds, including environmental considerations, consents and licences.

https://nfmea.sylva.org.uk/downloads/NaturEtrade%20NFM%20Measure%20Specification%206%20-%20Hedge%20Planting%20on%20Bunds.pdf

FWAG South West (nd) *NaturEtrade NFM measure specification 5: Soil bunds and leaky ponds*, Farming and Wildlife Advisory Group South West, Somerset, UK

⇨ Specification sheet about how to design, construct/plant and manage soil bunds and leaky ponds, including environmental considerations, consents and licences.

https://nfmea.sylva.org.uk/downloads/NaturEtrade%20NFM%20Measure%20Specification%205%20-%20Soil%20Bunds%20and%20Leaky%20Ponds.pdf

FWAG South West (2018) *Flood management information sheet 11: Leaky woody dams*, Farming and Wildlife Advisory Group South West, Somerset, UK

⇨ Specification sheet about how to design, construct/plant and manage leaky woody dams, including environmental considerations, consents and licences.

https://www.fwagsw.org.uk/Handlers/Download.ashx?IDMF=dd979e4e-fcfe-4567-ad35-30c449a12a1c

Freshwater Habitats Trust (2013) *Million ponds project. Designing wildlife ponds in the river floodplain*, supplementary habitat factsheet, Freshwater Habitats Trust, Oxford, UK

⇨ Factsheet that includes ecological and other environmental considerations for designing and implementing pond features in floodplains.

https://freshwaterhabitats.org.uk/wp-content/uploads/2013/09/FLOODPLAIN.pdf

Forbes, H, Ball, K and McLay, F (2015) *Natural flood management handbook*, Scottish Environment Protection Agency, Stirling, Scotland (ISBN: 978-0-85759-024-4)

⇨ Demonstrates how ecological considerations can be managed on NFM projects

https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf

National Trust (2015) *From source to sea. Natural flood management. The Holnicote Experience*, RM5508, National Trust Holnicote Estate, Somerset

⇨ A project that demonstrates how to manage environment considerations, including ecology (eg SSSI, SAC, NNR).

https://nt.global.ssl.fastly.net/holnicote-estate/documents/from-source-to-sea---natural-flood-management.pdf

continued...

Further reading (contd)

Ngai, R, Broomby, J, Chorlton, K, Maslen, S, Rose, S and Robinson, M (2020) *The enablers and barriers to the delivery of natural flood management projects*, Final report FD2713, Department for Environment, Food and Rural Affairs, London, UK

⇨ Raised awareness of potential barriers and enablers including ecological designations

http://sciencesearch.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=20187

STREAM (various dates) *Advice notes STREAM01 to STREAM17*

⇨ Natural England advice notes on river and floodplain restoration, with example projects

RRC (2021) *Manual of river restoration techniques, updated*, The River Restoration Centre, Bedfordshire, UK

⇨ Ecological opportunities and constraints in relation to floodplain restoration

https://www.therrc.co.uk/manual-river-restoration-techniques

Websites

FWAG South West and Hills to Levels provide various information sheets identifying ecological benefits and ecologically sensitive sourcing of natural materials on site:

https://www.fwagsw.org.uk/natural-flood-management-information-sheets

16.6 LANDSCAPE AND AMENITY

16.6.1 Introduction

This section discusses the factors to consider in delivering NFM measures, what to look for and what to avoid through the project cycle from planning and design through implementation, maintenance and adaptive management. NFM measures can help implement wider landscape-scale blue-green infrastructure improvements (eg improving habitat connectivity, landscape structure, and provide health and wellbeing co-benefits).

Landscape reflects the relationship between people and place, and the part it plays in forming the setting to everyday lives. It is a product of the interaction between the natural and cultural components of the environment, and how they are understood and experienced by people. All the environmental principles identified in **Section 16.2.3** apply to landscape issues and the opportunities for considering the wider environment and sustainability. NFM benefits present greater potential when considered at the landscape scale.

BOX 16.4 Good environmental practice for landscape and amenity (Section 16.2.3)

- Identify key valued landscape characteristics and consider the design of NFM interventions to complement these.
- Aim to achieve potential landscape enhancements.
- Use good practice for construction to avoid or mitigate negative impacts on landscape, amenity and recreation opportunities by considerate design of the project.

Table 16.11, alongside **Table 16.2**, summarises the typical landscape related activities that may be relevant at each stage when implementing NFM schemes. This is not intended to be exhaustive and will need to be tailored to the specific project and site conditions.

TABLE 16.11 When to consider the landscape

Delivery stage	What to consider
Understand catchment	Identify national, regional and local landscape designations: • **National:** national parks, national scenic areas, AONB, heritage coasts, wild land areas, access land or common land and PRoW. • **Regional and local:** local landscape designations/areas protect and promote scenery under non-statutory designations. Names differ regionally. Also consider registered parks and gardens and conservation areas if not addressed as part of the historic environment considerations (**Section 16.7**). Discuss proposals with relevant consenting authorities to identify requirements. For larger-scale schemes or works in designated areas/sensitive locations, a landscape character and visual impact assessment may be required to inform the assessment of options and to feed into EIA procedures. Review published landscape character assessments at national, regional and local scale as available.
Select measures	Respect key landscape characteristics/sensitivities. Consider wider environmental benefits and green infrastructure connectivity to feed into NFM options. In urban areas consider incorporating/retrofitting NFM options.
Design	Develop designs to recommend tree and shrub planting, land reinstatement, seeding and habitat creation. Works can also include hard materials, kerbs, walls, planters and paving works. The design will need to be site specific and respect key landscape characteristics/sensitivities.
Monitor and manage	Specify maintenance to ensure successful establishment of landscape planting and seeding areas.

16.6.2 Key considerations

Today's landscape is a result of complex interactions between natural and human factors and includes the influence of geology, soils, topography, land cover, hydrology, historical and cultural development, and climate considerations. The combination of characteristics arising from these physical and socio-economic influences, makes one landscape different from another and defines a unique 'sense of place' and local character. For example, building materials often reflect the local variation in geology and soils, as will the vegetation types and mix of species.

The interlinked relationship of landscape and the historic environment needs consideration, as the proposed works may affect the setting of a heritage asset as well as change the quality of the landscape, as perceived by local residents and visitors. Heritage considerations are discussed in **Section 16.7**.

The UK is a signatory to the European Landscape Convention, which recognises that all landscapes are valued, whether designated or not. However, the presence of landscape designations imposes a level of protection with the aim of conserving areas deemed to have remarkable natural beauty and/or distinctive character. In protected areas, understanding the special qualities that contribute to the unique sense of place and the key characteristics is fundamental to ensure that NFM interventions do not detract from these valued qualities and also meet the aims to protect and enhance the landscape where possible.

The devolved responsibility, legislation and guidance varies in the UK nations. However, the structure of legislation, guidance and protection is broadly similar. Key statutory consultees and individual authorities with planning responsibilities will provide advice and useful national/regional information.

Some examples of landscape consideration, relevant to NFM projects, which may influence the relationship between people and place are:

- Effects during construction, such as colour/turbidity of water, or introduction/loss of landscape features, such as trees, hedgerows.

- Effects during operation of a scheme that changes the appearance of the landscape, for example changes in water levels and/or alteration in vegetation cover that change the character of a landscape.
- Operational impacts that affect recreational users or access to an area, for example, changes in water levels and/or vegetation cover, or increased flooding.
- Wider interactions with other topics such as ecology, heritage and the water environment.

All landscapes, urban or rural, provide multiple functions. People's interest in a particular area may relate to where they live, play or work and does not necessarily relate to a national or local recognition of value. Values people place on their landscapes will vary for different reasons and they may reflect the benefits/services provided by the landscape or the component features and elements. These benefits are collectively known as 'ecosystem services' as discussed in **Chapter 15**.

Appreciating the potential of wider connections of natural and semi-natural areas in both urban and rural locations, while delivering the primary NFM measures, could achieve much wider environmental and social benefits. The benefits of ecosystem services and blue-green infrastructure has been recognised in UK policy and could include NFM measures. Examples of landscape opportunities constraints in relation to implementation of NFM measures are discussed in **Table 16.12**.

TABLE 16.12 Main opportunities and constraints linked to landscape and amenity

Key opportunity	Commentary
Strengthen existing landscape character	This may include: • improve semi-natural habitat connectivity in an agricultural setting • reinforce and strengthen existing hedgerows and woodland • improve opportunities to enhance people's enjoyment of the area by protecting tranquillity. The regional and local landscape character assessments typically highlight interventions/changes in management that would enhance existing landscapes. For example, the national character area profiles (Natural England, 2014) include statements of environmental opportunity which offer guidance on the critical issues, which could help to achieve sustainable growth and a more secure environmental future.
Create diverse rural and urban landscapes	This could reinforce landscape pattern, create a more visually interesting landscape, and deliver wider environmental benefits such as: • Maintain sustainable agricultural land use and connect semi-natural habitats, for example, buffer strips along field margins to strengthen landscape character, benefit water quality, reduce soil erosion and enhance biodiversity. • In an urban setting, surface water management techniques, for example, new urban green spaces that incorporate daylighting watercourses within parks; retrofitting 'rain gardens' or SuDS techniques in individual tree pits. Further discussion on the wider benefits, particularly in urban areas, is set out in the further reading section below.
Retain important landscape features	Retain features that contribute to landscape character and the quality of views. Recognise the value that existing trees, hedgerows, banks or ponds contribute to landscape value and amenity. Explore opportunities to incorporate features into future NFM proposals.
Incorporate/enhance public access	Seek opportunities alongside NFM measures.

continued...

TABLE 16.12 Main opportunities and constraints linked to landscape and amenity (contd)

Key opportunity	Commentary

Protected landscapes – National Parks, AONB/ National Scenic Areas, heritage coasts, wild land areas, access land or common land	• National parks (England, Wales and Scotland) impose duties on public bodies and statutory undertakers to conserve and enhance the natural beauty, wildlife and cultural heritage. In Scotland additional duties include: to promote the sustainable use of resources, understanding and enjoyment of the special qualities by the public, and sustainable economic and social development of the area's communities.
	• An AONB (England, Wales and Northern Ireland) is a designated exceptional landscape whose distinctive character and natural beauty are precious enough to be safeguarded in the national interest. They are protected and enhanced for nature, people, business and culture. Similar protection extends to National Scenic Areas in Scotland.
	• Heritage coasts: defined locally, but the majority fall within national parks and AONBs and benefit from their statutory status. Heritage coasts are designed to:
	  ○ conserve, protect and enhance the natural beauty of the coasts, their marine flora and fauna, and their heritage features
	  ○ facilitate and enhance their enjoyment, understanding and appreciation by the public
	  ○ maintain and improve the health of inshore waters affecting heritage coasts and their beaches through appropriate environmental management measures
	  ○ take account of the needs of agriculture, forestry and fishing, and of the economic and social needs of the small communities on these coasts.
	• Wild land areas are the most extensive areas of wildest landscape. They are identified as nationally important in Scottish planning policy but are not a statutory designation.
	• Access land (England), open access land (Wales) including registered common land, includes: mountains, moors, heaths and downs that are privately owned and open to people to walk, run, explore, climb, watch wildlife etc, without having to stay on paths. Separate right to roam legislation applies in Scotland. Common land may also be protected to safeguard the land and special qualities.

Local landscape designations	These protect and promote scenery that is cherished locally under non-statutory designations. Names and aims differ regionally but, overall, they work towards protecting areas of value and can play an important role in developing an awareness of the landscape qualities that make particular areas distinctive. As stated, all landscapes are valued, and consideration of the effects on local communities, residents and recreational users can help reduce risks and delays to project delivery.
Conservation areas, important hedgerows, tree preservation orders, ancient woodland and veteran trees	Trees may be protected if within conservation areas, covered by tree preservation orders or classified as ancient woodland or veteran trees. NFM works would require permission under the relevant planning legislation if trees or important hedgerows would be directly affected.
PRoW (Core Paths in Scotland) and other permissive or private access arrangements	NFM measures may affect accessibility under different flow conditions. Consider access rights alongside the NFM measures early in the project life cycle to identify key stakeholders and potential mitigation measures. Temporary and permanent closures and diversions of PRoW/Core Paths need consent (**Section 3.5**).

16.6.3 Methods

A professional landscape architect (**Section A3.2**) will help determine what, if any, landscape methods to use.

At the understanding the catchment stage, the information gathered from existing landscape character assessments, at national, regional and local scale, will provide evidence of the features and elements that create the local character and what is valued. This may include national and regional landscape character assessments as well as local assessments. Historic landscape assessments may also be available.

Policies, other statements, and evidence in public documents such as statutory development plans, strategies and supporting documents define current designations including those that relate to landscape and historic environment, biodiversity, and geodiversity. A review of designations, within and near to the area of study should be undertaken. Understand the reasons for the designation and any special qualities to inform the project team of:

- what is valuable in landscape terms
- what should be retained and ideally enhanced, including important views and vistas
- what are the likely causes of landscape change in the area
- what characteristics would be susceptible to change.

Further reading

Environment Agency (2017) *Natural flood management toolbox: guidance for working with natural processes in flood management schemes*, cbec co-engineering UK, Ltd, Inverness, Scotland

⇨ Discusses how management of water and resources can deliver multiple benefits to society and the environment.

https://catchmentbasedapproach.org/wp-content/uploads/2018/08/EA-NFM-Toolbox-Final-Draft.compressed.pdf

Woods Ballard, B, Wilson, S, Udale-Clarke, H, Illman, S, Scott, T, Ashley, R and Kellagher, R (2019) *The SuDS manual*, C753, CIRIA, London, UK (ISBN: 978-0-86017-760-9)

⇨ Addresses the management of water quantity, water quality, amenity and biodiversity. Relevant chapters: 11, 18, 19, 20, 22, 23, 29.

https://www.ciria.org

Landscape Institute (2014) *Management and maintenance of sustainable drainage systems (SuDS) landscapes*, Interim Technical Guidance Note 01/2014, LI Technical Committee Water Working Group. Landscape Institute, London, UK

⇨ Guidance addressing management, adoption and long-term maintenance of SuDS.

https://landscapewpstorage01.blob.core.windows.net/www-landscapeinstitute-org/2015/12/TGN1_14SUDS managementMar2014.pdf

Landscape Institute, (2013) *Green infrastructure, an integrated approach to land use*, Landscape Institute, London, UK

⇨ Information on the integrated use of green infrastructure.

https://landscapewpstorage01.blob.core.windows.net/www-landscapeinstitute-org/2016/03/Green-Infrastructure_ an-integrated-approach-to-land-use.pdf

RRC (2021) *Manual of river restoration techniques, updated*, The River Restoration Centre, Bedfordshire, UK

⇨ Information on understanding the site and consideration of the functional use (amenity and flood management).

https://www.therrc.co.uk/manual-river-restoration-techniques

16.7 HISTORIC ENVIRONMENT

16.7.1 Introduction

The historic environment (ie the evidence of human's cultural practices, knowledge and living experiences including historic buildings, archaeological sites, landscapes and places) should be considered for all NFM projects, in particular those that involve excavation. This is mainly because there are some historic environment features (referred to as heritage assets) that it is not possible to identify the location of in advance of construction (and therefore avoid). There are also other possible harmful effects to important features that can be above ground.

BOX 16.5 Good environmental practice for the historic environment (Section 16.2.3)

- Work with nature to achieve NFM as well as historic environment co-benefits.
- Identify the historic environment baseline early (ie what is currently on site).
- Avoid damage to known designated and non-designated heritage assets.
- Understand, and manage, the risks of unknown non-designated heritage assets (in particular, buried archaeology being encountered during excavation).
- Consider the historic landscape (where relevant).

Heritage assets are irreplaceable and should be conserved in a manner appropriate to their significance (also referred to as value), so that they can be enjoyed for their contribution to the quality of life of existing, and future generations. It is important to understand that it is not possible to rectify any damage to heritage assets after the event.

Legal protection and information for the historic environment varies across the UK nations, however, but their structure is similar.

Table 16.13, alongside **Table 16.2**, sets out key historic environment considerations at each of the delivery stages.

TABLE 16.13 When to consider the historic environment

Delivery stage	What to consider
Understand catchment	• What heritage assets are present (eg designated sites) or may be present (eg unknown heritage assets)? • What condition are these heritage assets in? • What is their significance, including any contribution made by their setting? • Whether historic environment surveys are required.
Select measures	• Focus on NFM measure selection to avoid effects, as heritage assets are irreplaceable and any damage is permanent. Note that it is not possible to mitigate damage and greater weight should be placed on avoidance rather than compensation for the loss.
Design	• Undertake any heritage assessments required. • Obtain any heritage consents required before construction/implementation.
Construct and implement	• Consider putting a process in place in case buried archaeology is encountered during excavation at this stage.
Monitor and manage	• If any new heritage assets were discovered during construction, additional actions might be required to manage them. Reporting may also be required.

16.7.2 What to consider

Some examples of historic environment opportunities and constraints that are relevant to NFM projects are given in **Table 16.14** and discussed in **Sections 16.7.2.1 to 16.7.2.2**.

The historic environment should be considered both on and off-site, for:

- effects that can occur downstream (eg where a river is affected during construction changing its course downstream, leading to erosion of the floodplain and exposure of archaeology)
- changes that may occur due to the operation of NFM (eg changes in areas of land that flood or the frequency that land floods and areas become wetter or drier, which can affect the preservation of underground archaeology and the integrity or condition of built heritage assets).

TABLE 16.14 Main opportunities and constraints linked to the historic environment

Key opportunity	Opportunity	Constraints
Restore historic landscapes	• Restoration of an ecological habitat or landscape to act as an NFM measure can also contribute to the restoration of a historic landscape that is still present, for example peatland.	
Re-wet heritage assets that are (or are at risk of) drying out	• Encourage wetting of these assets, where appropriate.	
Reduce flood risk to vulnerable heritage assets	• In particular, buildings at risk of damage or erosion.	
Increase archaeological knowledge	• If archaeological findings are of significance, this can increase knowledge of the historic environment. This could range from publication in an appropriate journal or inclusion on the Historic Environment Record (HER). Consider on-site interpretation or information provision.	
Finding buried archaeology		• If buried archaeology is found, works should cease and consultation with the statutory historic environment organisation (**Section A3.3**) should occur. They will provide advice. If archaeology of significance is found, preservation of the remains is preferred. For an NFM scheme this would probably mean not continuing with measures in this location as any mitigation would be too costly.
Designated heritage asset		• Work within or near to a designated heritage asset (**Section 16.7.2.1**) will require a consent before the construction stage. The application process will take time, and consultation will be needed with the relevant statutory consultee (**Section A3.3**) before submission. Changes to flood risk can alter preservation of assets underground or increase the risk of damage to buildings. Works can also directly cause damage to heritage assets by excavating or removing them.

continued...

TABLE 16.14 Main opportunities and constraints linked to the historic environment (contd)

Key opportunity	Opportunity	Constraints
Damage to designated heritage assets – changes to character or setting of heritage assets		• If working within or near to a designated site, the project has the potential to alter the character (what makes that place special) or the setting (the area surrounding an asset that contributes to its significance) of a heritage asset. Altering the character or setting of an asset can impact its significance, as it can change how an individual can understand or appreciate it. For example, the setting of a country house would be its formal gardens. If they were lost the significance of the heritage asset would be reduced. This is more likely if NFM measures are above ground and affect views to or from the heritage asset, for example woodland or earth bunds. If this were likely, consultation is required with the statutory consultee. Consent may be required where setting is affected. In these situations, the use of appropriate materials can be important (**Section 17.4**).
Known and unknown non-designated heritage assets		• If working within or near to a non-designated heritage asset, there are equivalent potential impacts to those described for designated heritage assets. As explained in Section 16.7.1, not all heritage assets are designated and not all heritage assets are known about, and they may be nationally significant or of importance to the local community.
Historic landscape		• If NFM is proposed on a landscape scale (covering a large area) it may be appropriate to consider the impact on the historic landscape. Consider the effect of alteration to the landscape, for example, by woodland planting over a large area or many smaller landscape changes that constitute a bigger change (**Sections 16.7.2.3 and 16.6**).

16.7.2.1 Designated heritage assets

Designated heritage assets can offer opportunities and constraints, and example asset names are included in Table 16.15. This is not an exhaustive list and other terms and designations may be used across the UK.

TABLE 16.15 Designated heritage assets

Designated heritage assets	Examples
Statutory historic environment designated sites	• Scheduled Monuments. • Listed Buildings. • Conservation areas.
Non-statutory historic environment designated sites	• World Heritage Site. • Registered or historic parks and gardens (England), gardens and designed landscapes (Scotland), registered historic parks and gardens (Wales), and register of parks, gardens and demesnes of special historic interest (Northern Ireland). • Registered or historic battlefields.

The difference between statutory and non-statutory designated assets is the way they are protected in UK law. Some designated assets only require consideration when other consents are needed (such as planning consent), whereas some designated sites require their own consents or assessments for working within or near them and causing harm to the features for which they are designated.

Some other types of designated sites can include historic environment criteria as part of the reason for designation, such as national parks (Section 16.6) or ancient woodland (Section 16.5). In addition, some of the historic environment designations listed (Table 16.20) include other topic considerations, such as World Heritage Sites, where there can also be relevance to landscape and ecology.

16.7.2.2 Non-designated heritage assets

Non-designated heritage assets should be considered on all projects where planning permission is required in line with paragraph 194 and 203 of the National Planning Policy Framework (NPPF). There is also the potential for unknown archaeological remains to be present which should be considered on all projects (especially where planning permission is required), to reduce risks of encountering buried archaeology (eg because of financial implications).

Non-designated heritage assets include buildings and archaeological sites of regional or local interest and are not afforded legal protection. However, they may be of equivalent significance to designated assets. Consideration of non-designated heritage assets is good practice and may be required by certain funding sources and/or as part of getting approval or notifying for certain works.

Historic England maintains Historic Environment Records (HER) which list all designated heritage assets (Section 16.7.2.1), as well as records of non-designated assets (Section A3.4). This data varies between the UK nations, but usually includes lists of historic buildings, archaeological sites, and places of historic interest such as parks or gardens and can contain a record of the historic landscape (Section 16.7.2.3). The HER is not an exhaustive record.

16.7.2.3 Historic landscape characterisation

Historic landscape characterisation (known as historic land use assessment in Scotland) will only require consideration for NFM projects if landscape-scale measures are planned, such as woodland planting or river restoration. If it is a consideration, effects can be avoided or managed through appropriate site selection, NFM measure selection, design and scale of implementation (Figure 16.1).

Historic landscape characterisation (HLC) is a tool designed to help secure good quality, well-designed and sustainable places. It is a method of identification and interpretation of the varying historic character within an area that looks beyond individual heritage assets to understand the whole landscape or townscape. The main HLC guiding principles are that all landscape is historic, all is of interest and value, and all can be managed appropriately. Its primary object is not an arbitrarily selected authentic or traditional aspect of landscape, but understanding the historic time-depth and importance of all landscapes. Historic landscape itself is the product of change and will continually change over time. An NFM project forms part of that change. HLC is used to identify areas with coherent or distinctive historic landscape characteristics to understand the degree to which these historic landscapes can accommodate change. This is complementary to a landscape-character assessment (LCA) (**Section 16.6**) and should be undertaken in collaboration to produce the best project outcome.

16.7.3 Methods

Archaeologists can use a variety of survey and assessment techniques. These should be proportionate to the site, NFM proposals and the level of risk, as well as the cost of dealing with the archaeology/project delays if found during construction. The methods chosen can also reflect the certainty of whether there is a heritage asset present. These can include desk and field surveys, following industry guidance. If any archaeological or heritage surveys or assessments are required, a competent archaeologist/archaeological contractor should undertake them in line with Chartered Institute for Archaeologists guidance (**Section A3.2**).

Further reading

CIfA regulations, standards and guidance: https://www.archaeologists.net/codes/cifa

⇨ Archaeology methodology guidance.

Freshwater Habitats Trust (2013) *Million ponds project. Designing wildlife ponds in the river floodplain*, supplementary habitat factsheet, Freshwater Habitats Trust, Oxford, UK

⇨ Factsheet which includes archaeological and other environmental considerations for designing and implementing pond features in floodplains.

https://freshwaterhabitats.org.uk/wp-content/uploads/2013/09/FLOODPLAIN.pdf

Forbes, H, Ball, K and McLay, F (2015) *Natural flood management handbook*, Scottish Environment Protection Agency, Stirling, Scotland (ISBN: 978-0-85759-024-4)

⇨ Practical guide to the delivery of natural flood management to benefit flooding, while also bringing about many other outcomes.

https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf

National Trust (2015) *From source to sea. Natural flood management. The Holnicote Experience*, RM5508, National Trust Holnicote Estate, Somerset

⇨ A project that demonstrates how to manage environment considerations, including the historic environment (eg archaeological features).

https://nt.global.ssl.fastly.net/holnicote-estate/documents/from-source-to-sea---natural-flood-management.pdf

Ngai, R, Broomby, J, Chorlton, K, Maslen, S, Rose, S and Robinson, M (2020) *The enablers and barriers to the delivery of natural flood management projects: final report FD2713*, Defra, London

⇨ Contains more information on world heritage sites in particular.

https://www.gov.uk/flood-and-coastal-erosion-risk-management-research-reports/the-enablers-and-barriers-to-the-delivery-of-natural-flood-management-nfm-projects

Yorkshire Dales National Park Authority, Yorkshire Dales Rivers Trust and North Yorkshire County Council (2017) *Natural flood management measures – a practical guide for farmers*, UK

⇨ Practical guidance for farmers and land managers on the provision of NFM measures.

Practical guidance for farmers and land managers on the provision of NFM measures.

Cumbria Strategic Flood Partnership

⇨ One of a number of regional guides which includes advice on managing risk relating to archaeology and heritage features.

https://catchmentbasedapproach.org/learn/natural-flood-management-measures-a-practical-guide-for-farmers-north-west/

16.8 WASTE AND CONTAMINATION

16.8.1 Introduction

Waste (eg spoil from excavations) and contamination are important environmental considerations, which are both also legal compliance issues. Key considerations, including example opportunities and constraints, are provided in **Section 16.8.2**.

BOX 16.6 Good environmental practice for waste and contamination (Section 16.2.3)

Identify the waste and contaminated land baseline early (ie what is currently on site).

Table 16.17, alongside **Table 16.2**, sets out key waste and contamination considerations at each of the delivery stages.

TABLE 16.16 When to consider waste and contamination

Delivery stage	What to consider
Understand catchment	• Is contamination present, or might it be? • Does the site topography or location present challenges for designing out waste? For example, is it in a floodplain?
Select measures	• Could any measures be used together to avoid generating waste?
Design	• Will any waste be generated? • Undertake any waste or contaminated land assessments required.
Construct and implement	• Obtain any waste/contaminated material consents/permits/licences required before construction/implementation.

16.8.2 What to consider

Some examples of the main waste and contamination opportunities and constraints that are relevant to NFM projects are given in **Table 16.18**. The following sections discuss the main areas of waste and contamination to consider for opportunities and constraints.

TABLE 16.17 Main opportunities and constraints linked to waste and contaminated land

Consideration	Opportunity	Constraint
Avoid generating waste	• Avoid excavation or earth moving where possible.	
Design out waste	• Avoid situations where excavation may be required and/or material (eg example soil) may be generated by understanding what is proposed and the topographical context. Reduce material generation through design and, for example, plan to reuse same amount of excavated material by creating bunds elsewhere, so that no waste is generated.	• It may not be possible to design out waste by, for example, constructing other NFM measures out of the material because the land level in floodplains cannot be altered (as this may increase flood risk to people and property), or the topography or material available is not suitable.
Use removed vegetation	• To create habitat for specific species, or to create additional NFM measures such as leaky barriers.	
Reduce or remove contamination	• Reduce or remove land contamination, through NFM measure selection and design, or plan it into the costs, design and programme. This may also remove the interaction of contaminated land with water, which would reduce water pollution.	• The cost to determine if there is contamination and/or then treating or removing it could make the project unviable.
Cost of waste treatment and disposal		• The cost of waste disposal, including waste that is contaminated and requires treatment or special disposal, may make the project unviable.
Potential for environmental damage		• Consider whether the construction or operation of NFM measures could create a new route between areas that might be contaminated. For example, subsurface works taking known or unknown contamination from the land surface into groundwater or exposing underground contamination that could be washed into rivers. It is also possible that installing NFM measures could bring floodwater into contact with existing contamination. Contamination of water or soils can result in legal proceedings against those who caused it.

16.8.2.1 Waste

If waste is being generated (such as spoil from excavations), then it will require careful consideration.

Waste is a legal compliance issue and anyone dealing with it must keep it safe, deal with it responsibly and only give it to businesses authorised to take it. The definition of waste is important (CL:AIRE, 2011), as waste can be generated and used on site or transferred to other sites.

Avoidance of waste is best considered early on in the project. If material might be generated and considered waste, 'design out waste' first, and consider the circular economy approach (where resources are kept in use for as long as possible before considering disposal). In some cases, the cost of dealing with waste could make NFM projects unviable. **Section 17.4** contains some ideas on dealing with waste. **Table 16.18** provides examples of how NFM projects may generate waste.

TABLE 16.18 How waste could be generated

Situation	Commentary
During construction	• Material from river works (eg material from re-meandering a watercourse that could be from the bed or banks). • Material from reprofiling, for example, a slope or creation of offline storage areas or ponds. • Removal of vegetation.
Maintenance or during design life	• Requires some disposal part way through its life, for example plastic tree guards for hedgerow or tree planting.
End-of-life	• If at the end of the NFM measure's useful life it requires removal and disposal and if it cannot be repaired or is no longer required, for example, engineered structures related to water storage overflows.

It is advisable that projects also consider the risk that the material to be removed or excavated could be contaminated. If it is, then plan how to manage it before undertaking the work and be aware that disposing of contaminated waste is more costly (**Section 16.8.2.2**).

16.8.2.2 Contamination

If contamination is present, or there is a risk of it being present, then it should be considered early in the project.

Contamination can affect land or material – it can be present, created on site, or brought on site. It can be caused by substances such as heavy metals (eg lead), oils and tars, chemicals (eg solvents), gases, asbestos, and radioactive substances, but can also include other substances such as invasive plants.

The local authority (**Section A3.3**) will consider land affected by contamination when planning consent is required, to ensure it has been dealt with appropriately. Consideration of contamination issues may also be required for other consents, such as an environmental permit for flood risk. If no consents are required then the project should still follow a similar good practice approach, to avoid causing harm and legal repercussions. Potential contamination issues on NFM projects are provided in **Table 16.19**.

Project teams should also consider ground conditions including buried utilities and potentially unstable landscapes (eg disused mines) when understanding the site (**Chapters 4 and 17**).

TABLE 16.19 Potential contamination issues

Situation	Commentary
Contaminated material brought to site	• Ensure that material is obtained from a reputable supplier and that it free from contamination (including biosecurity issues).
Construction causing contamination	• Machinery dripping oil or other substances onto bare ground or a spill during construction – follow good construction practice to prevent this (**Section 16.2.3**).
Contamination due to INNS	• Material is already contaminated (on site or brought on site) due to INNS. Special handling and disposal techniques are needed (**Section 16.5.2.4**).
The site is contaminated	• The site may already be contaminated: • It may be obvious from current use, or the risk may relate to historical use. • Historic maps (**Section A3.4**) can indicate historical land use, with more risk being associated with factories, mines, steel mills, refineries and old mine workings. • Mapping of historic landfill sites and inactive landfill sites can usually be found online (**Section A3.4**). • Rivers and lakes can hold contaminated sediments underneath non-contaminated sediments, which were deposited in the past when the waterways were more polluted. Avoid disturbance of contaminated sediment.
Biosecurity risks	• Reduce the risk of introducing or spreading INNS, pests and diseases. The 'Check, Clean, Dry' campaign is a biosecurity process for all who interact with soil, water, plants and animals in the natural environment.

16.8.3 Methods

An appropriate professional (**Section A3.2**) can help determine what, if any, waste or contamination methods to undertake. For example, a specific investigation may be required to determine if contamination is present.

Further reading

Forbes, H, Ball, K and McLay, F (2015) *Natural flood management handbook*, Scottish Environment Protection Agency, Stirling, Scotland (ISBN: 978-0-85759-024-4)

⇨ Considers contaminated land for NFM projects in Scotland, which broadly applies in other UK nations.

https://www.sepa.org.uk/media/163560/sepa-natural-flood-management-handbook1.pdf

ISNI (2021) *Check clean dry: latest biosecurity resources to download*, Invasive Species Northern Ireland, Belfast, Northern Ireland

⇨ Biosecurity process for Northern Ireland.

http://invasivespeciesireland.com/what-can-i-do/check-clean-dry

NNSS (2020) *Biosecurity and prevention: check, clean, dry – help stop the spread of invasive plants and animals in our waters!* GB Non-native Species Secretariat, York, UK

⇨ Biosecurity process for Great Britain (England, Scotland and Wales).

http://www.nonnativespecies.org/checkcleandry/index.cfm

Courtesy Yorkshire Dales Rivers Trust

17 DESIGN AND MATERIALS

Contents

Chapter 17 Design and materials

This chapter covers the design of both individual and combined NFM measures which require some engineering. It covers stages in the design process, provides a design toolbox, discusses choice of materials to use and provides information and links to further reading about risks and health and safety.

▸ *The design of measures sits between selection (Chapter 4) and construction (Chapter 18)*

17.1 INTRODUCTION

This chapter covers the design of NFM measures (individual or combined) that require some degree of engineering design. It gives principles and methods that may be applied to many NFM measures, focusing on those in specific locations such as runoff management, runoff storage and infiltration, leaky barriers and floodplain reconnection. It does not cover catchment scale design. The design of online or offline flood storage reservoirs are also not covered as these are typically larger scale, more formal structures covered by existing guidance and may be subject to reservoir safety legislation.

Measures can be installed individually, in series or in combination with other measures. Favourable combinations of measures are discussed in **Chapter 4**.

Design sits between the selection of measures (**Chapter 4**) and construction (**Chapter 18**). It typically involves two phases but is often iterative – outline design to define combinations of measures, location, geometry and required performance, and detailed design to ensure strength and durability and provide information for construction (**Figure 17.1**). CDM 2015 apply to design in the UK and designers must consider health and safety throughout the design process (see **Sections 3.7 and 17.5**). Early contractor involvement may be needed during the design process to ensure buildability.

NFM measures range from living or natural features to engineered structures constructed using processed materials and artificial fixings. While it may be argued that only living or natural features are 'true' NFM, in practice, all measures have some degree of artificial influence and engineered structures form an essential part of the spectrum. The art of good engineering is to design measures that restore or mimic natural hydrological functions for the design flows but look natural and remain intact during more extreme flows.

A quasi-engineered structure is perhaps the most dangerous. Without proper engineering, a structure may perform well during a smaller flood but fail during an extreme event. This could release a large volume of water and/or large pieces of material. The results of this may be blockage of a culvert or bridge, flooding of downstream areas and, potentially, catastrophic damage.

During design, it is important to:

- recognise the design objectives and performance aims (**Section 17.2**)
- avoid increasing flood or blockage risk locally (as a result of works) (**Section 17.3**)
- consider the environmental issues including using sustainable and local materials, and local skills, and minimise whole-life carbon footprint (**Section 17.4**)
- understand and eliminate or reduce safety risks (**Section 17.5**).

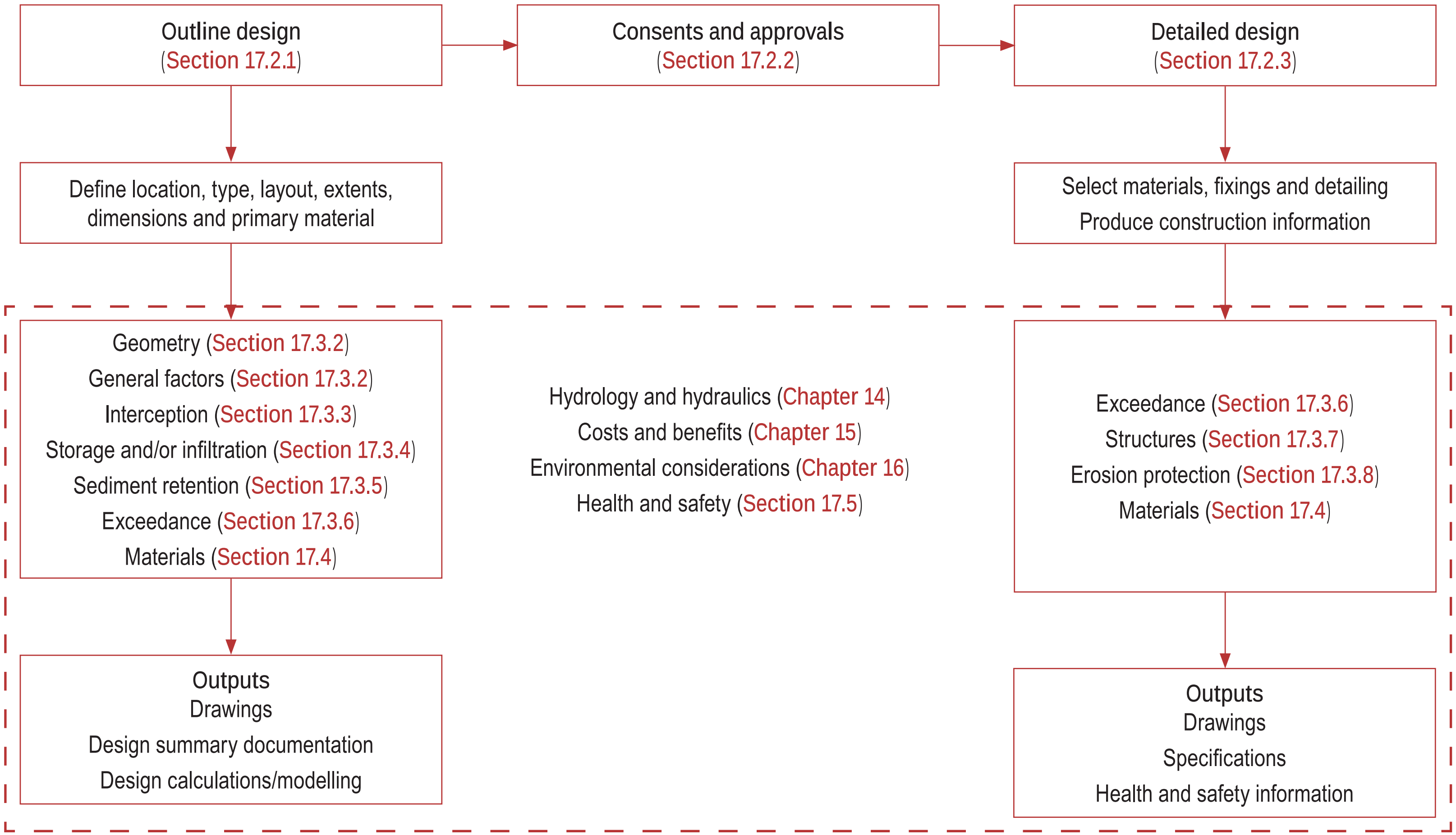


Figure 17.1 Design process

Section 17.2 covers the design process. Section 17.3 presents a design toolbox with a hierarchy of methods. Examples of suitable materials are detailed in Section 17.4 and health and safety in design in Section 17.5.

Some NFM measures will be relatively simple to design and implement. Others may require more experienced engineering design input and have specific risks to be addressed or transferred to the construction contractor. Where necessary, consider involving suitably experienced engineering design personnel (Appendix A3).

17.2 DESIGN PROCESS

17.2.1 Outline design

Outline design follows the initial selection of NFM measures. It involves defining objectives, identifying suitable locations and deciding whether to install measures individually, in series or in combination with other measures (Chapter 4). The overall performance requirements are then determined and the aim of the proposed measures defined.

Outline design tends to be iterative but broadly follows this process:

- consider the physical constraints of the site such as access, topography, ground conditions, existing utilities and rights of way.
- confirm the location, type, alignment, extents, levels and overall dimensions of measures needed to meet the objectives
- using modelling and calculations as appropriate, check that the measure will achieve its intended hydrological and hydraulic performance (eg infiltration, slowing flow, storing water or managing sediment) (Section 17.2.4)
- consider environmental constraints and opportunities and adapt the design to reflect these (Chapter 16)
- determine the primary construction material and overall dimensions (Sections 17.4 and 17.2.4).
- identify legal issues, consents and approvals that may be required.
- estimate outline costs for the proposed measures.

The outline design process may result in several differing NFM measures being developed and the merits and disbenefits of each assessed to determine the most suitable solution.

The outputs from the outline design stage typically include:

- layout plans detailing the location, type, alignment and extents of measures
- long-sections, cross-sections and detail drawings providing the overall dimensions and levels
- details of primary construction materials
- design summary documents describing the overall objectives and performance requirements
- design calculations and modelling results.

Outline design should be informed by initial data collection. More data may be collected between outline and detailed design (see Chapter 4). It can be helpful to sketch a plan and typical section through the site showing constraints such as boundaries, accesses, PRoW, existing properties and infrastructure, utilities (eg overhead lines or buried pipelines), or maximum allowable water levels.

17.2.2 Consents and approvals

Specific permissions and licences may be required from the relevant consenting authorities to provide the consents and approvals necessary for NFM measures to be implemented (Section 3.6).

The outputs from outline design often form the basis of information required to obtain the consents and approvals. For example, the outline design drawings and design summary documents can be used to support a planning application. So, it is important that the outline design is developed sufficiently to provide the information required. Discussions with the relevant consenting authority early in the design stage may be beneficial if there is uncertainty about the type and detail of information to be submitted.

The feedback from the consent and approval process may influence the detailed design stage.

17.2.3 Detailed design

Detailed design develops an outline design into something that is buildable, performs its functions for the design event and remains safe during above-design standard events. Detailed design should:

- consider the scenarios that may occur during the design life of a measure, for example, during construction, operation and high flows, and include allowances for deterioration over time
- ensure that the measure performs its function satisfactorily for the design event without increasing flood risk to people, livestock, wild animals, property or infrastructure (known as the serviceability limit state)
- design a measure to remain safe and intact, even if submerged or exceeded, during an above-design standard event to prevent materials washing away and causing blockage, flooding or catastrophic damage elsewhere (known as the ultimate limit state)
- assess health and safety risks and communicate any specific residual risks that cannot be eliminated by design, either on the drawings or in a designer's risk assessment
- provide information to discharge planning conditions or for any remaining consents and approvals
- provide information for construction purposes.

The process may include:

- detailed hydraulic design or assessment to confirm hydraulic performance, especially in relation to exceedance events
- stability design to prevent failure (eg due to sliding, flotation and overturning)
- design of impermeable elements of the structure to prevent excessive seepage and internal erosion
- design of erosion protection to prevent surface erosion (eg for bunds and leaky barriers)
- incorporation of measures to resist damage due to external influences (eg movement of people/ vehicles and burrowing animals)
- incorporation of environmental features and enhancements
- assessment and selection of construction materials
- structural design to ensure all elements are sufficiently strong to resist the actions on them and detail interfaces and fixings
- consideration of health and safety and minimising risk through the design process
- consideration of construction requirements.

The outputs typically include:

- layout plans showing the site location, access routes, site extent, site compound and storage areas, existing site topography, existing utilities. environmental constraints and landownership/access constraints
- general arrangement drawings showing the proposed NFM measures, as a whole, including their layout, location, type and overall dimensions
- long-section and cross-section drawings detailing the levels and dimensions of the NFM measures and summarising the materials and construction requirements
- detailed drawings to show specific construction requirements (eg fixings or interfaces between different materials)

- specifications for materials (and sometimes methods of working)
- designer's risk assessment
- health and safety information
- environmental information.

Throughout the design process, ensure that any design changes are recorded in the relevant project documents where appropriate. Checks should be made to determine if any changes are required to consents, permissions and assessments already undertaken or obtained and/or if additional submissions are required.

Consider safety in design (see **Section 17.5**) and responsibility for long-term operation and maintenance, particularly for measures that are designed to retain sediment (see **Part C**).

The detailed design process produces information that is subsequently used for construction, so it can be useful to arrange early contractor involvement. Input from construction personnel can help identify and address issues that may influence the design such as the most suitable construction approach and methods, availability of materials and construction sequencing.

17.2.3 Proportionate approach

The level of design should be proportionate to the type of measure, its location, geometry and level of risk. Creating a riparian woodland is unlikely to need such rigorous design as a bund or leaky barrier. The design complexity of design tasks and suitability for performance by different groups is given in **Table 17.1**.

TABLE 17.1 Complexity of design tasks or measures

Complexity	Design tasks or measures	Who could perform
Simple	• Outline design of relatively simply measures. • Detailed design of relatively simple measures. • Runoff management (cross drain, bund or banked hedgerow). • Runoff storage (scrapes, ponds and swales). • Leaky barriers on overland flow pathways (not exceeding 0.5 m high).	Communities Landowners Local authorities, government agencies, water and sewerage companies and water environment professionals or engineers (these would all incur costs)
Intermediate	• Outline design of intermediate/complex measures. • Detailed design of intermediate measures. • Runoff storage and infiltration (ponds, swales). • Leaky barriers on watercourses (not exceeding 0.5 m high). • Stone check dams or earth bunds (not exceeding 0.5 m high)	Local authorities, government agencies, water and sewerage companies Water environment professionals or engineers (these would all incur costs)
Detailed	• Detailed design of complex measures. • River storage and infiltration (offline storage to watercourses) • Leaky barriers on watercourses (more than 0.5 m high). • Stone check dams or earth bunds (more than 0.5 m high). • Floodplain reconnection and river restoration. • Detailed design of water-retaining structures where breach or washout could affect people, animals, property or infrastructure.	Water environment professionals or engineers

17.3 DESIGN TOOLBOX

17.3.1 Introduction

This section contains information that can be used to support the design of NFM measures. Factors applicable to all measures are given in **Section 17.3.2**. Function-specific information is given in **Sections 17.3.3 to 17.3.8**.

Table 17.2 lists the types of NFM measures likely to require notable design input, with their associated function and design elements, including the sections of this manual that can be referred to for assistance. In addition to the design elements, consideration should be given to the costs and benefits (**Chapter 15**) and environmental aspects (**Chapter 16**) of NFM measures.

Within each module, a hierarchy of methods is given where possible, from simple rules through to detailed methods, to allow a proportionate approach to be taken.

The design process specific to individual measures is given in **Part C**. Example designs are given in **Part C** and worked examples given in **Appendix A3**.

TABLE 17.2 Types of NFM measure and their design elements

Measure type	Function	Design elements
Cross drain	Diverts surface water from tracks and roads to areas of higher permeability such as fields, verges or runoff storage areas.	Location and spacing (**Chapter 7**)
Cross slope hedgerow (included banked hedges)	Diverts or retains surface water (and possibly sediment), hedges can infiltrate and transpire water.	Location and spacing (**Chapter 7**), interception (**Section 17.3.3**), storage and/or infiltration (**Section 17.3.4**), exceedance (**Section 17.3.7**).
Pond	Natural or excavated depression, or raised embankment, stores water permanently with additional capacity to store water during rainfall events and release in a controlled manner.	Location and general dimensions (**Chapter 8**), storage and/or infiltration (**Section 17.3.3**), sediment retention (**Section 17.3.5**), exceedance (**Section 17.3.6**).
Scrape	Natural or excavated depression stores water in winter and dries slowly over spring/summer.	Location and general dimensions (**Chapter 8**), storage and/or infiltration (**Section 17.3.4**), exceedance (**Section 17.3.6**).
Swale	Broad, shallow, linear vegetated channels that store or convey surface water and remove pollutants following rainfall.	Location and general dimensions (**Chapter 8**), planting/vegetation (**Section 16.5**), storage and/or infiltration (**Section 17.3.4**), sediment retention (**Section 17.3.5**), exceedance (**Section 17.3.6**), erosion (**Section 17.3.8**).
Bund	Bank provides flood storage or to help divert runoff. Typically earth but can be timber.	Location and general dimensions (**Chapter 8**), interception (**Section 17.3.3**), storage and/or infiltration (**Section 17.3.4**), exceedance (**Section 17.3.6**).
Leaky barrier	Partial obstruction in-channel or across an overland flow pathway to slow flow, store water and push water out into the floodplain.	Location and general information (**Chapter 10**), exceedance (**Section 17.3.6**), designing structures (**Section 17.3.7**), erosion (**Section 17.3.8**).
Offline storage (less than 10 000 m^3 storage capacity)	Diverts water from a watercourse/flow path to areas of the floodplain adapted with containment to temporarily store, and then slowly release it back after a flood has receded.	Location and general information (**Chapter 11**), storage and/or infiltration (**Section 17.3.4**), sediment retention (**Section 17.3.5**), exceedance (**Section 17.3.6**), designing structures (**Section 17.3.7**), erosion (**Section 17.3.8**)

continued...

TABLE 17.2 Types of NFM measure and their design elements (contd)

Measure type	Function	Design elements
Lower, remove or set back existing flood banks	Remove some or all flood banks to increase floodplain connectivity.	Location and general information (Chapter 12), storage and/or infiltration (Section 17.3.4), sediment retention (Section 17.3.5), exceedance (Section 17.3.6), erosion (Section 17.3.8).
Reconnect palaeochannels	Remove artificial obstructions to reconnect old channel. May need to de-silt and re-grade old channel.	Location and general information (Chapter 12), storage and/or infiltration (Section 17.3.4), sediment retention (Section 17.3.5), exceedance (Section 17.3.6), erosion (Section 17.3.8).
In-channel features to elevate flow into floodplain	Modify channel width or bed level, or install in-stream structures to throttle flow, increase water level and floodplain connectivity.	Location and general information (Chapter 12), storage and/or infiltration (Section 17.3.4), sediment retention (Section 17.3.5), exceedance (Section 17.3.6), erosion (Section 17.3.8).
Floodplain wetland restoration	Restore floodplain connectivity, with the aim of encouraging more regular floodplain inundation and floodwater storage.	Location and general information (Chapter 12), storage and/or infiltration (Section 17.3.4), sediment retention (Section 17.3.5), exceedance (Section 17.3.6), erosion (Section 17.3.8).

17.3.2 Factors to consider for all measures

Factors to consider when designing the geometry of NFM measures are summarised in Table 17.3. Measures should aim to work with natural processes. The form and orientation of a bund may determine the range of plant species it supports while the size and position of a woody feature may determine the micro-habitats it generates.

TABLE 17.3 Factors to consider for all measures

Factor	What to consider
Legal issues (see Section 3.5)	
Planning	Whether the type of measure and its location may require planning permission. Confirm if there are any specific planning requirements that must be addressed.
Reservoir safety	Individual measures (raised above normal ground level) capable of storing more than 10 000 m^3 (25 000 m^3 in England but due to be reduced) are subject to additional legal requirements under the applicable reservoir safety legislation. Measures this size should be considered separately alongside/instead of an NFM approach, with appropriate input from a civil engineer.
Design capability	Measures affecting flood banks or larger rivers need hydrological and hydraulic assessment, engineering design and proper implementation to ensure they are robust and will not increase flood risk elsewhere.
Hydrology and hydraulics (see Chapter 14)	
Work with natural processes	Protect, restore or mimic natural hydrological function of catchments, watercourses and their floodplains.
Hydrological function and design flow	Measures should mimic or restore natural hydrological and hydraulic function for the design flood flow, without increasing flood risk to people, animals, property or infrastructure. Temporary storage measures should consider the upstream extent of the stored water and the associated potential impacts.
Above-design standard flows	Measures should be capable of withstanding above-design standard flows or temporary blockage safely without breach or failure. Undertake risk analysis for failure of impoundments (breach and overflowing). If failure can be expected, consider the flow path for released water and incorporate measures to address potential downstream flood risks.

continued...

TABLE 17.3 Factors to consider for all measures (contd)

Factor	What to consider
Low flows	Measures to slow or store water should allow the free passage of low or normal stream flow at all times.
Emptying time	Measures for temporary storage should half-empty within 24 hours to allow refilling during subsequent events.
Residence time	Measures to retain sediment and/or treat dissolved pollutants should be designed with a longer residence time.
Geometry	
Height	Measures to slow flow or restore floodplain storage should be sufficiently high to raise upstream water level and store water on the floodplain upstream. Measures not exceeding 0.5 m high are easier to design and construct. Avoid measures over 1 m, which would need more engineering input and could create a flood hazard if breached.
Alignment	Measures that overflow should be aligned at a right angle to the approach flow to reduce the risk of bank erosion.
Layout and extents	The total footprint of the measure and the area affected. For temporary storage measures, this will include the maximum extents of stored water.
Inlets and outlets	Locate inlets and outlets to maximise the flow path length through a pond. Consider the effects of temporary blockage by sediment or debris.
Environmental factors (see Chapter 16)	
Geomorphology	Measures should avoid causing bed or bank erosion that could undermine it, nearby properties, infrastructure, or affect land use.
Fish and eel passage	In-channel barriers (eg leaky barriers) should avoid obstructing fish and eel passage under normal flow conditions (if applicable). Provide a clear opening 0.3 m above winter base flow level.
Environmental enhancements	Whether features can be incorporated that enhance the environmental benefits of the measure such as by wetlands, and planting to create diversified habitats.
Water quality	Measures to store water permanently should be designed to avoid areas without flow circulation that could stagnate.
Landscape	Measures should aim to blend into the existing landscape. Significant features may require planning permission and this may influence the final scale and appearance.
Construction and materials (see Section 17.4)	
Primary construction material	Choice of material may be influenced by the availability in the local area. In turn, this may influence the most suitable type of measure and, hence, the layout, extent, volume, land take and cost.
Performance and durability	The type of construction and materials proposed should aim to maximise performance while minimising ongoing maintenance. If a measure is expected to require repair following a significant flood event, reconstruction requirements may need to be considered.
Excavated material and waste	The volume of excavated spoil and method of reuse, spreading on land, or disposal. Consent or exemption may be needed. Avoid disposal in the floodplain, low-lying areas or areas of historic interest. Avoid creating mounds or banks that look unnatural.
Health and safety	The ease of construction and any specific health and safety issues that may require addressing. If possible, minimise the health and safety risks during the design process by careful consideration of the construction approach and sequencing and the materials to be used.

17.3.3 Designing for runoff diversion

Runoff management measures, such as cross drains, bunds and banked hedgerows, aim to divert runoff from vulnerable areas towards permeable areas or ditches where the water can infiltrate into the ground. Avoid directing water towards watercourses and accelerating flow into them.

Methods for the design of runoff management measures are given in Table 17.4. Simple rules generally suffice, although an intermediate method is offered for diversion bunds or banked hedgerows where runoff may be larger.

TABLE 17.4 Designing to divert runoff

Level of detail	Method
Simple	For cross drains on tracks or roads, determine spacing to suit longitudinal slope and permeability, with adjustments for location on the slope and aspect (see Copstead *et al*, 1998). Divert water to nearby land for infiltration. Diversion bunds may be up to 100 m long and 0.3 m to 0.5 m high. Side slopes should fit into the landscape and ideally be shallow. 1 in 5 is considered appropriate, especially for the downslope side that may be eroded by overtopping. A maximum slope is 1 in 3 to avoid the risk of collapse. Banked hedges may be up to 100 m long and 0.3 m high, with side slopes as for diversion bunds. They may have a ditch along the upslope. Longitudinal slope along a bund or banked hedge should be 1 in 200 to 1 in 17 (as for swales) to avoid velocity exceeding 0.3 m/s. The construction materials should be sufficiently robust to withstand the expected flows while minimise the risk of damage or failure. Consider the presence of silt and gravels. These can quickly block a cross drain or bund and render it ineffective. The design should aim to minimise this risk but regular maintenance may still be required.
Intermediate	For diversion bunds or banked hedgerows, determine the proposed bund alignment, length and height. Estimate the catchment area and peak runoff flow rate that will be intercepted by the bund for the design storm (see **Table 17.5**). Estimate flow depth and velocity of runoff using Manning's equation, assuming sheet flow for a strip catchment or channel flow for a defined catchment, also check that the total head does not exceed height of bund (see **Section 14.3.1**). Estimate flow depth and velocity of diverted flow along the toe of the bund using Manning's equation. Check that flow is contained by the bund and velocity is less than 0.3 m/s.

17.3.4 Designing for storage and/or infiltration

Cross drains, banked hedgerows, bunds, scrapes and swales aim to increase infiltration into the ground by diverting runoff onto larger areas of nearby ground and/or retaining water for a period of time. These measures, in addition to ponds, may be used to store water in areas where infiltration is less feasible. Infiltration is only increased if the soil or rock is able to absorb water and is dependent on geology, groundwater level and antecedent conditions. Saturated soil during wet periods will have a low infiltration rate.

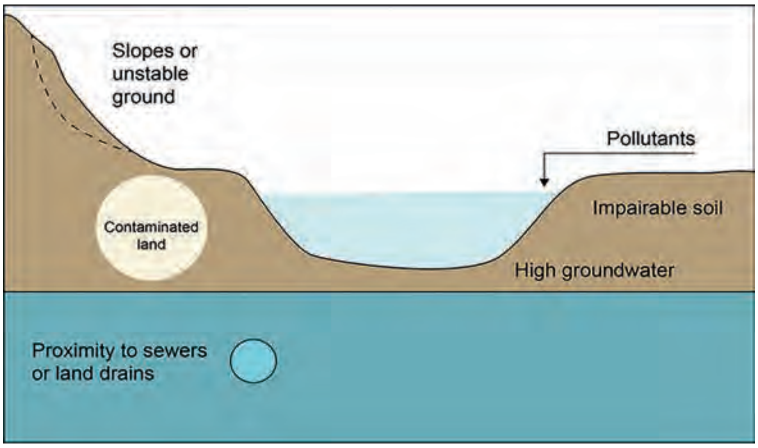
Infiltration increases with surface area, soil permeability and retention time. Sediment can cause clogging and reduce infiltration over time, depending on the incoming sediment load, retention time, and water levels (**Section 17.3.5**). Sedimentation can be reduced by appropriate design of flow paths/channels, installing a sediment trap upstream or planting dense vegetation. It may be necessary to remove sediment at intervals to restore the efficiency of infiltration.

Infiltration may also be affected by construction activities. Care should be taken to avoid compaction of the soil, which is likely to reduce its permeability, and to minimise the placement of materials that may form a more impermeable layer over the surface. In contrast, where infiltration is less viable and the focus is on providing storage, less permeable ground conditions may be beneficial.

The risk of pollution of groundwater and subsurface water sources should be considered for infiltration measures. The risk associated with surface water should be low. However, where water is to be diverted to an offline infiltration area, the existing land use along and immediately next to the flow path should be assessed.

The area downstream of storage and infiltration measures may also require consideration. If permeable ground conditions are present, infiltration at a specific location may result in subsurface water flows and, in turn, springs forming further down a slope. This could create flood risks that, otherwise, may not have been anticipated.

Factors to consider during the design of infiltration measures are shown in **Figure 17.2**.



Avoid locating measures near slopes, buildings, retaining walls or other structures. Assess the risk of ground instability, subsidence, heave or groundwater flooding. If in doubt, seek specialist geotechnical advice.

Soil type and permeability – coarse sand or gravels are more permeable than fine clay or silt. Some soils comprise a mixture of particle sizes.

High groundwater level will reduce infiltration.

Avoid creating new pathways for pollution or mobilising existing pollution. If in doubt, seek advice from a specialist geo-environmental engineer.

Avoid siting measures near sewers and creating a risk of seepage into the sewer network.

Figure 17.2 Factors to consider when designing for infiltration

There are no minimum hydrological performance requirements for NFM storage or infiltration measures. This is in contrast to SuDS infiltration measures which may be required to limit the runoff from a development to, for example, greenfield runoff rates. NFM measures may be constrained by the available land area, existing landform, ground conditions and scale of flows. It is likely that measures will be designed to suit topography, site constraints and landowner needs, rather than designing to achieve particular storage or infiltration volumes or rates.

Measures may combine temporary storage with infiltration, outflow via a pipe or spillway, and exceedance flow, so a hybrid approach to design is needed (**Figure 17.3**). Measures designed for storage and infiltration should:

- pass forward normal or base flows
- store an appropriate volume of water – partial storage of the inflow for a design storm (minus infiltration and outflow during that storm) may be more realistic than the storage of all runoff
- be fully used during the design storm
- pass forward exceedance flows safely during an above-design standard event (**Section 17.3.6**)
- empty within a reasonable period of time to allow refilling during subsequent storms.

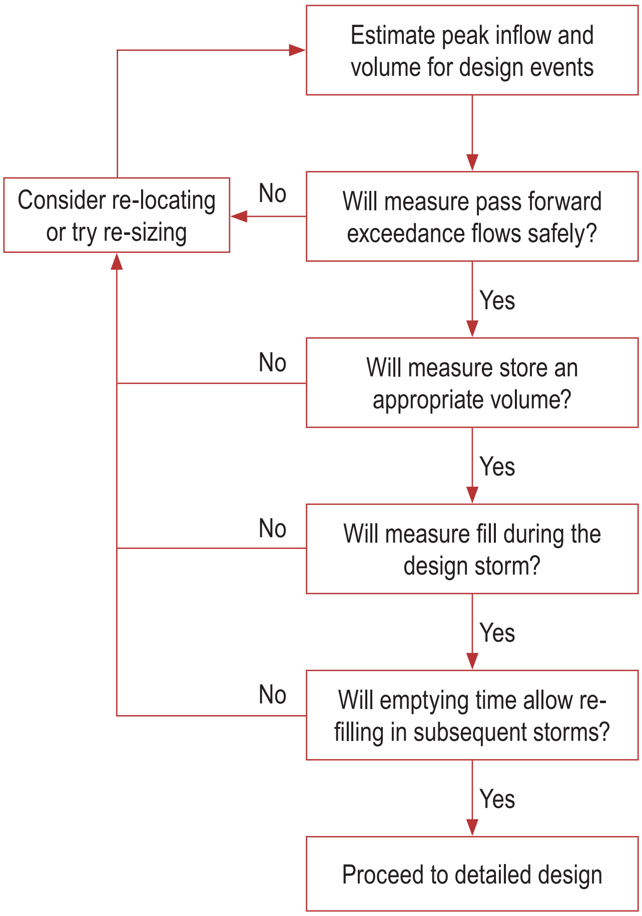


Figure 17.3 Design process for storage and/or infiltration

Methods of designing for storage and/or infiltration are given in **Table 17.5**.

The outflow from an NFM measure influences the filling and emptying of that measure and is controlled by the type and capacity of the outlet or overflow.

A fixed weir or outlet pipe is simple and controls outflow passively, but offers limited control over the rate of filling or emptying. A simple adjustable control, such as an outlet pipe with a lifting orifice plate or stop boards to vary the level and/or width of a weir, allows a landowner to actively control outflow and adjust the storage volume. This may also provide benefits for land use, such as, crop irrigation.

Outlets may need a headwall to support the earthworks above and prevent material falling down into the flow. Erosion protection may be needed if there is a significant drop in water level or fast flow velocities (see Section 17.8). An anti-seepage collar around an outlet pipe may be needed to prevent seepage and erosion of materials from around the external perimeter. Pipework should be designed to resist flotation.

Further information on designing for storage and infiltration is given in Woods Ballard *et al* (2015) (Chapter 25 (infiltration), Chapter 28 (outlets) and Chapter 32 (removing sediment)).

TABLE 17.5 Methods for designing storage and/or infiltration

Level of detail	Method
Simple	Estimate the normal-day base flow, Q_{bf}, either by assessment on site or calculation (**Chapter 14**). Peak inflow can be estimated using simple online tools (eg HR Wallingford greenfield runoff rate estimation tool). Alternatively, the rational method below could be used (**Equation 17.1**). $Q = CiA$ (17.1) where Q = peak flow (m^3/s) C = runoff coefficient (no units) but includes conversion for 'I' from mm/hr to m/s i = rainfall intensity (mm/hr) (see example in Box 2 of BRE, 1991) A = catchment area (m^2) Determine the critical storm duration by estimating the time of flow from the furthest point of the catchment to the location of the NFM measure. This will provide the time to peak, T_p, for the runoff flows (**Section 16.3**). The time for a flood event to recede will depend on the nature of the storm event and the catchment. For a simple assessment, it may be reasonable to assume that the time for base flow conditions to be restored is approximately twice the duration of the time to peak. Calculate the excess volume of water for storage and/or infiltration assuming that baseflow conditions are present at the start and end of the design event (**Equation 17.2**): $V_{sr} = 0.5\,(Q - Q_{BF})\,(3600(T_p + 2T_p)$ (17.2) where V_{sr} = volume of water for storage and/or infiltration (m^3) Q = peak flow (m^3/s) Q_{BF} = normal-day base flow (m^3/s) T_p = time to peak (duration for runoff to reach peak flow rate, Q) (hr) For more detailed assessments, the assessment of flows should follow the approach given in **Chapter 14**.

continued...

TABLE 17.5 Methods for designing storage and/or infiltration (contd)

<table>
<tr><th>Level of detail</th><th>Method</th></tr>
<tr><td>Intermediate</td><td>Check infiltration outflow: estimate the infiltration outflow and surplus flow (which needs to be either stored or passed forward safely).
Infiltration outflow is:
$$q_i = af \qquad (17.3)$$
where
q_i = infiltration outflow (m^3/s)
a = infiltration area/surface area of measure (m^2)
f = soil infiltration rate (permeability) (m/s) (from Table 17.6)
The surplus flow, Q_e, (in m^3/s) is
$$Q_e = Q - q_i \qquad (17.4)$$
If all the flow is passing through the NFM measure Q is equal to the peak flow. Where base flow bypasses an offline NFM measure, Q is the rate of inflow to the storage and infiltration measure, Q_{si} (or $Q - Q_{BF}$)
Check surplus volume and emptying time: the volume that should be stored or passed forward is:
$$V = 3600Q_eT \qquad (17.5)$$
where
T = flood duration (s) (hrs)
If this volume is stored rather than passed forward, the time taken for the NFM measure to empty by infiltration should be eight to ten hours or less, to allow refilling during subsequent storms. The emptying time (in hours) is:
$$t = \frac{V_s}{3600q_i} \qquad (17.6)$$
where
t = time to empty (hrs)
V_s = storage volume (m^3)
A check should also be performed for safe exceedance (Section 17.3.6). For large flows, a simple approach is to assume that the measure is full and the entire peak inflow for an above-design standard storm overflows the bund or spillway.</td></tr>
<tr><td>Detailed</td><td>Calculate inflow volume for a range of design storm durations and rainfall depths. Select the storm duration that gives the largest volume.
Assess inflow, infiltration, outflow and stored volume over time at regular intervals. Infiltration will depend on the stored water level (also referred to as ‘stage’) and the surface area of the ground submerged at any point in time. Outflow depends on stored water level and the discharge characteristics of the outflow control and will vary over time. The calculation accuracy will depend on the time interval and level of detail in the stage-area and stage-volume relationships. This can be undertaken by hand or using a spreadsheet but, for improved accuracy, consider hydraulic modelling (see Chapter 14).
Outflow over a bund or spillway can be estimated using the weir equation (broad-crested or thin-plate) (Section A4.1). Outflow through a sluice gate or short pipe can be estimated using the orifice equation (see Table 17.14). For long pipes, analysis should include friction losses (see Benn et al, 2019).
BRE (1991) is aimed at the design of soakaways and recommends ignoring the base area, but for NFM measures the base area can generally be included.</td></tr>
</table>

TABLE 17.6 **Soil infiltration rates for typical soils (from Woods Ballard *et al*, 2015)**

Soil type	Clay	Silt loam	Sand to sand/gravel	Gravel
Particle size (mm)	0.002	0.002 to 0.2	0.2 to 2	2 to 20
Permeability (m/s)	<3 x 10^{-8}	10^{-7} to 10^{-5}	10^{-5} to 10^{-2}	3 x 10^{-4} to 3 x 10^{-2}
Drainage characteristics	Very poor	Poor	Good	Good

17.3.5 Designing for sediment retention

Sediment retention measures, such as ponds and swales, can improve water quality by holding water for sufficient time to allow suspended sediment to settle out, although very fine particles may remain in suspension. They can also remove sediment-bound pollutants although additional measures may then be required for their safe disposal or treatment. The effectiveness of sediment retention measures depends on retention time, sediment particle size and density, flow depth and turbulence, and water temperature. The volume and land take of sediment retention measures can be large.

Examine the catchment to identify flow paths, land use, likely sources and types of sediment (eg clay, silt, sand). Observe runoff movement and quality throughout the year and during different rainfall events to estimate sediment load and need for treatment. Advice on sources is available in Stone and Shanahan (2011).

It may be possible to reduce sediment load at or near the source, for example, by using cover crops, restricting livestock access to watercourses, or using buffer zones or sediment traps to intercept runoff.

Methods of designing for sediment retention are given in **Table 17.7**. Sediment accumulation over time can reduce water volume, retention time and effectiveness of sediment retention, so consider providing additional volume or removing sediment at intervals – it may be possible to return sediment to the field.

If sediment retention is important to protect designated habitats or protected species, or to remove pollutants, take sediment samples and undertake laboratory testing to determine density, particle size distribution and nature of contaminants. Consider ground permeability and the risk of spreading contamination, either by seepage into groundwater sources or upwards from contaminated land.

Further information is available in Section 19.2.2 of Murnane *et al* (2006) and Chapters 17, 18, 23 and 32 of Woods Ballard *et al*, 2015. Information on rural SuDS suitable for removal of soluble contaminants is discussed in Avery *et al* (2012).

continued...

TABLE 17.7 Methods of designing for sediment retention

Level of detail	Method
Simple	Provide a permanent water depth no more than 1.2 m (2.0 m maximum during wet conditions). Very deep water can present a safety hazard and may be subject to stratification and anoxic conditions, while very shallow water may develop algal blooms in summer. Provide a long flow path from inflow to outflow to increase retention time. A nutrient-rich sediment load will need a longer flow path/retention time. For ponds, increase width and water depth gradually from inflow to outflow to allow flow to spread out and reduce the risk of sediment re-entrainment. Avoid stagnant areas where water will not circulate. Provide a bypass route for surplus, 'clean' flows during higher flow conditions to reduce the risk of large through-flows and sediment re-entrainment. Provide an overflow for exceedance flows and safe route to the next measure or watercourse (see **Section 17.3.6**). It may be more cost effective to provide additional volume to allow for the accumulation of sediment.
Intermediate	Estimate required storage volume for effective sediment retention: $$V_{sr} \geq \frac{(QD_{mw})}{v_{ss}} \quad (17.7)$$ where V_{sr} = storage volume for sediment retention (m³) Q = inflow to storage area (m³/s) D_{mw} = mean water depth (mm) v_{ss} = sediment settlement velocity (mm/s) (from **Table 17.8**) If volume is considerably lower, sediment retention will be limited. Provide extra volume to allow sediment accumulation on the bed between maintenance intervals.
Detailed	Hydraulic modelling (2D or 3D) of a water body to estimate flow velocities and to ensure suitable conditions for sediment retention. Suited to larger storage measures such as a pond.

TABLE 17.8 Settlement velocity and retention time (after Murnane *et al*, 2006)

Water depth (metres)	Retention time (settling velocity)			
	Fine clay (0.001 m/s)	***Fine silt (0.02 m/s)***	***Medium silt (0.05 m/s)***	***Coarse sand (30 mm/s)***
0.5	6 days	7 hours	3 hours	16 seconds
1.0	11 days	14 hours	5.5 hours	33 seconds
2.0	23 days	24 hours	11 hours	60 seconds

17.3.6 DESIGNING FOR EXCEEDANCE

Exceedance occurs when a measure is subjected to flows or water levels greater than those for which it has been designed. Due to their small scale, NFM measures may be exceeded by relatively frequent flood events. During significant flood events, the NFM measure may become totally submerged and the risk of failure reduced. There may be a greater risk of failure of NFM measures from flood events that exceed their design standard by relatively small amounts. Overflowing of an NFM measure, or a sudden release of water due to structural instability, erosion, washout or breach, can cause flooding or risk to life in the area downstream.

Measures that retain water and overflow intermittently should be designed for safe exceedance. In a series of NFM measures, such as leaky barriers, the most downstream should be designed to withstand any floating debris or water that may be released due to breach or washout of upstream NFM measures. This is most likely to apply to timber and earth bunds and stone check dams. The process of designing for exceedance is summarised in **Figure 17.4**.

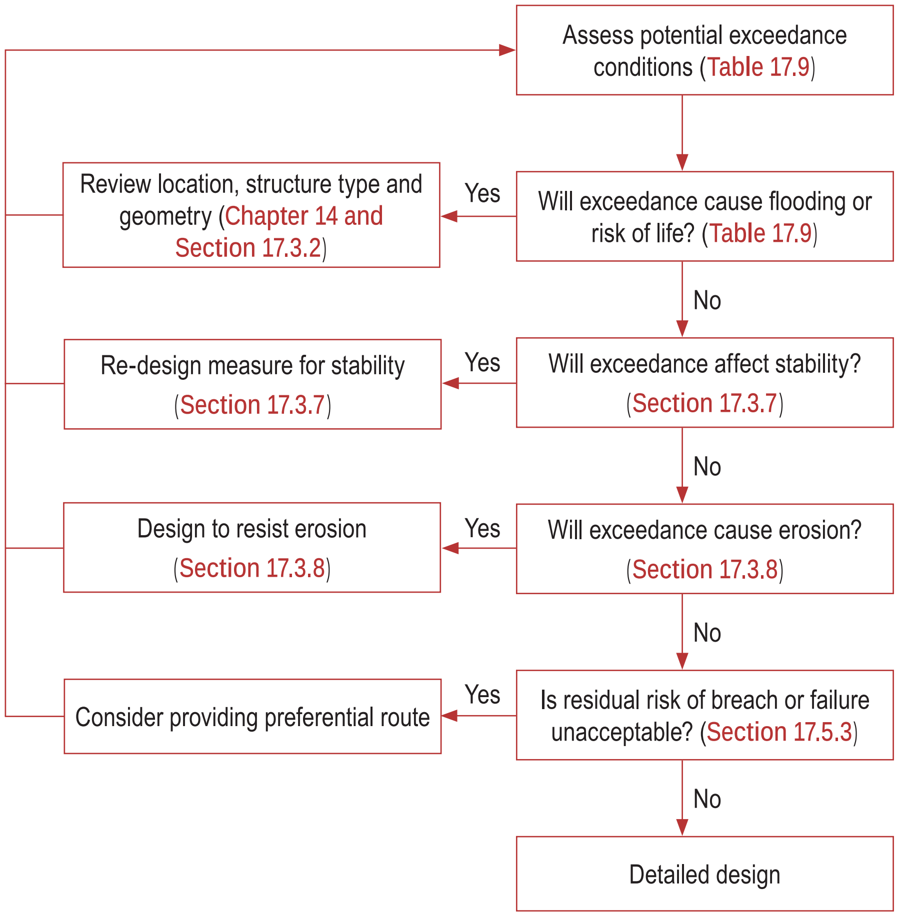


Figure 17.4 Designing for exceedance

An NFM measure should remain stable even when overflowing. Consider the stability with a full head of water and overflowing but including downstream water depth if appropriate (**Section 17.3.7**).

The risk of erosion depends on the frequency, duration and velocity of exceedance flows, the form of the NFM measure and the presence of vegetation, debris and other obstructions that may create areas of localised turbulence (**Section 17.3.8**). For structures with a sloping downstream face (eg earth bunds and stone check dams), estimate the flow velocity on the downstream slope. Grass surfacing can provide suitable erosion protection for flows up to 4.5 m/s up to one hour duration and up to 2 m/s for long duration exposure. Structures with a vertical downstream face (eg timber bunds) will have plunging flow and there will be a greater risk of erosion at the downstream toe. The need for erosion protection can be eliminated or reduced by designing a bund or dam to overtop along its entire length and by designing the downstream face to minimise flow velocities and areas of localised turbulence. Providing a low spot in the centre of a bund or dam can direct flow along a safe pathway, although this may need erosion protection (see *Section 17.3.8*).

Consider the residual risk of breach or failure (**Section 17.5.3**). Based on a review of available mapping and a site walkover, identify the likely flow route/s and the people, animals, property or infrastructure that may be at risk by breach flows. Consider the likely depth and velocity of the flows. Water follows the steepest route downhill but may be stored temporarily at any low spots en-route. If potential impacts downstream are unacceptable, consider either re-locating the measure or providing a preferential flow route that can direct water safely back to the watercourse further downstream, to another NFM feature or to an alternative area where the potential impacts are acceptable.

TABLE 17.9 Methods for exceedance design

Level of detail	Method
Simple	Check for safe exceedance: a simple approach is to assume the NFM measure is full and the entire peak inflow for an above-design standard flood overflows the bund or spillway and can freely discharge downstream. This could occur during an extreme event, or during a modest event if several occurred in quick succession before the measure has emptied. Assume a long duration for the exceedance event. The overflow velocity should not exceed 0.3 m/s unless erosion protection is provided. Good grass cover can provide suitable erosion protection up to 2 m/s for long duration exposure. Peak inflow can be estimated using the methods detailed in **Table 17.5**. The depth of overflowing can be estimated using a restructured form of the weir equation: $$h = \left(\frac{Q}{C_w L}\right)^{2/3} \quad (17.8)$$ where h = flow depth (m) C_w = weir coefficient (varies) L = length of bund or spillway (m) The weir coefficient is typically 1.70 for relatively deep flows over smooth surfaces. This can reduce to 1.45 or less for shallow depth flows and flows over rough surfaces. The coefficient is typically between 0.8 and 1.2 for natural ground (**Section 14.7.1**). The overflow velocity is: $$v = \frac{Q}{A} = \frac{Q}{Lh} \quad (17.9)$$ where v = overflow velocity (m/s) Q = overflow discharge rate (m^3/s) A = cross-sectional area of overtopping flows (m^2) L = length of bund or spillway (m) h = depth of overtopping flow (m)
Intermediate	A similar approach to the simple method can be used but considered in a time-step manner so that the duration of the exceedance event and the variation in overflow discharges can be considered. This can be undertaken by hand or by computer spreadsheet. Consider the flow velocity of slopes using open channel flow equations and the Manning 'n' values (**Section 14.2.4**). Estimate breach flow through an assumed breach using broad-crested weir equations (**Section A4.1**).
Detailed	Assess rate of overflowing, overland flow routes and breach using hydraulic modelling and DTM data (**Chapter 14**). Most accurate but can be time consuming and costly.

17.3.7 Designing structures

Structures, such as bunds or leaky barriers, are constructed across flow paths, watercourses or floodplains to divert runoff, slow flow or store water permanently or temporarily. They can act as an NFM measure in their own right (eg bunds or leaky barriers) or be a component needed as part of another measure (eg a leaky barrier to enable floodplain reconnection or offline storage).

Structures may be designed and constructed as impermeable (eg bund) or permeable (eg leaky barriers) using timber, stone or earth or a combination of materials. They should remain stable during the range of conditions they are likely to experience during their design life. Potential structural failure modes (also known as limit states) include uplift (flotation), sliding due to upstream water pressure or debris impact, bearing failure (soft ground). Failure may also be caused by hydraulic action including erosion due to fast or plunging flow, seepage through or around the structure and instability of slopes due to saturation of the material or the rapid drawdown of water against it.

BOX 17.1 Good practice principle – risks associated with water-retaining structures

Water-retaining structures are the most safety-critical feature of NFM, as their breach or washout could lead to the sudden release of a large quantity of water.

Avoid storing a volume within a single measure or series of measures that could endanger life if released suddenly by breach.

The approach to design depends on the type and size of structure, its location and the likely consequences of a sudden release of water due to breach, washout or failure:

- **Simple rules** are sufficient for low risk structures up to 0.5 m high on runoff pathways or minor watercourses where the sudden release of water due to failure would not cause flooding or risk to life.
- **Detailed methods** should be used for higher risk structures that exceed 0.5 m high and/or where the sudden release of water due to failure could cause flooding or risk to life.

General advice on the design of the structures related to NFM measures is given in **Part C**. Advice on the detailed design of structures is given in **Box 17.2** with advice on timber structures in **Table 17.10** and stone or earth bunds in **Table 17.11**.

BOX 17.2 **General advice on detailed design of structures**

The structural Eurocodes provide a good basis for detailed stability analysis and structural design (eg BS EN 1990:2002+A1:2005, BS EN 1991-1-1:2002, BS EN 1991-1-6:2005).

Load cases (also known as design situations) should consider the range of scenarios that could occur during the design life of a structure. These will depend on the site and proposed design, but may include:

- persistent situations, such as normal operation (eg pond stores water to normal water level)
- temporary situations, such as construction (eg pond is empty), design flood (eg pond stores water to design flood level) or exceedance (eg pond is overflowing
- accidental situations associated with exceptional conditions (eg leaky barrier is struck by floating debris from upstream).

All design situations should take account of predicted scour.

Actions (or forces) on a structure may include hydrostatic pressure on submerged faces, hydrodynamic action due to flowing water and debris impact due to floating debris. For structures or elements that are partially embedded, earth pressure will also apply. Resisting actions should exceed mobilising actions for each of the design situations and limit states. Sketching a free body diagram showing the typical mobilising and resisting actions on a structure is a good place to start (see **Tables 17.10 to 17.13**).

Input parameters include the cross-sectional area of structure exposed to flow and perpendicular to the approach flow, volume of wood or stone material in the structure, density of water, specific weight of water, specific gravity of wood, flow velocities, water levels, drag and lift coefficients. Assume approach flow is perpendicular to the structure. Partial safety factors, if used, should be proportionate to the design life and level of risk associated with the structure.

TABLE 17.10 **Designing timber structures – simple rules**

Description and application		Simple rules
Large log	A single log laid parallel to the flow with no embedment. Apply leaky barriers only on surface water runoff pathways and in ditches or gullies. Unsuited to watercourses or fast-flowing water.	Place large log on ground perpendicular to flow path and on reasonably level ground. Avoid placing on sloping ground.
Stake and wedged logs	A wall of logs laid horizontally across a watercourse, embedded into the banks at lower levels and restrained by four vertical stakes (strainer posts) driven into the ground immediately upstream and downstream. Apply leaky barriers on watercourses bank material that can allow driving of timber piles. Unsuited to areas with cobbles, boulders or shallow bedrock.	Use logs that are as long as possible- at least 1.5 times, but preferably 2 to 2.5 times the channel width, to reduce risk of mobilisation and maximise floodplain connection and water retention. Embed lower logs by 1 m into each bank (2 m if the banks are erodible as fast flow velocities during high-flow conditions could cause bank erosion). Lowest log should be 0.3 m above winter base flow level to reduce the duration and frequency of scouring flows due to flow acceleration beneath or through the structure and to allow fish passage. Install vertical stakes (strainer posts) in pairs upstream and downstream of log wall. Use vertical stakes at least three times barrier height, embed by at least twice the exposed height ('2 in, 1 out' rule) below the depth of the channel bed.
Interlocking/ lattice jam	Array of logs laid in an interlocking pattern across a watercourse, restrained by mechanical fixings to numerous vertical stakes driven into the ground. Apply leaky barriers in ditches or gullies that can allow driving of timber piles. Unsuited to areas with cobbles, boulders or shallow bedrock.	Length of vertical stakes should be at least three times barrier height; depth of embedment should be at least twice the exposed height ('2 in, 1 out' rule). Install vertical stakes either side of the watercourse at intervals of about 0.6 m. Install logs linking stakes in both longitudinal and transverse directions, varying the sequence of installation to create a 3D structure.

TABLE 17.11 Designing timber structures – detailed methods

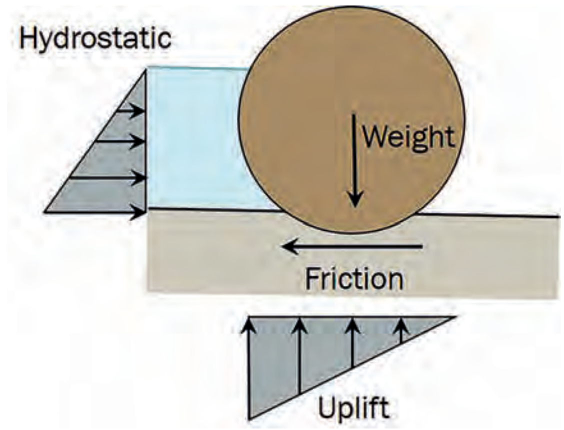
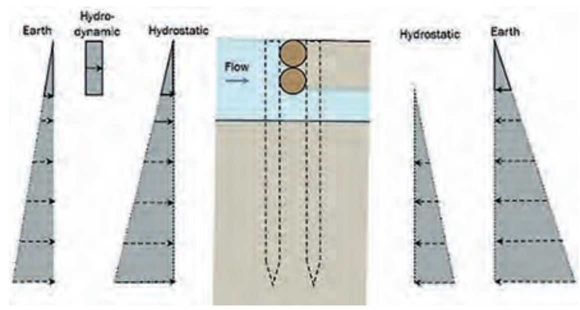
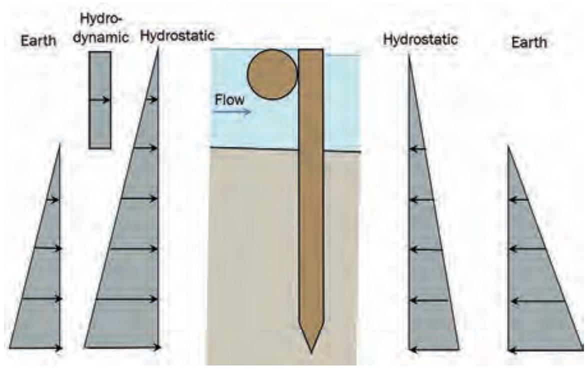
Detailed method	Free body diagram
Large log **Design situation:** water level above ground upstream and at ground level downstream for impermeable structure. **Mobilising actions:** hydrostatic pressure, uplift. **Restoring actions:** weight of log(s), frictional resistance. Ignore lateral earth pressure as it is not embedded. Failure mechanisms: uplift, sliding, rotation, flotation.	
Stake and wedged logs **Design situation:** water level at crest upstream and at base of logs downstream. **Mobilising actions:** hydrostatic, hydrodynamic, lateral earth pressure. **Restoring actions:** weight, frictional resistance, hydrostatic, lateral earth pressure. **Failure mechanisms:** sliding, overturning, lateral bearing failure of supporting ground, bed or bank erosion leading to loss of support or outflanking.	
Interlocking/lattice jam **Design situation:** water level at or above top of bank upstream and downstream. **Mobilising actions:** drag on logs, hydrostatic and hydrodynamic on stakes, lateral earth pressure on stakes. **Restoring actions:** weight, hydrostatic, lateral earth pressure on stakes. **Failure mechanisms:** uplift, sliding, overturning, lateral bearing failure of supporting ground, local scour leading to loss of support.	

TABLE 17.12 Designing stone check dams or earth bunds

Description and application	Simple rules
Stone check dam: piles of stone placed across a runoff pathway or watercourse and profiled by hand. **Applications:** leaky barriers in ditches or gullies, check dams on swales in upland areas with a supply of loose stone. Can be more durable than timber or earth structures if well-designed.	Height up to 0.6 m (maximum 1 m) for safety reasons. Provide side slopes of 1 in 2 gradient or shallower for stability. Foundation depth should be at least half the height. Embed by 0.5 m at the sides to prevent outflanking. Angular stone is more stable than rounded stone. Stones should be placed in layers, with the thickness of each layer being a minimum of 1.5x the average diameter of the rocks used. Stone should be placed so it interlocks, with a minimum of three points of contact with other stones within the layer being placed. Stones weighing 25 kg (recommended limit for manual handling) are suitable for stone check dams with a 1 in 2 gradient side slope and discharge intensity up to 0.3 m^3/s per metre length. Crest level should increase slightly near edges to direct flow to centre of dam and prevent erosion of banks. Failure mechanisms: sliding, bearing failure, lack of stability of rockfill, seepage through and erosion of stone fill and of the ground, erosion of the crest during exceedance events, scour at the downstream toe.

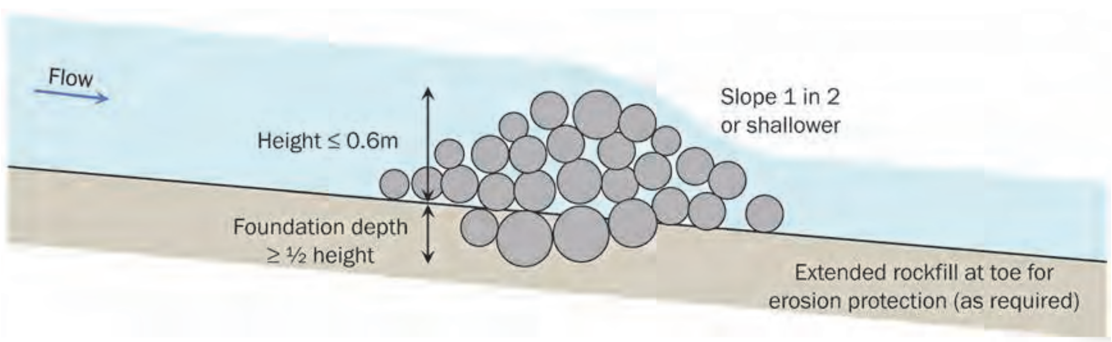


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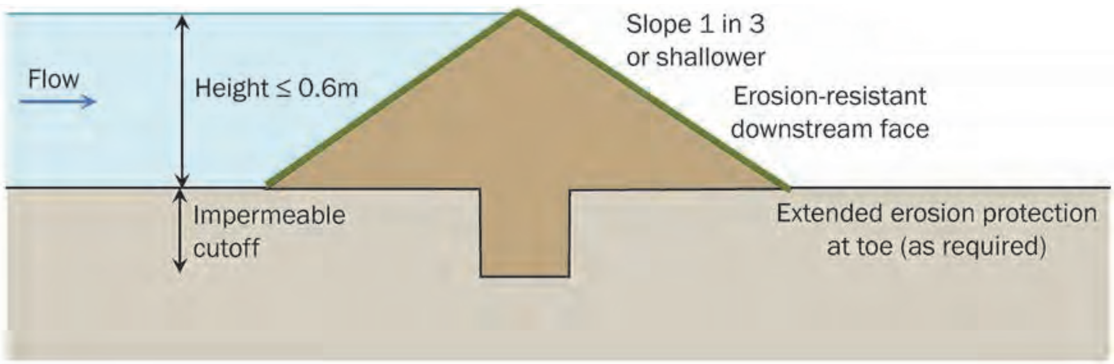
TABLE 17.12 Designing stone check dams or earth bunds (contd)

Description and application	Simple rules
Earth bund: earth bund with roughly trapezoidal profile and grass cover or erosion-resistant downstream face. **Applications:** bunds or ponds (to provide additional attenuation storage). Suited to lowland areas with plentiful topsoil.	Height up to 0.6 m (maximum 1 m) for safety reasons, unless designed in detail. Provide side slopes for raised bunds that are as shallow as possible and fit into the landscape. In particular, a shallow slope is preferable on the downslope face of the bund and/or at a designed low point for exceedance, where a feature may overspill. Shallow slopes also allow more for useable farmland with safer access for vehicles, people and animals. An appropriate side slope is 1 in 5 and a maximum slope, to ensure stability, is 1 in 3. Ideally, provide a crest width of 1 m or more to aid access for inspection and maintenance and to minimise the risk of damage due to exceedance flows. Embed the bund sufficiently deep into the ground or construct an impermeable cut-off below natural ground level to a suitable depth to minimise infiltration and risk of breach failure. Use locally-sourced fill materials to reduce carbon footprint if available and suitable. Clays that expand significantly when wet may be unsuitable. Granular fill (eg sand or gravel) may need an impermeable clay core or waterproof membrane on the upstream face. Cohesive fill (with clay or silt content) may not need additional seepage control. Construct in layers of no greater than 300 mm and compact each. This limits pore water pressure and seepage which can lead to failure. Consider the ground conditions. Clay will provide an impermeable layer. Sands and gravels may allow flow under the bund and risk erosion of the ground. Provide an erosion-resistant downstream face in case of overflowing during an exceedance event (see **Section 17.3.8**). Erosion protection may need to extend beyond the downstream toe. Failure mechanisms – sliding, bearing failure, loss of strength of embankment fill materials due to saturation or rapid drawdown, seepage through and erosion of embankment fill materials and of the ground, erosion of the crest during exceedance events, scour at the downstream toe. Avoid allowing livestock or vehicles onto bund features until the vegetation has established.



BOX 17.3 **Design of restraints or fixings**

Consider locating a structure immediately upstream of trees or bedrock features to provide additional restraint against sliding. Provide restraint at each end as a minimum.

Restraints or fixings should be capable of withstanding the mobilising actions on the structure and/or structural elements over the design life of the structure. Consider the imposed actions on the restrained material and the fixing or restraint. Applied stress should not exceed allowable stress.

Consider potential deterioration over the life of the structure and apply a factor of safety (FoS). Consider using durable materials that are resistant to environmental degradation, rotting and damage by animals (see **Section 17.4**).

BOX 17.4 **Design of stone dams and earth bunds – detailed method**

Check that the bearing pressure imposed by the dam does not exceed the bearing capacity of the ground. Design stone to resist mobilisation during the design flood and at minimum risk of disturbance during more extreme floods. Try all material sizing methods and select the mean or the largest, depending on uncertainty in design input parameters, site-specific risks and the need to avoid mobilisation. Typical stone properties are freely available online.

If there are concerns about the ground conditions, consider undertaking ground investigation. Consider ground permeability and the need for seepage control, overall stability and risk of erosion during overflowing. Detailed guidance on geotechnical design to Eurocode 7 is available in Pickles *et al* (2014).

17.3.8 Designing erosion protection

Erosion (or scour) is the removal of bed and bank material by flowing water. While erosion is a natural process on watercourses, excessive erosion can lead to the undermining or outflanking of an NFM measure or nearby structure. This can lead to failure of the measure with a sudden release of water, or structural failure and collapse.

Erosion protection may be needed for measures that impound or direct water where there is a risk of outflanking or the measure creates fast, turbulent or plunging flow. Typical locations can include in the area downstream of a bund, check dam or leaky barrier, downstream of a pond or swale outlet, or at the opening in a flood bank or spill to a former side channel. Erosion can occur on the NFM measure due to the impact of exceedance flows such as at the crest and downstream face of a bund.

First assess the risk of erosion to the measure (**Table 17.13**). Erosion is more likely if the bed and bank materials are non-cohesive (sand, gravel or cobbles). Non-cohesive sediments erode when the lift and drag forces on a particle from water flow exceed the resistance due to weight and friction. Cohesive sediments (clay and silt) have extra resistance due to cohesion between their particles. Well-maintained grass cover may provide sufficient erosion protection for a measure that operates or overflows occasionally (eg once or twice a year). A measure that operates or overflows frequently and/or for long durations may need more substantial erosion protection.

The risk of erosion may increase as a result of installing an NFM measure; if it impounds water it may increase flow velocity and turbulence downstream. Consider the range of conditions that could occur and the frequency – the worst case is often the onset of overflowing with no water downstream.

TABLE 17.13 Methods of assessing risk of erosion

Level of detail	Method
Simple	Site walkover to look for signs of erosion or erodibility at the location of the proposed measure and immediately upstream and downstream. A consistent cover of grass on ground with an even profile should provide good resistance to flows up to 2 m/s. Look for bank erosion, bank slumping or undermining, exposed cohesionless bank material without vegetation cover, exposed tree roots, trees or fences tilting towards the watercourse, or sediment bars within the channel.
Intermediate	Hydraulic assessment to estimate likely flow conditions and/or flow velocity for the design event (see **Table 17.14**). If flow velocity is less than 1 m/s, erosion is unlikely, but if it exceeds 2 m/s, erosion protection is probably needed.
Detailed	Hydraulic modelling to determine likely flow conditions and/or flow velocity for a range of discharges, up to and including the design event (see **Chapter 14**). Compare the flow velocity with the threshold velocity for erosion of the underlying material. Threshold velocity for erosion of exposed soils can be estimated using guidance in Kirby *et al* (2015). The erosion resistance of grass cover or bare earth/rock is given in **Tables 17.15 and 17.16**. If erosion is likely, estimate maximum scour depth and extent (see Table 17.14). Assess whether this is likely to undermine the NFM measure and/or nearby structures.

TABLE 17.14 Methods of assessing flow velocity and scour

Measure type	Flow velocity	Scour
Sloping downstream face (eg earth bunds)	Velocity of normal flow on downstream slope is given by Manning's equation (**Box 14.1**).	Surface erosion likely. Check allowable velocities in **Table 17.15 or 17.16**.
Vertical downstream face (eg timber bunds, leaky barriers)	Velocity (m/s) of flow over a low structure can be calculated using the weir equation (**Section A4.1**)	Scour hole immediately downstream. Estimate depth and extent of using method for weir flow in Section 5.3.9 of Kirby *et al* (2015).
Openings below water level (eg outlet pipes, leaky barriers)	Where flows pass through a small opening, the velocity (m/s) and discharge (m^3/s) can be assessed using the orifice equation detailed in Chapter 2 of Chadwick *et al* (2013). If a pipe is running full, velocity (m/s) and discharge (m^3/s) through it can be estimated using the Colebrook-White equation as detailed in Chapter 4 of Chadwick *et al* (2013).	Scour hole immediately downstream. Estimate depth and extent using methods for gates or culverts in Sections 5.3.7 and 5.3.8 of Kirby *et al* (2015). Treat a leaky barrier as a gate and pipe as a culvert.

TABLE 17.15 Allowable velocities for grass cover (in m/s) (after Hewlett *et al*, 1987)

Grass cover	1 hr	2 hrs	5 hrs	10 hrs
Good: dense, tightly knit turf established for two or more growing seasons	4.5	3.8	3.3	2.9
Average	3.8	3.2	2.5	2.2
Poor: uneven, tussocky with bare earth	3.0	2.4	1.8	1.5

TABLE 17.16 **Allowable velocities for different channel materials (after USDA, 2007)**

Channel material	Mean channel velocity (m/s)
Good rock	6.1
Soft sandstone	2.4
Clay or fine gravel	1.8
Coarse sand	1.2
Soft shale	1.1
Fine sand or sandy silt	0.6

If erosion is likely, consider whether this could undermine the measure or nearby structures. Estimate the maximum depth and extent of scour and consider whether this could encroach on structures or undermine foundations (**Table 17.14**).

If scour can be accommodated safely without causing damage, consider allowing a scour hole to develop naturally. This is the most environmentally favourable solution and can contribute to habitat diversity. For example, provided the supports for a leaky barrier are set back from the channel and driven to sufficient depth, the erosion of a scour pool or a small area of bank immediately downstream and deposition of a sediment riffle downstream of the pool will add diversity without compromising the function of the leaky barrier.

If erosion is likely and could damage the measure or nearby structures, consider whether the measure can be installed at an alternative, less erodible location, or whether the design can be modified to reduce the risk of erosion.

If erosion cannot be accepted or designed out, then consider designing and installing erosion protection. Types of erosion protection range from green to grey:

- **Green:** living materials such as grass, willow spiling or faggots, woody material or natural biodegradable mats such as coir or jute to provide erosion protection while grass or vegetation becomes established
- **Green-grey:** biotechnical measures such as vegetated geomats, geocells, reinforced earth, gabions or rip-rap that combine artificial, non-biodegradable materials with vegetation to provide additional erosion protection
- **Grey:** unvegetated artificial materials such as geotextiles, or rock-based measures such as rip-rap, rock rolls and gabion mattresses.

The selection and design of erosion protection should consider the frequency of inundation or overflow, flow velocity and turbulence, ground slope, the need for immediate protection, access to install it, the need for access by people or animals, direct sunlight which affects vegetation, maintenance requirements, availability of local materials, the local landscape, flexibility to accommodate movement (eg due to long-term channel incision) and risk of vandalism or damage by animals.

Green erosion protection is preferable to grey to reduce both the carbon footprint and the use of plastics or non-renewable material. It also can provide environmental and amenity co-benefits by creating habitat for wildlife and aquatic species, improving water quality by trapping sediment and improving visual amenity.

Simple rules may be used for the design of erosion protection at low risk structures in rural areas, where breach or failure would not increase flooding or risk to life downstream, or where erosion is unlikely to undermine properties or infrastructure (**Box 17.4**).

BOX 17.5 **Design of erosion protection – simple rules**

- Consider green erosion protection before grey.
- Provide erosion protection where flow is fast or very turbulent (eg at outlet or inlet pipes).
- Provide erosion protection beneath plunging flow (eg downstream of check dams or pond outlets), with a vertical toe that extends at least 500 mm below the bed of the watercourse.
- Provide a transitional length of less erodible material (eg wood or stone rip-rap) at transitions from hard material to natural bed material (other than rock).
- Design smooth transitions from natural bed or bank and erosion protection to avoid increasing turbulence and causing more scour.
- Embed leaky barriers and check dams into the banks of the watercourse to prevent undermining below the structure or outflanking around the sides of the structure.

Detailed design should be undertaken for erosion protection at high risk structures, where breach or failure could increase flooding or risk to life downstream, or where erosion could undermine properties or infrastructure (see Kirby *et al*, 2015, USDA, 2007 or Hewlett *et al*, 1987).

17.4 MATERIALS

The choice of materials can affect health and safety, ease of construction, environmental impact, carbon footprint, visual appearance, design life, the need for maintenance, and whole-life cost. A good choice can reduce whole-life cost and fit in with the surrounding landscape.

Factors affecting choice of materials are summarised in **Table 17.17**. NFM materials, their applications, advantages and disadvantages are in **Table 17.18**.

BOX 17.6 **Selection of materials**

- NFM aims to work with natural processes and should use sustainable, local materials where possible.
- Consider the balance between carbon footprint, cost, durability and ease of construction. The source can affect the carbon footprint more than the type of material. Locally-sourced materials may be lower cost (and carbon) than those purchased and imported to site, but imported materials may increase longevity.
- Consider the environmental impact. Locally-sourced materials may form a habitat for a protected species (such as nesting birds or bats in trees, or great crested newts in stone walls) and should be sourced with care (**Section 16.5**). Use of locally sourced materials may reduce the visual impact on the landscape (**Section 16.6**).
- Consider landowner preference.
- Consider recycled before new.
- Consider durability, the need for monitoring, maintenance and management, ease of disassembly and potential for end-of-life reuse.

BOX 17.7 Use of plastic

- Use natural and sustainable alternatives if these are suitable and available without jeopardising affordability.
- Plastic products may be exposed to significant abrasion and could release plastic particles. Avoid using plastic products for short-term applications where they will not be reused or recycled.
- Plastic products may be acceptable where they significantly reduce carbon footprint or allow soft engineering to be used in place of hard engineering. The benefits should be weighed up against the likelihood and quantity of plastic that will enter the environment over the design life of the asset.
- Consider performance and durability. If using plastic, ensure products are robust and meet engineering requirements, maintain their integrity over the long term, are ultraviolet (UV) resistant or UV protected, and contain recycled material where possible. For durability, the use of medium or high-density plastic products may be necessary. Ideally integrate plastics into the design so they are not visible within the landscape, for example, clad inlet and outlet headwalls with suitable materials such as stone pitching.

BOX 17.8 Dealing with waste

- Follow the waste management hierarchy: prevent, reuse, recycle, recover, dispose.
- Design measures based on typical material dimensions to reduce waste.
- Use reclaimed, recycled, recyclable, renewable or biodegradable materials where possible.
- Excavated or dredged material that is not contaminated may be deposited on nearby land or reused for agricultural or ecological benefit under a waste management exemption.
- Material that is contaminated due to historic land use or INNS may need to be disposed of as hazardous waste and will need an environmental permit (see **Section 16.8**).

TABLE 17.17 Factors affecting choice of materials

Factor	Design principles
General	
Availability	Consider availability within project timescale (eg stone may be available in upland areas with shallow soil, earth in a lowland or arable areas with deeper soil).
Cost	Consider relative cost of materials and affordability.
Performance	Select materials that achieve the required design performance, for example, the use of water-retaining materials and erosion protection.
Cultural	Use materials that are typical of other built elements within the landscape (eg stone may reflect local drystone walling or barns, split oak may be typical of local fencing).
Physical footprint and land use	Stronger materials have a smaller footprint than weaker materials, which may have a lower impact on land use (eg a timber bund is more compact than an earth bund).
Sources	Use locally-sourced materials in preference to materials imported to site (particularly outside the UK), to reduce transport and carbon footprint. Use locally harvested wood or timber for sustainability, biosecurity, wildlife and budget.
Health, safety and environmental	
Carbon footprint	Use materials that minimise embodied carbon and transport. Use local people and services.
Ease of use	Use materials that are easy to transport, construct or install. Use heavy materials sparingly due to manual handling risk and high carbon involved in transport. Where manual handling is proposed, ensure the weight and form of materials minimise the potential risk of injury. Where the use of heavy materials is necessary, consider transport and mechanical handling requirements.
Environmental hazards	Avoid materials that are toxic to humans, plants or animals, or at risk of damage by animals. Avoid materials that are soluble. Use untreated timber to prevent chemicals leaching into the ground or waterbodies.
Health and safety hazards	Avoid hazardous materials (eg physical, fire, chemical, biological, dust). Avoid fixings that create end-of-life entrapment hazards as material rots away.
Plastic	Use natural materials where possible. Use less plastic products, and use recycled in preference to new plastic. Consider the risk of releasing plastics into the environment (see **Section 17.2**).
Sustainability	Use sustainable forestry wood or timber (FSC-approved in the UK).
Waste	Use reclaimed, recycled, recyclable, renewable or biodegradable materials where possible. Design measures based on typical material dimensions to reduce waste.
Maintenance and end-of-life	
Adaptability	Use materials that allow adaptation if hydrological function is not as expected (eg a measure that fills during smaller rainfall events than predicted may need modification of the outlet or overflow).
Durability and design life	Use durable materials to minimise the need for repair or replacement. Consider the risk of erosion and impact damage for both the design event and exceedance events.
Maintenance	Use materials and associated forms of construction that minimise the need for maintenance or are easy to maintain. Use materials suitable for adaptive maintenance (eg rip-rap) (see **Chapter 19**).
End-of-life	Minimise different types of materials and keep components to a minimum. Design for ease of disassembly, reuse or recycling. Use mechanical rather than chemical fixings. Avoid contaminating materials with other substances that prevent recycling or affect disposal (eg timber treatments). Avoid fixings that may create a hazard as the material degrades (eg wire).

TABLE 17.18 Materials for NFM, applications, advantages and disadvantages

Material	Applications	Advantages	Disadvantages
Living materials (eg willow spiling)	Leaky barriers in woodland	• Freely available in woodland. • Renewable, biodegradable, reduces carbon, can reuse or recycle. • May take root and grow, improving stability and lasting indefinitely.	• Low cost if imported to site. • Can be heavy, may need lifting equipment. Increased carbon footprint if heavy equipment required. • May take root and grow, affecting the structure and performance of the NFM measure. • May need to regularly inspect and maintain.
Wood and timber (processed wood)	Cross drains, bunds, leaky barriers	• Freely available in woodland. • Renewable, biodegradable. • Durability depends on species, age, and exposure conditions. Design life varies from five years for softwood to 25 years or more for hardwood; indefinite if permanently submerged.	• Medium cost if imported to site. • May require equipment to fell and obtain the timber. Will require work to process the material into the required form. Bulky and heavy to transport. May need lifting equipment. Increased carbon footprint if imported or heavy equipment required. • Treated timber may have environmental impacts. • Limited design life. • Design life may be reduced if cyclically exposed to dry and wet conditions. • Need to regularly inspect and maintain.
Stone (cobbles, boulders, stone setts)	Cross drains, leaky barriers, check dams, erosion protection	• May be freely available in upland areas. • Natural material, can reuse or recycle. • Durability depends on design, type of material and exposure conditions.	• Medium cost if imported to site or dressed stone. • Non-renewable. • May require excavation to extract materials. Bulky and heavy to transport. May need lifting equipment. High carbon footprint.
Earth fill (cohesive silt/ clay/puddle clay, or granular sand/ gravel)	Bunds, ponds, scrapes, swales	• Freely available in lowlands. • Natural material, can reuse or recycle. • Cohesive materials can be impermeable and good for water retention. • Indefinite design life.	• Medium cost if imported to site or high cost for puddle clay. • Non-renewable. • Granular materials may be more easily eroded. • Cohesive materials may swell or crack under differing weather conditions. • Excavation likely to be required to extract materials. May require sorting and working to make suitable for use. Bulky and heavy to transport. High carbon footprint. • Risk of settlement or damage. • Need to regularly inspect and maintain.

continued...

TABLE 17.18 Materials for NFM, applications, advantages and disadvantages (contd)

Material	Applications	Advantages	Disadvantages
Biodegradable geotextiles (eg coir, jute)	Temporary erosion protection while grass establishes	• Low cost. • Readily available off the shelf. • Renewable, biodegradable.	• Limited performance and strength. • Limited design life.
Non-biodegradable geotextiles (eg geomat, geoweb, rock rolls)	Permanent erosion protection, filter, drainage or separation layers	• Low cost. • Readily available off the shelf. • Longer design life than biodegradable geotextiles. • Can provide improved structural performance (in combination with fill materials). • Can provide improved erosion protection (in combination with earth fill and vegetation cover)	• Depletes fossil fuels. • Contains plastic, risk of environmental harm (microplastics, UV degradation). • Reuse or recycling usually not viable.
Plastics	Outlet pipes, leaky barrier fixings	• Low cost. • Readily available off the shelf. • Recycled plastic re-uses material that might otherwise go to landfill. • Lightweight and inexpensive. • Some products may be re-usable and/or recyclable.	• Depletes fossil fuels. • Risk of environmental harm (UV degradation, microplastics). • Non-renewable, non-biodegradable.
Metal (eg stainless steel channels or fixings)	Cross drains, leaky barrier fixings (eg bolts, screws, anchors), structural members.	• Readily available off the shelf. • Can be strong and corrosion resistant (need specialist steel to resist corrosion in saltwater). • Long-lasting and durable when correctly designed. • Can reuse and recycle.	• Expensive option for leaky barrier fixings. • Use in structures may require specialist design experience. • Structural members can be heavy, may need lifting equipment. • May have notable visual impact where visible in the landscape. • Some materials can be prone to theft (eg stainless steel). • Non-renewable, manufactured materials. • High carbon footprint in manufacture, transport and placement.
Concrete (eg *in situ* concrete drainage channels, pre-cast concrete pipes)	Cross drains, outlet pipes, headwalls, structures	• Individual materials can be readily sourced for mixing on site. • Ready mixed concrete usually easily available from local producers. • In situ concrete can be shaped to suit the required form on site. • Pre-cast items usually readily available off the shelf. • Long-lasting and durable when correctly designed.	• Expensive. • Use in structures may require specialist design experience. • Pre-cast items can be heavy, may need lifting equipment. • May have notable visual impact where visible in the landscape. • Non-renewable, manufactured material. • High carbon footprint in manufacture, transport and placement. • Limited ability to reuse or recycle.

The properties of selected tree species are given in **Table 17.19**. Larger sections of more durable wood are preferable to smaller sections of less durable wood, and wood with a higher density will better resist mobilisation by water.

TABLE 17.19 Properties of selected tree species for wood and timber structures

Durability class (lifespan)[1]		Name	Dry density (kg/m^3)	Notes
2	Durable (15 to 25 years)	Chestnut, sweet	560	
		English oak	720	Density can vary by 20%
3	Moderately durable (10 to 15 years)	Douglas fir	530	
		European larch	550	
		Western red cedar	390	
4	Slightly durable (5 to 10 years)	English elm	560	Density can vary by 20% or more
		Scots pine	510	
5	Not durable (less than five years)	Alder	530	
		European ash	710	Density can vary by 20%
		Beech	720	
		Willow	450	Good for living barriers

Note

1 Durability class from BS EN 350-2:1994.

17.5 HEALTH AND SAFETY

17.5.1 Construction (Design and Management) Regulations 2015

CDM 2015 apply to the design, construction and maintenance of some NFM measures. CDM aims to improve health and safety in the industry by having the right information and communicating it effectively to those that need to know. The principle roles under CDM are the client, principle designer, designer and principle contractor.

It is recommended that anyone responsible for NFM projects is appropriately trained in CDM requirements. Where applicable, clients must make suitable arrangements to manage the work so that health, safety and welfare risks are controlled. They must also provide pre-construction information about the site and known hazards to those who need it. Designers must notify clients of their duties, and assess and manage the risks associated with the work. For projects due to last longer than 30 working days and which have more than 20 workers or exceed 500 person-days, formal notification to the HSE (Great Britain) or the HSE Northern Ireland (HSENI) is needed.

Where NFM measures are of a small scale, the CDM requirements may not apply. However, other health and safety legislation may remain relevant and the general approach to assessing and managing health and safety should still be followed.

The design process should seek to eliminate or reduce hazards such as buried or overhead infrastructure, and their associated risks. General advice on safety is given in **Section 3.7** and specific safety considerations for the design and construction of each NFM measure are in **Part C**. In relation to construction safety, further information is given in **Section 18.3**.

17.5.2 Assessment of risk

During the design process, it is necessary to consider the safety hazards associated with the construction, operation, maintenance and, ultimately, demolition or removal of an NFM measure. The hazards that can be encountered will depend on the specific location, the type of NFM measure, the type of construction work and the personnel involved. The overall safety risk associated with these hazards will depend on the probability of them occurring. Actions to remove or reduce risks should be identified. In the event of a risk occurring, contingency actions to reduce their impact should be summarised. This forms the basis of a risk assessment.

The hierarchy of control measures can be summarised by the acronym ‘ERIC’:

- Eliminate – remove the risk or prevent it from happening.
- Reduce – lower the likelihood of the risk occurring.
- Isolate – a risk may still be present but is managed by keeping it separated from those it could affect.
- Control – a risk is still present but measures are put in place to reduce the impact(s) should it occur.

Where possible, safety risks should be addressed as part of design development. Some safety risks can be significant and pose a major risk to life. Examples are lifting operations, works in the vicinity of high voltage cables and high-pressure gas mains and confined spaces. The design should aim to avoid or minimise significant safety risks where possible.

The risk assessment should consider who may be affected if a safety hazard arises. This may be construction, operations and maintenance staff or the general public. The construction of NFM measures may include the use of an unskilled, volunteer workforce and specific measures may be required to manage their safety.

Where NFM measures are within areas accessible by the public, a public safety risk assessment (PSRA) may be required. The results may influence the design of the NFM measure to ensure public safety is addressed. PSRA may assess risk for groups of similar measures for efficiency on a large project.

17.5.3 Residual risk

It may not always be possible to ‘design out’ safety risks, for example, it is possible that a significant flood could occur during construction. As a flood is a natural event, there is nothing a designer can do to prevent this, so a residual risk needs to be passed on to the construction contractor. The designer should provide relevant information relating to the residual risk, for example, the assessed frequency, scale and flow path of floods, so that the contractor can determine the potential impact on the construction works and implement mitigation measures as appropriate.

It is important to highlight residual risks that are significant, unusual or that a contractor could not normally be expected to encounter in routine construction activities. If residual safety risks are significant, it is likely the contractor will need to produce specific risks assessments and method statements to confirm the approach to manage and control them.

Some residual risks may be relevant to the future management, maintenance and end-of-life considerations of the NFM measure. Where they cannot be designed out, these should also be identified and documented so that the information can be passed to the relevant persons.

Further reading

Chadwick, A, Morfett, J and Borthwick, M (2013) *Hydraulics in civil and environmental engineering, 5th Edition*, CRC Press, London, UK (ISBN: 978-0-41567-245-0)

⇨ Comprehensive coverage of civil engineering hydraulics and an introduction to the principles of environmentally sound hydraulic engineering practice.

Kennard, M F, Hoskins, C G and Fletcher, M (1996) *Small embankment reservoirs*, R161, CIRIA, London, UK (ISBN: 978-0-86017-461-5)

⇨ Design of small reservoirs, including earthworks, geotextiles, drainage materials and pipework.

www.ciria.org

Kirby, A M, Roca, M, Kitchen, A, Escarameia, M and Chesterton, O J (2015) *Manual on scour at bridges and other hydraulic structures, second edition*, C742, CIRIA, London, UK (ISBN: 978-0-86017-747-0)

⇨ Guidance on design of erosion protection, mostly grey, some coverage of green.

www.ciria.org

Hewlett, H W M, Boorman, L A and Bramley, M E (1987) *Design of reinforced grass waterways*, R116, CIRIA, London, UK (ISBN: 978-0-86017-285-7)

⇨ Guidance on the planning and design of reinforced grass waterways and associated erosion protection measures.

www.ciria.org

ICE (2015) *Floods and reservoir safety, fourth edition*, ICE Publishing, Institution of Civil Engineers, London, UK (ISBN 978-0-7277-6006-7)

⇨ Guidance on the estimation of flood inflow, flood routing and overtopping assessments

Roca, M, Escarameia, M, Gimeno, O, De Vilder, L, Simm, J D, Horton, B and Thorne, C (2017) *Green approaches in river engineering*, HR Wallingford, Wallingford (ISBN: 978-1-89848-516-2)

⇨ Guidance on selection of green erosion protection.

https://eprints.hrwallingford.com/1250/

USBR (2007) *Reclamation. Managing water in the west. Rock ramp design guidelines*, US Department of the Interior, Bureau of Reclamation, Colorado, USA

⇨ Design of stone check dams and rip-rap erosion protection.

https://www.usbr.gov/tsc/techreferences/mands/mands-pdfs/RockRampDesignGuidelines_09-2007_508.pdf

Woods Ballard, B, Wilson, S, Udale-Clarke, H, Illman, S, Scott, T, Ashley, R and Kellagher, R (2019) *The SuDS manual*, C753, CIRIA, London, UK (ISBN: 978-0-86017-760-9)

⇨ Design of ponds, swales, bioengineering, soils/aggregates, erosion protection and geosynthetics.

https://www.ciria.org

Courtesy Herefordshire County Council

18 CONSTRUCTION AND IMPLEMENTATION

Contents

Chapter 18

Construction and implementation

This chapter provides information on good practice in construction and implementation of NFM from pre- to post construction.

▸ *It is vital to ensure that risks are managed appropriately and a qualified engineer should be consulted where any doubt remains (see Section A3.2).*

This chapter provides an overview of the general principles of NFM construction and implementation. **Part C** provides more specific details on the individual measures. It also covers broad principles that could be applied to all NFM measures.

18.1 GOOD PRACTICE

The aim is to construct and implement NFM measures as specified in the design process, safely and to mitigate any residual environmental impact. The approach chosen depends on the type of measure. Some measures may take several days to construct and require civil engineering operations such as excavation, grading, topsoiling, seeding and planting. These operations are specified in several documents UKWIR (2011). Other measures can be delivered in a day with a group of volunteers. Regardless of the approach, it is important that attention to detail is given to all forms of construction. There are risks associated with any construction project and if in any doubt it is vital to consult with a qualified engineer (**Section A3.2**) to ensure these are managed appropriately. **Table 18.1** provides a checklist of key considerations in the construction phase.

TABLE 18.1 Checklist of key considerations during the construction phase

Consideration	Description	✓
Planning and programming	Ensure measures are practical to construct and implement	
	Decide what can be achieved in each location to avoid unnecessary work	
	Undertake pre-site checks as early as possible to identify safe access, constructability, and other site risks	
	Develop method statements and pre-construction plans	
Access	Access routes for the site selection, design, construction and maintenance	
	Check there is adequate access for all machinery required during construction. Check bridges, crossing points and gates are large and strong enough to accommodate access	
	Field and land drains – heavy machinery can cause collapse	
	Check how to transport materials to site, especially in remote or hard to reach locations	
	Identify the most efficient routes for spoil removal to reduce time and impact	
	Access requirements for ongoing maintenance; permanent access routes for heavy machinery might be required	
Service checks	Ensure services checks are conducted before any construction works. Make considerations for cables, pipes and overhead wires	
	Liaise with the landowner and service operators to confirm the service check and identify any other known services (eg private water supply)	
	Make sure services are marked out accurately on-site, allowing a margin of error	
	Machinery used – overhead cables can dictate the maximum height of machinery. The HSE provides information on working near overhead power lines	
	Ensure service checks are revisited during the pre-construction phase to confirm nothing has changed since the design or planning phase	
	Engage a qualified surveyor to locate and trace services, especially if there is any doubt whether there are services running underground	
Environment	Consider key issues related to the water environment, geomorphology, ecology, landscape, the historic environment, and waste and contamination, for all stages of NFM delivery. Further information can be found in **Chapter 16**	
	Check for INNS. If present on site or nearby (particularly upstream), then they will require specific consideration to identify whether they present an opportunity or constraint. Further information can be found in **Chapter 16**	
Timings	Consider the best time for construction	
	Consider the farming calendar if working in agricultural areas	
	Be aware of key environmental restrictions, such as nesting birds, protected species or fish spawning	
	Consider weather and seasonality. Winter and during the non-growing season can be a good time to implement some NFM measures, such as cross slope hedges or tree planting. However, wet weather or waterlogged ground can be an issue for schemes that require heavy machinery	

continued...

TABLE 18.1 Checklist of key considerations during the construction phase (contd)

Consideration	Description	✓
Consents, permits and licences	Consider what consents, permits and licences might be required before construction starts. Further information can be found in **Section 3.6**	
Erosion and sediment control	Develop an erosion and sediment plan for the construction phase	
	Ensure any earth works are fully stabilised by planting or erosion protection	
Skills and essential training	Ensure everyone involved with the construction and implementation has a general understanding of wider environment issues and impacts that the construction process might cause	
	Ensure operations have the essential training for activities such as digger operation or use of chainsaw	
	Undertake regular engagement with contractors to increase the awareness of what is trying to be achieved	
Health and safety	Ensure appropriate risk assessments and method statements are undertaken and communicated to all involved	
	Ensure appropriate training and personal protective equipment (PPE) is provided	
Volunteer management	Be aware some features might be installed by unskilled volunteers. Volunteers may not be familiar with good health and safety practices	
	Enable close supervision, training, and guidance for volunteers to ensure the workplace is safe	
Long-term management	Develop a long-term maintenance plan which defines maintenance responsibilities (**Chapter 19**)	
	Consider long-term monitoring requirements where necessary (**Chapter 19**)	

18.2 PLANNING AND PROGRAMMING

Construction and implementation of NFM requires effective planning throughout. Construction activities do not usually happen in a linear sequence and may vary due to weather conditions, unpredictable factors and environmental constraints, for example, nesting birds or bat roosts in trees. This might require aspects of design or the method of construction to change.

Understanding the level of construction required will help to determine the appropriate level of planning and programming. **Table 18.2** describes the different levels of construction require for different measures.

TABLE 18.2 Level of construction for different NFM measures

Level of construction	NFM measures	Description
Simple	Leaky barriers, hedge planting, riparian buffer strips	Could be installed by volunteers.
Moderate	Cross drains and diverters, ponds, scrapes, bunds, leaky barriers	May require one to two days of construction. Generally not constructed by volunteers.
Detailed	Bunds, wetland creation, floodplain reconnection, river channel restoration	Requires over two days of construction. Machinery needed.

Timing of construction and implementation should be co-ordinated with the farmer or landowner taking environmental constraints into consideration. This will improve efficiency, works duration and subsequent associated risk.

Effective planning of the construction process is important to:

- reduce the risk of sediment laden runoff which could lead to flooding or cause pollution during construction
- protect existing habitats and enhance those features where possible
- promote rapid vegetation establishment to help reduce the duration of impact
- facilitate effective engagement with landowners and contractors during the construction phases, so they understand how the measures have been designed and constructed. This is especially important if they are taking on the maintenance liability of the measures.

The programming of construction and implementation occurs in three main phases:

1 Pre-construction.
2 Construction and implementation.
3 Completion (including ongoing maintenance and monitoring).

18.2.1 Pre-construction

Before any works start on site, ensure permission of all landowners has been sought and check that all the relevant consents, permits, licences (**Section 3.6**) and service checks are complete. If monitoring is required, it should be incorporated at pre-construction phase to ensure relevant baseline information is collected before work starts (**Chapter 19**).

For larger projects pre-construction plans are a good way to provide sufficient information specific to the project, including:

- description, overview and objective of the project
- health and safety checks
- INNS and biosecurity risk assessment
- environmental restrictions and on-site risks
- design and construction hazards.

A pre-construction walkover with the landowner is advisable. This is a good opportunity to address any access issues and highlight any on-site risks such as services installed by the landowner. Photograph and record the pre-construction condition. This is an effective way to ensure land is reinstated and recovers as far as possible back to pre-construction condition.

Before works start, mark out important areas such as location of planting, bunds or scrape outlines, and areas to protect or features to avoid, such as trees, habitats or services. If heavy machinery is required, mark out where they can move and where they need to avoid. This can be done with temporary fencing, coloured sprays or hazard tape. Ensure that everyone involved has site plans, which they can refer to throughout the construction and completion phase.

It is important to consider biosecurity and management of INNS for all construction sites. Avoid the introduction, movement and spread of INNS on and off-site. During the pre-construction phase, detailed INNS and biosecurity risk assessments should be carried out to ensure the correct mitigation measures are put in place.

Toolbox talks are an effective way of ensuring safe ways of working before any work begins. They include informal, on-site safety meetings, which focus on specific workplace hazards and safe working practices. It is an efficient method of exchanging information such as key environmental constraints, biosecurity and any last minute safety checks.

If volunteers are being used, toolbox talks are a good opportunity to run through the objectives of the project, key health and safety issues and information about the site. Likewise, if working with contractors, it's a good opportunity to talk about the purpose of the project, health and safety, everyone's role, access, decision making process, key outputs of the project and information about the sites.

18.2.2 Construction and implementation

During the construction and implementation phase, work can change as new information emerges. This might require aspects of design or methods of construction to change. At this point, it is important that the original designers, client and landowners are engaged and consents/permissions/licences are revisited. Variations can sometimes be sought, or a new application may be required before work can continue. Work may have to stop on site until this is obtained. In some situations, a variation or new application may not be possible, and the work may not be able to continue.

The construction and implementation of NFM could involve working with volunteers, contractors, heavy horses or machinery.

18.2.2.1 Working with volunteers

Several NFM measures or certain elements of measures can be implemented by volunteers. When working with volunteers, it is advised to work with organisations with relevant experience such as environmental NGOs or conservation charities. It is important to consider the skills, ability and age of volunteers to ensure that everyone can be involved. A role can be found for most people in volunteer activities.

It important that someone involved in the design of the project, who has appropriate health and safety training, is present with volunteers throughout the implementation activities. Ensure that all volunteers are clear on their roles and the objectives for the day. Schedule regular breaks and change roles to reduce fatigue. Volunteer events should be informative and fun – explain the purpose of the project and the wider environmental benefits.

18.2.2.2 Working with contractors

If possible, it is best to work with contractors who have experience of delivering NFM projects. However, in most cases, contractors might be used to working in ditches, agriculture or infrastructure schemes, but not constructing NFM, so it is important to spend time with them to ensure they understand the project aims. Ensure they work sensitively in the natural environment and can adapt to working with irregular slopes and rough finishes typically expected of NFM measures. Site visits with contractors to other locations where NFM measures have been delivered is a useful way of demonstrating the type of outcome anticipated.

Several measures will involve working with machinery. Moving machinery can cause injury and should be covered in risk assessment and toolbox talks. It is the responsibility of the contractor to ensure machinery is well maintained, fit for use and appropriate for the job.

Toolbox talks are an effective way of ensuring safe ways of working, and they are a good opportunity to explain the purpose of the project and what is going to be implemented. If construction occurs over several days, daily toolbox talks, prior to work commencing can be an effective method of engagement throughout the construction phase.

It is also important to schedule visits and formal inspections to check if everything is going to plan. This can help resolve problems at the earliest possible stage. Consider timing visits to align with key milestones and ensure contractors are easily contactable if issues arise.

18.2.3 Completion

Sign off work after it has been checked to ensure that:

- everything is complete as it was designed and specified

- critical levels have been delivered such as pond base, exceedance routes, inlet and outlet levels
- any obligations under licences or consents are met
- the site has been left in good order.

Where appropriate 'as-built' drawings should be completed. As a minimum, a plan and schedule showing the location and general arrangement of the installed NFM measures should be produced and stored for future management (**Section 19.3.3**).

The site should be left in good order. Some construction methods might have required the removal of gates, fences, tracks or vegetation – these should all be re-instated or returned to a satisfactory condition. Bare earth should be revegetated to ensure no excessive erosion or sediment loss. Remember that NFM measures are meant to mimic natural processes, so depending on landowner preference, it may mean the site does not need to be left perfectly neat, for example rough edges, wheel markings and scuffed turfs can provide additional variation. Walk the site with the landowner after project completion to ensure it meets the agreed expectations.

When working with volunteers, it is important that the work is checked by the project team to ensure everything is completed to a satisfactory level. In some cases, additional tasks might be needed, for example, to tighten tree guards or hammer stakes in correctly.

It is important to consider the provision for post-construction monitoring. Monitoring can be used to record change from the as-built situation and inform maintenance and adaptive management approaches (**Chapter 19**).

18.3 HEALTH AND SAFETY

Safety is paramount from the outset, decisions taken early in the project can have a big impact on it. During the construction phase it is important to understand the main requirements to control and supervise site activities to ensure safe systems of work are in place and followed. All NFM projects will require a risk assessment which should address key hazards associated with construction (**Section A3.1**) and should follow the five steps to risk assessment set out in **Section 3.7**. It is important to be aware that some organisations might have their own requirements and processes.

When working in or close to rivers, it is important to consider the upstream catchment and be aware of the weather forecast. Rivers can respond quickly to rainfall events and this will increase flow and velocity.

The majority of NFM measures will require simple or moderate levels of construction (see **Table 18.2**). Volunteers can be used when the risks have been deemed low, but it is important to be aware that a volunteer workforce may be less aware of hazards. Those managing the work should take particular care to ensure that appropriate risk assessments and method statements are undertaken and communicated, and appropriate training and PPE is provided. In addition, people that work on or visit NFM sites should understand the process of 'dynamic risk assessment', ie they should take account of any unforeseen risks or changes to a situation and take appropriate action. This could include a stop to work until conditions change or a safer way of to work can be put in place.

For complex NFM projects, CDM 2015 will apply. **Section 17.5.1** provides more detail on this along with issues specific to the design phase. General advice on safety is given in **Section 3.7** and specific safety considerations for the design and construction of each NFM measure are in **Part C**.

18.4 METHOD STATEMENTS

The purpose of a construction method statement is to:

- formalise who is responsible for completion of the work
- set out the approach, process and programme to construct and deliver the feature/scheme

- ensure that risks have been identified and a safe system of work is in place
- identify methods and highlight any issues on site.

Every task is different and will require its own specific method statement. This should include health and safety, general site management and also specific details on the construction of NFM. While contractors will be familiar with preparation of construction method statements for a variety of different applications, NFM is an emerging area of work for many contractors, and they can use these statements as a checklist.

A method statement should include:

- details of the work to be completed
- how long each activity should take
- site plan and full scheme drawing (depending on the scale and measures, this could range from a concept drawing to a detailed design)
- utilities and service search
- consents and permits
- access and movement on site
- site-specific hazards and any mitigation measures
- environmental and ecological issues to consider on site
- sediment and water management
- safe systems of work
- hazards that might arise and the appropriate preventative measures.

18.5 ACCESS AND TIMING

Access to land is needed to construct or implement NFM, and possibly over the longer term to allow monitoring, inspection, and maintenance. In some cases, NFM may lead to long-term land use change.

It is important to understand the short- and long-term impacts of NFM on land use and access requirements. Planning and preparation are key. Undertake a desk study of online mapping, aerial and street view photographs to identify the location of public highways, private roads, or PRoW. A site walkover is advisable to check for other constraints such as weight, width or height limits, watercourses, or adverse ground conditions. Consider access for people, machinery, and materials, and whether heavy lifting equipment or temporary welfare accommodation might be needed. Potential access constraints and mitigation measures are given in **Table 18.3**.

Access should be agreed with landowners before starting works; ideally this should happen during the planning and design phase (**Chapter 17**). It is advisable to walk all access routes with the landowner and photograph and record the current condition so that land can be reinstated to pre-construction condition.

Enabling works may be needed in advance of the construction phase to improve access. This could include vegetation clearance or the installation of temporary bridges or fords, haul roads or bog mats. Consider whether alternative transport or haulage methods such as pedestrian access only, heavy horses or helicopters are appropriate.

Access might be required beyond the construction phase. It is important to consider whether a long-term easement is needed for monitoring, inspection and maintenance. In some cases, a contract with the landowner might be required.

There is no ideal time period for the implementation of all NFM measures, and schemes involving a range of measures may require phased implementation.

Earthworks are best carried out when ground conditions are firm, typically in dry weather, although a sharp frost can stabilise soft ground. Attempting to carry out earthworks during wet weather can be challenging and hazardous. Tree planting is best undertaken during the dormant season (November to March).

When timing the implementation of NFM measures, it is important to be aware of environmental considerations (see **Chapter 16**), and the local farming calendar.

TABLE 18.3 Potential access constraints and mitigation measures

Constraint	Description	Mitigation measures
Landowner permission or easements	Permission may be needed to cross third party land. Easement may be needed for long-term maintenance.	Identify landowner, agree access for construction and any long-term maintenance.
Existing land use	Land use may present safety hazard, eg game shooting.	Agree timing of works with occupier.
Weight limits	Typically at under or overbridges, minor roads.	Check weight of plant, use small plant to suit.
Width or height limits	Typically at under or overbridges, minor roads, gateways, bends.	Check dimensions of plant and materials, select small plant or materials to suit.
Lack of formal access	Remote sites may lack formal access, even for agricultural use.	Consider using alternative sites, or methods such as heavy horses or helicopter.
Dense woodland or vegetation	Closely-spaced trees or vegetation may prevent access on foot or by vehicle.	Work in winter when vegetation dies back. Fell trees or clear vegetation. Use smaller plant, heavy horses or helicopter.
Stream crossings	Remote sites may have unbridged stream crossings.	Install temporary bridge or ford, with depth gauge and sediment control measures if needed. Avoid crossing fords during high-flow conditions.
Soft ground	Wet or low-lying ground may be too soft to support plant. Risk of soil damage.	Avoid wet weather or winter working, use bog mats or temporary tracking to provide firm surface. Install temporary haul road.
Steep ground	Measures in upland catchments may involve access across steep ground.	Seek alternative routes. If unavoidable, consider alternative methods such as conveyor belts, zip wire, pumping, and anchoring plant.
Services	Utilities, overhead and underground cables.	Clearly mark out services and seek alternative routes.

18.6 SEDIMENT MANAGEMENT

NFM construction and implementation can expose and disturb soils which increases their tendency to be mobilised by heavy rainfall or wind erosion. In the pre-construction phase (**Section 18.2.1**) is important to consider runoff pathways and where excessive sediment might be an issue; in some circumstance, excessive sediment can directly affect the ability of a measure to reduce flood risk. Sediment management is important to protect valuable soils, control water pollution, avoid environmental harm and achieve legal compliance. Control of sediment at source is the best way to avoid pollution events. This can be achieved by identifying areas where silt might be generated such as access routes, dewatering and excavation sites. Checks on these areas should be carried out regularly, particularly after adverse weather. Understanding sediment sources and the relevant control measures will help effective mitigation (**Table 18.4**).

Sediment and erosion control measures should be an ongoing consideration during construction. Ensure that only the land necessary for construction is disturbed and plan works so that bare ground is not broken unnecessarily to reduce the volume of sediment to be managed. Control of the runoff water which causes erosion, using traps or ditches, will also reduce management. **Table 18.4** identifies sediment sources and possible control measures.

TABLE 18.4 Sources and control measures for sediment

Source	Description	Control measure
Exposed or disturbed soil	Rainfall or wind erosion mobilises bare soil.	Time works to avoid wet periods and plant grass or cover crops.
Stockpiles	Rainfall or wind erosion mobilises unconsolidated soil on earth stockpiles.	Avoid high or steep-sided stockpiles, cover or seed stockpiles, install silt fences at toe of stockpile.
Plant and wheel washing	Soil washed off tyres.	Use wheel washer in contained bund, treat silty water in settlement tank.
Access and haul roads	Site traffic can mobilise mud.	Minimise length of haul roads, use temporary surfacing, road sweeping.
Water management	Water pumped from excavations or cofferdams can be silt-laden.	Treat silty water in settlement tank before discharging.
Work in watercourses, watercourse crossings	Disturbance of riverbank or bed material mobilises fine particles which are transported downstream.	Provide temporary crossings if needed, install sediment traps on watercourses.

Soil management plans may also be required. The protection of soil is a key consideration during construction to help minimise the potential impact on soil resources.

A soil management plan should:

- contain maps showing topsoil and subsoil types
- outline areas to be stripped of topsoil in certain situations
- give methods to strip soil, stockpile, re-spread and improve the soils
- provide schedules of volumes for each material
- give the expected after use for each material
- identify who is responsible for supervising soil management.

During construction, it is good practice to maintain vegetation cover and minimise soil stripping. After construction, vegetation should be established on bare ground at the earliest opportunity.

Further reading

Environment Agency (2012) *Working at construction and demolition sites: PPG6. Pollution Prevention Guidelines, second edition,* Environment Agency, Bristol, UK

⇨ Practical guidance for pollution prevention.

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/485215/pmho0412bwfe-e-e.pdf

SEPA (2009) *Engineering in the water environment: good practice guide. Temporary construction methods, first edition*, Scottish Environment Protection Agency, Stirling, Scotland

⇨ Guidance intended for use by those considering engineering activities in rivers or lochs.

https://www.sepa.org.uk/media/150997/wat_sg_29.pdf

18.7 WATER MANAGEMENT

Water management may be needed for more complex measures such as floodplain reconnection or river restoration. It is unlikely to be needed for runoff management works or the installation of leaky barriers on small watercourses.

The decision to install temporary water management depends on a range of issues that surround work in, near or over water:

- health and safety risks due to poor visibility, uneven surfaces, deep silt and fluctuating water levels
- efficiency and effectiveness – flooding of the works can lead to repeated demobilisation and mobilisation of plant, standing time and increased cost. Conversely, water management may allow work to be carried out safely and more quickly
- environmental requirements such as the need to maintain pass forward flows or any consenting requirements
- cost – all of these points can affect this.

Dewatering might be required for certain measures to mitigate environmental impacts. Dewatering is usually carried out by mechanical pumping which can include removal of water from behind temporary barriers or ongoing removal of water from behind cofferdams. It is important that all discharges receive appropriate treatment. Temporary dewatering from excavations to surface water usually requires an environmental permit. Water management methods for different applications are given in **Table 18.5**.

TABLE 18.5 Methods of water management

Method	Applications	Description
Temporary flow diverter	Runoff management measures	Construct temporary bund (eg earth, sandbags) to direct surface water runoff away from works.
Temporary dams with over pumping	Small watercourses with low dry weather flows, shallow flow and mild gradient	Construct temporary dams upstream (and possibly downstream) of the works, install pipeline and pumping, and de-water culvert.
Temporary dams with gravity flow	Small watercourses with sufficient gradient to drive gravity flow	Construct temporary dams upstream (and possibly downstream) of the works, install a temporary pipe or flume to convey flow around the works by gravity.
Temporary cofferdam	Larger watercourses	Construct temporary cofferdam around the working area (eg steel sheet pile) leaving sufficient channel cross-sectional area for the passage of flood flows along the watercourse.

Further reading

Environment Agency (2020e) *Temporary dewatering from excavations to surface water*, Environment Agency, Bristol, UK

⇨ Provides information on temporary dewatering from excavations to surface water and conditions that must be complied with.

https://www.gov.uk/government/publications/temporary-dewatering-from-excavations-to-surface-water/temporary-dewatering-from-excavations-to-surface-water

SEPA (2009) *Engineering in the water environment: good practice guide. Temporary construction methods, first edition*, Scottish Environment Protection Agency, Stirling, Scotland

⇨ Guidance intended for use by those considering engineering activities in rivers or lochs.

https://www.sepa.org.uk/media/150997/wat_sg_29.pdf

Courtesy Mike Norbury

19 MONITORING AND MANAGEMENT

Contents

Chapter 19 Monitoring and management

Monitoring enables a project to demonstrate success and can help to understand the co-benefits provided by NFM and how they should be maintained. Monitoring and management should be included as part of project planning and design.

▶ *Chapter 2 discusses aims and success factors of NFM.*

This chapter provides an overview of the general principles of monitoring and management for NFM. It reiterates the need to work with natural processes where possible and to reduce reliance on, or preferably to design out, the need for maintenance through measure selection and design.

Co-benefit objectives will often be built into NFM schemes (eg habitat restoration). Appropriate environmental monitoring methods should compare change against baseline conditions to determine the effectiveness of NFM measures and the achievement of environmental co-benefits.

For individual measures or features installed, monitoring will often be by inspection to record change from the as-built situation. This will link to the design intent of those measures and how they contribute to the overall flood risk management aim.

It is important to work with all parties involved to co-ordinate monitoring and maintenance, and to agree responsibilities as summarised in **Box 19.1**.

BOX 19.1 Responsibilities for monitoring and managing NFM schemes and measures

Flood risk management benefits

Likely to be the responsibility of the flood risk authority not the landowner. Statutory monitoring and adaptive management of performance. Baseline data collection, ideally three year's pre-works and/or a control catchment.

Co-benefits

Likely to be flood risk authority, local authority or partner objectives. Bespoke monitoring programme based on the project's success factors. Needs associated monitoring objectives and plan (eg ecology, hydromorphology, and water quality) usually related to statutory targets (eg WFD good ecological status, or SSSI condition assessment) or as part of partnership funding objectives. Baseline data collection, ideally three years pre-works.

Component measures

Likely to be designed and implemented by project team/contractors. Landowner is likely to be required to take on responsibility for inspection and any risk for measures on their land, as set out in initial discussions. Site management plan to set out inspection, recording, repair and reporting plan. Baseline is the 'as-built' scheme documented on completion.

19.1 MONITORING

Monitoring enables a project to demonstrate success, refine designs, maximise the sustainability of implemented measures, minimise the requirement for maintenance and incorporate adaptive management (Environment Agency, 2017b). Monitoring and evaluation needs to be incorporated as part of initial project objective setting, planning and design to ensure relevant baseline information is collected to measure change (**Figure 19.1**) (RRC, 2017). Monitoring the important wider natural environment co-benefits will also show which NFM measures work most closely and effectively to restore habitats and ecosystems. Monitoring can also identify unexpected negative environmental effects, and action should be taken to address these.

Figure 19.1 The relationship between monitoring and assessment to increase future confidence

19.1.1 Purpose of NFM monitoring

Monitoring NFM needs to cover two key aspects:

1. NFM schemes: to demonstrate that the objectives of the scheme have been achieved (**Chapter 15**). This should involve monitoring the benefits of the NFM scheme, both flood risk and co-benefits if this is part of its success factors (eg habitat, species, public use).
2. NFM measures: to ensure that the component parts are working as predicted. Monitoring individual measures over time will help to inform the necessary level and frequency of maintenance and adaptive management.

Monitoring should target the elements and the scale that they are expected to change.

19.1.2 Planning monitoring

Project objectives or success factors and specific monitoring objectives are likely to be different, as the latter need to be more detailed. For example, the project may seek ‘to reduce flood risk to community X’ and the monitoring objective ‘to reduce the risk of flooding to community X for flood events up to a 1 in 30 year standard of protection by 2025.

The RRC has produced a tool to plan monitoring. Use this at the beginning of the project and consider key questions such as:

- What are the project objectives?
- What is the monitoring objective/what is the monitoring trying to observe?
- How will the project collect data and what assessment methods are being used?
- Is there any pre-project baseline data?
- When is data being collected – timing and frequency?
- Who will collect the data?
- How much will the monitoring and its analysis cost?
- How much confidence is there that this method will show what the project is trying to achieve?
- How will the monitoring data collected be processed, analysed and reported?

To quantify the effect of NFM measures, the monitoring plan needs to enable change to be detected. This needs careful thought and planning.

BOX 19.2 Monitoring resources for NFM

There are existing widely used resources available to help plan monitoring, including:

Atkins (2019) *Catchment science field-scale monitoring handbook,* Atkins, UK

⇨ A helpful guide to a range of small scale, in-field monitoring methods for NFM data collection applicable to practitioners and landowners.

https://catchmentbasedapproach.org/wp-content/uploads/2019/08/Atkins-Catchment-Science_Fieldscale-Monitoring-Handbook-2019.pdf

Burgess-Gamble, L, Ngai, R, Wilkinson, M, Nisbet, T, Pontee, N, Harvey, R, Kipling, K, Addy, S, Rose, S, Maslen, S, Jay, H, Nicholson, A, Page, T, Jonczyk, J and Quinn, P (2018) *Working with natural processes – the evidence directory*, SC150005, Environment Agency, Bristol, UK

⇨ Chapter 6 (page 220) summarises the gaps in research and knowledge of the effectiveness of NFM and how to set objectives for monitoring NFM. It provides some of the more common monitoring techniques and information to help make informed decisions. Additional further reading is provided.

https://assets.publishing.service.gov.uk/media/6036c5468fa8f5480a5386e9/Working_with_natural_processes_evidence_directory.pdf

CABA (2020) *Monitoring and evaluation – natural flood management projects*, Catchment Based Approach, Interreg North Sea Region VB programme, funded by the European Regional Development Fund, UK

⇨ Practical on-line tools and links related to monitoring and evaluating NFM projects

https://catchmentbasedapproach.org/learn/monitoring-and-evaluation-natural-flood-management-projects/

Defra (2019b) *Reporting, monitoring and evaluating the Defra funded natural flood management projects: Annex 1 – Technical guide on how to monitor natural flood management*, Department for Environment, Food and Rural Affairs, London, UK

⇨ Guidance on monitoring provided for the Defra funded England NFM pilots. Why, how and what to monitor - with technical guidance and case studies.

https://catchmentbasedapproach.org/wp-content/uploads/2019/08/TechnicalAnnex070619.pdf

Hammond, D, Mant, J, Holloway, J, Elbourne, N, and Martin, J (2011) *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO)*, The River Restoration Centre, Cranfield University, Cranfield, Bedfordshire, UK

⇨ Guidance on monitoring river restoration (including NFM) projects, from setting SMART project objectives and monitoring objectives to selecting appropriate methods based on size of project and risk.

https://www.therrc.co.uk/monitoring-guidance

River Restoration Centre monitoring planner: https://www.therrc.co.uk/monitoring-planner

⇨ A simple excel spreadsheet guiding how to approach and plan the content of a monitoring strategy.

19.1.3 Monitoring methods

Many standard monitoring methods are available that can be applied to monitoring NFM. A successful monitoring programme will combine the appropriate methods to answer the monitoring and project objectives.

Monitoring equipment should be positioned in areas that will provide representative monitoring of the impact of NFM measures but are not overwhelmed by other environmental variables or catchment areas not covered by the NFM measures.

TABLE 19.1 Monitoring most applicable to NFM schemes (from Atkins, 2019)

Monitoring	How
Fixed point photography and mapping flood extent	• camera or phone camera and level gauge • time lapse camera • repeat drone footage
Flow/discharge (flood and normal flow)	• multiple flow gauges • control site/catchment
Hydraulic roughness	• in-channel (eg CES roughness adviser)* • floodplain (eg CES roughness adviser)*
Soil infiltration and soil water storage	• soil pit • observations • moisture probe and hydraulic conductivity
Fine sediment (and nutrient) loads	• silt depth survey and fixed point photography • silt fencing/mats • sediment/nutrient flux (auto samplers)
Habitat mapping	• desk-based assessment • walkover surveys

Note

* CES reducing uncertainty in estimation of floods: http://www.river-conveyance.net/

Monitoring every aspect of an NFM project is rarely practical. Planning should consider what can be realistically achieved within the budget and timeframe and what is needed to satisfy the scheme objectives and requirements of funders. Collecting pre-project or baseline data can be time consuming. For example, for a three year project, there may not be more than one season before the works start. Locally-based 'citizen science' can support the monitoring of NFM benefits.

Larger schemes should apply detailed monitoring programmes to be able to contribute significantly towards understanding the benefits of NFM for flood risk management and the co-benefits such as biodiversity, restoration of freshwater habitats, habitat integrity and connection, carbon storage and resilient ecosystems.

19.2 INSPECTION

For individual measures or features installed, monitoring will often be by inspection (eg post-construction after an initial high-flow event and annual condition assessment) to record change from the as-built situation. This should link to the intent of the measures and how they are designed to contribute to the overall flood risk management objectives.

A risk-based approach should be taken to consider what inspections of NFM structures and features are required and their frequency. Use local knowledge and engineering judgement and engage with stakeholders early on to agree the appropriate inspection and site management plan (**Section 6.3.3**) (Environment Agency, 2018). This should set out when inspections are needed and who should carry them out (eg required level of technical competency).

There may be uncertainty over how NFM features will perform in a high-flow event so an inspection regime triggered by events may be needed to take an adaptive management approach.

Inspection will be based on:

- the design specification and aim of the measures
- who is responsible

- what is reasonable and proportionate
- what are the visual indicators
- how will it be reported
- frequency (eg event/monthly/annual).

19.3 MANAGEMENT

Unlike most traditional flood risk management measures, management of an NFM scheme should require minimal formal maintenance as it will have been designed to reduce this need. Even where there is no planned maintenance schedule, there should be a management plan, with inspection, monitoring and adaptation in response. Management should also acknowledge that there may be a lag time between completion of works on site and the aim, at which point the measure can be considered fully operational/self-sustaining (eg a newly planted versus a mature hedgerow). Management of NFM measures should be planned and undertaken in a way that ensures the management/maintenance activities align with the wider project objectives and do not cause harm to the environment or create any legal compliance issues (eg sediment removal leads to habitat disturbance which then needs a waste licence).

Management can be split into:

- maintenance activities (periodic/event based – tree management, treatment of INNS, debris removal, sediment removal, replacement etc)
- adaptive management (eg changes, repairs and alterations)

This work will be informed by monitoring and inspection findings.

19.3.1 Maintenance activities

Maintenance will vary according to which NFM measures are used. Where pre-planned routine maintenance is considered necessary, responsibility should be allocated, with appropriate resourcing arrangements in place and advice on reporting. Generally, 'what-if' scenarios should not fall under maintenance, but should be led by monitoring/inspection and part of adaptive management. However, this might also lead to a revision of routine maintenance requirements.

Each NFM measure requires an assessment of possible maintenance. NFM schemes that actively work with natural processes will ideally avoid the need for complex, significant ongoing maintenance work. Periodic moderate levels of follow up work could be necessary for storage and interception measures that accumulate sediment and organic material. Consideration should also be given to the design life of the feature. It may be more cost effective to oversize a measure (build additional capacity for sediment or vegetation) or install new measures in alternative locations (new leaky barriers) rather than repair existing measures. This also avoids disturbance/destruction of establishing co-benefit habitats.

Table 19.2 provides a basic grouping of common measures by the likely level of routine maintenance. The scale of the measure and the site-specific planning and design work will confirm the actual scheme- and measure-specific maintenance requirements. This should be built into the site management plan (**Section 19.3.3**) and might be timetabled or inspection-triggered.

TABLE 19.2 Likely level of planned maintenance for different priority NFM measures

Level of planned maintenance	NFM measure types	Description
Low	• buffer strips • scrapes • floodplain wetland restoration • palaeochannel reconnection • in-channel features	No or very limited planned maintenance, but inspection required that may trigger a response
Simple (normal good practice)	• cross drains and deflectors • cross slope hedgerows • leaky barriers • swales	Simple or infrequent maintenance applying usual good practice which could be carried out by landowners or volunteers
Moderate	• bunds • ponds	May require infrequent planning and machinery. Generally not carried out by volunteers
Detailed	• set-back embankments	Anything that requires frequent and significant ongoing work to maintain operation

19.3.2 Adaptive management

Compared to traditional flood risk management measures, NFM is intended to be more widespread and part of the catchment landscape. An NFM scheme may rely upon a network of low-cost measures which incorporate a degree of uncertainty, natural variation and change over time. So, the scheme needs to be flexible and allow adjustments to be made. For example, additional capacity could be built in to a measure to allow for vegetation colonisation, growth and succession over time to still meet the desired NFM aim, without disturbing the developing habitat.

Monitoring and inspection and a flexible or modular approach to the NFM scheme will inform and allow for adaptive management, which may be needed due to unexpected failure, natural process adjustment, or extreme flood events. Changes could also reflect increased understanding of the catchment, new evidence or developments in good practice and improved guidance.

19.3.3 Site management plan

A simple site management plan showing the location and general arrangement of installed NFM measures should be produced as part of the design process and stored for future management. Where appropriate as-built drawings should be completed. The plan should be concise and set out what is required and when, against the objectives of the scheme. Its content should be easily derived from the project phases. Its purpose is to:

- define management objectives and any maintenance actions, for the short and long term
- enable all involved to have a shared understanding of the management of the site
- be updatable if management needs to be adapted to incorporate new work/changes.

This should be formally handed over to those tasked with managing, monitoring or inspecting the work post-implementation and also enable commitments to be passed onto others not previously involved in the work (eg personnel or landowner changes).

Suggested content:

- purpose of the plan
- site information (location, component measures and how they function, eg as-built drawings and schedule)
- overall scheme aims and objectives (performance and co-benefits)

- actions (objective and action required, responsibility, timing):
- monitoring (refer to monitoring plan if produced)
- inspection (specify what, by who and when)
- maintenance (specify what, by who and when)
- a way to record information or changes to the plan (where is this information collated and who agrees the changes).

The level of detail should be proportionate to the scale and complexity of the scheme, the measures used and the degree of co-benefit monitoring included.

19.3.4 Reporting

With traditional flood risk management measures, details are held in a register of assets with specific operational requirements. This may also be a needed by some NFM funding sources and should be stipulated as part of the site management plan and formal agreements.

Where no formal funding requirement is specified, it is good practice to record and report inspection, adaptive management and monitoring results. What and how this is recorded and who it should be reported to should be agreed within the site management plan.

Delivery organisations across the UK can record their NFM work on an NFM database (eg ArcGIS Online (AGOL) tool was developed to evaluate the England Defra NFM programme). This provides added visibility of individual NFM schemes across the country and gives a way to collate the national picture of benefits that are being achieved.

Further reading

Defra (2019a) *Reporting, monitoring and evaluating the Defra funded natural flood management projects, version 1*, Department for Environment, Food and Rural Affairs, London, UK

⇨ Provides information for both the community and catchment scale projects about the data they are expected to record to satisfy the funding agreement for DEFRA funded projects.

https://catchmentbasedapproach.org/wp-content/uploads/2019/08/NFM-MonitoringFull_v6.pdf

Defra (2019b) *Reporting, monitoring and evaluating the Defra funded natural flood management projects: Annex 1 – Technical guide on how to monitor natural flood management*, Department for Environment, Food and Rural Affairs, London, UK

⇨ Provides information on why monitoring is a worthwhile, some examples of monitor methods and case study examples of past NFM projects that have been monitored.

https://catchmentbasedapproach.org/wp-content/uploads/2019/08/TechnicalAnnex070619.pdf

Hammond, D, Mant, J, Holloway, J, Elbourne, N, and Martin, J (2011) *Practical River Restoration Appraisal Guidance for Monitoring Options (PRAGMO)*, The River Restoration Centre, Cranfield University, Cranfield, Bedfordshire, UK

⇨ Provides guidance on setting monitoring objectives as part of a river restoration project.

https://www.therrc.co.uk/monitoring-guidance

Appendices provide case studies, worked examples and other supporting information.

Appendices

Image courtesy Yorkshire Dales Rivers Trust

Courtesy Tweed Forum

A1 CASE STUDIES

Contents

Appendix A1 Case studies

A1.1 INTRODUCTION

This appendix includes nine case studies from across the UK (**Table A1.1**). Additional examples of NFM projects are given in **Section A1.2**.

Key NFM measures		
Upland peatland restoration	Catchment woodland	Leaky barriers
Soil and land management	Cross slope woodland	Floodplain reconnection
Runoff management	Riparian woodland	River channel restoration
Runoff storage	Floodplain woodland	Offline storage

TABLE A1.1 Case studies

Case study	Title	Description	Organisation(s)
A1.1	Afon Merin, Ceredigion	Stage zero river restoration in upland catchment draining peat moorlands. Runner-up in RRC Conference Rivers Prize 2020.	NRW
A1.2	Bishopdale, North Yorkshire	Defra NFM pilot project. Working with other organisations, farmers, landowners and local community. Includes measures such as runoff management, runoff storage (ponds, scrapes), woodland creation and helping farmers improve soil health/infiltration. Monitoring and comparing effects against neighbouring valleys.	Yorkshire Dales Rivers Trust, Environment Agency and iCASP
A1.3	Eddleston Water restoration, Peebleshire\ (2012 to date)	Woodland, new wetland creation, re-meandering. Academic pilot project; partnership is monitoring results, including any reduction in downstream flood risk.	Tweed Forum
A1.4	Littlestock Brook, Oxfordshire (2017 to 2022)	Part of Thames Water Smarter Water Catchment Initiative. Runoff management and storage (field corner bunds, cross drains), woodland, wetlands. Various monitoring, modelling and research studies (eg effectiveness of woody features).	Evenlode Catchment Partnership, Natural England and Atkins
A1.5	Smithills Moor living barriers, Bolton	Living leaky barriers on upland runoff pathways. Rainfall and flow monitoring late 2019 to early 2020 illustrate flow attenuation.	Woodland Trust and Mersey Forest
A1.6	River Soar and Welland catchments Water Friendly Farming (The Allerton Project), Leicestershire	Landscape-scale demonstration project. Storing water (eg ponds, bunded ditches) and leaky barriers. Monitoring water quality and ecology. Baseline monitoring from 2010, reports published in 2013 and 2016.	Freshwater Habitats Trust, Game & Wildlife Conservation Trust
A1.7	Stroud rural sustainable drainage, Gloucestershire (2014 to date)	Leaky barriers, runoff management and storage (eg bunds, cross drains) to reduce flood risk, improve water quality and biodiversity. Working with landowners, farmers, community groups and partner organisations. Monitoring performance of leaky barriers, morphological and river habitat changes, and biodiversity.	Stroud District Council
A1.8	River Wye and Lugg NFM, Herefordshire (2020 to date)	Range of measures including land management, woodland, runoff management and storage, leaky barriers and floodplain restoration. From opportunity mapping to implementation.	Herefordshire Council
A1.9	Spains Hall Estate, Essex	A pair of Eurasian beavers were released in a fenced enclosure on a tributary to the Finchingfield Brook. Timber leaky barriers were constructed on the main Brook. Forms part of a planned transition towards more sustainable management of the Spains Hall Estate.	Spains Hall Estate, Environment Agency, Essex and Suffolk Rivers Trust, Essex Wildlife Trust and Atkins

CASE STUDY A1.1 Afon Merin, Ceredigion, Wales

Summary

Organisations involved:	NRW
Location:	Ceredigion, Wales
Key measures:	River channel restoration, floodplain reconnection, leaky barriers

Background

The Afon Merin is a tributary of the Rheidol system, flowing from its upland SSSI catchment, through Myherin woodland, which is part of the Welsh Government estate managed by NRW. A three kilometre section of the Afon Merin provided landscape-scale intervention opportunities to 'kick-start' natural processes to benefit biodiversity, water quality and quantity, and carbon sequestration.

Historical maps showed a more dynamic river system before agriculture, the creation of conifer plantations and associated land drainage in the catchment. The river had cut down into its bed, severing it from its floodplain in all but extreme events. Gravels had been scoured out of large areas of the watercourse leaving a cobble substrate that was sub-optimal for spawning salmonids. Significant lengths of the river were also dry during the extended dry period in summer 2018.

Project details

Figure A1.1 The site following completion (courtesy NRW)

The project began in early 2018 with the felling of conifers within the floodplain area of the watercourse that was bounded by the forestry haul roads. Some of the more readily accessible timber was removed from site and the remainder was left in situ. The project focused on ditch blocking and the installation of in-stream structures to wet up the site and reconnect the river to the floodplain. A scoping survey undertaken in summer 2018 highlighted that natural processes were already happening – a conifer felled across the stream had trapped woody debris and dammed the flow, creating a ponded area upstream and braiding the river below into relict channels. This formed the template for the installation of 15 leaky barriers and a number of scrape features within the catchment.

Works used the available timber and brash on site, with most of the leaky barriers situated at bends in the river. Water immediately started to spill out of the bank picking up a network of relict channels within the floodplain.

Subsequent high-flow events have led to:

- gravel depositing in-stream and as shoals
- more dynamic flow patterns and a complex of side channels
- the creation of permanent and temporary pond features.

The phase 1 project costs, including tree felling and the installation of dams and scrapes, were about £30 000.

continued...

CASE STUDY A1.1

Afon Merin, Ceredigion, Wales (contd)

Figure A1.2 Diverse channel, bank and floodplain habitats (courtesy NRW)

Internal sharing around the experience from the first phase of the project led to additional funds to complete a second stage. This enabled the reinforcement of several of the earlier dams, placement of locally-sourced long woody debris lengths onto riverside land and into the river flood channels to further slow overland flow, and placing whole tree lengths into the river to provide a different woody dimension and to observe movement over time. An additional 15 new dams and on-land timber were constructed immediately downstream of the initial site.

The restoration of planted and self-set conifer forest to functioning wetland systems will deliver priority wet woodland, peatland and riparian habitat, and for key species such as water vole, otter, trout, birds, bats and invertebrate species.

Figure A1.3 Well connected floodplain following completion (courtesy NRW)

The re-wetting and ponding will also store water for longer periods in the uplands, having the potential to provide flood risk and water resource benefits to downstream catchments through flood flow attenuation, delay in time to peak, and low flow protection in the summer months. Although it is unlikely the project will deliver a measurable reduction in flood risk, the techniques used could be easily scaled up across the myriad comparable afforested and upland catchments across Wales. If this were achieved with peatland ditch blocking and lowland riparian planting, then real benefits could be delivered.

Challenges and solutions

Locations where water was likely to simply flow around a leaky barrier and back into the existing channel were actively avoided, both for reasons of barrier stability, and because of the likely lower ecological benefits.

Long lengths of timber jam naturally in watercourses, but these can be transient. The project aimed to construct leaky barriers that retained their structure for longer and presented less of a risk of being washed out during flood events. So, the log ‘foundations’ of the dams were well anchored into the banks of the river.

Lessons learnt

- **Yielding multiple benefits.** The implementation of this scheme on Welsh Government woodland estate has shown that there are high value gains possible at low-cost inputs, which can be implemented alongside current forest management techniques. These can yield multiple benefits. The study of these develops the case to spread this work and ethos across the wider government

continued...

CASE STUDY A1.1 **Afon Merin, Ceredigion, Wales (contd)**

Figure A1.4 Debris dam (courtesy NRW)

estate with potential for large-scale projects. The multiple benefits are closely aligned with NRW's wider corporate and business plans. In particular, they provide a way to generate positive outcomes through NbS giving many benefits across a broad spectrum of habitats, species and communities.

- **Maintenance.** On one occasion during the second phase of work, some water coloration was observed, despite the mitigation channels to divert water onto land. This was traced to three dams in close succession, where overflow washed through some disturbed ground and partly decayed timbers. Installing a 'catch' or 'filter dam' at the downstream end of the project area might have helped alleviate this. The coloration cleared quickly.
- **Monitoring strategy.** Pre-work aerial studies of the area and fixed point photography at key areas through the valley have supported the overall study of early geomorphological changes within the system, including stream number and width, and changes within the network of wet areas across the valley floor. Aberystwyth University are undertaking flow measurements and will continue to do so over an extended time period. Ecological studies will be undertaken across this and a control site on the same waterbody to monitor changes.

CASE STUDY A1.2 Bishopdale, Leyburn, North Yorkshire

Summary	
Organisations involved:	Yorkshire Dales Rivers Trust (lead delivery partner), Defra and Environment Agency (funders), Yorkshire Dales National Park Authority and Yorkshire Integrated Catchment Solutions Programme (iCASP).
Location:	Bishopdale, Leyburn, North Yorkshire
Key measures:	Runoff management, runoff storage, riparian woodland, soil and land management

Background

The Bishopdale NFM project is based in the 41 km^2 catchment of Bishopdale Beck, a tributary of the Upper Ure in North Yorkshire. The upstream part of the catchment is sparsely populated while the lower catchment includes the three settlements of Thoralby, Newbiggin and West Burton. The valley has steep sides and is mainly pastoral farmland. Bishopdale Beck regularly experiences flooding in heavy rainfall events, often affecting the main road through the dale, isolating the local communities.

The Bishopdale NFM project was set up to explore how NFM can be delivered at a catchment scale. The project started with engaging landowners across the catchment with hydrological opportunity modelling and evidence-based NFM farm plans. These helped identify possible interventions to reduce flood risk through intercepting, slowing and/or holding water within the catchment. Interventions were co-designed with the landowners and the Yorkshire Dales National Park Authority. The majority of large interventions, such as scrapes, fencing and large leaky dams, were installed by local agricultural contractors. Volunteers were used to help with less skilled activities such as tree and hedgerow planting, creation of small leaky dams and assisting with monitoring. A monitoring programme was devised by the Yorkshire Integrated Catchment Solutions Programme (iCASP) to measure the impact of the interventions.

Project details

The project started in 2018 and was initially funded £167 000 by the Environment Agency for a three year project. This was supplemented in the final six months with a further £100 000. Over the three year period the project has enabled:

- engagement with 11 landowners/managers
- production of 10 NFM farm plans
- planting of 28 000 trees, including 4.5 km of hedges, in a range of sites targeted to intercept overland flow and flood pathways
- installation of 12 leaky barriers and 17 shallow scrapes.

Monitoring is being undertaken using a ‘partner catchment’ approach of comparing the flood response from the control catchment of neighbouring Waldendale. Data is continuing to be collected and will be independently analysed by Dales Land Net, who are monitoring the extent to which the installation of hedges and riparian woodland is effecting surface flow and for selected scrapes the rate at which they fill and the point at which they start to overflow. All data and information from the project is being been collated using the Rivers Trust monitoring and evaluation tool.

Research has also been undertaken on Bishopdale by Leeds University to evaluate the effectiveness of land use management in reducing flood risk at the catchment scale. Characterisation of soil hydraulic conductivity under varying land management regimes was undertaken to investigate the potential impact of NFM interventions. These data were then used to parameterise a physically based spatially distributed hydrological model (SD-TOPMODEL). The influence of land use management interventions on catchment flood risk was assessed using a sequence of model scenarios, permitting the quantification of the impact on the timing and the size of the peak discharge at the catchment outlet. The findings support the implementation of NFM interventions as a means to reducing flood risk within a catchment. Improved soil infiltration provided the greatest reduction in the size and timing of the peak

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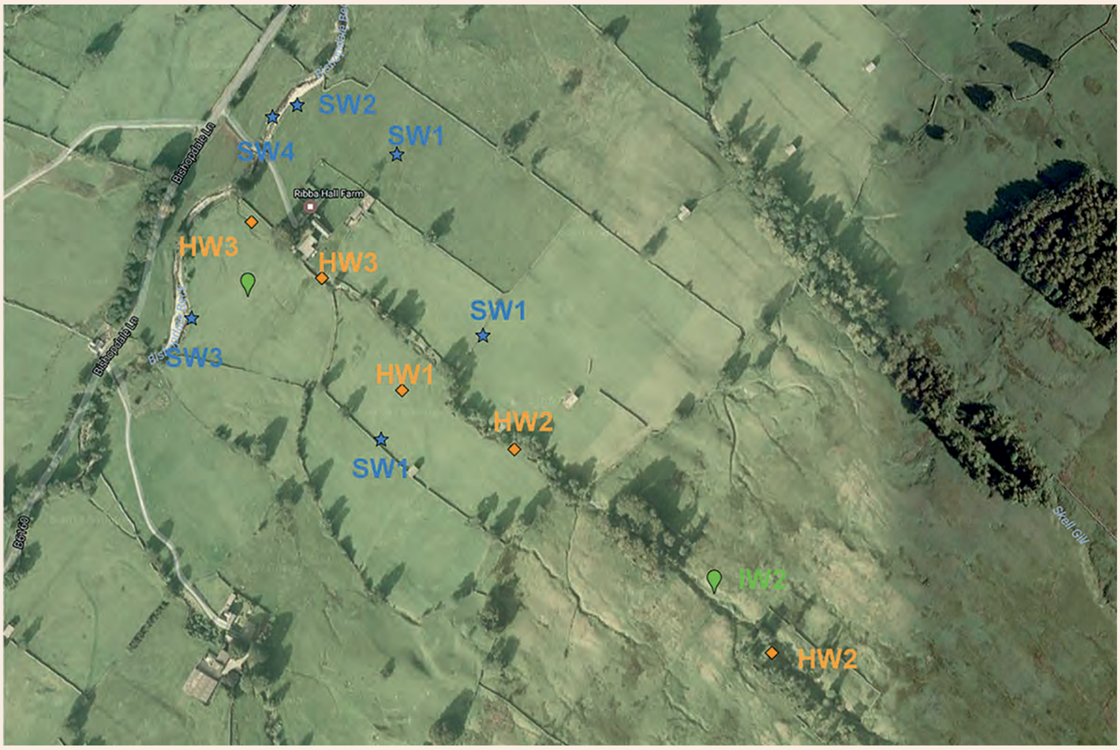
CASE STUDY A1.2 **Bishopdale, Leyburn, North Yorkshire (contd)**



Key

SW1 – hedge planting, SW2 – woodland planting, SW3 – fencing and tree planting, SW4 – large woody debris

IW2 – Gill planting
HW1 – scrapes, HW2 – leaky dams, HW3 – sediment trap

Figure A1.5 Example of the opportunity mapping within the NFM farm plans (courtesy Yorkshire Dales Rivers Trust)

flow during a 10-year and 100-year storm event. Catchment-wide woodland planting reduced peak flow significantly during a large storm event but was not effective during the smaller event. Riparian buffer strips provided consistent reductions in peak flow and in the timing of the peak across both storm events with no significant differences between vegetation ages. Critically, it was observed that the effect of implementing multiple NFM interventions was not additive and that efficiencies can be made in using this modelling approach to prioritise the most effective outcomes.

Challenges and solutions

A key challenge for this project was engaging and incentivising farmers and landowners to adopt new solutions. NFM opportunity modelling set out the most effective locations to deliver NFM measures in the catchment. However, funding constraints meant that the project could only pay for the capital implementation of the measures. This required working closely with farmers and landowners, building good working relationships and looking for opportunities that would complement existing farm businesses but still reduce downstream flood risk. This was effectively achieved through the delivery of NFM farm plans, which involved spending time with the farmers and landowners, understanding their business, walking their land, looking for opportunities and then creating a simple but informative plan. These plans are also useful resource for farmers and landowners for future environmental land management schemes.

Capital investment can be a barrier to delivering NFM at scale. So, the project looked for opportunities to work in partnership. Multiple benefits helped to identify co-funding opportunities. Some tree planting was part funded by the Woodland Trust, and the Yorkshire Dales National Park Authority helped fund initial opportunity modelling. Additional funds from the Environment Agency for riparian tree planting enabled more tree planting opportunities to be funded, allowing the remaining budget to be spent on other measures including additional scrapes and leaky dams.

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CASE STUDY A1.2

Bishopdale, Leyburn, North Yorkshire (contd)

Figure A1.6 Riparian fencing and leaky boards installed in Bishopdale (courtesy Yorkshire Dales Rivers Trust)

Figure A1.7 Scrape measures in action, intercepting and storing overland flow (courtesy Yorkshire Dales Rivers Trust)

Lessons learnt

- **Early farmer and landowner engagement.** At the start of the project, NFM was still an emerging approach. Farmer facilitation groups or cluster groups are an effective way to engage several farmers and landowners over a large area, building trust and a common understanding. However, one-to-one farmer engagement is vital; spending time understanding their business and appreciating constraints from existing agri-environmental schemes can help build good working relationships. Early identification of opportunities and constraints meant that the delivery of the project could be programmed throughout the project to avoid conflicts.
- **Modelling and taking an opportunistic approach.** A significant proportion of funding was spent on catchment opportunity modelling. While this provided a greater understanding of the catchment, often still the limiting factor is access to land to deliver the measures. So, a balance needs to be found between modelling and taking an opportunistic approach. It is important to spend time with modellers so they understand the constraints facing the land managers, enabling a fit for purpose and pragmatic approach to be taken.

CASE STUDY A1.3 Eddleston Water restoration, Peebleshire, Scotland

Summary	
Organisations involved:	Tweed Forum, Scottish Environment Protection Agency, Scottish Government (funders) and the University of Dundee
Location:	Eddleston and Peebles, Peebleshire
Key measures:	River channel restoration, floodplain reconnection, catchment woodland, leaky barriers, runoff storage

Background

Eddleston Water is a small tributary of the River Tweed in Scotland. It drains a catchment of 69 km^2 flowing 20 km north to south before reaching the Tweed in the town of Peebles. The river has been extensively altered in the last 200 years to enable the building of a road and railway. Changes in land management, both in the river valley and on the surrounding hill slopes, have also altered how the land drains. The river has been straightened, shortened and embanked, such that connections with its floodplain have been lost. These changes have resulted in an increased risk of flooding to Eddleston and Peebles, as rainfall and flood waters travel more quickly and directly from the hill slopes and along the river channels towards these communities. These changes have also damaged the river environment, leading to the loss of over a quarter of the main river's original length, and habitat loss for plants and animals, including salmon and trout, as well as rare and protected species such as otters and lamprey.

Figure A1.8 Eddleston Water re-meandering (stage 1) in flood conditions (courtesy Tweed Forum)

The Eddleston Water project was set up both to reduce flood risk to downstream communities and to improve the river habitats, while at the same time maintaining sustainable farming. The project worked with landowners and managers to explore whether and where NFM measures might be installed, and to assess the impact of these measures on temporarily storing and slowing the flow of flood waters.

The project started with an initial scoping study in 2010, which identified a range of potential NFM and habitat restoration measures that could be introduced in the headwaters and floodplain of Eddleston Water. A detailed hydrological and ecological monitoring network was installed at the start to collect baseline data, followed by implementation of a wide range of NFM measures and monitoring undertaken.

Project details

Working with land managers, the project has been able to introduce a wide range of changes to land management practices to slow water flow off the hills and to reconnect the river with its floodplain. This has included:

- Fencing off and planting over 330 000 native trees covering 207 ha of largely less productive farmland in the headwaters.
- As well as impacts of planting trees on infiltration, evapotranspiration and surface roughness, modelling landscape-scale tree planting under different climate change scenarios shows up to a maximum of 40% reduction in peak flows (5% AEP) with flood peaks delayed by 45 minutes.
- Installation of 116 leaky barriers and high-flow log restrictors in the upper tributary streams which increase the lag time in flood generation, temporarily hold back flood flows and reduce flood peaks.
- Creating 30 new ponds across the catchment, to act as runoff attenuation features, to temporarily hold back flood waters in the uplands or on the floodplain.

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CASE STUDY A1.3 Eddleston Water restoration, Peebleshire, Scotland (contd)

- Restoration of the natural meandering form of the river for a length of 2.9 km. This increases river length, reduces the slope and speed of water flow and provides more space for flood waters. It also creates additional and more diverse in-stream habitats for wildlife and fisheries.

Figure A1.9 Eddleston Water re-meandering (stage 2) during construction. Earlier re-meandering undertaken as part of stage 1 is also visible (courtesy Tweed Forum)

Figure A1.10 Restoration of wetlands in the upper catchment (courtesy Tweed Forum)

Challenges and solutions

The SEPA risk assessment shows that 582 properties are at risk of flooding in Eddleston and Pebbles under a 0.5% AEP scenario – the most recent floods being in 2016. The river was also classified by SEPA as being of 'bad' ecological status in 2009 (using WFD criteria), largely due to historical physical changes to the channel and banksides. In this context, NFM is seen as one part of an integrated approach to sustainable flood risk management at the catchment scale that also explores traditional flood alleviation measures, flood warning, planning and behavioural changes as well.

The identification of different types of NFM measures that could be used to reduce flood risk and improve riparian habitats and the location of potential sites across the catchment for their introduction was only part of the challenge. Achieving buy-in from the respective land managers for their establishment and long-term maintenance was another key aspect that needed to be addressed from the start. Involvement in the project by farmers is entirely voluntary, so detailed engagement, and technical and financial support is necessary to ensure uptake. In this respect understanding the aspirations and challenges faced by farm businesses is crucial, as is working through a 'trusted intermediary' organisation such as the Tweed Forum.

The final challenge is proving the effectiveness of NFM measures and assessing the costs and benefits of its use. A monitoring strategy was put in place to assess how specific types of NFM measures reduced flood risk and improved ecological status, alongside assessment of the overall impact of river restoration on flood risk and habitats at a catchment scale. Further modelling enabled lessons learnt to be shared with other catchments. Other studies explored the barriers to uptake of NFM measures by farmers, and also the costs and benefits of their implementation both on farm business plans and on the wider catchment.

Lessons learnt

- **Working with others.** Restoration of the catchment can be undertaken alongside continuation of sustainable farming and livelihoods, working through a trusted intermediary to identify opportunities and support engagement.
- **Engaging with landowners.** The location, installation and long-term maintenance of NFM features needs to be financially attractive and robust to appeal to landowners and farmers.
- Multi-functional designs. Different NFM measures can reduce flood risk through both temporarily storing surface waters and delaying peak floods, as well as through increased surface roughness, evapotranspiration and groundwater connectivity.
- **Taking a catchment based approach.** Appreciable flood risk reduction through NFM is only likely

continued...

CASE STUDY A1.3 **Eddleston Water restoration, Peebleshire, Scotland (contd)**

to be achieved through widespread application of many types of approach throughout the entire catchment.

- **Monitoring strategy.** Collecting robust empirical data to demonstrate the effect of NFM measures on flood risk at the catchment scale will take time. However, this is essential to persuade landowners, policy makers and other stakeholders of its potential for flood risk reduction in real life.
- **Modelling.** Using the data to assist with improved modelling can complement and extend the approach in the short term.

Figure A1.11 Kitson Mill flood storage pond (courtesy Tweed Forum)

- **Understanding the catchment.** When considering where to locate NFM measures, the catchment needs to be assessed in terms of sources (upland), pathways (channels) and receptors (floodplain and downstream communities).
- **Understanding the catchment.** Geology, soil type and soil health are a strong influence on surface water and groundwater flooding. For example, the project demonstrated that infiltration under mature broadleaf woodland can be five to eight times that under nearby grazed pasture or younger plantation forestry.
- **Yielding wider benefits.** NFM measures to reduce flood risk provide a wide range of additional benefits and ecosystem services, not only to habitats and species, but also in terms of carbon management, water quality, landscape, recreation, access, biodiversity and fisheries.
- **Economic benefits.** Appraisal of NFM measures already implemented show benefits of £950 000 (PV value, 100-year appraisal period) from flood damages avoided. It is estimated that an enhanced NFM scenario, based on further installation of measures across the catchment, has the potential to provide benefits of up to £2.85M (PV) from flood damages avoided.
- **Economic benefits.** The net PV of other co-benefits delivered by the same NFM measures may be much higher. Existing benefits from water quality improvements, carbon management, recreation, biodiversity and fisheries amount to £4.2M (PV) in addition to the £950 000 from flood damages avoided, and £17.7M (PV) for the scenario proposed with additional NFM across the catchment.
- **Recognising wider benefits.** Economic and flood study appraisals should consider benefits for NFM beyond flood risk reduction. This will enable policy makers and operational managers to make decisions reflecting the true value of investment in NFM as part of an integrated approach to catchment-wide flood risk reduction.

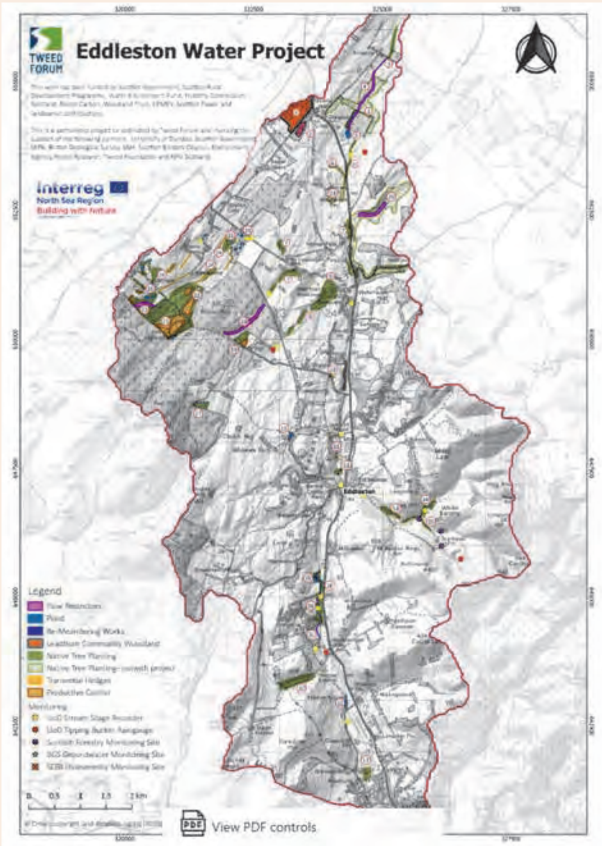

Figure A1.12 Map showing the location of NFM features implemented as part of the Eddleston Water project (courtesy Tweed Forum)

CASE STUDY A1.4 Littlestock Brook, Evenlode Catchment, Oxfordshire

Summary	
Organisations involved:	Environment Agency, Wild Oxfordshire, Bruern Estate, Milton-under-Wychwood Parish Council, Evenlode Catchment Partnership, Windrush AEC Ltd, West Oxfordshire District Council, HR Wallingford, UK Centre for Ecology and Hydrology (CEH), White Horse Contractors, Thames Water and Atkins
Location:	Milton-under-Wychwood, Burford, Oxfordshire
Key measures:	River channel restoration, leaky barriers, soil and land management, runoff storage

Background

The Littlestock Brook is in the Evenlode catchment and is a headwater tributary of the River Thames. The soils are largely impervious clay that generates a responsive flow regime putting the small rural community of Milton-under-Wychwood at risk of flooding. As with many agricultural catchments there is a legacy of widespread land drainage which has led to the river channels being straightened or becoming overwide/deep and disconnected from their floodplains.

Figure A1.13 Wetland (courtesy Ann Berkley, Wild Oxfordshire)

This scheme was initiated to assess the effectiveness of using natural riverine processes, land management and soft engineering approaches as a long-term sustainable solution to reduce the risk of flooding and improve water quality and biodiversity. Hydraulic modelling and a comprehensive monitoring network of water levels, sediment and nutrient fluxes in heavy rainfall events has generated detailed evidence on the effectiveness of these features for flood risk and wider ecosystem services of water quality, habitat and carbon.

Project details

The project started with opportunity mapping with landowners and the community to identify runoff pathways with the landscape. This was followed by collaborative working to identify and agree NFM and diffuse pollution measures that would work hydrologically to slow and store flows while fitting in with the farming businesses.

The project started by installing 12 leaky woody structures upstream of Milton-under-Wychwood to reduce the transport of coarse bed material, the build-up of which was impeding flow conveyance in the village. Work then moved to the upper catchment where opportunity mapping with Bruern Estate identified several areas in the landscape where interventions and land management changes could slow and store overland flows. The NFM measures included:

- soil management measures on steep clay slopes and along runoff pathways
- creating 10 nutrient retention ponds and 1.1 km field margin sediment/nutrient traps in fields
- constructing 15 bunds and scrapes to store floodwater in riparian field corners
- installing woody material in-channel to create 27 leaky barriers
- de-culverting 100 m of watercourse
- creating 230 m of new watercourse.

Soft engineering measures have been incorporated within a Forestry Commission Woodland Grant scheme which has delivered 14.4ha of new riparian woodland. Over time this will improve interception of rainfall and runoff and store carbon.

continued...

CASE STUDY A1.4

Littlestock Brook, Evenlode Catchment, Oxfordshire (contd)

Figure A1.14 Drone image of earth bund (courtesy Stuart Malaure, Environment Agency)

With this combination of NFM features, a total of 30 000 m³ of storage has been created upstream of Milton-under-Wychwood. The final phase of the project included 1.1 km of field edge nutrient trapping swales, additional retention pond creation, and an agroforestry trial which will supply the local community with produce. New project interpretation boards will educate visitors and encourage them to engage by taking photos of the new ponds and landscape features to provide a visual record of their location, scale and evolution.

Challenges and solutions

Littlestock Brook is failing under the WFD for water quality (phosphate due to sewage effluent and rural diffuse pollution) and fish habitat; a reflection of the uniform and disconnected channel morphology because of the history of land drainage. Channel incision in Littlestock Brook, as it responded to historical re-alignment from its natural valley bottom, led to excessive production of coarse bed material. This material moved downstream during flood events, causing a reduction in the flow capacity of the channel in Milton-Under-Wychwood, and increased the risk of properties flooding. Land drains under the agricultural land are also considered to contribute to the very flashy response of the tributary catchment to rainfall.

Previous interventions to manually dredge the brook had not reduced flood risk. It was economically inefficient, unsustainable and had not reduced the gravels that were contributing to the flooding issue.

Engaging the local community, landowners and farm managers was critical. Their local knowledge and experiences of flooding generated a wealth of photographic and anecdotal evidence that added to the understanding of the catchment issues. Flooding from the Littlestock Brook is due to a combination of factors including historic management of the channel and surrounding land, the restrictive size of the road bridge, and the very responsive flow regime.

Working closely with the landowners and community, the project team used hydrological and hydraulic modelling combined with opportunity mapping informed by surface water flow maps and catchment walkovers to identify significant runoff pathways within the landscape. From these initial visits, NFM and diffuse pollution reduction measures were discussed and proposed for installation. These would work both hydrologically to slow and store flows and fit with the existing farming business and landscape.

Lessons learnt

- **Understand the catchment.** Although NFM measures are field based and more flexible to deliver, it is important to understand the hydrology of the area to work out which types of measures are needed.
- **Landowner engagement.** The land management changes for NFM and diffuse pollution reduction need to integrate with the existing farming business and stewardship schemes. Supportive landowners and payment schemes are crucial to agree works on their land and to ensure the measures are maintained in the landscape.
- **Catchment partnerships.** Integrated delivery through the Evenlode Catchment Partnership has been critical in addressing multiple local environmental issues and empowering the local community of Milton-under-Wychwood to invest in catchment based approaches, using local contractors and locally-sourced materials. This integrated catchment partnership approach is a cost-effective delivery model which maximises the potential for multiple local outcomes.

continued...

CASE STUDY A1.4 **Littlestock Brook, Evenlode Catchment, Oxfordshire (contd)**

- **Monitoring strategy.** A comprehensive monitoring network and hydraulic modelling of the project is providing quantitative evidence of the effectiveness of the NFM measures to delay and reduce flood flows, and sediment and nutrient delivery. This information has enabled an assessment of both flood risk reduction to properties in Milton-under-Wychwood and wider water quality benefits.
- **Modelling outcomes.** Hydraulic modelling of the catchment, with the measures installed, shows that the severity of flooding to 12 properties has been reduced for a range of flood events. The greatest reductions occur during a 33% AEP flood, but there is also flood reduction benefits for all events including the 1% AEP event with climate change. Extreme events will still deliver severe outcomes, but results show that NFM contributes to reducing the frequency and severity of flooding for this small rural community.
- **Knowledge sharing.** Collation and sharing of evidence on the effectiveness, costs and benefits of these measures for flood risk and the environment (including carbon, BNG and natural capital services), through two PhD studentships and demonstration events will contribute to the design of future NFM projects nationally.

CASE STUDY A1.5 Smithills Moor living barriers, Bolton

Summary	
Organisations involved:	Environment Agency, Woodland Trust, Natural Course, Mersey Forest
Location:	Smithills, Bolton
Key measures:	Leaky barriers, runoff storage, catchment woodland

Background

The Smithills community has a history of flooding. Dean Brook, flows from the West Pennine Moor SSSI downstream into Smithills, and in a 1%AEP flood event causes impacts to over 50 properties. Smithills Estate is about 900ha and was acquired by the Woodland Trust in 2015. Working in partnership with the Environment Agency, Mersey Forest and University of Liverpool, a NFM programme was developed to decrease downstream flood risk, increase climate resilience, create storage volume and maximise habitat creation.

Figure A1.15 Living barriers (courtesy Mike Norbury, Mersey Forest)

Project details

Mersey Forest was contracted to produce location and design specifications for the project, with individual designs drawn where appropriate.

Interventions focused on first and second order streams, following a general rule that if the watercourse was 'too wide for a person to jump across' it was not suitable for in-stream NFM measures.

Leaky barriers were delivered through collaborative effort between the contractor and volunteers. To ensure stability, fence posts were installed by contractor plant. The Woodland Trust had cleared some areas of woodland to promote understorey species growth and this was used to construct leaky barriers. This was carried to site by volunteers and fixed in place.

Challenges and solutions

The project required a guide of flood water volumes spilling onto the floodplain to decide where and how to implement NFM measures. Existing 1D and 2D models were used to estimate these volumes during the 1% AEP event. This volume was then used as a guide to deliver NFM interventions on the estate, and plant 65ha of native broadleaf trees. Interventions included willow planting, log jams, clay core piped bunds, detention basins and daylighting previously piped sections of watercourses. Monitoring data estimates that the leaky barriers implemented can reduce peak flows by up to 20%.

It was important that the structures were self-sustaining and had limited maintenance requirements. This design ethos meant the leaky barriers have willow woven into their structures so that as non-living timber decays over time willow thicket growth is encouraged. This reduces future maintenance liability and provides habitat.

continued...

CASE STUDY A1.5

Smithills Moor living barriers, Bolton (contd)

Figure A1.16 Living barriers locations map (from Norbury *et al*, 2021)

Lessons learnt

- **Communications strategy.** The importance of an effective communication strategy to facilitate all organisations working in partnership and ensure they are accurately recognised for their individual contributions to the project.
- **Funding.** Early adopters of the scheme were hesitant to participate due to concern their participation would hinder future agri-environmental scheme funding opportunities.
- **Clear frameworks.** The importance of a clear project specification, framework and contract to support the transition between different personnel.
- **Flexible working.** Outdoor working and flexibility on the part of the contractors enabled delivery to be maintained during the Covid-19 pandemic.

CASE STUDY A1.6 River Soar and Welland Water Friendly Farming (The Allerton Project), Leicestershire

Summary	
Organisations involved:	Freshwater Habitats Trust, Game and Wildlife Conservation Trust, Environment Agency, University of York, Syngenta, Anglian Water, University of Sheffield, The Welland Rivers Trust and Oxford Brookes University
Location:	River Soar and Welland catchments, Leicestershire
Key measures:	Runoff storage, leaky barriers

Background

Figure A1.17 Initial leaky barrier designs from 2016 (courtesy Water Friendly Farming)

Water Friendly Farming is a long-term catchment scale research demonstration project aiming to explore the multiple benefits of nature-based measures in three headwater subcatchments across the upper Welland and Soar river basins in Leicestershire. The project comprises one control and two experimental catchments. It is a mixed farming landscape on clay soils. Beginning in 2010, the project aims to investigate the effect of NbS on diffuse pollution, the enhancement of freshwater biodiversity and flood risk where commercial farming is the main land use. A combination of 11 types of water quality and flood risk mitigation measures were installed across the two experimental catchments including earth bunded ditches, field drain interception ponds and clean water ponds to improve water resources and provide additional habitat benefits.

Project details

Leaky barriers have been installed annually since 2016 in the Eye Brook experimental catchment to investigate their impact on flood risk. Modelling helped inform the siting of interventions. A total of 27 barriers were created between 2016 and 2018 with some replaced, using a new design, in 2019. Additional barriers with a range of different designs will be tested between 2020 and 2025.

Observational data and modelling demonstrate that the leaky barriers currently installed reduce downstream flood peaks by 4% to 15% in 2% AEP events and by 1% in 1% AEP events. Results also indicated that the effect of leaky barriers was detected 10 km downstream. This is thought to be due to their influence in de-synchronising flows.

Monitoring over five years focused on how the leaky barriers are changing the hydrology, geomorphology and ecology of the river channel, looking particularly on the effect of barrier design on flood flows and longevity. Gauge boards and time lapse cameras have been installed at some sites, with the findings fed back into the flood model.

To identify the rate and extent of erosion around a structure, data are collected annually to describe the channel width at the base of the dam, and height between the channel base and the bottom log. Additional data are collected upstream and downstream of the barrier.

Challenges and solutions

Assessing the most effective ways to hold floodwater back in the lowland farmland environment water was a key challenge in the scheme. Soil and Water Assessment Tool (SWAT) (**https://swat.tamu.edu/**) modelling showed that changes in land use would have a limited effect on peak flows in the study area. The interception ponds and basins installed supported flood storage but their capacity was too low to significantly affect downstream flood risk, and there were few opportunities to create additional

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CASE STUDY A1.6 **River Soar and Welland Water Friendly Farming (The Allerton Project), Leicestershire (contd)**

storage basins in the agricultural catchments. In contrast, modelling demonstrated that installing leaky barriers could potentially reduce peak flows by up to 20%. As a result, an initial five year programme was developed with the Environment Agency to assess the effect of in-stream leaky barriers on flood risk.

Figure A1.18 Updated leaky barrier designs from 2020 (courtesy Water Friendly Farming)

Lessons learnt

- **Iterative design approach.** The study found that a larger flow gap beneath the barrier increased stability and flood storage. By allowing average high flows to pass unimpeded (rather than backing-up behind the leaky barriers) there was greater storage capacity available during flood events. Barriers constructed later in the project, from 2020, had a larger flow gap beneath them and greater spacing between horizontal logs than those constructed previously.
- **Structural longevity.** Monitoring led to greater understanding of erosion and instability issues around the barriers and longer lengths of timber were used in newer dams. Consequently, the project increasingly used brought-in rather than local timbers, to increase barrier stability and longevity.
- **Monitoring and maintenance.** To catch the early danger signs of dam instability, annual, monitoring of dams needed to be undertaken by wading into the stream (rather than from the bankside), using a measuring stick to identify the extent of stream bed and bank erosion close to banks, and to probe into the bank around the barrier to find scour cavities.

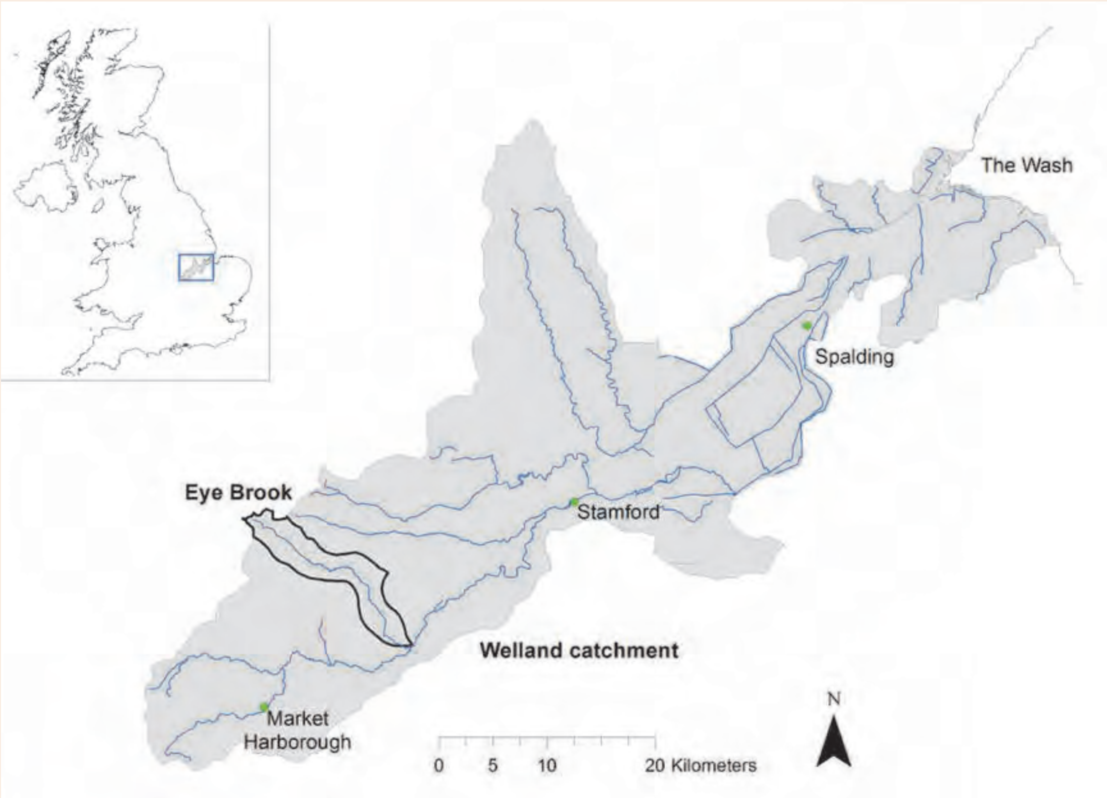

Figure A1.19 Eye Brook subcatchment (courtesy Water Friendly Farming)

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CASE STUDY A1.6 **River Soar and Welland Water Friendly Farming (The Allerton Project), Leicestershire (contd)**

Figure A1.20 Leaky barriers in the Eye Brook catchment. Installation dates and total capacity are: barriers 1 to 7, September 2016, 887 m^3; barriers 8 to 18, September 2017, 8090 m^3; and barriers 19 to 27, September 2018, 8697 m^3 (courtesy Water Friendly Farming)

CASE STUDY A1.7 Stroud Rural SUDs, Gloucestershire

Summary	
Organisations involved:	Stroud District Council, Environment Agency, Gloucestershire County Council, Seven and Wye RFCC, Gloucestershire Wildlife Trust, National Trust and Natural England, local community groups and landowners
Location:	Stroud, Gloucestershire
Key measures:	Leaky barriers, runoff management, runoff storage

Background

The Stroud Rural SUDs scheme was established in response to flooding in Stroud in 2007. The five valleys upstream of the town are regularly subject to flooding, however in 2007 the impact was much worse and over 200 properties, mostly in the Slad Valley, were flooded. Following this flood the community formed a flood action group to address the issue and campaign for better protection for residents. The Slad valley was also designated as a rapid response catchment.

Project details

The project started with a series of walkovers and consultations with the local community to identify key areas for NFM. The scheme initially worked with the National Trust and the Wildlife Trust, and private landowners were approached later.

All interventions were co-designed with landowners to ensure no negative economic effects from their implementation. The scheme also championed working directly with the landowners and their preferred contractors. As a result many local contractors now have the skills to construct NFM interventions.

The interventions used have included leaky barriers, sediment traps, field bunds to attenuate water, attenuation ponds, deflectors, earth bunds, check dams, and the re-meandering and reconnection of a stream to its natural floodplain.

The project has resulted in:

- installation of 687 different interventions through the catchment
- enhancement of 28.5 km of river/flow pathways
- observed reduction of peak river levels on the Slad Brook – measured during two comparable heavy rainfall events.

Challenges and solutions

The main challenges faced were that interventions needed to fit within the physical characteristics of the landscape without diminishing the natural beauty and heritage of the area, and the dispersed location of the properties flooded meant a solution that was localised was unlikely to benefit all the community. The initial designs were for conventional engineered approaches such as concrete dams. However, these designs would not have protected many properties or fit within the landscape character of the AONB.

The preferred solution was to implement a programme of NFM schemes throughout the Frome catchment to reduce flood risk, and to add to the overall picture of improving resilience to climate and environmental challenges. The project aimed to copy the natural processes that would occur within a wild, unmanaged woodland system, allowing trees to act as the 'engineers' of watercourses.

Lessons learnt

- **Collaborative working.** A collaborative and co-design approach which involved local organisations and using local knowledge to build on natural processes and techniques meant that the emphasis was on establishing long-term working relationships between the groups.
- **Working with landowners.** Flexibility in the funding model allows for landowner preferences to be incorporated into the delivery process such as the choice of contractor. This gives ownership of the

continued...

CASE STUDY A1.7 **Stroud Rural SUDs, Gloucestershire (contd)**

delivery to the landowner, who will continue to work with their choice of contractor as they return for maintenance works every year. This skill set can then be used locally on other projects.

- **Using local knowledge.** Not to develop fixed designs before involving landowners; their knowledge of the land and their requirements need to be built into the design. A site visit is the best place to cover these aspects.
- **Assessing risk.** Particularly when constructing features on steep slopes in woodland. Full consideration must be given to the safety of those building the features – both at design and construction stages.
- **Considering local geology.** An understanding of local geology is key to implementing effective NFM measures. For impermeable geologies, choice of interventions may be limited to those which slow overland flow. In permeable geologies interventions encouraging infiltration can also be used.
- **Design.** Build small and many, rather than few and large, leaky barriers. Ensure that baseflow can pass beneath structures unimpeded. Design will vary depending on the aim of the intervention, for example to store, deflect, raise bed levels to reduce incision, or increase infiltration.
- **Location.** Start as upstream as possible and concentrate on smaller watercourses.
- **Implementation.** Do not wait for perfect data before building. Focus on low risk and certain wins to gain confidence.
- **Maintenance.** Long-term protection is required for implemented measures, such as fencing surrounding leaky barriers and bunds.

CASE STUDY A1.8 River Wye and Lugg, Herefordshire

Summary	
Organisations involved:	Defra (funder), Herefordshire Council (lead partner), Environment Agency, Severn Rivers Trust, Wye & Usk Foundation, Natural England, National Trust, National Farmers Union, Farm Herefordshire, Herefordshire Wildlife Trust, Woodland Trust, Herefordshire Meadows and Forestry England. local flood action groups, local community groups and other project partners
Location:	Herefordshire
Key measures:	Soil and management, riparian woodland, runoff management, runoff storage, leaky barriers and floodplain reconnection

Background

The River Wye and Lugg NFM project was one of 26 catchment scale projects in England that had been allocated a total of £15M by Defra. In addition to reducing flood risk, the project aimed to deliver wider benefits including improved water quality and biodiversity as well as socio-economic benefits.

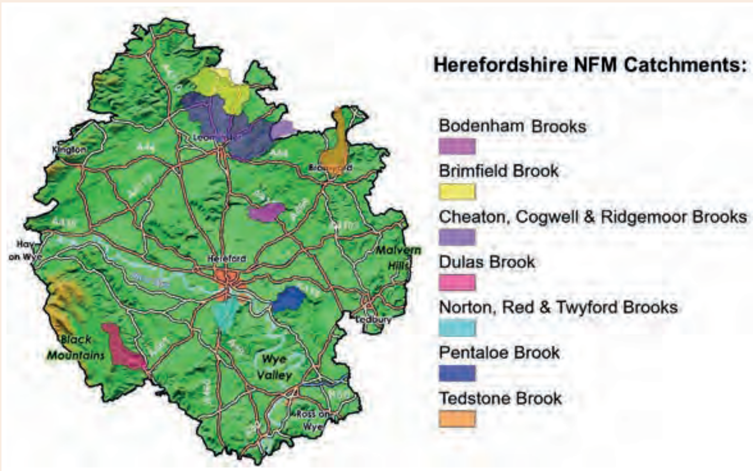

Figure A1.21 Herefordshire NFM catchments (courtesy Herefordshire Council)

To deliver the project, Herefordshire Council worked in partnership with the Environment Agency, local flood action groups, local community groups and other project partners including Severn Rivers Trust, Wye & Usk Foundation, Natural England, National Trust, National Farmers Union, Farm Herefordshire, Herefordshire Wildlife Trust, Woodland Trust, Herefordshire Meadows and Forestry England.

The project aimed to reduce flood risk to over 900 properties in seven Herefordshire catchments affected by fluvial and surface water flooding (**Figure A1.21**). These catchments are home to small rural communities, have steep upper catchments and are subject to significant land use modifications.

Project details

Aims:

- Reduce flood risk to local communities.
- Gather evidence and develop knowledge around NFM where there are currently gaps.
- Engage communities around NFM and develop partnerships.
- Deliver wider benefits, eg water quality, enhanced biodiversity, socio-economic benefits.

Objectives:

- Contribute towards the alleviation of flood risk in seven distinct catchments in Herefordshire by reducing flood risk for up to 902 properties.
- Contribute towards improved WFD status in all catchments.
- Develop community partnerships and engagement strategies.
- Enhance the NFM evidence base.

By engaging with over 145 landowners and communities within seven catchment areas, the project has successfully delivered a wide variety of NFM measures including:

- Soil management measures such as 61ha grassland aeration and 106ha arable subsoiling.

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CASE STUDY A1.8

River Wye and Lugg, Herefordshire (contd)

- Over winter cover including 189ha cover cropping and 87ha under sewing maize.
- 20 attenuation areas offering collectively around 4400 m^3 of storage.
- Three in-ditch seepage barriers.
- 137 leaky barriers.
- 1100 m of fencing to enhance channel roughness or protect newly planted trees.
- 26 cross drains (traditional and natural design).
- 5ha tree planting and 800 m hedgerow planting.
- Two rainwater harvesting systems.
- 0.8ha meadow creation.
- 60 m of enhanced wetland ditch.

The project has also helped fund landowners to adopt innovative practices that can help reduce flood risk. For example, the project helped fund the purchase of an under sewing maize drill which ensured maize fields were not left bare after cropping, to help reduce runoff. Funding was also awarded to help landowners cover the costs of direct drilling 176ha of field and purchasing a GPS system to help prevent the need for tramlines.

One particular project highlight was the collaborative approach taken in January 2020 to slow the flow of water at Croft Castle (the source of Ridgemoor Brook). Staff from the National Trust, Forestry England, Environment Agency, Wye and Usk Foundation and Herefordshire Council worked together to install 27 leaky barriers over two days. The first day was a training day led by experienced staff at from the Wye and Usk Foundation and the Environment Agency. This enabled everyone to develop their knowledge on the different techniques available to build and install leaky barriers. For example, pleaching and pinning logs using natural materials. All the staff involved were trained to use equipment including chainsaws and winches. On the second day, using their shared experiences and skills, everyone worked collectively to build the remaining leaky barriers. National Trust volunteers also helped out for the day, building the four leaky barriers which are installed in Fishpool Valley SSSI. By working together, pooling resources and sharing knowledge, the team successfully installed a series of leaky barriers that are now slowing the flow of water through the valley, helping to reduce the flood risk to downstream communities.

Challenges and solutions

A key challenge for the project was to establish a method to co-ordinate and award funding for NFM delivery. The NFM construction grant scheme was set up to provide funding for farmers and landowners to implement land and water management works and practices to reduce downstream flood risk. Awarded funding was used by the applicant to conduct the works themselves, or to employ a contractor. The scheme was competitive, and funding was not guaranteed. The grant scheme received a total of 73 grant applications and paid £83 500 to landowners to implement a wide variety of NFM measures within the seven catchment areas. Tree and hedge planting applications were supported by the Woodland Trust, who contributed a further £15 000 towards this. Some NFM measures within the grant scheme also required landowners to contribute towards the cost of implementation, for example, arable subsoiling was 50% grant funded. In total, landowners contributed £49 000 towards implementing NFM measures on their land.

Another challenge was to ensure that communities were engaged with the project. NFM catchment community groups were set up in each catchment to provide residents with the opportunity to learn more about the project and be updated on its progress. A newsletter was also published to keep local residents informed on works carried out in the catchments and encourage them to share local flood knowledge and shape the project’s delivery. River and rainfall monitoring station data was also made publicly available, enabling greater community engagement with the project. Residents are encouraged to get involved with the monitoring strategy by gathering photographic evidence of watercourses following rainfall events to help the project gain greater understanding of the catchments’ response to rainfall.

continued...

CASE STUDY A1.8

River Wye and Lugg, Herefordshire (contd)

Lessons learnt

Figure A1.22 Project partners working together to build leaky barriers at Croft Castle

- **Importance of partnership working.** By working in partnership with numerous organisations, community groups and landowners it has been possible to deliver a wide variety of NFM measures over a relatively short period of time. This approach has also ensured local knowledge and expertise has guided project delivery.
- **Catchment advisors.** To help deliver the project, catchment advisors from the Wye and Usk Foundation and Severn Rivers Trust were funded to engage with landowners and provide them with free tailored advice about the different NFM opportunities available on their land and the different funding mechanisms to help implement them. These engagements also included free soil tests, site walkovers, advisory reports and support to apply for grant funding to deliver NFM.
- **Public investment.** The catchment advisors' experience and trusted reputation within the farming community helped deliver a wide variety of NFM measures at pace (£83 500 using the River Wye and Lugg NFM construction grant scheme and around £500 000 through the mid-tier countryside stewardship scheme). Their involvement was integral to the successful delivery of the project.
- **Flood defence consents.** Features such as leaky barriers require an Ordinary Watercourse Flood Defence Consent (FDC). Normally the landowner would apply to the Lead Local Flood Authority (LLFA) for this consent and pay a fee of £50. To reflect the ethos of the project (partner organisations, residents and landowners all working together to reduce flood risk), a bespoke FDC process was adopted. This removed the need for landowners to apply for separate FDC consents for each structure as they were captured by one catchment scale FDC. This was issued to Herefordshire Council's NFM project officer, who then distributed copies to all participating landowners.
- **River and rainfall monitoring.** River level and rainfall monitoring stations were installed at the start of the project in all of the project catchment areas. To ascertain the full benefits of NFM, several years of data will need to be collected and analysed as ideally baseline datasets would have been collected before the start of the NFM project.
- **NFM projects take time.** While the three year Defra pilot project achieved a lot in a small space of time, there is still a lot more NFM work to do within the catchment areas. It takes time to develop trusted relationships with landowners and communities, and to achieve positive long-term behavioural changes.
- **Development of knowledge and skills.** As the knowledge around NFM is constantly improving and developing, it is essential that projects keep up-to-date with the latest guidance and techniques. To enhance the advisory skills of the catchment advisors and the NFM project officer, a training session was run at Herefordshire Meadows. This aimed to provide advisors with the necessary skills and confidence required to advise landowners on meadow creation and restoration. The training session resulted in the creation of 0.8ha of species-rich meadow which will achieve multiple benefits including flood risk reduction and habitat creation.
- **Education.** As NFM is a new concept to many, it has taken time to explain the principles of NFM to communities and to reassure them that it is an effective way to reduce their flood risk. The importance of educating the younger generations about NFM has been recognised and two educational videos aimed at KS2 and Year 7 pupils have been developed.

For more information go to: **www.wyeuskfoundation.org/natural-flood-management-videos**

CASE STUDY A1.9 Spains Hall Estate, Essex

Summary	
Organisations involved:	Spains Hall Estate, Environment Agency, Essex and Suffolk Rivers Trust, Essex Wildlife Trust and Atkins
Location:	Finchingfield, Essex
Key measures:	Leaky barriers, catchment woodland

Background

Spains Hall Estate in Essex has been in the same family ownership for over 260 years. Although the estate has evolved hugely over this time, land use has predominantly been focused on farming for food production. In recent years the business has gradually diversified into, for example, wildlife photography and holiday lets. The current strategy is to accelerate this change and move a large part of the estate into regenerative agriculture, agroforestry and rewilded areas.

A recent component of this transition recognises the flood risk management potential of the estate. Spains Hall Estate is in the upper reaches of the Blackwater catchment and immediately upstream of the flood risk hotspot of Finchingfield. It is ideally located to attenuate and store flood water and reduce flood risk in the village.

In 2019 a catchment scale experiment was set up to investigate whether NFM measures could be effective at reducing flood risk in Finchingfield. Co-benefits of these measures were also of interest – either in non-monetary form or as additional income streams for the farming business. Two different approaches to NFM were implemented on two separate tributaries upstream of the village. On the main arm of Finchingfield Brook eight leaky barriers were installed. On a smaller channel a 4ha enclosure was constructed to accommodate a pair of beavers.

The collection of evidence to assess the effectiveness of measures is a central part of the experiment. Extensive water level monitoring is in place in the soils, channels and floodplains of both tributaries to assess storage and attenuation of flood water. Botanical, ecological and water quality monitoring is also in place to understand the value of the co-benefits of the two approaches. An integrated assessment of the effect of current (and proposed future) interventions both on flood risk and co-benefit ecosystem services has been captured in an assessment of the natural capital.

Project details

In March 2019, a pair of Eurasian Beavers were released under licence into a 4ha fenced enclosure on a tributary to the Finchingfield Brook. In the same year, eight timber leaky dams were constructed on the main brook.

The phrase ‘busy as a beaver’ is grounded on fact; in only 24 months the beavers at Spains Hall have transformed their enclosure from a largely uniform, predominantly dry plantation woodland into a rich wetland mosaic. Where water and sediment once flowed rapidly along a straight deep ditch there is now a network of over 20 dams that constantly process flow. The enclosure may be relatively small, but in a remarkably short period of time it has become an effective and self-sustaining flood management and water quality improvement system.

Monitoring the NFM started with a BioHack that brought together over 30 volunteers to collect pre-project baseline surveys. Organisations have collected data across the site, often voluntarily or as part of linked programmes. These include the Environment Agency (water quality sondes), Affinity Water and Essex and Suffolk Water (spot nutrient and pesticides sampling), Kings College London (weather, water level and soil moisture loggers), Essex Wildlife Trust (eDNA and wetland mapping), Shropshire Botanical Association (botanical monitoring grid within the beaver enclosure) and Atkins (topographic survey and hydraulic modelling). BSc, MSc and PhD students are also helping collate, analyse and extend the data already collected.

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CASE STUDY A1.9

Spains Hall Estate, Essex (contd)

Figure A1.23 Beavers at work at Spains Hall (courtesy Russell Savory)

Much of this data is being shared across an open-source platform:
www.spainshallestate.co.uk/nfm_beavers

The project is a partnership, with about 100 volunteers and specialists contributing their time and expertise to making the project happen, and co-ordinated by the Spains Hall Estate.

The initial NFM experiment forms part of a planned transition towards more sustainable management of the Spains Hall Estate. From the perspective of water management this focuses on the concept of a 'whole farm reservoir' in which vegetation, soil, in-field drainage and ditch management, as well as attenuation features a shared use reservoir and beaver wetlands work together to retain moisture, capture sediment and pollutants, and manage flood risk in local communities.

The planned next steps are to plant 32 000 trees in woodland creation and agroforestry systems; undertake ~400ha of land use change, create a demonstration project focusing on the incorporation of diversity in agricultural landscapes, and to create a social, skills and educational hub.

Challenges and solutions

The main challenge has been how to implement substantial change in land use and management while still sustaining a viable farming business. Respecting the interests and retaining the support of local communities and stakeholders has also been important. Although the NFM scheme is one component of a longer-term goal to move the estate to more sustainable land use, it is important because it is an early step in the transition, includes some progressive land uses and has the potential to help the local community.

But, change comes at a cost. Grants from both the RFCC and Coca-Cola UK have funded big capital items. However, there remained a funding shortfall to implement the entire NFM scheme. Solutions to the funding gap have included:

- direct investment by the estate (financially and in time)
- development of income streams linked to the measures (eg wildlife viewing and tours)
- being ambitious and novel in what is implemented (to attract both interest and funds)
- recognition of the non-financial benefits of the scheme (eg goodwill within the local community)
- 'in-kind' contributions from partnership bodies – allowing time, and providing equipment without charge, which is important for the monitoring element of the scheme.

These are all short-term solutions to funding shortfalls. Long-term success depends on the transition to sustainable agriculture; becoming self-sustaining through commercial agricultural income combined

continued...

CASE STUDY A1.9 **Spains Hall Estate, Essex (contd)**

with income streams related to water management, water quality, carbon credits, BNG, eco-tourism, social care and local food.

Resourcing the project, particularly for specialist monitoring activities, has been a challenge. In-kind contributions from project partners have been effective when interests overlap. However, the best evidence base is founded on regular consistent data collection and analysis, which is difficult to organise when relying on the goodwill of others or opportunistic partnership arrangements. One way to overcome this has been to find common interests – personal, professional or commercial. Innovation attracts people and organisations to a project, however, this required substantial time investment by the estate to both promote the project and facilitate monitoring activities.

Lessons learnt

- **Building an evidence base.** The NFM scheme at Spains Hall Estate has been conceived and implemented in just over three years. While the project has been carefully planned, design has largely developed organically. Starting small, it has quickly sustained stakeholder interest and created early 'demonstrators' for future more ambitious phases of the project. Progress has created its own momentum and belief that the project will develop and succeed.
- **Engaging with others.** Realising synergies and recognising common ground have made the project much easier to deliver, if sometimes more complex. For example, while beavers do create habitats that attenuate and store floodwater, they are also a novel wildlife in the UK, attracting photographers, nature lovers and general interest within the local community, and local and national press. Another example is that human-constructed and beaver-made NFM features have created very different environments. This had made testing their water level and quality a challenge for the team at Kings College London. Considering a range of perspectives, rather than focusing on NFM has generated widespread interest and publicity and, in some cases, small additional income streams.

Figure A1.24 Drone image of NFM works (courtesy Spains Hall)

- **Recognising multiple benefits.** The most interesting lesson learnt to date is the flood risk management value of NFM relative to the co-benefits it delivers. A natural capital assessment undertaken in 2020 revealed that while the NFM elements of the planned transition to more sustainable agriculture on the estate would generate a modest flood management benefit, the biggest gains came in biodiversity, air quality and carbon sequestration services. These findings emphasise the importance of valuing the total ecosystem service benefit of NFM interventions (flood risk and co-benefits combined) rather than focusing solely on flood management benefit.

A1.2 OTHER PROJECTS

Table A1.2 provides a list of other NFM projects identified with links to find out more about each.

TABLE A1.2 Summary of further case studies

Project	Description
Bannisdale, Cumbria (part of Cumbria NFM programme)	Large-scale Defra-funded pilot project with monitoring of hydrological change involving stone and wood leaky barriers, woodland and re-meandering.
Environment Agency: https://ewn.el.erdc.dren.mil/symposiums/May2019/CaseStudies.pdf	
Belford, Northumberland	Long running and highly documented example involving runoff management (bunds, ditch barriers), runoff storage (ponds), leaky barriers and other measures. Still standing after more than 13 years and has experienced several large (up to 1% AEP) events. Hydraulic modelling and post-scheme monitoring.
Newcastle University: https://research.ncl.ac.uk/	
Brompton Beck, Northallerton, North Yorkshire	Hydraulic modelling study assessing the potential effectiveness of up to 60 in-channel (leaky) barriers at attenuating flood flows. Works include storage pond.
Yorkshire Dales Rivers Trust: http://www.yorkshiredalesriverstrust.com/	
Building blocks – next steps in gully blocking, South Pennines	Gully blocking with site selection using hydrological assessment. Primary aim to improve biodiversity rather than flood risk. Work since 2003 has resulted in some useful guidance.
Moors for the Future: https://www.moorsforthefuture.org.uk/	
Cache la Poudre River floodplain reconnection, Fort Collins, Colorado	Floodplain restoration (defence removal) in urban corridor as part of larger Poudre River master plan for flood risk management and river corridor revitalisation. Multiple benefits.
City of Fort Collins: https://ewn.el.erdc.dren.mil/symposiums/May2019/CaseStudies.pdf	
Calderdale Slow the Flow, West Yorkshire	Community group has constructed over 500 leaky barriers with further 100 built by contractors.
Slow the Flow (Calderdale): http://slowtheflow.net/	
Collingham Beck, West Yorkshire	Defra-funded community pilot involving soil and land management (buffer strips, hedgerows), woodland, runoff storage (swales) and leaky barriers.
Yorkshire Dales Rivers Trust and Mott MacDonald: **https://www.therrc.co.uk/sites/default/files/files/events/ICD/2._collingham-modelling-opportunities-emma-wren.pdf**	
Ellis Meadows, Leicester (part of Leicester flood risk management scheme)	Riverside strategy and river restoration involving re-meandering of river reach and lowering bank sides to allow water into meadow areas. Funded by a range of sources, but mostly from a source to enable development in parallel.
Environment Agency, Leicester City Council: **https://www.trentriverstrust.org/wp-content/uploads/2019/01/Intro-to-Soar-CP-Event-6th-Nov-RN.pdf**	
Englefield Estate, Pangbourne, Berkshire	Defra-funded community pilot involving construction of leaky barriers on River Bourne at Englefield Estate to reduce flood risk to Pangbourne (120+ homes flooded in 2007). Flow monitoring by Reading University.
Englefield Estate, Pang Valley Flood Forum: https://www.englefieldestate.co.uk/estate-news/pang-valley-flood-forum-reduce-risk	

continued...

TABLE A1.2 Summary of further case studies (contd)

Project	Description
FramWat, Eastern Europe (Austria, Croatia, Hungary, Poland, Slovakia, Slovenia)	Pilot studies developing framework for using small water retention measures in six catchments in six countries to improve water balance and nutrient mitigation. GIS analysis to select sites, hydraulic modelling to assess likely impacts and preparation of decision support system.
Interreg Central Europe: https://www.interreg-central.eu/Content.Node/FramWat.html	
Ffrwd Wyllt catchment, Port Talbot, South Wales	Number of debris dams, which have naturalised well. Also have plans to reconnect side channel.
NRW: https://www.therrc.co.uk/sites/default/files/files/Conference/2020/programme_2020_v68_online.pdf	
Gala Water Restoration, Scottish Borders	Floodplain and riparian woodland, water storage (ponds, scrapes) and leaky barriers.
Tweed Forum: https://tweedforum.org/	
Greater Easterhouse integrated green infrastructure, East Glasgow	De-culverting and repurposing derelict site to make wetland park.
NatureScot: https://www.nature.scot/	
Haltwhistle Burn, Northumberland	Community-based catchment management research project using citizen science. 'Total catchment' approach aims to improve fisheries, water quality, hydromorphology, and flood risk. Work included attenuation ponds and interlocking lattice (or kerplunk) leaky barrier designed to trap stones and debris and reduce flood risk downstream.
Newcastle University National Green Infrastructure Facility, Tyne Rivers Trust: https://research.ncl.ac.uk/haltwhistleburn/ **River Restoration Centre: https://www.therrc.co.uk/sites/default/files/projects/44_haltwhistle.pdf**	
Hills to Levels programme, Somerset	Runoff management (cross drains, field corners, hedgerows), runoff storage (ponds), leaky barriers and floodplain restoration.
FWAG South West: https://www.fwagsw.org.uk/hills-to-levels	
Holnicote, Somerset	Long-running, highly-documented Defra demonstration project involving land management, woodland, runoff management (bunds) and natural leaky barriers.
National Trust: https://www.nationaltrust.org.uk **River Restoration Centre: https://www.therrc.co.uk/sites/default/files/projects/20_holnicote.pdf**	
River Irt, Cumbria	Reconnecting side channels, riffle features, leaky dams and bunds to reconnect floodplain, earth bunds and large-scale ponds.
West Cumbria Rivers Trust: https://www.westcumbriariverstrust.org/	
Isle of Axeholme, Baston & Thurlby Fen, South Lincolnshire	Plan to restore wet grassland, used for grazing and hay production, reedbeds, swamp, wet woodlands and open water over next 25 to 50 years. These wetlands form part of a larger project proposal to restore over 10 000ha across the East Midlands and East Anglian Fens.
South Lincolnshire Fenlands Partnership, Lincolnshire Wildlife Trust: https://www.iucn-uk-peatlandprogramme.org/projects/isle-axeholme-baston-thurlby-fens-south-lincolnshire-fens	
Kentmere NFM, Cumbria (part of Upper Kent flood risk management scheme)	NFM to supplement linear defences and conveyance improvements, to include peatland restoration, runoff management, runoff storage (bunds, swales, dry stone walls), leaky barriers, woodland.
Environment Agency Flood Hub: https://thefloodhub.co.uk/upperkent/	

continued...

TABLE A1.2 Summary of further case studies (contd)

Project	Description
Leeds FAS2 NFM, Marlfield Farm, Earby, North Yorkshire	Pilot project involving series of leaky barriers, runoff management (buffer zones, cross slope hedgerows), runoff storage (scrapes) and woodland. Photographs and video footage of implementation and measures in action during February 2020 floods.
River Stewardship Company, Environment Agency: https://www.marlfieldfarm.co.uk/about/natural-flood-management.html	
Leeds FAS2 NFM Programme, West and North Yorkshire	Local authority led programme, starting with pilot project at Marlfield Farm (see above), now expanding to wider scheme (£15M).
Leeds City Council, Environment Agency, Mott MacDonald: **https://www.leeds.gov.uk/emergencies/flooding-advice/how-were-reducing-the-risk-of-flooding/leeds-flood-alleviation-scheme**	
Long Preston floodplain project, North Yorkshire	Partnership project involving floodplain restoration for flood risk management and habitat benefits.
RSPB, Natural England, Environment Agency, Yorkshire Dales Millennium Trust, North Yorkshire County Council, local landowners and Yorkshire Dales National Park Authority: https://longprestonfloodplainproject.org/	
Lustrum Beck FAS Phase 2, County Durham	Develop successful business case for NFM for flood defence grant-in-aid (FDGIA). Combines NFM to store water in upstream catchment area with traditional flood defences. Issues included designing for health and safety, and cost of access tracks for maintenance.
Environment Agency, Arup: https://www.therrc.co.uk/sites/default/files/projects/21_lustrum.pdf	
Medway NFM, Kent	Leaky barriers (various designs including live materials) in ancient woodland/ sensitive lowland sites. Long-term ecological monitoring planned.
Kent Countryside Partnerships: https://medwayvalley.org/rivers/beyond-flooding/	
Melsterbeek catchment, Flanders, Belgium	Land management (buffer strips) and runoff management (swales, earth and straw bunds) to reduce soil erosion, interrupt flow, increase retention and prevent 'muddy floods' in 300ha catchment. Monitoring gave quantitative data on peak flows, runoff duration and lag time.
Flemish Government: **https://www.researchgate.net/publication/279866843_Water_and_muddy_flood_management_in_the_Melsterbeek_catchment**	
Micro-catchments action planning, Rwanda	Micro-catchment action planning including NFM to achieve multiple benefits.
Rwanda Integrated Water Resources Management programme: https://waterportal.rwb.rw/	
River Pinn Cannon Brook and Mad Bess Brook FAS, London (part of River Pinn project)	GiA and Local Levy funded project including catchment approach to flooding. Includes leaky dams in Mad Bess Wood (part of Ruislip Woods SSSI/National Nature Reserve), NFM appraisal for land management and riparian buffer works. Key features include urban area, designated sites and gaining permissions.
London Borough of Hillingdon: https://www.thames21.org.uk/ River Restoration Centre: https://www.therrc.co.uk/	
River Pinn Park Wood and Pinn Meadows, Ruislip, London (Quick Wins) (part of River Pinn project)	Early works being delivered by the London Borough of Hillingdon ahead of Environment Agency appraisal (outline business case and full business case). Includes floodplain reconnection to lower section of artificially raised bank to bring floodplain into action. Within urban green space and there are issues in the river with invasive species (Himalayan Balsam). Environmental Permit obtained for works from Environment Agency. Key features are quick wins, working with others, INNS, consents.
Park Wood and Pinn Meadows Flood Partnership, Environment Agency, London Borough of Hillingdon, local community and Thames Water: https://www.thames21.org.uk/	

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TABLE A1.2 Summary of further case studies (contd)

Project	Description
River Pinn Park Wood Slow the Flow, London (part of River Pinn project)	Leaky barriers with evolution of design as more constructed. Natural England consent needed for construction within National Nature Reserve and SSSI. Heavy community involvement in planning and delivery. Opportunity appraisal in house in-line with Environment Agency NFM toolbox. Hydrogeological modelling during site selection. Vandalism of leaky dams as the land is publicly accessible. Key features include urban, designated sites, community project, design, vandalism, monitoring and maintenance.
Thames21, London Borough of Hillingdon: https://consult.environment-agency.gov.uk/hnl/the-river-pinn-project-information-page/	
River Pinn Salmons Brook, Upper Brent, London (part of River Pinn project)	Defra pilot project involving leaky barriers, possible other measures in four subcatchments. Key features include citizen science, visual monitoring, monitoring water level and geomorphology.
Thames21: https://www.thames21.org.uk/	
Pipp Brook, Dorking	Leaky barriers (various designs including costs) and wet woodland. Partnership project to include monitoring to 2025.
Environment Agency, Forestry England and University of Surrey: https://www.surreyhills.org/	
Q-NFM, Kent, Derwent and Eden, Cumbria	Research project aiming to quantify impact of NFM on flood peaks and hydrographs from micro-basin (<1 km^2) to large basin scale (>2000 km^2). Measures include runoff management (hedgerows, wall restoration), leaky barriers, floodplain reconnection, woodland and agricultural interventions in pasture.
Natural Environment Research Council (NERC), Lancaster University: https://www.lancaster.ac.uk/lec/sites/qnfm/	
Room for the River project, the Netherlands	Floodplain restoration (setting back defences, channel features to throttle, slow and elevate water onto floodplain) to cope with increased river flows without increasing the height of flood defence dykes.
Rijkswaterstaat (Ministry of Infrastructure and Water Management): https://www.rijkswaterstaat.nl/	
Scandal Beck and River Lyvennet, Upper Eden, Cumbria	Working with and through natural river processes to improve habitats, slow flow and alleviate flood risk. Walkover surveys, opportunity mapping and landowner discussions to identify sites that will make biggest differences. River restoration looking at straightened, reinforced, over-deep and disconnected channels. Working with landowners and farmers to put in variety of river restoration and NFM measures to improve the rivers and habitat. Key features are SAC, SSSI, working with others, volunteers, school children.
Eden Rivers Trust: https://edenriverstrust.org.uk/	
Restoring Europe's Rivers: https://restorerivers.eu/wiki/	Exploration of opportunities for water storage, riparian and floodplain woodland, and leaky barriers within Horner Water and River Aller catchment (same catchment as Holnicote).
National Trust, JBA Consulting: https://ifm.org.uk/wp-content/uploads/2019/03/Spec-Conference-2019-Programme-DRAFT-FINAL-V2-1.pdf	
Severn Trent Environmental Protection Schemes (STEPS)	Grant scheme for farmers to implement land management changes/schemes to help reduce risks to drinking water supplies. Flood risk management not primary driver, but some measures deliver flood risk management benefits.
Severn Trent Water: https://www.stwater.co.uk	

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TABLE A1.2 Summary of further case studies (contd)

Project	Description
Shipston on Stour, Warwickshire	Local flood action group worked with the local university to install a number of measures on various farms with many landowners. One farm implemented 15 large woody debris dams and two offline ponds.
Shipston Area Flood Action Group (SAFAG): https://safag.org/	
Shropshire slow the flow	Runoff management (bunds) and storage (ponds, swale), leaky barriers, woodland and wetland creation. Research team working on leaky barrier design with a focus on flood attenuation, scour effects, sediment trapping and structural integrity. Defra funded.
Shropshire Council, Environment Agency, Cardiff University: https://www.shropshirewildlifetrust.org.uk/rivers/slow-flow	
Southwell Flood Alleviation Scheme, Nottinghamshire	NFM measures were installed as part of the wider ‘hard engineering scheme’. Delivered in partnership with the Environment Agency, Trent Rivers Trust and Via East Midlands.
Environment Agency, Trent Rivers Trust, Nottinghamshire County Council **Southwell Flood Forum: http://www.southwellfloodforum.org.uk/** Restoring Europe’s Rivers: https://restorerivers.eu/wiki/	
Slowing the Flow, Pickering, North Yorkshire	Long running, highly documented Defra demonstration project (over £1M) involving land management, runoff management (bunds), woodland and leaky barriers.
Forest Research: https://www.forestresearch.gov.uk/	
Sussex Flow Initiative	Leaky barriers. Numerous case studies, guidance leaflet, reports on multiple benefits to society.
Sussex Flow Initiative: http://www.sussexflowinitiative.org/uploads/1/6/3/1/16313516/sfi_lwd_guidance_booklet_nfm.pdf	
Weardale NFM, County Durham	Defra pilot project investigating large-scale NFM (100 km^2) and effects on peak flow, synchronisation, sediment conveyance, timing and duration of benefits, ecosystems benefits, variation between catchments.
Environment Agency: https://wear-rivers-trust.org.uk/natural-flood-management	
River Wensum restoration, Raynham estate, Norfolk	Three phase river restoration including pool creation, berms, bed raising, large wood, daylighting, reprofiling, woodland and embayments. SSSI, protected species. Used on-site materials and specialist plant to reduce environmental impact during construction. Countryside Stewardship funding.
Norfolk Rivers IDB: https://norfolkriverstrust.org/ **Fiver Rivers: https://five-rivers.com/**	

Courtesy Evenlode Catchment Partnership

A2 TERMINOLOGY

Contents

Appendix A2 Terminology

A2.1 GLOSSARY

Action	A set of forces or loads acting on a structure (after BS EN 1990:2002+A1:2005).
Adaptive management	A management approach that involves taking action when trigger points are observed, in order to maintain flexibility in the face of future uncertainties (eg climate change).
Aeration	See *Soil aeration*.
Amenity (value)	Something that is useful and/or brings enjoyment.
Anchoring	A means of fixing a moveable structure to the riverbed or banks of a watercourse, or fixing sufficient materials together, in order to create sufficient weight to restrain the structure and prevent mobilisation by water flows.
Attenuate/attenuation	The act of slowing the flow of water. Intended to reduce the peak discharge of a flood as it passes down a watercourse, due to water storage or flow constrictions.
Banked hedgerows	Hedges planted cross slope on a raised bed or bank, to intercept flow pathways and store water, to increase infiltration and transpiration. May also act as a long-term field boundary. Local terms include kested or Devon hedges.
Bankfull flow/condition	Bankfull flow is the point when a river channel is flowing at capacity and more water will cause flow to spill out into the floodplain.
Baseline	An option against which all other options are tested, typically taken as the existing condition.
Baseflow	The proportion of the flow in a watercourse that has been contributed by groundwater flow. Also referred to as the normal flow condition.
Benefit	Positive changes that an NFM measure is expected to produce, including damages avoided. May be quantifiable or unquantifiable. This manual distinguishes between the primary and co-benefits of installing NFM, where the primary benefit is flood risk management and co-benefits are all the benefits other than flood risk management.
Benefit-cost ratio	The relationship between the benefits and costs of a scheme. Calculated by the PV whole-life benefits divided by PV whole-life costs.
Berm	A low shelf or raised earth barrier either within a watercourse channel or separating two areas.
Biodiversity	The variety of plant and animal life in the world or in a particular habitat, a high level of which is usually considered to be important and desirable.
Bioengineering	The use of vegetation to achieve engineering objectives, eg to stabilise riverbanks or provide scour protection.

Blue-green infrastructure	A strategically planned network of high-quality natural and semi-natural areas with other environmental features which is designed and managed to deliver a wide range of ecosystem services and protect biodiversity in both rural and urban settings. Green infrastructure relates to the on-land elements and blue to the water elements.
Brash	Dead and felled wood, including the tops of trees and branches, which is left on the ground after felling.
Borehole	A narrow shaft (or hole) drilled into the ground, for the extraction of water and/or to sample and monitor the groundwater environment. Typically used as part of a site investigation, ground investigation or for groundwater monitoring.
Breach	The damage of part of a flood embankment or water-retaining structure, creating a gap, with the release of water.
Buffer strip	A vegetated strip of land that is either across a slope or alongside a watercourse. It helps reduce runoff and trap sediment.
Bund	A low barrier, dam or mound, typically constructed from earthworks, to contain or exclude water.
Calibration	The process of adjusting model input parameters (within an allowable range) to achieve a reasonable fit between modelled results and observations or data.
Carbon footprint	The total greenhouse gas emissions (carbon dioxide and methane) generated by the provision, construction, installation, use or management of something, expressed in carbon dioxide equivalent.
Catchment	An area of land that drains to a given point on a drainage system, watercourse or other waterbody.
Catchment based approach	Working at a river catchment scale to deliver a range of environmental, social and economic benefits and protect the water environment for the benefit of all.
Catchment scale	Catchments classification according to size when considering the relative effectiveness of NFM. A common hierarchy is: Small (sub)catchment: ~10 km^2 Medium (sub)catchment: ~100 km^2 Large catchment: ~1000 km^2
Catchment woodland	Woodland planted within a catchment (but not directly within a river floodplain) to intercept, slow, store and filter water, and help reduce flood flows.
Channel incision	Erosion of a riverbed leading to a reduction in bed elevation.
Check dam	A small dam constructed across a ditch, swale or watercourse channel to slow the flow, reduce erosion and encourage the settlement of sediments.
Citizen science	Scientific research conducted partly or wholly by volunteers or amateur (non-professional) scientists.
Climate resilience	The ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate.
Co-benefits	The associated additional benefits of installing NFM schemes besides flood risk management (eg improved biodiversity or increased carbon storage).
Cofferdam	A temporary barrier constructed within or across a watercourse or waterbody to keep water out and allow work to be carried out safely in the dry.
Control structure	A structure used to control the volume or rate of flow, or water levels.
Conveyance	A measure of the flow carrying capacity of a watercourse or section of floodplain.
Cost	The inputs to a project (monetary, environmental or social) including design, construction, monitoring, maintenance or land compensation costs.
Cost-benefit analysis	A process of comparing benefits and costs to identify the options that are economically worthwhile and the option that provides best value for money, in economic appraisal.

Cross drain(age)	A transverse drain set into the surface of a track or road to intercept and convey surface water runoff to surrounding areas with greater permeability, eg fields and verges. Similar to a diverter but set below ground level.
Cross slope woodland	Woodland planted across a hill slope to intercept water as it runs down the hill, reducing rapid runoff, encouraging infiltration and the storage of water in the soil.
Delivery	The process of site selection, design, construction, monitoring and maintenance of an asset.
Design flood	The discharge or flow adopted for design, usually defined in terms of annual exceedance probability or return period.
Design life	The service life of an asset intended by the designer. This assumes some rate of deterioration up to a point where the asset requires replacement or refurbishment.
Design standard	The design flood for an asset or system chosen to provide an acceptable risk during the design life.
Designated site	A site with statutory status as a result of its ecological, habitat, heritage or landscape value, typically protected in law.
De-silting	Removal of sediment accumulated in the natural or design bed level of a channel or culvert, generally as a maintenance activity. Not to be confused with dredging, which is underwater excavation, usually including removal of the excavated material and normally affecting the riverbed below its 'natural' level.
De-synchronising	The process of delaying flood peaks on one or more watercourses within a catchment, with the aim of avoiding the coincidence of flood peaks at an area vulnerable to flooding.
Disbenefit	A negative benefit or an adverse impact resulting from something, eg reduced amenity, loss of habitat or increased flood risk.
Discharge	Also known as flow rate or abbreviated to flow. The volume of water passing a given point of an open channel or closed conduit in unit time, normally expressed in cubic metres per second (m^3/s).
Disconnected floodplain	The loss of or reduced floodplain connectively between a watercourse and its floodplain, possibly due to the construction of flood defences or channel incision.
Diverter	A transverse drain set above the surface of a track or road to intercept and convey surface water runoff to surrounding areas with greater permeability, eg fields and verges. Similar to a cross drain but above ground.
Economic appraisal	A comparison of options using monetary values to represent the costs and benefits of each. Separate to financial assessment which considers the affordability of options.
Ecosystem services	The benefits people obtain from ecosystems. These include provisioning services such as food and clean water, regulating services such as flood protection, carbon sequestration and disease control, and cultural services such as recreation and wellbeing. See also *Co-benefits* and *Multiple benefits*.
Engineered log jam	An in-stream structure designed and constructed from wood to restore habitat and treat problems such as bank erosion, flooding, bridge damage, and channel incision. See also *Leaky barrier*.
Ephemeral watercourse	A watercourse that flows only some of the time in response to high groundwater levels, rainfall or snow melt.
Exceedance	A rainfall or flow event that exceeds the design standard of an asset, which may result in overflowing.
Extreme events	An event that is observed infrequently and is statistically 'rare', typically defined as having less than 1% chance of occurring in any one year. See also *Frequent flood*.
Evapotranspiration	The loss of moisture from soil or the ground, both by evaporation and by uptake and transpiration from plants.
Failure	Inability to achieve a defined performance threshold. 'Catastrophic failure' describes the situation where the consequences are immediate and severe.
Flood defences	Artificial structures such as walls, earth embankments or sluices, constructed to reduce the risk of flooding to land, people, property or infrastructure.

Flood embankment	An embankment to control the extent of flooding, usually constructed from earth.
Flood frequency	The annual exceedance probability of a flood (eg a 1% AEP flood has a 1% chance of being exceeded in any year). Sometimes expressed as return period, the average period of time expected to elapse between flood events of a certain size at a given site, although in practice, the number of years between consecutive floods varies considerably because of variations in climate and weather.
Floodplain	Land on either side of a river that is below the highest defined flood level.
Floodplain connectivity	The ability of water to pass between a watercourse and its floodplain.
Floodplain reconnection	The process of restoring floodplain connectivity, with the aim of encouraging more regular floodplain inundation and floodwater storage. This can reduce flood peaks and downstream flood depths.
Floodplain woodland	Woodland planted on a floodplain to slow the flow and increase water depth, with the aim of helping to reduce and delay flood peaks. This can help to desynchronise flood peaks and enhance sediment deposition on the floodplain.
Flood storage reservoir	A reservoir designed to store water during heavy rainfall events, attenuate flood flows and reduce peak flows downstream. May be located online (on a river) or offline (next to a river).
Flow rate	Also known as discharge. The volume of water passing a given point in unit time, normally expressed in cubic metres per second (m/s).
Frequent flood	A commonly occurring flood event, with greater than 10% chance of being exceeded in any one year. See also *Extreme flood.*
Geographical information system	A computer software system that can be used to capture, store, analyse and display data which has a known position on the surface of the earth.
Geodiversity	The natural range of geological (rocks, minerals, fossils), geomorphological (landforms, topography, physical processes), soil and hydrological features, including their assemblages, structures, systems and contributions to landscapes.
Geomorphology	The scientific study of the evolution and configuration of landforms. Known as fluvial geomorphology (when applied to rivers). See also hydromorphology.
Grip blocking	Blocking moorland drainage ditches (grips) to slow the flow and store water.
Ground investigation	Intrusive survey to determine the condition of the ground, typically before beginning construction works. Typical techniques include use of trial pits and boreholes to establish the water table level and water flow, the presence of fissures, faults and voids below ground, as well as the ground thickness and mechanical properties of the soil.
Groundwater	Water contained in the soil and fissures of rocks below ground.
Groundwater flow	The flow of water beneath the ground surface that has entered the subsurface due to infiltration.
Gully	A well-defined channel or valley formed by the action of water.
Gully stuffing	Bundles of wood (logs or brash) placed in a watercourse or ditch, to slow the flow and trap sediment or floating vegetation.
Hard engineering	An artificial structure that controls or disrupts natural processes, typically constructed from concrete, masonry or steel, (see also *Soft engineering* and *Bioengineering*).
Headwater management	Measures that intercept, slow and filter surface water runoff and encourage attenuation and infiltration, thereby delaying and reducing peak flows locally for small flood events. Includes grip and gully blocking.
Hydraulics	The scientific study of water and other liquids, in particular, their interaction with structures and behaviour under the influence of mechanical forces.
Hydrograph	A graph showing change in water flow (discharge) or water depth (stage) over time.

Hydrology	The scientific study of the water cycle, including precipitation (rainfall and snow melt), surface water runoff, groundwater and water in rivers and streams.
Hydrological cycle	See *Water cycle*.
Hydromorphology	The physical characteristics of rivers, estuaries and open coastlines, such as flow variation, cross-section size and shape, planform and bed substrates.
Impermeable	An impermeable surface is one that water cannot soak into (eg concrete). See *Permeable*.
Infiltration	The process by which surface water enters the ground.
In-kind contribution	In-kind contributions are non-cash contributions of a good or a service can include: Voluntary labour. Donated equipment. Services donated from other companies or organisations. Use of premises or office space for the project.
Interception	The process by which rainfall is trapped before reaching the ground. This may be because it falls onto the leaves of trees (the canopy), other vegetation or buildings.
Invasive non-native species	An animal or plant that has been introduced (by accident or intent) that can spread and cause damage to the environment or humans.
Land management	See *Soil and land management*.
Large wood	Also known as large woody debris and woody debris. Trees, roots, trunks, logs, branches and other large pieces of wood that are no longer attached to the ground, typically defined as exceeding 0.1 m in diameter and 1.0 m in length.
Lateral connectivity	The ability of a river to adjust and move freely in a lateral (side to side) direction in the floodplain.
Leaky barriers	Also known as ‘leaky dams’ or ‘leaky woody structures (LWS)’. Formed naturally or are installed across streams, their floodplains or overland flow pathways, using living materials, wood, timber or stone, to reduce flood risk, slow flow and improve floodplain connectivity.
Living materials	Wood that retains its root wad and/or is capable of re-establishing eg willow.
Longitudinal connectivity	The connectivity of a river along its length in terms of vertical change. In a connected river water will be able to flow freely downstream (eg no dams or weirs).
Longitudinal slope	The slope along a river or along the direction of a runoff pathway
Lowland watercourse	Usually flowing through land that is below 250 m above sea level. These are slower flowing watercourses that have a low drop in elevation leading to slow flows. They have meandering courses, lacking rapids and a river bed dominated by fine sediments.
Maintenance	Work required to keep an asset fit for purpose.
Match funding	The stipulation set by a grant-providing body that the recipients of a grant raise a certain percentage of the money they require, this is generally a sum more or less equal to that of the sum of money being granted.
Meander	The bends of a river as it winds its way across the floodplain.
Measures	A way of working with hydrological processes to reduce flood risk
Measure types	A subset of NFM measures. For example, a pond is a type of runoff storage measure.
Mitigation	The action of reducing the severity, seriousness, or consequences of the impacts of a proposed intervention.
Mitigation hierarchy	The mitigation hierarchy is a set of tasks intended to limit as far as possible the negative impacts on biodiversity from development or interventions. Typically: avoid, minimise, remedy, compensate.
Monitoring	A process to observe and understand the impacts and outcomes of NFM measures, or the systematic checking or inspection of an asset and its potential effects (positive or negative).

Multi-criteria analysis	A decision support technique involving the appraisal of multiple success criteria.
Multiple benefits	All the benefits associated with NFM, including the primary benefit of flood risk management and all the co-benefits.
Natural capital	Stocks of the elements of nature that have value to society, such as forests, fisheries, rivers, biodiversity, land and minerals. Natural capital includes both the living and non-living aspects of ecosystems. Stocks of natural capital provide flows of environmental or 'ecosystem' services over time.
Natural processes	Processes that operate naturally without human intervention, such as infiltration, groundwater recharge/discharge, sediment erosion, conveyance and deposition, and coastal evolution.
Offline storage area	An area used to store and then release floodwater in a controlled manner.
Opportunity mapping	Identifying areas with potential for the effective installation of NFM measures.
Optimism bias	A factor applied in economic appraisal to offset a proven tendency for appraisers to be over-optimistic about costs, benefits and/or programme.
Outturn cost	The actual or total cost of a project after it has been completed and all costs are known. Commonly used in reference to the cost of a single contract.
Outlet	A fixed opening in a structure used to control the flow of water.
Overflowing	The passage of water over a component such as a road or railway embankment or riverbank due to high water levels. Overflowing does not necessarily represent failure of an asset to perform its function.
Overtopping	The passage of water over a component such as a flood bank or seawall, due to wave action. Overtopping does not necessarily represent 'failure' of a flood defence to perform its function.
Palaeochannel	A remnant channel of an inactive watercourse that has been filled or buried by younger sediment.
Pathway	Route that enables a hazard to propagate from a 'source' to a 'receptor', ie the 'source-pathway-receptor' concept. A pathway needs to exist for a hazard to be realised. Pathways can be constrained to mitigate the risks.
Permeable	A permeable surface is one that can absorb water (eg soil) and an impermeable surface is one where it cannot soak in (eg concrete).
Planform	The shape (of a river) as seen from above.
Pond	A permanent or near-permanent pond or pool with additional storage capacity to attenuate surface runoff during rainfall events. May be a natural depression, constructed by excavation or by constructing embankments.
Precipitation	It can take several forms, rainfall and snow being the most common. For simplicity, the term rainfall is used throughout this guide to encompass all forms of precipitation.
Present value	The present-day value of future costs and benefits, discounted over the life of a scheme to account for the preference to receive goods and services now rather than in the future.
Primary benefit	The primary benefit of NFM is flood risk management. See also *Co-benefits* and *Multiple benefits*.
Relic channel	See *Palaeochannel*.
Re-meandering	The process of creating a new meandering watercourse or reconnecting cut-off meanders, to slow down the river flow, restore natural processes and provide habitat.
Residual value	Represents the value of the infrastructure at the end of the project lifetime in terms of the benefit it can generate.
Resilience	Ability to continue to work, or to quickly reinstate something so that it functions, under a wide range of circumstances. See also *Climate resilience.* is the ability to anticipate, prepare for, and respond to hazardous events, trends, or disturbances related to climate.

Return period	The average interval in years between events of similar or greater magnitude. For example, a flow with a return period of 1 in 100 years will be equalled or exceeded on average once in every 100 years. However, this does not imply regular occurrence, but that the 100-year flood should be expressed as the event that has a 1% probability of being met or exceeded in any one year.
Riparian	Land along the banks of a watercourse.
Riparian woodland	Woodland planted on land immediately next to a watercourse, to slow flood flows, reduce bankside erosion and help reduce sediment delivery to the watercourse. May also store water below ground.
Risk	Risk can be considered as having two components – the **probability** that an event will occur and the **consequence** associated with that event to receptors.
River planform	The shape of a river channel when viewed from above (eg straight, sinuous, or meandering).
River restoration	The process of re-introducing more natural form to previously modified rivers and restoring natural physical process, which can help to slow and store flood water to reduce flood peaks.
Runoff	Water flowing across the ground (overland) towards a watercourse. It occurs when either the soil is waterlogged and at full capacity or rainfall arrives more quickly than the soil can absorb it.
Runoff attenuation features	See *Runoff storage.*
Runoff management	Measures that intercept, slow and filter surface water runoff.
Runoff pathway	A route that runoff takes across the land surface before it reaches the stream network.
Runoff storage	Measures that store surface water runoff.
Scrape	A pool or ribbon of shallow water in a depression, fills in wet weather and then dries slowly in dry conditions.
Scour	Erosion of the bed or banks of a watercourse by the action of moving water, typically associated with channel narrowing, increased gradient, or some kind of blockage/restricting feature.
Scour protection	Works to prevent or mitigate scour.
Sediment	Granular or cohesive material transported overland or in flowing water in a watercourse channel, that tends to settle in areas where flow slows down (eg clay, silt, sand, gravel, cobbles or boulders).
Sediment trap	An artificially widened section of watercourse designed to reduce flow velocity and encourage deposition of sediment, at a location from which it can be easily removed. Typically installed to reduce excessive siltation of a feature such as a pond, lake or culvert.
Sensitivity analysis	Testing the potential variations in an outcome by altering the values of contributory factors that are uncertain.
Side channel	See *Palaeochannel*.
Siltation	The process of fine sediment accumulation on the bed of a watercourse or waterbody. May smother gravels and affect habitat for fish spawning.
Sinuosity	The tendency to bend in an S-shaped pattern across the floodplain.
SMART objectives	Objectives that are specific, measurable, achievable, realistic and time-limited.
Soft engineering	Engineering that achieves an objective using ecological and geomorphological principles, while enhancing habitat and improving aesthetics (for example, to reduce erosion). See also *Hard engineering* and *Bioengineering*.
Soil aeration	Mechanical or other methods to reduce soil compaction and increase the porosity and air content of the soil which creates more space to store water.

Soil and land management	Measures that encourage interception, evapotranspiration and infiltration into the soil to store and slow water where it falls as rainfall, therefore reducing waterlogging in winter and reducing runoff.
Soil compaction	Compression of the soil structure by an external force (eg the weight of animals or machinery) resulting in a soil with fewer pore spaces (less air content) and therefore less ability to infiltrate and store water.
Soil organic matter	The amount of organic (plant or animal) material within the soil. A higher organic matter content leads to an improved soil structure and increases the ability of soil to store water and transport water within the soil profile rather than runoff over the surface.
Soil structure	The way that the soil is structured – the organic matter content, the groups of soil particles and the pore spaces (air pockets). A healthy soil structure is free draining, has abundant organic matter and is more stable, so is less likely to result in overland runoff.
Stage zero river restoration	A river restoration technique that allows channels to naturally re-form a new course, focusing on improved river floodplain connectivity and wetland restoration.
Stakeholder	An individual or group with an interest in, or having an influence over, the success of a proposed project or other course of action.
Streamflow	Water that has entered the channels of the drainage network of the catchment through either groundwater flow or overland runoff.
Surface water runoff	Also known as overland flow. Rapid movement of water over the land surface, downslope towards a watercourse or stream/river.
Sustainable drainage system	Artificial drainage systems that are considered to be environmentally beneficial, causing minimal or no long-term detrimental impact.
Sustainability	The concept of meeting the needs of the present without compromising the ability of future generations to meet their own needs.
Swale	A shallow vegetated channel designed to convey, treat and occasionally store surface water, and may also permit infiltration.
Timber	Wood that has been processed to create beams or planks.
Time to peak	Time period (length) of rainfall that will generate peak flow in a drainage or watercourse system.
Uncertainty	Lack of confidence, possibly due to lack of information or scientific knowledge.
Upland watercourse	Usually flowing through land that is above 250 m above sea level. These are fast-flowing watercourses that drain elevated or mountainous country. They have a rapid drop in elevation, with a fast flow of water, an incised course and a riverbed dominated by bedrock and course sediments.
Uplift	Pressure (from the water) on the underside of a structure that can destabilise the structure.
Washland	Lowland near to a river or other channel used for the temporary storage of floodwater. Often developed for use by the erection of bunds and control structures.
Washout	The mobilisation of materials from a leaky barrier, potentially leading to transport along the watercourse and downstream accumulation at a pinch point.
Watercourse	All burns, cuts, culverts, ditches, drains, dykes, rivers, sluices, sewers, streams and passages carrying or designed to carry water.
Water Framework Directive	Directive 2000/60/EC, commits Member States to achieve good qualitative and quantitative status of all water bodies, and transposed into local legislation across the UK.
Water cycle	The cycle of processes through which water is transferred between atmosphere, land and oceans.
Water management	Temporary measures to control or divert the flow of water along a watercourse or through a waterbody during construction.

Water quality	The physical, chemical and biological properties of water.
Weir	A low dam built across a watercourse to raise the water level upstream, or to control or divert flows.
Wetland	Land that is flooded some of or all of the time with shallow water or saturated soil that supports the growth of aquatic plants.
Whole-life cost	The cost of creating, managing and disposing of an asset over its life, including construction, monitoring, maintenance, repair, refurbishment, replacement and decommissioning.
Working with natural processes	The process of managing flood and coastal erosion risk by protecting, restoring and emulating the natural regulating function of catchments, rivers, floodplains and coasts.

A2.2 ABBREVIATIONS AND ACRONYMS

AEP	Annual exceedance probability
AGOL	ArcGIS Online tool
AONB	Area of Outstanding Natural Beauty
ASSI	Area of special scientific interest
B£ST	Benefits Estimation Tool
BGS	British Geological Survey
BHS	British Hydrological Society
BNG	Biodiversity net gain
BTO	British Trust for Ornithology
CaBA	Catchment based approach
CDM 2015	Construction (Design and Management) Regulations 2015
CEH	Centre for Ecology and Hydrology
CES	Conveyance Estimation System
CIEEM	Chartered Institute of Ecology and Environmental Management
CIWEM	Chartered Institute of Water and Environmental Management
DEFRA	Department for Environment, Food and Rural Affairs
DfI	Department for Infrastructure
DTM	Digital terrain model
EIA	Environmental Impact Assessment
ERIC	Eliminate, reduce, isolate, control
FAG	Flood action group
FCERM	Flood and coastal erosion risk management
FDC	Flood Defence Consent
FDGIA	Flood defence grant-in-aid
FEH	Flood estimation handbook
FIRM	Farm Integrated Runoff Management
FMP	Floodplain Meadows Partnership
FoS	Factor of Safety
FWAG	Farming and Wildlife Advisory Group
GIS	Geographic information system
GSL	Geological Society of London
HER	Historic Environment Record
HERoNI	Historic Environment Record of Northern Ireland
HLC	Historic landscape characterisation
HOST	Hydrology of soil types
HSE	Health and Safety Executive
HSENI	HSE Northern Ireland
ICE	Institution of Civil Engineers
IDB	Internal Drainage Board
IIRC	International Integrated Reporting Council
INNS	Invasive non-native species
ISNI	Invasive Species Northern Ireland
LCA	Landscape-character assessment
LET	Landowner engagement team

LiDAR	Light detection and ranging
LLFA	Lead local flood authority
LNR	Local nature reserve
MCH	Multi-Coloured Handbook
NbS	Nature-based solutions
NERC	Natural Environment Research Council
NIEA	Northern Ireland Enviroment Agency
NFM	Natural flood management
NGO	Non-governmental organisation
NNR	National Nature Reserve
NNSS	Non-native species secretariat
NRW	Natural Resources Wales
NWRM	Natural water retention measures
OS	Ordnance Survey
PDM	Probability distributed model
PPE	Personal protective equipment
PRAGMO	Practical river restoration appraisal guidance for monitoring options
PRONI	Public Office of Northern Ireland
PRoW	Public right of way
PSRA	Public safety risk assessment
PV	Present value
ReFH	Revitalised flood hydrograph
RFCC	Regional Flood and Coastal Committee
RMA	Risk management authorities
RRC	River Restoration Centre
RSPB	Royal Society for the Protection of Birds
RSUDs	Rural sustainable drainage systems
SAC	Special area of conservation
SAFAG	Shipston Area Flood Action Group
SEPA	Scottish Environment Protection Agency
SHE(W)	Safety, health and environmental (and welfare)
SMART	Specific, measurable, achievable, realistic, time-limited
SSSI	Site of special scientific interest
STEPS	Severn Trent Environmental Protection Schemes
SuDS	Sustainable drainage systems
SWAT	Soil and Water Assessment Tool
WFD	Water Framework Directive
WWNP	Working with natural processes
UKCP	United Kingdom climate projection
UN SDG	United Nations Sustainable Development Goals
USBR	United States Bureau of Reclamation
USDA	United States Department of Agriculture
UV	Ultraviolet

A2.3 NOTATION

A	Catchment area
A_{or}	Cross-sectional area of orifice
B	Width perpendicular to flow direction
C	Runoff coefficient
C_d	Discharge coefficient for orifice flow
C_w	Discharge coefficient for weir flow
d	Diameter of driven stakes
d_{50}	Size of stone (for which 50% of the material is finer by weight)
D	Diameter of logs
e	Embedded length of driven stakes
E	Embedded length of logs
E	Exceedance volume
f	Soil infiltration rate
g	Acceleration due to gravity (= 9.81m/s²)
I	Infiltration volume
K_a	Active earth pressure coefficient
K_p	Passive earth pressure coefficient
l	Length of driven stakes
L	Length of logs
M	Mass
n	Manning's roughness value
n	Number of driven stakes
N	Number of logs
p	Percentage of solids in a bundle
q	Discharge per unit width
q_e	Exceedance flow rate
q_i	Soil infiltration rate
q_o	Outflow rate
Q	Discharge (or flow rate)
R	Rainfall depth
S	Storage capacity
S	Slope
T	Storm duration
V	Flow velocity
V	Volume
V_s	Submerged volume
W	Weight
x	Exposed height of driven stakes
y	Depth of water
γ_s	Unit weight of soil
ρ_s	Density of soil
ρ_t	Density of timber/wood
ρ_w	Density of water
φ'	Friction angle of soil

Courtesy Rob Dryden, Environment Agency

A3 SUPPORTING INFORMATION

Contents

Appendix A3 Supporting information

Please note that the content of the following tables is not exhaustive, data sources are subject to change and terminology used can vary locally.

TABLE A3.1 Prompt list of hazards and control measures

Hazard	Who might be harmed and how?	Control measures
Location and access		
Access for works	Landowner, occupier, inspector or maintainer has difficulty gaining access for construction, installation, monitoring or management leading to departure from the work plan or postponement of tasks.	Locate measures in areas with safe, permitted access or easement for routine tasks during dry or low flow conditions, and for emergency responses during wet or high-flow conditions.
Access by public	Public, particularly children, climb, walk on, enter or interfere with measures with risk of injury.	Locate measures with care near PRoW, public open space or residential areas. Discourage or prevent unauthorised access if there is a risk of harm (eg warning signs, fencing or dense vegetation).
Measures obscured by dense vegetation or crop growth	Inspector or maintainer struggles to locate measure, leading to fatigue or going off track.	Provide field markers or signage to facilitate identification of measures that may become difficult to spot due to vegetation growth.
Instability		
Breach of impounding measure	Breach of impounding NFM measure leads to sudden release of water, deep and/or fast flows, injury or drowning of public, livestock or wild animals.	Avoid storing large volumes of water immediately upstream of a flood risk area, where a sudden release could cause flooding.
Blockage/washout and flooding	Blockage/washout of NFM measure leads to blockage of another structure, restricting flow and causing water levels upstream to rise and flood property, infrastructure or land with risk to life of public, livestock or wild animals.	Avoid locating leaky barriers immediately upstream of a pinch point (eg bridge or culvert), where washout of materials could cause blockage and flooding. Avoid locating leaky barriers upstream of roads and railways where washout of materials could collision or derailment.
Increased infiltration and ground saturation	Increased saturation of infrastructure assets such as embankments or steep slopes may lead to ground instability or movement, with risk to life of landowner, occupier or public.	Avoid locating measures at toe of embankments, near buildings, or where saturation could lead to instability.
Water		
Deep or fast-flowing water	Landowner, occupier, inspector, maintainer, public, livestock or wild animals knocked off balance, washed away, trapped underwater or trapped against a structure, leading to drowning. Combinations of water depth and velocity that cause a hazard to people are given in Defra (2006).	Avoid creating water depth exceeding one metre and/or install scour protection to prevent excessive scour. Provide warning signs for deep water. Provide sloping banks or ramps to allow animals to escape from deep water.
Flashy catchment	Landowner, occupier, inspector or maintainer working in a watercourse caught unaware by a sudden increase in water depth or flow velocity and unable to escape.	Avoid entering water during high-flow conditions or rainfall, or if rain is forecast. Work in, over or near water during low flow conditions or drier weather.
Cold water	Landowner, occupier, inspector, maintainer enters water intentionally or unintentionally, suffers cold water shock, heart attack, hypothermia, drowning.	Avoid entering water if reasonably practicable. Work in, over or near water during warmer weather. Provide water safety training.

continued...

TABLE A3.1 Prompt list of hazards and control measures (contd)

Hazard	Who might be harmed and how?	Control measures
Structures		
Entrapment (eg between logs of leaky barrier)	Landowner, occupier, inspector, maintainer, public, livestock or wild animals entrapped within or against structures, leading to injury or drowning.	Avoid creating narrow gaps or pinch points between logs or timber, provide safe access for maintenance from channel bed, provide stock-proof fencing to limit access by animals.
Slippery, soft, uneven or steep surfaces	Landowner, occupier, inspector, maintainer, public, livestock or wild animals suffer slips, trips and falls, leading to injury or death.	Locate measures in areas with safe access during both dry and wet conditions. Ensure adequate footwear is worn that protects the ankles. Steel toe capped boots might be required in certain situations. Consider providing simple aids such as rope grabrail, earth steps or gravel surfacing.
Materials and tools		
Working at height	Construction staff overreach or fall from height while installing measures (eg driven stakes, fixings), leading to injury or death.	Eliminate or reduce the need for materials or fixings installed from height. If unavoidable, provide safe working platform.
Manual handling	Construction staff handle large, heavy or awkward materials during construction or maintenance, leading to injury.	Use smaller or lightweight materials if reasonably practicable. Assess risks and consider need for lifting equipment.
Work equipment	Construction staff use mobile, heavy or sharp tools, plant or machinery incorrectly leading to injury or death.	Eliminate or reduce need to process materials by using readily available sizes if possible. Process materials in sheltered location. Wear appropriate PPE, tools should be clearly visible, adequate training should be provided and safe working distance should be ensured when swinging equipment.
Farm machinery or operations	Construction staff work near ongoing farm operations, leading to injury or death.	Isolate by avoiding work near farm operations or machinery, timing work or isolate by marking out a clear safety zone.
Sharp materials	Construction staff, inspectors, maintainers or public contact sharps, eg sawn off branches, stakes, anchors, leading to injury.	Avoid creating puncture hazards. Round off or protect the exposed ends of embedded stakes or anchors. Wrap tools, equipment and materials during transit.
People and animals		
Volunteers	Volunteers, community groups and young people may have little experience or be unskilled, have little awareness of hazards or not be physically fit.	Consider who will construct/install measures, their physical fitness, knowledge and skills, ability to lift large materials or use tools, the need to work in, near or over water or on soft ground, ease of construction. Provide training and briefings before starting work.
Livestock	Construction staff, inspectors, maintainers approached by animals, leading to bites, trampling, injury or death.	Obtain local knowledge, relocate animals temporarily during construction/installation if possible, or install temporary fencing.
Vandalism	Intentional damage of measures leads to structural failure, breach or washout, causing blockage or flooding and risk to life for public, livestock or wildlife.	Eliminate or reduce the use of valuable materials such as metals if located near residential areas, public open spaces or PRoW.

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TABLE A3.1 Prompt list of hazards and control measures (contd)

Hazard	Who might be harmed and how?	Control measures
Chemical or biological		
Biological hazards	Insects or harmful plants cause stings, bites, cuts or burns (eg wasps, bees, nettles, brambles, giant hogweed).	Avoid locating measures near harmful plants or treat and remove plants before starting work.
Contaminated water, sediment or other materials (eg discarded needles)	Construction staff, contact with contaminated water or mobilisation of sediment, potentially leading to burns, illness or death.	Obtain local knowledge, PPE (eg safety boots, gloves), awareness and good hygiene.
Weil's disease (Leptospirosis)	Waterborne disease caused by bacteria in rat or cattle urine. Humans may be infected if open cuts or mucus membranes come into contact with urine or contaminated water.	Awareness and good hygiene.
Lyme disease	Tick bites leading to illness or death.	Awareness.

TABLE A3.2 Consulting a professional

Topic	When to consult	Type of organisation (Section A3.7)	Relevant professional or professional organisation
Flood risk specialist/ hydrologist/ hydraulic modeller	Need to understand where to work to achieve maximum flood risk benefits, understand the hydrology of the catchment, calculate flood risk benefits of the project and understand flood risk/ undertake a flood risk assessment	Flood risk authorities.	British Hydrological Society (BHS): www.hydrology.org.uk Chartered Institute of Water and Environmental Management (CIWEM): www.ciwem.org/ Institution of Civil Engineers (ICE): www.ice.org.uk/
Water environment	Works in or near a river.	Statutory and non-statutory water environment consultees.	BHS CIWEM The Geological Society of London (GSL): www.geolsoc.org.uk/
	Works affecting overland flow routes or volumes.		
	Works below ground (eg excavation into a floodplain).		
Geomorphology	To provide useful understanding of river and catchment scale physical processes, including advice on the selection and location of NFM measures; particularly in relation to opportunities, constraints and consideration of natural processes and sediment dynamics. Recommended for works in or near a river or river catchment with known erosion or deposition problems.	Statutory and non-statutory water environment consultees.	British Society for Geomorphology: www.geomorphology.org.uk/ CIWEM Royal Geographical Society: www.rgs.org/
Ecology	Works in or near statutory nature conservation designated sites	Statutory nature conservation organisation.	Ecologists Chartered Institute of Ecology and Environmental Management: cieem.net/i-need/
	Works in or near non-statutory nature conservation designated sites	Statutory nature conservation organisation, nature conservation organisation(s), local authority.	
	Works in or near known or suspected protected plant or animal species	Statutory nature conservation organisation, nature conservation organisation(s).	
	Works in or near known or suspected priority habitats or species		
	Invasive non-native species		Ecologists (as above) or invasive species management company.

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TABLE A3.2 Consulting a professional (contd)

Topic	When to consult	Type of organisation (Section A3.7)	Relevant professional or professional organisation
Landscape and amenity	Works in or near statutory designated sites.	Statutory landscape consultees	Landscape architects The Landscape Institute: www.landscapeinstitute.org/member-content/li-registered-practices/
	Works in or near non-statutory designated sites.	Statutory landscape consultees, local authority	
Historic environment	Works in or near known or unknown historic environment features, or considerations related to historic landscape characterisation.	Statutory historic environment consultees	Historic environment practitioners, conservation specialists and archaeologists; can specialise in buildings or features below or above ground. Chartered Institute for Archaeologists: www.archaeologists.net/ Institute for Historic Building Conservation: www.ihbc.org.uk/
Waste	If waste may be generated on site.	Statutory waste management organisations	Chartered Institution of Wastes Management directory: www.circularonline.co.uk/directory/ CL:AIRE: www.claire.co.uk
Contamination	Known or suspected land or material contamination.	Local authority, statutory contaminated land regulatory organisations.	Contaminated land consultant/organisation. Specialist in Land Condition register: www.silc.org.uk/silc-register/
Civil engineering	Design of high risk or complex bunds or leaky barriers where the sudden release of water could cause flooding or risk to life.	None	CIWEM ICE
Geotechnical engineering	Works near slopes, buildings, retaining walls or other structures, or at risk of groundwater flooding, heave, subsidence or ground instability..	None	ICE GSL
Geo-environmental engineering	Risk of ground or water contamination, upwards from the ground into the measure, or down into groundwater – avoid creating new pathways for pollution or mobilising existing pollution.	None	GSL
Legal advice	Legal issues or advice	None	The Law Society: https://solicitors.lawsociety.org.uk/ Chambers and Partners: https://chambers.com/

TABLE A3.3 Organisations linked to NFM within the UK

Name given to group of organisations in this manual text	Description of the group of organisations	Relevant organisation within this group in[1]:			
		England	**Northern Ireland**	**Scotland**	**Wales**
Statutory nature conservation organisation	Manage and provide consents for statutory designated nature conservation sites. Can also be responsible for some non-statutory designated nature conservation sites. Provide wildlife and species licences for protected species.	Natural England	Northern Ireland Environment Agency	NatureScot	NRW
Nature conservation organisation	Usually specialise in a specific type of wildlife and may be local groups with local knowledge.	Various, for example, RSPB, Wildlife Trusts, The Rivers Trust, Amphibian and Reptile Groups, National Trust/ National Trust for Scotland. Many more can be found online.			
		Bat Conservation Trust	Northern Ireland Bat Group	Bat Conservation Trust/ The Scottish Bat Project	Bat Conservation Trust/ Wales Bat Project
		Angling Trust	Ulster Coarse Fishing Federation	Fisheries Trust	Fishing in Wales
Local authority	Organisations that would receive and approve/reject applications for planning permission Responsible for designating and protecting some non-statutory nature conservation sites and managing (public) rights of way.	Local planning authority – can be a local authority or national park authority	Local councils	Local authorities National Park Authority	Local planning authority – can be a local council or National Park Authority

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TABLE A3.3 Organisations linked to NFM within the UK (contd)

Name given to group of organisations in this manual text	Description of the group of organisations	Relevant organisation within this group in[1]:			
Flood risk authority	Organisations that manage flood risk and provide permits or consents for works that may affect flood risk, including risk management authorities (RMAs)	Environment Agency (main rivers and strategic overview) LLFA (ordinary watercourses, groundwater and surface water flooding) Other RMAs include: Tier 2 local authorities Water and sewage companies IDBs: https://www.ada.org.uk/member_type/idbs/	Department for Infrastructure Rivers (DfI Rivers) Environmental Protection Agency (EPA)	SEPA (strategic flood risk management authority) Responsible authorities (including local authorities, Scottish Water, Scottish Government, Forestry and Land Scotland and National Parks)	NRW LLFA Other RMAs include: Tier 2 local authorities Water and sewage companies IDBs
Non-statutory water organisation		Canal and River Trust The Rivers Trust	The Rivers Trust	Scottish Canals The Rivers Trust	Canal and River Trust The Rivers Trust
Water environment regulatory authority	Organisations that regulate the wider water environment	Environment Agency Defra Water and sewerage companies	EPA Defra Water and sewerage companies	SEPA Defra Water and sewerage companies	NRW Defra Water and sewerage companies
Statutory historic environment organisation	Organisations that provide advice and manage consents for statutory heritage designations	Historic England	Northern Ireland Department of Communities, Historic Environment Division	Historic Environment Scotland	Cadw
	Local council/authority statutory stakeholders	Conservation or heritage officers (for listed buildings, conservation areas and non-designated built heritage assets) and archaeological officers (for archaeological assets and historic landscapes)			
Heritage groups	Organisations that can be national or local and specialise in an aspect(s) of the historic environment	Numerous, including for example the National Trust/National Trust for Scotland, Garden's Trust, Heritage Alliance, Twentieth Century Society, and local history/historical societies. Many more can be found online.			

continued...

TABLE A3.3 Organisations linked to NFM within the UK (contd)

Name given to group of organisations in this manual text	Description of the group of organisations	Relevant organisation within this group in[1]:			
Statutory landscape organisation	Organisations that provide advice and manage consents for statutory landscape designations	Natural England National Park Authorities	Department of Agriculture, environment and rural affairs (DAERA) Local authorities	NatureScot National Park Authorities	NRW National Park Authorities Local authorities
Landscape organisation	Organisations that can be national or local and specialise in an aspect(s) of the landscape	Numerous, including for example the National Trust/National Trust for Scotland, Garden's Trust and local organisations with management responsibilities for areas valued for landscape, amenity and recreation. More can be found online.			
Statutory waste regulatory organisation	Government departments or organisations that manage waste policy, provide advice and manage licences/permits.	Environment Agency	DAERA	SEPA	NRW
Statutory contaminated land regulator	Organisations that regulate identified contaminated land sites (usually identified by local councils)	Natural England	Northern Ireland Environment Agency	SEPA	NRW
Flood forum	Organisations that help, support and represent people at risk of flooding	National Flood Forum	N/A	The Scottish Flood Forum	National Flood Forum
Flood interest group	Grass roots organisations made up of the local community, who are motivated to reduce flood risk.				
Forestry authority	Organisation responsible for activities such as woodland creation, felling and research.	Forestry Commission	Forest Service	Scottish Forestry	NRW

continued...

Note

1 Note that the contents of this table is not exhaustive, the names and roles of these organisations is subject to change, and terminology used can vary locally.

TABLE A3.4 Useful websites to assist in understanding the catchment[1] (contd)

Topic	Sub-topic	England	Wales	Scotland	Northern Ireland
General environment (may also include data for topics below)		Defra's Magic: https://magic.defra.gov.uk/ Environment Agency data from what was 'What's in Your Backyard': http://apps.environment-agency.gov.uk/wiyby/default.aspx LandIS Digital Soil Datasets: http://www.landis.org.uk/data/	Defra's Magic: https://magic.defra.gov.uk/ The Lle Geo-Portal for Wales: https://lle.gov.wales/home?lang=en Data sources (available in English and Welsh): https://naturalresources.wales/evidence-and-data/maps?lang=cy LandIS digital soil datasets: http://www.landis.org.uk/data/	Defra's Magic: https://magic.defra.gov.uk/ NatureScot data sources: https://www.nature.scot/information-hub/snhi-data-services SiteLink map: https://sitelink.nature.scot/map Scotland's environment map: https://map.environment.gov.scot/sewebmap/	Accessing environmental information website: https://www.nidirect.gov.uk/articles/accessing-environmental-information Natural environment map viewer: https://appsd.daera-ni.gov.uk/nedmapviewer
Water environment and flood risk	Catchment context (topography and land use)	OS mapping: https://www.bing.com/maps Google Earth software Copernicus CORINE land cover mapping: https://land.copernicus.eu/pan-european/corine-land-cover			
	Hydrology (rainfall and flow data)	National River flow archive monitoring data: https://nrfa.ceh.ac.uk/ CEH: https://www.ceh.ac.uk/data Met Office historic station data: **https://www.metoffice.gegov.uk/research/climate/maps-and-data/historic-station-data**			

continued...

Note

* The contents of this table is not exhaustive, the data sources are subject to change, and terminology used can vary locally.

TABLE A3.4 Useful websites to assist in understanding the catchment[1] (contd)

Topic	Sub-topic	England	Wales	Scotland	Northern Ireland
Water environment and flood risk	Flood risk	Environment Agency flood map for planning: https://flood-map-for-planning.service.gov.uk/ Environment Agency long-term flood risk map: https://flood-warning-information.service.gov.uk/long-term-flood-risk Environment Agency and NRW working with natural processes mapping: https://naturalprocesses.jbahosting.com/Map Defra hydrology data explorer: https://environment.data.gov.uk/hydrology/explore Environment Agency AIMS asset bundle dataset: https://data.gov.uk/dataset/a3861a23-78a1-438d-8c36-1f9f1133c572/aims-asset-bundle	NRW flood maps: https://naturalresources.wales/evidence-and-data/maps/long-term-flood-risk/?lang=en Environment Agency and NRW working with natural processes mapping: https://naturalprocesses.jbahosting.com/Map	SEPA flood maps: https://www.sepa.org.uk/environment/water/flooding/flood-maps/	Flood maps: https://www.infrastructure-ni.gov.uk/topics/rivers-and-flooding/flood-maps-ni Water level network: https://www.infrastructure-ni.gov.uk/articles/dfi-rivers-water-level-network
		Also see documents, reports and maps produced by other RMAs on a regional/catchment basis available through their websites.			
	Water quality	Catchment data explorer: https://environment.data.gov.uk/catchment-planning/ Drinking water safeguard zones: https://environment.data.gov.uk/farmers/	Water environment data: https://naturalresources.wales/guidance-and-advice/environmental-topics/water-management-and-quality/?lang=en	Water environment data: https://www.sepa.org.uk/environment/water/	Water environment data: https://www.daera-ni.gov.uk/articles/niea-and-water-pollution
		Defra data service platform: https://environment.data.gov.uk/			

continued...

TABLE A3.4 Useful websites to assist in understanding the catchment[1] (contd)

Topic	Sub-topic	England	Wales	Scotland	Northern Ireland
Water environment and flood risk	Geology	Geological mapping: https://www.bgs.ac.uk/map-viewers/geology-of-britain-viewer/			Geological mapping: https://www2.bgs.ac.uk/gsni/data/index.html British Geological Survey (BGS) mapping shown for England, Scotland and Wales
Geomorphology	Morphological features	Aerial imagery to identify morphological features and long-term channel change: Google Earth software: https://www.google.com/maps OS mapping: https://www.bing.com/maps			
	Long-term channel change	National Library of Scotland georeferenced historic maps: https://maps.nls.uk/geo/explore/#zoom=15&lat=57.63487&lon=-3.21159&layers=11&b=1 Old maps online: https://www.oldmapsonline.org/			
Ecology	Designated sites, habitats and species	See General environment NBN Atlas for species records: https://nbnatlas.org/			
		Some designations are only available by viewing local plan documents for the relevant local planning authority (available online).	NBN Atlas Wales for species records contains data https://wales.nbnatlas.org/	NBN Atlas Scotland for species records contains data: https://scotland.nbnatlas.org/	NBN Atlas Northern Ireland: https://northernireland.nbnatlas.org/
	Invasive non-native species	See *Designated sites, habitats and species*			
		Non-native species secretariat for data, factsheets and resources to assist in identification: http://www.nonnativespecies.org//index.cfm?pageid=356			

continued...

TABLE A3.4 Useful websites to assist in understanding the catchment[1] (contd)

Topic	Sub-topic	England	Wales	Scotland	Northern Ireland
Landscape and amenity	National landscape character assessments	See *General environment* National character area profiles: https://www.gov.uk/government/publications/national-character-area-profiles-data-for-local-decision-making/national-character-area-profiles	See *General environment* LANDMAP: https://naturalresources.wales/guidance-and-advice/business-sectors/planning-and-development/evidence-to-inform-development-planning/landmap-the-welsh-landscape-baseline/?lang=en National landscape character areas: https://naturalresources.wales/evidence-and-data/maps/nlca/?lang=en	See *General environment* Scottish landscape character types: https://www.nature.scot/professional-advice/landscape/landscape-character-assessment National Scenic Areas of Scotland https://www.gov.scot/publications/national-scenic-areas-of-scotland-map/	See General environment NI regional LCA: https://www.daera-ni.gov.uk/services/regional-landscape-character-areas-map-viewer NI LCA including geodiversity and biodiversity profiles: http://www.daera-ni.gov.uk/search/type/publication?query=LCA
Historic environment	Designated assets	See *General environment*	The Lle Geo-Portal for Wales: https://lle.gov.wales/home?lang=en	Historic Environment Scotland map search: https://hesportal.maps.arcgis.com/apps/Viewer/index.html?appid=18d2608ac1284066ba3927312710d16d	Heritage datasets are available in GIS online as open data by searching the Northern Ireland Department of Communities Historic Environment Division: https://www.opendatani.gov.uk/dataset?organization=department-for-communities-historic-environment-division
		See *Non-designated assets for HER*			

continued...

TABLE A3.4 Useful websites to assist in understanding the catchment[1] (contd)

Topic	Sub-topic	England	Wales	Scotland	Northern Ireland
Historic environment	Non-designated assets	HER – maintained by local planning authorities in England and access to these records is through the individual authorities.	HER – maintained by the four regional Welsh archaeological trusts on behalf of the Welsh Ministers through the Welsh Historic Environment Record known as Archwilio: https://archwilio.org.uk/arch/	HER – maintained by local authorities but are also centrally registered by Historic Environment Scotland in the National Record of the Historic Environment known as Canmore: https://canmore.org.uk/	HER – maintained by the Department for Communities through the Historic Environment Record of Northern Ireland (HERoNI): https://www.communities-ni.gov.uk/topics/historic-environment/historic-environment-record-northern-ireland-heroni
		Historic maps: https://www.old-maps.co.uk/#/ National Library of Scotland (for Great Britain): https://maps.nls.uk/			Public Record Office of Northern Ireland (PRONI) historical maps: https://www.nidirect.gov.uk/services/search-proni-historical-maps-viewer
Contamination	Historic maps, historic (closed) landfill sites (and active/inactive landfill sites where available)	Historic landfill sites: https://data.catchmentbasedapproach.org/datasets/historic-landfill-sites/explore Historic maps: https://www.old-maps.co.uk/#/	Historic landfill sites on the Lle geo-portal for Wales: https://lle.gov.wales/home?lang=en	Historic landfill sites: https://data.gov.uk/dataset/9cf13560-e7cc-443c-827a-cccd4406479e/historic-landfill-sites	See *PRONI Historical Maps*
		See National Library of Scotland (for Great Britain) and Historic maps in Historic environment.			

courtesy River Restoration Centre

A4 HYDROLOGY AND HYDRAULICS

Contents

Appendix A4 Hydrology and hydraulics

A4.1 PEAK FLOW ESTIMATION AND HYDRAULIC EQUATIONS

BOX A4.1 Peak flow for mean annual flood accessible via the Greenfield runoff estimator tool (from Marshall and Bayliss, 1994)

$$Q_{BAR} = 0.00108 AREA^{0.89} \times SAAR^{1.17} \times SOIL^{2.17} \quad \text{A4.1}$$

Where:

Q is peak flow at the point of interest for the mean annual flood with a 1 in 2.3 chance of occurring in any year (m^3/s)

AREA is the contributing area draining to the point of interest in km^2

SAAR is the standard average annual rainfall for the period 1941 to 1970 in mm

SOIL is the soil index, based on the *Flood Studies Report* soil maps or the WRAP map, which represent the proportion of runoff from the catchment (Boorman *et al*, 1995). This can be automatically extracted by selecting the catchment in the greenfield runoff rate estimation tool and can be modified based on any observed date or local and professional judgement

All relevant data can be readily accessed for the UK via the Greenfield runoff rate estimation tool: **https://www.uksuds.com/tools/greenfield-runoff-rate-estimation**

The catchment area can be downloaded from the FEH website for areas > 0.5 km^2 in size. Alternately, catchment areas can be determined manually through analysis of the OS mapping contours (1:50000 or 1:25000), GIS hydrological mapping techniques.

FEH: **https://fehweb.ceh.ac.uk/**

Alternatively, catchment areas can be determined manually through analysis of the OS mapping contours (1:50000 or 1:25000) using GIS hydrological mapping techniques.

BOX A4.2 **FEH statistical method peak flow for median annual flood (after Kjeldsen *et al*, 2008) accessible via the Greenfield runoff estimator tool**

$$Q_{MED} = 8.3062\, AREA^{0.851} \times 0.1536^{\frac{1000}{SAAR}} \times FARL^{3.4451} \times 0.0460^{BFIHOST^2} \quad \text{(A4.2)}$$

Where:

QMED is peak flow at the point of interest for the median annual flood with approximately a 1 in 2 chance of occurring in any year (m^3/s)

AREA is the contributing area draining to the point of interest in km^2

SAAR is the standard average annual rainfall for the period 1941 to 1970 in mm

FARL is a reservoir attenuation function and is set at 1.0 and so has effectively been ignored. This means that areas with water bodies which attenuate the runoff will over-predict the greenfield runoff rate

BFIHOST is the base flow index derived using the HOST classification. This can be automatically extracted from the FEH website and can be modified based on any observed date or local and professional judgement.

All relevant data can be readily accessed for the UK via the Greenfield runoff rate estimation tool: **https://www.uksuds.com/tools/greenfield-runoff-rate-estimation**

The catchment area can be downloaded from the FEH website for areas > 0.5 km^2 in size. Alternately, catchment areas can be determined manually through analysis of the OS mapping contours (1:50000 or 1:25000), GIS hydrological mapping techniques.

FEH: **https://fehweb.ceh.ac.uk/**

Alternatively, catchment areas can be determined manually through analysis of the OS mapping contours (1:50000 or 1:25000) using GIS hydrological mapping techniques.

BOX A4.3 **ReFH time to peak (T_p)**

$$Tp\ (0) = 4.270 * DPSBAR\text{-}0.35\ PROPWET\text{-}0.80\ DPLBAR0.54\ (1+URBEXT)\text{-}5.77 \quad \text{(A4.3)}$$

Where:

DPSBAR is the mean drainage slope (m/km)

PROPWET is the proportion of time catchment soil moisture deficit was below 6mm during the period 1961 to 1990. Typically in a range 0.0 to 1.0

DPLBAR is the mean drainage path length (km)

URBEXT is the proportion of the urban extent within the catchment

All physical characteristics can be extracted from the FEH website for catchments > 0.5 km^2 or scaled down for smaller catchments where terrain data does not allow calculation of these parameters.

FEH: **https://fehweb.ceh.ac.uk/**

BOX A4.4 **Flood hazard rating (after Surendran *et al*, 2008)**

$$HR = d.(v + n).DF \quad (A4.4)$$

Where:

HR = (flood) hazard rating

d = depth of flooding (m)

v = velocity of floodwaters (m/sec)

n = a constant of 0.5

DF = debris factor (0, 0.5, 1 depending on probability that debris will lead to a hazard)

BOX A4.5 **Simple approach to calculate basic weir flow for exceedance of bund features**

$$Q = C_d\, b\, h^{1.5} \quad (A4.5)$$

Where:

Q is the volumetric flow (m^3/s)

C_d is a coefficient typically between 0.8 and 1.2 for natural ground

b is the length of the weir (can be set to 1 m for a nominal weir)

h is the depth of water overtopping the weir crest/top of bund/top of barrier (m)

It can also be approximated using the following when fully rough flow influenced by roughness akin to open channel flow conditions are expected.

$$C_d = \frac{\sqrt{(1-m)}\, d^{0.67}}{n\sqrt{DX}} \quad (A4.6)$$

Where:

d is the average depth of flow (m)

DX is the distance between upstream and downstream (m)

n is the Manning's n for region of flow (eg 0.1)

m is the modular limit (eg 0.8)

BOX A4.6 **Simple approach to calculate orifice-type flow under a leaky barrier**

$$Q = C_d\, A\sqrt{2gh} \quad (A4.7)$$

Where:

Q is the volumetric flow (m^3/s)

A is the area of the opening of the orifice of opening under the leaky barrier (m^2)

g is accelerating from gravity at 9.81 m/s^2

h is the water depth or hydraulic head acting on the centreline of the opening

C_d is a coefficient typically between 0.6 for a circular shape increasing up to 0.8 for a rectangular one

A4.2 FLOW ESTIMATION METHODS AND FLOOD IMPACT ASSESSMENT

TABLE A4.1 Methods to estimate flow for NFM

Method	Flood flow estimation		Low flow estimation	Recommended catchment application	Data requirements	Reference
	Peak runoff	*Runoff volume/ hydrograph*				
Rational/ modified rational method	✓			Small catchments < 8ha Care should be taken highly urban or permeable catchments	Delineated catchment area from FEH website, or locally assessed through contour mapping. Land cover to estimate soil runoff coefficient.	HR Wallingford (1981)
IH124	✓			Small catchments < 50ha Care should be taken in highly urban or permeable catchments		Marshall and Bayliss (1994) Greenfield runoff rate estimation
FEH statistical method	✓			Catchments > 25 km² Care should be taken for small catchments 0.5 km² – 25 km²	Ideally gauged data but can be also be calculated from physical catchment descriptors from FEH web service.	CEH (1999) and updated methods in Kjeldsen *et al* (2014)
Lumped rainfall-runoff modelling such as ReFH/ReFH2	✓	✓		Care should be taken for small catchments 5 km² – 25 km², highly urban or permeable catchments		Kjeldsen and Fry (2006) and Kjeldsen *et al* (2014) Access through software, eg CEH, Flood Modeller, Infoworks
Conceptual rainfall-runoff modelling	✓	✓	✓	Any size of catchment with data Useful for permeable or more complex hydrological responses Requires experienced hydrologist	Gauged data in catchment or a proxy gauge and catchment to help calibrate the various parameters.	Moore (2007) GLUE uncertainty modelling of lumped hillslope model (Metcalfe *et al*, 2017b)
Semi-distributed rainfall-runoff	✓	✓	✓			Beven and Freer (2001) Arnold *et al* (2012)
Fully-distributed rainfall-runoff	✓	✓	✓			For example MIKE-SHE software, DHI (2017)
Direct rain to grid in 2D hydraulic models	✓	✓		Any size of catchment but suits larger scale Only represents overland flow and loss to infiltration. Less suitable for very permeable catchments Needs experienced hydrologist/hydraulic modeller	National scale topographic, soil, landcover and rainfall datasets.	Hankin *et al* (2019)

continued...

TABLE A4.1 Methods to estimate flow for NFM (contd)

Method	Flood flow estimation		Low flow estimation	Recommended catchment application	Data requirements	Reference
	Peak runoff	*Runoff volume/ hydrograph*				
Flow routing techniques –spreadsheet based	✓	✓		Any size but tending towards simpler and smaller catchments < 25 km^2 as the number of subcatchments limited to six in standard tool	Hydrograph estimation for each subcatchment such as ReFH.	Nicholson *et al* (2019)
Flow routing techniques – model based	✓	✓		Any size but suited towards more complex and larger-scale catchments > 25 km^2	Typical channel section, slope and floodplain survey or topographic data for each subcatchment.	CES/AES Routing methods Muskingham routing in 1D hydraulic software
Low flow gauge record analysis			✓	Any size	Long-term gauge data	National River Flow Archive: **https://nrfa.ceh.ac.uk/** Methods in Shaw *et al* (2011)
Low Flows 2 Software			✓	Any size	Ideally gauge data. Can also be calculated from physical catchment descriptors from FEH website	Wallingford Hydrosolutions (2012) Zaidman *et al* (2002)

TABLE A4.2 Hydraulic and hydrological tools to assess flood impacts for NFM

Method	Flood impacts					Suitability for assessing NFM measures				Catchment application requirements	Reference
	Water level/ depth	*Overland flow and velocities*	*Subsurface hillslope flows*	*Hazard rating*[1]	*Flood extent*	*Runoff management*	*Runoff storage*	*Floodplain reconnection*	*Leaky barriers*		
Basic hydraulic calculations for open channel flow	✓	✓			(✓) Floodplain width at section only	✓ Local site only	✓ Local site only	✓ Local site only		Suitable for site scale Topographic information required Requires some mathematical experience	**Section 14.2.1**
Basic hydraulic calculations for hydraulic structures	✓	✓				✓ Local site only	✓ Local site only	✓ Local site only	✓ Local site only		**Section A4.1** for application to design.
1D physical-based cross-section	✓	✓			(✓) Floodplain width at section only	✓ Local site only	✓ Local site only	✓ Local site only		Suitable for at site scale Topographic survey and flow estimation required Software freely available but unsupported Requires no mathematical experience	AES/CES roughness software tool: **http://www.river-conveyance.net/**
Flow routing techniques – spreadsheet or model based		✓	(✓) When combined with rainfall-runoff			✓	✓			Suitable for small catchments < 5 km^2 or larger catchment with a few tributaries Catchment area and flow estimation required Requires some mathematical experience	Nicholson *et al* (2019) Spreadsheet software available through the Environment Agency, eg Muskingum Routing methods Access through hydraulic software, eg Flood Modeller, Infoworks

continued...

TABLE A4.2 Hydraulic and hydrological tools to assess flood impacts for NFM (contd)

Method	Flood impacts					Suitability for assessing NFM measures				Catchment application requirements	Reference
	Water level/ depth	*Overland flow and velocities*	*Subsurface hillslope flows*	*Hazard rating*[1]	*Flood extent*	*Runoff management*	*Runoff storage*	*Floodplain reconnection*	*Leaky barriers*		
1D full shallow water equation models	✓	✓	(✓) When combined with rainfall-runoff		(✓) Requires expertise in GIS	(✓) If coupled with rainfall-runoff inflows	(✓) If adjacent/ in-channel modelled	✓	✓	Suitable for all catchments but limited to channel flow paths Topographic survey of channel reach required at regular intervals Requires professional expertise	Any listed in Crowder *et al* (2004)
2D reduced term or diffusion wave models with direct rainfall to terrain	✓	(✓) Calculated but may have greater uncertainty		(✓) Calculated but may have greater uncertainty	✓	✓	✓	✓	(✓) Strategic level only	Suitable for all catchments where deep gravity driven flow can be assumed May be less reliable on steep, shallow flows over slopes Full DTM, soil class and land use data required Only considers infiltration as loss Requires professional expertise	Any reduced term or diuffion software listed in Néelz and Pender (2013)

continued...

TABLE A4.2 Hydraulic and hydrological tools to assess flood impacts for NFM (contd)

Method	Flood impacts					Suitability for assessing NFM measures				Catchment application requirements	Reference
	Water level/ depth	*Overland flow and velocities*	*Subsurface hillslope flows*	*Hazard rating*[1]	*Flood extent*	*Runoff management*	*Runoff storage*	*Floodplain reconnection*	*Leaky barriers*		
2D full shallow water equation models with direct rainfall to terrain	✓	✓		✓	✓	✓	✓	✓	(✓) Strategic level only	Provide better representation for shallow overland flow on hillslopes Full DTM, soil class and land use data required Only considers infiltration as loss Requires professional expertise (**Section A3.2**)	Any full shallow water equation software listed in Néelz and Pender (2013)
1D-2D hydrodynamically linked modelling	✓	✓	(✓) When combined with rainfall-runoff	✓	✓	✓	✓	✓	✓	As above but enables more detailed representation of in-channel structures, eg leaky barriers Requires full channel survey and DTM data Requires professional expertise	Any software with 1D to 2D linking listed in Néelz and Pender (2013)

continued...

TABLE A4.2 Hydraulic and hydrological tools to assess flood impacts for NFM (contd)

Method	Flood impacts					Suitability for assessing NFM measures				Catchment application requirements	Reference
	Water level/ depth	*Overland flow and velocities*	*Subsurface hillslope flows*	*Hazard rating*[1]	*Flood extent*	*Runoff management*	*Runoff storage*	*Floodplain reconnection*	*Leaky barriers*		
Lumped or conceptual rainfall-runoff modelling		✓	✓			✓	✓			Suitable for small to large-scale catchments More accurate consideration of hillslope process and subsurface flows to a given point Requires gauge data and physical catchment characteristics Requires professional expertise	PDM (Moore, 2007) ReFH/ReFH2 (Kjeldsen and Fry (2006) and Kjeldsen *et al* (2014) GLUE uncertainty modelling of lumped hillslope model (Metcalfe *et al*, 2017b)
Semi-distributed rainfall-runoff modelling		✓	✓			✓	✓	(✓) Strategic level may be possible	(✓) Strategic level may be possible	Suitable for small to moderate scale catchments More accurate consideration of hillslope process and subsurface flows to a spatially distributed grid Calibration for larger-scale catchment may impractical. Parameters are often scale dependent Requires gauge data, physical catchment characteristics, and soil horizon data Requires professional expertise	TOPMODEL (Beven and Freer, 2001) SWAT (Arnold *et al*, 2012)

continued...

TABLE A4.2 Hydraulic and hydrological tools to assess flood impacts for NFM (contd)

Method	Flood impacts					Suitability for assessing NFM measures				Catchment application requirements	Reference
	Water level/ depth	*Overland flow and velocities*	*Subsurface hillslope flows*	*Hazard rating*[1]	*Flood extent*	*Runoff management*	*Runoff storage*	*Floodplain reconnection*	*Leaky barriers*		
Fully-distributed rainfall-runoff modelling		✓	✓			✓	✓			As for semi-distributed but more accurate consideration of hillslope process and subsurface flows to a fully-distributed grid and soil horizon	MIKE-SHE software (DHI, 2017)
Combination of any rainfall-runoff modelling technique and 1D-2D or 2D modelling approaches	✓	✓	✓	✓	✓	✓	✓	✓	✓	As above for the relevant combination of methods Combination of hillslope process for rainfall-runoff modelling feeding into floodplain modelling provides fuller assessment to the catchment processes than one approach alone Requires professional expertise	Hankin *et al* (2019) for combined TOPMODEL and JFLOW/HEC-2D modelling of NFM in Swindale, Cumbria Ferguson and Fenner (2020) combined TOPMODEL-HECRAS-Infoworks ICM to model the impacts of hillslope tree planting and in-channel large woody debris in the Asker catchment, Bridport

A4.3 GIS MAPPING ASSESSMENT

GIS methods are a way to plot the likely flow path based on the underlying terrain and soil information. These include two main types of mapping methods:

- Opportunity mapping by overlaying topographic, geology and land use layers to identify areas with suitable physical characteristics for NFM.
- Rolling-ball type methods to establish overland runoff pathways based on available topographic and soil information.

NFM opportunity maps are readily available nationwide in England, Wales, and Scotland. They avoid the need for GIS expertise to create an initial understanding of your catchment. More refined catchment-specific or community-based opportunity mapping may be available for Devon and Cornwall (Environment Agency), Upper Thames (Thames RFCC and Landwise project), Upper River Aire (Environment Agency). See **Section 14.2** for a summary of all available pre-prepared opportunity mapping.

Rolling-ball methods are simplified GIS approaches that assess excess flow using the principles of gravity and storage with limited consideration of evaporation, infiltration, or subsurface flow processes. Despite these shortcomings, these tools are highly useful to quickly plot flow paths at the catchment scale for impermeable catchments and an initial estimate to focus efforts for permeable catchments as well.

Various open source standalone software, open source GIS plugins, and commercial GIS plugins can be used to apply this method. The more detailed the underlying data is, the more insightful the analysis of potential flow paths and stores will be, however, the more detailed the underlying data, the more data intensive the process and more checking is required to verify each pathway.

BOX A4.7 Flow mapping resources

There are existing widely used resources available to help map flow paths, including but not limited to:

- *InVEST 3.7.0* (Sharp *et al*, 2021). Software platform; urban flood risk mitigation model.
- *The floods and agriculture risk matrix: a decision support tool for effectively communicating flood risk from farmed landscapes* (Wilkinson *et al*, 2013)
- *Land Utilisation and Capability Indicator v0.9 (LUCI)* plugin to ArcGIS® (Jackson et al, 2020)
- *Arc Hydro Toolbox* plugin to ArcGIS® (Djokic, 2011)
- *System for Automated Geoscientific Analyses (SAGA) v. 2.1.4* (Conrad et al, 2015). Terrain analysis – hydrology
- SCIMAP (Diffuse Pollution and Flood Water Source Mapping) (Lane et al, 2009). Further refinement on flood hazard generation coming in 2022

In all these tools, the quality and treatment of the input terrain and soil data, and ability to interpret meaningful results, can make the difference in producing useful maps. Key considerations in the selection and use of rolling-ball GIS methods for the four main types of measures are set out in **Table A4.4**.

TABLE A4.3 Considerations and treatment when applying GIS mapping methods

<table>
<tr><th>Consideration</th><th>Floodplain reconnection, river restoration, woodland, and leaky barriers</th><th>Runoff management and storage</th></tr>
<tr><td>Vertical accuracy of terrain data</td><td>National composite LiDAR DTM datasets are accurate to ±0.15 m on open ground.
Check and validate LiDAR DTM datasets in areas of dense vegetation as the remote sensing techniques cannot fully penetrate the canopy.</td><td>National composite LiDAR DTM datasets are accurate to ±0.15 m on open ground.</td></tr>
<tr><td>Resolution of terrain data</td><td colspan="2">National composite LiDAR DTM datasets available at 2 m horizontal resolution. 1 m resolution available for some fluvial floodplains and finer resolutions of 0.5 m and 0.25 m available in some high flood risk areas.
Headwaters and hilltops have less coverage – may require additional survey to provide comparable resolution.
Coarser resolutions of 2 m+ more appropriate for catchment scale to pick up continuous flow paths while avoiding localised ‘noise’ of low depressions and ponds that interrupt local flows. This may need to be resampled to smooth the terrain. There is no set threshold but larger-scale catchment may need to consider up to 50 m resolutions to get meaningful flow path results at manageable data sizes as was used in CEH (1999).
Finer resolutions (< 1 m) are more appropriate for field scale where the local depressions on the hillslope are more important for site location.</td></tr>
<tr><td>Treatment of terrain</td><td>Data smoothing processes can be applied to reduce ‘noise’ created by small depressions and pond features by resampling or filling techniques. There is no set threshold. This is an iterative process specific to your catchment to fill sufficiently to reduce ‘noise’ in the slope and flow direction analysis.</td><td>Care should be taken with such smoothing – these micro-scale hillslope features are exactly the sorts of features that runoff management measures seek to exploit.
Known flow paths may need to be enforced manually.</td></tr>
<tr><td>Availability and resolution of soil data</td><td colspan="2" rowspan="2">Nationally available soil classifications set out in Section 14.2 are at relatively coarse resolutions (> 50 m). Local hillslope processes, vegetation root structure and land management practices can significantly impact the horizons and their capacity for infiltration.
Local knowledge can be used to refine the assumed infiltration rates based on Table 18.6.
Simple infiltration rate tests on site can be used to validate assumed rates to reduce uncertainty.</td></tr>
<tr><td>Accuracy/level of detail on soil horizons</td></tr>
</table>

A4.4 VARIATION OF HYDROLOGICAL AND HYDRAULIC PARAMETERS TO ASSESS NFM

Key hydrological and hydraulic parameters can be varied to represent different types of NFM measures at a strategic scale as part of the sensitivity tests to assess the impacts on flow, depth, or velocity at your receptors (see **Table A4.5**).

When determining the applicable range to test in intermediate and detailed hydrological and hydraulic methods, the following aspects should be considered when testing variation in these parameters:

- change over time
- change with rainfall intensity and flood probability
- change over spatial scales.

TABLE A4.4 Variation of hydrological and hydraulic parameters to consider NFM

Type of NFM	Hydrological parameters	Hydraulic parameters
Runoff management measures	Time to peak or flood route connections in flood routing methods	Representation of cross slope drains in the terrain at a strategic level, eg with a bund of up to 1 m high.
Runoff infiltration measures	Infiltration or soil type parameters	Infiltration or soil type parameters as loss from the hydraulic model. Changes in net rainfall in direct rainfall modelling.
Runoff storage measures	Time to peak Surface depression storage parameters in semi- and fully-distributed methods Volume stored in flood routing methods	Roughness (Manning's 'n') as a proxy for reach-scale storage. Representation of hillslope bunds in the terrain at a strategic level eg with a bund of up to 1 m high.
Floodplain reconnection measures	Time to peak	Roughness (Manning's 'n') as a proxy for reach-scale storage. Removal of raised embankments from the terrain. Reconnecting identified palaeochannels.
Leaky Barriers	Time to peak	Roughness (Manning's 'n') as a proxy for reach scale. Channel area reduction or blockage of channels. Representation of leaky barrier as hydraulic structures.

Sensitivity testing can be undertaken on each of these parameters within the valid range based on expert judgement to assess to relative contribution and efficiency of NFM measures in each subcatchment. The quantification of how much each parameter should vary is still a growing area of research and should be informed by recommended valid ranges for each parameter, gauge data and expert knowledge.

At early stages of the NFM delivery process, it is often desirable to undertake a very high-level assessment of the potential benefit before the specific site location and design of the NFM measures are known to support the funding application. In some specific aspects of leaky barriers, there is growing (yet still limited) evidence to give some indication of the slowing effect of leaky barriers at a reach scale that can help support this (**Table A4.6**). However a high-level assessment of other parameters are often limited to expert judgement or limits of the valid ranges at these early stages. More informed testing can be undertaken as the specific site locations are known and more monitoring evidence becomes available at site for later detailed design and appraisal stages (where required).

TABLE A4.5 Summary of potential roughness changes as a starting point estimate the impact of single or multiple leaky barriers at reach scale (after Addy and Wilkinson, 2019)

Type of leaky barrier	Catchment area (km^2)	Reach slope (m/m)	Channel type[1]	Manning's 'n' mean value at bankfull flow (range)[2]
Active extended across channel like a weir	<10	0.06–0.18	Step- pool gravel-cobble bed	0.6 (0.2–1.5)
Active extended across channel like a weir	10-15	0.004–0.006	Meandering coarse gravel bed	0.24 (0.137–0.677)
Partial only extending across part way across the channel		0.012–0.013		0.083 (0.027–0.199)
Partial only extending across part way across the channel	>100 (large)	0.0005–0.0015	Straight sandy bed	0.058 (0.044–0.081)
			Sinuous gravel/sand bed	0.075 (0.065–0.088)

Note

1 The diversity of river types, materials and catchment characteristics means that the tabulated information is not necessarily transferrable without considering the significant uncertainty in the evidence base . These values should only be considered where the leaky barrier type and catchment characteristics are similar to the subject catchment. See Addy and Wilkinson (2019) for further discussion.

1 The suggested ranges are stage-dependant and reflect condition during flood flows up to bankfull capacity. They are not suitable predictors for very low flow depths or very high flows where flood water may bypass the obstruction.See Addy and Wilkinson (2019) for further discussion.

The assessment of cumulative NFM effects for catchments greater than 25 km^2 in area is still a developing research area and may never be fully quantified as NFM takes time establish at the same time as climate change and land use change elsewhere in the ctachment . There are limited examples where wide-scale implementation of NFM or even land use change has been carried out, and fewer still where there is monitoring and evidence to support it. The suggested parameter changes to represent NFM at a reach- or subcatchment scale may not be applicable at larger scales. For example, an increase in frictional effective with hedgerow or woodland planting may be represented with an average roughness increase of assumed infiltration loss for a field. However, the frictional or infiltration effect of that hedgerow may not be as effective in larger floods when the depth of flow is greater (Section 17.4 in Woods Ballard *et al*, 2019), or equally applicable at the wider scale without monitoring to evidence this (Dadson *et al*, 2017). Improved validation of the downstream hydrological impacts from multiple NFM measures in catchments 10 km^2 to 1000 km^2 would increase confidence in upscaling from reach scale to catchment scale. So, effective monitoring of medium scale catchments or larger-scale catchments is required to reduce uncertainty in the future.

Courtesy Atkins

A5 DESIGN EXAMPLES

Contents

Appendix A5 Design examples

This appendix gives worked examples of calculations required for design of NFM measures. This includes hydraulic design (conveyance, storage, infiltration and exceedance) and structural design.

▶ *These design examples can be used to check the performance of measures designed using processes described in Chapter 17.*

The calculations omit partial factors on material properties and actions; consider applying partial factors in line with Eurocodes for a more robust design.

A5.1 HYDRAULIC DESIGN

A5.1.1 Designing for conveyance

This example shows how to check the performance of conveyance and infiltration measures. It could apply to runoff storage bunds or swales (**Section 17.3.4**).

A landowner proposes to construct a grass-lined swale to increase infiltration and convey surface water runoff to a pond. They want to ensure it will contain flows for a range of size of storms without experiencing erosion.

The proposed 30 m long, 0.4 m deep swale will have a base 0.6 m wide and 1 in 4 side slopes (**Figure A5.1**). The longitudinal slope is 0.01 and Manning's 'n' value for short grass is 0.025. Soil infiltration rate is 0.000033 m/s. Design peak inflow is 0.016 m^3/s for a 10% AEP event and 0.03 m^3/s for a 1% AEP event.

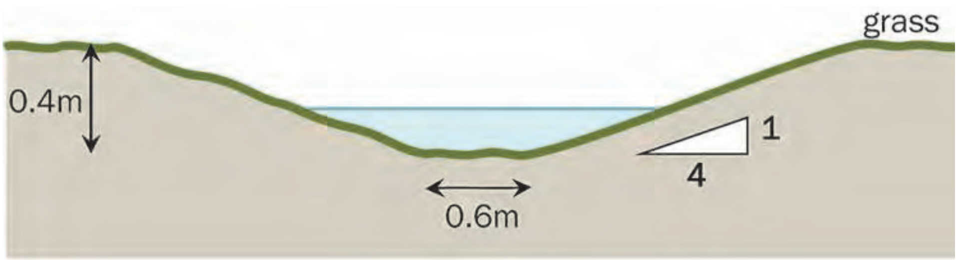

Figure A5.1 Cross-section through proposed swale

Check conveyance

The depth of flow along the swale can be estimated using the method in Box 14.1. This should be solved indirectly by estimating water depth and calculating flow, repeating until the resulting flow equals the design flow.

For the 10% AEP event, estimating water depth of 0.045 m, the flow along the swale is:

$$q_c = \frac{1}{n}AR^{2/3}S^{1/2} = \frac{1}{0.025}0.035 \times 0.036^{2/3} \times 0.01^{1/2} = 0.015m^3/s \qquad \text{A5.1}$$

The infiltration outflow rate is:

$$q_i = af = (PL)f = (0.971 \times 30)0.000033 = 0.001m^3/s \qquad \text{A5.2}$$

The total outflow is:

$$Q_o = q_c + q_i = 0.015 + 0.001 = 0.016m^3/s \qquad \text{A5.3}$$

The total outflow is the same as the peak inflow, so the water depth was a good guess and there is no need to provide storage within the swale. If total outflow was less than the peak inflow, the swale would need to provide some storage.

Check flow velocity

The flow velocity along the swale is:

$$v = \frac{Q}{A} = \frac{0.016}{0.035} = 0.46m/s \qquad \text{A5.4}$$

This is less than the allowable velocity of 1.0 m/s for grass hence erosion is unlikely.

Similar checks could be carried out for larger events to check that the swale can convey, infiltrate and/or store the design flows and volumes without erosion.

A5.1.2 Designing for storage and infiltration

This example shows how to check the performance of storage and infiltration measure. It could apply to runoff storage bunds or ponds (Section 17.3.4).

A landowner proposes to construct a low bund to store and infiltrate surface water runoff and wishes to ensure it will remain safe during above-design standard events and empty within a reasonable period of time, to allow refilling during subsequent storms.

The proposed 25 m long, 0.5 m high bund will store up to 225 m^3 of water over an area of 900 m^2 (Figure A5.2). Soil infiltration rate is 1 x 10^{-6}m/s. For a 1% AEP event, one-hour design storm, peak inflow is 0.030 m^3/s and inflow volume is 109 m^3.

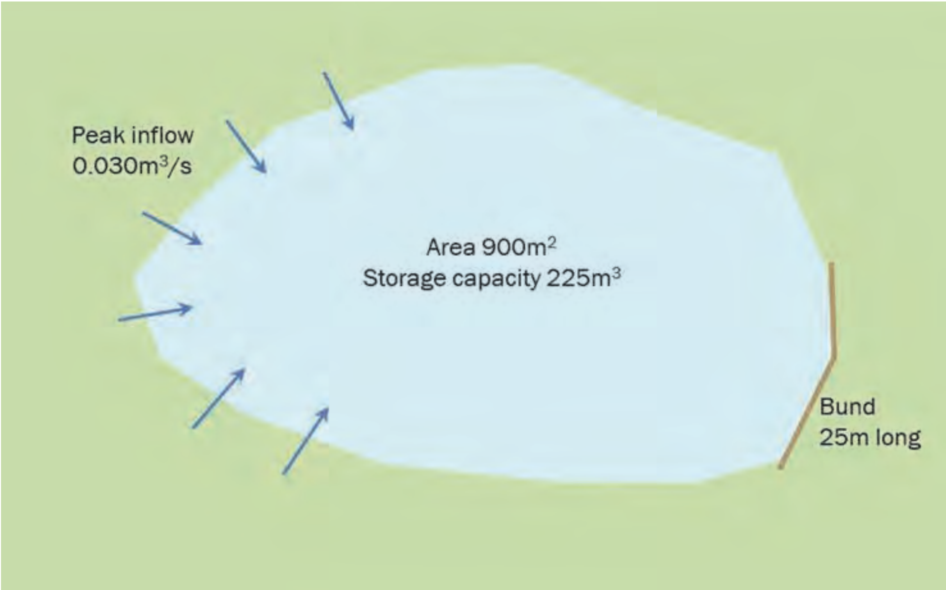

Figure A5.2 Proposed storage bund

Check for safe exceedance

A quick check for safe exceedance is to assume that the bund is full and the entire peak inflow overflows. This could occur during an extreme event, or during a modest event if several occurred in quick succession, before the bund has emptied (Section 17.3.6).

For the 1% AEP event and assuming a weir coefficient, C, of 1.5, the depth of water, h, spilling over the bund is given by the weir equation (Table 17.9):

$$h = \left(\frac{Q}{CL}\right)^{2/3} = \left(\frac{0.030}{1.5\times25}\right)^{2/3} = 0.009m \quad \text{A5.5}$$

The velocity of water, v, spilling over the outlet spillway is:

$$v = \frac{Q}{A} = \frac{Q}{Lh} = \frac{0.030}{25\times0.009} = 0.14m/s \quad \text{A5.6}$$

This is less than the allowable velocity of 0.3 m/s, so scour is unlikely.

Check stored volume and emptying time

The infiltration rate into the soil is:

$$q_i = af = 900\times10^{-6} = 0.0009m^3/s \quad \text{A5.7}$$

The surplus flow which should be stored (or passed forward) is:

$$Q_e = Q - q_i = 0.030 - 0.0009 = 0.0291m^3/s \quad \text{A5.8}$$

The stored volume is:

$$V = 3600Q_eT = 3600\times0.0291\times1 = 92m^3 \quad \text{A5.9}$$

The emptying time is:

$$t = \frac{V}{3600q_i} = \frac{92}{3600\times0.0045} = 32.3hours \quad \text{A5.10}$$

This is more than 8 to 10 hours which is not acceptable, an additional outlet pipe will be necessary to drain the bund in sufficient time.

A5.2 DESIGNING STRUCTURES

A5.2.1 Restraint by self-weight

This example shows how to check stability for a simple log or timber structure restrained by self-weight. It could apply to bunds or leaky barriers constructed using large logs or timber sleepers (**Section 17.3.7**).

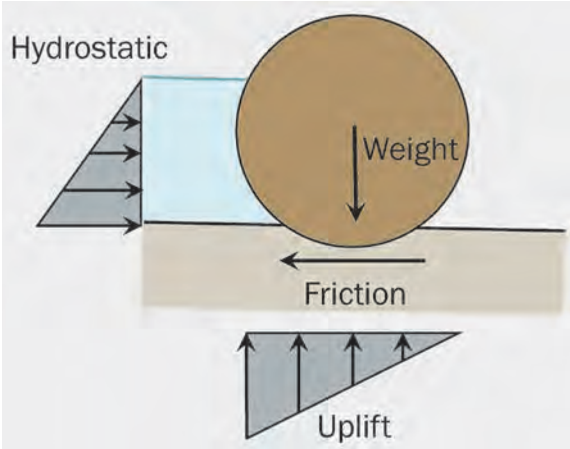

Figure A5.3 Free body diagram for single log restrained by self-weight

A landowner proposes to install a series of large logs as leaky barriers to retain surface water runoff and wishes to ensure these will remain stable even when retaining water.

Each log will be placed on the ground surface without embedment. It will retain 200 mm deep water upstream (y in **Equation A5.12**) and bypass flow will travel downslope, giving negligible downstream water depth (**Figure A5.3**). The logs have a diameter, D, of 500 mm and density, ρ_t, of 530 kg/m^3. Acceleration due to gravity, g, is 9.81, so 1 kg is equivalent to 9.81N (Newtons). Soil friction angle, φ', is 35°.

Assess uplift (flotation)

Linear structures restrained by self-weight can be assessed by actions per metre length.

The weight of the log, W, (per metre length) is:

$$W = \rho_t g\left(\frac{\pi D^2}{4}\right) = 530 \times 9.81 \times \left(\frac{\pi 0.5^2}{4}\right) = 1021\text{N/m} \quad \text{A5.11}$$

The hydrostatic uplift on the log, F_1, (per metre length) is:

$$F_1 = \left(\rho_w g \frac{y}{2}\right) D = \left(1000 \times 9.81 \times \frac{0.2}{2}\right) 0.5 = 491\text{N/m} \quad \text{A5.12}$$

The FoS against uplift is:

$$FoS = \frac{W}{F_1} = \frac{1020}{490} = 2.1 \gg 1.0 \quad \text{A5.13}$$

The FoS greatly exceed 1; the log will be stable against uplift for this water depth.

Assess sliding

The hydrostatic action, F_2, on the log (per metre length) is:

$$F_2 = (\rho_w g y)\frac{y}{2} = (1000 \times 9.81 \times 0.2)\frac{0.2}{2} = 196N/m \quad \text{A5.14}$$

The frictional resistance, F_3, (per metre length) is:

$$F_3 = (W - F_1)tan\varphi = (1020 - 490)tan35° = 371N/m \quad \text{A5.15}$$

The FoS against sliding is:

$$FoS = \frac{F_3}{F_2} = \frac{371}{196} = 1.9 \gg 1.0 \quad \text{A5.16}$$

FoS greatly exceeds 1; the log will be stable against sliding for this water depth.

A5.2.2 Logs and driven stakes

This example shows how to check stability for a log and driven stake structure on a watercourse, with logs partially embedded into both banks and a pair of stakes driven into each bank to help restrain the logs. It could apply to leaky barriers installed on watercourses (**Section 17.3.7**).

A landowner proposes to install a series of log and driven-stake structures as leaky barriers to slow flow within a watercourse and wishes to ensure they will remain stable during flood conditions.

The watercourse is 3.0 m wide and 0.8 m deep with a flow velocity of 2.0 m/s (V_f).

Two 0.25 m diameter logs will be installed across the watercourse to create a 0.5 m high barrier. The 5.0 m long logs will be embedded by 2.0 m (1.0 m into each bank). The logs will retain water to crest level upstream with downstream water at the base of the log (**Figure A5.4**).

Two pairs of 1.5 m long, 0.1 m diameter timber stakes will be driven fully into each bank, one upstream and one downstream of the logs.

Log and timber stake density, ρ, are 600 kg/m^3. Acceleration due to gravity, g, is 9.81, so 1 kg is equivalent to 9.81N (Newtons). Soil friction angle, φ', is 35° and submerged density, ρ'_s, 1050 kg/m^3. Drag coefficient is 2.0 for a log blocking two-thirds of a watercourse (after Appendix A3.3.2 of Kirby *et al*, 2015)

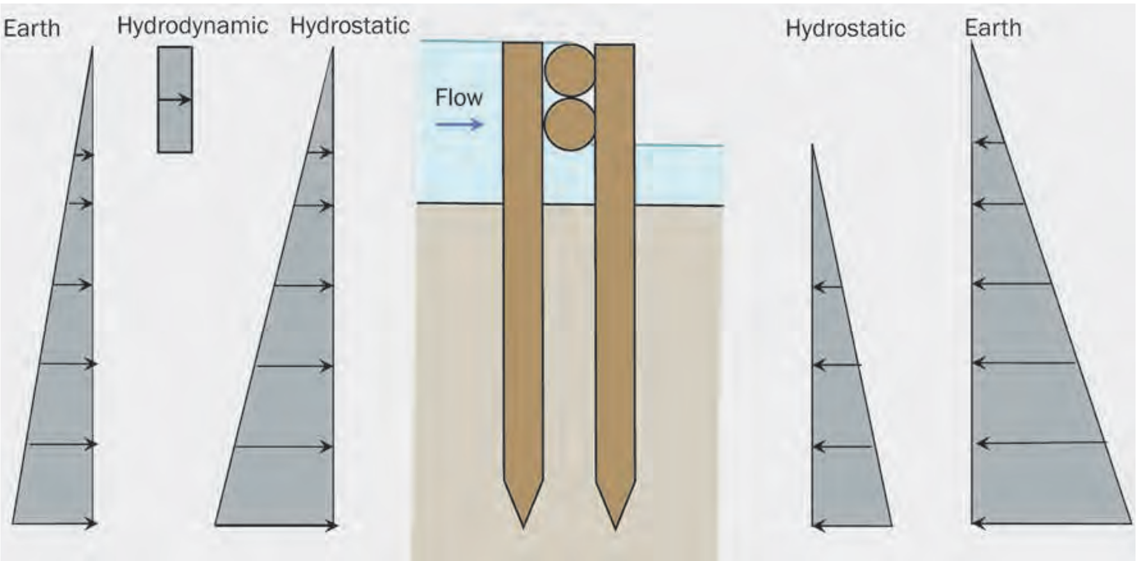

Figure A5.4 Free body diagram for logs and driven stakes

Assess uplift

The volume, *V*, and weight, *W*, of the 2 logs combined are:

$$V = \left(\frac{\pi D^2}{4}\right) LN = \left(\frac{\pi 0.25^2}{4}\right) \times 5.0 \times 2 = 0.49m^3 \quad \text{A5.17}$$

$$W = \rho_t g V = 600 \times 9.81 \times 0.49 = 2884N \quad \text{A5.18}$$

The submerged volume, V_s, and hydrostatic uplift, F_1, on the logs are approximately:

$$V_s = \frac{V}{2} = \frac{0.49}{2} = 0.25m^3 \quad \text{A5.19}$$

In order to determine the submerged volume, it was assumed that a sloping energy line runs through the stakes linking the upstream and downstream water levels. This effectively results in the assumption that half of the total volume of the logs is considered to be submerged during these flow conditions.

$$F_1 = \rho_w g V_s = 1000 \times 9.81 \times 0.25 = 2453N \qquad \text{A5.20}$$

The FoS, against uplift is:

$$FoS = \frac{W}{F_1} = \frac{2884}{2453} = 1.18 > 1.0 \qquad \text{A5.21}$$

The FoS exceeds 1, so the structure will resist uplift for this water depth.

Assess sliding

The active and passive earth pressure coefficients, K_a and K_p respectively (in cohesionless soils), are:

$$K_a = \frac{(1-\sin\varphi)}{(1+\sin\varphi)} = 0.27 \qquad K_p = \frac{(1+\sin\varphi)}{(1-\sin\varphi)} = 3.69 \qquad \text{A5.22}$$

Actions on logs

The mobilising hydrostatic action, F_2, on the full length of the logs is:

$$F_2 = (\rho_w g \mathrm{H})\frac{H}{2}L = (1000 \times 9.81 \times 0.5)\frac{0.5}{2} \times 5.0 = 6131N \qquad \text{A5.23}$$

The mobilising drag, F_3, on the exposed length of the logs is:

$$F_3 = C_D\left(\frac{\rho_w \mathrm{Vf}^2}{2}\right)HX = 2\left(\frac{1000 \times 2.0^2}{2}\right)0.5 \times 3.0 = 6000N \qquad \text{A5.24}$$

The mobilising active earth pressure, F_4, on the embedded sections of the logs is:

$$F_4 = K_a(\rho_s' gH)\frac{H}{2}E = 0.27(1050 \times 9.81 \times 0.5)\frac{0.5}{2} \times 2.0 = 695N \qquad \text{A5.25}$$

The restoring passive earth pressure, F_5, on the embedded sections of the logs is:

$$F_5 = K_p(\rho_s' g\mathrm{H})\frac{H}{2}E = 3.69(1050 \times 9.81 \times 0.5)\frac{0.5}{2} \times 2.0 = 9502N \qquad \text{A5.26}$$

The frictional resistance, F_6, on the embedded sections of the logs is:

$$F_6 = (W - F_1)\tan\varphi = (2884 - 2453)\tan 35° = 301N \qquad \text{A5.27}$$

Actions on stakes

The mobilising hydrostatic action, F_7, on the stakes is:

$$F_7 = (\rho_w g l)\frac{l}{2}dn = (1000 \times 9.81 \times 1.5)\frac{1.5}{2} \times 0.1 \times 2 = 2207N \qquad \text{A5.28}$$

Where 'n' is the number of stakes providing resistance to the forces being considered. In this case, only two stakes on the downstream side of the logs are providing resistance, hence $n = 2$.

The active earth pressure, F_8, on the stakes is:

$$F_8 = K_a(\rho_s' g l)\frac{l}{2}dn = 0.27(1050 \times 9.81 \times 1.5)\frac{1.5}{2} \times 0.1 \times 2 = 626N \qquad \text{A5.29}$$

The restoring hydrostatic action, F_9, on the stakes is:

$$F_9 = \rho_w g(l - H)^2\frac{1}{2}dn = 1000 \times 9.81(1.5 - 0.5)^2\frac{1}{2} \times 0.1 \times 2 = 981N \qquad \text{A5.30}$$

The passive earth resistance, F_{10}, on the stakes is:

$$F_{10} = K_p(\rho_s' g l)\frac{l}{2}dn = 3.69(1050 \times 9.81 \times 1.5)\frac{1.5}{2} \times 0.1 \times 2 = 8551N \qquad \text{A5.31}$$

The FoS, against sliding, is:

$$FoS = \frac{F_5 + F_6 + F_9 + F_{10}}{F_2 + F_3 + F_4 + F_7 + F_8} = \frac{9502 + 301 + 981 + 8551}{6131 + 6000 + 695 + 2207 + 626} = \frac{19335}{15659} = 1.23 > 1.0 \qquad \text{A5.32}$$

The FoS exceeds 1, so the structure will resist sliding for this water depth and velocity.

The calculations above omit partial factors on material properties and actions; consider applying partial factors in line with Eurocodes for a more robust design (**Section 17.3.7, Box 17.1**).

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WSP
Zero Waste Scotland

May 2022

Natural flood management (NFM) is a tool to help reduce flood risk. It complements other flood risk management approaches and involves working across the landscape to protect, restore or mimic the natural hydrological processes that occur. These include increasing infiltration of water, slowing the flow of water across the landscape, storing water and holding back sediment. Importantly, natural flood management can have a range of complementary, co-benefits such as habitat creation, carbon storage, water quality improvement and recreational and wellbeing benefits if delivered effectively and considered from the outset. These co-benefits can be maximised by working with others.

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