Working with Natural Processes to reduce flood risk

The evidence behind Natural Flood Management

Introduction

What is it?
Working with Natural Processes (WWNP) to reduce flood and coastal erosion risk (FCRM) involves implementing measures that help to protect, restore and emulate the natural functions of catchments, floodplains, rivers and the coast. WWNP takes many different forms and can be applied in urban and rural areas, and on rivers, estuaries and coasts. It is also referred to as Natural Flood Management (NFM).

What did we do?
There has been much research on WWNP, but it has never been synthesised into one location. This has meant that it has been hard for flood risk managers to access up-to-date information on WWNP measures and to understand their potential benefits.

We have developed a WWNP Evidence Directory, which looks in detail at the effectiveness of different measures at reducing flood risk. This is supported by maps which help practitioners think about the types of measure that may work in a catchment.

These 1 page summaries provide a high level summary of key findings from the Evidence Directory and point you to where you can find more information.

What did we find?

- It is not new, there are many examples of its application across the UK.
- It works. It can reduce flood risk, by slowing, storing and filtering water.
- It complements rather than replaces traditional engineering.
- Typically reduces flood risk for smaller magnitude floods, across small to medium catchment scales.
- Almost always achieves multiple environmental benefits.
- It is currently reliant on modelled data, more observed data is needed to help validate model findings.

But we still need to understand …

- The effectiveness of WWNP measures across different catchment scales for a range of return period events (observed and modelled data).
- How to design and construct different measures so they perform as designed (this includes engineering design standard).
- How different measures function in different catchment types and different geologies.
- The role WWNP could play in making catchments more adaptable/resilient to climate change.
- More fully the ecosystem service benefits of different measures.

How do I access it?

- Click on the measures listed here to access a 1 page summary

Are there any top tips?

- Take a catchment-based approach
- Choose the right tool(s) for the job
- Think about timescales – it’s a marathon rather than a sprint
- Achieve multiple environmental benefits
- Work with others
- Learn through doing

IMPORTANT! - The science of NFM is still evolving and developing. Many of the measures covered in these 1 page summaries have yet to be fully tested during extreme flood events. This means that we are still learning how to design and construct them.

When selecting the types of measures to use and the locations in which to place them care is needed to ensure they do not synchronise flood peaks and inadvertently increase flood risk downstream, or inadvertently create a backwater effect and increase flood risk upstream. As with all FCRM schemes it is incumbent on those who design and construct them to ensure that they are robust and do not pose a public safety risk to downstream communities.
Introduction

What is it?
River restoration reintroduces meanders to rivers and restores physical process.

Making a river more sinuous can reduce flood peaks, water velocities and attenuate flow by slowing and storing flood water.

The extent of this flood risk effect depends on the length of river restored relative to the overall size of the river catchment.

Examples
On the River Cherwell, a flood model showed that restoring 5km of the river’s channel could reduce peak flow by 10-15% (Acreman et al., 2003).

In a 25 km² catchment in the New Forest the results of a monitoring study found river restoration led to a 21% reduction in flood peak and a 33% increase in peak travel for 2 year recurrence event (Sear et al, 2006).

What did we find?
We have a Medium level of confidence in the flood risk benefits of river restoration because our evidence is mainly from flood models.

We still need
- More observational data to verify model findings.
- To understand standards of flood protection that could be provided by river restoration.
- Information on the flood risk benefits of different types of river restoration measures across a variety of spatial scales.
- To understand the conveyance capacity and water storage effects of restored rivers.

Multiple benefits

Benefits summary
River restoration can provide a wide range of benefits across most ecosystem services (see benefits wheel).

Examples
- Regeneration benefits of improving the river and surrounding park at Mayes Brook was valued at £7.8 million over 100 years, based on the uplift to property prices (Everard et al., 2011). This study showed that post restoration the need for maintenance could be reduced by approximately 50%, leading to annual savings of £5,000.
- On the River Frome (Dorset) river restoration is expected to also help manage diffuse pollution, accumulating silt on the floodplain.
- River restoration benefits recreation and tourism, the estimated per person per trip value provided by rivers and floodplains is £3.35 (Sen et al., 2012).

Further reading, case studies and maps

Case studies:
- River Avon
- Dorset Frome
- Mayes Brook
- New Forest

Maps:
- Wetland vision
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

Benefits wheel

Further reading:
- Green approaches in river engineering
- Manual of River Restoration Techniques
- River restoration and biodiversity

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Terms of reference

<table>
<thead>
<tr>
<th>Term</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Scientific confidence</td>
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</tr>
<tr>
<td>Modelled or observed?</td>
<td>For each measure we have summarised the multiple benefits which they could provide using a wheel which covers 10 benefit indicators that have been ranked on a scale from 1 to 5 to give an indication of the relative contribution the measure can make to the provision of a certain benefit.</td>
</tr>
<tr>
<td>Created or increased</td>
<td>Benefits are created or increased if they are new to the river system and/or increased in magnitude as a result of restoration.</td>
</tr>
<tr>
<td>Maintained or enhanced</td>
<td>Benefits are maintained or enhanced if they are already present in the river system and restoration is expected to improve the level of provision.</td>
</tr>
<tr>
<td>Reduced or eliminated</td>
<td>Benefits are reduced or eliminated if they are already present in the river system and restoration is expected to reduce the level of provision.</td>
</tr>
<tr>
<td>Not provided</td>
<td>Benefits are not provided if there is no evidence that restoration would provide a benefit in this catchment.</td>
</tr>
</tbody>
</table>

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Floodplain Restoration

Introduction

What is it?
River floodplain restoration restores the hydrological connectivity between the river and floodplain, which encourages more regular floodplain inundation and flood water storage.

This can decreases the magnitude of the flood peak and reduce downstream flood depths especially for high frequency, low return period floods.

The extent of this flood risk effect depends on the length of river restored relative to the overall size of the river catchment.

Examples
On the River Glaven, modelled and observed data showed that embankment removal led to floodplain inundation at high flows, with up to a 5% peak reduction in flood peak (Cliverveld et al., 2013 and 2015).

At Eddleston Water modelling indicated that increasing floodplain roughness could be the most effective means of flood management, with peak flows reduced by up to 23%.

What did we find?
We found that
We have a Medium/Low level of confidence in the flood risk benefits of floodplain restoration, because we would benefit from more observational data to verify model findings. We also need to better understand where floodplain restoration could have its greatest impact and locations where it could have a neutral or negative impact on flood risk across (across different watercourse types and at different spatial scales).

We still need
• To understand the hydraulic performance of restored floodplains and their impacts on channel conveyance and d/s receptors.
• More floodplain roughness data to calibrate flood models.
• To understand the role of groundwater in floodplain restoration.

Multiple benefits
Benefits summary
Floodplain restoration can provide a wide range of benefits across most ecosystem services (see benefits wheel), most of these benefits increase substantially if floodplain wetland habitat is restored (see arrows and shading on the benefits wheel).

Examples
1 ha of restored floodplain provides £52 per tonne of carbon sequestration benefits
Creating an extra 50 ha of floodplain (Norfolk Broads) provides £1 m of carbon sequestration benefits and £27 m of recreational value over 100 years (Tinch et al., 2012).
Freshwater wetlands have been valued at £1 300 per ha per year (2008 prices) (eftec, 2010).
1% increase in area of freshwater within 1 km of a development attracts a premium of 0.36% or £694 (Gibbons et al., 2014).
Morris and Camino (2011) found the marginal value associated with floodplain/wetland provision (per ha per year) is for flood risk management £407; increased biodiversity £304; water quality improvements £292; aesthetics and amenity £227; and non-consumptive recreation £82.

Further reading, case studies and maps

Benefits wheel

Further reading:
• How To Use Floodplains for Flood Risk Reduction
• Floodplain Meadows: Beauty and utility. Technical handbook
• SEPA’s Natural Flood Management Handbook

References:
• Working with Natural Processes - The Evidence Directory
• Using the Evidence base to make the case for Natural Flood Management

Case studies:
• Chelmer
• Eddleston
• Glaven
• Low Stanger

Maps:
• Wetland vision
• Mapping the potential for Working with Natural Processes (England)
• NFM Opportunity Maps (Scotland)

Terms of reference

Terminology

Benefits wheels

Scientific confidence

For each topic, the level of confidence in the science that underpins the individual measures is defined using the approach shown in the figure below, which attaches a confidence level (high, medium or low) based on the potential effectiveness of each measure at reducing flood risk. This confidence level, assigned by scientific experts, reflects both the degree of agreement of scientific studies and the amount of information available.

The Twiggeries, Padgate Brook river floodplain restoration post-construction in 2016 (source: Environment Agency)
Leaky Barriers

Introduction
What is it?
Leaky barriers are usually formed of wood and they are either formed naturally or are installed across watercourses and floodplains.

They reduce flood risk by intercepting the flow of water in a river, this can help restore river-floodplain connectivity which can reduce flood peaks, slow water velocities and attenuate flow by storing water on the floodplain.

Examples
Observed data collected during the Boxing Day floods (2015) in Pickering found the flood risk scheme reduced flood peaks by approx. 15-20%. Half this reduction was due to upstream NFM measures and the other half the engineered storage area in the town.

Modelling by Odoni and Lane (2010) found installing 100 leaky barriers could reduce flood flows by 7.5% (from 29.5m³/s to 27.3m³/s).

Important! There is limited evidence of how these measures perform during extreme flood events. Caution is needed when installing leaky barriers to ensure they do not become detached, cause a downstream blockage with consequent impacts on public safety.

What did we find?
We have a Mixed level of confidence in the flood risk benefits of leaky dams. Observed and modelled evidence shows they are effective at reducing flood risk at a local scale for small flood events (Med confidence). We have a High level of understanding of their effect on sediment and geomorphology. However, there is limited evidence of their flood risk effect for large events at greater catchment scales (Low confidence).

We still need
- To understand their effectiveness at mitigating flood peaks at larger catchment scales for larger flood events.
- More floodplain roughness data to calibrate flood models.
- Guidance on how to design and construct them.

Multiple benefits

Benefits summary
Leaky barriers provide greatest benefits to the environmental services shown in the benefits wheel.

There are limited studies to show cultural, aesthetic, air quality or health access benefits.

Examples
- One study valued the ecosystem services provided by wood placement projects from 1-08 to 1-81 € m⁻³ year, with the largest economic value for recreational opportunities (Acuña et al., 2013).
- On the Blackbrook 4 engineered log jams have reduced average phosphate concentration by 3.6mg per litre. Nitrate is also reduced. By 2035, it is predicted that 92m² of sediment will be stored in 3 ponds retained by the jams.
- Wood dams provide increased resilience to climate change by regulating temperature and water level (Wild Trout Trust, undated).

Further reading, case studies and maps

Further reading:
- Fish live in trees too
- Woody dams, deflectors and diverters
- Stroud RSUs project film
- Evaluation of Large Woody Debris in Watercourses

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Case studies:
- Belford
- Blackbrook
- Bowmont
- Devon Beavers
- New Forest

Maps:
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

Terms of reference

Table: Leaky Barriers

<table>
<thead>
<tr>
<th>Catchment size</th>
<th>Flood magnitude</th>
<th>Modelled or observed?</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not provided</td>
<td>Small</td>
<td>Observed</td>
<td>Wenzel et al (2014) found a delay in flood wave propagation over the local reach due to increased channel roughness and a decrease in peak discharge (2.2%) for a 3.5 year return period event</td>
</tr>
<tr>
<td>Medium</td>
<td>Small</td>
<td>Modelled</td>
<td>Kit's (2010) found that leaky barriers in ~12 km² wooded catchments can slow small flood peak by up to 33%</td>
</tr>
<tr>
<td>Small</td>
<td>Medium</td>
<td>Modelled</td>
<td>Thomas and Nisbet (2012) found that installing 5 leaky barriers reduced flood velocities by 2.1m/s, delaying the flood peak by 15 min over a 0.5 km reach for a 1 in 100 year event</td>
</tr>
</tbody>
</table>

Click here to download all River and Floodplain Case Studies

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Offline Storage Areas

Introduction

What is it?
Offline storage areas, are areas of floodplain which have been adapted (with a containment bund, inlet and outlet spillway) to store and then release flood waters in a controlled manner. They provide temporary flood storage which can reduce peak flow.

The extent of their flood risk effect depends on the number of storage areas provided throughout a catchment and their total storage volume.

Examples
In the Holnicote catchment, modelled and observed data showed that 25,000m³ of storage decreased peak flow by 10% during the December 2013 floods (National Trust, 2015). In a 1 in 5 year event, this storage could lead to a 25% reduction in peak flow.

On the Lustrum Beck, modelling showed that providing 100,000m² of storage in the upstream catchment could reduce discharge from a 1 in 100 year event by 11.5%.

Important! There is limited evidence of how these measures perform during extreme flood events. A great deal of caution is needed when designing them to ensure that any associated infrastructure are robustly designed and do not impact public safety.

What did we find?

We found that
We have a Medium level of confidence in the flood risk benefits of offline storage areas. More research is needed to understand the flood risk benefits of installing a network of small-scale storage areas throughout a catchment, and their impacts on peak synchronisation during a series of flood events.

We still need
• To understand how effective they are in different watercourse types and in groundwater fed catchments.
• To understand how quickly storage will fill with sediments and require maintenance.
• Guidance on how to design and construct them.

Other examples

<table>
<thead>
<tr>
<th>Catchment size</th>
<th>Flood magnitude</th>
<th>Modelled or observed?</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medium</td>
<td>Small</td>
<td>Modelled</td>
<td>In the Tarland catchment: 27,000m³ storage area attenuates a 1 in 2 year event by ~9%; multiple storage ponds providing 23,000m³ of storage would attenuate the same event ~5% (Ghmire et al., 2014)</td>
</tr>
<tr>
<td>Small</td>
<td>Small</td>
<td>Both</td>
<td>In Belford 35 storage areas could reduce peak flow 15-30%, when ~10,000m³ of storage was added, the peak of the largest event was reduced by ~5%</td>
</tr>
<tr>
<td>Medium</td>
<td>Medium</td>
<td>Modelled</td>
<td>On the Beam washlands, increasing the storage capacity of the existing washlands from 433,000m³ to 458,660m³ provides a 1 in 25 year SOP.</td>
</tr>
<tr>
<td>Medium/</td>
<td>Large</td>
<td>Modelled</td>
<td>In Guisborough, installing 15,000m³ of storage in the catchment could reduce the 100-year peak flow by 10.9% (2 m³/s)</td>
</tr>
</tbody>
</table>

Multiple benefits

Benefits summary
Offline storage areas have greatest benefits to flood risk management and the regulation of low flows (see benefits wheel).

Examples
In 1999, the landscape value of maintaining higher water levels was estimated at £175/ha/year (Hickman et al., 2001).

The amenity value of Beam Parklands, based on a projected 3% uplift to property values, was found to be £26 million over 99 years (eftec, 2015).

Well-managed washlands can generate tourism and recreational benefits, a non-market valuation of urban washlands demonstrated that the recreation services they provide are highly valued (Boyer and Polasky 2004).

Further reading, case studies and maps

Further reading:
• Achieving More: Operational Flood Storage Areas and Biodiversity
• Flood Planner - A Manual for the Natural Management of River Floods
• Sustainable Flood Defence - The Case for Washlands

References:
• Working with Natural Processes - The Evidence Directory
• Using the Evidence base to make the case for Natural Flood Management

Case studies:
• Beam Washlands
• Belford
• Guisborough
• Holnicote

Maps:
• Mapping the potential for Working with Natural Processes (England)
• NFM Opportunity Maps (Scotland)

Terms of reference

Scientific confidence
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Catching the Flood

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NFM Opportunity Maps (Scotland)

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Mapping the potential for Working with Natural Processes (England)

Water
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Woodland for Water: Woodland measures for meeting Water Framework
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Planting a 100ha forest within a 10 minutes driving distance results in an average individual
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catchment, modelled and observed data showed that if 90% of a
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What did we find?

We found that
We have High to Medium confidence in the flood risk benefits of catchment woodland, because we have a strong process understanding of the ways that woodlands reduce flood risk. 16 out of 50 studies of catchment scale felling showed increases in peak flow between 20 to 172%. More research is needed to better understand their impact during larger flood events.

We still need

- To understand how the type of woodland, its placement in the catchment and the catchment’s size affect its flood risk impact.
- More model parameter ranges to represent woodland hydrological processes, properly assess flood risk impacts and to test the up-scaling of these to the catchment level.

Other examples

<table>
<thead>
<tr>
<th>Catchment size</th>
<th>Flood magnitude</th>
<th>Modelled or observed?</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Not provided</td>
<td>Not provided</td>
<td>Modelled</td>
<td>A study in New Zealand demonstrated that 67% catchment afforestation reduced mean flood peaks 55-65% across three different flood peaks (Fahey &amp; Jackson, 1997).</td>
</tr>
<tr>
<td>Not provided</td>
<td>Medium</td>
<td>Not provided</td>
<td>In Chiemsee (Germany) conifer planting in two farmland catchments reduced average peak flows by approx. 100% after 20yrs (Robinson et al. (2003).</td>
</tr>
<tr>
<td>Medium/Large</td>
<td>Not provided</td>
<td>Modelled</td>
<td>A Europe-wide assessment of the water retention potential of forests in 287 catchments found to be 25% higher in catchments with 30% cover and 50% higher in those with 70% cover (EEA, 2015).</td>
</tr>
</tbody>
</table>

Multiple benefits

Benefits summary
Catchment woodlands provides benefits across most ecosystem services (see benefits wheel). They can take time to establish so potential benefits are not realised immediately.

Examples

- Marginal benefits of woodland were estimated to be 35p per household/year due to enhanced biodiversity in 12,000 ha (1%) of conifer forest. This increased to 84p for broadleaved native forest and £1.13 for ancient semi-natural woodland (Willis et al., 2003).
- Carbon regulation has been valued at £6.67 per tonne of carbon sequestered (Willis et al., 2003).
- Planting a 100ha forest within a 10 minutes driving distance results in an average individual welfare gain of £3.02 per year (Bateman and Day, 2014).
- Willis et al (2003) valued air pollution health benefits as £124,998 per annum for each death avoided and £562 for 11 day hospital stay avoided.
- A single recreational visit to a woodland has been valued at £1.66 - £2.75 (Willis et al., 2003).

Further reading, case studies and maps

Further reading:
- Catching the Flood
- Woodland for Water: Woodland measures for meeting Water Framework Directive objectives

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Case studies:
- Brackenhurst
- Coalburne
- Torne

Maps:
- Wetland vision
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

Terms of reference

Table: Benefits wheels

<table>
<thead>
<tr>
<th>Benefits wheel</th>
<th>Scientific confidence</th>
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<tbody>
<tr>
<td>Cultural Activity</td>
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</tr>
</tbody>
</table>

Legend:

- High
- Medium
- Low
- Not provided

Figure: Scientific confidence level scale
Cross-slope Woodland

Introduction

What is it?
A cross-slope woodland is a woodland which is planted across a hill slopes. It intercepts the flow of water as it runs down the hill reducing rapid runoff and encouraging infiltration and storage of water in the soil.

There is an absence of measured data to show the flood risk impact of cross-slope woodland at the catchment scale.

Examples
In the Pontbren catchment observed data showed that soil infiltration rates were 67 times higher within woodland plots and shelterbelts planted on improved grassland compared with grazed pasture, which reduced run-off volumes by an average of 78% compared to control sites (Marshall et al. 2014).

Modelling of woodland planting across 19-37% of the River Tone catchment was predicted to have little effect on the largest peak flow event in January 2002 (McIntyre & Thorne, 2013 and Park et al, 2009).

What did we find?
We found Medium to Low confidence in the flood risk benefits of cross-slope woodlands because there is limited field-based evidence available to demonstrate its flood risk benefit. It is also unclear how widely we can transfer the results from Pontbren elsewhere.

We still need
- To understand the effect of a targeted and integrated network of cross-slope woodland across a range of catchment sizes for a range of flood events.
- To understand the impact of cross-slope planting during a sequence of storm events.
- To understand how the type of woodland, its placement in the catchment and the catchment’s size affect its flood risk impact.

Multiple benefits

Benefits summary
Cross-slope woodlands provides benefits across certain ecosystem services (see benefits wheel). Limited literature is available covering the wider benefits of cross-slope woodlands, that which was available showed greatest benefits to flood risk and water quality.

Examples
- Cross-slope woodland is beneficial for water quality as it reduces sediment and nutrient loading from upslope land (Nisbet et al. 2011a).
- A study in Poland found that concentrations of nitrate in groundwater within shelterbelts adjacent to cultivated fields were reduced by 76–98% of the input (Ryszkowski and Kędziora 2007).
- Ghyll woodlands found in the valleys of south-east England are species-rich and support distinctive assemblages of plants (Burnside et al. 2006).
- The use of shelterbelts can achieve reductions in agricultural spray drift of between 60% and 90% (Ucar and Hall 2001, Lazzaro et al. 2008).

Further reading, case studies and maps

Further reading:
- Catching the Flood
- Woodland for Water: Woodland measures for meeting Water Framework Directive objectives

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Case studies:
- Pontbren

Maps:
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

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<tr>
<th>Benefit Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultural Activity</td>
<td></td>
</tr>
<tr>
<td>Water Quality</td>
<td></td>
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<tr>
<td>Habitat</td>
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<tr>
<td>Climate Regulation</td>
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<td>Low Flows</td>
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<tr>
<td>Health Access</td>
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<tr>
<td>Air Quality</td>
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<tr>
<td>Aesthetic Quality</td>
<td></td>
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<tr>
<td>Flood (Fluv)</td>
<td></td>
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<tr>
<td>Flood (SW or GW)</td>
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</tbody>
</table>

For each measure we have summarised the delivery, costs, the multiple benefits which they could provide using a wheel which covers 10 benefit indicators that have been ranked on a scale from 1 to 5 to give an indication of the relative contribution the measure can make to the provision of a certain benefit.

For each topic, the level of confidence in the science that underpins the individual measures is defined using the approach shown in the figure below, which attaches a confidence level (high, medium or low) based on the potential effectiveness of each measure at reducing flood risk. This confidence level, assigned by scientific experts, reflects both the degree of agreement of scientific studies and the amount of information available.
Floodplain Woodland

Introduction

What is it?

Woodlands in floodplains can slow floodwaters and increase water depth on the floodplain. This can help reduce flood peaks (0-6%), delay peak timing (2 hours or more), desynchronise flood peak and reduce peak height. It can also enhance sediment deposition on the floodplain.

Floodplain woodlands have greatest flood risk effect in the middle and lower river reaches of medium to large catchments.

Examples

Dixon et al. (2016) predicted that the restoration of floodplain woodland within 10-15% of sub-catchments of the Lymington River would reduce the 3% AEP flood by 6% 25 years following planting.

Planting <1% of River Laver catchment (40ha) with floodplain woodland could delay the progression of the 1% AEP flood by 1hr and reduce the d/s flood peak by 1-2% (JBA, 2007).

What did we find?

We found that

We have a Mixed level of confidence in the flood risk benefits of floodplain woodlands because our evidence is mainly from flood models, we now need more observational data to verify their findings. More research is needed to better understand their impact during larger flood events across a range of spatial scales (Medium/Low confidence).

We still need

- To improve how models represent floodplain woodland processes.
- Understand the effect of floodplain woodland on low flows/droughts.
- To understand how combine the use of floodplain woodlands and leaky barriers to avoid peak synchronisation.

Multiple benefits

Benefits summary

Floodplain woodlands provide benefits across most ecosystem services (see benefits wheel), the greatest benefits seen in the habitat and climate regulation categories.

Examples

- Floodplain woodland reduces diffuse pollution by enhancing sediment deposition (Jeffries et al. 2003).
- Floodplain forests have high biologically diversity, high productivity and high habitat dynamism (Girel et al. 2003).
- Increased canopy shading prevents lethal water temperatures and restricts weed growth, protecting fish and other organisms (Broadmeadow et al. 2010).
- Low river flows can be boosted by the slow release of water stored in pools, side channels and floodplain soils (McGlotten et al. 1988).
- Mature hardwood and cottonwood forests have the highest total carbon stocks (474 and 403 tonnes per ha respectively), followed by softwood forests (356 tonnes per ha) and young reforestations (217 tonnes per ha) (Clerjacks et al. 2010).

Further reading, case studies and maps

Further reading:

- Floodplain woodland hydrodynamics
- Restoring floodplain woodland for flood alleviation

Case studies:

- Cary
- Great Trilley
- Sussex Flood Initiative

Maps:

- Wetland vision
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

References:

- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Terms of reference

Scientific confidence

For each topic, the level of confidence in the science that underpins the individual measures is defined using the approach shown in the figure below, which attaches a confidence level (high, medium or low) based on the potential effectiveness of each measure at reducing flood risk. This confidence level, assigned by scientific experts, reflects both the degree of agreement of scientific studies and the amount of information available.

Benefits wheel

Cultural Activity

Water Quality

Habitat

Climate Regulation

Low Flows

Health Access

Air Quality

Flood (Fluv)

Flood (SW or GW)

Aesthetic Quality

Description

Catchment size | Flood magnitude | Modelled or observed? | Description
--- | --- | --- | ---
Local scale | Small | Modelled | Planting floodplain woodland at 3 sites in the Mawddach catchment was predicted to increase water depths by 0.5-1.2m, and delay peak by >30 minutes (O’Connel, 2008).
Local scale | Medium | Modelled | Rose and Rosolova (2015) found planting short rotation willow across the floodplain could have a 1% AEP flood increase floodplain flood depth >20cm and velocities by >40%.
Not provided | Small | Modelled | Johnson (2006) predicted large-scale planting on the floodplain of the River Enrick could reduce a 0.5% AEP flood by 0.8% and delay flood peak by one hour.

Further reading:

- Floodplain woodland hydrodynamics
- Restoring floodplain woodland for flood alleviation

References:

- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management
Restoring and Managing Riparian Woodlands

Introduction

What is it?
Riparian woodlands are planted on land immediately adjoining a watercourse, they can slow flood flows and can help reduce sediment delivery to the watercourse and reduce bankside erosion. They also have high evaporation losses and can create below ground water storage.

Largest reductions in flood risk have been seen at the reach scale, in middle and upper catchments.

Examples
The effects of planting deciduous riparian woodland on 9% of the 25 km² Hodder catchment was modelled to show it could reduce peak flows by 2% (McIntyre & Thorne, 2013).

A similar study by the same authors on the River Tone showed no significant effect on peak flows (McIntyre & Thorne, 2013).

What did we find?

We found that

We have a Mixed level of confidence in the flood risk benefits of riparian planting because our evidence is mainly from flood models, we now need more observational data to verify their findings. Whilst we understand the flood risk benefits at the reach scale, more research is needed to understand flood risk benefits across a range of spatial scales (Medium/Low confidence).

We still need

- To understand how the type of woodland, its placement in the catchment and the catchment’s size affect its flood risk impact.
- More model parameter ranges to represent woodland hydrological processes, properly assess flood risk impacts and to test the up-scaling of these to the catchment level.

Benefits summary
Riparian woodlands provide benefits across most ecosystem services (see benefits wheel).

Examples
- The value of a woodland landscape view on the urban fringe was estimated at £269/household/year (Wills et al., 2003).
- Planting over 150 ha of riparian woodland across the Tweed catchment combined with improving recreational facilities resulted in an additional visitor spend of approximately £3 million per year (Jura Consultants, 2007).
- One study found that riparian vegetation removed more than 20% of nitrates than the channelised river section (Peter et al., 2012).
- Shade provided by trees in the New Forest reduced water temperature by up to 5.5°C on hot summer days compared with open grassland sections, preventing it from rising above the lethal limit for brown trout (Broadmeadow et al., 2010).

Multiple benefits

Benefits wheel

Further reading, case studies and maps

Further reading:
- Restoring and Managing Riparian Woodlands
- The effects of riparian forest management on the freshwater environment

Case studies:
- Eddleston
- Pickering

Maps:
- Wetland vision
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Terms of reference

For each measure we have summarised the multiple benefits which they could provide using a wheel which covers 10 benefit indicators that have been ranked on a scale from 1 to 5 to give an indication of the relative contribution the measure can make to the provision of a certain benefit.

For each topic, the level of confidence in the science that underpins the individual measures is described using the legend shown in the figure below, which attaches a confidence level (high, medium or low) based on the potential effectiveness of each measure at reducing flood risk. This confidence level, assigned by scientific experts, reflects both the degree of agreement of scientific studies and the amount of information available.
Introduction

What is it?
Soil and land management techniques can reduce peak flow by slowing and storing surface water runoff and encouraging infiltration with the soil. They can include a wide range of different measures as shown in the following flow chart.

Examples
Modelling from the Hills to Levels project suggests that soil and land management measures coupled with other types of NFM could reduce peak flow by up to 10% (1 in 30 year event) in steep sub-catchments, and up to 40% in flatter sub-catchments.

In Devon, Puttock and Brazier (2014) found Culm grassland stores more water than intensively managed grasslands (approx 241 l m⁻² compared to 62 l m⁻²), scrub and woodland.

What did we find?
We found that
These measures have been found to slow, store and filter water, reducing flood risk locally for small events.

However, the science which underpins these types of measures has not tended to focus on the potential flood risk benefits of the measures. Whilst the evidence that does exist shows that land management measures can reduce runoff locally, there is limited field based evidence which show a significant flood risk impact at a catchment scale (Fowler, 2005). As a result we have Low confidence in the flood risk benefits of soil and land management techniques.

Additionally, for some of the land management measures covered the evidence that does exist is conflicting.

Multiple benefits

Benefits summary
Soil and land management measures can provide a wide range of benefits (see benefits wheel), especially with regards to water quality and surface water flood risk.

Examples
- Improving land and soil management practices can have a significant impact on diffuse pollution from agricultural land.
- Soil retention and land use diversity are generally beneficial for habitats. Buffer strips managed for biodiversity can increase plant diversity and provide wildlife corridors and habitat connectivity (Constanza et al., 1997 and Boutin et al., 2003).
- Land management practices including set-aside and the conversion of arable land to grassland have had a significant impact on increasing UK soil carbon storage (Bell et al., 2011).

Further reading, case studies and maps

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Benefits wheel

Terms of reference

Terminology

<table>
<thead>
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<th>Scientific confidence</th>
<th>Benefits wheels</th>
<th>Terminology</th>
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<tbody>
<tr>
<td>High</td>
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<td>Medium</td>
<td>For each measure we have summarised the multiple benefits which they could provide using a wheel which covers 10 benefit indicators that have been ranked on a scale from 1 to 5 to give an indication of the relative contribution the measure can make to the provision of a certain benefit.</td>
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<td>Low</td>
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Other examples

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<thead>
<tr>
<th>Catchment size</th>
<th>Flood magnitude</th>
<th>Modelled or observed?</th>
<th>Description</th>
</tr>
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<tbody>
<tr>
<td>Small</td>
<td>Not provided</td>
<td>Observed</td>
<td>In Pontbren (Wales), Marshall et al. (2014) found that the grazed plot had the shortest time to peak and the largest surface runoff volume and the ungrazed plot had a shallower rising limb, smaller peak and runoff volume.</td>
</tr>
</tbody>
</table>

We still need
- More research to determine the effect of soil and land use management measures on flood risk.
Headwater Management

Introduction

What is it?
Headwater drainage management techniques can delay and flatten the hydrograph and reduce peak flow locally for small flood events by intercepting, slowing and filtering surface water runoff and encouraging attenuation and infiltration with the soil.

They can include a wide range of different measures as shown in the following flow chart. They usually work best as a cluster of features working as a network throughout the landscape.

Examples

Modelling and observed data from Kinder Scout shows that gully blocking and vegetation restoration of 12% of the catchment (9 km²) could reduce peak discharge by 5% (Pilkington et al., 2015)

The Exmoor Mires project, has shown a 33% reduction in peak flow from restored sites.

Important! There is limited evidence of how these measures perform during extreme flood events. Caution is needed when installing in-channel barriers to ensure they do not become detached, cause a downstream blockage with consequent impacts on public safety.

What did we find?

We have Medium to Low confidence in the flood risk benefits of headwater drainage techniques.

Agricultural headwater management measures can be used to disrupt flow and reduce flood risk, by slowing and storing water (Medium to Low confidence). Restoring peatland slows storm water as it moves through the catchments, attenuating flow and altering storm-hydrograph, with potential flood risk benefits downstream (Medium confidence).

Whilst these measures have been found to slow, store and filter water, reducing flood risk locally for small events, there is limited evidence to demonstrate their benefits for bigger flood events at larger catchment scales.

Multiple benefits

Benefits summary

Headwater drainage management can provide a wide range of benefits (see benefits wheel).

Examples

- At a carbon price of £20 per tonne CO2e, restoring severely degraded peatland to a moderately degraded state could provide a carbon revenue of around £600 per ha per year (Quick et al. 2013).
- Peat bog has been valued at approximately £300 per ha per year (2008 values) for its contribution to water quality improvement, recreation, biodiversity and aesthetic amenity (eftec, 2010).
- The per person per trip value for moors has been estimated at £9.19 (Sen et al., 2012).

Further reading, case studies and maps

Further reading:
- An appraisal of the Defra Multi-Objective Flood Management Projects
- Land use management effects on flood flows and sediment
- Restoration of blanket bog (NEER003)

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Case studies:
- Dunnuchan Farm
- Eyecott Hill
- Exmoor Mires
- Hills to Levels

Maps:
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)

<table>
<thead>
<tr>
<th>Fieldwork agencies</th>
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<td>NFM</td>
<td>NFM Opportunity Maps (Scotland)</td>
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Table: Scientific confidence

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Runoff Management

Introduction

What is it?
Run-off pathway management techniques can delay and flatten the hydrograph and reduce peak flow locally for small flood events by intercepting, slowing and filtering surface water runoff.

They can include a wide range of different measures as shown in the following flow chart. They usually work best as a cluster of features working as a network throughout the landscape.

Examples
The Water Friendly Farming project has installed approx. 30,000m³ of storage, modelling indicates that this could reduce the 1.000 year flood peak by 20%.

In Debenham, modelling has shown installing 10 NFM features could provide 34,250m³ of storage in 3 sub-catchments reducing annual average damages to properties and farmland by 31%.

Important! There is limited evidence of how these measures perform during extreme flood events. A great deal of caution is needed when designing them to ensure that any associated infrastructure are robustly designed and do not impact public safety.

What did we find?

We have a Medium level of confidence in the flood risk benefits of runoff pathway techniques because our evidence is mainly from flood models, we now need more observational data to verify their findings. We also need to better understand their flood risk effects across a range of spatial scales for bigger flood events.

We still need
• To understand the effectiveness of these measures in different catchment types and geologies.
• To understand how to model clusters of these features throughout a catchment.
• To know how these measure affect flood flows once full.
• To know how they function during storms to optimise their design.

Multiple benefits

Benefits summary
Runoff pathway management can provide a wide range of benefits (see benefits wheel), but with greatest impact on flood risk and water quality.

Examples
• Run-off attenuation features benefit water quality by retaining sediment and pollutants. They effectively minimise the ability of faecal bacteria, fertilisers and heavy metals reaching watercourses through run-off (Scholes et al. 1999, Atkin 2003).
• A study of temporary ponds found that 75% supported at least one uncommon species (Nicolet et al. 2004). Ponds provide habitats for a range of aquatic mammals, amphibians and invertebrates, as well as farmland birds (Sayer et al. 2012, Davies et al. 2016).
• Deposition of organic material in ponds is an important part of the carbon budget (van der Wal 2011).

Further reading, case studies and maps

Further reading:
- Rural Sustainable Drainage Systems
- Runoff Attenuation Features: A guide for all those working in catchment management
- Rural Sustainable Drainage Systems: a practical design and build guide for Scotland’s farmers and landowner

References:
- Working with Natural Processes - The Evidence Directory
- Using the Evidence base to make the case for Natural Flood Management

Terms of reference

Benefits wheels
For each measure we have summarised the multiple benefits which they could provide using a wheel which covers 10 benefit indicators that have been ranked on a scale from 1 to 5 to give an indication of the relative contribution the measure can make to the provision of a certain benefit.

Scientific confidence
For each topic, the level of confidence in the science that underpins the individual measures is defined using the approach shown in the figure below, which attaches a confidence level (high, medium or low) based on the potential effectiveness of each measure at reducing flood risk. This confidence level, assigned by scientific experts, reflects both the degree of agreement of scientific studies and the amount of information available.

Benefits wheel
- Cultural Activity
- Water Quality
- Habitat
- Climate Regulation
- Air Quality
- Health Access
- Flood (Fluv)
- Flood (SW or GW)
- Aesthetic Quality
- Low Flows

Case studies:
- Afon Clywd
- Belford
- Debenham
- Eddleston
- Evenlode
- Haltwhistle
- Nant Barrog
- Trawden
- Water Friendly Farming

Maps:
- Mapping the potential for Working with Natural Processes (England)
- NFM Opportunity Maps (Scotland)
Saltmarsh and Mudflats

Introduction

What is it?
Saltmarsh and mudflats reduce and dissipate wave and tidal energy in front of flood defences and can extend their design life.

They can reduce the forces impacting on flood defences, and also reduce tidal surge propagation and lead to slightly lower water levels at defences.

Examples
At Hesket Outmarsh managed realignment, 322ha of priority saltmarsh habitat will help to provide a more robust defence system, providing a 1 in 200 year standard of flood protection to 143 residential properties, 3 commercial buildings and 300ha of farm land.

Over 600 properties were identified as having a reduced risk of tidal flooding due to the provision of the Alkborough flood storage facilities.

What did we find?

We found that
We have High to Medium confidence in the flood risk benefits of saltmarsh, mudflat and managed realignment. We have good modelled and observed data which help us understand their flood risk benefits. Most aspects of managed realignment are now relatively well understood.

We still need
- Further studies to develop financial values for the various ecosystem services provided by saltmarsh and saltmarsh for UK settings.
- To understand whether flood storage areas in estuaries could be more widely applied across the UK.
- Improved models for silation and vegetation development to better understand the progress of mudflat to saltmarsh.

Multiple benefits

Benefits summary
Saltmarshes and mudflats provide a wide range of benefits across most of the ecosystem services (see benefits wheel). The greatest ecosystem service benefit associated with this measure is a habitat, climate regulations and flood and coastal risk management.

Benefits summary
Saltmarshes and mudflats provide a wide range of benefits across most of the ecosystem services (see benefits wheel). The greatest ecosystem service benefit associated with this measure is a habitat, climate regulations and flood and coastal risk management.

Examples
- Saltmarsh is valued at approx. £1400 per ha per year (2008 prices) for benefits to water quality improvement, recreation, biodiversity and aesthetic amenity, while intertidal mudflat is valued at approximately £1300 (eftec, 2010).
- An 80m width of saltmarsh in front of a flood defence structure could potentially save about £4,600 per metre in additional wall protection (Empson et al, 1997).
- Coastal wetland has a value of £1,793 ha/year for water quality (Morris and Camino, 2011).
- Saltmarshes sequester 2.35 × 10^10 tonnes CO2 per year (2008), which covers 10 benefit indicators that have been ranked on a scale from 1 to 5 to give an indication of the relative contribution the measure can make to the provision of a certain benefit.

Further reading, case studies and maps

Further reading:
- Coastal and estuarine managed realignment - design issues
- Greening the Grey: a framework for integrated green grey infrastructure (IGGI)
- The cost of undertaking managed realignment schemes in the UK
- Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience

References:
- Working with Natural Processes - The Evidence Directory
- Maps:
  - NFM Opportunity Maps (Scotland)

Terms of reference

Terminology

Benefits summary

Scientific confidence

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Sand Dunes

Introduction

What is it?

Beach-dune systems form a natural barrier that reduce the risk of tidal inundation landward of the dune, they also act as reservoirs of sand to nourish beaches during storms.

They act as a buffer protecting flood defence structures or cliffs behind from direct wave attack and erosion, this in turn enhances the design-life of other flood risk management infrastructure.

They can also protect estuaries and lagoons through restricting the passage of storm surges and waves (Pye et al., 2007).

Examples

At Hightown works were undertaken to reinstate dunes to the same position they were in 30 years ago, increasing the dune volume by 28,000 cubic metres has ‘bought’ the frontage 28 years of time. Prior to the project this section of coast was losing, on average, 1000 cubic metres of sand per year.

What did we find?

We have High to Medium confidence in the flood risk benefits of sand dunes. More observed data is need to better understand how dunes respond to a storm or series of storms.

We still need

• Design guidance on the best ways to implement different dune management measures.

• Further observed studies to examine how dunes respond to a storm or series of storms.

Multiple benefits

Benefits summary

Sand dunes provide a wide range of benefits across most of the ecosystem services (see benefits wheel). The greatest ecosystem service benefit associated with this measure its value is a habitat.

Examples

• The sea defence value of dunes is estimated at £1,734 per metre dune (Connors, 2016).

• Dunes are a major reason for visiting the coast, on the Seton Coast (Merseyside) there are 4.5 million visits per year, generating £62.7 million towards the economy (Jones, 2011).

• Willingness to pay estimations for SSSI conservation activities related to sand dunes include £1377/ha/yr for a ‘maintain funding’ scenario, the highest of any habitat measured. The willingness to pay for increasing funding is £860/ha/yr (Christie and Rayment, 2012).

• As dunes are an early successional habitat, carbon accumulation rates are high, approximately 2.16 ± 0.91 t CO₂ per ha (Jones et al., 2008). This equates to £18.36 – £45.9 per ha per year (Connors, 2016).

Further reading, case studies and maps

Further reading:

• A guide to managing coastal erosion in beach/ dune systems

• Beach Management Manual (Second Edition)

• Sand dune processes and management for flood and coastal defence

References:

• Working with Natural Processes - The Evidence Directory

Case studies:

• Hightown

• South Milton Sands

Maps:

• NFM Opportunity Maps (Scotland)

Terms of reference

Terminology

<table>
<thead>
<tr>
<th>Benefit Type</th>
<th>Description</th>
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<tr>
<td>Cultural Activity</td>
<td>Aesthetic Quality, Water Quality, Health Access</td>
</tr>
<tr>
<td>Low Flows</td>
<td>Flood (SW or GW), Climate Regulation</td>
</tr>
<tr>
<td>Habitat</td>
<td>Air Quality</td>
</tr>
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</table>

Benefits wheels

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Introduction

What is it?
Beaches provide an effective form of coastal defence, but only if they are of sufficient width and level. Where beach systems become depleted this affects their flood risk management value.

Beach nourishment is the process of adding material to the shoreline. It is undertaken to improve or restore beach and their coastal defence function, it helps retain the standard of flood protection to the section of coast where implemented. to be effective it is a long-term maintenance activity usually repeated annually.

Examples
The Pevensey sea defences reduces the risk of flooding to between 7,000 and 10,000 properties who’s standard or protection has been improved from a 1 in 20 year event to a 1 in 400 year event through beach nourishment and bypassing.

The Dutch Sand Engine is a nourishment of 21.5 million m³, intended to last for 20 to 30 years.

What did we find?
We have High confidence in the flood risk benefits of beach nourishment.

Observed and modelled data indicates that it can be an effective tool in helping retain the stand of protection of landward defences.

We still need
- Process-based models for open coastlines to predict system behaviour over the meso-scale change (>10 km and >10 years).
- More observed data is need to understand the potential in the UK for shoreface nourishment which is currently more commonly undertaken in the Netherlands.

Multiple benefits
Benefits summary
There is little literature which specifically explores the wider benefits of beach nourishment, that which is available points to this measure having mainly a flood and coastal erosion risk management benefit (see benefits wheel).

Examples
- There are approx. 200 million visits to seaside resorts in the UK every year (Natural England, 2015), with seaside tourism valued at £17 billion (Jones, 2011).
- For large scale beach nourishment, a feasibility study of the Sand Engine approach in North Norfolk concluded that increasing the beach width over a 3km frontage would create 30ha of new intertidal habitat with a value of £1.5million (Crown Estate, 2015).

Further reading, case studies and maps
Further reading:
- Beach Management Manual (Second Edition)
- Eco-engineering in the Netherlands: Soft measures with a solid impact
- Use of Natural and Nature-Based Features (NNBF) for Coastal Resilience

References:
- Working with Natural Processes - The Evidence Directory

Case studies:
- Pagham
- Pevensey
- Poole Harbour
- Sandscaping
- Shoreham

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Benefits wheel

Benefits summary
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Benefits wheel