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Catchment-Wide Flood Management

Changing weather patterns have made structural defences less effective at managing flooding. An approach that employs a range of natural flood management measures across a river catchment is likely to reduce the probability of flooding and pressure on structural defences. This POSTnote describes the measures and the challenges of implementing them over large catchments.

Overview

- Flood management measures that work with natural features and processes reduce flood risk at local scales.
- Networks of these measures over a larger scale have the potential to enhance the resilience of existing flood defence systems and reduce the need for dredging. They need to be tailored to catchments using expert and local knowledge.
- Catchment-based approaches may be more cost-effective than relying solely on structural defences, and deliver wider long-term economic, social and environmental benefits.
- A lack of empirical evidence on the effectiveness of catchment-wide approaches is a barrier to their implementation.

Flooding in the UK

Severe flooding in the past decade has prompted renewed debate about flood management approaches. Over 55,000 homes and businesses were flooded in 2007 causing an estimated £4 billion in damages.[1] The total costs associated with flooding annually probably exceed £1 billion.[2,3] In addition to economic costs, flooding has social and health effects on communities and individuals, with psychological impacts often more severe and longer lasting than physical flood damage.[4,5,6]

UK climate projections suggest a change in rainfall patterns, and it is predicted that events now considered 'extreme', such as the exceptionally wet 2012 UK summer, will become more commonplace.[7,8] It has been estimated that by 2035 an additional £20 million of spending on flood defences annually will be needed to maintain current levels of flood risk.[9] Adaptability to climate change is a key consideration for future flood and coastal erosion management plans.[10] However, the Committee on Climate Change has recently warned of national underinvestment in long-term adaptive flood management.[11]

A Catchment-Wide Approach to Flood Risk

Traditional Flood and Coastal Risk Management approaches are usually centred on structural flood defences such as floodwalls, which aim to keep floodwater away from vulnerable areas. Structural defences are restricted by high capital, maintenance and upgrade costs, and cannot be raised indefinitely in response to increasing risk (Box 1).[12] Instead, approaches have been proposed that treat catchments as a connected system, and integrate structural defences with a range of other measures that address the sources and movement of flood water (Box 2).[13,14] This catchment-wide approach is commonly based around measures that enhance, restore or mimic natural processes,[15] referred to as Natural Flood Management (NFM), which form the basis of this POSTnote.

As no strategy can eliminate flood risk, NFM measures are designed to manage risk: a key component of this is allowing identified areas to flood in order to decrease the flood risk elsewhere. Catchments are a whole system; rivers are highly interlinked and flooding in lowlands may be a result of local conditions and activities upstream affecting surface run-off. As the geography, biology and water cycle of every catchment is unique, NFM plans are tailored to specific areas using expert and local knowledge.

Identifying Opportunity and Risk

National flood maps are available that identify where floods may occur and where current flood defence structures or other measures decrease the flood risk.[16] Identifying areas at risk of flooding involves combining information about the landscape, rainfall, geological and soil factors, as well as the location of existing defences. [17] Opportunity maps of

Box 1. Flood Risk
The *likelihood* that an area will flood is described by the probability of flooding occurring in any given year. For example, an area may have a one in 200 (1:200 or 0.5%) chance of flooding in any year. Flood *risk* is a combination of the likelihood of a flood event and the negative consequences of such an event occurring. An area with a high likelihood of flooding may be at low risk if the flooding would cause little damage to the area.

Areas where flooding would cause extensive damage are either protected through structural defences, by lowering the flood peak (the maximum water height of a flood), or by delaying its arrival to give time for appropriate flood warnings and preparations. Over half of England's Grade 1 agricultural land is located in floodplains, of which 78% has a 1:200 chance of flooding[18], along with nearly 2 million UK properties and 14% of the country's electricity infrastructure.[19,20]

potential areas for NFM measures can be identified by combining similar data sets. These areas do not necessarily overlap with areas at risk of flooding; measures often work most effectively by holding back water or keeping soil on the land in other areas of the catchment. In particular, the management of upland areas can ameliorate flooding by slowing run-off at its source, through peatland restoration, blocking upslope drainage channels, and other measures.[21]

In Scotland, creation of these strategic opportunity maps is part of a national programme to promote the use of natural flood management (Box 2).[22,23] They are combined with risk maps to identify areas that could be investigated more closely. In England, regional opportunity maps have been developed to identify where there is potential for wetland creation, tree planting or both to mitigate flood risk or improve water quality.[24,25]

Natural Flood Management Measures

Reducing the likelihood or severity of flooding by gradually lowering or spreading out the flood peak as it passes along a river is known as **attenuation**. This approach expands the drainage network of a river during periods of high flow and purposefully floods some areas while reducing the flow of water to areas more vulnerable to flood damage,[26] as well as trapping sediment. It is important to control overland flows in the upper catchment by placing appropriately designed measures as close to the source of surface run-off as possible. Seven measures that can be used are described below, some or all of which may be applicable in different catchments.

Agricultural Soil Management
Soils can be degraded by intensive farming practices, such as replacing grazed permanent pasture with arable cultivation or overstocking cattle. Such practices leave soils bare and compacted, with degraded soil structure that lowers absorbency, causing more rainfall to run-off across the surface of the land.[27,28] Adopting different agricultural practices, such as alternative crop rotations or less intensive grazing in key areas, can be effective in reducing this run-off at a local scale, but evidence of the impact at large catchment scales (>100 km^2) is not conclusive (POSTnote 396).[29,30] Practices that keep soil on the land are not only beneficial for farming, but are more cost effective than managing excess sediment build up in river channels.

Box 2. Current UK Policy on Flooding
The Flood and Water Management Act 2010[31] requires Lead Local Flood Authorities in England and Wales to develop and apply local flood risk management strategies. The national co-ordination of these strategies is the responsibility of the Environment Agency (EA), in England, and Natural Resources Wales in Wales. The national strategies for England[32] and Wales[33] promote managing the risks of flooding, recognising that it can never be prevented completely. A similar approach was set out by The Water Environment (Floods Directive) Regulations (Northern Ireland) 2009, with flood prevention and control the responsibility of the Rivers Agency NI.[34] In Scotland, the Flood Risk Management (Scotland) Act 2009 took this approach further, and the Scottish Environment Protection Agency (SEPA) requires NFM techniques to be considered in all FCRM plans.[35] A catchment-wide approach to water and environmental issues, concentrating on the multiple uses and benefits of the natural environment, is set out in the 2011 'Water for Life'[36] and 'Natural Environment' White Papers[37]. The Department for Environment, Food, and Rural Affairs (Defra) has proposed a policy framework for a catchment-based approach to water management.[38]

Sediment Retention
Excess sediment from poorly managed land can build up in river channels where rates of sediment erosion are less than deposition. It is estimated that 76% of sediment in rivers comes from agricultural activity,[39] and preventative measures can address this source (Box 3). These include filtration features such as floodplain grassland and wet woodland, tree belts and vegetated buffer strips around fields, and the restoration of riverside corridors and storage features (see below). Nutrient rich sediment can be recovered from storage features and returned to farmland.

Slowing Rural Surface Water Run-off
When run-off occurs it can be controlled at source by a range of run-off attenuation features such as storage ponds, drain and ditch barriers, rough-grassland or vegetated buffer strips and soil banks (disconnection bunds). A combination of targeted measures across 2-10% of a farm or small rural catchment can alter the local run-off regime and lower local flood risk.[40] Storage ponds, drain and ditch barriers, need regular maintenance to manage sediment build-up, but can reduce diffuse pollution as well as mitigating flood risk (POSTnote 478). Such measures are particularly effective in reducing flood risk for farms and small communities for which structural flood defences are neither feasible nor cost-effective, but catchment-wide effects are uncertain.[41]

Floodplain Reconnection
The floodplain is the area of land around a river that naturally floods when the river rises above its banks. Floodplains slow and store flood water by allowing it to spread outside the river channel. A typical structural defence are embankments constructed adjacent to a river. Floodplain reconnection refers to the restoration of inactive floodplains by lowering these embankments or moving them further away from the river channel, allowing flooding in selected areas. In some circumstances, this can be accommodated through flood-compatible farming practices such as seasonally flooded species-rich hay meadows. Seasonally flooded habitats may provide other benefits (Box 5), such as improvements to water quality.[42] Water levels in washlands (periodically flooded land) and wetlands (land

Box 3. Sediment Management
In steeper parts of the catchment, silt will be moved downstream in high flow conditions unless flows are slowed through use of features such as in-stream log jams. In lowland areas, if rivers have been modified by structures or artificially widened, sediment deposition may be increased. Repeated dredging to increase channel capacity may maximise the conveyance of water past developed areas where maintenance of water levels is necessary to avoid reversion to marshland. While this can reduce flooding in the immediate area, it can pass on problems further downstream. In steeper parts of the catchment, there should be no need to remove sediment in this way.

that is permanently saturated) must be managed carefully to maintain sufficient storage capacity for flood waters, and prevent them from adding to flood risk.[43]

River Restoration
Many UK lowland floodplains, particularly in urban areas, have been disconnected from the river channel by a combination of land drainage, channel straightening, or embankments. This disconnection can increase the risk of passing flooding on to critical areas downstream. River restoration is usually applied alongside floodplain reconnection. It includes re-meandering straightened channels in order to decrease the river's gradient, increase its length, and slow the flow of water downstream.[44] It can also involve removing artificial constraints on river flow such as culverts and weirs, as well as restoring riverside and in-channel habitats.[45,46]

Woodland Planting
Model studies suggest that woodland planting reduces flood peaks for individual events in a number of ways such as enhancing infiltration of water into the soil (POSTnote 396). Targeted planting along watercourses, and subsequent woody debris in channels upstream of vulnerable areas, can slow the flow of floodwater.[47,48]

Managing Urban Surface Water Run-off
There are a number of green infrastructure options for managing the flood peak and volume from urban and developed areas (POSTnote 448). They include sustainable drainage systems (SuDS), which aim to manage surface water run-off in a way that mimics the natural water cycle. They do this using features that slow and store water (such as vegetated roofs, restored urban watercourses and retention ponds) or increase infiltration (such as permeable paving, swales and rain gardens).[49] Requirements for new developments to adopt SuDS were set out in the Flood and Water Management Act 2010.[50] However, as the Environment, Food and Rural Affairs Select Committee noted, the Government has yet to publish the necessary national standards.[51] Defra have recently consulted on a new approach to implementing SuDS.[52]

Partnerships and Co-operation
Early engagement of stakeholders can improve schemes by including local knowledge, and support from communities can increase the uptake of measures.[53,54] While some schemes can be undertaken by a sole large landowner (such as water companies or the National Trust), they usually require financial incentives and collaboration between many different landowners. The importance of partnerships has been shown in numerous case studies (Box 4). Partnerships facilitate public and private funding combinations from multiple sources, and can help mediate conflicts. The importance of co-producing and sharing knowledge has been highlighted.[55]

Box 4. Case Study: The Eddleston Water Project
The Eddleston Water is a tributary of the Tweed, with a catchment of 69 km^2. Extensive channel straightening and changes in land management since the early 19th century has increased the flood risk to some 600 properties in Eddleston and Peebles, and degraded the ecological quality of the river and its floodplain. This major restoration project aims to reduce the risk of flooding to these communities and, in doing so, to restore natural habitats. Led by the Tweed Forum, it is a partnership initiative of the Scottish Government, SEPA and Dundee University, working with farmers and landowners in the valley to deliver a network of land management changes. A key objective is to assess the costs and benefits of this approach.

The project includes measures designed to reconnect the river to the floodplain, including lowering river embankments, restoring natural meanders and riverside tree planting. Along with extensive woodland planting and measures to slow the flow of water in upstream areas, restoring these floodplain features has reduced the speed of water flow and provided more space for floodwaters. Prior to restoration, a detailed network of monitoring stations and surveys was established to collect data on the impact of each restoration technique and on the catchment as a whole. While the effects on flood risk are not yet conclusive, the catchment is one of the most extensively monitored in the UK, and improvements in biodiversity are already evident. Further progress is expected as features become established and new ones are implemented. Other schemes showing the potential for integrating floodplain and upland measures to address local flood risk include Crookston, Bowmont Water and River Dee in Scotland, and Netherton Burn, the River Till and Wychavon in England.

Challenges to Catchment-Wide Approaches
Despite the success of several pilot schemes throughout the UK,[56] catchment-wide flood risk management has yet to be widely implemented. A joint Defra Environment Agency report summarised a range of research gaps in the evidence base. [57] Test catchments would be required to build on the lessons of the smaller pilot studies, and establish how local impacts scale up to large catchments.[58]

Evidence Base
Individual NFM measures are supported by varying levels of evidence, but there is a lack of empirical evidence that networks of such measures result in a reduction of flood risk at a catchment scale. This can create difficulties in proposing integrated schemes, particularly in qualifying for funding on the basis of current cost-benefit analysis practices. In the Netherlands, an attitude of 'acceptable uncertainty' is adopted, allowing experimental flood management initiatives such as the 'Sand Engine'[59] and 'Room for the River'[60], without first accruing proof of effectiveness. In the UK, government funding of experimental measures is unlikely, as resources are prioritised to achieve the greatest reduction of flood risk possible, with a demand for high levels of outcome certainty. This is seen as inhibiting the implementation of innovative approaches.[61]

Upscaling Local Evidence to Larger Scales

Test schemes have been successful in alleviating flood risks in individual farms and villages, such as at the National Trust Holnicote Estate Project,[62] but there are discrepancies of scale between these and what would be necessary at the scale of a catchment. For example, small-scale land management changes have been shown to reduce surface run-off and prevent local 'muddy floods'.[63] However, there is no conclusive evidence as yet that this lowers the flood peak downstream.[64] Monitoring of current schemes (such as Eddleston Water,[65] Holnicote,[66] SCaMP[67] and Upstream Thinking[68]) will increase this evidence base.

Assessing the Effectiveness of Proposed Measures

The potential reduction in flood risk that may result from the catchment-wide implementation of NFM measures can be estimated using various modelling tools (Box 5). However, the complexity of the water cycle (the natural variability of rainwater evaporating, infiltrating into the soil or running over the land surfaces) makes modelling the exact effect of specific proposals on flood risk very uncertain. These model studies have been designed to combine national-scale data with local knowledge to make predictions more accurate for particular areas. [69,70] However, they are still criticised for making high-level generalisations, particularly where local data are sparse. Toolkits are available that aim to assess the other benefits provided by NFM proposals,[71,72] such as improvements to biodiversity, water quality or landowner income (Box 5).

Long-term Monitoring

Historically, many of the measures outlined above have highlighted flood management as a secondary objective in biodiversity or water quality schemes and there has been a lack of monitoring of the specific impacts on flood risk. Gathering quantitative data is hampered by the cost of long-term monitoring, while analysis of the data is hampered by a lack of baseline measurements and difficulties in differentiating the impacts of a scheme from natural variability. Very few schemes have been applied at a suitable scale or measured for long enough pre- and post-intervention to provide conclusive evidence of their effectiveness in reducing flood risk. Even with a greater evidence base, uncertainty will always remain and innovative monitoring and modelling methods will be needed to inform decision making.

Compartmentalised Governance

Numerous bodies are involved in delivering flooding and water management, with different levels of organisation in England, Scotland, Wales and Northern Ireland.[73] UK legislation emphasises decentralised planning of flood risk management, with local authorities responsible for the strategy for their area, with overarching national bodies responsible for national strategies (Box 2). This regional approach is a benefit when creating local partnerships and developing participative Flood and Coastal Risk Management (FCRM) plans. In England, Defra, the EA, the Forestry Commission, and Natural England are all working towards identifying shared objectives across FCRM plans.[74] However, the divisions of powers and responsibilities are complex and not always clear,[75] and could create an impediment to that the sharing of expertise and the development of multi-objective projects is being hampered.

Funding and Multiple Benefits

Funding is required not only to install the measures, but to ensure sufficient maintenance and as compensation for land use. However, there is a lack of agreement about what economic values to put on agricultural land and additional services such as flood management (POSTnote 378), and on the land use constraints that the provision of temporary flood storage creates. These issues are being reviewed by the Natural Capital Committee and the follow-on phases of the National Ecosystem Assessment.[76]

The new agri-environment scheme in England,[77] Countryside Stewardship, will provide opportunities to deliver multiple benefits. For example, river restoration, riverside planting and the creation of wetlands can increase biodiversity and improve water quality[78,79] as well as providing amenities, recreation, and improvements in public health and well-being.[80] Recognising multiple benefits widens the scope of funding sources, but where flood risk management is not a scheme's primary objective, special steps will be required to guarantee its delivery throughout the life of the scheme.

Box 5. **Modelling Flood Risk Reductions and Other Benefits**

Several methods have been developed to aid the planning of integrated NFM projects. Multi-criteria assessments involve comparing specific proposals with the services currently delivered at a site, and the benefits of other potential land use scenarios. Different ecosystem services such as food production, biodiversity, floodwater storage, and recreation can be differently weighted to reflect the objectives of the project proposed.[81,82,83] There are also a number of models that aim to demonstrate, numerically or visually, the level to which a scheme will reduce flood risk, but their reliability is dependent on the level of site-specific data available. These can aid project development, and are also useful tools for engaging with landowners. Examples include:

- Decision Support Matrices, such as the Floods and Agriculture Risk Matrix,[84] which uses a 2-D grid to communicate visually the flood risk of different land management scenarios.
- Modelling software such as the EA Catchment Flood Management Plan land management tool, which numerically estimates the flood risk of changing land use.
- GIS-based modelling software, such as Polyscape,[85] which can be used to produce traffic light coded impact maps of different land use.

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