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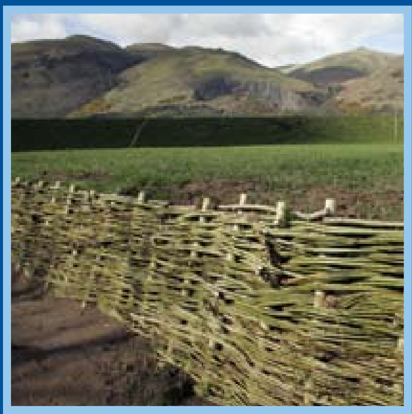
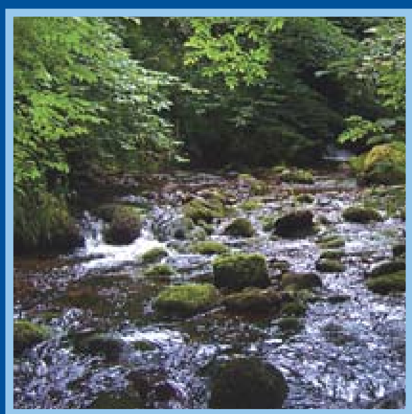


FLOOD PLANNER



A MANUAL FOR THE NATURAL MANAGEMENT OF RIVER FLOODS

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FLOOD PLANNER

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Executive Summary

THE requirement for a sustainable approach to flood management involves taking an informed catchment approach, using natural river processes to manage floods where they arise, not just where they have their effect, and putting the emphasis on soft engineering solutions. Achieving sustainable flood management involves social, economic, planning and natural components.

- *Flood Planner* describes the natural component of sustainable flood management: natural flood management (NFM). This unique and practical resource for flood risk managers outlines the background to natural flood management and helps them perform their role in meeting current and future legislation. It provides evidence of the effect of NFM on run-off rates and storage and describes the techniques required to successfully lower flood risk to communities within that catchment

- Natural flood management is extremely cost-effective. It works with the catchment's natural defences to slow the flow upstream and increase water storage in the whole catchment. In time, it becomes self maintaining, bringing long term benefits to communities and the environment, particularly in this time of climate change. Latest estimates for NFM reveal huge cost savings and multiple benefits when compared to traditional schemes.

- Scottish legislation already requires a whole catchment approach to flooding. The European Water Framework Directive (WFD) has shifted focus away from single remedies by requiring local authorities to achieve 'good ecological status' for river catchments by 2015. Scotland was the first European country to incorporate the European Directive into law through the Water Environment Water Services (Scotland) Act (2003). That legislation imposes a duty on local authorities to promote sustainable solutions to flooding. The imminent European Floods Directive will furthermore have, as one of its principles, the integrated, catchment approach linked to the WFD process.

- The River Devon Demonstration Project puts a range of natural flood management techniques into practice at appropriate sites throughout the catchment. As a result, the effectiveness of NFM on a catchment scale can be quantified for the first time, as well as showing how these principles can be applied to any river.

- Sustainable flood management brings many other benefits for communities and local authorities. The approach encourages participation in decision-making processes, especially through river basin management planning. Further, it can help provide Best Value in community planning and is Strategic Environmental Assessment friendly. The process also greatly contributes to Local Biodiversity Action Plan duties, is a proven method for diffuse pollution control and provides greenspace.

- A non-technical summary of SFM, ***Slowing the Flow: A Natural Solution to Flooding Problems***, is available from WWF Scotland, Mountain Environments or **www.wwf.org.uk/betterriverbasins**

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Introduction

FLOODS occur naturally in rivers throughout the world. They are a major land-forming process, developing river valleys, creating floodplains and maintaining a rich diversity of aquatic and riparian habitats. But the natural hazard of flooding is becoming an increasingly unnatural force, damaging the landscape, destroying buildings and disruptingms of lives every year. As the effects of climate change combine with human pressure on the land the risk of flooding is likely to grow. There is now an urgent need to take action and manage the flood hazard in a more effective and sustainable manner.

Traditional flood defences are not the most effective way of protecting villages, towns and cities against rising floodwaters. Although the hard engineering solution may be appropriate in some situations, this deals only with the symptoms and not the causes of the flood. A truly sustainable approach to flood management works with the whole river catchment. It addresses the causes of flooding, by looking at flood generation processes upstream.

Sustainable flood management (SFM) is an evolving way of working with rivers on a catchment scale to manage flooding. Scottish legislation now encourages this whole catchment approach, including coastal areas. Scotland was the first European country to transpose the European Water Framework Directive into law through the Water Environment Water Services (Scotland) Act

2003. Under this Act all responsible authorities have a duty to promote sustainable flood management.

In future, flood management will need to be economically viable, effective and sustainable. Costly hard engineering can be replaced with a realistic alternative of 'soft engineering' using solutions such as regeneration of native woodlands, river channel management and restoration of wetlands and floodplains. When developed on the catchment scale, NFM will be more effective than river canalisation or floodbanks and cost significantly less. Once established they are self maintaining, there are social and economic benefits and there is considerable environmental gain.

Flood Planner explains flood generation processes and the background to natural flood management as well as describing techniques involved and how to apply these to a catchment. Detailed technical instructions are given in Parts 3 and 4. Part 5 details the results yielded by the actual demonstration of these techniques.

1.2

Duties and Responsibilities for Flood Management

CURRENT duties and responsibilities for flood management in Scotland are complex. WWF Scotland continues to work with the government to improve legislation by integrating it with other catchment approaches to make it more user friendly and more effective. The Flood Prevention (Scotland) Act, 1961 gave local authorities powers to manage or repair watercourses using hard engineering solutions. The Flood Prevention and Land Drainage (Scotland) Act 1997 amended the 1961 Act and included duties to assess whether watercourses were likely to cause flooding and also to produce biennial reports detailing the occurrences of flooding in the past two years and the measures needed to prevent or mitigate flooding. The Water Environment and Water Services (Scotland) Act 2003 made provision for protection of the water environment under the European Water Framework Directive. The Act required Scottish Ministers, SEPA and the responsible authorities to promote sustainable flood management and adopt an integrated approach by cooperating with each other.

Local authorities therefore have a duty to maintain rivers, streams, drains and culverts so that flooding of non-agricultural land is prevented or mitigated. SEPA must ensure that any work is carried out without causing damage to the natural environment while Scottish Water has responsibility for storm water drains (responsibility for

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road drainage lies with the Roads Authority). Maintenance of rivers, streams, drains and culverts could include the whole catchment upstream of the site if that would prevent or mitigate the flooding of the non-agricultural land. The situation with existing drains and culverts is open to some interpretation however it would be difficult to argue against the local authority having responsibility for any public drain or culvert which caused flooding of neighbouring properties or roads. Private drains or culverts would then be the responsibility of the land owner who should ensure maintenance is carried out to prevent flooding of that property or neighbouring properties. For new drains and culverts a Controlled Activities Regulations (CAR) licence issued by SEPA should ensure that the drain or culvert is correctly designed and maintained to prevent flooding.

The catchment approach to flood management is increasingly being promoted within local authorities however there are some who still support the hard engineering solution. In a recent survey of biennial flood reports it was shown that councils have different approaches to flood recording, management and reporting. Public opinion is often in conflict about solutions to flood management: communities at risk of flooding want the reassurance of a large wall between them and the river without losing access to the river.

The Scottish Planning Policy 7: Planning and Flooding (SPP7), published in February 2004, prevents further development which would be at significant risk of being flooded or increasing the probability of flooding elsewhere. SPP7 stated that planning authorities must take the probability of flooding from all sources into account during the preparation of development plans and in determining planning applications. It also states that developers have a key responsibility to take flood risk into account before committing themselves to a site or project. Each new development must be free from significant flood risk from any source, must not materially increase the probability of flooding elsewhere and must not affect the ability of the functional floodplain to store flood water. The functional floodplain is the area within the estimated 0.5% (1 in 200) probability of flooding in any year and built development should not take place on functional flood plains.

Planning authorities are responsible for making decisions on developments where there is a flooding issue but are required to consult SEPA where it appears that a development will result in a material increase in the number of buildings at risk of being damaged by flooding. SEPA has a duty, if requested by a planning authority, to provide advice on the risk to the public or properties of flooding in the authority's area but has no responsibility for making decisions on planning applications. If the planning authority intends approving a development contrary to the advice of SEPA then it is required to notify the Scottish Ministers.

Sustainable flood management is an evolving way of working with rivers on the catchment scale to prevent flooding of non agricultural land. The legislation covering SFM is key to ensuring that it develops in an appropriate way. Local authorities are still likely to be the responsible agency in the development of flood management for specific localities but they have no authority for the management of agricultural land.

Sustainable flood management can therefore only work only with cooperation from responsible agencies, landusers and communities in the whole river catchment.

Floods Legislation Applicable to Scotland

CURRENT Scottish flood prevention legislation is based on three Acts: the Flood Prevention (Scotland) Act 1961; the Flood Prevention and Land Drainage (Scotland) Act 1997 and The Water Environment and Water Services (Scotland) Act 2003.

The Flood Prevention (Scotland) Act, 1961 gave local authorities powers to manage or repair watercourses using hard engineering solutions. Watercourses were defined as rivers, streams and burns and also ditches, drains, culverts together with any related walls, pipes or other structures but not sewers or water mains. The Act continues to form the basis of flood protection or flood. Currently proposed schemes have to be considered and approved by the Scottish Executive but they may also require other statutory consents such as planning. An outline of a flood prevention scheme should describe the proposed flood prevention operations, the land which would be affected and the costs involved. It should also be designed to provide protection against flooding over its design life with an annual probability of occurrence no greater than 1% and have a benefit to cost ratio greater than unity. The local authority must advertise the scheme in the locality and Ministers must consider all objections before confirming the scheme. Grants of 80% of the eligible cost of confirmed schemes are available from the Scottish Executive and it is the responsibility of the local authority to apply for such funds.

Amendments in the Flood Prevention and Land Drainage (Scotland) 1997 Act charge local authorities with a duty to reduce risk of watercourses flooding. The local authorities are also required to produce reports at least every two years detailing the measures needed to prevent or mitigate flooding of non-agricultural land, as well as measures taken since the previous report and all occurrences of flooding of non-agricultural land.

The Water Environment Water Services (Scotland) Act 2003 (WEWS) transposed the European Water Framework Directive into Scots Law. The WEWS Act requires Scottish Ministers, SEPA and the responsible authorities to adopt an integrated approach by cooperating with each other to promote sustainable flood management.

The Water Environment (Controlled Activities) (Scotland) Regulations 2005 (CAR) bring into effect the requirements of the WEWS Act for control over point source discharges, abstractions, impoundments and engineering works in or near inland waters. The regulations are therefore relevant to both sustainable flood management and flood protection schemes. Flood protection schemes are specifically mentioned in the SEPA guidelines: Levels of Authorisation for Controlled Activities. In the guidelines they are said to probably involve multiple engineering activities however the licence will be determined by grouping all of the activities within the scheme. Most of the activities involved in natural flood management are also likely to require a CAR licence however this will depend on the extent of the work carried out, e.g. sediment removal from a channel will require a licence only if it is carried out over a length greater than 20m.

The European Floods Directive recognises that major European rivers such as the Rhine and Danube cross borders and so flood management has to take a catchment approach and may involve several countries. This is less relevant to UK rivers although proposed methods of managing floods should be relevant to Scottish catchments. The proposed Directive talks about improving cooperation and coordination, developing flood risk maps, improving information exchange and increasing awareness of flood risk. It is also intended to be strongly linked with the WFD process, particularly river basin management. It refers to NFM almost as a concession to the environment and gives little guidance of how it wants it to be used in flood management. It states that flood protection must be dealt with in a concerted and coordinated manner along the whole length of the river. However it also points out that there is an increased flood risk in Europe caused by higher intensity rain linked to climate change and an increase in the number of people and economic assets located in flood risk zones. Agricultural policy is seen as contributing to flood prevention particularly through the reform of the Common Agricultural Policy (CAP) by promoting soil protection, maintaining permanent pasture and promoting less intense stocking rates. It refers to the restoration of floodplains and wetlands without explaining their role in flood management.

The Scottish Planning Policy 7: Planning and Flooding (SPP7) was prepared with a central purpose to "prevent further development which would have a significant probability of being affected by flooding or which would increase the probability of flooding elsewhere". The policy also states that new development should not add to the areas of land requiring flood protection, affect the functional flood plain to attenuate flood flows, interfere detrimentally with the flow of water in the flood plain and compromise future options for future river management. The functional floodplain is defined for planning purposes as the area which has a greater than 0.5% probability of flooding in any year, commonly termed the 200 year flood line.

1.4

Guidance Available to Local Authorities

THE Scottish Executive is preparing Guidance on Flood Prevention Schemes for Local Authorities and this is available from Climate Change and Air Division, 1G(N) Victoria Quay, Edinburgh, EH6 6QQ.

The Scottish Environment Protection Agency (SEPA), which is responsible for implementing CAR and WFD, will provide guidance to local authorities including advice on structure plans, local plans and also individual planning applications where there may be a flood risk.

SEPA also works with local authorities Flood Liaison Advisory Groups. (FLAGs). Under Section 21 of the Environment Act 1995 discretionary powers to implement flood warning schemes were transferred to SEPA. This enables SEPA to commission appropriate instrumentation and telemetry but does not detail the nature, timing or recipients of flood warnings. In SEPA Policy No. 34: Flood Warning Strategy it is recognised that local authorities have a key role to play during flood events. In addition to the existing flood warning schemes SEPA will consider formal requests from local authorities for new schemes however all requests will be assessed based on a standard cost-benefit analysis.

1.5

Social and Economic Costs of Flooding

FLOODING from rivers is a major hazard to human life and property throughout the world. In recent years, record floods have caused significant damage to both rural and urban environments in the UK. The damage can be so great that the cost of the clean up and reconstruction often requires central government support and funding. There is also a human cost: people can be killed or injured by floods and the trauma inflicted on communities and individuals is long lasting.

Record flood flows cause devastating damage. The highest flow ever measured on a UK river was recorded on the Tay in 1993 when the river inundated the North Muirton estate in Perth and caused an estimated £34m damage. In 1994, the Strathclyde flood caused £100m of damage. Lifetime costs can be substantial for a hard engineered scheme. Regular maintenance has to be carried out requiring annual expenditure on repairing banks, dredging channels and clearing vegetation. As authorities

often reduce this maintenance, many flood defences are now inadequate for the increasing flood flows linked to climate change. The result is a reduction in the level of protection from many flood defences. There are also questions over the reliability of new hard engineered schemes. The scheme in Milnathort, Perth and Kinross was only a few months old when it failed in December 2006, causing misery and fear for many of the village's residents and employers.

In Scotland, around 80,000 homes are currently at risk from river flooding. The annual flood losses are estimated at around £31m and are predicted to rise steadily through the 21st century to reach £68m by the 2080s.

Social costs are hard to calculate but both flooding and the fear of flooding cause stress and insecurity. From January 2006, flood insurance was no longer guaranteed to households in areas of high flood risk in the UK. Scottish properties are being treated differently because of the progressive approach to sustainable flood management encouraged by the 2003 Water Environment Water Services (Scotland) Act.

The costs of hard engineering are rising. Although higher walls cannot guarantee lasting protection against the risk of greater flood flows, most proposed flood defence schemes would cost between £20m and £50m. Natural flood management solutions are likely to be less than 10% of this cost, probably much less. Recent estimates from the River Devon Project and a natural flood management project on the River Teviot, upstream of Hawick, show that major savings can be made. They also reveal multiple benefits in taking the natural approach. Two hard engineered schemes may be considered by the local authority for Hawick. The first, costing an estimated £28m, has no upstream attenuation and relies solely on flood walls. The other, costing an estimated £95m, adds attenuation ponds further upstream. In comparison, spending £2m on NFM techniques, in the appropriate places, lowers the flood risk by the equivalent of a 0.5m drop in the height of the flood walls. Spending in the region of £4–5m would lower the flood risk by the equivalent of a 0.75m to 1m drop in the flood walls.

1.6

The Causes of Flooding

CLIMATE change and land use changes within catchments have had significant effects on flooding. In natural conditions, flood flows in rivers are primarily caused by prolonged intense rainfall often supplemented by snowmelt. The process begins on the steep slopes of upland areas but flooding occurs mainly in the lowlands. When the natural defences of the river are in place they can slow the flow upstream while dissipating and dispersing the floods downstream.

In recent years climate change has increased the frequency and magnitude of intense rainstorms throughout Europe. In Scotland, a recent survey of local authorities found that 82% of responding councils highlighted river and coast flooding related to climate change as an issue with likely impacts in their region. At the same time, land use changes have occurred in many upland regions with deforestation, land drainage and agricultural expansion resulting in more rapid run-off rates which concentrates storm waters into natural gullies and increases flood peaks in the rivers. There have also been changes in the lowlands caused by agricultural intensification, housing developments, industrial expansion, and construction of railway embankments, roads and bridges. These have damaged river channels, reduced the areas of natural floodplain and weakened the buffering effect and storage capacity of flood flows.

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Traditional flood protection schemes use hard engineering but this has, in fact, contributed to increased pressure on the river. Flooding of housing developments on floodplains has given rise to the construction of floodbanks along rivers to protect the houses and confine the river and its sediment load within the banks. In most situations this confinement has simply transferred the floodwaters and sediments downstream, raising the channel beds and thus reducing the capacity of the channel while at the same time increasing the risk of localised high velocity flows if a breach occurs. Better planning control has limited new floodplain developments and the construction of floodbanks. However, the original housing developments still exist and river flows are changing, bringing an ever-increasing threat to properties previously not at risk from flooding.

After a flood, valuable evidence is left around the catchment in damage caused to river channels, fields and bridges, but it is rarely collated and analysed to understand why the flood occurred. Floods can have a variety of causes, usually a high river flow linked to a secondary reason. Understanding the secondary reason can often produce a solution to reduce the risk of it happening again.

The Future for Flood mangement

RIVER floods are greater and more frequent today than they were in past years. There is little practical chance of eliminating major flood flows altogether and, indeed, many reasons for maintaining flood flows. However, there is an urgent need to prevent (and where possible remove) floodplain developments and there are many other opportunities for managing catchments to reduce flood risk.

Reversing the effects of extensive land use changes throughout a catchment could take decades before reducing run-off rates and flood peaks. Nevertheless, river channel management can usually be addressed over a much shorter timescale potentially giving a quick solution to the flooding problem.

A Scottish survey showed that 19 local authorities have already adapted plans for flood prevention and control due to climate change predictions. Land use practices are also beginning to change. There are widespread moves away from commercial forestry towards restoration of native woodlands although flood management has only recently been linked to forestry. There is also encouragement for wetland restoration although this tends to be for biodiversity reasons rather than flood management.

The foundation for natural flood management is in place. Scottish legislation does now include sustainable flood management through river basin management plans. Planning guidance allows for control of floodplain developments and flood management could also be linked to activities in watercourses and agricultural support schemes. But the essential policy framework is still not complete and the gaps make for difficulties in implementing the law. Greater coordination is required to achieve sustainable flood management throughout Scotland.

Sustainable Flood Management brings many other benefits for communities and local authorities. It creates structures for participation, enhances local economies, improves amenities and can help provide Best Value in community planning. The process is Strategic Environmental Assessment friendly, greatly contributes to Local Biodiversity Action Plan duties, is a proven method for diffuse pollution control and provides greenspace.

For flood management to be sustainable it must take proper account of costs and benefits to the economy, society and the environment. Major flood events are usually assessed in terms of their overall cost of the damage

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caused, clean-up costs, loss of revenue for businesses, insurance claims and increased insurance premiums. These costs are balanced against the estimated cost of building a flood defence scheme and if the cost to benefit ratio is less than one then the scheme may be considered for funding. Most proposed flood defence schemes are costed in the range £20-50m but catchment flood management is likely to be less than 10% of this cost (see section 1.2). Therefore if the catchment approach is as effective as the defence scheme then the cost to benefit ratio is likely to be significantly less than one.

A requirement of future flood management is resilience which in this context refers to life expectancy, operational costs and long-term maintenance of the scheme. Most flood defence schemes are designed with a life expectancy of 30-50 years while natural flood management could have an unlimited life. Operational costs of flood defences can be low if it is a large solid wall but if defences are designed to address the wishes of communities they may require gates to be closed, temporary barriers erected etc which require extra funding. There is increasing evidence that flood schemes themselves now suffer large amounts of damage from floods requiring large amounts of resources to repair them.

Natural flood management has low or no operational cost and may even provide an income for the landowner. Engineered flood defences may provide sufficient protection for the current or predicted climatic conditions but they take years or decades of designing, planning, consulting and construction and they are inflexible if the climatic change predictions are found to be incorrect. Natural flood management includes a range of techniques; some can be effective immediately and others in 10-20 years time. They are also flexible and can be either modified or designed to be self-adjusting in response to the climatic change.

Application of NFM on a Catchment Scale

NATURAL flood management has developed as the process within sustainable flood management which applies traditional land management techniques to address the causes of the flooding problem rather than trying to protect the impacted site.

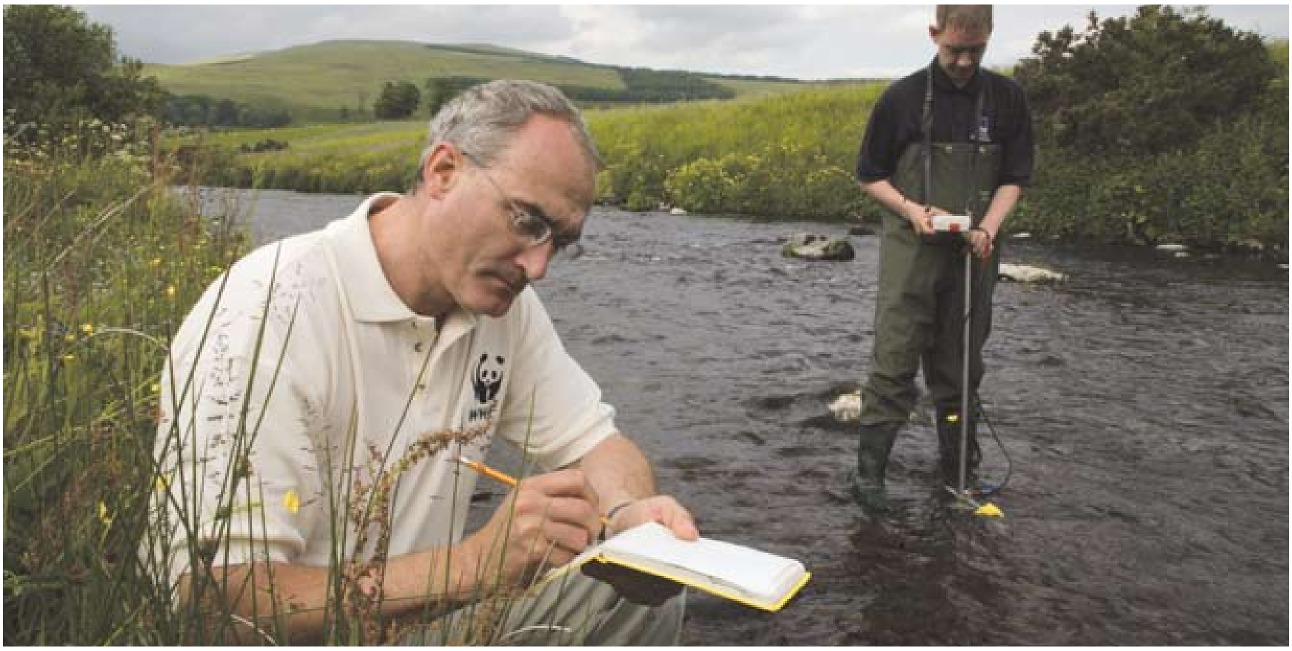
The two fundamental aims of NFM are firstly to reduce the rate of run-off in the uplands and secondly to increase flood water storage in the lowlands. These aims are achieved by using the catchment's natural in-built flood defences such as soil profiles, sediment bars, channel meanders, wetlands, natural levees and the ground cover which intercepts rainwater, protects snowpacks and removes soil water as well as helping to stabilise soils and reduce erosion. The catchment therefore becomes the buffer between the climate and the river networks. NFM addresses flooding issues by considering all changes which have impacted the natural flood defences of the catchment and restores the defences in a strategic and integrated way using the whole catchment. The techniques used in NFM are described in section 3.1.

Natural flood management should always be considered on a catchment scale. The combined effect of a variety of priority sites, all complementing each other, make a quantifiable contribution to the lowering of flood risk.

NFM techniques for reducing run-off rates are best applied in the upper catchment where rainfall and snowmelt are usually greatest and where flood waters are dispersed over the surface or in small tributaries. Techniques for increasing flood storage areas are, however, best applied

The techniques used in NFM include:

- Restoration of upland wetlands to increase flood storage in headwater areas
- Upland re-forestation to increase interception of rainfall and snowfall and increase potential soil water storage
- Rehabilitation of drains and watercourses in plantation forests to reduce run-off rates
- Rehabilitation of river channels to restore canalised reaches and restore meanders to slow down flood flows
- Loch and reservoir management to increase their capacity for flood water storage
- Improving floodplain storage to increase the areas of land available for inundation and increasing retention rates for floodplain storage
- Restoration of boulders and large woody debris in upland rivers to slow down the flow rates and removal of obstructions from lowland river channels to increase the river channel capacity
- Urban watercourse rehabilitation to reduce the risk of channel blockages



in the middle or lower catchment where the topography has a gentle relief and flood waters can accumulate over a relatively large area.

It is important to apply a range of NFM techniques throughout the catchment as this provides a robust flood management plan which can adapt to changes and be effective both in the short and long term. A range of approaches is also needed so that flood management does not rely solely on any single technique, such as wetland restoration, but can use woodlands, channel management and so on to support and complement the benefits of wetland restoration. It is also important to consider the varying timescales of different techniques. Woodland restoration will take at least 10 years to become effective while techniques such as drain blocking will provide immediate benefits. Sites should be spread around the catchment so that any unexpected occurrence such as a change of land ownership does not significantly affect the plan.

NFM within a catchment is therefore adaptable. Some of the techniques used will respond to anticipated changes such as increased winter precipitation linked to climate change but will also be robust enough to adapt to unexpected changes. The techniques applied to a catchment provide individual site benefits but most importantly they combine to provide overall flood alleviation.

2.2

Identification of NFM Priority Sites

IN PRACTICE, not all potential sites will be effective or possible to implement. Some sites, for example a remote wetland, may be too small and too far away from the river network to have any effect on the flood risk site although one wetland combined with several others in the area might be effective. In addition landownership issues and limited funds may restrict the number of possible sites so that only priority sites are included.

The identification of priority sites for NFM should consider the whole catchment above each flood risk site and determine the flood generation processes which are likely in that catchment. This is an investigative process following each watercourse up to its source and building an understanding of the flood generation processes. Much of this involves gaining visual and anecdotal evidence from the catchment on rates of run-off from the hills, rates of flow down the watercourses and what has changed over past decades but there are also other quantifiable sources of information such as rainfall records, river flow records and debris left from recent flood events. In this way options can be developed for which NFM techniques to use in the catchment and an assessment can be made of the potential for reducing flood risk.

Identification of specific NFM sites should be undertaken using GIS where spatial data is overlain as attributes to identify these sites and quantify the total potential area for applying the NFM techniques. For example topographic data can be used to identify areas with surface gradients of less than 2^o, these areas can then be categorised in terms of vegetation cover, altitude and distance from a watercourse. The GIS has therefore identified areas of the catchment closely linked to watercourses which could be restored as wetland features. In addition to wetlands the GIS can be used to identify areas for woodland restoration, upland gullies, mature plantation forests, floodplain storage cells and channel gradients.

Quantification of the priority sites likely to be most effective in reducing downstream flood risk should be carried out by developing a catchment based hydraulic model. This should include all major watercourses and all other significant inputs and would be based around a series of topographic sections across the river channels and floodplains. Flood hydrographs are entered into the upper extremes of each major watercourse and the model run in a dynamic mode so that the flood is simulated as it

The output of the modelling exercise should include:

- Detailed, dynamic flood maps, showing the progression of a flood wave through the catchment, highlighting areas with high flood probability
- Time series of run-off can be simulation, to display the temporal propagation of a flood through any selected part of the catchment
- Quantified water level and discharge information can be produced at any selected point in the catchment

passes down each watercourse. Calibration is carried out by adjusting the model parameters so that simulated water levels at key points agree with observed levels during the calibration flood.

The results of various simulations can be readily compared, illustrating the effectiveness of various proposed flood management scenarios, involving both sustainable and hard engineering solutions.

Therefore a series of NFM techniques can be identified and quantified in terms of the potential reduction in the flood peak at the flood risk site through the catchment-based assessment of flood generation processes, the use of spatial data within GIS and the development of a catchment based hydraulic model.

2.3

Prescriptive Flood Management Plans

POTENTIAL reduction in flood peaks could be quantified using the results from the assessment of flood generation processes along with the identification of potential sites for implementing NFM techniques. Catchment-based NFM takes this a step further by considering the synchronicity of flood peaks from different watercourses and the timescale of NFM techniques becoming effective. The product is a long-term prescription for applying NFM to a catchment.

Synchronicity of flood peaks may not be applicable to all catchments however in many situations where a major flood has occurred there is a river confluence at or immediately upstream of the site. If the flood peaks from the various watercourses coincide then there will be a much larger combined flood peak compared to the situation where flood peaks do not coincide. In some situations the timing of the peaks may only depend on the distribution and timing of rainfall in the headwaters but in other situations one sub-catchment may be more responsive than the others and the flood peak always passes through the site before others. In this latter case it would be wrong to apply NFM in the responsive catchment as it would delay the flood peak and possibly synchronise it with the other flood peaks. It is therefore important to observe a series of floods in all major watercourses to investigate synchronicity of flood peaks.

Timescale is important. Protection of communities from flooding is usually required as soon as possible and will most likely be needed to remain effective for future generations. Some NFM techniques, such as drain blocking, will be effective immediately while others, such as tree planting, will take many years to become effective. In addition some, such as the use of straw bales, are only a short-term fix while others, such as wetland restoration, provide very long-term protection.

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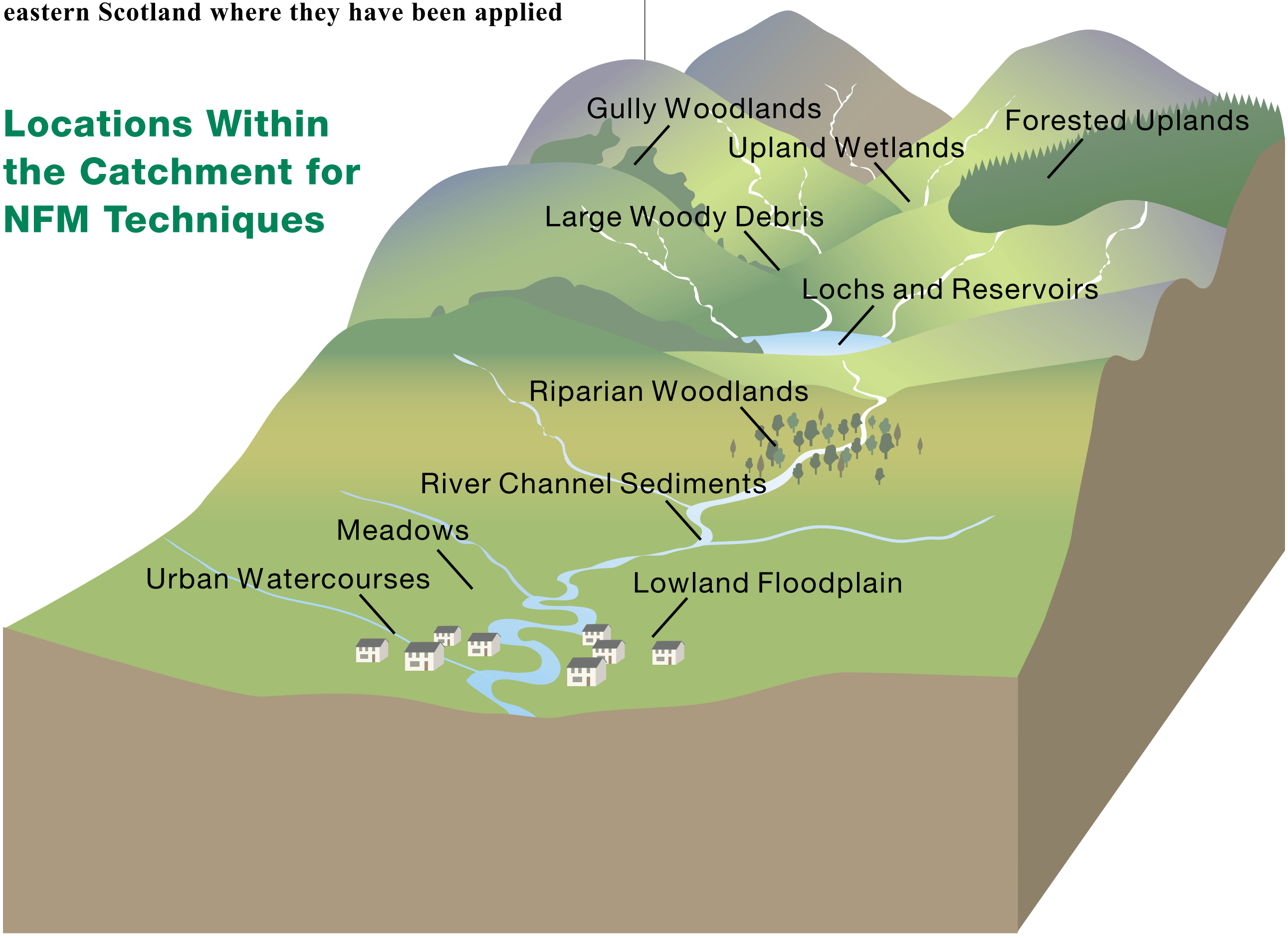
Effective NFM techniques should complement each other with some providing immediate and long-term protection, some immediate but short-term and others providing delayed but long-term. The overall effect provides a sustainable solution for communities and is a prescription for sustainable flood management.

3.1

Natural Flood Management Techniques

MANY NFM techniques have been developed from good practices in forestry, agriculture and river restoration. These practices have given benefits to woodlands, farmland and river habitats and have been used and adapted to benefit flood management. The techniques have been developed in the River Devon catchment in eastern Scotland where they have been applied at selected sites to demonstrate the practicalities involved and also to quantify their effectiveness. Additional work has been carried out at the sites to show the benefits to the wider natural environment and also the benefits to local communities and economies.

Locations Within the Catchment for NFM Techniques



3.2

Restoration of Wetlands

WETLANDS are natural water storage areas which exist throughout most catchments in a variety of sizes, shapes and locations. By definition they are wet features but the water content will vary during the year and between rain storms so there will be some available capacity to store water during storm conditions. In upland situations wetlands can be either in-line with the surface water drainage features, i.e. natural watercourses either rise in them or flow through the wetlands or they can be off-line, i.e. separated from surface water courses. In lowland situations they are usually in-line features, i.e. natural watercourses flow through the wetlands. Upland wetlands are also usually relatively small in size compared to the lowland wetlands but there will be many more of them. In terms of flood management, upland wetlands act as buffers to rapid flows and rapid run-off while lowland wetlands act as overspill storage areas. Many wetlands have been drained in the past to try to improve the agricultural potential. This has reduced their capability to act as buffers in the uplands and reduced the retention of flood waters in the lowlands.

3.2.1 Upland Wetlands

In many upland areas natural hollows exist where water accumulates and creates a wetland. These are often small features but throughout a catchment there will be a significant number which when added together form a large net area. They are naturally dynamic features filling up with water in storm events possibly forming small lochans but then slowly releasing the water over a period of days after the event. In a natural state they would not dry out and even during a summer drought should be sources of water to sustain the flow of water down the burns. They are a crucial part of the hydrology of an upland catchment acting as buffers to flood flows and providing water reserves during droughts.

Most upland areas of the UK have been used in the past for intensive sheep grazing and in the more sheltered areas for summer cattle grazing. In wetlands, open drains were dug to lower the water table and regular maintenance carried out to keep the drains free-flowing. Trees were cleared and grassland improved to provide relatively rich vegetation in a sheltered environment and increase the ground available for grazing. In addition to lowering the water table, drainage reduced the flood storage capability of the area and run-off from the surrounding hills was not buffered by the wetland but, instead, the water ran straight into the burns and down into the main rivers.

3.2.2 Lowland Wetlands

Lowland wetlands can function as significant flood water storage features. In a natural condition they can absorb water into the soils, store water over the surface and release water slowly back into the river so reducing the magnitude of downstream flood peaks.

Lowland wetlands are part of the floodplain and usually have the main river flowing through them but are often separated from the river by natural levees. They have deep soils, they are expansive and they should have a dense wet woodland cover. The wetlands will store considerable volumes of water over the surface when the river overtops its banks and that can reduce the flood peak in the downstream river. If the wetland supports natural woodland the trees and bushes will also create a leaky barrier which in large flood events will hold back water, and releasing it into the river very slowly. This can be enhanced if the woodland is mature; a natural build up of tree debris on the ground can create large woody dams over the surface. A dense woodland cover will also intercept rainwater and absorb soil water through the rooting systems, reducing the soil water content and enabling the wetland to absorb more water during flood events.

Many of these wetlands have been modified through attempts to improve the land for grazing or hay meadows. Deep drains have been dug in attempts to lower the water table and reduce the wetness of the ground; flood banks have been constructed between the rivers and the wetlands and in addition the natural vegetation has been greatly altered with the removal of the trees and bushes usually by over-grazing of the land. These actions damage the wetlands and cause a significant change to their function during flood events.

3.2.3 Restoration Techniques

Restoration of the wetlands for flood management includes blocking drains, removing flood banks and regenerating woodlands.

The drain blocking should be carried out by building a series of small leaky dams down the length of the drain forming small reservoirs to trap silt which gradually fills in each section of the drain. The dams should be built from natural materials, either tree debris anchored across the drain or straw bails anchored by fence posts and woven willow walls. As the straw rots down the willow takes root and grows to replace the straw dam.

Removing flood banks can be carried out by simply creating breaches in the banks along the outsides of meanders or by removing the entire length of flood bank to the level of the natural levee. Creating breaches enables the flood water to flow into the wetland and become trapped by the remaining lengths of flood bank while removing entire lengths of flood bank gives logistical problems in removing the material from the site and potentially damaging other parts of the wetland.

The tree planting should use species native to the area with different species planted according to their preferred ground conditions. The density of the trees should be low over the majority of the wetland so that the trees will perform their hydrological functions but also retain the storage capacity of the wetland. At key points along both river banks, such as on the outsides of meanders and at the lower end of the wetland, the trees should be planted more densely to create leaky barriers which hold back flood waters.

Upland Reforestation

MOST of the uplands in the UK have been cleared of their natural forest cover because of historical demands for fuel, building materials and to expand the land available for grazing. Only remnants of the native woodlands remain and most of these are in a degraded condition. Apart from providing woodland habitats and shelter for animal populations, the native woodlands would have had a significant effect on storm water run-off and snow melt.

Upland woodlands can be described as either hillslope woodlands or gully woodlands. The upland woodlands grow extensively over the hillslopes providing a buffer between intense rainfall and the soils while gully woodlands provide a buffer between run-off from the hillslopes and the river network.

3.3.1 Upland woodlands

Upland woodlands create a robust buffer between heavy storm rainfall and the ground surface. The upland areas of a catchment usually have the highest and most intense rainfall totals and the steepest slopes so are key areas where floods are generated. Trees provide a deep ground cover which intercepts large proportions of the rain and snow and for broadleaf trees particularly in summer when the leaves are still on the trees. The intercepted rain can be evaporated back into the atmosphere or, more likely in storm conditions, drips off the foliage or runs down the branches and trunks. This creates a buffer for intense rainfall by providing a temporary storage of the rain water. In addition significant amounts of snowfall can be held on the tree canopies again providing storage before melt occurs.

The trees also take water out of the soils for nutrient uptake and release water back into the atmosphere by transpiration. This process results in the soils below the trees having lower water contents than soils with vegetation cover such as grasses and heather. Lower water content results in more rainfall and snow melt being able to infiltrate into the soils during storm conditions and be held in storage rather than flowing rapidly into the rivers. The trees also help to stabilise soils, provide debris onto the forest flood to reduce overland flow rates and provide shading for the snow which avalanches off the canopy reducing melt rates.

The loss of natural forest cover in the Scottish uplands is well documented particularly for the loss of habitats and impact on wildlife. Without upland woodlands the hillslopes are very vulnerable to intense or prolonged rainfall and rapid rates of snowmelt. Rainfall will rapidly run off the steep slopes with little storage and protection in the short grasses, heathers and tree debris covering the ground. More rapid run-off will concentrate storm waters into the burns and main rivers and also increases erosion and landslides which reduces soil depths and further increases run-off rates. Restoration of native woodlands is occurring in many parts of Scotland although the rate of restoration is slow because of the expense of planting thousands of trees, the need to erect deer fences and the slow rates of growth in hostile climates.

Trees in the uplands have a number of roles in flood protection:

- The tree canopies intercept significant proportions of the rain and snowfall providing temporary storage and releasing it more gradually onto the ground surface
- The trees also take up large amounts of water through the root systems which reduces the water content of the soils and allows storm water to be absorbed into the upper soil profiles
- Broken tree branches accumulate on the forest floor and combine with the tree roots to buffer overland flows and slow down surface run-off
- In winter the trees provide shelter for snow accumulations on the forest floor and so prevent rapid melting during storm conditions
- In addition the tree roots help to stabilise the soils reducing erosion and the build up of sediments in the river channels

3.3.2 Gully woodlands

Gullies are found in most catchments varying from shallow gently sloping features to steep gorge features. The gullies concentrate storm water run-off and become the main route for water to flow rapidly off the hills and into the lower valley. They develop where overland flow from heavy rainfall forms a series of small burns. When they combine down steeper slopes they erode into the soils to form gullies. Within the gullies there will be a range of active hillslope processes all reacting to the concentrated flows. The channels will be eroding down into the soils exposing rocks and boulders which in turn form steps and pools along the channel. The side slopes will be eroding to maintain stable gradients as the gully is deepened and the burns will be transporting material down the gully.

Through the process of forming the gullies the flow rates will increase as the gullies grow and collect more surface water drainage from the upper slopes. The bedrock and boulders within the channel will form buffers to break up the energetic flows but they will only be successful in the upper gully areas before the burns have formed into a single watercourse. Lower down the gullies the flows will be highly energetic and turbulent with capabilities of moving large boulders and causing further erosion possibly triggering landslides. In this situation the burn is a highly unstable feature with the potential to discharge the high energy water into the main river where there are not such robust defences for this type of flood and the water will rip through the lower channel and down towards the floodplain.

Flood flows down the gullies can be buffered and slowed down if there is mature and dense gully woodland. Gullies, sheltered from the harsh upland weather, are suited for woodlands to develop. Shallow and gently sloping gullies usually have only remnants of woodland because sheep and deer use the gully for shelter. However, many woodlands have survived in the deeper gullies. In gullies woodlands should protect the soils on the steep side slopes with roots binding the soils together. Trees also form buffers to surface water naturally flowing into the gully but in addition the trees or branches fall into the channel to form large woody debris dams which help to break up energetic flows in the burns.

The gully woodlands can therefore play an important role in the control of run-off. Unfortunately many gully woodlands have been degraded or completely lost and so flows into and down the gullies are much higher than they would be with natural woodland. In addition the loss of gully woodlands has resulted in reduced shelter for sheep and deer, degradation of woodland habitats, loss of shading for snow accumulations and greatly reduced stability of the hillslopes.

3.3.3 Restoration Techniques

Upland woodland should create a buffer between intense rainfall and the ground surface, intercepting rainfall and reducing soil water content and protecting snow packs from rapid melt. Gully woodland should also intercept rainfall but in addition should stabilise soils and provide woody debris to the river channel.

Tree planting in the uplands and the gullies should use species native to the area and suited to ground conditions. In some situations, especially in gullies, natural regeneration may be possible if sheep and deer are excluded until the trees are mature. Care should be taken to retain winter sheltering areas for deer and these areas should left unfenced and unplanted. When planting, ground preparation and use of heavy machinery should be kept to a minimum. Fencing may be needed depending on the deer population but should be removed once the trees are mature.

Within the gullies the trees should be planted more densely to form an interlocking canopy. Trees along the sides of the watercourse should be grown by natural regeneration so that they form a variable density along the watercourse with some growing into the channel bank.

3.4

Lowland Riparian Woodlands

THE role of riparian woodlands in sustainable flood management is to provide a leaky barrier along channel banks to hold back floodwaters on the floodplain. Floodplains are one of the most valuable agricultural sites in a catchment with fertile soils, a good supply of water and a natural replenishment of nutrients from flood waters. This encourages good natural habitats and a rich wildlife. Many riparian zones on the floodplain have been greatly modified by human developments and there has been widespread loss of habitats due to land drainage, clearance of trees and bushes and confinement of the river by channel protection, road embankments and bridges.

The stripping away of the trees and bushes and confinement of the river has caused dramatic changes to riparian zones including their behaviour in floods. In moderate flood events a river is mostly confined within its natural channel and any lateral flows are usually into relict channels. In the higher and more rare events the riparian zone will be inundated with the extent of the flood waters controlled by natural levees over the floodplain, river bluffs and sediment deposition features on the edges of the floodplain. In the past artificial floodbanks would have been built to prevent this inundation and in many places throughout the UK these still remain. If the floodbanks were overtopped the aim was to encourage the water to return to the river as quickly as possible by the construction of networks of open ditches, often with flap valves, to let the water back into the river. The effect of the floodbanks was to push the floodwater downstream while the ditches caused rapid drainage of the floodplain which simply increased the volumes of floodwater in the lower catchment causing a greater impact.

To reduce impact on the lower floodplain the water should be retained in the upper floodplain areas and slowly released back into the river. These floodplain areas start in the piedmont zone where the river starts to meander creating a river corridor with small cells of flat ground on the insides of the meanders. As the river progresses out of the piedmont zone the floodplain will become more extensive forming a large expanse of flat ground. In high flood conditions the river will flood these areas. It is likely to flow over the floodplain cells in the piedmont zone effectively broadening the river but in the lower floodplain the river flow will remain in the vicinity of the channel with the wider floodplain becoming inundated with almost stagnant water.

Riparian woodlands are most effective in the piedmont zone where they can slow down the flow of water over the floodplain cells and increase the volumes of water stored in these areas. The role of the woodlands should be to provide a leaky barrier along the channel bank so flood waters can spread over the floodplain but the trees and bushes release the water slowly and also trap large debris which could cause a downstream problem. The woodlands therefore need to comprise species which are strong and thrive in wet soils and they should be constructed on individual floodplain cells so that the water can spill over the upstream section and be caught by trees and bushes on the downstream section of the cell. As it becomes established the riparian woodland will create a diverse range of habitats with some dense patches of woodland and some open areas. It will also protect and stabilise the riverbank, prevent cattle using the river for watering, provide a buffer to prevent polluted water entering the river, create a variety of light and shade over the water and improve the habitats within the river channel.

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3.5

Rehabilitation of Drains and Watercourses in Plantation Forests

PLANTATION forests exist throughout the uplands of the UK and there has been much research carried out on the impacts of forest management techniques on environmental issues such as hillslope hydrology. The original ground preparation technique was to plough the hillslope to improve drainage of the soils and to create a better site for establishing the individual trees. Ploughing was always perpendicular to the slope with no breaks for watercourses. This caused rapid run-off and erosion during storm events with the rivers highly impacted. In addition to the hillslope drainage there were many forest roads built at the time of planting with roadside drains and culverts installed. Roads were not needed by heavy vehicles until clearfelling took place and so many were left un-managed.

The Forests and Water Guidelines, introduced in the mid 1980s, included new forest practices such as shorter plough lines with cut-off drains at regular intervals down the slope, buffer zones along water courses and instructions to leave tree debris in the burns to provide buffers to high flows and filters for sediments. More recent developments have completely rejected ploughing in favour of mounding where single pieces of turf are turned over without creating a continuous drain. This reduced the risk of rapid run-off and erosion during storm events while retaining the site for tree planting. In addition the forest road problem was addressed with road gradients reduced, resurfacing and grading improved and silt traps installed in roadside drains.

New planting techniques and forest road techniques will therefore address flood management issues but there are still extensive areas of plantation forestry where old plough lines exist, trees are planted up to the sides of water courses and old forest roads exist. Many of these forests are reaching the end of their first cycle so clearfelling and replanting are occurring, the plough lines, drains and watercourses are being exposed and roads will be used for timber abstraction. Questions for forest management now focus on whether the old drains should be cleaned out, infilled or left, how woody debris should be managed in the water courses and how forest road drains should be managed.

NFM techniques for plantation forests depend on whether the artificial drainage features are hydrologically active or not. An assessment should be carried out before clearfelling to determine whether old plough lines could become active or if years of tree debris has infilled them. Cut-off drains and forest road drains usually remain active through the forest cycle so the forest clearfelling programme might include upgrading the road and its drainage to take heavy logging lorries. Natural watercourses should be assessed to determine the large woody debris content and whether it needs to be managed. In general many plantation forests throughout Scotland have inactive plough lines when the trees reach maturity. Cut-off drains are still active and should be blocked off using tree debris dams along the channels. Forest road drains will be deep and active and after timber extraction is complete they should be allowed to become overgrown and finally all large woody debris associated with the plantation forest should be removed from the channels.

3.6

Loch, Lochan and Reservoir Management

IN upland Britain, particularly highland Scotland, there are vast numbers of natural lochs and lochans of varying size and in varying locations throughout the catchments. Many of these water bodies have been changed by the excavation of sediments from the outfall channel or from the construction of a weir at the outfall. Some lochs have been increased in size by the construction of large dams and reservoirs have been created either to generate hydro-power or to supply potable water to urban areas. Apart from some hill lochans, most of these water bodies are in-line with rivers and hence provide significant buffering of flood flows. In addition many of the water supply reservoirs are directly above the villages and towns which they feed and so could have a significant influence on flood flows.

Small hill lochans behave in a similar way to small upland wetlands with the ability to buffer energetic flows in small burns. Unlike wetlands, most of these features have not been affected by past land management and so most are in a natural condition with little opportunity for increasing their buffering effect. The larger lochs are usually located in the deep straths and glens of highland Scotland and are usually associated with past glaciation where the valley bottom has been deeply eroded and a blockage left across the valley floor formed from either glacial depositional features, cones of alluvial or colluvial sediments or a bedrock outcrop possibly formed from a volcanic sill or dyke. Many lochs also have a wetland feature associated with the inflow channel where the river has deposited sediments and organic material to form a delta feature which is usually colonized by trees and bushes with the river developing a meandering channel.

Many of these features have been altered in the past with channel management carried out at the inflow and outflow points. Delta features at the inflow have been attractive for use as grazing land and so trees have been removed, the channel straightened and artificial drains constructed. Restoration of these features would improve the buffering effect of the wetland and slow down the flood flows. In many situations attempts have been made both to raise the outfall and increase the area of the loch or to excavate the outfall to decrease the area of the loch. In addition some very large lochs have had concrete structures constructed at the outfall to permanently raise the loch level. It is unlikely that removal of concrete structures will be possible for NFM but restoration of outfall levels to a natural and sustainable level may be possible. In terms of NFM each situation needs to be studied individually taking into consideration the rate of inflow into the loch, the bathymetry and topography of the loch and its shore lines, the level of the outfall and any channel constrictions at the outfall.

Operation of reservoirs for flood storage is not commonly undertaken as the water is a valuable resource and the operating company would be unwilling to release water before a forecast storm in case the rain was less than expected. If reservoirs are full before a storm there will still be some buffering of the flood waters however the buffering will be more effective if there can be some drawdown before the storm. The use of reservoirs for flood management has some practical difficulties such as the time required in some systems to draw down the water and the potential structural impact if the water was drawn down too quickly. Reservoirs therefore cannot be entirely relied upon for flood attenuation but can form part of an integrated system of flood management in the catchment.

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3.7

Management of River Channels

RIVER channels are the natural route for water to drain out of the catchment and must be maintained to allow the continuous flow of water within the banks. In NFM it is important not to confuse holding back water in certain parts of the catchment with allowing the flow of water down the main river channel. Techniques to hold back water involve sites in the upland areas, along headwater channels and through the piedmont zone. The river channel in the lower catchment should be maintained as the route where the water is discharged from the catchment in a controlled way. By controlling the flow the potential flood storage areas will not fill up in the early part of the flood but will be available to accept more water even during the flood peak. This control means keeping the water within the river banks for as long as possible where it does not cause a problem and where it is beneficial for habitat maintenance and sediment cleaning.

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3.7.1 Management of Large Woody Debris

Large woody debris (LWD) occurs naturally in watercourses in the form of entire trees, branches, trunks and root wads. LWD items are found both in isolation and in accumulations and usually comprise one or more immobile ‘key members’ which trap debris flowing downstream, creating a ‘debris dam’. The quantity and characteristics of LWD dams are shaped by catchment conditions such as riparian tree species and density and river processes flow rates and hillslope stability. In a natural situation the LWD will comprise a range of tree species and a range of decay with each member anchored by both the remains of the rooting system and also by the crown which becomes entangled in neighbouring trees. This enables a population of debris dams to form along the river channel so that when one rots and breaks up the next one downstream is strong enough to trap the tree and sediment material released. For NFM the LWD material is important in small upland rivers where flows can be high and energetic and the LWD forms a series of dams across the channel breaking up the flows and reducing the speed of water. The LWD has other benefits for the watercourse creating pools where sediments can accumulate and developing high habitat quality and diversity.

LWD management traditionally was carried out to remove all tree debris and "clean the river" so that the material would not block culverts, bridges and hence cause flooding and damage to infrastructure. LWD was also viewed as a cause of channel instability, a danger to navigation and a barrier to fish migration. The outcome of centuries of stream-cleaning, combined with the loss of riparian woodlands is that many river networks have been rendered devoid of LWD resulting in increased flow rates, increased sediment movement, incision of the channel bed, homogenisation of in-stream habitats and reduced the abundance and diversity of macroinvertbrates and fish.

For NFM all watercourses should be assessed for the stability of the LWD population with the removal of potentially unstable material. The identification of stable wood should be based on the size of the deposit, anchoring by branches or roots, wedging against channel obstructions, burial in substrate and state of decay in relation to neighbouring material. Stability is also affected by the proportion of the deposit resting on channel banks and its position in the flow. Materials orientated perpendicular to flow retain more water and sediments than those orientated parallel to flow. Items flanking the channel banks can protect them from erosion, while items oriented more perpendicular to flow can cause channel widening and flow diversion, enhancing water storage capacity.

NFM therefore uses LWD as a technique for flood management. Watercourses should be assessed for types and abundance of material and inappropriate material removed. In watercourses where there is no LWD the restoration of a riparian woodland might be too long for the replenishment of LWD and material may have to be artificially placed in the watercourse. The same principles should be followed, i.e. introducing key members which are of different sizes and ages and anchored at points on both sides of the watercourse.

3.7.2 Restoration of Meanders in the Piedmont Zone

The piedmont zone of a catchment is where high energy flood flows emerge from the uplands and flow into the lowlands. Without significant buffering of these flood flows there would be extensive damage to the floodplain with erosion caused by the power and turbulence of the water, followed by deposition of the sediments over the floodplain and widespread flood inundation. If a watercourse is slowed down it naturally forms bends in the channel which develop into meanders which in turn slow the water, disperse the energy and deposit the sediments within the river corridor.

In situations where meanders have been artificially removed from the channel there needs to be blocking of the new channel with robust material, preferably large boulders, so that the river flows around the old meander and restores this as part of the channel. This then enables other features to be restored such as channel bank woodlands and floodplain storage cells. Restoration should be carried out at a time when spawning or migrations are not occurring so that there is no damage to the local ecology.

3.7.3 Removal of Obstructions in the Lower Catchment

The most common obstructions in river channels related to flooding problems are sediment accumulations, weirs, bridges, culverts and dumped waste materials. At many river confluences there is an accumulation of coarse sediment usually transported to the site from the tributary and deposited when it meets the less energetic water in the main river. Step features are created along the long profile of the main river creating long pools and riffles in low flows and blockages in high flows. These step features are naturally dynamic and will usually build up during a series of floods and then be partially removed during a major flood. Problems occur when the build up is excessive caused by high erosion rates and large sediment loads in the tributaries. This can be considered a natural process but if the high erosion rates are caused by human interference in the headwater areas then the sediment build up is not necessarily natural. Removal of the material could be left until the next major flood but there is also a risk of extensive flood damage before the material is removed. In these circumstances excavation down to an agreed level should be considered to remove the obstruction but maintain the river feature. The agreed level should be determined using a hydraulic model of the confluence to determine the minimum excavation needed to achieve the flood level reduction.

Apart from sediment accumulations at river confluences there are usually a large number of other blockages within the channel which potentially cause localised flooding. These can include fallen trees, excessive vegetation growth, old weir structures related to mill lades, low bridges, culverts, fly tipping and other debris from failed river bank protection works such as concrete blocks or gabion baskets. A decision of whether to clear these obstructions for flood management needs to consider other potential environmental benefits. Debris such as that from fly tipping, concrete blocks or old gabion baskets is unlikely to have any environmental benefits for the river and can usually be cleared out of the channel. Low bridges do not usually reduce the capacity of the river channel as they span the tops of the river banks but they may impede the inundation of the floodplain. They can however be an obstruction for flows in the channel if large debris, such as trees, is carried down during the flood. In these situations the debris can become trapped reducing the flow of water under the bridge and should therefore be cleared away.

Obstructions caused by fallen trees and overhanging dense bankside vegetation need sensitive management as these features offer significant environmental gain with the creation of bankside habitats and shading of the river. Clearance of this type of obstruction should only be carried out if the accumulated debris is considered excessive. Excessive can be described as if a large tree has fallen across the whole width of the river or if bankside vegetation is so dense as to restrict access to the river. It would not be excessive if the tree was lying along the bank and if the vegetation was growing in patches overhanging in places but with gaps leaving contrasting areas of light and dark along the water surface.

3.8

Floodplain Management

FLOODPLAINS are areas of low relief in the lower catchment where the river system can disperse its energy and deposit its sediment load plus any other debris brought down from the upper catchment. They should be areas where natural processes control the river and allow an organised system of channel forms and deposition features to develop. The natural role of the floodplain is to act as a large storage area which will fill up with water and then be gradually released back into the river. For flood management the lower floodplain is a simple storage area where there are few opportunities for improvements in flood control. However, the upper floodplain is an area where features in the river channel and on the floodplain can make a difference to flooding in the lower areas.

Floodplains have attracted intense industrial, housing and agricultural developments over the centuries. The flat ground, deep soils and sheltered environment are ideal for agriculture and most floodplains have been artificially drained, fences erected, fields ploughed and pasture improved. In addition housing developments occur on the floodplain with the original villages expanding as new housing schemes are built and communications networks develop with roads and railways linking towns and crossing the floodplain and rivers. The original natural flood storage areas have therefore been changed with drains to take the water off the fields as quickly as possible, embankments to keep roads and railways above the flood levels and urban drainage systems to take water off roofs and roads.

In the lower catchment area flood management must include the prevention of further inappropriate housing and road development. It may even require removal and relocation of properties in very high risk areas. In the upper floodplain there are other opportunities for flood management although many of these opportunities could be in conflict with other demands on the land. The most appropriate approach involves good land management practices such as maintaining woodlands along the river banks, avoiding deep drainage of fields, controlling river bank erosion, removing agricultural flood banks, incorporating sustainable urban drainage systems into housing schemes, preventing road or railway embankments across the floodplain and avoiding low bridges across river channels.

In areas where the floodplain is not protected by floodbanks, flood water should be allowed to spill into the area and be retained for a significant amount of time. Where floodplains have been drained, woodlands removed and hard surfaces created the floodwaters are quickly pushed back into the river coinciding with the passage of the flood peak down the river. This results in minimal flood attenuation. The flood wave needs to be held back in the flood storage areas so that the flood peak in the river can pass by and then the stored water is gradually released behind the main flood wave.

Attenuation can most simply be achieved by developing riparian woodlands which create leaky barriers along the river bank. If the woodlands are only developed along the downstream ends of the storage areas the flood water will still enter the area at the upstream end and will accumulate on the downstream section where the woodland helps to confine the water. The leaky barrier then slowly releases the water and also filters out any debris brought down the river in the flood event. This is the most beneficial floodplain development for NFM as the woodlands also provide a significant environmental gain to the land and the river.

Additional flood peak attenuation could be achieved by blocking off field drains in the floodplain, protecting river banks from excessive erosion and controlling storm water run-off from urban areas. In practice it is very difficult to remove or alter existing drainage systems except if the area is poor farm land. The only realistic control will be in the renovation of floodplain wetlands. Protecting river banks from excessive erosion can be carried out in parallel with the development of riparian woodlands. Riparian strips should be fenced off to enable the trees to become established and to prevent livestock entering the river channel and eroding the banks. Where banks are made from fine sediments the bank protection should use live willow woven walls constructed to form benches. Where bank material is coarser the protection should use rip-rap of appropriate size depending on the river flows.

Urban Watercourse Rehabilitation

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MODIFICATION to all urban watercourses has been taking place for over a century to enable the use of water for industries, recreation, transport, waste water disposal and flood control. To achieve this stormwater drains have been constructed, surfaces covered with non-porous materials, significant amounts of debris thrown into rivers and many rivers have been canalised, culverted or gated. These watercourses now have some of the greatest flood risk sites in the catchment with the highest potential damage and cost involved.

Because of their highly developed nature it is very difficult to restore urban watercourses to their natural state. NFM in the urban environment may need to adapt solutions used in more rural settings. Storm water drainage from roofs, car parks and roads needs to be addressed and this often involves having to trace underground pipe systems which may have been installed decades ago. It also potentially involves large amounts of money if for example the storm water drainage from a large car park is going to be restored.

Blocked culverts are probably the major cause of flooding. Culverts may have been built too small, additional storm water might be discharged into them and metal grills are often secured to the ends for safety reasons. A blocked culvert soon causes flooding problems and there is little chance of rectifying the problem during a flood. If all culverts could be removed then the problem would be resolved however this is rarely an option and the solutions include controlling the discharge of water through the culvert, carrying out regular cleaning of safety grills and keeping debris out of the channels. The latter solution is almost impossible to achieve in some urban areas.

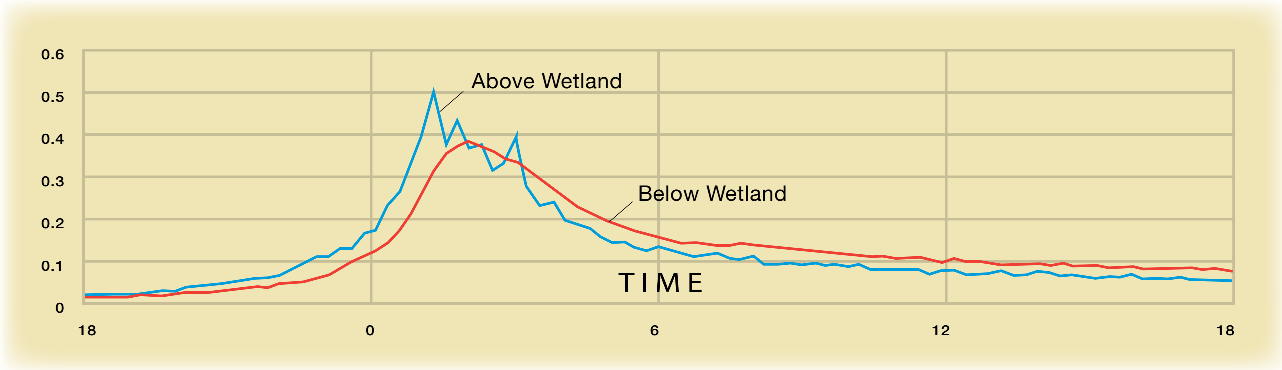
Maintenance programmes are essential, including excavation of sediment accumulations under low bridges, cutting back of selected trees, clearing out debris from the channel (and providing alternative waste disposal points). Other more radical solutions are sometimes needed such as replacing culverts under roads with bridges and fencing an area around a culvert rather than installing a metal grill. Where there is no longer a demand for water from industrial users there may be opportunities to divert the watercourse into a new channel to bypass the developed area. This is sometimes possible as the watercourse was probably already diverted to take it to the factory or mill. Planners and developers can contribute to this by installing any new developments with storm water management systems and individual house owners can contribute by installing roof-water collectors.

4.1

The Evidence: How, Why and When Natural Flood Management Works

USING data from the hydrological monitoring stations in the Glen Devon demonstration sites the changes in the flood hydrology of each site are being analysed in relation to variations in the climate and to the other applied NFM techniques. The changes in the processes of storing water and reducing run-off rates are being quantified at each site and so the effectiveness will be quantified. Available results are presented below. Ongoing results from the demonstration sites will be published in the future on WWF Scotland's and Mountain Environment's websites, as the data becomes available.

Some techniques, such as the drain blocking, will have an immediate effect while other techniques such as woodland restoration, will take longer to have an effect. Therefore a computer modelling approach has to be taken so that the effectiveness of the long-term techniques can also be quantified. Hydraulic models of the demonstration sites are being developed and results are presented below to quantify the effects of wetland restoration, introduction of large woody debris and river channel management.



River flow data collected from the stations above and below the demonstration site. The blue line indicates the flow through an unrestored wetland. The red line shows how a restored wetland smooths the flow and holds onto water longer.

Glendey Demonstration Site

THE Glendey demonstration site is in the upper River Devon catchment and covers an area of 0.0175km^2 within a catchment of 2km^2. The site includes an area of plantation forest, a gully woodland, a river channel with large woody debris and an upland wetland. Past land use changes have included the clearfelling of the plantation forest, removal of the gully woodland, introduction of tree debris to the watercourse from the clearfell, loss of natural tree debris in the channel and artificial drainage of the wetland. These changes have affected the run-off characteristics of the hillslopes, increased run-off and erosion down the gully, increased flow rates in the watercourse and degraded the wetland.

NFM techniques were applied to the site and included tree planting on the hillslopes and down the gully, removal of tree debris from the watercourse, creation of meanders through the wetland, blocking of artificial drains and planting of tree barriers across the wetland. To plan the work the site was instrumented with gauging stations at the upstream and downstream ends of the site and a raingauge in the centre of the site. In addition the site was surveyed and a hydraulic model of the site developed.

Several flood events have been recorded since the instrumentation was installed enabling the hydraulics of the existing system to be investigated. Comparison of the data from the upper and lower gauging stations shows that the gully and wetland attenuate floods resulting in a smoother hydrograph with an average reduction in peak flows of 16%, a delay in the time of the peak of 45 minutes and an increase in baseflow of 35% six hours after the peak. The volume of water stored over the wetland site during the largest recorded event (1.344cumecs) was 2594m^3 covering an area of 10312m^2. This event was estimated to have a return period of 1 in 25 years. Restoration added 1209m^3 in storage capacity.

River flow data collected from the stations above and below the demonstration site showing how the gully and wetland smooth the flood hydrograph, reduces the peak flow and increases the base flow after the peak.

The hydraulic model of the demonstration site was used to show how effective the restoration work in the wetland and the gully will be. Restoration of the wetland was considered in two stages firstly the blocking of the artificial drains and secondly the blocking of the drains combined with the restoration of a woodland over the site. The table below gives details of the changes for three flood events of different magnitudes. For the largest event (estimated to have a return period of 1 in 25 years):

- The peak outflow was reduced by over 11% after the drains were blocked and the woodland restored
- The mean velocity in the main channel was reduced by over 70% after the drains were blocked
- The area flooded at the time of the peak increased by over 5%
- The volume of water stored over the site increased by over 46% with the drains blocked and trees planted

It is clear from the results that restoration of the wetland will have a major effect on flood flows. The effects are most significant for the smaller events however even in a large flood event the blocking of the drains slows down the speed of the water and the restoration of the woodland reduces the peak flow and increases the volume of water stored. Considering this additional storage for the whole of the Glendey catchment, if all four wetlands in the catchment were restored there would be an additional 4836m^3 of flood water stored during the 1 in 25 year flood and if 50 similar wetlands were treated in the whole of the River Devon catchment there would be 60450m^3 of additional water stored.

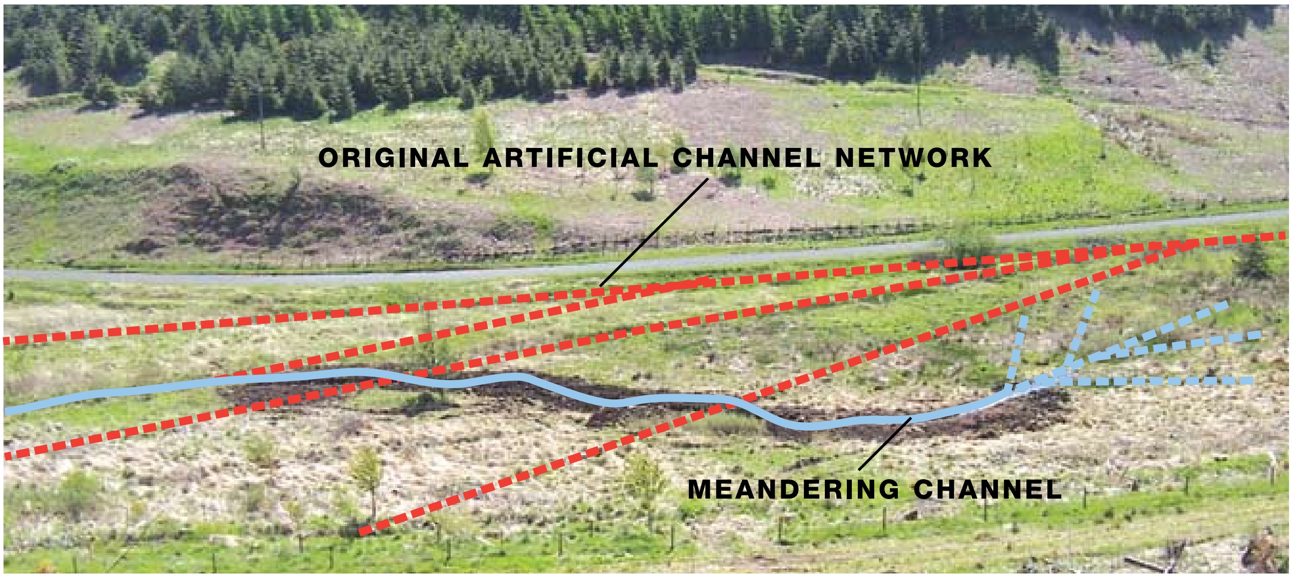
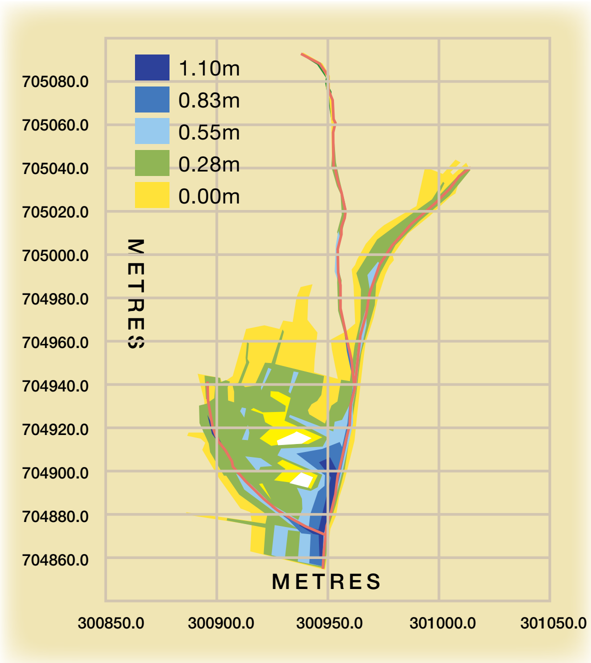
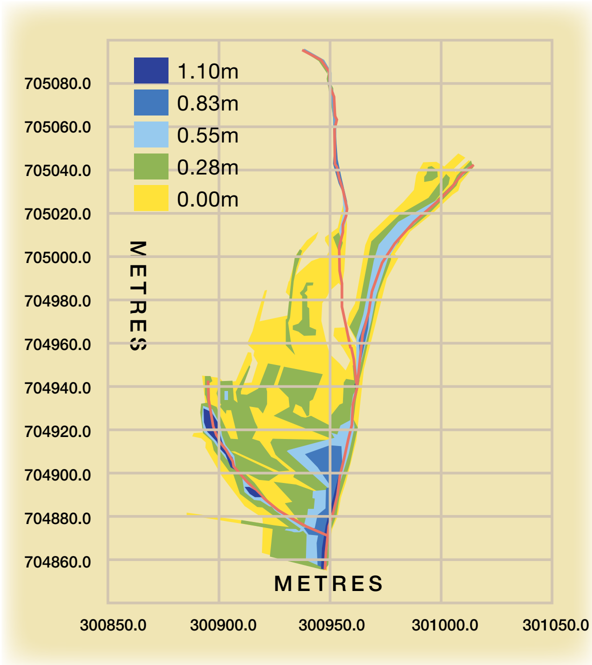


Diagram of the wetland showing the artificial drains which were blocked and the meandering channel which was constructed



Area of the wetland (with depths of water, m) inundated during the flood event 26th October 2006 - before restoration



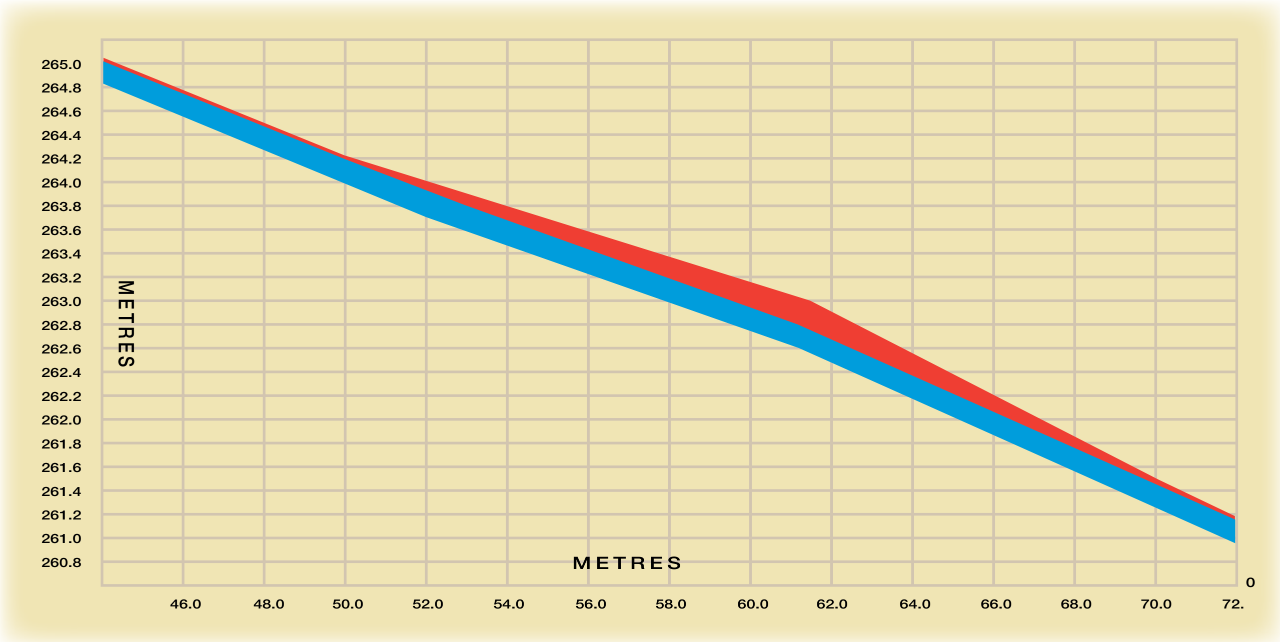
Area of the wetland (with depths of water, m) inundated during the flood event 26th October 2006 - after restoration

	Flood Event								
	26th October 2006			16th November 2006			30th October 2006		
	1	2	3	1	2	3	1	2	3
Peak Outflow (cumecs)	1.344	1.289 (-4.1%)	1.190 (-11.5%)	0.421	0.401 (-4.8%)	0.355 (-15.7%)	0.278	0.263 (-5.4%)	0.231 (-16.9%)
Travel Time Between Gauging Stations (mins)	39	41	45	31	36	39	39	38	43
Peak Flow Velocity (m/s)	1.94	0.51 (-73%)	0.48 (-75%)	1.47	0.37 (-75%)	0.35 (-76%)	1.46	0.41 (-72%)	0.39 (-73%)
Peak Volume Stored (m^3)	2594	2617 (+0.9%)	3803 (+46.6%)	737	848 (+15.1%)	1250 (+69.6%)	423	572 (+35.2%)	942 (+122.6%)
Peak Flooded Area (m^2)	10312	10867 (+5.4%)	10923 (+5.9%)	4397	5753 (30.8%)	5955 (35.4%)	2478	3878 (56.4%)	4285 (72.9%)

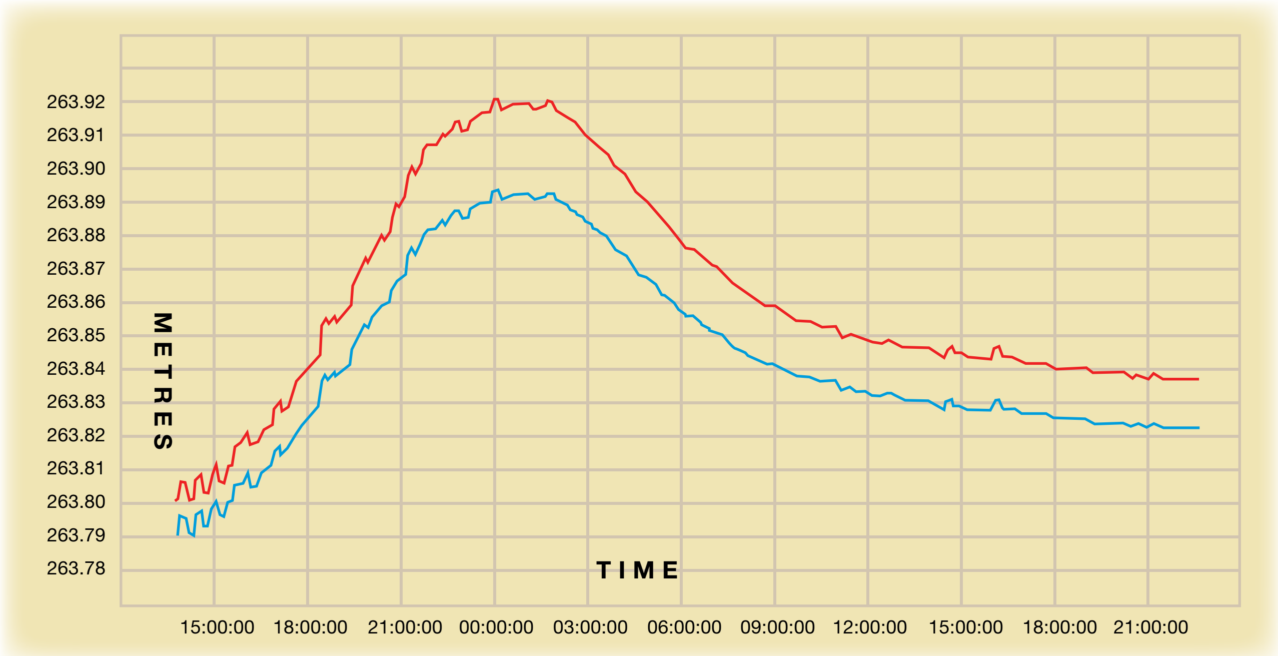
Summary of changes to the flood hydrology of the wetland site. Intervention tested in the model: 1 Original site conditions, 2 Artificial drains blocked, 3 Drains blocked with a woodland restored

The hydraulic model of the Glendey demonstration site was used to simulate the effects of managing large woody debris in the gully. A moderate flood flow of 0.421 cumecs was used as the input to the section of the model from the upper gauging station down to the base of the gully. The model was run with the channel having no woody debris and then with debris across the channel at 30m spacing down the channel. This simulated the situation where the large woody debris spans the channel with the branches touching the channel bed allowing low flows to pass under the debris but flood flows to be partially blocked. Results showed that the water depths at the peak flow immediately upstream of the debris increased from 22cm to 31cm after tree debris was placed in the channel and at the base of the gully the water depths in the channel decreased by 2.9cm. In addition the velocity of the water decreased from 3.01m/s at the top of the gully to 2.03m/s at the base of the gully.

The results therefore showed that large woody debris placed in the channel of a steep gully will increase the storage of water and reduce the speed of the water during a flood flow. The effects were equivalent to an additional 34% of water stored and a velocity reduction of 13% per 100m of channel.



Channel long profile showing the change in water depth as the water flows over tree debris
blue = original; red = additional depth at tree debris



Time series of water level in the channel before (blue) and after (red) tree debris was placed into the channel

Tillicoultry Demonstration Site

THE Tillicoultry demonstration site is in the lower catchment around the confluence of the Tillicoultry Burn with the River Devon. The site includes the extensive floodplain, the main river channel, deposits of coarse sediments and infrastructure developments including a road bridge over the main river. In addition there is a sediment deposition feature related to the Tillicoultry Burn which extends over the floodplain almost to the main river. This has created a site above flood levels for Tillicoultry to be built on and an elevated route for the road down to the bridging point over the River Devon.

Past developments in the area have removed most of the riparian woodland, severe river bank erosion has been caused by cattle and high river flows, large accumulations of sediments have built up in the main channel caused by high erosion rates in the upper catchment of the Tillicoultry Burn, a low flood bank has been constructed on one side of the river, ground raising has occurred over the floodplain with the building of road embankments and a low bridge over the river and the river has been straightened to direct it under the bridge. These changes have affected the conveyance of the channel and the capacity of the floodplain to store flood water. A computer model of the site was developed to demonstrate the effects of the past changes and to identify flood management options.

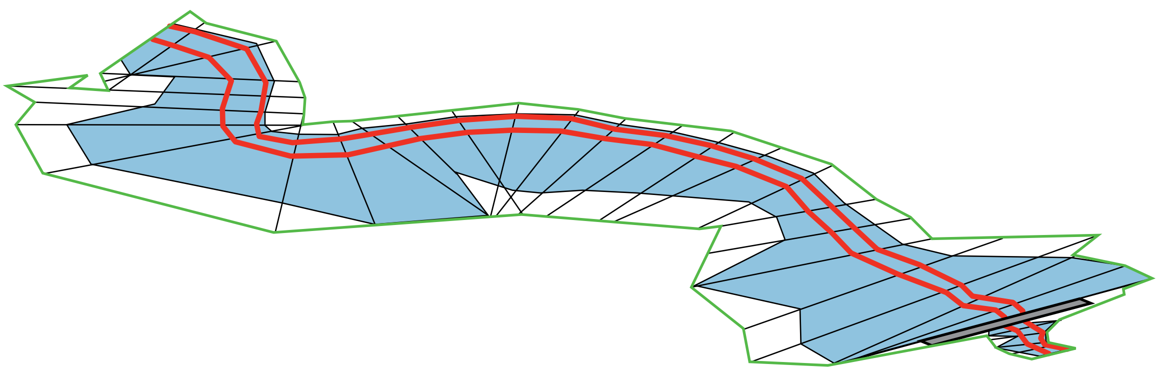
Two peak flows were tested in the model, an observed relatively low flood flow which just spilled out of bank (24 cumecs) and the 1 in 200 year flow (96 cumecs) estimated from a downstream river gauging station. The model was established with the existing topography and infrastructure and then run with the following series of interventions:

- **Stabilisation of the upstream channel banks and removal of sediment accumulations in the channel**
- **Restoration of two meanders in the river channel**
- **Removal of low flood bank**
- **Removal of the road bridge**
- **Raising of the road on the south side of the river**
- **Removal of the road bridge plus road embankment**
- **Removal of the sediment accumulation in the main river channel at the Tillicoultry Burn confluence**

The extent of the flooding in the 1 in 200 year event with the site in its current condition is shown in the figure below. The road bridge appears to create a significant block across the floodplain but the effect is due to the cone of sediment deposited by the Tillicoultry Burn extending over the floodplain. The various interventions were individually tested in the model with the changes quantified and four parameters selected for comparison. The results are shown in the following table.

Results from the model showed that:

- **The flood level upstream of the bridge was only lowered slightly, the greatest effects being removal of the sediments downstream of the bridge lowering the level by 6cm and removal of the bridge lowering the level by 8cm.**
- **The volume of water stored at the peak of the 1 in 200 year flood was increased by 10290m^3 by removing sediments upstream of the bridge but decreased by 5600m^3 by removing the bridge.**
- **The speed of the water downstream of the bridge was only decreased by the removal of the sediments at the Tillicoultry Burn confluence.**
- **The speed of the water in the main channel immediately upstream of the bridge decreased dramatically after restoration of the two meanders. In the 24 cumec event the speed decreased from 1.02 to 0.28 m/s while in the 1 in 200 year event the speed decreased from 0.79 to 0.47 m/s.**



Plan of the site showing the extent of flooding in the 1 in 200 year event with the site in its current condition - the river is flowing to the bottom right of the figure, the channel is denoted by the red lines and the road bridge shown in grey with the inundated area in blue

	Intervention Tested							
	1	2	3	4	5	6	7	8
Elevation of the water surface immediately upstream of the bridge (m)	12.17	12.17	12.20	0.421	12.18	12.18	12.15	12.11
Volume of water stored within the modelled section of river channel and flood plain ($1000m^3$)	24.02	24.26	24.66	22.52	22.52	22.58	22.29	21.75
Speed of water in the channel immediately upstream of the bridge (m/s)	1.02	1.02	0.28	1.02	1.02	1.10	1.06	1.14
Speed of water in the channel downstream of the bridge (m/s)	2.88	2.88	2.88	2.88	2.88	2.88	2.88	2.40

Changes to the 24 cumec event resulting from various interventions

	Intervention Tested							
	1	2	3	4	5	6	7	8
Elevation of the water surface immediately upstream of the bridge (m)	13.62	13.62	13.62	13.62	13.77	13.54	13.53	13.59
Volume of water stored within the modelled section of river channel and flood plain ($1000m^3$)	91.78	102.07	92.56	90.68	99.01	86.18	85.88	87.39
Speed of water in the channel immediately upstream of the bridge (m/s)	0.79	0.79	0.47	0.78	0.69	0.85	0.86	0.81
Speed of water in the channel downstream of the bridge (m/s)	4.21	4.21	4.21	4.21	4.21	4.21	4.21	3.91

Changes to the 1 in 200 year event resulting from various interventions

Key to interventions:

1 Existing situation
2 Sediment deposits in the channel upstream of the bridge reduced in height
3 Two meanders immediately upstream of the bridge restored
4 Low floodbanks immediately upstream of the bridge removed
5 Road on south side of the river raised above flood level
6 Bridge removed
7 Bridge and road embankment removed
8 Coarse sediments in the main channel at the Tillicoultry Burn confluence (downstream of the bridge) removed

4.4

Effectiveness of NFM

IN summary the results from the demonstration sites have shown that NFM does work and can make significant differences to run-off rates and the storage of flood waters. The upper catchment site showed that restoration of steep watercourses can slow down the speed of flood flows and even small wetlands can attenuate floods. The lower catchment site showed that changes to both the infrastructure over the floodplain and the river channel make very little difference to the flooding. A significant difference can however be made to the speed of the water by restoring the natural shape of the channel. Results from other demonstration sites will be published later.

The River Devon demonstration sites have therefore shown that NFM techniques are effective in reducing peak flows by increasing upstream storage and reducing upstream flow rates. The results support the fundamental approach of NFM to concentrate on intervention works in the upper catchment where most benefits can be gained.

5.1

Description of River Devon NFM Demonstration Sites With Initial Results

THE aim of the River Devon project was to develop, test and quantify sustainable flood management (NFM) techniques. This has been achieved by implementing a range of NFM techniques at demonstration sites throughout the catchment. Some of these techniques, such as wetland restoration, are already known but there is little understanding of how they should work in flood management or how they should be developed.

On demonstration sites techniques can be tested, improved, quantified and shown to other organisations involved in flood management. The development of demonstration sites also identified the need for a better understanding of flood management on a catchment scale. Although the sites were developed as individual units it was always stressed that in practice they would be used in a strategic way so that there was maximum benefit at all flood risk sites throughout the catchment.

The River Devon demonstration sites were developed so that each one of the above techniques was represented by one site. The following sections give a background to each demonstration site and include results from monitoring and modelling work carried out to quantify the effects.

The techniques are varied and include:

- Riparian woodland development
- Native woodland restoration
- Management of large woody debris in watercourses
- Wetland restoration
- Gully woodland development
- Management of artificial drains in plantation forests
- Loch and reservoir management
- Floodplain channel management

5.2

Riparian Woodland Development

RIPARIAN woodlands provide a leaky barrier along the river channel to hold back floodwaters on the floodplain. Many riparian zones on the floodplain have been greatly modified by agriculture including land drainage, clearance of trees and bushes and confinement of the river by flood banks. These modifications have had significant impacts on flood management in the lower catchment.

In NFM, riparian woodlands are most effective around the periphery of the floodplain. These are the places where highly energetic headwater streams impact the floodplain potentially causing most damage as the water disperses its energy. If control over the flood flows is not established in these areas the flood will rapidly transfer its energy into the lower floodplain causing more extensive damage.

Rivers develop a range of defences around the periphery of the floodplain including sediment deposits and meandering channels. Riparian woodlands can enhance these natural defences by forming the robust and self

maintaining barriers between the river channel and the floodplain. These leaky barriers retain water and trap debris and slowly release the flood water back into the river. The woodlands therefore need species which are strong and thrive in wet soils and should be constructed in cells so that the water can spill over the upstream section and be caught by trees and bushes on the downstream section of the cell. As it becomes established, the woodland will create a diverse range of habitats with some dense patches of woodland and some open areas. It will also protect and stabilise the riverbank, prevent cattle using the river for watering, prevent polluted water entering the river, create a variety of light and shade over the water and improve the habitats within the river channel.

The Balruddrie riparian woodland demonstration site comprises some 5000 mixed species trees planted along the banks of the upper River Devon. The trees have been planted to form a series of crescent-shaped woodlands down both floodplains so that flood water can easily inundate the floodplain from the upstream end but it becomes trapped by the leaky woodland barrier along the river bank and at the downstream end. A river gauging station exists at the upper and lower ends of the site to monitor the effectiveness of the woodland in flood conditions.

5.3

Native Woodland Restoration

MOST UK uplands have been cleared of their natural forest cover by intensive agricultural practices. Apart from providing woodland habitats and shelter for animals native woodlands would have had a significant effect on storm water run-off and snow melt. Trees can intercept large proportions of the rain and snow. Trees also take water out of the soils during the whole year. Soils below trees have less water content than soils with other vegetation cover. During storm conditions more rainfall and snow melt can be held in storage instead of flowing rapidly into the rivers. Upland areas with native woodlands therefore have lower rates of storm-water run-off than areas cleared of the natural forest cover. Reduced run-off rates result in less responsive headwater river systems which will reduce flood peaks in the main rivers and downstream.

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The upper Glen Devon native woodland demonstration site is monitoring the hydrological changes resulting from extensive re-planting of native woodland. Two small catchments, both planted in 2004 have been instrumented to monitor the rainfall and run-off. One catchment is south facing and the other north facing and it is anticipated that differences will be observed in their responses especially during winter snow melt conditions when the north facing catchment should retain its snow longer than the south facing catchment.

5.4

Management of Large Woody Debris in Watercourses

LARGE woody debris (LWD) is an essential feature of natural river systems providing in-stream habitats, trapping debris and slowing flood flows. It is supplied to watercourses through natural tree mortality, wind-blow, bank erosion and landslides and may be found in isolation or in accumulated “debris dams”. In small watercourses the LWD can span the channel while in larger watercourses the LWD is either entirely within the channel or overhanging the bank. Debris dams are constantly replenished with the fragmentation of the existing LWD components compensated by new LWD material supplied from upstream.

LWD was historically viewed as a cause of channel instability, a barrier to fish migration and a hazard blocking rivers, culverts and bridges. Traditional LWD management has involved its complete removal from the channel in “stream cleaning”. Recent studies have shown that the cumulative effect of LWD is largely positive at the catchment scale but decades of stream cleaning combined with the loss of riparian woodland has created many river networks deficient in LWD. Improved management is needed to retain the natural balance of this material and restore its role in the river system.

The River Devon LWD demonstration site includes two headwater streams with contrasting riparian woodlands and LWD populations. The first stream is the Dollar Burn where a mature native woodland completely fills the gully. The woodland is largely unmanaged and trees overhang the channel with substantial amounts of debris falling into the stream. The debris dams range in size and structure but importantly there are numerous examples where large trees have fallen over the channel forming the nucleus of the debris dam. This first stream demonstrates how debris dams form in a densely wooded gully and how effective they are in slowing down the flood flows and trapping debris.

The second demonstration site is in upper Glendey where the catchment of a tributary stream had a mature conifer plantation which has recently been clearfelled. When the conifers were standing they did not provide much LWD and the channel was largely devoid of this material. After clearfelling some cut logs were left in or straddling the channel. This second site contrasts with the first site showing how lack of native woodland prevents the development of debris dams. The site will also be used to show how inappropriate material should be selected and removed from the channel and riparian area and how the LWD population can recover as native woodland is re-established in the gully.

5.5

Wetland Restoration

WETLANDS are natural water storage areas which can function as significant flood attenuation features. In a natural condition they can absorb and store water releasing it slowly back into the river so reducing downstream flood peaks. Wetlands exist either as very small features in the uplands or extensive areas covering the floodplain. In addition they can be directly connected to a stream or river or only during flood conditions. Wetlands often have deep soils which are usually saturated with a flat surface. They support a range of plant species. Many should support dense wet woodlands but most have lost this ground cover.

In an unmodified condition the wetland will have the capacity to store some storm water in the soils and also have significant depths of water over the entire site. Woodland cover will intercept rainwater, reduce soil water content by root uptake and can also act as a leaky barrier increasing the surface water storage capacity of the wetland. There is therefore a great potential for a wetland to provide storage for storm water run-off from the surrounding ground and reduce downstream flood peaks. Wetlands have a significant role in flood management however many have been greatly modified with alterations to the hydrology and the ground cover.

The Glendey wetland demonstration site included the restoration of a natural hydrological regime through a valley wetland and restoration of a wet woodland. All artificial drains through the wetland were blocked off and a length of eroding channel bank stabilised. New channels were created for two streams which now flow into the wetland as a series of meanders and 3000 trees were planted over the site creating a wet woodland and forming a leaky flood barrier.

Gully Woodland Development

HILLSLOPE gullies, found in the upper parts of most Highland catchments, are where stormwater is concentrated to form highly energetic flood flows. In the uplands rainfall intensity is often high and with steep slopes and thin soils there will be rapid run-off. This run-off initially forms into numerous small burns which combine to form larger watercourses. Over time the energetic flows in the watercourses will form deep gullies cut into the hillslopes. These gullies become the main route for water to flow rapidly off the hills and into the lower valley.

Energetic flood flows down the gullies potentially have a high impact on the lower valley unless the rates of flow are slowed down. These sheltered gullies are suited for woodlands to develop as a natural way to slow the flood flows, breaking the flow with the root systems and tree debris which regularly falls into the channels. The tree roots also help to stabilise the soils and reduce erosion rates and soil losses which again help to slow down the flood flows.

The gully woodlands are an important buffer against storm run-off and also provide shelter for sheep and deer and form rich upland habitats for plants and wildlife.

The Glendey gully woodland demonstration site was developed in an area where there had been extensive clearfelling of a non-native plantation forest. With the total removal of the trees there was no buffering of the rapid flows down the gully, the soils were vulnerable to erosion and there was an unstable population of large woody debris left in the river channel. Tree planting was carried out in the gully using a range of native tree species including rowan, alder, oak and birch.

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Management of Artificial Drains in Plantation Forests

THE development of plantation forests was a major change in upland use in the 20th century. For the first few decades the forest design included hillslope ploughing, wetland drainage and blanket forestry although in the 1980s and 1990s new guidelines changed forest management practices to reduce the impact on the natural environments. Many of the original plantation forests are now being clear felled with the exposure of the old style drains, degraded wetlands and extensive forest roads. The current guidelines do not include measures to manage these artificial drainage systems which could become active again as the tree protection is removed.

The Glendey plantation forest demonstration site is an upland area where clearfelling was recently carried out. During the process branches and tree tops were stripped off and left on the ground to protect the soils and recycle nutrients from the decaying wood. Debris was removed from watercourses and road culverts kept clear. The old artificial drainage system was however exposed including old plough lines and cut-off drains.

A series of drainage rehabilitation measures was undertaken over the selected area to restore a natural drainage system and reduce storm water run-off rates. This included blocking off and rehabilitating cut-off drains, infilling plough lines, re-creating wetlands and managing road drains and culverts.

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Loch and Reservoir Management

IN upland Britain lochs and reservoirs often have the ability to buffer flood flows in the rivers. Many lochs and some reservoirs have developed extensive wetland features around the inflow river where sediments form alluvial deltas which develop into wetlands. Here trees usually become established helping to slow the flood waters. At loch outfalls there are many examples where the channel bed has been artificially raised or lowered or a construction, such as a bridge, has been built. Both affect the storage capacity of the loch, sometimes reducing it and other times increasing it.

Using reservoirs for flood storage is not common. The water is a valuable resource and the operating company would be unwilling to release it before a storm in case the rain was less than expected. If the reservoirs are full there will still be some buffering of the flood waters but buffering will be more effective if there can be some drawdown before the storm. Other practical difficulties include the time required to draw down the water and the potential structural impact if the water was drawn down too quickly.

The loch demonstration site is being developed as a computer base model of an existing loch. Loch level and river flow measuring stations have been installed in the loch and the topography of the surrounding ground and outfall have been obtained from a DTM and surveyed data. The model will be used to demonstrate the effectiveness on the downstream flood hydrograph of building a low arch bridge, a low bund and a weir across the outfall channel and also excavating the sediment at the outfall.

5.9

Floodplain Channel Management

FLOODPLAINS develop over centuries with the rivers bringing down large volumes of sediments from the uplands. The main rivers spread fine material over the lower catchment forming a basically flat floodplain while the tributaries bring down coarser material which forms depositional features over the floodplain and into the main river channel. The confluences are therefore where natural processes develop features which potentially slow down and store flood waters. Correct management of the confluence deposits is essential to maintain the flood management properties. Excessive clearance of the sediments could make downstream areas more vulnerable to flood waters while unmanaged accumulations of sediment could result in localised flooding around the confluence area.

Rivers flowing through extensive floodplains usually form deep meandering channels as the high energy generated in the headwater streams is dissipated. Bank erosion is a natural process but in many locations it can occur at a rapid rate with the loss of agricultural land and the deposition of large amounts of sediment into the river. The coarser sediments accumulate and reduce the capacity of the channel so reducing its ability to convey flood waters. This results in the overtopping of the banks in the early part of a flood event and when the main part of the flood arrives all of the potential storage in the channel and floodplain is already filled. By controlling river bank erosion the capacity of the channel is greater, the early part of the flood is confined within the channel and the main flood has ample floodplain storage to fill later in the event.

The Tillicoultry floodplain demonstration site is located on the lower Devon floodplain around the confluence of the River Devon and Tillicoultry Burn. Over geological time the burn has brought down tonnes of coarse sediments building up a fan of sediment which gradually extended over the Devon floodplain. It appears that the deposition feature formed a good foundation for a road over the floodplain and a bridge over the Devon. During the construction the Tillicoultry Burn was diverted to the west so that it entered the Devon downstream of the bridge site. The sediment deposit was raised to form ramps leading to the bridge and the channel of the Devon was re-aligned to ensure the water passed directly under the bridge. Immediately upstream of the confluence there is a series of large meanders which the land owner demonstrated had been eroding rapidly supplying large amounts of sediment to the channel probably contributing to the accumulation at the confluence.

To reduce the rate of erosion the river bank needed to be stabilised in short sections by interweaving green willow to form a growing wall, willow spiling. The use of short sections allowed the river bank to become an irregular feature with inlets and benches rather than a straight wall. Natural materials had to be used to provide deep stabilization of the bank, protect the exposed soils from energetic flood waters, improve the habitats and be self maintaining for decades.

The channels at the confluence were modelled to show the effect of the historical changes to the river channels on downstream flood levels. Sediment deposits were removed from the channel to quantify the reduction in flood levels by removing excessive accumulations at the confluence. ■

Flood Planner was written by Dr Richard Johnson, a hydrologist who has worked in the Antarctic, Middle East, Nepal, India and China. In 1998 he founded *Mountain Environments*, a Scotland-based environmental consultancy specialising in river gauging, flood management and river restoration. The River Devon Natural Flood Management Demonstration site in Clackmannanshire is managed by Richard Johnson at Mountain Environments.

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WWF Scotland's Freshwater Policy Officer, Mike Donaghy sits on government advisory groups on flood management and has been instrumental in promoting, and providing expertise on sustainable flood management in Scotland.
www.wwf.org.uk/scotland

Flooding Issues Advisory Committee
www.scotland.gov.uk/Topics/Environment

SEPA Water Framework Directive information:
www.sepa.org.uk/wfd

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Slowing the Flow: A Natural Solution to Flooding Problems is a partner report to *Flood Planner* which describes the principles of sustainable flood management, details the legislative background and outlines future priorities for implementation. *Slowing the Flow* is available from Mike Donaghy at WWF Scotland, from Mountain Environments and from
www.wwf.org.uk/betterriverbasins

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Flood Planner and the River Devon Natural Flood Management Demonstration site in Clackmannanshire, Scotland are part of WWF-UK's Natural Rivers Programme. This programme is developing innovative techniques for the management and restoration of rivers and wetlands for the benefit of people and nature.

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