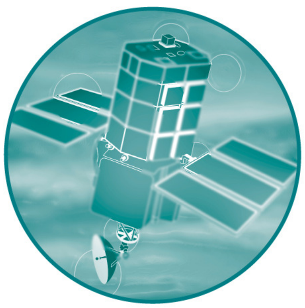
Defra FCERM Multi-objective Flood Management Demonstration project



PROJECT RMP5455: SLOWING THE FLOW AT PICKERING

Final Report

May 2015

Department for Environment Food & Rural Affairs

The Slowing the Flow Partnership

The Slowing the Flow Partnership, comprising:

Project RMP5455: Slowing the Flow at Pickering

Final Report: Phase II

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Date of Commencement: 1st April 2011
Date of Completion: 31st March 2015

Statement of use: This report describes the work done on Phase II of the RMP5455 project.

Dissemination status: Contract report

Keywords: Multi-objective Flood Management Demonstration project, flood risk management, natural flood management, woodland measures, working with natural processes, flood alleviation

Research contractor: Forest Research

Defra project officer: Paul Murby

Total Defra project cost: £235,000 Phase II; £247,000 Phase I.

Publishing organisation
Department for Environment, Food and Rural Affairs
Flood Management Division,
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London SW1P 2AL
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www.defra.gov.uk/environ/fcd

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Executive Summary

This report presents the results of Phase II of the Slowing the Flow at Pickering project in North Yorkshire (2011-2015). The project was originally set up in April 2009 to look at how changes in land use and land management can help to reduce flood risk. It was one of three pilot projects funded by Defra in response to Sir Michael Pitt's Review of the 2007 floods in England and Wales, which called for Defra, the Environment Agency and Natural England to work with partners to deliver flood risk management involving greater working with natural processes. The overall aim of the project was to demonstrate how the integrated application of a range of land management interventions can help reduce flood risk at the catchment scale, as well as provide wider multiple benefits for local communities.

A strong local partnership was formed in Phase I to deliver an agreed set of interventions that would protect Pickering from a 1 in 25 year flood. This report describes progress made by the partnership in implementing the outstanding interventions (as documented in the Final Report on Phase I (2009-11); Nisbet *et al.* (2011)) in the Pickering Beck and neighbouring River Seven catchments. The 4-year extension of the project has allowed nearly all of the original objectives to be achieved or exceeded. By March 2015, the following had been delivered:

1. 129 large woody debris (LWD) dams constructed within the Pickering Beck catchment and a further 38 in the River Seven, exceeding the project target of 150 dams. An additional trial of two novel 'timber bunds' installed in the latter catchment.
2. 187 heather bale check dams constructed within moorland drains and gullies, no-burn buffer zones established along all moorland watercourses, 3.2 ha of heather reseeded and 800 m of eroding footpaths repaired in the Pickering Beck catchment, achieving the original target of blocking any problem drains and establishing no-burn buffers.
3. 19 ha of riparian woodland planted within the Pickering Beck catchment and 10 ha in the River Seven. The partnership worked hard to maximise the level of woodland creation but could not meet the target of 50 ha riparian woodland and 30 ha floodplain woodland due to biodiversity and landscape sensitivities in the Pickering Beck catchment and landowner financial considerations in the River Seven catchment.
4. 15 ha of farm woodland planted in the River Seven catchment, exceeding 5 ha target.
5. Site operational planning revised within Cropton Forest and the wider Forest District to help secure opportunities for forest re-design and management to maximise benefits and minimise risks for flood mitigation, in line with project target. 5.9 ha of riparian buffer restored in the two catchments; 3.3 ha (1,470 m of streamside) in the Pickering Beck catchment and 2.6 ha (1,309 m of streamside) in the River Seven catchment.
6. Roof, yard and related works undertaken on 10 farms in the Pickering Beck and River Seven catchments under Catchment Sensitive Farming, including the construction of check dams (no specific target set for the number of farms or works).
7. A large flood storage bund constructed in the Pickering Beck catchment (subject to completion of the embankment in May-July 2015), as per the original target.

Modelling predicted that these measures will deliver the primary objective of protecting Pickering from at least a 1 in 25 year flood, reducing the chance of flooding in the town from 25% to 4% or less in any given year. The flood storage bund alone was designed to deliver this standard of protection by providing 120,000 m^3 flood water storage, with the other measures acting to further reduce the flood risk. It has not been possible to model the interaction between the different measures but an assessment was made of the additional flood storage created. This gave rough estimates of ~8,000-9,000 m^3 flood storage created by the woodland measures and ~500 m^3 for the moorland and farm measures in the Pickering Beck catchment, and ~7000-8,000 m^3 (mainly from the woodland measures) in the River Seven catchment. The delaying effects of the wider catchment measures are not accounted for in these figures and were predicted to significantly enhance the flood attenuation effect.

A monitoring programme has been established to quantify the effect of the measures in reducing flood flows. Although some of the land management interventions such as woodland creation will take time to become fully effective, an attempt was made to determine if they had any impact on a near-flood recorded in Pickering in November 2012. The local community believe that the measures implemented by then (pre-dated bund construction) helped to prevent an expected flood but an analysis of the data proved inconclusive, possibly due to the multiple peak nature of the event. A longer run of data and larger number of flood peaks are required for a more robust assessment.

The ecosystem services provided by the different measures were evaluated, with the most significant being climate regulation, flood regulation, habitat provision, community engagement, erosion regulation, and education/knowledge. The costs of the measures, as well as losses in agricultural income resulting from land use change, were also assessed. Combined values for all services for all measures, and for a subset that excludes the main flood storage bund, gave mean annual gains of £194k and £53k, respectively. Allowing for the costs of the measures and for the timing of these plus benefits (over a nominal 100 year period) gave aggregated net present values (NPV) ranging from £0.6m to £3.2m for the complete set, with a central estimate of £1.9m. This compared to a range of -£0.3m to £2.4m and a central estimate of £1.0m for all measures minus the main bund. The positive NPV in each case for the Pickering Beck catchment for the whole set of interventions indicate that from a societal perspective the benefits significantly outweighed the costs. A comparison of the benefit-cost ratios gave values ranging between 1.3 for the large bund to 5.6 for the woodland measures.

Knowledge transfer was another major outcome. The project has gained a very strong national profile and is well cited as a case study demonstrating the value of working with natural processes. Of special note has been its role in guiding and integrating government policy on flood risk and land use management. In particular, it has underpinned key regional and national initiatives on woodlands for water, including introduction of a woodland for water grant payment of £2,000/ha under the previous English Woodland Grant Scheme that closed in December 2013. More recently, it has informed the Countryside Stewardship scheme and a new forest industry initiative on the role of productive woodland in water management. Locally, the project is guiding the development of the Local Flood Risk Strategy and Flood Risk Management Plans, the new Derwent Catchment Strategic Plan, and an on-going joint FC/EA Woodland for Water project aimed at securing targeted planting on private land.

The project has received much local and regional media attention, as well as national interest, most notably as part of an episode of the BBC's science programme 'Bang Goes the Theory', which was aired on BBC 1 on 14 April 2014. It has also been the subject of many invited presentations at conferences, workshops and training events held around the country. A total of 14 site visits were hosted for a range of key individuals and groups to share knowledge and experience. The local community in Pickering have been fully engaged with the project and readily embraced the concept of a whole-catchment approach to flood risk management. The project has clearly demonstrated how a strong partnership approach can succeed in delivering an integrated set of land management measures to reduce flood risk at the catchment scale, as well as provide wider multiple benefits for local communities.

1. Introduction

The ‘Slowing the Flow at Pickering’ project was established in April 2009 to look at how changes in land use and land management can help to reduce flood risk in the town of Pickering in North Yorkshire. Pickering has a long history of flooding, with four floods in the last fifteen years (1999, 2000, 2002 and 2007). The 2007 flood was the most serious to date, causing an estimated £7 million of damage to residential and commercial properties. Whilst a flood alleviation capital scheme had been proposed to alleviate the problem, a cost-benefit analysis showed this to be unaffordable when set against national cost-benefit thresholds and other priorities.

The project represents a new approach to flood management that seeks to work with natural processes to help reduce the risk of flooding for affected communities. It was one of three pilot projects funded by Defra under their multi-objective flood management demonstration programme in response to Sir Michael Pitt’s Review of the 2007 floods in England and Wales. Recommendation 27 of the review called for Defra, the Environment Agency and Natural England to work with partners to establish a programme, informed by Catchment Flood Management Plans, to deliver flood risk management projects involving greater working with natural processes.

A crucial element of the approach was to understand better how floods are generated in a catchment and how the way the land is used and managed affects the speed and volume of flood flows. The combined effects of past land management practices by humans over centuries are thought to have increased flood risk by promoting rapid runoff and increasing siltation within river channels, although more recent changes, for example planting for upland forestry since 1945, may have partly offset these trends. There are four principal land uses in the *c.* 69 km^2 catchment of the Pickering Beck that drains to Pickering, comprising forest, arable, heather moorland and improved grassland. The overall aim of the project was to demonstrate how land use change and improvements in management practices could help to restore the catchment’s natural flood attenuation capacity.

At the core of the whole-catchment approach being trialled at Pickering was to implement and evaluate a number of land management interventions to help slow down and reduce flood flows. Most of these measures were targeted to the Pickering Beck catchment but some extended into the neighbouring catchment of the River Seven to help contribute to managing flood risk for the village of Sinnington.

While the focus of the project was on managing flood risk, it was also recognised that the planned measures would deliver wider environmental, economic and social benefits. These were expected to include improved water quality, provision of new habitats and/or an improvement in condition of existing habitats, enhanced carbon sequestration, an enhanced local skill base in estate management, improved recreation/tourism access, and increased public understanding and engagement in land management for flood risk reduction. An attempt was made to evaluate these ecosystem services so that they can be recognised and factored into future flood risk management planning and related decision making processes.

The project has involved two phases of work. The first (2009-2011) focused on building a strong local partnership of organisations to help drive the project forward and bring the local community on board. Efforts concentrated on identifying and agreeing a set of land management interventions and where these would be best located. Work began on implementing the measures and while much had been achieved by the end of the two-year period, a number of interventions were incomplete. The results were documented in a final report on Phase I (Nisbet *et al.*, 2011) and led to Defra funding a four year extension to the project (2011-2015). This report describes progress made in implementing the outstanding land management interventions in the Pickering Beck and River Seven catchments. It also evaluates the associated modelling and monitoring work, assesses the value of ecosystem services provided by the measures, highlights the main project outcomes, considers lessons learned, provides details on knowledge exchange activities, and makes recommendations on future work.

2. Aims and Objectives

The overall aim of the project was to demonstrate how the integrated application of a range of best land management practices can help reduce flood risk at the catchment scale, as well as provide wider multiple benefits for local communities. Specific objectives were linked to individual management practices and comprised:

1. Construct 100 large woody debris dams within the Pickering Beck catchment and a further 50 within the River Seven catchment to increase floodplain storage and delay flood flows.
2. Identify and block moorland drains causing rapid runoff and erosion in the Pickering Beck catchment. In addition, establish no-burn buffer zones along main watercourses to retard flood generation.
3. Plant 50 ha of riparian woodland within the Pickering Beck catchment and 30 ha of floodplain woodland in the neighbouring catchment of the River Seven at appropriate sites to delay and reduce flood flows.
4. Plant 5 ha of farm woodland on sensitive soils within the Pickering Beck and/or River Seven catchments to increase soil infiltration and reduce rapid surface runoff, soil erosion and sediment delivery to watercourses.
5. Identify problem drains and restore streamside buffer zones within Cropton Forest to reduce rapid runoff. Amend felling plans to minimise impact on flood risk.
6. Implement farm-scale measures to improve soil infiltration and reduce rapid runoff.
7. Agree design, secure funding and establish timeline for the construction of low-level bunds within the Pickering Beck catchment to increase flood storage capacity within the floodplain.

3. Project Governance and Management

The established Slowing the Flow Partnership Board comprising senior representatives from the main partners and funders continued to steer and oversee the project, while a Programme Delivery Group with representatives of the regulatory bodies and land owners and managers guided the development and implementation of the agreed interventions. The main partners were:

Lead: Forest Research (FR)

Government and Regulatory agencies: Defra (lead funder)[1], Forestry Commission England (FCE)[1], Environment Agency (EA)[1], Natural England (NE)[1] & the Yorkshire Flood & Coastal Committee (YFCC)[1].

[1] Key funders – see Appendix 14.1

Major Land Owners: FC(E), North Yorkshire Moors National Park Authority (NYMNPA)[1], Duchy of Lancaster Estates & North York Moors Railway.

Local Authorities: NYMNPA, North Yorkshire County Council[1], Ryedale District Council[1], Pickering Town Council & Sinnington Parish Council.

Community Representatives: Ryedale Flood Research Group, Pickering Civic Society & Pickering Flood Defence Group.

Research: FR, Durham University.

4. Implementation of Measures

This section of the report describes the progress made in delivering each of the seven land management interventions. The land use based measures were taken forward by FCE, NYMNPA, NE and private landowners, while the construction of the low-level bunds was led by the EA. It is important to note that the work undertaken involved a considerable level of match funding in terms of staff time and grant/capital support from partners, details of which are listed in Appendix 14.1. A selection of images and a map of the location of the different measures are provided in Appendix 14.2.

4.1 Construction of large woody debris (LWD) dams

A LWD dam is an open or 'leaky' framework of logs and branches that straddles the water channel, often secured in place by wedging and wiring the logs to bankside stumps or posts (see Appendices 14.2 & 14.3 for more details). They restrict and slow high flows, forcing water out-of-bank and thereby increasing upstream flood storage. The target of constructing 100 LWD dams in the Pickering Beck catchment was achieved in Phase 1. These were mainly small dams built between June 2010 and March 2011 by a NYMNP team of Modern Apprentice estate workers and FCE staff along four tributary streams draining Cropton Forest. This left 50 dams to be constructed within the River Seven catchment.

Two tributary forest streams had already been selected in the River Seven catchment guided by an application of the OVERFLOW model in Phase I. A total of 38 dams were built by FCE staff in May-June 2011, including a number of larger dams on Sutherland Beck. In view of the issues with the low level flood storage bunds in the Pickering Beck catchment (see 4.9), attention turned to building more dams in this catchment rather than completing the target for the River Seven catchment.

The OVERFLOW model had indicated that building LWD dams within the main channel of the Pickering Beck would be particularly effective at retaining flood flows, although the close proximity of the railway to the river greatly constrained the number of suitable sites. Survey work identified three potential reaches where there was an opportunity to construct dams without affecting the railway line or posing a risk of flooding upstream properties. Construction was timed for summer periods of lower flow, with three major dams built by FCE staff along one reach near Yorfalls Wood in June 2011 and a further four by a local contractor in a second reach at Newtondale in August 2012.

One of the four dams built in 2012 failed during a 1 in 8 year flood event in November 2012 and a second below it shifted slightly on one bank. These were located within a straightened section of channel alongside the railway with limited floodplain storage. The logs from the failed dam were caught within the downstream reach between that and the next dam. The failed and shifted dam plus one other were found to be deflecting flows into the river banks, causing some local scouring. The North Yorkshire Moors Railway requested their removal in case the scouring extended to undercut the railway embankment and after a period of monitoring they were removed in summer 2014. To replace these, five new dams were constructed by a contractor in the third of the originally identified reaches on the main Pickering Beck, below the Skelton Tower.

Another 18 dams were built by a NYMNP team of Modern Apprentices in November 2011 along target reaches in the Levisham Beck, a tributary of the Pickering Beck. Landscape and biodiversity sensitivities prevented the planting of riparian woodland in this area but LWD dams were favoured for trying to slow flood flows and increase site wetness. FCE provided the logs and the team constructed a network of low-level log dams to force more water out of bank during high flow events.

Applications were made for Consent for all of the LWD dams plus for two timber bunds (see below), and approved by the EA or the North Yorkshire County Council as Lead Local Flood Authority.

4.2 Construction of timber bunds

In addition to the LWD dams, a trial of two timber bunds was established in August 2011 on Sutherland Beck in the River Seven catchment. These extend the LWD dam concept to store a much larger volume of flood water. They involved constructing a 1.5 m high wall of stacked logs (braced against and secured to adjacent tall tree stumps and/or posts) across the full width of the floodplain to form a leaky bund (see Appendices 14.2 & 14.4). Two locations were selected with reasonably wide floodplains, one 16.5 m wide and the other 57.5 m wide. The timber wall extended down into the river channel to approximately half the channel frontal area so that the bunds only impeded high flows and filled during flood events. The design and locations were agreed between the FC and EA, and the bunds built by a local contractor. Funding was provided by the EA, with the FC providing materials and logs from felled trees on the site.

4.3 Blocking moorland drains and controlling erosion

Work during Phase I involved blocking three of five moorland drains that had been identified as discharging too much runoff and causing localised erosion and drain deepening. The NYMNPA appointed a specialised contractor to install 130 check dams in February 2011 using 200 small heather bales cut from Fen Moor (see Appendix 14.2). This work continued during Phase II with a further 57 check dams built in the remaining two, larger, problem drains in January 2012. These were formed using 84 round, large heather bales, which were placed at intervals along each drain to intercept, temporarily store and divert surface runoff over the adjacent ground.

Other work undertaken by the NYMNPA to help reduce rapid runoff and sediment delivery to watercourses included the reseeding of 3.2 ha of bare peat in spring 2012 and the repair of 800 m of eroding footpath in summer/autumn 2013, both located in and around the Hole of Horcum in the Pickering Beck catchment.

4.4 Establishing no-burn buffer zones

Five metre 'no-burn' buffer zones were established along all watercourses draining Levisham Moor in Phase I. These were designed to protect the vegetation and soils from heather burning, which reduces surface roughness and can make the soil more hydrophobic, speeding up runoff. The measure was strengthened in Phase II, when a 10-year Environmental Stewardship Scheme agreement was reached in November 2013 to extend protection to a 10 m wide buffer.

4.5 Planting riparian and floodplain woodland

Woodland planting within riparian and floodplain zones can be particularly effective at increasing channel and floodplain hydraulic roughness, which can delay flood flows and raise upstream water levels, enhancing flood storage. Benefits also accrue from the ability of trees to protect soil and stream banks, reducing sediment delivery and downstream siltation. The presence of the North Yorkshire Moors Railway, the narrow valley floor and existing woodland restricted opportunities for planting floodplain woodland to the River Seven catchment, but earlier mapping had shown that there was significant scope for riparian planting in the Pickering Beck catchment.

An application of Durham University's OVERFLOW model identified the upper reaches of the Pickering Beck catchment as where riparian woodland planting would be most effective for mitigating downstream flooding (planting in the lower third of the catchment was predicted to potentially increase flood risk by synchronising flood flows). This presented a much greater challenge for woodland creation than originally expected due to the high open landscape and biodiversity value of the area. As a result, initial planting was limited to 4.1 ha, comprising three headwater reaches in the Hole of Horcum and one in Havern Gill. The planting was grant aided by the Forestry Commission and carried out by National Park volunteers.

Close working by the partnership led to an additional 11.5 ha of land being identified for planting low density woodland. This comprised the bracken covered, gully slopes in the Levisham Griffs, which were planted in March 2011 by a local contractor and funded by the NYMNPA. As a results, almost a third (16 ha) of the original 50 ha target had been achieved by the end of Phase I.

Another attempt was made by FCE, FR, NYMNPA and NE in Phase II to try and increase the level of woodland creation. All potential sites were reassessed and a number selected for closer scrutiny by the partnership during a field visit in October 2011. This led to a further three sites being identified for potential tree planting, amounting to ~7 ha in area. Almost half (3.4 ha) proved suitable and was planted by the NYMNP with FC grant aid in March 2013, comprising a steep bracken slope adjacent to the Pickering Beck on the edge of Levisham Moor. This brought the total area of riparian woodland creation in the catchment to 19 ha or nearly 40% of the target, which was considered to be a significant success in view of the highly sensitive nature of the catchment.

No applications were forthcoming to plant floodplain woodland in the River Seven catchment during Phase I and so another attempt was made to encourage landowner interest. It was hoped that the increase in the Forestry Commission's basic planting grant in 2012 from £1,800 to £2,800 per ha plus an 'Additional Contribution' of £2,000 per ha for planting to reduce flood risk and/or improve water quality would generate more applications. This proved insufficient to persuade landowners to plant woodland on their higher value, floodplain land. However, an application was secured in 2013 for planting 9.9 ha of native broadleaved woodland on unimproved riparian land and adjacent steep side slopes at Spaunton Moor. This formed an almost continuous stretch of woodland (aside for a 200 m gap) along a 2.4 km length of the west bank of the main River Seven and helped to compensate for the lack of floodplain woodland planting.

4.6 Planting farm woodland

Farmland can generate rapid runoff due to 'poaching' of the soil by livestock or compaction by cropping practices. Woodland planting on vulnerable soils can help mitigate such effects by increasing soil infiltration and water evaporation, although financial considerations often make land use change unattractive to farmers, especially on higher quality land. Consequently, the project set a relatively low target of 5 ha for planting farm woodland on priority soils across both catchments.

The partnership was successful in exceeding this target during Phase 1. A 14.8 ha scheme was planted in 2011 at Skipster Hagg in the River Seven catchment, funded by FCE's English Woodland Creation Grant. FCE continued to pursue opportunities for woodland creation on farmland within both catchments during Phase II, offering the higher level of basic grant and the Woodland for Water Additional Contribution payment introduced in 2012. While no new applications for planting were received within the project area (aside from those reported above for riparian woodland), significant interest was shown in woodland creation across the wider Yorkshire and North East area (leading to 867 ha of targeted planting of woodland to reduce flood risk and/or diffuse pollution in Yorkshire and the North East Region by December 2014, and 1,857 ha across England).

4.7 Amending forest plans and restoring streamside buffer zones

This measure focused on Cropton Forest, which occupies a significant proportion of both the Pickering Beck and River Seven catchments. Changes to the long-term Forest Design Plan and FCE District's operational planning procedure (Ops 1) were made in Phase I to highlight opportunities for forest design and management to maximise benefits and minimise risks for flood mitigation. This included checking the scale of planned felling to limit the temporary loss of woodland cover (by avoiding felling >20% of a catchment within any three-year period), creating wider riparian buffer zones alongside main watercourses to slow flood flows and reduce bank erosion, and flagging opportunities when felling to construct LWD dams within incised watercourses to increase flood storage. A total of 2.1 ha of conifer forest were cleared from streamsides at two sites to create a total length of 370 m of riparian buffer zone.

Forest felling and restocking operations have continued in Cropton Forest throughout Phase II of the project. A total of 34 ha were felled across five sites in the Pickering Beck catchment, of which 22 ha involved plantations on two ancient woodland sites. The latter will be restored to native broadleaved woodland by natural regeneration, while 1.1 ha or 1,100 m of riparian buffer was created adjacent to areas to be restocked with conifer. Around 33 ha of conifer forest felled in Phase I or earlier were restocked with conifer, while 9 ha was converted to open ground for biodiversity.

A larger area of forest was felled in the River Seven catchment, amounting to 115 ha across nine separate sites. A minimum of 2.6 ha or 1,309 m of riparian buffer will be retained when this is restocked and expected to regenerate to native broadleaved woodland. In addition, 213 ha were restocked from previous felling, involving 14 separate sites. A total of 31 ha were converted to open ground for mire or deep peat restoration.

No additional LWD dams have been installed to date as part of normal felling operations in either catchment but logs have been left at three sites for blocking forest drains in 2015/16.

4.8 Implementing farm-scale measures

As noted above, a number of farm practices can damage the soil and increase rapid runoff to streams. Under the Catchment Sensitive Farming Capital Grant Scheme, two workshops and a number of farm visits were held in Phase I to raise awareness among farmers of the availability of grants to cover 50% of the cost of measures to help improve runoff management and related diffuse pollution issues. No applications were received but the workshops led to greater interest in the Scheme in Phase II.

Two applications were approved in 2011 for £20k of funding for yard works to manage runoff from roofing and tracks. This included installing sediment ponds, swales and check dams, cross drains on farm tracks, and providing drinking troughs to avoid the need for livestock accessing watercourses. A 'Farm Grants evening' was held in February 2012 in Pickering to promote interest in the 2012 Scheme, which led to the approval of an application to construct five check dams to slow surface runoff on a farm at Raindale Head in the Pickering Beck catchment. There was stronger interest in the 2013 Scheme, with seven farmers awarded grants totalling £125,000 for a range of works to reduce site runoff. No applications were funded under the 2014 Scheme.

4.9 Construction of low level bunds

An integral part of the original concept was to create significant flood storage behind one or more low level (1.5 – 2.5 m high) clay bunds across the floodplain upstream of Pickering. However, the Pickering Beck floodplain does not lend itself easily to any major structure because of the close proximity of the line of the North York Moors Railway to the river, the deeply incised nature of the river channel, the number of designated sites and complicated archaeology. Finding sites and designs which could reconnect the river to its floodplain and provide sufficient flood storage while meeting the provisions of the Reservoirs Act at affordable cost proved very challenging. After a number of false starts and disappointments for the local community, a suitable site was found at Newbridge and a design agreed for a single flood storage bund with a capacity to hold 120,000 m^3 of flood water (see Appendix 14.8 for more details). This would reduce the risk of flooding in Pickering from 25% to 4% in any one year. The final cost is estimated to be around £3.2m, giving a cost of £26.67/m^3 flood storage. A funding package was secured with substantial partner investment from Ryedale District Council, North Yorkshire County Council, the Regional Flood and Coastal Committee and Pickering Town Council, alongside grant in aid from Defra and the Environment Agency. Construction work started in January 2014 and will be finished later in 2015. The risk reduction will be greater when combined with the other land management interventions, but more modelling and experience of actual flood peaks is required to better understand the whole cumulative effect (see below).

5. Evaluation – Modelling and Monitoring

A key aspect of the project has been evaluating the contribution of the implemented measures to flood risk management. Quantifying a change in flood response is an extremely difficult task, especially at the catchment scale. This is partly due to the relatively rare nature of flood events, the difficulty of precisely measuring these and the fact that their frequency and nature are thought to be changing due to climate warming. To prove that a flood event has significantly changed requires the collection of robust, long-term flow records, including many years of baseline and post intervention data to capture repeated flood events for the affected catchment. In addition, a similar run of data are required for a nearby 'control' catchment that has not been subject to any significant land use alterations during the study period. This is to check that any detected changes in flood response are not due to climate shifts. These challenges explain the paucity of observed data quantifying the effects of land management interventions on flood risk and the continued reliance on modelling studies for an evidence base, underpinned by process and small-scale catchment experiments. Modelling and monitoring approaches were used to assess the impact of the project measures at Pickering, the results of which are reported below, along with site observations.

5.1 Modelling

The project has relied heavily on modelling to evaluate the impact of the land management measures. In Phase I, Durham University applied an existing, calibrated model called 'OVERFLOW' to guide the placement of the woodland-based interventions and to predict their contribution to reducing flood flows in the town. The model indicated that the planned changes would be insufficient to protect Pickering from the target 1 in 25 year flood, but could make a significant contribution to reducing downstream flood risk. In particular, the model predicted that the planting of 50 ha of riparian woodland and construction of 100 LWD dams in the Pickering Beck catchment could reduce peak discharge for a 1 in 25 year event by 0.8 cubic metres per second (cumecs) or 4%. While this sounds like a relatively small effect, it equated to 21% of the margin needed to reduce the flood peak to the critical level of 15 cumecs at which major flooding begins in the town. It is also important to note that the OVERFLOW model did not incorporate all of the known woodland processes affecting flood flows (e.g. the higher water use/evaporation by woodland vegetation and associated improvements to soil infiltration and soil water storage) or the contribution of the moorland and farm measures. Circumstances prevented any further development or application of the OVERFLOW model during Phase II.

Other models were used by the EA and their contractors Arup throughout both phases of the project to determine the best placement and design of the low-level flood storage bund(s). The final scheme was designed so that a single large bund would provide sufficient flood storage to protect Pickering from a 1 in 25 year event, reducing the risk of flooding in any year from the current 25% chance to 4%. Its function was optimised by controlling the river channel so that the bund only fills when the water level approaches the critical flood discharge.

While it was not possible to combine the modelling to look at the interaction of the woodland, moorland and farm measures with that of the main bund, separate evaluations were made of their individual contribution in terms of potential flood storage volumes. Details are described below.

Woodland LWD dams

Cross-sectional surveys were undertaken of ten stream and river reaches containing a total of 104 LWD dams in the Pickering Beck catchment to calculate storage volumes using the HEC-RAS hydraulic model. The results of this work are reported in Appendix 14.3. Volumes ranged between 0.1 m^3 and 108.9 m^3 for individual dams, depending on channel width and gradient, floodplain area and dam spacing. Taken together, the 104 dams provided a total of ~1,020 m^3 storage for a 1 in 25 year flood, assuming that there was sufficient porosity to prevent them from filling during higher frequency events. Dam performance is likely to vary through time with changing porosity, depending on the balancing effects of debris capture vs washout. Storage volumes were predicted to gradually rise with increasing flood flows as more water is forced onto the floodplain. Based on the above numbers, it was estimated that the 129 LWD dams built in the Pickering Beck catchment and 38 in the River Seven would provide around 1,300 m^3 and 300 m^3 flood water storage, respectively. Larger LWD dams appear to be much more cost effective for flood storage, averaging £5.43/m^3, compared to £22.30/m^3 for smaller dams.

Timber bunds

Site survey and the HEC-RAS model were also used to assess the performance of the two timber bunds on Sutherland Beck in the River Seven catchment. The results are described in Appendix 14.4 and gave storage volumes of up to 1,260 m^3 for the smaller downstream bund and 3,620 m^3 for the larger upstream one. Model predictions suggested that the downstream bund would fill by a 1 in 5 year event, while the upstream bund would not become active until a 1 in 100 year flood, although no allowance was made for leakage through the timber walls. This highlights the need for pre-planning survey and modelling work to guide the most effective placement and design (particularly of the channel freeboard) of such bunds for flood risk management.

Increasing the height of the bunds from 1.5 m to 1.9 m by adding another two logs onto the top of the timber wall would generate a further 880 m^3 and 1,970 m^3 storage volume to the downstream and upstream bunds, respectively. Together, the two bunds were estimated to delay the passage of the 1 in 100 year flood peak by around 18 minutes. Timber bunds are potentially very cost effective for providing flood storage at £1.69/m^3, although their life span is unknown (thought to be a minimum of 8-10 years).

Moorland heather and LWD dams

No survey data were available to allow modelling of the 187 heather bale check dams and 18 LWD dams in moorland areas within the Pickering Beck catchment, but rough estimates were made based on their average dimensions. Assuming a storage volume of 1 m^3 per small check dam, 2 m^3 per large check dam and 10 m^3 per LWD dam, gave a potential total volume of 400-500 m^3. A very rough estimate of the contribution of the farm measures was 100 m^3 flood storage.

Woodland planting

Aside from the LWD dams and timber bunds, an estimate was also made of the equivalent water storage generated by the increased water use resulting from the woodland planting in both catchments. Nisbet (2005) describes how the evaporation or 'interception' of rain water from tree canopies can reduce the volume of rainfall landing on the ground by 25-45% on an annual basis. While the effect diminishes for shorter-periods of heavy rainfall associated with flood events, Calder (2003) noted that the interception loss as a proportion of rainfall could still be up to 7 mm/day for conifers and between 1 and 2 mm/day for broadleaves, depending on season. These values translate to a potential reduction of 10-20 m^3/ha of flood runoff for planting broadleaved woodland on grassland and up to 70 m^3/ha for conifer trees. Applying this to the 19 ha of broadleaved woodland planting in the Pickering Beck catchment and 25 ha in the River Seven, equates to a flood storage volume of 190-380 m^3 and 250-500 m^3, respectively. These numbers will be partly offset by the ongoing redesign of Cropton Forest, particularly the clearance of conifer stands to create more open space.

In addition to the direct interception loss during a flood event, the cumulative effect of the higher water use by trees during spring and summer periods can lead to drier soils and a build-up of a greater soil moisture deficit. This can amount to several 10s of mm of additional potential soil water storage available under trees (Calder *et al*, 2003; Green *et al*., 2006), which could help to significantly reduce flood runoff during summer storms. With climate warming predicted to lead to more extreme summer rainfall events, this could become an increasingly important contribution in the future. Applying a precautionary approach and assuming the planted broadleaved woodland would be able to generate an additional 10 mm or 100 m^3/ha of available soil water storage, would equate to a total volume of 1,900 m^3/ha and 2,500 m^3/ha in the Pickering Beck and River Seven catchments, respectively. The soil-drying effect is usually lost after re-wetting of soils in the autumn and therefore has less influence on winter floods.

Combined land use measures

Taken together, the above values gave a total of ~4,000 m^3 potential flood water storage generated by the land use based measures in the Pickering Beck catchment and ~7,000-8,000 m^3 for the River Seven. The Pickering Beck number is significantly lower than the 15,000 m^3 predicted by OVERFLOW for creating 50 ha of riparian woodland and building 100 LWD dams, although this can be partly explained by the reduced level of planting (19 ha) achieved by the project and the fact that unlike the model, the above numbers do not include the expected natural formation of LWD dams within the planted riparian zones (adjusting for these factors would have reduced the model prediction to around 8,000-9,000 m^3). It should also be noted that the model incorporates the effect of the riparian woodland and LWD dams on increasing hydraulic roughness and slowing flood flows, while the separate calculations of flood storage volumes do not. However, the model does not include the effects of the moorland and farm measures.

Overall, these calculations strongly suggest that the combination of the woodland, moorland and farm measures should extend the performance of the flood storage bund to reduce the risk of flooding in Pickering to a <4% chance in any year. In addition, unlike the bund, most of the land use measures are expected to exert an effect across a wide range of flood flows, with some appearing to have a greater influence with increasing flow. For example, the OVERFLOW model predicted that the woodland measures could reduce the 1 in 100 year flood peak by 8% (compared to 4% for a 1 in 25 year event) due to their ability to force more water out of bank and resist its passage downstream.

5.2 Monitoring

Six water level recorders were installed along three reaches within the Pickering Beck catchment in Phase I to measure the effect of the LWD dams (on two reaches; one tributary stream and one on the main channel of Pickering Beck) and riparian woodland planting in reducing flood flows. Due to the drive to implement the land management interventions within the initial two-year period of the demonstration project, there was little time to collect baseline data. This was particularly the case for the LWD dams, which exert an immediate effect, unlike the woodland planting, which will take many years to fully develop. An additional water level recorder was installed in one of the LWD dam reaches in June 2011, along with three devices in the reach with the two timber bunds in the River Seven catchment in October 2011.

It is too early to make a meaningful assessment of the effect of the woodland planting but a limited analysis was made of the data from the two LWD dam reaches. The absence of any significant length of baseline data meant that only an upstream-downstream comparison of flows was possible. A lack of high flow/out of bank ratings precluded an assessment of differences in discharge but an evaluation of time to peak provided some evidence of a lag in downstream response. More high flow events need to be captured to build on these inferences from the initial data.

The EA also operate three river flow gauges in the Pickering Beck catchment. The most reliable and longest running is situated at Ropery Bridge in Pickering and provides a better record for determining the early impact of the catchment interventions. However, its downstream location means that it was not possible to separate out the effects of any of the individual measures in the catchment. A joint EA-FR analysis of the data was undertaken in 2013 following a near-flood in November 2012, which is the biggest event recorded since the project started. This event caused flooding in the wider region and the local community in Pickering believe that the only reason they escaped was due to the upstream land management interventions. Rainfall-runoff modelling and flood hydrograph analysis were used to determine whether there was any evidence of the measures having reduced the flood response.

As noted above, the analysis depended on comparing the November 2012 flood peak with similar ones recorded prior to any measures being implemented. Unfortunately, no two flood peaks are the same, differing in terms of pre-event/antecedent conditions (e.g. in terms of soil wetness and level of river flow) and the nature of the rainfall event generating the flood peak (e.g. rainfall duration, amount and intensity). This makes it difficult to compare before and after events, especially where the number of these is limited. For Pickering, a reasonably good flow record was available since 2000, which allowed a comparison of five pre-project high flow peaks (November 2000, August 2002, June 2007, September 2008 and November 2009) with two post events (September 2012 and November 2012). An additional analysis was also made of smaller flow peaks exceeding various multiples of median flow to see if the measures had affected the general hydrological response.

The results of the analyses failed to show any consistent changes to the flood and flow response between pre and post intervention periods. The smaller September 2012 event behaved in line with the pre-period response. Some differences were noted for parts of the November 2012 event, including a reduced first peak and a delayed recession, but it was not possible to conclude that these differences were due to the measures (the main peak of the event was higher than predicted, although this was complicated by its multiple peaked nature). Moderate peak flows appeared to be higher than expected in 2012 but this was likely to be due to the very wet summer and autumn of that year. Overall, a longer run of post intervention data and a greater number of flood peaks are required for a more robust evaluation of the effect of the land management measures on flood response. It is also important to note that some of the measures such as the woodland planting will take a number of decades to fully develop.

An attempt was made to compare the estimates of the flood storage created by the land use based measures in the Pickering Beck catchment (4,000-9,000 m^3) with the difference in the volume of water between the November 2012 near flood and the point at which flooding could have been expected to have occurred in Pickering. The latter is difficult to estimate but a value of between 40,000-60,000 m^3 was derived using the Revised Flood Estimation Handbook method. This suggests that the measures were unlikely to have been sufficient to have bridged the difference and prevented a flood at the time, although there is much uncertainty in the data and the method of assessment (which did not include the delaying effect of the measures). It is also important to note that local observations at the time suggested a positive impact (see 5.3 below).

5.3 Site Observations

A number of photographs and video footage have been taken of the LWD dams and timber bunds during high flow events, including the near-flood in November 2012 (see Appendix 14.2). These all show the measures to be working as expected by encouraging out-of-bank flows and the backing-up of flood waters, enhancing local flood storage. Remote cameras have also been installed by a number of partners at the timber bunds, some of the LWD dams and at the main bund to take frequent photographs during flood events. These are helping to gauge the performance of the measures, including providing a record of the spatial extent of upstream flooding. An annual survey of around 100 of the LWD dams is undertaken to monitor their development and in particular, changes to porosity and stability.

Local observations from both the Pickering Beck and River Seven catchments by various members of the public are generating an increasing amount of anecdotal evidence that the rivers appear to be slower to respond to rainfall events. These views, together with the lack of flooding experienced in the town in November 2012, when given the amount of rainfall many local people had expected to be flooded, are leading to a growing belief that the implemented land use measures have already made a difference.

6. Evaluating Multiple Benefits

This section summarises work done to update and extend the preliminary economic evaluation in Phase I of the ecosystem services provided by the land management interventions (a full report is provided in Appendix 14.5). The original appraisal involved a qualitative assessment by the Wider Programme Delivery Group of the ‘likelihood of impact’ of the planned interventions across the full set of ecosystem services. The measures were considered to provide potential significant positive effects for flood regulation (by increasing flood storage and delaying flood flows), erosion regulation (by woodland planting protecting soils and LWD dams retaining sediments), community engagement (through events/meetings and volunteer support), education & knowledge (by hosting site visits) and habitat provision (by woodland creation) services, with none yielding any potential significant negative effects. An economic valuation was then undertaken of the services provided by the woodland measures. This included climate regulation (through carbon sequestration by woodland creation) as an additional significant positive effect and a loss in agricultural production (through woodland planting) as a potential negative impact.

A fuller assessment of the identified services provided by all of the measures was carried out in Phase II. As before, a 100-year time horizon was selected for this purpose and minima, maxima and means for the indicative central estimates for each of the impacts were determined. Separate values were calculated for the group of woodland, moorland and farm measures (construction of LWD dams and timber bunds, riparian and farm woodland planting, streamside restoration, heather check dams, retention of no-burn buffers and farm works) and for the complete set, including the construction of the large flood storage bund. A summary of the results split by the two catchments is provided in Tables 1 & 2 below. For the woodland measures, climate regulation was the largest benefit in both catchments, followed by flood regulation and then habitat creation (based on mean and maximum values; the large negative minimum values for climate regulation reflects the impact of converting existing riparian conifer stands to native broadleaves). Flood regulation was by far the largest benefit for the whole set of project measures in the Pickering Beck catchment, which was dominated by the contribution of the flood storage bund.

The benefit calculations are gross values and do not allow for the costs of the measures implemented or for the timing of both these and the benefits to accrue (i.e. their distribution over the 100 year period considered). These aspects are accounted for in Tables 3 & 4 where each 100 year flow of annual values has been converted into a present value by discounting based upon the Treasury Green Book protocol. Aggregating gave combined net present values (NPV) for the woodland, moorland and farm measures for the two catchments ranging from -£0.3m to £2.4m, with a central estimate of £1.0m. This compares to a range of £0.6m to £3.2m and a central estimate of £1.9m for these plus the large flood storage bund.

Table 1: Indicative annual ecosystem service values based on central estimates for the woodland, moorland and farm measures

	Pickering Beck catchment			River Seven catchment		
	Min (£k/yr)	Max (£k/yr)	Mean (£k/yr)	Min (£k/yr)	Max (£k/yr)	Mean (£k/yr)
Habitat creation	0	£6.3	£5.6	0	£6.2	£5.5
Flood regulation	£5.2	£7.6	£7.5	£6.0	£7.7	£7.7
Climate regulation	-£313.9	£66.7	£13.9	-£390.1	£53.0	£20.0
Erosion regulation	£0.009	£0.097	£0.092	£0.001	£0.028	£0.026
Education and knowledge	£0.022	£0.173	£0.030	n.a.	n.a.	n.a.
Community development	£1.2	£2.4	£1.3	n.a.	n.a.	n.a.
Agricultural production	-£1.9	-£1.5	-£1.9	-£7.0	-£6.0	-£7.0

Note: n.a. = not available (not estimated)

Table 2: Indicative annual ecosystem service values based on central estimates for the whole set of the land management interventions (woodland, moorland and farm measures plus the main bund)

	Pickering Beck catchment			River Seven catchment		
	Min (£k/yr)	Max (£k/yr)	Mean (£k/yr)	Min (£k/yr)	Max (£k/yr)	Mean (£k/yr)
Habitat creation	0	£6.3	£5.6	0	£6.2	£5.5
Flood regulation	£5.2	£154.7	£149.5	£6.0	£7.7	£7.7
Climate regulation	-£313.9	£66.7	£12.9	-£390.1	£53.0	£20.0
Erosion regulation	£0.009	£0.097	£0.092	£0.001	£0.028	£0.026
Education and knowledge	£0.022	£0.17	£0.030	n.a.	n.a.	n.a.
Community development	£1.2	£2.4	£1.3	n.a.	n.a.	n.a.
Agricultural production	-£1.9	-£1.5	-£1.9	-£7.0	-£6.0	-£7.0

Note: n.a. = not available (not estimated)

Table 3: Indicative ecosystem service present values (£k at 2015 prices) for the woodland, moorland and farm measures

	Pickering Beck catchment			River Seven catchment		
	Low (£k)	Central (£k)	High (£k)	Low (£k)	Central (£k)	High (£k)
Habitat creation	£72	£131	£172	£59	£127	£186
Flood regulation	£18	£221	£334	£35	£226	£232
Climate regulation	£128	£366	£667	£181	£532	£1,000
Erosion regulation	£2	£2	£3	£0	£1	£1
Education and knowledge	£0	£1	£9	-	-	-
Community development	£0	£39	£68	-	-	-
Agricultural production	-£76	-£56	£2	-£272	-£208	-£16
Forestry costs	-£99	-£74	-£50	-£200	-£144	-£87
Non-forestry costs	-£69	-£69	-£69	-£64	-£64	-£64
Net Present Value	**-£25**	**£562**	**£1,137**	**-£260**	**£470**	**£1,252**

Table 4: Indicative ecosystem service present values (£k at 2015 prices) for the whole set of land management interventions (woodland, moorland and farm measures plus the main bund)

	Pickering Beck catchment			River Seven catchment		
	Low (£k)	Central (£k)	High (£k)	Low (£k)	Central (£k)	High (£k)
Habitat creation	£72	£131	£172	£59	£127	£186
Flood regulation	£3,911	£4,114	£4,227	£35	£226	£232
Climate regulation	£86	£283	£542	£181	£532	£1,000
Erosion regulation	£2	£2	£3	£0	£1	£1
Education and knowledge	£0	£1	£9	-	-	-
Community development	£0	£39	£68	-	-	-
Agricultural production	-£76	-£56	£2	-£272	-£208	-£16
Forestry costs	-£99	-£74	-£50	-£200	-£144	-£87
Non-forestry costs	-£3,020	-£3,020	-£3,020	-£64	-£64	-£64
Net Present Value	**£876**	**£1,420**	**£1,954**	**-£260**	**£470**	**£1,252**

The positive NPV in each case for the Pickering Beck catchment shows that the sum of the present values of the ecosystem service impacts for the whole set of interventions exceeded the present value of the costs of implementing these (Table 4). This indicates that from a societal perspective the public benefits significantly outweighed the costs. A comparison of the benefit-cost ratios (based on the central estimate) for the Pickering Beck catchment gave values ranging between 1.3 for the large bund to 5.6 for the woodland measures (that for all measures excluding the main bund was intermediate at 3.8). The high value for the woodland measures reflected the significant climate regulation benefit, while the relatively low value for the flood storage bund was due to its high cost.

Although the climate benefit was the largest woodland service, the flood regulation benefit was also significant and notably exceeded (by 62%) the forestry costs plus the loss in agricultural production. However, in terms of the costs for private landowners, the estimates (based upon Treasury Green book discount rates) for the Pickering Beck catchment suggested that the present values for woodland grant payments applying in 2011 (£3,800/ha) only partly covered the costs of forestry establishment and lost agricultural production combined (central estimate -£7,400/ha). The benefit-cost ratio (2.5) for the woodland measures in the River Seven catchment was less than half that in Pickering Beck, mainly due to planting on better quality farmland.

7. Influencing Private Landowners

An evaluation was made of the potential for using behavioural economics to help encourage more woodland planting on better quality farmland, particularly within the floodplain. This drew on a recent evidence review of the motivations, decision-making and behaviour of British landowners and their agents in woodland creation and explored how ‘nudge’ type policies could be applied to affect change. Intervention points, where nudges could be used were identified in relation to five different stages of ‘motivational readiness’ of individual landowners, managers, and investors, from pre-contemplation to action, and maintenance. Evidence suggested that individuals are heavily influenced by who communicates the information (the Messenger) and nudge type approaches need to be tailored towards different types of land managers and owners, and stages of decision-making. A summary of the evidence and potential application of nudge-type approaches to encourage woodland creation for flood mitigation, along with a number of recommendations for further work, is provided in Appendix 14.6.

8. Project Outcomes

The project has delivered a number of key outcomes, which are summarised as follows:

1. By the time the main flood bund is completed, the risk of flooding in the town of Pickering will have been reduced from a 25% chance in any year to a less than 4% chance.
2. A very strong and enthused local partnership is in place to take forward the established demonstration project, including maintaining the implemented measures and seeking opportunities to extend these to further reduce the risk of flooding in Pickering and Sinnington.
3. An engaged local community, who have embraced the concept or working with natural processes and believe this new approach to flood risk management is making a difference.
4. A perception by the residents in both Pickering and Sinnington that the measures helped to avert flooding in 2012, when other communities in the Region were adversely affected, which has improved local confidence and support for land management interventions.
5. A much more joined up and inclusive approach to flood, water and land use management, driven by stronger local and regional delivery partnerships, including those developing the Local Flood Risk Strategy, associated Flood Risk Management Plans and the new Derwent Catchment Strategic Plan.
6. The project strap line ‘Slowing the Flow’ has gained strong currency across the region and wider country with those engaged in flood risk management, leading to greater awareness and consideration being given to the benefits of working with natural processes. This includes informing FC national guidance on managing forestry and flooding, the EA’s Working with Natural Processes Framework and Catchment Sensitive Farming.
7. The success of the project has been replicated by influencing Forestry Commission policy on woodland creation, contributing to the introduction in 2012 of a Woodland for Water grant payment of £2,000/ha under the previous English Woodland Grant Scheme. This led to 867 ha of targeted planting of woodland to reduce flood risk and/or diffuse pollution in Yorkshire and the North East Region by December 2014, and 1,857 ha across England. It has also helped shape the new Countryside

Stewardship scheme and a national forest industry initiative on the role of productive woodland in water management.

8. Helped raise awareness of the multiple benefits/services provided by working with natural processes and informed the economic evaluation of ecosystem services.

9. Lessons Learned

The main lessons learned can be summarised as:

1. Land management measures can make a significant contribution to downstream flood alleviation. They vary in type, size, scale of operation and mode of action but are most effective in combination as part of a whole catchment approach to managing flood risk.
2. Some land management measures make an immediate contribution following implementation (e.g. flood storage bunds and LWD dams), while others take a number of years or even decades to fully develop (e.g. woodland planting). The bigger the contribution to flood protection that the measures are required to make, the larger and/or more extensive the measures need to be at the catchment level to make a difference.
3. Of the measures, flood storage bunds offer more visible, secure and potentially effective storage. However, legislation in the form of the Reservoirs Act, especially governing design standards and risk management, greatly increases build costs. A change in the classification of the originally planned twin bund design at Pickering based on modelled risk to a small number of downstream properties resulted in a tripling of the cost to ensure that the bunds could withstand a 1 in 10,000 year event. This reduced the benefit-cost ratio to 1.3 and increased the flood storage cost to £26.67/m^3.
4. Another effect of the Reservoirs Act is to favour the use of single, large bunds that require more engineering. The Acts treatment of a series of small bunds as reservoirs in cascade acts against the use of this potentially cheaper and attractive option. Where the combined storage volume exceeds the defined threshold and there is any potential loss of life, each of the small bunds need to be engineered to a very high design standard (to withstand a 1 in 10,000 year flood), making them a more expensive option. Decisions on the design standard do not appear to properly balance the risks involved. The reduction in risk to life and damage to property from the more frequent operation of a series of small bunds would appear to more than offset the relative increase in risk caused by their eventual failure during a very extreme event.
5. Timber bunds appear to provide a cheap (£1.69/m^3 flood water stored) and sustainable flood storage option, although their effectiveness remains to be tested under a larger flood event and their longevity determined. Pre-planning survey and modelling work are needed to optimise design and placement for flood risk management. Their use in cascade would be covered by the Reservoirs Act and unlikely to meet the required design standards.
6. The use of smaller, more diffuse, storage features such as LWD dams, heather bale check dams and swales are not limited by the Reservoirs Act but could collectively contribute a sizeable flood storage volume, depending on their design and management. This would need catchment level planning to guide and achieve the optimum placement and combination. To be most effective, they need to store water above the critical flood flow that causes damage to downstream assets. LWD dams are naturally porous and can be expected to mainly fill and force water out of bank during

high flow events, although it is difficult to predict at which point. This is likely to vary through time as the dams naturally develop and respond to floods. Check dams and swales can also be expected to provide effective storage as they only operate when rapid surface runoff occurs during more extreme events.

7. Larger LWD dams placed in main channels appear to be much more cost effective for flood storage, averaging £5.43/m^3, compared to £22.30/m^3 for small dams in drains or small streams.
8. LWD dams are particularly valuable as on-line features for raising water levels within incised river channels and reconnecting floodplains. This was a notable issue in the Pickering Beck catchment where past land drainage and channel straightening mean that even relatively extreme flood flows do not come out of bank until constrained by bridges and other infrastructure in the town.
9. Concerns are often raised about the use of LWD dams due to the potential washout of woody debris and blockage of downstream structures. However, these can be allayed by fixing LWD dams into banksides using slot trenches and wooden posts, or tying-in and bracing logs against bankside trees. Their stability can also be increased by restricting their use to channels <5 m wide. Only one of the 167 constructed dams in the two catchments failed during the November 2012 near flood and the logs from this were trapped within the immediate downstream reach, where they remained until removed two years later.
10. Broader acting land management measures such as woodland creation, streamside restoration, heather regeneration, controlled burning and improved cropping practices act differently from bunds and dams by changing hydrological processes that affect flood generation, such as evaporation and soil infiltration, as well altering flow pathways and hydraulic roughness. Some of these effects can be expressed in terms of an equivalent flood storage volume but others cannot. Some vary seasonally and mainly affect summer floods. Their contribution to flood risk management depends to a large degree on the overall scale of change in the catchment upstream of flood prone assets.
11. Efforts to reduce flood risk via land management interventions can be counteracted by other activities in the same catchment. An example from Pickering was the ongoing management and redesign of Cropton Forest. In addition to normal, small-scale felling activities that will temporarily remove the water use effect of forest stands, sizeable areas of conifer forest are being removed for the restoration of open habitats such as mires and peatland, or converted back to broadleaved woodland on ancient woodland sites or within riparian zones and gills. Forest conversion to open space, in particular, will act to counteract gains made from woodland creation elsewhere within the catchment. These aspects need to be addressed in Flood Risk Management Plans and the long-term Forest Design Planning process.
12. Measuring the impact of land management measures on flood flows at the catchment level is extremely difficult and requires a robust, well planned and long-term funded research study. In view of the level of commitment and investment required, resources are best focused on small to medium sized catchments that can be expected to deliver large-scale changes in land use and/or management. At least several years of baseline data are required before making any interventions and ideally should include a nearby control catchment. Separate or nested studies are required to distinguish the effects of different measures.
13. For the evaluation of demonstration studies on sites lacking longer-term baseline data, it may be better to focus on measuring the extent of the implemented measures and their effects on relevant site processes, such as on evaporation, soil infiltration, flood

storage or hydraulic roughness. These numbers can then be used by models to predict outcomes for flood risk management.

14. Modelling is a key step in the process of locating and designing land management measures to reduce downstream flood risk. Unfortunately, there is no consensus on the best model to use and a wide range of hydraulic, hydrological and combined models to choose from. The models vary in complexity, representation of key processes and data demands, but need to be spatially distributed if to be used to guide effective placement of measures. A combined hydrological and hydraulic model should be used where there is a need to integrate the effects of different measures, such as woodland creation and the operation of downstream flood storage bunds. It is important to check which processes are included within models and how they are parameterised (e.g. models rarely include all four processes by which woodland can reduce flood runoff).
15. Significant effort is involved in setting up and calibrating a model to an individual catchment and thus potentially costly. This needs to be properly resourced and allow for revised model runs to assess changes to plans. It is important to undertake ground truthing to check results and take care in communicating any changes to minimise the risk of confusion and loss of confidence.
16. The simplified, coupled, hydrological-hydraulic OVERFLOW model provided a very useful tool for optimising the location of land management interventions. It showed that slowing the flow at some sites can increase rather than decrease flood flows as a result of synchronising catchment contributions. In general, measures are likely to be most effective when placed in the upper half of a catchment (with the exception of large flood storage bunds).
17. A strong and inclusive partnership and governance structure are required to deliver a successful project. Decisions on the siting and design of land management interventions need to balance a range of factors and interests, which intensify within sensitive and designated landscapes. An example at Pickering was tension between effective placement of small flood storage bunds and potential impacts on protected habitats. Opinions can differ within and between organisations and best resolved through open discussion and consensus building via a strong partnership.
18. Decisions on woodland creation can also be contentious. While planting can offer significant benefits for flood risk management and other ecosystem services, there are many barriers to land use change. The selection of Pickering Beck as a demonstration catchment was partly guided by the relatively high level of public land ownership, which was expected to make decision making easier over woodland creation. However, planting was affected by the sensitive nature of the landscape, especially by its existing high biodiversity and valued openness. Decisions were also influenced by the narrower benefit for flood management from planting moorland compared to more intensive farmland. A strong partnership was key to resolving differences and identifying where planting could proceed.
19. Persuading private land owners to plant woodland in target locations is very difficult. A review of the potential use of nudge-type approaches suggests that individuals are heavily influenced by who communicates the information and efforts need to be tailored towards different types of land managers/owners and stages of decision-making. However, achieving a sizeable level of change on higher quality land is likely to require greater financial incentives. The new, integrated, Countryside Stewardship scheme should help by offering up to £6,800/ha (depending on the capital options selected) for planting that provides a number of benefits, including reducing flood risk and diffuse pollution.

20. Good communication is vital to ensure that plans are understood by all and incorporate local knowledge. In particular, the local community need to be fully engaged, kept well informed of progress and expectations carefully managed. Measures such as including community representatives and local champions on the Programme Delivery Group, drawing up a community engagement plan as part of the EA's 'working with others' approach, and holding a series of community engagement days, all assisted in this regard. It also helped the local community better understand the working procedures and constraints affecting regulators when making land management decisions. They readily accepted the benefits of working with natural processes and were quick to perceive the measures as making a difference.
21. Demonstration projects should include a formal ecosystem services assessment, which needs to be carefully planned from the outset. An initial qualitative assessment of the expected costs and benefits would help to guide data collection and thereby assist the final quantitative evaluation. The exercise also needs to be properly costed and resourced, as well as include protocols for handling sensitive data.
22. Five to six years is a more effective time scale for delivering a demonstration project, especially one involving persuading landowners to change land use.

10. Knowledge Exchange

Much effort has been spent on promoting the work of the project, which has resulted in it gaining a very strong national profile and being well cited as a case study demonstrating the value of working with natural processes. It has received much local and regional TV, Radio and press attention, as well as national interest, including on Sky News, the BBC's Politics Show and most notably as part of an episode of the BBC's science programme 'Bang Goes the Theory, which was aired on BBC 1 on 14 April 2014. Many invited presentations have been given at conferences, workshops and training events held around the country. A total of 14 site visits were hosted for a range of key individuals and groups to share knowledge and experience. The local community in Pickering were kept fully informed by local champions on the Wider Programme Delivery Group, through three community engagement days, newsletters, and via the project website. A summary of the main items of knowledge exchange is provided in Appendix 14.7.

11. Conclusions and Recommendations on Future Work

A strong project partnership was formed in Phase I to engage with the local community in delivering a more sustainable approach to managing flood risk. The four-year, Phase II extension of the project has succeeded in achieving or exceeding nearly all of the original objectives and success criteria. Only the very ambitious woodland creation targets for riparian and floodplain woodland were not met due to the high landscape and biodiversity value of the target area in the Pickering Beck catchment and difficulties in persuading landowners to plant woodland on the higher value floodplain in the River Seven catchment. The seven sets of implemented land management interventions were predicted to protect Pickering from at least a 1 in 25 year flood, reducing the chance of flooding in the town from 25% to less than 4% in any given year, which was the primary objective of the project.

The large flood storage bund alone was designed to deliver the target standard of protection, with the other measures acting to further reduce the flood risk. It has not been possible to model the interaction between the different measures but an assessment was made of the combined flood storage created. This gave a total of around 129,000 m^3, 120,000 m^3 from the flood storage bund, ~8000-9,000 m^3 for the woodland measures and ~500 m^3 from the moorland and farm measures. A number of measures have also been implemented in the neighbouring River Seven catchment, providing 7,000-8,000 m^3 of flood storage to help reduce flood risk to the village of Sinnington. The delaying effects of the wider catchment measures are not accounted for in these figures and were predicted to significantly enhance the flood attenuation effect.

A monitoring programme has been established to quantify the effect of the measures in reducing flood flows. Although some of the land management interventions such as woodland creation will take time to become fully effective, an attempt was made to determine if they had any impact on a near-flood recorded in Pickering in November 2012. The local community believe that the measures implemented by then (pre-dated bund construction) helped to prevent an expected flood but an analysis of the data proved inconclusive, possibly due to the multiple peak nature of the event. A longer run of data and larger number of flood peaks are required for a more robust assessment.

The ecosystem services provided by the different measures were evaluated, with the most significant being climate regulation, flood regulation, habitat provision, community engagement, erosion regulation, and education/knowledge. Allowing for the costs of the measures and for the timing of these plus benefits (i.e. their distribution over a nominal 100 year period) gave aggregated net present values (NPV) ranging from £0.6m to £3.2m and a central estimate of £1.9m for the whole set of project measures. This compared to a range of -£0.3m to £2.4m and a central estimate of £1.0m for the woodland, moorland and farm measures (i.e. minus the main bund). The positive NPV in each case for the Pickering Beck catchment for the whole set of interventions indicate that from a societal perspective the benefits significantly outweighed the costs. A comparison of the benefit-cost ratios (based on the central estimate) for this catchment gave values ranging between 1.3 for the large bund to 5.6 for the woodland measures (that for all measures was 1.5, while the value for those excluding the main bund was intermediate at 3.8).

The project has gained a very strong national profile and is well cited as a case study demonstrating the value of working with natural processes. Of special note has been the role of the project in helping to guide and integrate the implementation of government policy on flood risk and land use management. In particular, it has underpinned key regional and national initiatives on Woodlands for Water, including the use of opportunity mapping to identify priority locations for planting to reduce flood risk, and the introduction of a Woodland for Water grant payment of £2,000/ha under the previous English Woodland Grant Scheme. More recently, it has helped shape the Countryside Stewardship scheme and a new national forest industry initiative on the role of productive woodland in water management. Locally, the project is guiding the development of the Local Flood Risk Strategy and Flood Risk Management Plans, as well as a new Derwent Catchment Strategic Plan for tackling related water quality issues.

The project has received much local and regional media attention, as well as national interest, most notably as part of an episode of the BBC's science programme 'Bang Goes the Theory, which was aired on BBC 1 on 14 April 2014. It has also been the subject of many invited presentations at conferences, workshops and training events held around the country. A total of 14 site visits have been hosted for a range of key individuals and groups to share knowledge and experience. The local community in Pickering have been fully engaged with the project and readily embraced the concept of a whole-catchment approach to flood risk management. The project has clearly demonstrated how a strong partnership approach can succeed in delivering an integrated set of land management measures to reduce flood risk at the catchment scale, as well as provide wider multiple benefits for local communities.

A number of recommendations are made to build on the success of the project:

1. Partners use the results and success of the project to inform future revisions of existing catchment and land use plans, as well as the development of new plans and strategies. A good example is the ongoing work of the Derwent Catchment Partnership in developing an overarching strategy to meet the requirements of the River Basin Management Plan and Water Framework Directive. This needs to realise the potential win-wins for the environment and society through working with natural processes to provide a more integrated approach to water, flood and land use management, including scope to deliver the objectives of the Local Flood Risk Strategy, Flood Risk Management Plans and the Floods Directive.

2. Partners continue to work together to oversee how the implemented measures develop, including conducting occasional surveys (such as of the LWD dams) and carrying out appropriate maintenance work. Opportunities should also be sought to install additional measures to further reduce flood risk to Pickering and Sinnington. Consideration should be given to holding an annual meeting to provide an update on catchment management for flood risk, discuss any issues and review plans.

3. Monitoring is maintained to allow the longer-term effectiveness of the measures to be established. This includes the FC continuing to operate their network of water level recorders to monitor the effects of the LWD dams, timber bunds and new planting on flood flows. The EA maintain their main river gauges in both catchments to provide an integrated assessment of the effect of the combined measures on flood risk. They should also re-assess the role of their tributary river gauging sites and perhaps upgrade these as appropriate.

4. Partners seek opportunities for funding to extend the modelling work to integrate the effects of the large flood storage bund with the other land management measures. This could also include exploring the effects of climate change and existing land use and management, such as forest redesign, as well as updating the cost-benefit analysis.

5. The partnership continues to communicate and promote the benefits of a whole-catchment approach to flood risk management, by hosting site visits, giving presentations, publishing results and through the media. A final Phase II event should be held to launch the completion of the main bund and to promote the achievements of the project.

6. Partners continue to apply the lessons learned in developing future flood risk and land use management policy and support mechanisms to secure wider implementation of land management measures to help protect affected communities. This includes further development of payments for ecosystem services, such as more targeted and integrated grant payments under Countryside Stewardship, as well as alternative approaches for rewarding service provision. Guidance on the placement, design and use of some of the measures (e.g. LWD dams, timber bunds and heather bale check dams) would also be helpful.

12. Acknowledgements

The authors would like to gratefully acknowledge the support of all of the project partners in delivering a successful project: Forestry Commission England, the Environment Agency, North York Moors National Park Authority, Durham University, Natural England, the Yorkshire Flood & Coastal Committee, Duchy of Lancaster Estates, North Yorkshire Moors Railway, North Yorkshire County Council, Ryedale District Council, Pickering Town Council, Sinnington Parish Council, and not least the community representatives, especially Mike Potter. Particular thanks are due to the members of the Slowing the Flow Partnership Board, especially the Chair, Jeremy Walker, in helping to oversee and steer the project, as well as to the members of the Programme Delivery Group in assisting with implementing the measures. Finally, the authors would like to thank Defra as the lead funder for the project, Forestry Commission England, the North York Moors National Park Authority and Natural England for funding the land management measures, and Ryedale District Council, Defra, the Environment Agency, North Yorkshire County Council, the Regional Flood & Coastal Committee, and Pickering Town Council for funding the large flood storage bund.

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14. Appendices

14.1 Report on match funding
14.2 Photo selection of implemented measures
14.3 Report on quantifying the contribution of the large woody debris dams to flood water storage
14.4 Report on evaluating the performance of the two timber bunds in the River Seven catchment
14.5 Report on ecosystem services evaluation
14.6 Report on potential of behavioural policy ‘nudges’ to encourage woodland creation for flood mitigation
14.7 List of media interviews, press articles, publications in trade press and journals, presentations given and events attended
14.8 Development of the flood storage bund