Case study 12. Slowing the Flow at Pickering

Authors: Tom Nisbet, Huw Thomas, Philip Roe

Main driver: Flood risk management

Project stage: Multi-objective, long-term, demonstration study

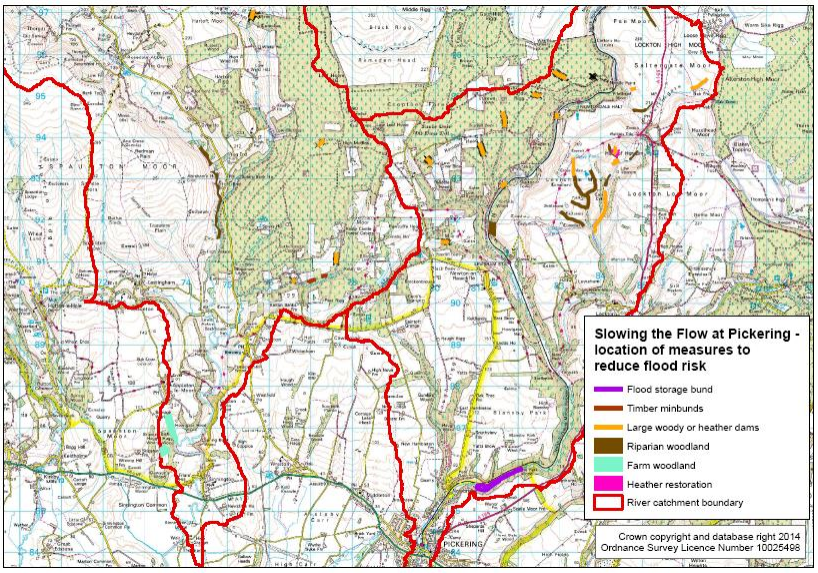
Photo 1: Woody dams upstream of Pickering (source: Forest Research)

Project summary:

The project was established in April 2009 to look at how changes in land use and land management can help to reduce flood risk for the town of Pickering in North Yorkshire (Map 1). It was 1 of 3 pilot projects funded by Defra in response to Sir Michael Pitt's Review of the 2007 floods in England and Wales and his call for greater working with natural processes. The project's overall aim is to demonstrate how the integrated application of a range of land management interventions/measures can help reduce flood risk at the catchment scale, as well as providing wider multiple benefits for local communities. A strong local partnership was formed, which put in place an agreed set of measures designed to reduce the chance of flooding in the town from 25% to 4% or less in any given year. Initial results have been very positive and work continues to evaluate the effectiveness of the measures in reducing flood risk.

Key facts:

An analysis of flow measurements from the Boxing Day 2015 storm event, when 50mm of rain fell over a 36-hour period, concluded with a relatively high degree of certainty that the project measures prevented flooding to a small number of properties in the town. It was estimated that the measures reduced the flood peak by 15–20%, with around half of the reduction due to the upstream land management interventions and half due to the large flood storage bund. The results are consistent with other observations that show the measures to be working as expected in reducing flood generation by storing and slowing flood waters within the catchment.



Map 1: Pickering Beck and adjacent River Seven catchment showing the location of land management interventions upstream of the town of Pickering and village of Sinnington

1. Contact details

Contact details	
Name:	Tom Nisbet
Lead organisation:	Forest Research
Partners:	Defra, Forestry Commission England, Environment Agency, North Yorkshire Moors National Park Authority, Natural England, Durham University, Ryedale Flood Research Group, North Yorkshire County Council, Ryedale District Council, Pickering Town Council, Sinnington Parish Council, North York Moors Railway, Yorkshire Flood and Coastal Committee, and Duchy of Lancaster Estates
e-mail address:	tom.nisbet@forestry.gsi.gov.uk

2. Location and catchment description

Catchment summary	
National Grid Reference:	SE 797841
Town, County, Country:	Pickering, North Yorkshire, UK
Regional Flood and Coastal Committee (RFCC) region:	Yorkshire
Catchment name(s) and size (km^2):	Pickering Beck (69km^2) and River Seven (92km^2)
River name(s) and typology:	Pickering Beck and River Seven Low, small and calcareous

Water Framework Directive water body reference:	GB104027068470 (Pickering Beck)
Land use, soil type, geology, mean annual rainfall:	Mix of forest, heather moorland, improved grassland and arable on brown earth and podzol soils derived from sandstone and limestone Mean annual rainfall: 829mm (1981 to 1990)

3. Background summary of the catchment

Socioeconomic/historic context

Pickering has a long history of flooding, with 4 floods in the past 15 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. While a flood alleviation capital scheme had been proposed, a cost–benefit analysis showed this to be unaffordable when set against national cost–benefit thresholds and other priorities. Instead, attention turned to developing a whole catchment approach to flood risk management. Previous land management practices were considered to have enhanced the flood risk by promoting rapid run-off and increasing sediment delivery. Land drainage, overstocking, overgrazing, inappropriate cultivation and poor run-off management were thought to be contributory factors. Opportunities existed to correct these problems and help restore the catchment's natural flood attenuation capacity.

In 2008, a Rural Economy and Land Use programme funded study 'Making Space for People' enabled Durham University to develop a bespoke catchment simulation model to investigate the potential contribution of upstream flood storage bunds and changing 'hydraulic roughness' to retain floodwaters in the floodplain and slow flood flows. The results showed that targeted interventions could delay the response of the catchment to rainfall and thereby lower the flood peaks. Local community representatives were closely involved in the model development, contributing local knowledge and ideas about the placement of temporary storage measures.

A project partnership formed to build on this work made a successful bid to Defra to test and demonstrate how the integrated application of different land management measures could help to reduce flood risk to downstream communities, as well as provide wider multiple benefits. The Slowing the Flow at Pickering project commenced in April 2009, initially with 2 years' funding.

Flood risk problem(s)

The town of Pickering and the village of Sinnington are located on the southern side of the North Yorkshire Moors, on the banks of Pickering Beck and the River Seven, respectively. The rivers flowing off the moors are very flashy, meaning that properties located close to watercourses are prone to flooding, with events occurring on a regular basis. In Pickering, ~20 properties were flooded in 1999, 2000 and 2002. These events were followed by a major flood in June 2007, when 85 properties and the main A170 were directly affected, causing around £7 million of damage. A smaller number of properties (~13) are at risk of flooding in Sinnington. The communities are not protected by any traditional engineered flood defences.

Other environmental problems

Diffuse water pollution is a major issue, with both Pickering Beck and the River Seven failing to meet good water status due to a range of issues within component water bodies. These include failures for fish and macrophytes due to sedimentation from bank poaching, and failures for macrophytes and phytobenthos due to chemicals. There are also morphological problems caused by agricultural and flood protection fish barriers. Consequently, the area has been identified as a Priority Catchment under the England Catchment Sensitive Farming Delivery Initiative and a high priority for delivery of agri-environment schemes to address these issues.

4. Defining the problem(s) and developing the solution

What evidence is there to define the flood risk problem(s) and solution(s)

Much work was done by the Environment Agency and its consultants, and by Durham University and Forest Research, to understand the flooding problem and explore potential solutions. Hydrological data from past flood events, together with 'opportunity mapping', LiDAR (light detection and ranging) and other physiographical information informed the use and development of hydrology and hydraulic models to design and test different land management options. Efforts focused on the Pickering Beck catchment in view of the larger flooding issue affecting the town of Pickering.

Standard hydraulic models were used to evaluate potential locations for upstream flood storage. This revealed that the creation of bunded areas alone would not have the desired effect without additional work to restrict the flow of water in the main river channel. Extended sections of the river channel had become too deep such that channel flows were effectively 'disconnected' from the floodplain.

Data collected during a near-flood event in December 2009 refined understanding of the critical flow threshold for the onset of flooding in the town, driven by waters backing up from one of the main road bridges. This showed that a group of around 6 properties within the Beck Isle area were the first to flood as the flow reached ~12m^3 per second (cumecs). There was then a gap until the flow exceeded 15 cumecs, when floodwaters extended out across Pickering to affect 50+ properties.

Durham University's coupled hydrological–hydraulic model OVERFLOW was particularly useful for assessing optimal locations for catchment-wide, land management interventions to reduce flood risk in both the Pickering Beck and River Seven catchments. A particular strength of the model was its ability to separate sites where measures would have a beneficial effect (flood reducing) from those where it could be damaging (flood increasing) by assessing whether slowing the flow synchronised or desynchronised tributary responses. The model allowed the impact of different interventions to be quantified and thereby their effectiveness compared.

What was the design rationale?

The overall aim of the project was to demonstrate how the integrated application of a range of land management interventions/measures could help reduce flood risk at the catchment scale. This was to be achieved by implementing a set of 7 measures:

- Constructing low -level bunds within the Pickering Beck catchment to increase flood storage capacity within the floodplain
- Planting 50ha of riparian woodland within the Pickering Beck catchment and 30ha of floodplain woodland in the neighbouring catchment of the River Seven at appropriate sites to delay and reduce flood flows
- Constructing 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
- Planting 5ha of farm woodland on sensitive soils within the Pickering Beck and/or River Seven catchments to increase soil infiltration and reduce rapid surface run-off, erosion and sediment delivery to watercourses
- Identifying and blocking moorland drains causing rapid run-off and erosion in the Pickering Beck catchment, together with establishing no-burn buffer zones along main watercourses to retard flood generation
- Identifying problem drains and restoring streamside buffer zones within Cropton Forest to reduce rapid run-off and amending felling plans to minimise impact on flood risk
- Implementing farm-scale measures to improve soil infiltration and reduce rapid run-off

Early on in the project, the project partnership agreed 12 criteria for measuring success. The principal criterion was to reduce flooding in the town of Pickering from the existing 25% chance in any year to a 4% chance. This shaped the design of the selected measures and in particular the construction of the bunded flood storage. The greater scope for engineered control allowed this to be designed to solely provide the target level of protection. In contrast, it was more difficult to quantify the contribution of the

other land management measures and therefore their design tended to be driven by practicalities, site sensitivities and constraints. These measures were expected to further reduce the chance of flooding to less than 4% in any year.

Project summary	
Area of catchment (km^2) or length of river benefitting from the project:	The series of land management measures are expected to benefit most of the 69km^2 of the Pickering Beck catchment. The more restricted nature of the measures within the River Seven catchment means that a much smaller area of this larger, 92km^2 catchment is affected (10–15%).
Types of measures/interventions used (Working with Natural Processes and traditional):	Flood storage bund Timber bunds Large woody debris dams Drain blocking Woodland planting and felling control Moorland no-burn buffer zones Heather reseeding Erosion control Soil aeration Farmyard and road/track works
Numbers of measures/interventions used (Working with Natural Processes and traditional):	One large flood storage bund was constructed plus 2 timber bunds, 167 large woody debris dams and 187 heather bale check dams. 29ha of riparian woodland and 15ha of farm woodland planted 5.9ha of riparian woodland restored and forest site operational plans revised 3.2ha of heather moorland reseeded 800m of eroding footpath restored Mixture of roof, yard and related works carried out on 10 farms
Standard of protection for project as a whole:	Risk of flooding in Pickering reduced from a 25% chance in any year to a less than 4% chance.
Estimated number of properties protected:	40–50

How effective has the project been?

The project has been very effective in delivering a set of measures that are expected to meet the target level of flood protection for the town of Pickering. In terms of flood storage, the large bund makes the greatest contribution by providing 120,000m^3, followed by an estimated 8,000–9,000m^3 for the woodland measures and ~500m^3 from the moorland and farm measures. A number of woodland measures were also implemented in the neighbouring River Seven catchment, providing 7,000–8,000m^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 are 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 the first high flow event recorded in November 2012. The local community believed that the measures implemented by then (it 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.

The next main storm event was on Boxing Day 2015, when 50mm of rain fell over a 36-hour period. An analysis of the flow measurements concluded with a relatively high degree of certainty that the project measures prevented flooding to a small number of properties in the town. It was estimated that the measures reduced the flood peak by 15–20%, with around half of the reduction due to the upstream land management interventions and half due to the flood storage bund. The results are consistent with other observations that show the measures to be working as expected in reducing flood generation by storing and slowing flood waters within the catchment.

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 (WWNP). It has received much local and regional media attention, as well as national interest, and been the subject of many invited presentations at conferences, workshops and training events held around the country. 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.

5. Project construction

How were individual measures constructed?

Mapping and modelling informed the design, placement and integration of the individual measures.

The large flood storage bund was constructed with a clay core, grass-crete spillway and concrete pipe bridge to throttle flood flows for maximum effectiveness. The 2 timber bunds consisted of a 1.5m high wall of stacked logs (braced against and secured to adjacent tall tree stumps and/or posts) that extended across the full width of the river floodplain.

The large woody debris dams were built using a number of logs to form an open or 'leaky' framework that extended across the river channel and onto the river banks. Early designs mimicked natural dams, while later ones were more engineered, leaving a set gap so as not to affect low–moderate flows and secured into place by wedging and wiring the logs to bankside stumps or posts. Heather check dams were formed using a number of small square or large round bales of cut heather placed at intervals within eroding drains or gullies.

Woodland creation ranged from low density to standard spaced tree planting of native broadleaved species, protected by tree tubes or fencing. Riparian woodland restoration entailed the removal of conifer trees and replacement with native broadleaves, as well as the blocking or redesign of drainage systems to create a riparian buffer area.

The other listed moorland and farm measures mainly involved standard techniques.

How long were measures designed to last?

The design life of the measures varies according to their nature. This ranges from semi-permanent measures such as riparian woodland planting to more temporary features such as the heather bale check dams, which are likely to need replacing every 5–10 years. Large woody debris dams and the timber bunds are expected to last for at least 10 years; these are being surveyed every year to gauge their evolution and performance.

Were there any landowner or legal requirements which needed consideration?

A strong and inclusive partnership and governance structure are required to deliver a successful project, as well as the support of landowners and the local community. 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 such as at Pickering. A large number of issues affected the construction of the main flood storage bund, including planning permission, legislation such as the Reservoirs Act, environmental impact, landowner agreements and compensation for affected activities and site afteruse.

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. Opinions can differ within and between organisations, and are best resolved through open discussion and consensus building via a strong partnership.

Persuading private landowners to plant woodland in target locations is very difficult. A review of the potential use of nudge-type approaches suggested 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. Achieving a sizeable level of land use change on higher quality land is likely to require greater financial incentives.

Consent was required from the Environment Agency or local authority for the construction of the large woody debris dams and timber bunds. Grant payments to support various measures are subject to a number of requirements to ensure appropriate design and effective delivery.

6. Funding

Funding summary for Working with Natural Processes (WWNP)/Natural Flood Management (NFM) measures	
Year project was undertaken/completed:	The project began in 2009 and involved 2 main phases of funding (2009 to 2011 and 2011 to 2015). Work continues to monitor the effectiveness of the measures, to maintain these and, where opportunities arise, to expand activities within both catchments and in the wider region. Partners also continue to communicate and promote the benefits of the whole catchment approach to flood risk management.
How was the project funded:	Project management, co-ordination, research and reporting were primarily funded by Defra (£480,000 over 6 years). Match funding from partners for project support and implementation of measures totalled around £3 million over 6 years. Additional costs were involved in completing the main flood storage bund in summer 2015. Longer term project management, monitoring and evaluation costs are £20,000–£30,000 per year and are primarily funded by the Forestry Commission.
Total cash cost of project (£):	~£4 million
Overall cost and cost breakdown for WWNP/NFM measures (£):	The flood storage bund cost ~£2.7 million to construct; the 2 timber bunds £5,000 each. Individual large woody debris dams ranged from £50 to

	£500 each, depending on size. Heather bale check dams averaged around £27 each. Woodland planting costs varied according to density of planting, design and use of volunteers, ranging between £2,200 and £7,800 per hectare. The farm measures cost £145,000 in total. The other moorland measures (heather reseeding, footpath repairs and non-burn buffers) were estimated to total around £2,000.
WWNP/NFM costs as a % of overall project costs:	~85% for implementation of measures, with remainder on project management and support
Unit breakdown of costs for WWNP/NFM measures:	See above
Cost–benefit ratio (and timescale in years over which it has been estimated):	Benefit–cost ratios based on central estimates for all assessed ecosystem services (habitat creation, flood regulation, climate regulation, erosion regulation, education and knowledge, and agricultural production) over a 100-year time horizon, for the Pickering Beck catchment, ranged from 5.6 for the woodland measures, 3.8 for the combined set of woodland, moorland and farm measures, to 1.5 for these plus the large flood storage bund. The range of values reflect the significant climate regulation benefit of the woodland measures, the relatively limited impact assumed for the farm measures compared with their cost, and the relatively high construction cost of the flood storage bund.

7. Wider benefits

What wider benefits has the project achieved?

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 (that is, their distribution over a nominal 100-year period) gave aggregated net present values (NPV) ranging from £600,000 to £3.2 million, and a central estimate of £1.9 million for the whole set of project measures. This compared with a range of -£300,000 to £2.4 million and a central estimate of £1.0 million for the woodland, moorland and farm measures (that is, minus the main bund). The positive NPV in each case for the Pickering Beck catchment for the whole set of interventions indicated that, from a societal perspective, the benefits significantly outweighed the costs.

The project has gained a very strong national profile and is well cited as a case study demonstrating the value of WWNP. 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 per hectare 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 the Derwent Catchment Strategic Plan for tackling related water quality issues.

How much habitat has been created, improved or restored?

- For woodland habitat, 29ha of riparian woodland, 15ha of farm woodland and 5.9ha of riparian woodland buffers have been either planted or restored.
- For moorland habitats, 3.2ha of heathland have been improved through reseeding and 800m of eroding footpath have been repaired.
- The large number of installed large woody debris dams and heather check dams can be expected to have improved riparian and wetland habitats by reconnecting river channels with the floodplain and enhancing site rewetting, although this has not been quantified.
- The established 10m wide no-burn buffers along all watercourses draining Levisham Moor will also have improved streamside and aquatic habitats.

8. Maintenance, monitoring and adaptive management

Are maintenance activities planned?

Grant payments for woodland creation require site maintenance to achieve satisfactory establishment. Annual surveys are made of the condition of the large woody debris dams and timber bunds, with repairs made when necessary. Funding for these activities (currently provided by Forestry Commission England) and the eventual replacement of the measures is not assured, being dependent on annual budgets.

Annual maintenance of the large flood storage bund is carried out by the Environment Agency with funding support from Pickering Town Council.

Moorland measures are expected to be maintained by the North Yorkshire Moors National Park Authority.

Is the project being monitored?

Yes – 10 water level recorders have been installed along 4 stream reaches (3 in Pickering Beck and one in the River Seven catchment) to measure the effects of riparian woodland planting, the large woody debris dams and the 2 timber bunds. Due to the drive to implement the land management measures within the first 2-year phase of the project, there was less time to collect baseline data. A number of remote cameras have been installed to record the response of the timber bunds and some of the large woody debris dams during flood events.

The Environment Agency also operates 4 established river flow gauges (3 in Pickering Beck and one in the River Seven catchment) that allow the integrated effects of all of the measures to be determined. Data are available back to at least 2000.

An annual survey of the large woody debris dams and timber bunds is made to monitor their development and, in particular, changes to their porosity and stability.

Has adaptive management been needed?

The main need for adaptive management was in relation to plans for the large flood storage bund. An integral part of the original concept was to create significant flood storage behind one or more low-level (1.5–2.5m high) clay bunds across the floodplain upstream of Pickering. However, the Pickering Beck floodplain did 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 that 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 120,000m^3 of floodwater. A funding package was secured with substantial partner investment from Ryedale District

Council, North Yorkshire County Council, the RFCC and Pickering Town Council, alongside grant in aid from Defra and the Environment Agency. Construction work started in January 2014 and finished in summer 2015.

Another case for adaptive management concerned the design of the large woody debris dams. Initially, an unsecured and open framework of logs was used to mimic the formation of natural dams, which was left to evolve with the in-wash and release of woody material during high flow events. While this design proved to be relatively stable, it was thought to be less suited to the construction of larger dams on the main Pickering Beck. A more engineered design was adopted involving a stack of logs spanning the width of the channel and fixed to the bankside using wiring, posts and bankside trees. The lower log was positioned at around half bank full height, allowing low and moderate flows to pass unhindered.

9. Lessons learnt

What was learnt and how could it be applied elsewhere?

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. 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.

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. Another effect of the Reservoirs Act is to favour the use of single, large bunds that require more engineering. The Act's treatment of a series of small bunds as reservoirs in cascade acts against the use of this potentially cheaper and attractive option.

Timber bunds appear to provide a cheap and sustainable flood storage option, although their effectiveness remains to be tested under a larger flood event and their longevity determined. The use of smaller, more diffuse, storage features such as large woody debris dams, heather bale check dams and swales can collectively contribute a sizeable flood storage volume, depending on their design and management. This requires catchment level planning to achieve optimum placement and combination.

Measuring the impact of land management measures on flood flows at the catchment level is extremely difficult. For the evaluation of demonstration studies on sites lacking longer term baseline data, it may be better to focus on measuring the effects on relevant site processes. These numbers can then be used by models to predict outcomes for flood risk management.

Modelling is an important step in the process of locating and designing land management measures to reduce downstream flood risk. Models vary in complexity, representation of key processes and data demands, but need to be spatially distributed if they are to be used to guide effective placement of measures. It is important to check which processes are included within models and how they are parameterised.

The 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 flood storage bunds).

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Project background

This case study relates to project SC150005 'Working with Natural Flood Management: Evidence Directory'. It was commissioned by Defra and the Environment Agency's Joint Flood and Coastal Erosion Risk Management Research and Development Programme.