Case study 16. Belford Natural Flood Management Scheme, Northumberland

Authors: Alex Nicholson (Arup), Paul Quinn (Newcastle University), Mark Wilkinson (James Hutton Institute)

Main driver: Flood risk management – repeated flooding in the community of Belford

Project stage: Completed 2015

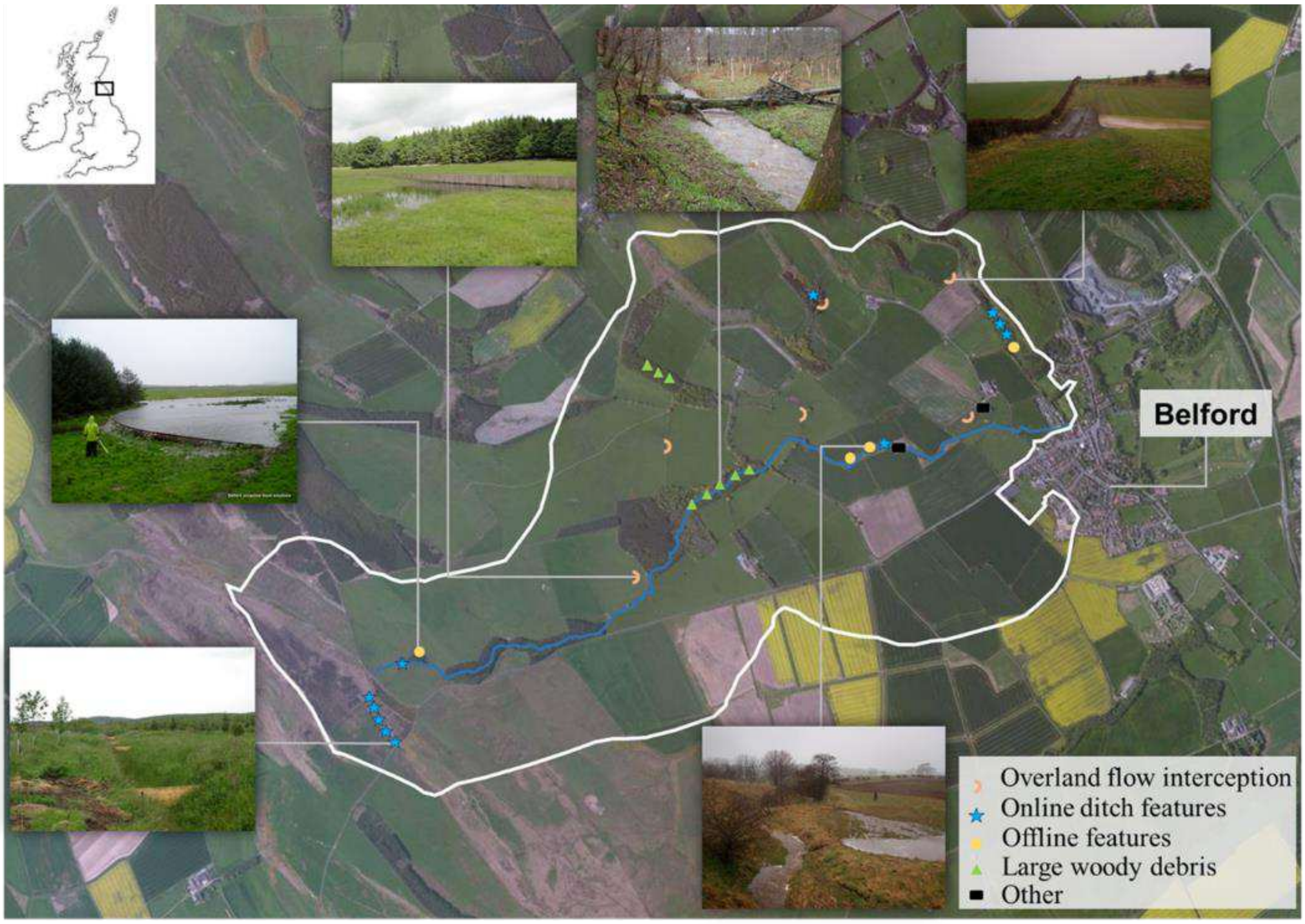


Photo 1: Belford Natural Flood Management project with pictures of some of its interventions (source: Newcastle University)

Project summary:

The Belford Burn is a small stream that runs through the centre of Belford village, hard up against garden boundaries and walls. The 6km² catchment is predominantly rural upstream of the village and is privately owned by 3 main landowners. Prior to the scheme, the burn presented a risk of flooding to 54 properties and a caravan park from a 1 in 100 year event. However, 25 properties were at risk from a 1 in 2 year event.

Belford village flooded 10 times between 1997 and 2007. The flood in 1997, which inundated the East Coast mainline railway, is estimated to have a return period of between 10 and 20 years. Traditional flood defences were not adopted owing to a lack of space between properties and the watercourse, and an unfavourable cost–benefit assessment at the project appraisal phase.

Project summary (continued):

Local Levy funding (~£350,000) was allocated by the North East Regional Flood and Coastal Committee (RFCC). The Environment Agency used ~£250,000 to commission Newcastle University to monitor the catchment, conduct hydraulic modelling, design run-off attenuation features (RAFs), engage with landowners and the community, and appoint specialist contractors to deliver the interventions. The remaining funds were used to repair a damaged wall on the bridge in Belford village and to improve the drainage network in the village. (Note that only 2 landowners were willing to take part at the early stages.)

Catchment monitoring of rainfall, river level and river flow began in winter 2007 and the first 4 RAFs were constructed in September 2008. Water level sensors were installed in each of these RAFs to monitor response during storm events. The monitoring network expanded in 2009 with the addition of 2 more temporary river level gauges, a permanent Environment Agency flow gauge and an Environment Agency rain gauge.

By the end of summer 2012, approximately 35 RAFs had been constructed in the catchment area. Eight of these had water level monitors within them.

In 2013, the Environment Agency used Local Levy funding (~£100,000) to construct an additional 10 RAFs in the catchment. Several of these RAFs were constructed on the private land of the third landowner.

Monitoring of individual RAFs has shown that they are able to have a significant impact (up to 10% reduction) on the flood peak in small to medium events, but that they were overwhelmed by larger events (by filling with floodwater during the rising limb of the hydrograph during observed storms). The RAFs have also provided multiple benefits including sediment capture and water quality improvements.

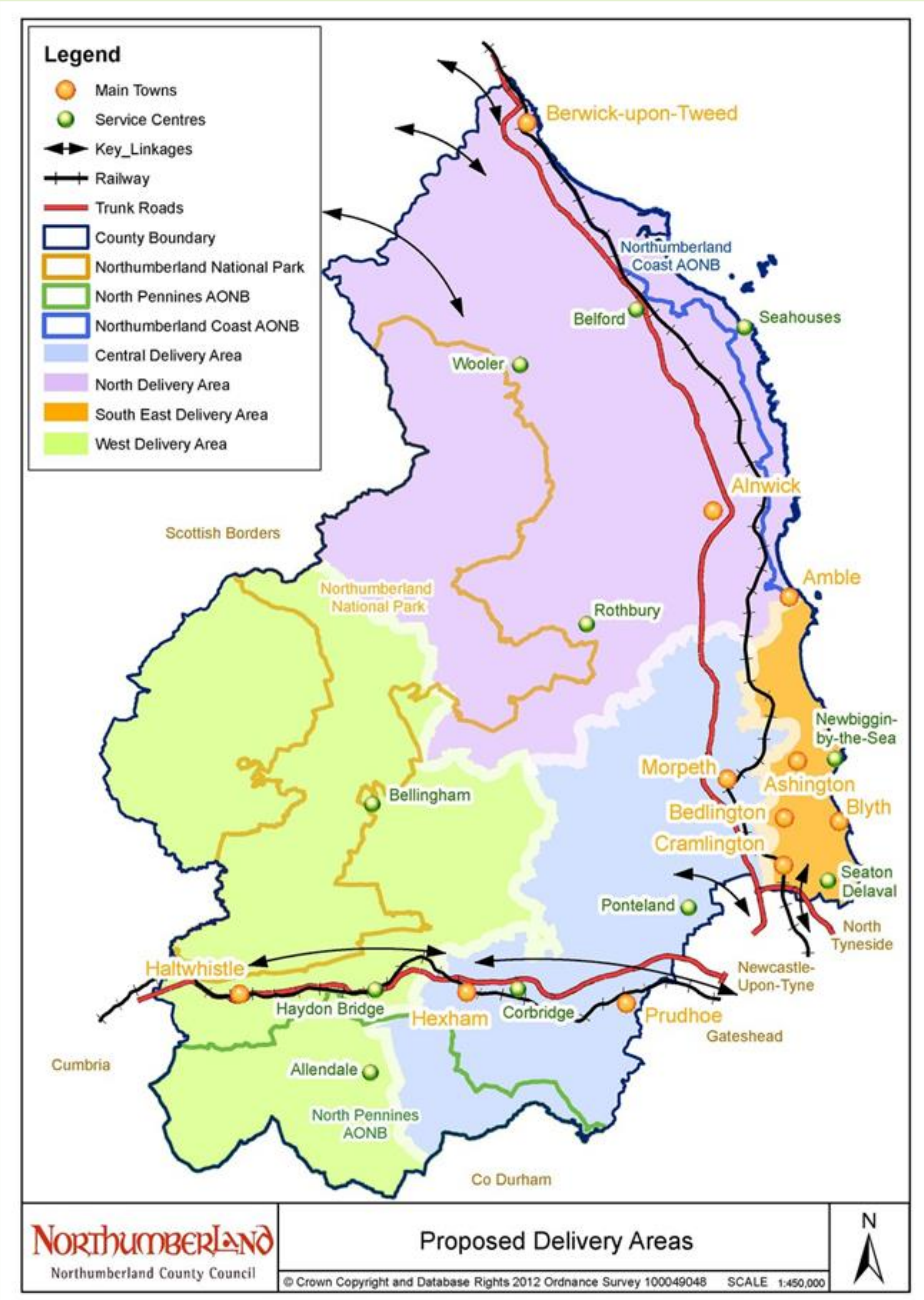
The development of a bespoke hydraulic modelling tool has shown that the design of existing RAFs could be improved to 'target' larger return period events. The Pond Network Model was developed to demonstrate how a series of hypothetical offline storage ponds could reduce peak magnitude in a range of return period events including the 1 to 100 year design storm (15–30% net reduction at Belford village). The Pond Network Model was validated using 2D hydraulic modelling software and a hydrological model.

Key facts:

Monitored evidence from Belford RAFs shows the impact of individual features during a range of storm events. Modelling hypothetical networks of RAFs shows the potential for the RAF approach within the Belford catchment. A trial of different modelling techniques has demonstrated high levels of confidence in the RAF approach.

From a landowner and community engagement perspective, the project has been hugely successful. Belford flooded 7 times between 1997 and 2007. Since the 35 RAFs were constructed (amounting to ~8,000m³ storage), only one property has been impacted by flooding. There is now a total of 45 RAFs (amounting to ~12,000m³ storage).

See the official Environment Agency video for more information.



Map 1: Belford catchment (source: Northumberland Country Council)

1. Contact details

Contact details	
Name(s):	Phil Welton, Paul Quinn, Alex Nicholson, Mark Wilkinson
Lead organisation(s):	Environment Agency, Newcastle University, Northumberland County Council, North East Regional Flood and Coastal Committee
Partners:	Amalgamated Construction (AMCO), Ian Benson Design, Royal Haskoning
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Official video	https://www.youtube.com/watch?v=MqSHSIHcBes
Project website	https://research.ncl.ac.uk/proactive/belford/

2. Location and catchment description

Catchment summary	
National Grid Reference:	410900, 633800
Town, County, Country:	Belford, Northumberland, UK
Regional Flood and Coastal Committee (RFCC) region:	North East
Catchment name(s) and size (km^2):	Belford Burn catchment, 5.7km²
River name(s) and typology:	Belford Burn from Source to Ross Low (410796, 633867)
Water Framework Directive water body reference:	GB103022076460
Land use, soil type, geology, mean annual rainfall:	**Topography:** A low lying catchment of gentle relief, ranging from 178m above Ordnance Datum (AOD) to 20m AOD **Soils**: The soils in Belford are described as slowly permeable and seasonally wet (using Soilscapes, Cranfield University). There are extensive boulder clay deposits overlain by deep slowly permeable soils (Stagnogleys) belonging to the Dunkeswick Association throughout the Belford catchment (Jarvis et al. 1984). Shallower, better drained soils are found where the Fell Sandstone and Dolerite outcrop. Reconnaissance surveys conducted in Belford have confirmed the accuracy of this mapping (Palmer 2012), although the soils in the upper catchment in particular are dominated by the fine loamy Brickfield Series member of the Dunkeswick Association, and there are well-drained soils over a small outcrop of Dolerite in the north-west of the catchment. Small areas of peat are present at the top of the catchment, upstream of the R1 monitoring station. This association consists of a deep, wet organic blanket, which is perennially

	waterlogged. These areas of peat, however, are unlikely to have any significant implications for catchment hydrology (which is likely to be controlled by the response of the boulder clay soils that cover 90% of the catchment area). The dominant soils in the catchment are relatively deep, but have limited infiltration below approximately 60cm (Jarvis et al. 1984). The active hydrological zone is therefore largely limited to within 1m of the ground surface. Land use**: Despite having impeded drainage, Belford's soil is able to support grassland, arable fields and some woodland (** Figure 1). The dominant land use at lower elevations, specifically in the south-east of the catchment, is arable rotation – primarily cereals. The upper catchment (to the west) is predominantly utilised for permanent pasture (sheep and cattle), rough grazing and coniferous plantation on steeper slopes. There is a mixture of deciduous and coniferous woodland along the main stream corridor. Three farmers manage the agricultural land within the upper Belford Burn catchment. **Rainfall**: Seasonal annual average rainfall (SAAR) 1961 to 1990: 695mm (Nicholson 2013) **Factors affecting run-off**: The standard percentage run-off (SPRHOST), defined as the percentage of rainfall that causes a short-term increase in flow, is 40% and the Baseflow Index (BFIHOST), the long-term average of flow that occurs as baseflow, is 0.313 (Institute of Hydrology 1999). The relatively high BFIHOST can be attributed to the presence of the permeable rock formations (for example, limestone) within the geology of the catchment. The time-to-peak (a measure of the time between the flood-producing rainfall and the resulting flood response) is 2 hours. These attributes are typical of rapid response catchments that are prone to flooding (Environment Agency 2011). Long-term mean annual rainfall is 695mm, but this value can vary significantly from year to year. The seasonal totals of discharge and rainfall measured during the study indicate a clear change in run-off response and subsequently run-off coefficients in winter and summer. Although run-off coefficients and SPRHOST cannot be directly compared, simple analyses of hydrological measurements revealed that, on average, the run-off coefficient calculated over the 4-year study period was approximately 50% greater than the SPRHOST being used by the Flood Estimation Handbook (Nicholson 2013).

3. Background summary of the catchment

The Belford Burn flows 10.5km from its source, near Bowden Crags, before discharging into the North Sea at Budle Bay (Wilkinson, et al., 2010). The study area focuses on the Belford Burn catchment upstream of the village of Belford (5.7km²). The Belford Burn drains from Bowden Crags (185m AOD) in an easterly direction for 4.5km to the village of Belford. The catchment is predominantly rural and has an average elevation of approximately 115m AOD.

The village experienced a number of flood events in the years preceding this study. The A1 and East Coast mainline railway are immediately downstream of Belford village and have both been affected by flooding from the upper Belford Burn catchment. This prompted engineering works to be carried out, including concrete flume sections and new culverts that are still present in the existing channel. The Environment Agency obtained funding for a non-traditional flood defence scheme, which began in late 2008.

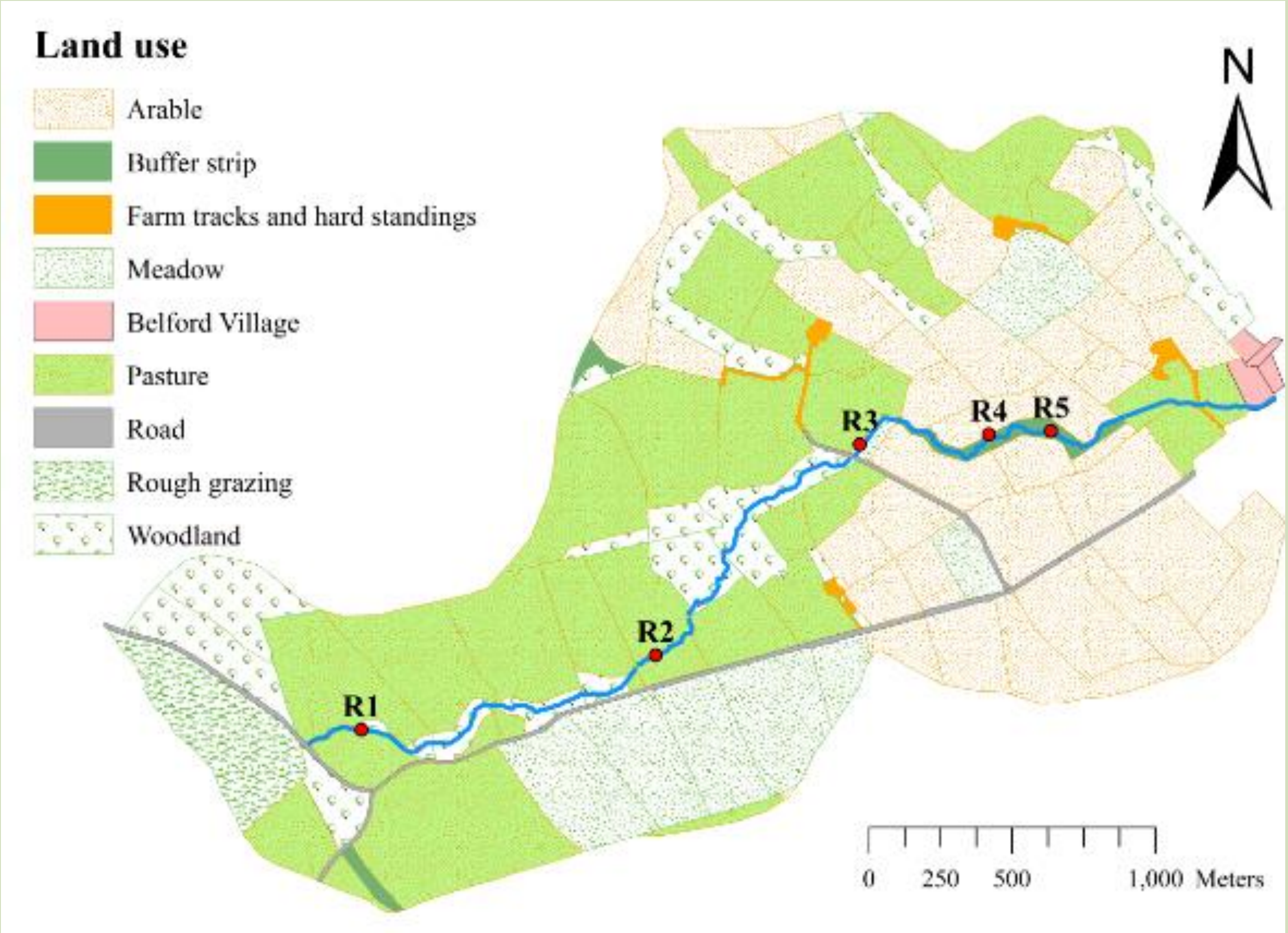

Figure 1: Land use in the Belford catchment (source: Newcastle University)

Flood risk problem(s)

The updated flood outlines for Belford show 25 properties at risk from a 1 in 2 year event and 54 properties at risk from a 1 in 100 year event (Figure 2). The A1 and East Coast mainline railway are also at risk of flooding from the 1 in 100 year event.

Other environmental problems

The overall Water Framework Directive status of the Belford Burn was poor at the time of the cycle 1 assessment in 2009. The cycle 2 assessment in 2015 showed the overall status as moderate (moderate for ecology, but good for chemical composition), with a target of reaching good status by 2027.

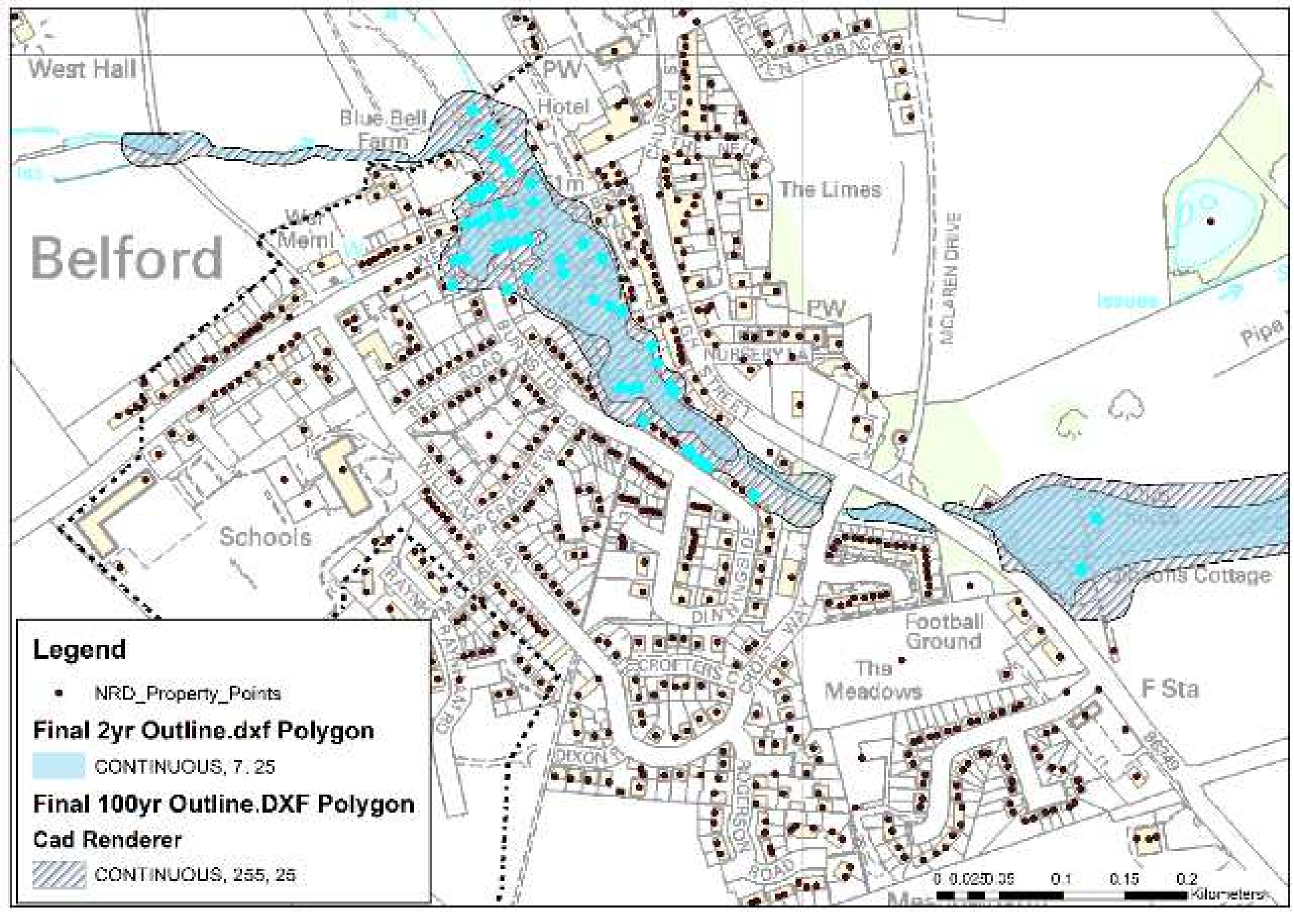

Figure 2: Updated flood outlines for Belford village, showing 2 year and 100 year outlines

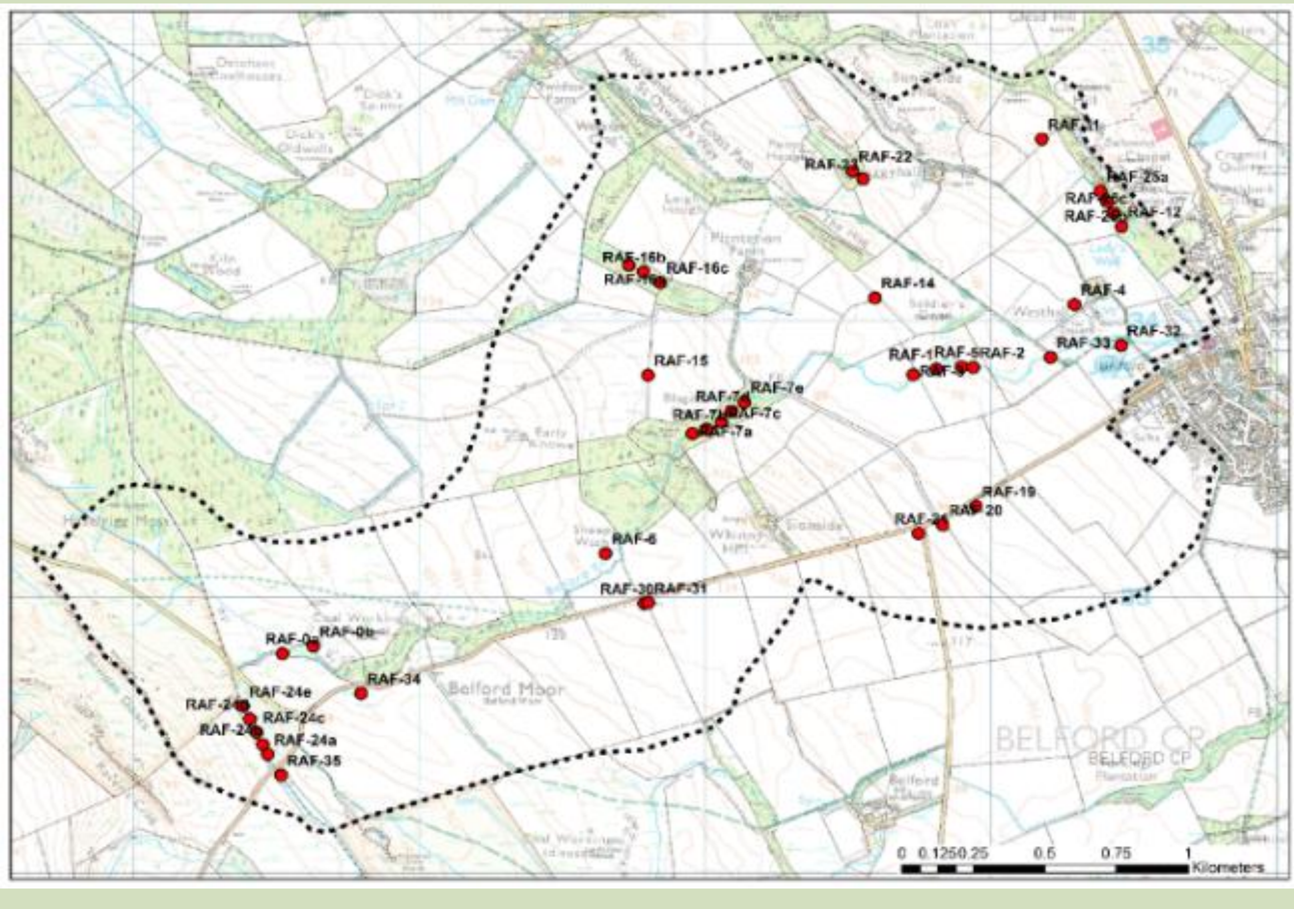

Figure 3: RAFs in the Belford catchment (not all RAF locations are shown on this map)

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

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

A one-dimensional HEC-RAS hydraulic model, originally developed by JBA Consulting to assess risk to the East Coast mainline railway, was utilised by Halcrow in the pre-feasibility study (Halcrow 2006) to generate revised flood outlines for Belford village. A steady state ISIS model was also utilised by Halcrow in the pre-feasibility study to simulate the impact of a storage reservoir upstream of Belford village.

The Floods and Agricultural Risk Matrix (the FARM tool) was applied to subcatchments of the Belford catchment. The tool indicated the a high risk of run-off during intense events (see Wilkinson et al. 2013 and http://research.ncl.ac.uk/thefarm/).

A PhD study funded by the Engineering and Physical Sciences Research Council (EPSRC) through the Flood Risk Management Research Consortium (FRMRC2) and the Environment Agency was initiated to monitor and develop hydraulic tools to measure and simulate the impact of Natural Flood Management (NFM) in the Belford catchment. The study also investigated catchment dynamics and hydrology. Two other PhD studies investigated the NFM installed in Belford to assess impacts upon water quality and sediment transport as a result of the measures (Palmer 2012, Barber 2013).

Catchment monitoring of rainfall, river level and river flow began in winter 2007 and the first 4 RAFs were constructed in September 2008. Water level sensors were installed in each of these RAFs to monitor response during storm events. The monitoring network expanded in 2009 with the addition of 2 more temporary river level gauges, a permanent Environment Agency flow gauge and an Environment Agency rain gauge. By summer 2012 the project had 5 river gauges on a 5-minute time series, one river gauge on 15-minute time series, 3 tipping bucket rain gauges, 2 barometers and 8 stage gauges inside RAFs all on 5-minute time series.

Monitoring and analytical method

RAFs have been monitored using pressure transducers (measuring on a 5-minute interval) as part of the wider catchment monitoring regime since 2008. Surveys using GPS real time kinematic devices have allowed the generation of stage–volume look-up tables, which have played a crucial role in the analysis of RAFs during storm events. An analytical technique was developed – utilising the observed data from within the RAFs and from nearby river gauging stations – to demonstrate the impact of individual RAFs on downstream discharge. This method has been able to detect percentage decreases (up to 10%) in discharge downstream of RAFs during observed short duration, low to medium magnitude events (for offline diversion ponds) (Figure 4). An evolved methodology was also able to infer the impact of overland flow interception RAFs during a large storm event – demonstrating a 50% decrease in the magnitude of discharge in the form of local surface run-off.

Modelling

The analytical method allowed the development of the bespoke modelling tool, the Pond Network Model, which was used to simulate changes to existing RAFs, the impacts of new RAFs and to identify how many RAFs (storage) would be required to mitigate against the highest magnitude historical events and design storms at Belford village.

The Pond Network Model was validated using observed data from historical storm events and comparisons with the analytical method described above. Simulations of RAF-0 during the large September 2008 storm identified that the RAF can reduce peak flow in the river, adjacent, by 15%. It was shown that a network of 35 RAFs (550m^3 capacity, with an inlet height of 0.45m) could potentially reduce discharge at the catchment outlet by between 18% (for the 1 in 100 year winter design storm) and 30% for the high magnitude historical events observed during the monitoring period (classed as 1 in 100 year rainfall events) (Figure 5 and Figure 6).

The model was also used to estimate the impact of a network of overland flow interception RAFs over a 1km^2 experimental reach. Modelling suggested that:

- a sequence of 4 RAFs could decrease peak overland flow by approximately 40% at the end of the 1km^2 reach
- strategic placement of these features throughout the catchment had the potential to significantly

change run-off response at the catchment outlet

RAF networks have been simulated using both hydraulic and hydrological models to demonstrate transferability to other catchments and other studies. The NewChan hydraulic model (Liang 2010a, 2010b) was used to simulate RAFs 1–3 in the Belford catchment and showed a closeness of fit to both the observed levels in the RAFs and the Pond Network Model predictions. This approach proved difficult due to the nature of editing Belford's Digital Elevation Model (DEM). It was decided to create a simple DEM (Figure 7) to provide an independent comparison with the results from the Pond Network Model (Figure 8).

The NewChan simulations demonstrated a greater reduction in flow from the network of RAFs than the Pond Network Model. This was attributed to the hydraulic effects being observed at pond inlets and outlets in the model schematisation (which are not represented by the Pond Network Model). Finally, the Pond Model has been emulated using the simple lumped conceptual rainfall run-off model, TOPCAT (Quinn et al. 1997, 2008 and 2013). Instead of topographic data, this model used observed rainfall and run-off alongside potential evaporation to calibrate the existing run-off regime with the model parameters. A unit hydrograph technique was then applied to represent physical storage and a change in time-to-peak as a result of mitigation within the catchment (Figure 9). TOPCAT has shown that an estimate in the reduction in peak discharge can be demonstrated in catchments of a similar size to Belford (<10km²).

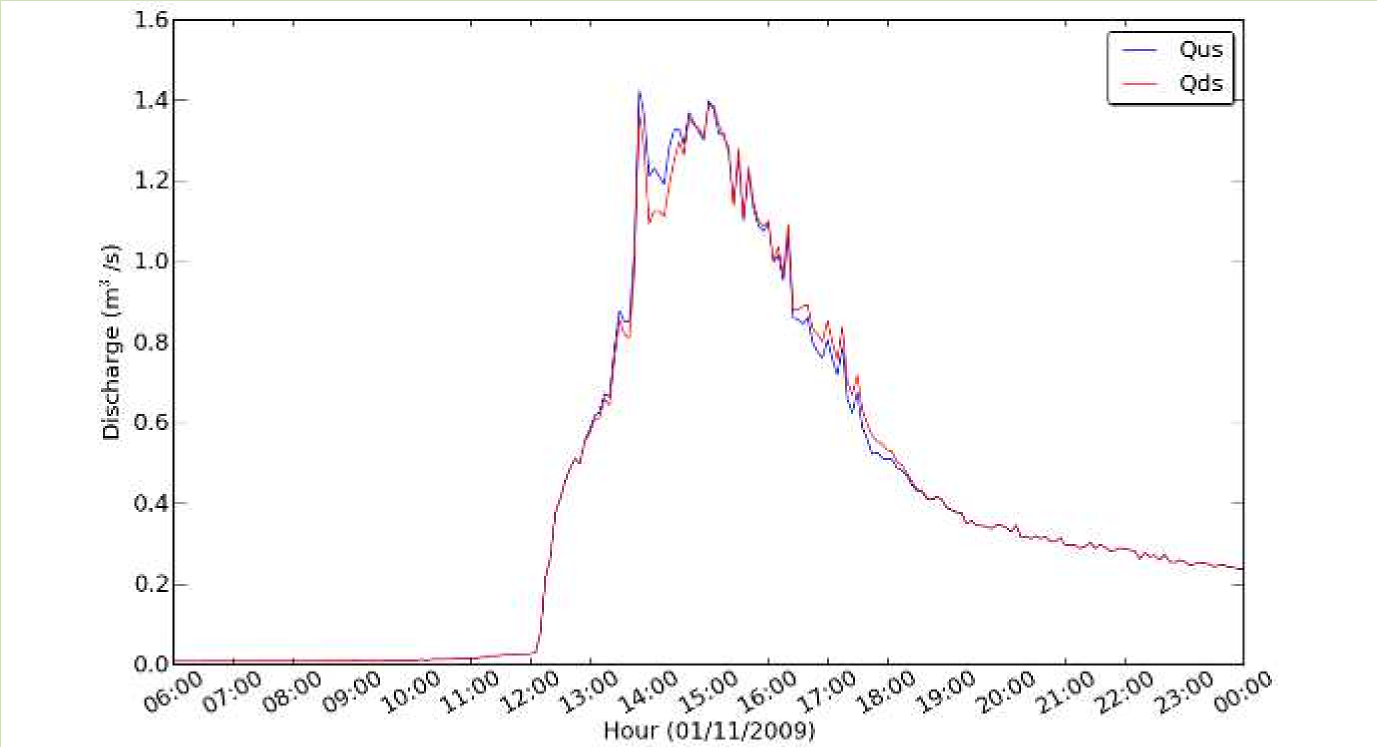

Figure 4: Measured impact of a single RAF on downstream discharge. The blue line shows discharge without the RAF and the red line shows discharge in the river with the RAF in place. Graph shows a 10% reduction in discharge as a result of the RAF during this small to medium magnitude event.

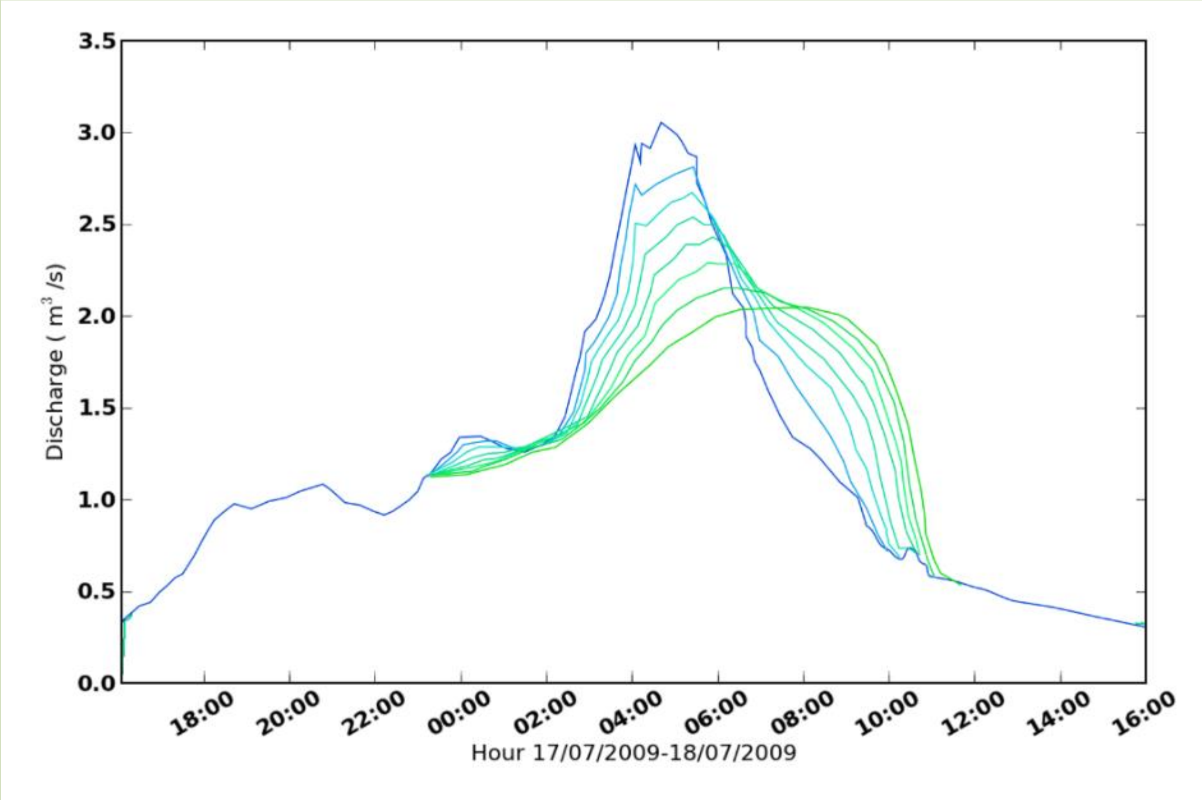

Figure 5: Pond Network Model output for July 2009 for a 1 in 100 year rainfall event. Simulation of 30 hypothetical RAFs of 550m³ storage each. Scenario shows a 30% reduction in peak flow.

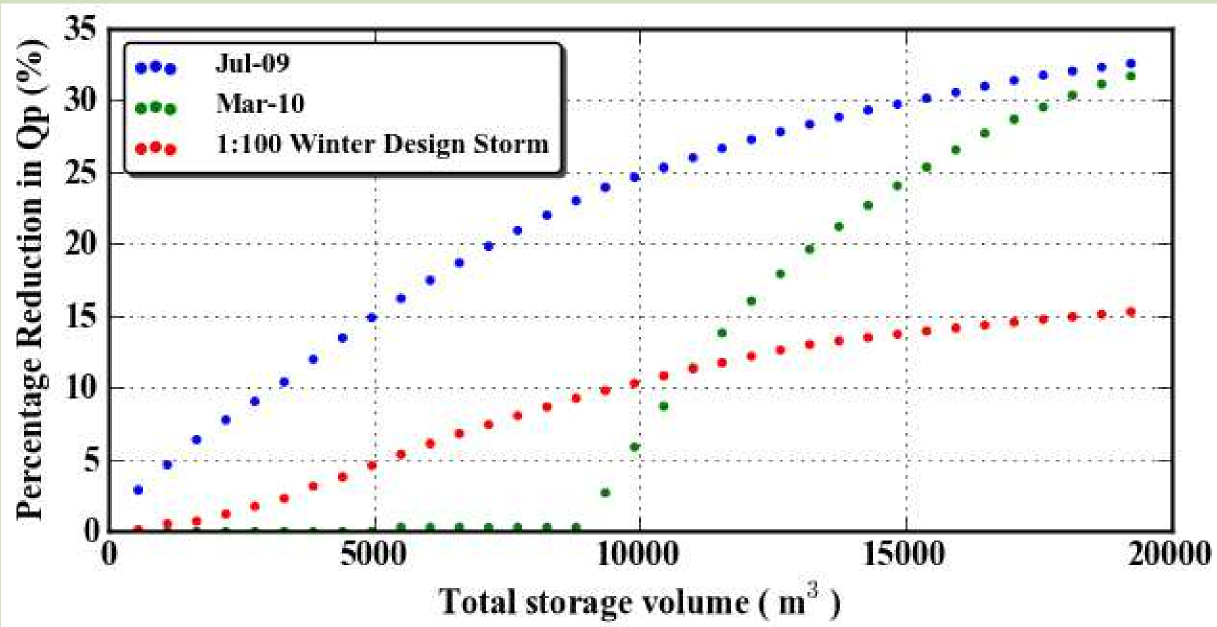

Figure 6: Percentage change in peak for July 2009 and March 2010 events, and 1 in a 100 year winter design storm. Each dot represents a RAF in the network and the cumulative reduction in peak flow by that RAF in the network.

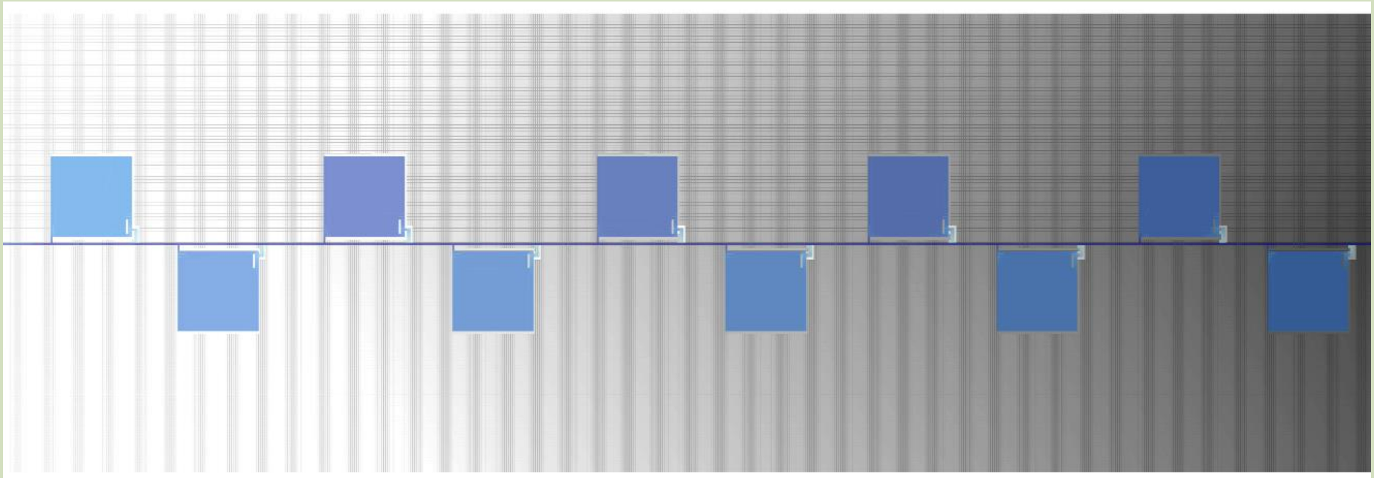

Figure 7: NewChan output for 10 RAFs during July 2009 storm event

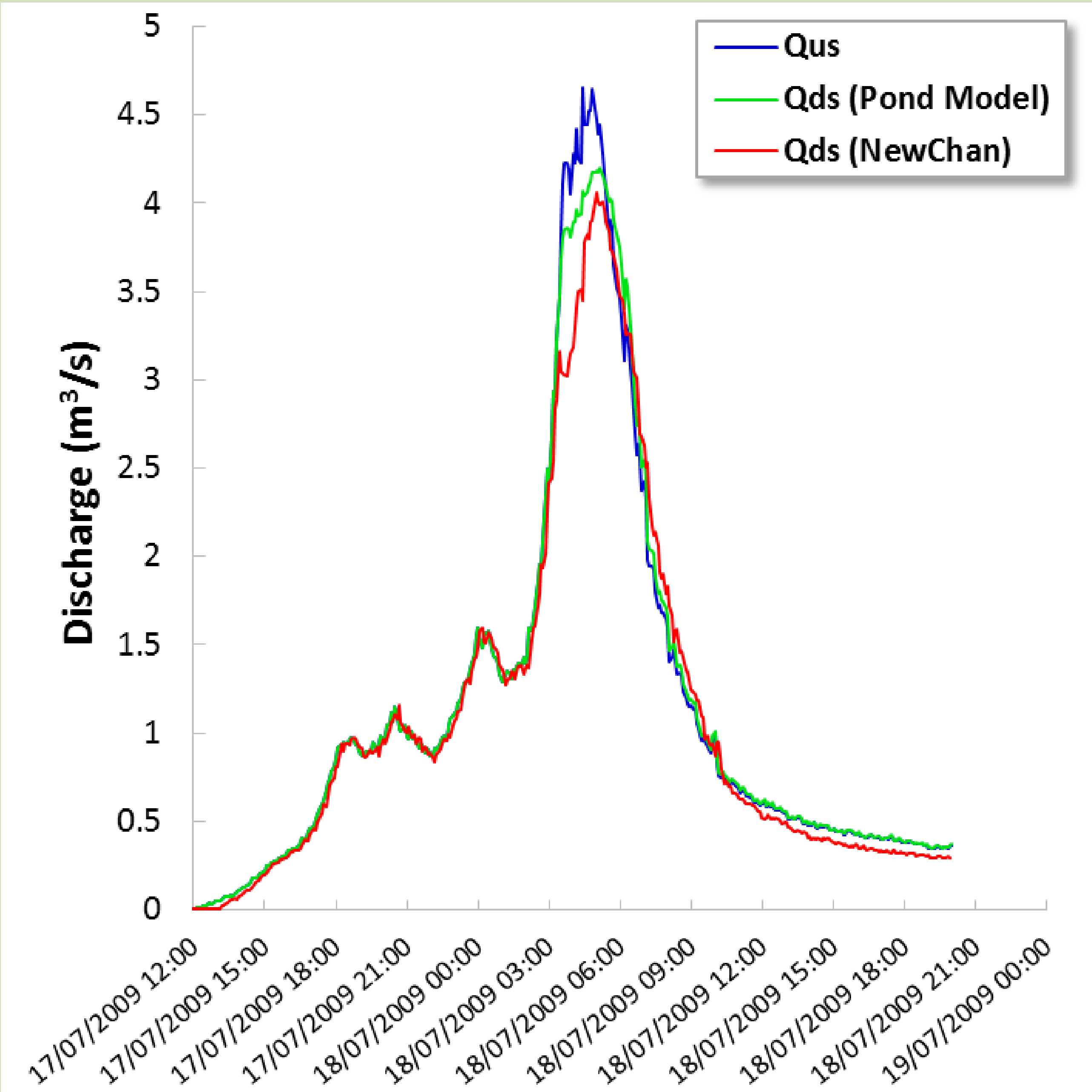

Figure 8: Pond Network Model and NewChan output showing pre- and post-change hydrographs at downstream point (10 RAFs) during July 2009 event (flows increased by factor of 1.75 in all simulations)

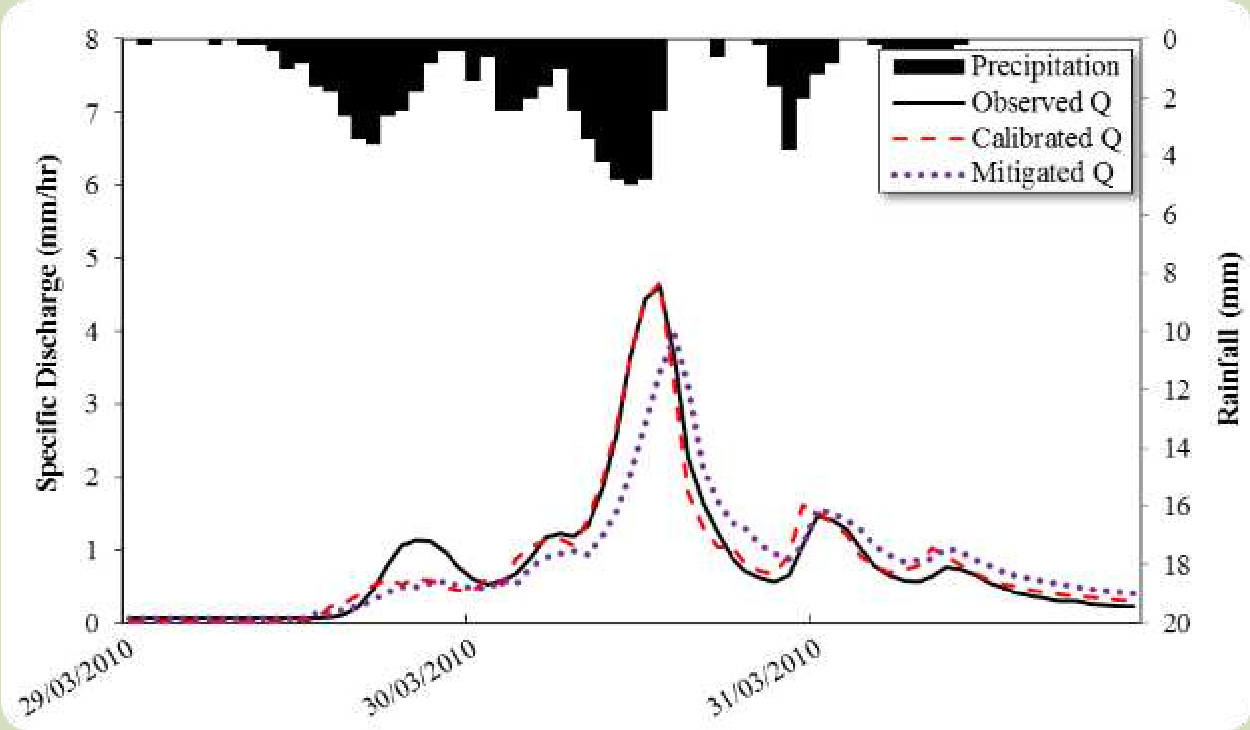

Figure 9: TOPCAT simulation emulating results from the Pond Network Model by changing hydrological parameters

What was the design rationale?

The analysis made by Halcrow concluded that traditional options and formal flood defences or upstream storage areas would not be cost-effective (Halcrow 2006). The report acknowledged that upland catchment management – typically in the form of afforestation, farmland buffer strips, localised storage and management of grazing and cropping patterns – could be a possible solution to the flooding problem at Belford. However, the report pointed out the difficulty in assessing the level of protection from such measures and that such schemes can only be regarded as experimental at present.

Following the pre-feasibility study by Halcrow, the Environment Agency funded the application of an upland catchment management programme. This followed early evidence gathered as part of a research project at Nafferton Farm, where corner of field ponds and ditch management were used to mitigate against high flows. The approach presented in the 'proactive' study was to install passive intervention on farms to mitigate against large amounts of run-off (Quinn et al. 2007).

Belford's upland catchment management programme began in September 2008 and has involved the construction of approximately 45 individual mitigation features (Figure 3 and **Error! Not a valid bookmark self-reference.**) in the form of small storage features, ditch management, large woody debris, soil bunds installed across fast run-off pathways and some bespoke designs tested during the study. These became known collectively as 'run-off attenuation features' (Wilkinson et al. 2010).

Table 1: RAFs in the Belford catchment by type

Offtake structures:

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Leaky timber barriers:

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Offline storage areas:

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Soil bunds and outflow pipes:

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Wooden screens:

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Large woody debris:

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Flow controls (adjustable sluices and penstocks):

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Source: Wilkinson et al. (2010), Nicholson et al. (2012)

An RAF is defined as a man-made landscape intervention that intercepts and attenuates a hydrological flow pathway to provide multiple benefits, including flood management and improving water quality. Put simply, the design philosophy is to create features that 'slow, store and filter' run-off in the rural landscape. Important design attributes of RAFs are that they:

- are easily accommodated in the landscape
- do not have a significant impact on farming
- are typically small in size (500–1,000m^2) or are located within a ditch or small stream channel
- are designed to be an extension of the farming and land drainage scheme drainage regime (that is, they must not be viewed solely as flood engineering projects)
- potentially provide multipurpose benefits, for example, in terms of nutrient transport (Barber and Quinn 2012, Wilkinson et al. 2014)

Rationale

For RAFs, the magnitude and duration of the flood peak has a huge impact on the type of intervention required. The desired impact of the RAFs should be determined at an early stage in a project, so that it becomes possible to identify what magnitude of storm they are being designed to attenuate. The greater the flow magnitude, the higher chance a particular RAF will have of filling during a storm event. It has been identified, through analyses, that single RAFs (~500m^3 capacity) will have piecemeal impact on the flood hydrograph during high magnitude events, which is why RAFs must work as a collective unit (or network) during these large events to have significant impact.

Figure 10 demonstrates the rationale behind the Belford RAF approach using a hydrograph and rainfall for a large winter event (March 2010) (Nicholson et al. 2012). The discharge is expressed as flow per unit area (mm/hour) to allow direct comparison against the rainfall. The signature of the rainfall is clearly present in the hydrograph shape, indicating a rapid response. During the early part of the storm the rainfall intensity approaches 4mm/hour, with the discharge 1mm/hour, indicating significant antecedent catchment storage. This contrasts with the response at the time of the main peak when discharge (4.5mm/hour) is marginally lower than rainfall (5mm/hour), indicating that storage has been depleted and overland flow is generated. This was verified from walkover surveys during large events.

The horizontal dashed line in Figure 10 corresponds to the rate of discharge at which historic flooding has occurred in Belford. The volume of run-off above this line is approximately 20,000m³ over a duration of 4 hours (calculated by multiplying the rainfall depth and catchment area, 5.7km², by the number of hours and converting into m³). This simple analysis has been performed to provide an approximate guide to the volume of flow that would need to be managed to reduce flood hazard in the downstream settlement of Belford for this event. In interpreting such an analysis, caution is necessary.

- The amount of flood management required will depend on the magnitude of the flood peak and the duration above the desired level of protection.
- The flood management interventions need to be active at the time of the flood peak (Nicholson et al. 2012).
- Attenuation effects (for example, due to large woody debris) need to be considered carefully; attenuation and storage work together.

During extreme events, the drainage network expands with ephemeral flow pathways generated by overland flow linking fields and hillslopes to the ditch and stream network. The RAF approach advocates targeting this expanded drainage network through the installation of features that attenuate and store run-off.

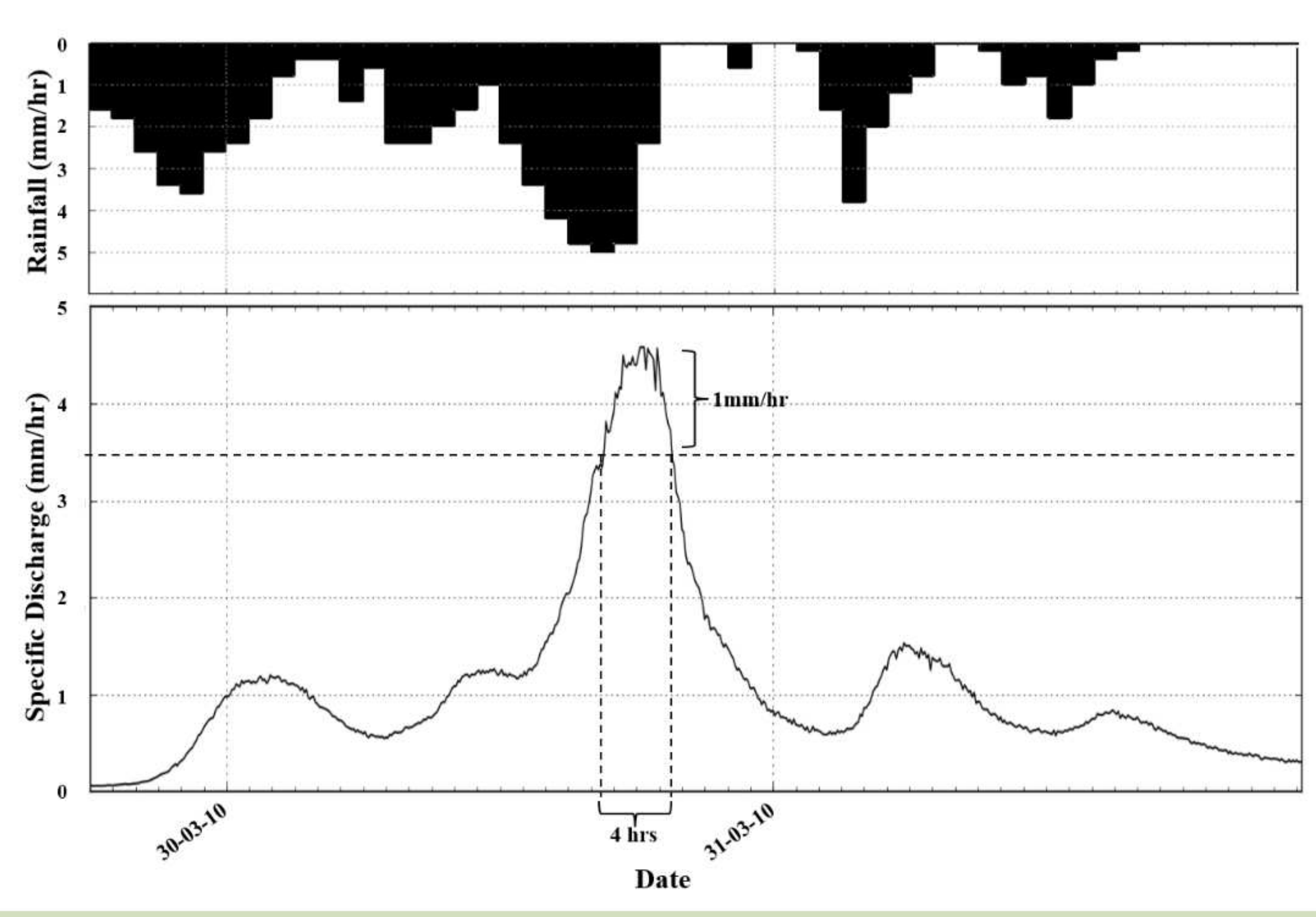

Figure 10: Storm event in March 2010 – demonstrating the need to target key components of flow

Project summary	
Area of catchment (km^2) or length of river benefitting from the project:	5.7km^2
Types of measures/interventions used (Working with Natural Processes and traditional):	Soft engineered structures: RAFs in the form of: • corner of field ponds and overland flow disconnection • flow diversion structures • leaky dams • offline floodplain storage • online ditch management features • wooden screens • large woody debris dams
Numbers of measures/interventions used (Working with Natural Processes and traditional):	45
Standard of protection for project as a whole:	Currently unknown The rationale of the Belford scheme was to install enough additional storage in the catchment to mitigate flow above the flooding threshold up to the 1 in 100 year event. The target storage was ~20,000m^3. The total estimated 'new' storage provided by the scheme is ~12,000m^3. Aside from storage, other attenuation effects may be present (as revealed by the 2D hydraulic modelling), though these are more difficult to quantify.
Estimated number of properties protected:	To some degree, all 54 properties in Belford will have a better standard of protection with the upstream RAFs in place. Certainly the 25 properties originally at risk from the 1 in 2 year event have been provided better protection.

How effective has the project been?

Monitored evidence from Belford RAFs shows the impact of individual features during a range of storm events. Modelling hypothetical networks of RAFs shows the potential for the RAF approach within the Belford catchment. Trialling different modelling techniques has demonstrated high levels of confidence in the RAF approach.

From a landowner and community engagement perspective, the project has been hugely successful. Belford flooded 7 times between 1997 and 2007. Since the project reached 35 constructed RAFs (amounting to ~8,000m^3 storage), only one property has been affected by flooding. There is now a total of 45 RAFs, amounting to ~12,000m^3 storage.

5. Project construction

How were individual measures constructed?

Table 2 shows some photographs taken during the construction of a selection of RAFs in Belford:

- soil bunds constructed using excavator
- 150–300mm diameter pipes installed within the bank structure
- rip-rap used inside inlet structures and downstream of outlet pipes

- large woody debris dams constructed by felling sycamore trees (within a short distance of the watercourse) and interlocking them across the full width of the channel
- leaky dams constructed using piled timber beams with small gaps (~5mm)
- laterally braced with timber beams for additional support

Table 2: Belford RAFs during construction

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How long were measures designed to last?

This varies.

Large woody debris dams are expected to degrade between 5 and 15 years, with adaptive management to involve total replacement of the structure if degradation is severe.

Leaky dams made of untreated hardwood are designed to last between 20 and 30 years, but this will depend on location. Exposure to fluctuating conditions of moisture and waterlogging (more than once every storm event) may shorten the lifespan of structures.

Soil bunds made from compacted soil are designed to last indefinitely if vegetated. Their lifespan will depend on how often they fill and empty during flood conditions, how well they are maintained, and whether overflow structures and mini spillways are adequately incorporated into the design. Overflow of the structure should be made through a control structure (that is, a low point of the structure designed to overtop) and protected with rip-rap to ensure minimal scour during storm events. Inlet structures and outflow pipes should also be protected using rip-rap to ensure minimal scour at the structures.

Outflow pipes should initially be oversized. Flow controls (for example, sluice gates or penstocks – see

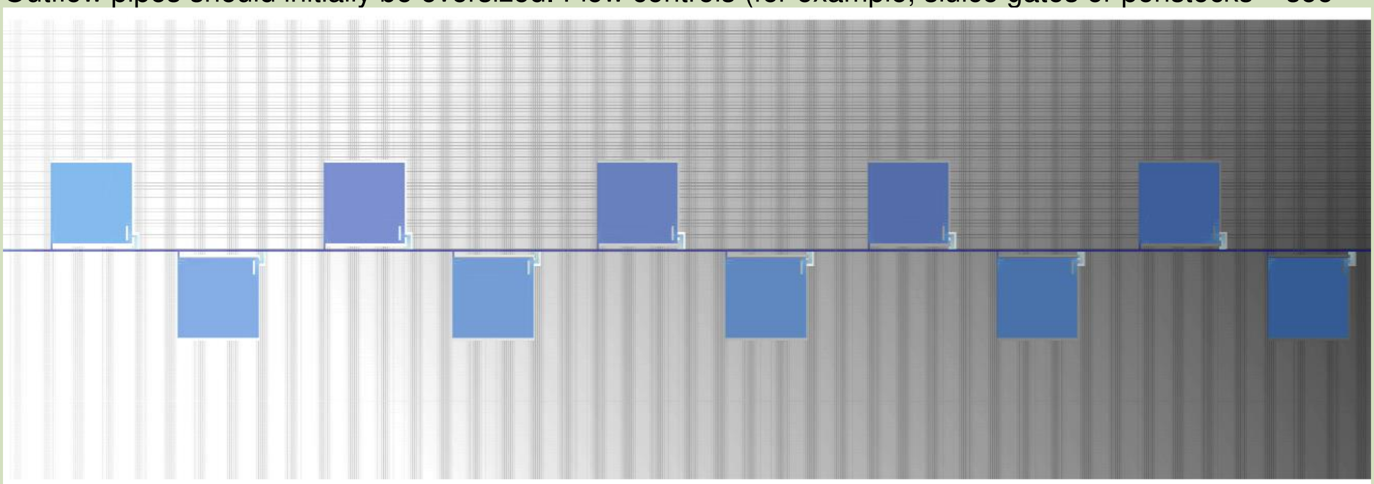
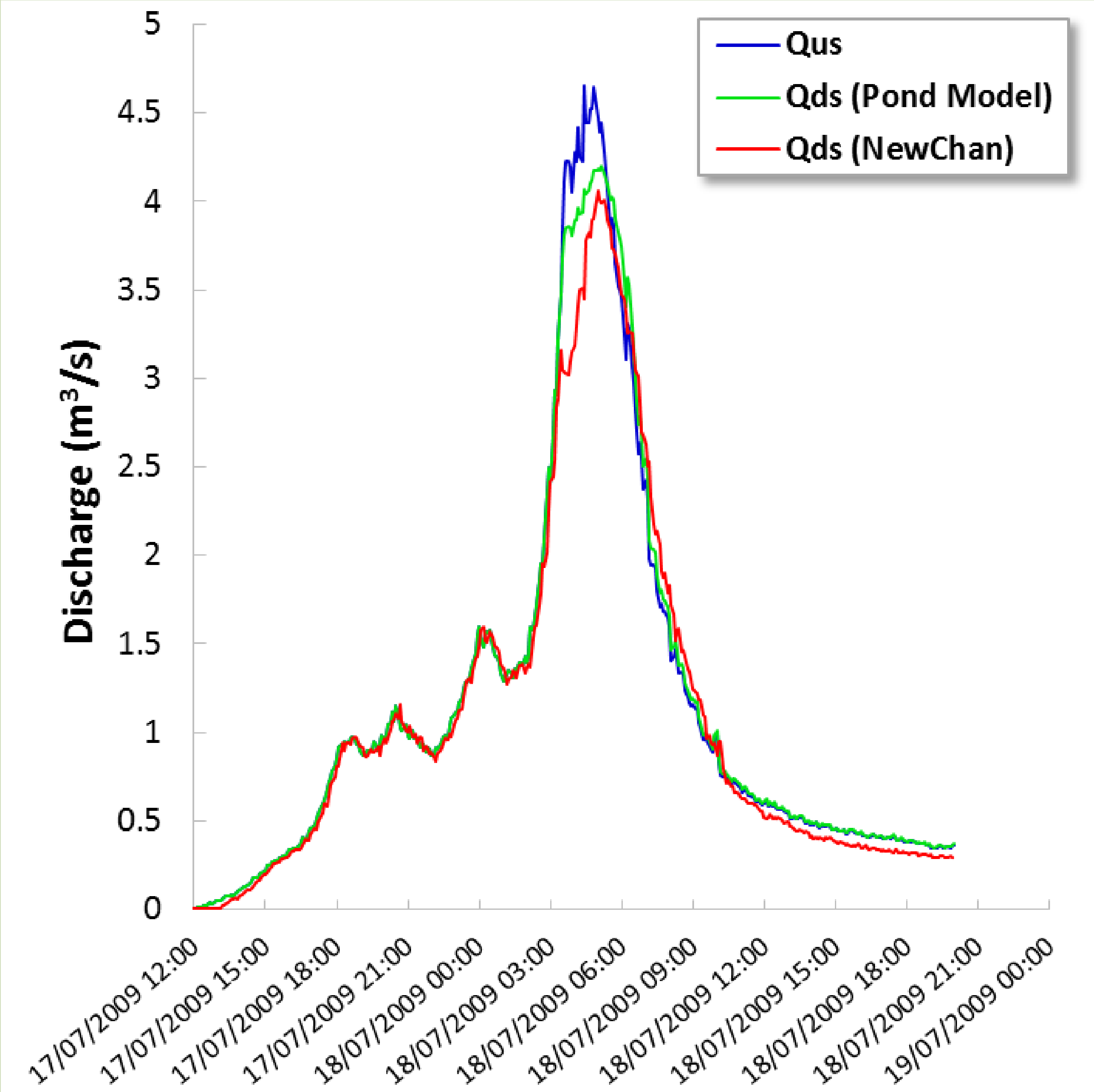


Figure 7: NewChan output for 10 RAFs during July 2009 storm event



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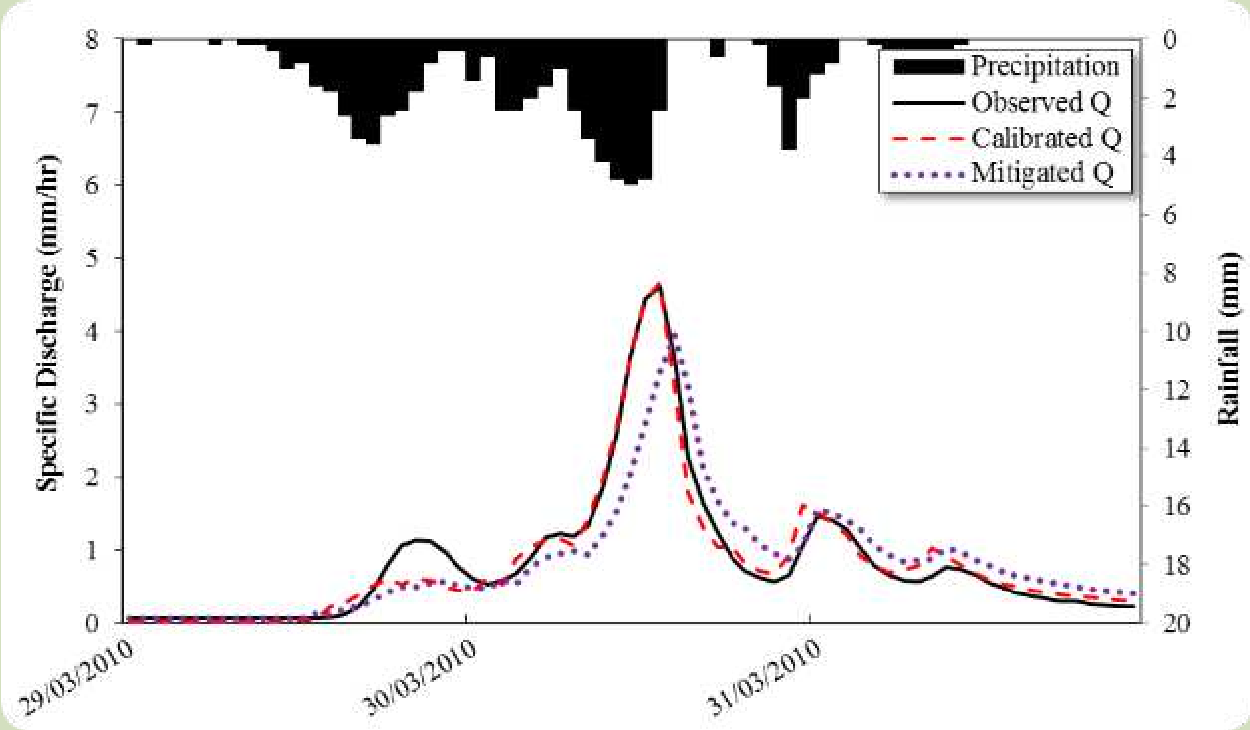

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Table **1**) can be easily retrofitted to pipes should the orifice need reducing in size. Laying a larger diameter pipe through a soil bund is much more onerous.

Were there any landowner or legal requirements which needed consideration?

The nature of the flood storage had to be discussed with regulators. The Reservoirs Act was in a period of flux, meaning the threshold level could potentially drop from 25,000m³ to 10,000m³. The project team had to demonstrate that there was no potential for cascade from RAFs failing in multiple locations in the catchment at the same time. This is good practice to consider. It is also worth thinking how a storage feature could fail and what the impact could be.

Landowner consultation was crucial to progressing the NFM scheme. Once initial agreements were in place, Newcastle University collated a long list of RAF options and locations. The options were discussed with the Environment Agency to ensure the correct regulations were considered before being passed to the landowner for final approval. In many cases, the designs were reached iteratively by combining the desires of the landowners, regulatory requirements and the overall outcomes of the project. This open relationship ensured swift project development.

6. Funding

Funding summary for Working with Natural Processes (WWNP)/Natural Flood Management (NFM) measures	
Year project was undertaken/completed:	2007 to 2015
How was the project funded:	Local Levy funding from North East RFCC Flood risk PhD study 80% funded by EPSRC through FRMRC2 research programme Water quality and sediment transport PhD study funded by EPSRC
Total cash cost of project (£):	£450,000
Overall cost and cost breakdown for WWNP/NFM measures (£):	£450,000
WWNP/NFM costs as a % of overall project costs:	100% including consultancy and research costs and part of PhD funding
Unit breakdown of costs for WWNP/NFM measures:	Overland flow interception: £500–£5,000 Online ditch features: £1,000–£3,000 Offline ponds: £2,000–£6,000 Large woody debris: £100–£3,000 Opportunistic RAF sites: £1,000–£10,000
Cost–benefit ratio (and timescale in years over which it has been estimated):	

7. Wider benefits

What wider benefits has the project achieved?

Wider benefits include:

- water quality restoration – through sediment retention (Figure 11 and Figure 12)
- reduced nutrient concentration (see Palmer 2012, Barber, 2013)
- habitat creation – through woodland planting

Figure 11: Fine sediment collected in offline storage RAF

Figure 12: Sediment captured in overland flow RAF. Approximately one tonne of sediment was captured in a single event in January 2010.

How much habitat has been created, improved or restored?

New woodland planting in the riparian area replaced sycamore trees, which were felled to create the large woody debris dams, with lower growing native tree species. The trees do not have large canopies and allow more light to enter the woodland, which enables a greater amount of vegetation to develop on the woodland floor. Apart from helping create greater floodplain roughness during periods of spate, the vegetation provides a richer habitat to small mammals and birds. Great crested newt habitat was restored in one online RAF in particular.

Are maintenance activities planned?

The Environment Agency is currently maintaining all the features at Belford with the exception of large woody debris, which it has have identified as a replaceable asset (once it degrades).

Is the project being monitored?

Monitoring of the Belford Burn began in 2007 and for the first RAFs in 2008. By summer 2012, the project had 5 river gauges on a 5-minute time series, 1 river gauge on 15-minute time series, 3 tipping bucket rain gauges, 2 barometers and 8 stage gauges inside RAFs all on 5-minute time series. Although intensive monitoring ended in early 2013, an Environment Agency rain gauge and gauging station remain in the catchment.

Has adaptive management been needed?

See above. The Environment Agency is currently managing the maintenance of the Belford NFM features. Large woody debris features have degraded and will continue to degrade over time. One of the dams has moved from its original position. The management plan for these dams is to replace them entirely once they degrade. In addition, care is required when storing water above subsurface field (tile) drains as this can lead to pressure build-up and rupture of the subsurface field drain.

8. Lessons learnt

What was learnt and how could it be applied elsewhere?

Over the project life time many lessons have been learnt with respect to delivering a NFM project that considers multiple benefits. This work led to the formation of a framework for managing run-off and pollution in the rural landscape using the Catchment Systems Engineering approach (see Wilkinson et al. 2014).

A framework for applying a Catchment Systems Engineering approach to the catchment is shown in a step by step guide to implementing mitigation measures in the Belford Burn catchment (Figure 13). The framework is based around engagement with catchment stakeholders and uses evidence arising from field science (Wilkinson et al. 2014). Good community engagement was essential for the successful implementation of the project. However, the framework shows that measures can be modified if necessary to provide a wider range of ecosystems services.

Lessons learnt from Belford were communicated to stakeholders in Aberdeenshire using approaches in the framework shown in Figure 13. This led to the construction of overland flow disconnection bunds by farmers in that area.

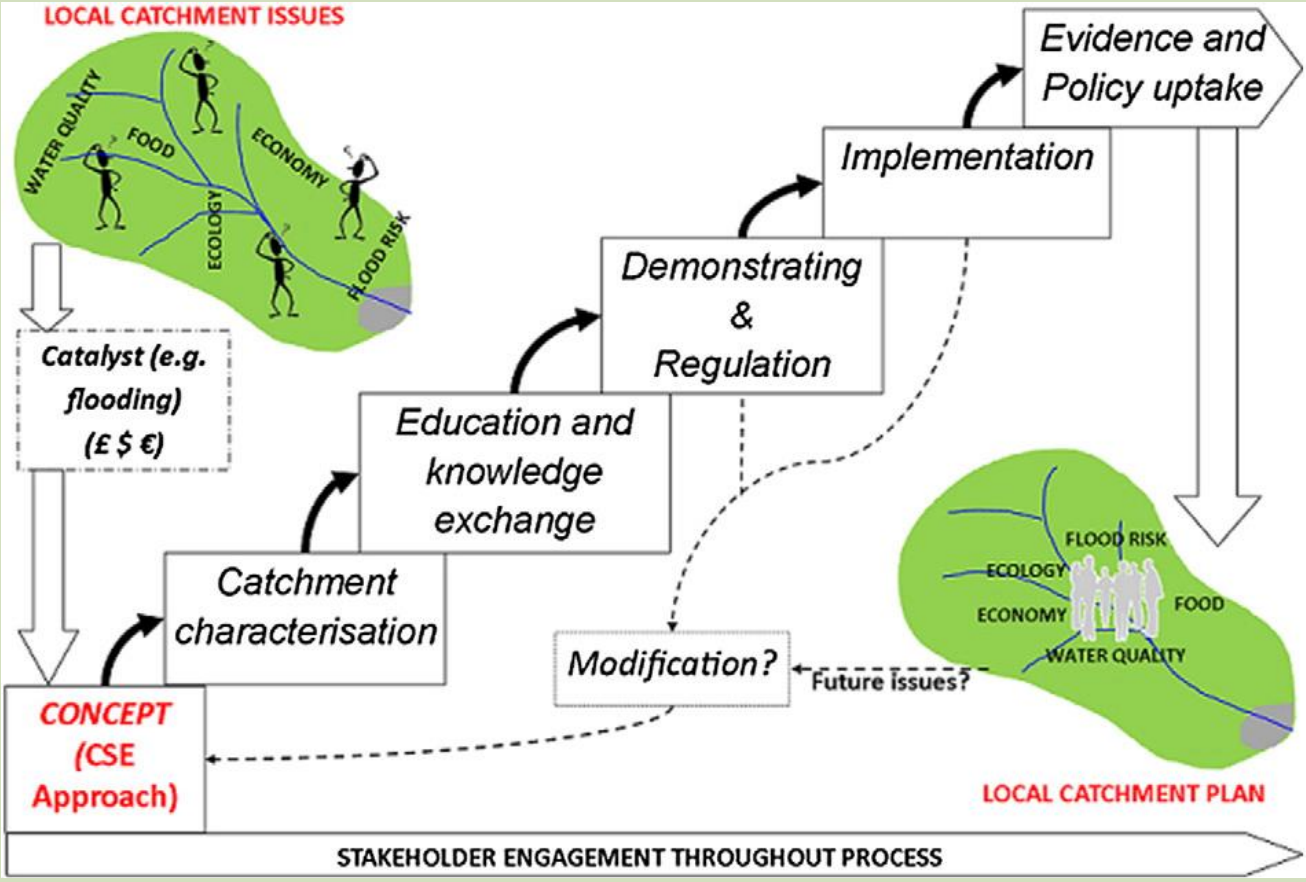

Figure 13: Run-off management framework developed for Belford Burn catchment (Wilkinson et al. 2014).

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Project background

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