Belford catchment proactive flood solutions: storing and attenuating runoff on farms

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Abstract

The Belford pilot pond study is the first part of a series of Farm Integrated Runoff Management (FIRM) plans (http://www.ncl.ac.uk/iq/Proactive/FIRM.html) to be implemented across the Belford catchment (funded by the Environment Agency). Agricultural runoff enters the Belford Burn which then flows through the village of Belford (6 km^2), Northumberland. Numerous houses in Belford, are at flood risk and traditional flood defence measures are not considered to be cost-effective. This paper presents the hydrological characteristics of the catchment, the design and building of pilot ponds, and initial results from the effect of the pilot pond on high stream flow. Stakeholder meetings helped to produce a catchment flood plan using a range of runoff storage features, attenuation zones and flow control structures. The overall goal of the project is to protect Belford from flooding by storing and attenuating high flows on farmland with a minimal impact on farm economics.

Introduction

The risk from flooding continues to be of concern to people, properties and infrastructure. There is reason to suggest that our climate is changing to produce more intense and prolonged rainfall events. The estimation of future flood risk is difficult due to future uncertainties. However, all climate scenarios point to substantial increases (Foresight 2007). Increasing demand for buildings for homes and businesses means that developers will build not only on new land outside the city but also on hazard zones such as flood plains and reclaimed land from coasts and estuaries. This has the potential to increase flood risk. According to the Environment Agency (EA), 10% of the UK population lives on natural floodplains. It is estimated that 1.8 million homes, 130 000 commercial properties and 14 000 km^2 of agricultural land (12% of the total) are at risk from flooding. For example, the floods that occurred in the summer (June–July) 2007 caused flooding to over 55 000 homes and businesses across the UK. The EA (2007) estimate that the human impact is difficult to measure but insured losses are approaching £3 billion. These were the most costly floods ever to occur in the UK.

A common way to protect urban areas from flooding is to build flood defences at the area of concern. This technique has been applied to many urban areas to great success. However, if flood risk estimates are correct and we are to see more intense rainfall events, such as the summer of 2007, then it is likely that our flood defences will need to be improved to cope with larger return period floods. This could be a costly process for most urban areas or in some cases, impossible to do as there is no room to improve defences due to a shortage of land. Therefore it is likely that different flood storage strategies need to be considered. One such flood risk management strategy is presented, along with its current application to a small rural catchment. Farm Integrated Runoff Management (FIRM) plans (http://www.ncl.ac.uk/iq/Proactive/FIRM.html) are committed to the concept of the storage, slowing, filtering and infiltration of runoff on farms at source. This is believed to be practical, achievable and could easily be funded by the strategic investment of agri-environment and flood mitigation funding. The best place to control runoff is at source and within hours of the runoff generation. These spatial and temporal windows of opportunity are not being fully exploited in environmental management.

Study area

The Belford Burn catchment (Figure 1), North Northumberland, is a small, predominately rural catchment which flows through the village of Belford. The catchment area to the village of Belford is 5.7 km^2. After Belford, Belford Burn flows under the A1 and the East Coast Railway Mainline. These are two very important transport routes that link the north and south of the UK. Belford burn discharges into Budle bay, North Sea (a total catchment area of 28.7 km^2). Budle Bay is an important nature reserve to wading birds.

At the start of this project there was no hydrometry present within this catchment. Recently, as a response to flooding issues, the Environment Agency has installed a telemetered gauging station (for flood warning purposes) in the village of Belford. This station is defined in this study as the catchment outlet. The Environment Agency

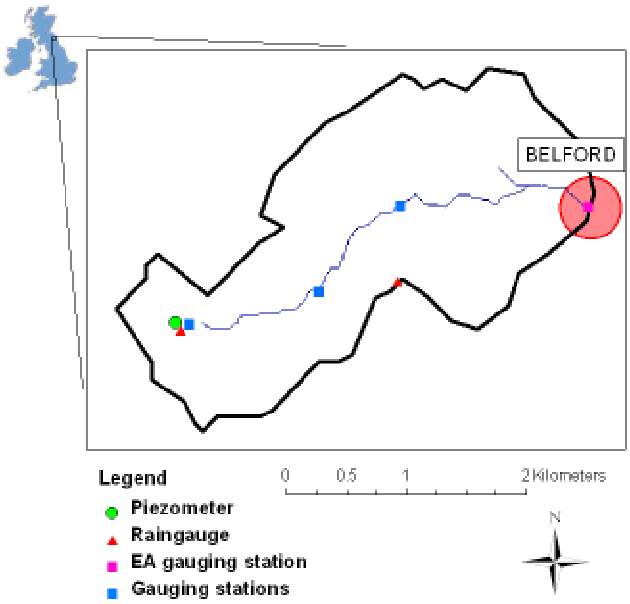

Figure 1 *The upper Belford burn catchment (5.7km²) and instrumentation*

also installed a tipping bucket raingauge at a nearby farm (telemetered) to help with flood warning predictions. Alongside this, Newcastle University have installed another raingauge and three flow gauging stations. Data from these sub-catchments will help to understand the impact the features are having on the flood peak hydrograph.

The Top Field, Pheasant Wood and Wood Outlet catchments are 0.74 km^2, 1.46 km^2 and 2.58 km^2 respectively, in area. Land use within the Top Field catchment is pasture grazing and a small area of rough moorland. The Pheasant Wood catchment has similar land use. The Wood Outlet catchment also is grazed pasture but includes a large wood area. The area downstream of this station to Belford is predominantly hay meadow and intense arable cropping. Three farmers manage most of the agricultural land within the upper Belford Burn catchment. The yearly average catchment rainfall for Belford is 695 mm. The geology of the catchment is somewhat complex. The top of the catchment is characterised by Fell Sandstone, the mid and lower parts of the catchment are dominated by Tyne Limestone and Alston formations. An intrusion of Oxford Limestone occurs through the middle of the catchment (between the Pheasant Feeder and Wood Outlet catchments). A small band of Great Whin Sill can be located to the north of the village at the outlet of the catchment. The Dunkeswick soil series (typically stagnogley soils with a fine loamy topsoil and clayey subsurface horizons) (Soil Survey of England and Wales, 1984) covers the catchment study area. This type of soil is prone to waterlogging in winter and local farmers have commented on runoff occurring during heavy rainfall events.

Flooding in Belford

There has been a long history of flooding in Belford. In the past 15 years there have been numerous flood events within the village and affecting the A1 and railway transport infrastructure nearby. Some examples are as follows: On the 1st July 1997, the East Coast railway mainline had to be temporarily shut down due to flooding. A few years later in October 2002, West Street and the Bluebell Farm caravan park were flooded from the nearby Burn. Flood events have also occurred in the same areas on January 2005 and recently, in July 2007, when surface water runoff from the B6349 road ponded in the village due to blocked drains. There are estimated to be 35 properties at risk within the revised Indicative Floodplain within the West Street and Burnside areas of Belford (Environment Agency, 2003).

Farm Integrated Runoff Management plans – “slow, filter and store runoff at source”

Farm Integrated Runoff Management (FIRM) Plans are at the heart of the PROACTIVE approach (www.ncl.ac.uk/iq). The PROACTIVE approach (Quinn *et al.,* 2007) is committed to:

- Changing land use management in order to mitigate a range of environmental problems at demonstration farms at full scale, in partnership with stakeholders;
- Instrumenting and quantifying processes on small research catchments that are undergoing land use management change;
- Creating multi-functional, economically viable land units by combining pollution, flooding, waste recycling and renewable energy/ carbon into a common integrated framework;
- Producing decision-support tools and modelling frameworks that support catchment management and policy making.

Following the *proactive* approach, FIRM plans would be used to propose active intervention on most farms to store and slow down large amounts of runoff, that is, at source, within hours of the flow being generated. The features recommended have multiple purposes, as they can address nutrient pollution problems, help trap and recycle waste (sediments and nutrients) and can benefit ecology and contribute to carbon storage (see the *Proactive approach to FIRM plans for nutrients* report, Quinn *et al*., 2008). However, the target would be on small man-made ditches and channels on farms. These locations offer many kilometres of low grade ditches that can be engineered without damaging existing conservation and ecological factors (as might exist on a larger river). If a typical farm or small catchment can sacrifice 5–10% of the landscape to runoff storage and mitigation features then the properties of the runoff regime can be radically altered.

Ponds, bunds, wetlands, buffer strip and flow control structures have all been designed, constructed and tested at Nafferton farm in Northumberland. All features not only reduce flood risk but are multi-functional in that they address pollution reduction, trap and recycle waste, use recycled material and create new ecological zones.

FIRM Plans propose:

- a small pond in every field, to slow flow and capture sediment and phosphorus;

- flow control structures within ditches;
- wetlands and sediment traps in ditches
- buffer strips that are put to effective work, for example willow strips;
- bunds and gutters to control flow across the farm.

The design of the feature is important. The size, location, materials and vegetation used in the proposed features are the key to the practical, economical implementation and maintenance of FIRM plans. Solid evidence and experience to support FIRM plans has been gained at Nafferton Farm. The message is simple but achievable: INTERCEPT, STORE, SLOW and FILTER runoff during storm events, using strategically placed soft engineered features.

FIRM plans application on Belford Burn catchment

A common flood defence strategy that could be deployed in Belford is to build flood defences next to the stream within the village. This plan could not work in Belford due to the shortage of space between the channel and the nearby houses (Figure 2). Therefore, another flood management strategy was needed. The PROACTIVE team at Newcastle University were approached by the Environment Agency with regards to upscaling the FIRM plans produced for Nafferton for the upper Belford catchment. The FIRM plan implementation is part of the overall flood risk management plan for Belford by helping to protect Belford from flooding through storing and attenuating high flows in the rural upstream area.

An important part of this work is interaction with the local community about the work being carried out. As this is a novel flood risk management plan, it is important to get feedback from the stakeholders who will be affected by the FIRM plans. It is important that the three farmers within the catchment co-operate with the FIRM plan ideology. However, FIRM plans do not want to disrupt the normal farming activity. Other work includes culvert widening in the village and some minor flood defences near the caravan park. This is all part of a £600 000 scheme running over three years in which a collaborative agreement has been set up between the Environment Agency and Newcastle University. The project is currently in its second year.

Figure 2 *Belford Burn flowing through Belford. The channel is constricted between properties.*

The first step of the FIRM for the catchment was to install hydrometry to understand the local hydrology of the catchment and also to get a baseline period of data. A pilot pond was proposed at the top of the catchment, initially to demonstrate how FIRM plans will work in the catchment. It is important to have a demonstration pond so that local stakeholders (Farmers, EA, villagers, etc.) can come and understand how FIRM plans will work within their catchment. The pilot pond is an example of one mitigation strategy that can be applied to the catchment. The pilot study will be a highly visual demonstration of what is likely to occur throughout the catchment in the future. The flow attenuation features will serve three key purposes:

(1) To show how flow can be stored within catchments.
(2) To familiarise the community on the approach to be taken.
(3) To gain practical experience of controlling flows within this catchment on agricultural land.

Numerous factors will then be open for discussion with the stakeholder community, including:

- The size of flow barriers
- The material chosen for the barriers
- Who would be best suited to build and maintain the feature
- How much land would be lost to the FIRM plan
- Where would any further washland be situated
- How a viable compensation / incentive scheme for farmers will operate
- Broader dissemination of the approach using a Decision Support Tool (DST), e.g. The Floods and Agriculture Risk Matrix (FARM) tool.

The pilot pond

The pilot pond is located at the top of the catchment. The pilot pond site was mapped using GIS. The Bowden field near Bowden Crags offers a great opportunity to show that any natural hollow/swale in the landscape could be used to hold flood water. The site probably already slows and stores some flow, but with the addition of a small retaining structure, will hold substantially more. Flow into the structure will arise from within the field and extra flow can be forced from the nearby channel. The site is already very boggy and the area is heavily poached by farm animals seeking shelter from the weather. This poaching causes the soil to become degraded and it may be contributing some sediment and nutrient pollution to the Burn. Hence, all FIRM plans try to address water quality and ecology at the same time.

Figure 3 is a picture of the field to be used. A natural swale in the landscape by the forest plantation has been chosen. Flow in the ditch indicated at Site A, will be forced under higher flow to spill into a small trench and enter the field. A soil bund will deliver flow to the end of the pond. The average flow in the ditch will be allowed to

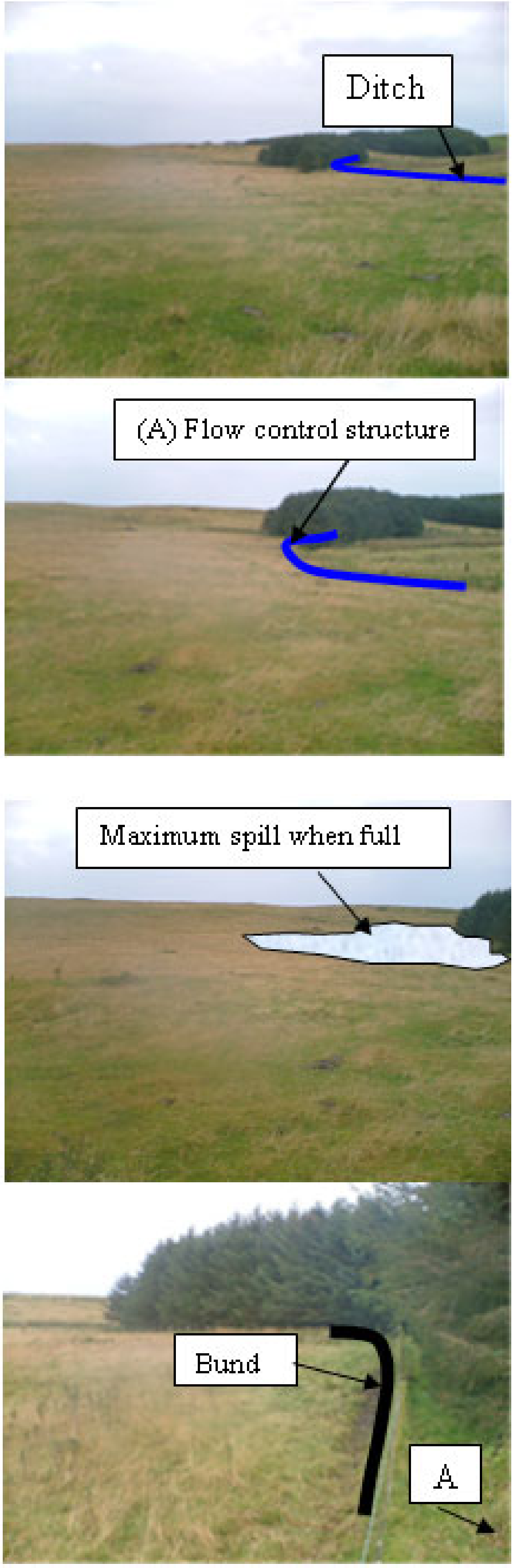

Figure 3 *The Bowden field as we approach the site moving downhill. The ditch is indicated in blue. Site A is where the ditch structure will be built. The black line will be the position of a soil bund.*

pass through the barrier.

In essence, the soil bund will deliver flow to the pond. The main retaining structure for the flow will be a vertical timber barrier (see Figure 4), constructed from sustainably sourced green oak.

The height chosen for the barrier will be 1 m at its deepest point. A height of 1.5 m was considered and such a feature is possible. However, little extra stored volume would be achieved from raising the barrier by 50 cm but would increase the cost. The barrier is designed to leak, and the pond should start to fill in most storms. If the pond fills too frequently, the leakiness of the barrier can be increased. This will form part the next year's study. The choice to use treated wood as the best material was based on several considerations:

- The material will be sourced from sustainable material.
- A soil bund if constructed to a height of 1 m will in fact occupy up to 6 m of the pond area and will lose a significant amount of the storage capacity.
- A wish to demonstrate that we are willing to consider design options other than soil bunds.
- Soil bunds would need to be fenced off as animals will erode the top surface.
- Soil bunds and their maintenance may be perceived to be less important than a timber barrier. It is important to stress to the farmers that the structure, though empty for most of the time, is a vital, engineered feature serving an important purpose.

It is envisaged that soils bunds (or scrapes) will be used throughout the catchment as part of the runoff management plan; as a result, a stretch of bund has been included in the pilot study design. The total length of green oak (including a small section in the ditch) will be 100 m (Figure 4). The catchment area draining to the in-stream leaky barrier, where the ditch enters wood, is approximately 0.74 km^2 (top field catchment). This area would generate 740 m^3 of flow for every 1mm of runoff generated (rainfall depth equivalent). Hence, 10 mm of runoff would require 7400 m^3 storage. Detailed considerations of the flow conditions under which the

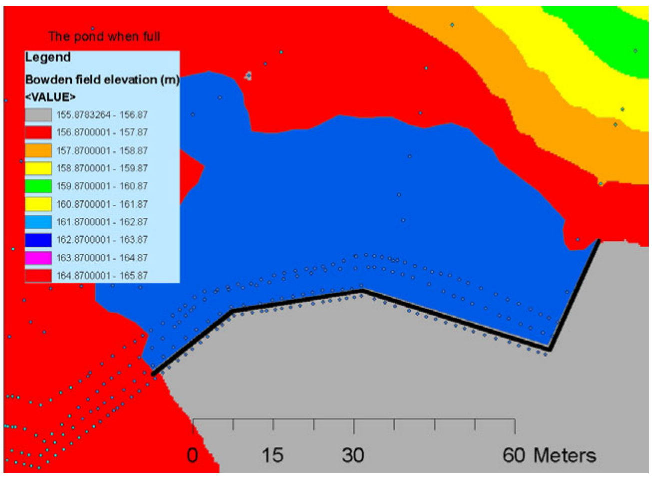

Figure 4 *The path of the 1 m tall green oak barrier on a GIS elevation raster. The blue area is the area of the pond when full.*

pond will fill must determined over the next year as part of the rainfall–runoff study. This option is referred to as the 'off-line' option, with a timber wall along the fence line, tapering out into pasture.

The volume for the off-line option, if assumed equivalent dimensions of 60×20 m rectangular pond with a mean depth approximately 0.5m, would store 600 m^3, which is a conservative estimate. Analysis from ArcGIS (allowing for some interpolation error and the assumption of an average depth of 0.5 m) gives ~800 m^3 of storage. The costs of materials and construction of this pond come to around £20 k (this includes a high detail survey of the area and the technique; other similar ponds will cost significantly less). The pond will store approximately 3 mm of runoff for 0.74 km^2. A further slowing / attenuation of the flow will also be occurring, so a 'transient' storage effect will also be in operation. Storm events do not occur instantaneously, so the routing for the storm events must also be considered. Although the total storage may seem small, it must be remembered that the pilot pond is meant to be a modest visual demonstration site. This pond is the first of what is hoped to be 20–40 runoff control features within the catchment.

Figure 5 *The wooden barrier at the bottom of the pond as it tapers out towards the hillside (to the left)*

Flow data is still being collected from the top field gauging station which is located 20 m below the leaky barrier. It is hoped this station will record how effectively the leaky barrier is working in high flows.

To date, there have been no flood events in the catchment since the pilot pond has been constructed. Therefore no data are available to show how well the feature is working. Figure 5 shows the wooden barrier at the bottom of the pilot pond.

Other features

The pilot pond is serving as a good demonstration site to the local community. It has helped to show farmers in the catchment how FIRM plans work. Other sites are currently being constructed.

These sites vary in type, material used in construction and cost. An example series of features is presented in Figure 6. This diagram displays how a series of runoff storage features, attenuation zones and flow control structures can aid in reducing the flood peak and increasing the lag time of a flood. Figure 6 also shows benefits to water quality by creating wetland zones and trapping sediment. New temporary ecological zones are also created.

The simplest feature planned to be constructed shortly in Belford are corner of field storage ponds (Figure 6). These ponds are designed to capture overland flow, disconnecting fast flow paths from the stream. These ponds are designed to be leaky so they do not hold water after the flood wave has passed. This makes them more effective storage units for the next flood wave but also means the farmer does not lose productivity of his land if it is a grazing pasture. A selected few of these ponds, primarily on arable land, are designed to hold a small amount of water. This is to promote a wetland area to encourage ecological biodiversity. Most of these types of

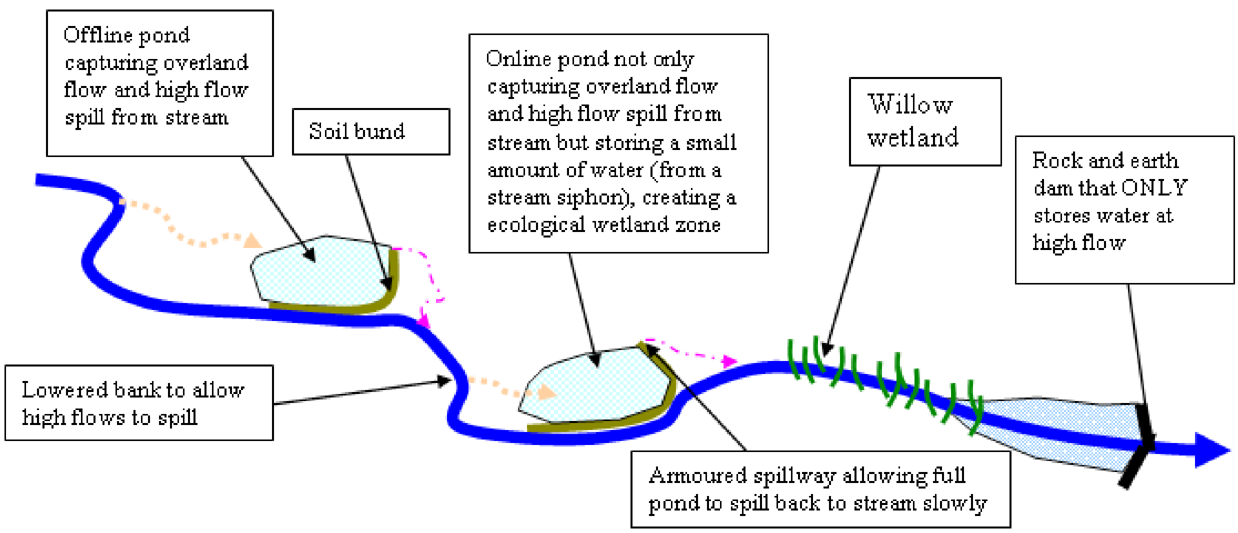

Figure 6 *A diagram of a series of flow attenuation features being planned at one site in the Belford catchment (trial site 2)*

pond will be constructed using a soil bund (around a stone core if the bund is large). The soil will be either from scrapes or sourced from other parts of the farm. In some areas, scraping cannot be performed due to a thin top soil which will damage the field's productivity and soil may need to be sourced elsewhere. These features, if located next to a stream, can also be adapted to take water from the stream in high flow. Water can enter into the pond by lowering of the stream bank upstream of the pond. It is important to understand that the most effective way of reducing the flood peak is to get the flood peak out of the stream and to store flow in a pond (thus attenuating the peak).

Slowing the flow in the stream is another idea proposed in the FIRM plans for Belford, for example through the modification of a small existing dam within Belford Burn to store only flood peaks (Figure 6). At low flows this would act as a wetland and also helps to improve water quality within the stream. A small 1.2 m dam will store 500 m^3 of flow. However, installation of in-stream features requires more consent from the Environment Agency. This process can take some time and therefore creating in-stream features does take longer. A willow wetland planted upstream of this dam will also help to slow the flow, breaking up the flow's energy. A woody debris network is planned to be installed within the wood that Belford Burn flows through.

The ponds will also strive to take water from problematic areas. This includes removing surface runoff from the roads (which has been identified as a factor in flooding in Belford) and diverting this into ponds. These features do not just help to attenuate the flood peak, they are multi-purpose,as has been demonstrated at Nafferton Farm where these features improve water quality, reduce sediment load and promote biodiversity (see Quinn *et al.,* 2007:2008). A bird survey is being conducted by Newcastle University's Ecology department during the lifetime of this project to see the influence on bird populations and, likewise, a water quality station is also being installed in Belford.

Public consultation and uptake: the FARM tool

Community meetings are scheduled to take place in Belford over the next few years to understand how the community feel about this project. An important part of this will be how the farmers take on board the FIRM plans proposed. A tool developed by Newcastle University called the FARM tool will be trailed at these meetings (www.ceg.ncl.ac.uk/thefarm). This tool will help farmers and other landowners to identify the risk of runoff generation on their land and the mitigation strategies available to them. In the FARM tool matrix, there are two axes reflecting the dominant factors that affect runoff:

(1) Soil storage factors (including infiltration and tillage regime)
(2) Flow connectivity (based on the prevailing hillslope hydrology)

It is hoped that using this tool alongside the FIRM plans will help with the uptake of FIRM plans with farmers across the UK.

Conclusions

Belford Burn flows through the large village of Belford. There have been numerous cases of flooding in the village and a flood risk management plan is needed. Conventional flood defence strategies are not applicable to Belford so a new way of thinking is needed to protect Belford from flooding. The EA and Newcastle University are implementing FIRM plans within the Belford catchment. The philosophy behind FIRM is to INTERCEPT, STORE, SLOW and FILTER runoff during storm events, using strategically placed engineered features. A range of different types of feature has been proposed. A pilot pond has helped in the community uptake of this project. It is hoped that 20–40 runoff control features will be constructed over the next two years. These features will be especially important in trapping sediment, tackling water quality issues and creating new ecological zones. Using the FARM tool and public engagement meetings, it is hoped farmers will take a 'hands-on' approach to the FIRM plan ideology. FIRM plans could be upscaled further if the cost for the installations was available from Agri-environment schemes.

Acknowledgements

We thank the Environment Agency (especially Peter Kerr) for funding FIRM plans in the Belford catchment and Ian Benson of Ian Benson, Build and Design, for site expertise and construction of the pilot pond.

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