Runoff management: Mitigation measures for disconnecting flow pathways in the Belford Burn catchment to reduce flood risk

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Abstract

Evidence that intensive farming leads to increased runoff rates has been established. Fast, well connected flow paths are clearly contributing to the 'muddy floods' observed at the local scale. By targeting runoff in fields and farm ditches then a significant component of flood generation can potentially be managed at the catchment scale. The Belford Burn (Northumberland, UK) catchment is a small rural catchment with a catchment area of 6 km^2. Normal flood defences are not suitable for this catchment as it failed the Environment Agency (EA) cost benefit criteria for support. There was a desire by the local EA Flood Levy Team and the Northumbria Regional Flood Defence Committee at the Environment Agency to deliver an alternative catchment-based solution to the problem. Four different types of mitigation feature have been created in the catchment to reduce flood risk whilst also benefiting water quality and ecology. These measures include bunds disconnecting flow pathways, diversion structures in ditches to spill and store high flows, 'Beaver dams' placed within the channel and riparian zone management. Evidence collected from these features, along with construction advice and management issues, has helped to create the first draft of a Runoff Attenuation Features Handbook.

Introduction

Over the past ten years (1999–2009) there has been an increased number of severe flood events which have occurred in the UK. In addition, over the past fifty years, significant changes in UK land use and management practices have occurred, driven by UK and EU agricultural policies (O'Connell *et al.*, 2007). There is substantial evidence that modern land-use management practices have enhanced surface runoff generation at the local scale (O'Connell *et. al.*, 2007). Surface runoff can mobilise vast amounts of sediment also leading to water quality issues within river channels. Increased runoff from agricultural land with increased rainfall totals could result in larger flood peaks.

There is a strong desire, based on field-scale science, to use land management to deliver flood and coastal erosion risk management (Parrott *et al.*, 2009). *Making Space for Water* (Defra, 2005), the *Water Framework Directive* (WFD, 2000/60/EC), Defra's *Water Strategy* (Defra, 2008) and climate change all drive us to deliver sustainable solutions for flood and coastal erosion risk management (Parrott *et al.*, 2009). There is also currently support within the Environment Agency for sustainable flood management solutions (see Environment Agency, 2008b; Environment Agency, 2008a). One such flood risk management strategy is presented here, along with its current application to a small rural catchment. Farm Integrated Runoff Management plans are based on the concept of the storage, slowing, filtering and infiltration of runoff on farms at source (Wilkinson *et al.*, 2010; Quinn *et al.*, 2009; Quinn *et al.*, 2007). This is believed to be practical and achievable strategic investment of agri-environment and flood mitigation funding. There are great advantages in controlling runoff at source and within hours of the runoff generation. These spatial and temporal windows of opportunity are not being fully exploited in environmental management.

The most common way to control flow pathways within Runoff Managment plans is to construct Runoff Attenuation Features (RAFs) (Wilkinson and Quinn, 2010; Wilkinson *et al.*, 2010). RAFs include bunds, drain barriers, runoff storage features (both online and offline), woody debris dams, buffer strip management and willow barriers (Wilkinson *et al.*, 2010). If a typical farm or small catchment can sacrifice 2–10% of the landscape to runoff storage and mitigation features then the properties of the runoff regime can be radically altered (Quinn *et al.*, 2007a). However, after a few years these features can fill with sediment, reducing their water retention capacity (Verstraeten and Poesen, 1999). Therefore the management of these features is an important issue (Wilkinson *et al.*, 2010).

The Belford Burn (Northumberland, UK) catchment is a small rural catchment which drains an area of 6 km^2. It flows through the large village of Belford. Over recent years Belford has witnessed many flood events; 35 properties are at risk from flooding. Traditional flood defences are not suitable for Belford because of the high cost, lack of space for flood walls and banks and the low number of properties at risk does not meet the criteria for Grant-in Aid funding. There was a desire by the local EA Flood Levy Team and the Northumbria Regional Flood Defence Committee at the Environment Agency to deliver an alternative catchment-based solution to the problem. With funding from the Northumbria Regional Flood Defence Committee, the Environment Agency North East Local Levy team and Newcastle University have created a partnership to address the flood problem using soft engineered runoff management features.

The partnership project, *"Belford proactive flood solutions"* are testing novel techniques in reducing flood risk in small sub-catchments for the Environment Agency. The project provides the evidence which is needed to understand whether the mitigation measures are working at the sub-catchment scale. It also provides a demonstration site for

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interested stakeholders to come and look at and learn about this approach to flood risk management (Wilkinson and Quinn, 2010). The aim of this paper is to show four different runoff management techniques in the Belford Burn catchment and how they can help to reduce flood risk in the village of Belford.

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 for wading birds. There is a dense, multi-scale hydrometric network in place within the catchment. This constists of raingauges, piezometers, stream gauges, RAF water level recorders and water quality samplers (Figure 1). This has collected over one year's pre-intervention data and has now been logging continuosly since November 2007. This hydrometric network will allow an assessment of the performance of the RAFs in the catchment. Land use within the catchment varies from pasture and rough grazing at the top of the catchment and arable crops at the bottom of the catchment (Figure 1). 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.

Managing runoff with Runoff Attenuation Features (RAFs)

Mitigation measures were first installed in May 2008 and there are currently 13 active features in the catchment (with over 20 more planned). The methods include (which will be discussed further in this paper):

1. Woody Debris (Beaver dams) placed across streams;
2. Offline RAFs: bunds intercepting flow pathways which store storm runoff and slowly release it over a day;
3. Points on the stream which spill into storage features on buffer zones;
4. Riparian zone management (willow strips, etc.), this will not be discussed in this paper.

Woody debris

The object was to provide floodwater detention ponds behind barriers constructed from 'Large Woody Debris' (LWD). Woodland is often of low agricultural value, and it is generally very tolerant of temporary inundation. So, woodland seems to be an obvious choice for a flood management project such as the one at Belford. However, the flood storage capacity of woodland is limited in many landscapes, simply because the woodland near watercourses is mainly restricted to steep ground with poor access, the better and flatter ground having been adopted for more intensive farming. In addition, woodland soils are prone to damage during construction work, being heavily shaded and

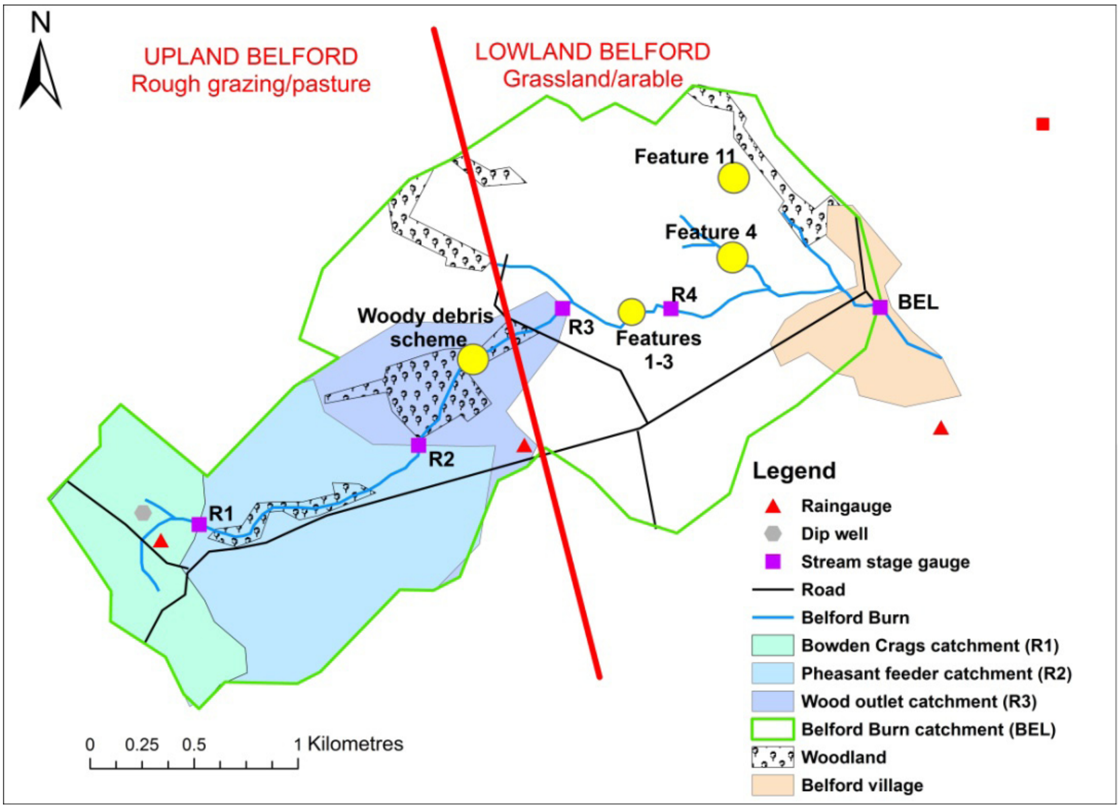

Figure 1 *The Belford Burn catchment instrumentation network and feature location*

 

Figure 2 *A woody debris beaver dam constructed in a stream with locally felled sycamore trees. Tree trunks are placed cross over to avoid bank scour*

having very variable drainage and gradient. These conditions may also make them prone to erosion due to scour around structures placed in the stream.

These matters considered, the method adopted at Blagdon Dene was to place a number of structures in close succession to reduce the stream power available for scouring at each location (Figure 2). The structures installed have sufficient height to connect the floodplain to the main channel during flood events, but they are also porous enough to allow moderate floods through almost unhindered (Figure 2). The floodplain is approximately 15 m in width and the channel region approximately 3 m wide and 0.75 m below the floodplain. The approximate height of each LWD structure is 1.25 m above the streambed and 0.5 m above the floodplain. They were all constructed of sycamore tree trunks and logs, which were felled in the immediate work area. The size of these logs varies between about 0.2 and 0.7 m in diameter, and their lengths are up to 7 m. The smaller parts of the felled trees (the ‘branchwood’ and ‘brash’) were used on the floodplain to create porous barriers that were pegged into the soil using the straighter sections of branches having around 70 mm diameter. There were 6 structures and associated floodplain barriers installed in total.

It was not possible to undertake this work successfully without a good grasp of woodland ecology, stream ecology and woodland management. The impact upon the local ecosystem was significant, and the biodiversity in the woodland was judged more important than that in the nearby intensive farmland. Happily, the engineering requirements for the LWD structures coincided well with woodland habitat and biodiversity requirements and they were also well suited to working without heavy plant or machinery:

- The felled trees reduced the population of mature sycamores, generally regarded as invasive in UK broadleaf woods when these are unmanaged,
- The selective felling created a significant clearing, which will result in a more diverse range species and age-class, both of which are regarded as healthy changes in woodland.
- The materials for the barriers, coming from the very same felled trees, eliminated all road transport and timber certification requirements, although use of such materials did require more specialist skills.
- The use of manual work and craft skills (rather than machines and generic groundwork engineering) both made the bureaucratic processes shorter and kept the potential damage to the woodland floor to a minimum.

Two problems had to be overcome:

- The disadvantage of using sycamore was the relatively fast rate of decomposition of the smaller sizes — for example, all the material below 50 mm in diameter can be expected to have rotted away within five years.
- Water voles are present in much of the lower part of the selected reach, as identified by the EA’s biodiversity officers, so we had to restrict the work to just one barrier in this region.

The first problem was not so significant, as we had already decided to replant with a mix of tree species suited to the clearing we had created. It was decided to plant more trees and more densely, all secured with hardwood stakes and tree guards. It is believed that these will be collect floodplain debris and be strong enough within a few years to replace the floodplain roughness lost as the deadwood sycamore rots. The larger sections of sycamore obstructing the channel will probably last 10–20 years before they decompose. The trees planted to provide floodplain roughness were chosen to suit their immediate soil and lighting conditions: alder for the wettest areas and hazel (a strong under-story tree, and traditional coppice wood favourite) for general floodplain roughness in the somewhat drier places. The woodland was also observed by the EA biodiversity team to be lacking in birch and holly so these were also planted in suitable places, mostly a little above the floodplain.

Offline RAFs: Disconnecting flow pathways and storing runoff with bunds

A common occurrence in a storm event is that the soil becomes fully saturated and surface runoff arises. Surface runoff flows into preferential flow pathways. This fast flow can not only result in a flashy flood peak but can also mobilise vast amounts of sediment. One of the easiest forms of runoff management is to disconnect surface flow pathways which become active during storm events. The disconnecting flow pathways RAF can achieve this. This can be done by constructing a bund across the flow pathway (Figures 3 and 4). The bund can be either made of soil (preferably sourced on the farm) (Figure 4), stones (sourced on the farm) or sustainably sourced wood (Figure 3). Slowing, storing and filtering the surface flow can attenuate the flood peak at the local scale and reduce sediment loads. Storing this runoff at the right time can help to reduce the flood peak and lag time of an event (Figure 5).

However, the design of the offline storage RAF is important. After a flood, the water stored in the RAF must slowly drain away over a period of 6 to 24 hours (depending on capacity) (Figure 5). This is to allow further storage in

Figure 3 *The pilot feature; a wooden bund disconnecting a flow pathway (left and centre: at full capacity draining slowly through the gaps in the wood and right: normal status of the feature, no disruption to farming practice.*

Figure 4 *Bund built across a major flow pathway (base of a hollow). Left; The West Hall RAF being constructed using local soil and contractors and right; the Upper Lady's Well RAF disconnecting and storing sediment rich runoff during a storm event. This bund also acts as a road for machinery.*

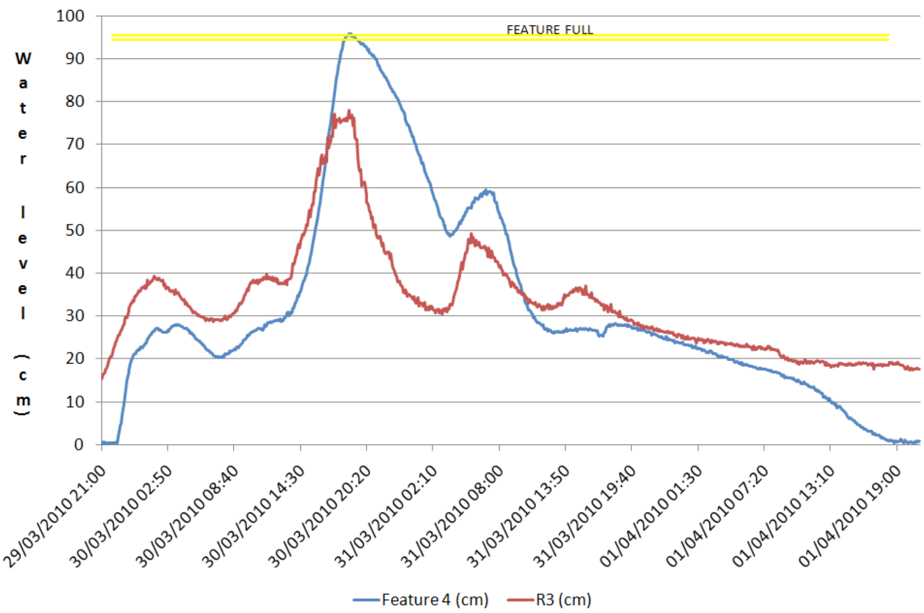

Figure 5 *West Hall (Feature 4 on Figure 1) RAF (blue line) filling and emptying during the March 2010 flood event (red line indicates nearby R3 stream gauge level, see Figure 1).*

the RAF if another storm were to occur the following day. A full RAF would provide no further storage and in fact could increase flood risk, so it is therefore important to allow the water to drain out slowly. For example, in Figure 4 (left) the West Hall pond takes nearly 24 hours to drain from full to empty (Figure 5). Bunds should be placed along obvious flow pathways or small ditches (Figure 4) i.e. where the least material (and therefore cost), preferably low productivity is occurring and greatest storage potential can be achieved. The bund should have an armoured spillway at the lowest point. This allows in the largest events excess runoff to spill over the bund safely. If water were to spill over an unprotected bund then there is a risk of the bund failing. The outlet pipe draining the bund should be slightly raised of the ground. This

Figure 6 *The simplest way to spill high channel flows into a storage feature is to lower the bank on a meander (left). However, a properly designed structure can be used in a stream to spill water out of the channel (right).*

will allow better sedimentation of the storm runoff to take place. Also, holding back a little water can have ecological benefits to birds and insects although this can only be done in certain sites. It is likely that some preferential sites to disconnect flow pathways and store runoff are in prime agricultural land.

Therefore, it is important that RAFs in these areas only hold runoff in the most severe storms and for most of the time the feature will not affect the everyday running of that prime land. However, if a farmer/landowner were to have poor quality land (i.e. a boggy area) then this would be the ideal place to build a RAF that not only functions as a RAF but can become a wetland afterwards which will improve water quality and ecology. This type of setup of disconnecting flow pathways / RAFs would therefore have win/win benefits to flood risk mitigation, water quality, ecology and also for the farmer. The cost of constructing this type of feature is: soil bund £10–100 metre, wood bund £200–300 metre and stone bund £50–300 metre. Some maintenance is needed, such s unblocking pipes and emptying sediment.

Stream diversions in high flows

It is not just overland flow and small drains that creates flashy flood peaks and transports sediment. Subsurface flow (e.g. drains) can deliver runoff to a channel quickly. There is a common misconception that the bulk of the flow is generated by overland flow. In a large storm event, subsurface stormflow is equally responsible for runoff volumes (Weyman, 1970; Sklash and Farvolden, 1979). To manage runoff in a catchment we also need to manage channel runoff with high flow peaks. If we can remove the peak discharge from the channel and attenuate it in a storage feature, the hydrograph can be radically altered. By storing the high flow peak in a RAF described above, sediment will also be captured. Stream can be spilled by lowering the bank beside the feature (Figure 6, left). This should be lowered to roughly the height of a typical large flood event. When using an in-stream diversion structure, follow EA guidelines and gaining consent (Figure 6, right). Allow spill to take the most torturous route to the storage feature. This will allow for further attenuation. Natural features, such as a large within-stream boulders, can help water to back up and improve the spill process.

Conclusions

Traditional flood defences are not suitable for Belford because of the high cost, lack of space for flood walls and banks and the low number of properties at risk does not meet the criteria for Grant-in Aid funding. Working with the EA local flood levy team, numerous flow pathways have been altered. These practical, low cost soft engineered interventions have been called Runoff Attenuation Features. Three types of feature have been discussed in this paper, such as bunds disconnecting flow pathways, diversion structures/bank lowering of streams to store high flow peaks in RAFs, and woody debris placed within the stream.

There is a vast array of hydrometry in the catchment which has been assessing the functioning of these features, along with one year's background data. Since May 2008, Belford has endured four floods and these saw the mitigation measures work effectively. For example, travel time of the peak of the flood has increased from 20 minutes to 35 minutes (over 1 km) where one stream spill feature is present. In the area of the beaver dams, the travel time has more than doubled. The visual evidence of storage is apparent. However, as rating curves are improved this should also support the view that the features are reducing the peak discharge of floods. The multi-purpose benefits of these features are also being assessed. However, matters such as ownership and maintenance (such as sediment removal, pipe blockages, etc) still need to be tested and resolved.

References

Defra 2005. *Making space for water, taking forward a new government strategy for flood and coastal eriosion risk management in England*. First response.

Defra 2008. *Future Water: The Government's Water Strategy for England*.

Environment Agency 2008a. *Delivery of making space for water: the role of land use and land management in delivering flood risk management.* Final Report.

Environment Agency. 2008b. *T*he Environment Agency's position on land management and flood risk management, position statement, Final version.

O'Connell, P.E., Ewen, J., O'Donnell, G. and Quinn, P. F. 2007. Is there a link between agricultural land-use management and flooding? *Hydrol. Earth Syst. Sci.,* **11**, 96–107.

Parrott, A., Brooks, W., Harmar, O. and Pygott, K. 2009. Role of rural land use management in flood and coastal risk management. *J. Flood Risk Manage.* In press.

Quinn, P.F., Hewett, C.J.M., Wilkinson, M.E., Jonczyk, J., Rimmer, D. and Burke, S. 2009. *Integrated runoff.* Available at: http://www.ncl.ac.uk/iq (Accessed: 20th April).

Quinn, P.F., Jonczyk, J., Rimmer, D. and Hewett, C.J.M. 2007. *The Proactive approach to Farm Integrated Runoff Management (FIRM) plans with respect to nutrients.* Newcastle University

Sklash, M.G. and Farvolden, R.N. 1979. The role of groundwater in storm runoff. *J. Hydrol.,* **43**, 45–65.

Verstraeten, G. and Poesen, J. 1999. The nature of small-scale flooding, muddy floods and retention pond sedimentation in central Belgium. *Geomorphology,* **29**, 275–292.

Weyman, D.R. 1970. Throughflow on hillslopes and it relation to stream hydrographs., *Bull. Int. Assoc. Sci. Hydrol.,* **15**, 25–33.

Wilkinson, M.E. and Quinn, P.F. 2010. *Climate, Water and Soil: Science, Policy and Practice: SAC/SEPA Biennial Conference 2010.* Edinburgh.