Water Friendly Farming Case Study – lessons learnt

Optimising leaky barriers to prevent collapse and improve performance

1 Water Friendly Farming

Water Friendly Farming is a long-term catchment-scale research and demonstration project which began in 2010. It is an evidence-based initiative that objectively investigates whether 'nature-based' measures can protect against flooding, reduce diffuse pollution and enhance freshwater biodiversity in agricultural landscapes. The project is based in three headwater sub-catchments of the Welland in Leicestershire. It is a collaboration between Freshwater Habitats Trust, Game & Wildlife Conservation Trust, the University of York, the Environment Agency and landowners in the three catchments. The project has mainly been funded by the Environment Agency, with Anglian Regional Flood and Coastal Committee contributing funding from 2016 to 2021.

The leaky barriers

Leaky barriers have been installed annually as a flood amelioration measure in the headwaters of one catchment (the Eye Brook) since 2016. The local geology is relatively soft: dominated by Mesozoic mudstones and more recent diamicton (till).

The aim has been to create barriers that are long-lived and low maintenance. It is also important that barriers are stable: in our farming landscapes, landowners often require that the dams do not cause bank erosion that could encroach into adjacent fields. All barriers have been monitored annually to look at physical change. Linked SWAT (Soil and Water Assessment Tool) and EA Mike 11 models, validated with observed flow data, have been used to investigate how channel and barrier changes post-installation have affected flood performance.

2016 design

2020 design

Fig 1. The design of our leaky barriers has changed significantly to improve their stability and flood performance

Evolution of the leaky barriers

Over the years, the design of Water Friendly Farming's leaky barriers has changed significantly to increase barrier stability and function (Fig 1). Modifications have been based on: (i) modelling the changing flood performance of the barriers as they settled in, and (ii) measurement and observations of collapsed or degrading barriers in Water Friendly Farming and other projects.

Core messages from this work are that:

- Designs that increase leaky barrier stability can also increase flood performance.
- To prevent degradation and collapse, leaky barrier design and construction needs to protect against the multiple ways that erosion can undermine the structure, particularly through bank scour. It is especially important not to skimp on the length of cordwood (logs), particularly in larger streams with higher erosive power.
- Monitoring – should be undertaken from the channel, not the bank – to ensure that barriers which begin to degrade are identified and repaired before wider damage and loss of flood storage capacity occurs.

Freshwater Habitats Trust
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2 Leaky barrier performance in reducing flood peaks

2019 data and modelling show that the Water Friendly leaky barriers have been successful at reducing flood peaks. They reduce peak flows immediately downstream by 4% – 15% in storms up to 1:50 events. In 1:1000 events the models predict an 0.1% reduction in peak flow from this headwater catchment. Small effects from the leaky barriers can also be detected 10 km downstream, with a 0.4% reduction in peak flow for 1:1000 event. This is probably because they are desynchronising flows.

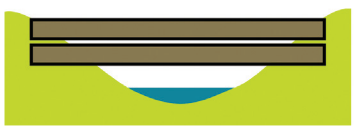
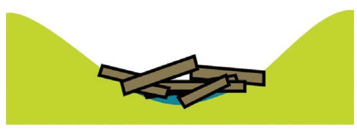
BOX 1

Difference between leaky barriers and debris dams

There can be confusion about the terms used in Natural Flood Management. Here we make a distinction between structures at the two ends of the Leaky Woody Structure spectrum:

Leaky barriers which are placed above the stream's normal water levels. They are created for flood amelioration purposes: and block storm flows, enabling water to be very temporarily stored in the upstream channel and sometimes forced onto the floodplain. These are the features we have created.

Debris dams are barriers placed in the stream where they block normal flows, ponding water behind the dam. They cause enhanced erosion and deposition around the dam which can diversify the stream habitats. Because debris dams already pond-up water and sediment under normal flow conditions they often have little extra capacity to store water in floods, particularly if filled by antecedent rainfall. Because of the erosion around them, debris dams are not inherently stable features and can collapse in storms, which may exacerbate peak flows.

	Leaky barriers	Debris dams
		
Flow	Only impedes flood flows	Impedes all flows
Flood prevention effect	Yes	Limited. May have little or no effect on water storage particularly if there is antecedent rain. Can collapse in floods potentially increasing flood peaks
Channel diversification	Not if well designed!	Yes, creates more varied flows, erosion deposition and in-stream habitats
Stability / longevity	Should remain stable for many years if well designed	Often become unstable as a result of stream erosion and can be washed out if not repaired

Modelling barrier permeability (how leaky they are) shows that the barriers perform well over a wide range of permeabilities. Hence, a range of different designs can be effective, and the barriers can continue to function well even after some settling in and adjustment.

However, somewhat counter-intuitively, a larger flow gap underneath barriers and between logs can sometimes increase flood storage and reduce flood peaks in damaging storms. This is because barriers that are leakier do not back up and store water during antecedent rain (i.e. normal rainfall before a flood), so they have more water storage capacity available when it is needed in flood.

For this reason, the most recent Water Friendly Farming barriers (constructed in 2020) have: (i) a larger bottom flow gap and (ii) spacing between logs to create greater storage capacity for the largest floods (Fig 2). Note that adding a gap between the cordwood is an experimental approach, and the ideal gap between logs, and how well these barriers function in practice, is the subject of investigation.

Fig 2. Larger gaps below and between the leaky barrier logs are designed to ensure they rapidly drain away flow from preceding rain events creating greater storage capacity for large floods

3 Why leaky barriers collapse – and how to prevent this

Causes of barrier collapse

Across all barriers studied so far in the Water Friendly Farming project and other similar landscapes the main cause of collapse has been barrier instability *significantly exacerbated by scour of the stream bank around the barrier*. There is no evidence that logs have been broken by the weight of flood water – rather the barrier's logs have been wrenched from their moorings in flood because the whole structure has become unstable as a result of bank erosion. In our study area, none of the logs from damaged barriers were freed by floodwater to move downstream and become a potential hazard. However, there are sites elsewhere where this has occurred. and become a potential hazard. However, we are aware of at least one other site where logs from a flood-damaged barrier have been washed downstream.

Fig 3. Lateral bank scour created by a collapsed leaky barrier (now removed)

BOX 2

Things that exacerbate barrier erosion and collapse

- Barrier is too low: so water is held back in minor rain events – this creates semi-continual turbulence around the base of the barrier which increases scour. Small brash is also easily trapped upstream of the low barrier which significantly exacerbates erosion.
- Cordwood (i.e. log) lengths do not span the whole width of the stream – so the structure is less stable and more prone to collapse.
- There is an insufficient length of cordwood embedded in the bank- so the barrier collapses when there is lateral bank scour (Fig 1).
- Logs rest on each other – so if one log fails, the whole fails.
- Vertical support posts are: (a) set too close to the channel edge (b) placed in the channel and/or (c) are not set deep enough – so are easily eroded out by base erosion.
- The barrier is impermeable so, in flood, there is greater weight of water (hydraulic pressure) on its upstream face, and fewer areas from which water can drain; increasing the potential for failure.

4 The importance of erosion

Water Friendly Farming data show that the most significant cause of barrier collapse is the lateral erosion of the stream bank around the barrier. In some cases scour embayments over 1m long have been eroded into the bank next to barriers within 2-3 years. There are multiple factors that can cause this erosion (Box 2 and overleaf).

What damage does lateral bank erosion do?

Lateral bank scour loosens the footings of horizontal logs and support posts so that the barrier structure becomes weak and unstable under the weight of floodwater. This is sometimes a two-stage process:

(i) scour is often greatest where the bottom log meets the bank ('end erosion'), this undermines the stability of the lowest log which collapses into the channel, (ii) the fallen log then obstructs normal channel flows and traps woody debris which rapidly accelerates further bank and bed erosion. The dropped log can also destabilise other parts of the barrier that rest on it.

Bottom scour: in some places pools up to 1.2 m deep have been eroded under the Water Friendly Farming barriers. However, although channel bed scour may contribute to barrier instability, in clay catchments like ours, where the stream bed is cohesive, it is generally a far less significant issue than lateral bank scour. In our catchment, bottom scour has mainly been a problem where it eroded out the base of vertical posts that help to support the barrier (Fig 7).

BOX 3

Old design:
a five year old barrier with considerable bank erosion and partial collapse

Factors that cause erosion and collapse:

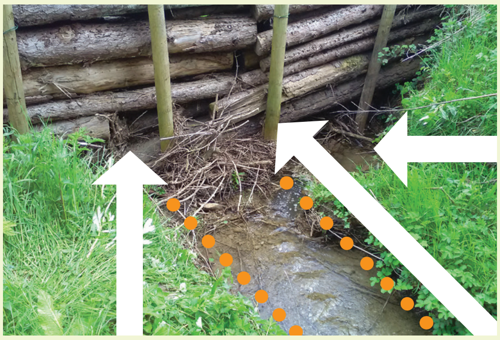
(i) base of the barrier is too low and traps brash which blocks the stream, forcing it sideways and causing lateral scour of the bank. Vertical posts in the channel also trap brash

(ii) the bottom log is not embedded deeply enough into the bank, and has been undermined by lateral bank scour

(iii) other logs do not span the whole channel and rest on each other making the whole barrier unstable

(iv) the structure has low permeability: this increases water pressure against the dam's upstream face, and hence its potential to fail in flood

Erosion downstream



Stream has eroded into bank to find an alternative route around the brash

Vertical posts and a low bottom log means that brash is trapped upstream of the barrier

Bottom log has fallen into the channel upstream of the barrier because the bank into which it was embedded has been eroded. The log now blocks normal flows

Erosion upstream

ORIGINAL CHANNEL

5 How to increase stability and prevent bank erosion

Ensure the base of the barrier is not too low

It can be tempting to set the base of the barrier low to ensure it traps floodwater. However, our data shows that trapping normal winter flows is counter-productive because it leads to enhanced bank erosion, greater need for barrier repair and higher likelihood of collapse.

How large should the bottom gap be?

Existing sources of design advice for leaky barriers suggest various rules for the bottom level of leaky barriers. For example: that it should be around 30 cm above base level, or it should allow normal flows to pass beneath, or should permit the unhindered passage of low-medium flows.[1,2,3,4] For many practitioners, these measures can be confusing. For example, Is it *summer* or *winter* base flow? And how can the base flow level be identified at a site?

Our starting point is to find the winter base flow level (Fig 4) and ensure that the level of the bottom log lies above this. Since our evidence shows that brash trapped upstream of the barrier is a considerable catalyst to bank erosion, we add an extra 30+ cm gap to ensure that sticks and other floating debris borne by winter flows are not regularly caught upstream of the barrier (Fig 5).

From this starting point, a bespoke bottom gap can then be decided upon, for example, increasing the gap to accommodate particularly flashy streams, stronger currents carrying large wood, or to target water retention that comes into operation at different flood heights or different parts of the flood cycle.

Finding the winter base flow level

Base flow level is a site-specific measure that varies with location and channel dimensions, so it needs to be identified by eye at each leaky barrier site. Where there is sufficient time and resources, the ideal option is for a gauge board and time lapse camera to be placed in at least one likely barrier location per stream section the winter before barriers are installed. This will identify the level of both the winter base flow and normal stream fluctuations which should not be trapped by the barrier. Alternatively, winter base flow level can be identified, and marked (with a stake for example), during field visits, with at least one *under normal winter flow conditions*.

Where a winter visit is not possible, it is usually possible to ***estimate*** the winter base flow level at other times of year using a combination of evidence from wetland vegetation growth, bank erosion and discolouration marks on fixed structures, for example, in-channel trees (Fig 4, 5).

Fig 4. Estimating winter flow level from field evidence

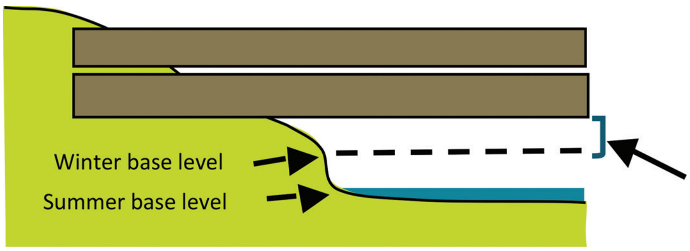


Fig 5. Ensure there is sufficient gap to let both winter flows and their debris, pass below the barrier unimpeded

Ensure horizontal logs are long enough

Current advice from Countryside Stewardship[1] says that a barrier's lowest logs should extend 0.5 m into the bank. Other guides recommend that logs should be 1.5 to 2.5 times the width of the channel.[2,5] Our evidence shows that, in areas of soft rock geology, bank scour can erode well over 1 m into the bank within just a few years and that this erosion is a critical factor that reduces barrier stability. To address this we now ensure that, even on the smallest small streams and ditches, the lowest log always extends at least 1m into the bank. Where there is higher erosive potential (i.e. bank substrates are soft, or the stream is large, gradients are steep and currents are stronger), then cordwood may be embedded 2 m or more into each bank (Fig 6). Long lengths of cordwood can be expensive, and will often need to be imported from off-site. However, our experience is that it is a more cost-effective option in the long run.

Fig 6. Bank erosion / embayment

Typical advice is that that cordwood should be 1.5 times the width of the channel. However, this may be insufficient, particularly where bank substrates are soft or the erosive power of the stream in flood is high.

Ensure vertical support posts are carefully placed and deep enough

Vertical support posts should not be sunk into the stream channel itself because it encourages brash to pile upstream of the barrier, blocking flows and exacerbating channel and bank erosion (Box 3). In-channel posts also quickly become ineffective because the are easily eroded out by bottom scour.

It is equally important to set support posts back from the winter channel edge, so they are not vulnerable if lateral bank erosion occurs.

To provide a belt and braces approach, vertical support posts that are closest to the channel edge should extend below the depth of the channel so that lateral bank scour cannot undermine them (Fig 7). A hydraulic post driver is helpful to ensure that a sufficient depth is reached.

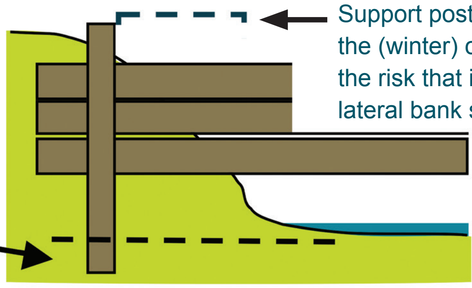


Fig 7. Support posts: a belt and braces approach to ensure stability

Locate barriers in stable places

It is preferable to locate barriers on straight sections of stream, rather than close to bends where erosional and depositional processes are already more active and the thalweg (deepest point in the river and main line of erosion) lies close to the outer bank causing enhanced erosion here.

Likewise, locating barriers just below the confluence of two streams, or below where a large floodwater ditch enters a stream, is risky because confluences are naturally areas of high scour, and barriers located here are more likely to suffer end erosion.

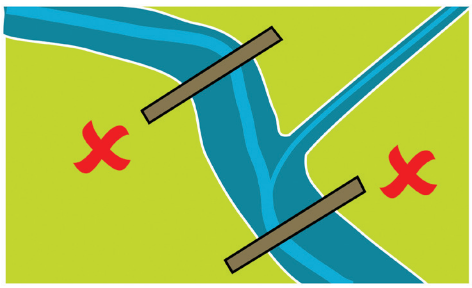


Fig 8. Avoid locating dams either on bends or below inflows: where scour (pale blue line) is likely to become focussed close to one bank

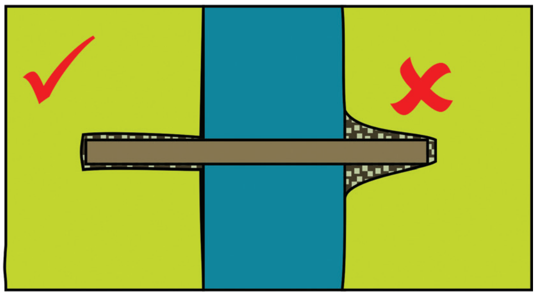
Design barriers for stability

As far as possible, ensure that each horizontal log is stable in its own right, so that if one log fails, the rest of the barrier can remain intact. Don't pile logs on a bottom log, or rely on wire to hold barriers together – galvanised tensioning wire is not strong enough and will wear through before the logs.

Minimise spoil removal when creating the barrier

Dig a *narrow* trench to slot logs into place rather than over-digging and back-filling the bank around the logs. This retains as much undisturbed soil, roots and vegetation around the barrier as possible, reducing the potential for bank erosion. Where soil is disturbed, tamp it down hard when back-filling around the barrier.

Fig 9. Bottom log partially collapsed and logs above now fallen or unstable



Using a narrow bucket allows logs to be slotted into their trench with minimal bank disturbance

Fig 10. Minimising disturbance around the barrier

New barrier, two weeks after construction

Ideally:

- The bank could have been excavated so as to slot in the logs with less spoil removed
- Remaining gaps should have been back-filled to the original bank profile and thoroughly tamped down to minimise opportunities for erosion

Keep log size even

Ideally, cordwood lengths used to create the barrier should have similar diameter. Our logs are not pinned together and uneven-width logs are difficult to brace against the vertical support posts, so it is likely that logs will be more easily wrenched out of their bed under the pressure of floodwater.

Horizontal batons are needed here to brace the upper logs against the vertical support post because the lowest log is wider than those above. This is not an optimal solution and it is not clear how well the batons will persist in the longer term.

Fig 11. Measures needed to brace logs of uneven width

6 Maintaining and repairing leaky barriers

Monitoring barriers

It is usually possible to identify barriers that are vulnerable to collapse. However, to do so, at least annual assessments of barrier condition are advisable with additional checks after particularly heavy storms.

Checks are best undertaken by wading into the stream (rather than from the bankside), using a measuring pole to: (i) identify the extent of stream bed and bank erosion – particularly noting evidence of erosion close to a bank, and (ii) to probe into the bank around the barrier to find scour cavities. It may be necessary to clear away debris to do this.

Identifying the extent and rate of erosion is easier if there is baseline survey data for each barrier. For this reason we now collect as-built information from up and downstream of each structure including, at minimum (i) channel width at the base of the dam and (ii) the height between the channel base and the bottom log.

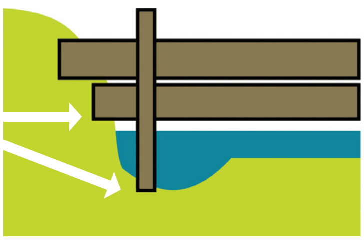
Danger signs

It is well known that if large woody debris accumulates upstream of leaky barriers this can significantly enhance rates of bank and bed scour. Most guides suggest that this debris should be regularly removed.

Our aim has been to create flood barriers that are relatively long-lived and low maintenance. Debris is less of an issue in the type of barrier recommended here, because the higher base provides an air gap that is large enough for smaller branches and logs to pass through unhindered. However, large tree branches may still be trapped and require removal before they entrain further debris that blocks base flow.

Other danger signs include: (i) evidence of scour cavities around short lengths of cordwood, and (ii) base erosion close to the bank, particularly if this is beginning to undermine, or erode behind, support posts (Fig 12).

Lateral and basal scour are close to eroding out short cordwood. Support post is close to being undermined



Scour cavities forming around a short length of cordwood

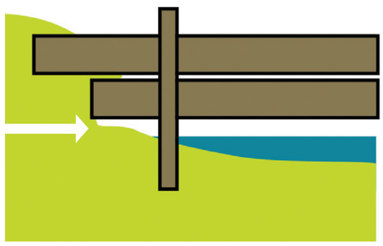


Fig 12. Danger signs that require remediation

Repairing and modifying barriers

There is surprisingly little information about how to repair leaky barriers. In the Water Friendly Farming project we are investigating, or considering, a range of remediation techniques that include:

- Supporting short cordwood in eroding banks by packing the end with new vertical support posts, and re-filling bank cavities
- Sawing-out the bottom cordwood log where it is too low to increase the flow gap
- Back-filling basal scour hollows close to the bank with rocks
- Re-directing the line of the thalweg away from the bank and towards the channel centre, using flow deflectors, or by deepening the centre of the channel itself.

7 Other studies and the future

We expect that our monitoring of Water Friendly Farming barriers will continue to provide useful new data over the next few years. However, other designs and techniques are likely to be equally, or more, appropriate, particularly in areas of gravel/sand or hard rock geology.

In this fast evolving field new information and resources are continually becoming available. See for example: *bit.ly/assessing-the-risk* for a guide to leaky woody structure design based on risk. There are different methods for stabilising dams than the ones that we have used, including pinning logs or using reinforcement bars as an alternative to embedding cordwood into banks. New techniques, such as tree-hinging, also have the potential to become part of the NFM tool-kit.

Water Friendly Farming will continue to test different NFM methods as they are developed, and we remain interested in hearing from, and collaborating with, other projects that have similar or different experiences to ours.

References

1. DEFRA. Countryside Stewardship Higher Tier Manual commencing January 2021. Annex 2c: Indicative designs for leaky woody dams.
2. Yorkshire Dales Rivers Trust Natural Flood Management techniques- Level 2. http://www.yorkshiredalesriverstrust.com/wp-content/uploads/2018/01/Natural-Flood-Management-Techniques-Leaky-Dams.pdf
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Contact: Jeremy Biggs *(jbiggs@freshwaterhabitats.org.uk)*

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