River Dove Natural Flood Management Potential Assessment

Final Report

October 2021

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This report describes work commissioned by Kirkbymoorside Town Council, by a letter dated 28th July 2021. Kirkbymoorside's representative for the contract was Nick Holroyd of Kirkbymoorside Town Council. Ryan Jennings, Eleanor Pearson, Eleanor Williams and Steve Rose of JBA Consulting carried out this work.

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Purpose

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JBA Consulting has no liability regarding the use of this report except to Kirkbymoorside Town Council.

Acknowledgements

JBA would like to acknowledge Kirkbymoorside Town Council for sending through valuable knowledge on the existing flood risk issues within the area and possible mitigation options. In addition, Chris Tinkler who also spent time to brief JBA on the potential issues and his personal thoughts on flood mitigation.

Carbon Footprint

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Executive Summary

Properties in Kirkbymoorside, Keldholme and Kirkby Mills are known to regularly suffer from flooding from the River Dove and surface water runoff, causing internal and external damage. Flooding mechanisms are further complicated by both groundwater influences across the catchment and the existing urban drainage system. Kirkbymoorside Town Council requested the feasibility for the use of Natural Flood Management (NFM) features to be investigated, both in the immediate vicinity of Kirkbymoorside and in the wider River Dove catchment.

JBA Consulting undertook a desk-based assessment for the feasibility of NFM to identify opportunities, benefits and potential constraints to the uptake of measures. The opportunities for NFM were then ground truthed during a two-day site visit on the 1st and 2nd September 2021.

Flow pathways contributing to flooding in Kirkbymoorside were dry during the site visit. However, opportunities for bunds to create offline storage areas were apparent in the arable and grass fields upstream of Kirkbymoorside Golf Course. Once flow enters Manor Vale Woods, the footpath and then Manor Vale Lane act as efficient routes for water to quickly reach the town. Here, modifications to the path and road could be made through the introduction of small-scale speedbump type features, to reduce the efficient conveyance of water downstream. Within the ditches and channels, fed by springs, upstream of the churchyard, leaky barriers and woody debris could be added to help slow and store water, attenuating the flow before entering the urban drainage system.

Within the wider River Dove catchment, NFM opportunities mainly consist of leaky barriers in the smaller tributaries of the River Dove, moorland grip/drainage blocking, and clough tree planting in the steep valleys running down from the open moorland headwaters. Some larger floodplain storage opportunities exist within the floodplain adjacent to Ravenswick Hall. Further opportunities may be present, however, much of the main channel in the upper reaches of the River Dove does not sit on publicly accessible footpaths. Therefore, increased landowner engagement here would be beneficial to grow the understanding of channel/floodplain character and, thus, NFM potential.

Significant NFM implementation will be a hugely beneficial aid to flood risk mitigation across the catchment, however directly at Keldholme and Kirkby Mills it would be more appropriate that combined approach should be taken forward, where NFM opportunities within the wider River Dove catchment should be used in conjunction with engineered options within the vicinity of the flood risk receptors, including the potential removal of weirs and flood embankments together with the implementation of robust property level protection, especially in larger floods. NFM could be targeted at especially lower magnitude flooding issues within the local area. A greater understanding of the contribution of groundwater to flood risk in the catchment would also be beneficial.

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Abbreviations

AEP	Annual Exceedance Probability
BFI	Baseflow Index
EA	Environment Agency
FEH	Flood Estimation Handbook
KTC	Kirkbymoorside Town Council
mAOD	metres above ordnance datum
NFM	Natural Flood Management
NGR	National Grid Reference
NRFA	National River Flow Archive
NNIS	non-native invasive species
OS	Ordnance Survey
RAFs	Runoff Attenuation Features
RoFRS	Risk of Flooding from Rivers and Sea
RoFSW	Risk of Flooding from Surface Water
SPR	Standard Percentage Runoff
SSSI	Site of Special Scientific Interest
SuDS	Sustainable Urban Drainage Systems
WFD	Water Framework Directive
WwNP	Working with Natural Processes

Definitions

This report quotes the frequency of a flood in terms of an annual exceedance probability (AEP), a number between zero and one (commonly converted to a percentage) which is the inverse of the return period. A return period is defined as the average time between years with at least one larger flood. AEPs can be helpful when presenting results to members of the public who may associate the concept of return period with a regular occurrence rather than an average recurrence interval. The table below is provided to enable quick conversion between return periods and annual exceedance probabilities.

Return period (years)	2	5	10	20	25	30	50	75	100	200	1000
AEP	0.5	0.2	0.1	0.05	0.04	0.033	0.02	0.013	0.01	0.005	0.001
AEP (%)	50	20	10	5	4	3.3	2	1.3	1	0.5	0.1

1 Introduction

1.1 Background and aims

JBA Consulting was commissioned by Kirkbymoorside Town Council (KTC) to investigate the feasibility of Natural Flood Management (NFM) within the River Dove catchment to Kirkby Mills, including the surface water flow pathway running through Kirkbymoorside (Figure 2-1). Properties in Kirkbymoorside and Kirkby Mills have flooded frequently in recent years, with additional damage to gardens etc. and from surcharging of the foul sewer network.

Current flood risk within Kirkbymoorside, Kirkby Mills and Keldholme has previously been attributed to the influence of the undersized and poorly conserved urban drainage network[1], backing up of the Mill Race[2] and alterations to the headwater moorland drainage system[3]. This project builds on this understanding to include potential influences and mitigation options upstream within the catchment. The Environment Agency (EA) 2002 Flood Risk Mapping Studies[4] report should be read in connection with this report. It is understood that these previous recommendations have not yet been implemented and therefore maybe still encouraged to provide further mitigation of flood risk. These options should be reviewed.

This report analyses the current understanding of the flood risk in Kirkbymoorside to determine the feasibility of implementing NFM measures across the River Dove catchment. Potential benefits and constraints of the use of NFM are considered before next steps are evaluated.

The project involved a desk-based assessment of the current flood risk and potential NFM opportunities, and which was ground-truthed by JBA Consulting over a two-day site visit. A desk-based assessment of potential constraints, including a hydrogeological review of the catchment, and benefits to the use of NFM was also undertaken, and detailed in the subsequent report.

2 Catchment hydrological understanding

2.1 Site location and topography

Kirkbymoorside (National Grid Reference (NGR) SE 69500 86500) and Kirkby Mills (NGR SE 70500 85700) sit within the River Dove (Ryedale) catchment, which is an approximately 59 km^2 catchment extending from Kirkby Mills in the south, to the headwater moorland of Farndale in the north (Figure 2-1).

The catchment rises from a minimum altitude of 35.7 m above Ordnance Datum (mAOD) at the southern boundary of the study catchment, to 432.5 mAOD at the catchment boundary between Middle Head and Stockdale Moor, in the north. The annual average rainfall is 903 mm compared to the UK average of 1020 mm.

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[1] WSP, 2019, Kirkbymoorside - Rye Catchment Alleviation Studies

[2] Kirkbymoorside Town Council, 2021, Flood Management - Town Council Meeting Notes

[3] Kirkbymoorside Town Council, 2008, Flooding Issues within Kirkbymoorside, Keldholme and Kirkby Mills – Town Council Meeting Notes

[4] Environment Agency, 2002, Flood Risk Mapping Studies – River Dove, Kirkby Mills

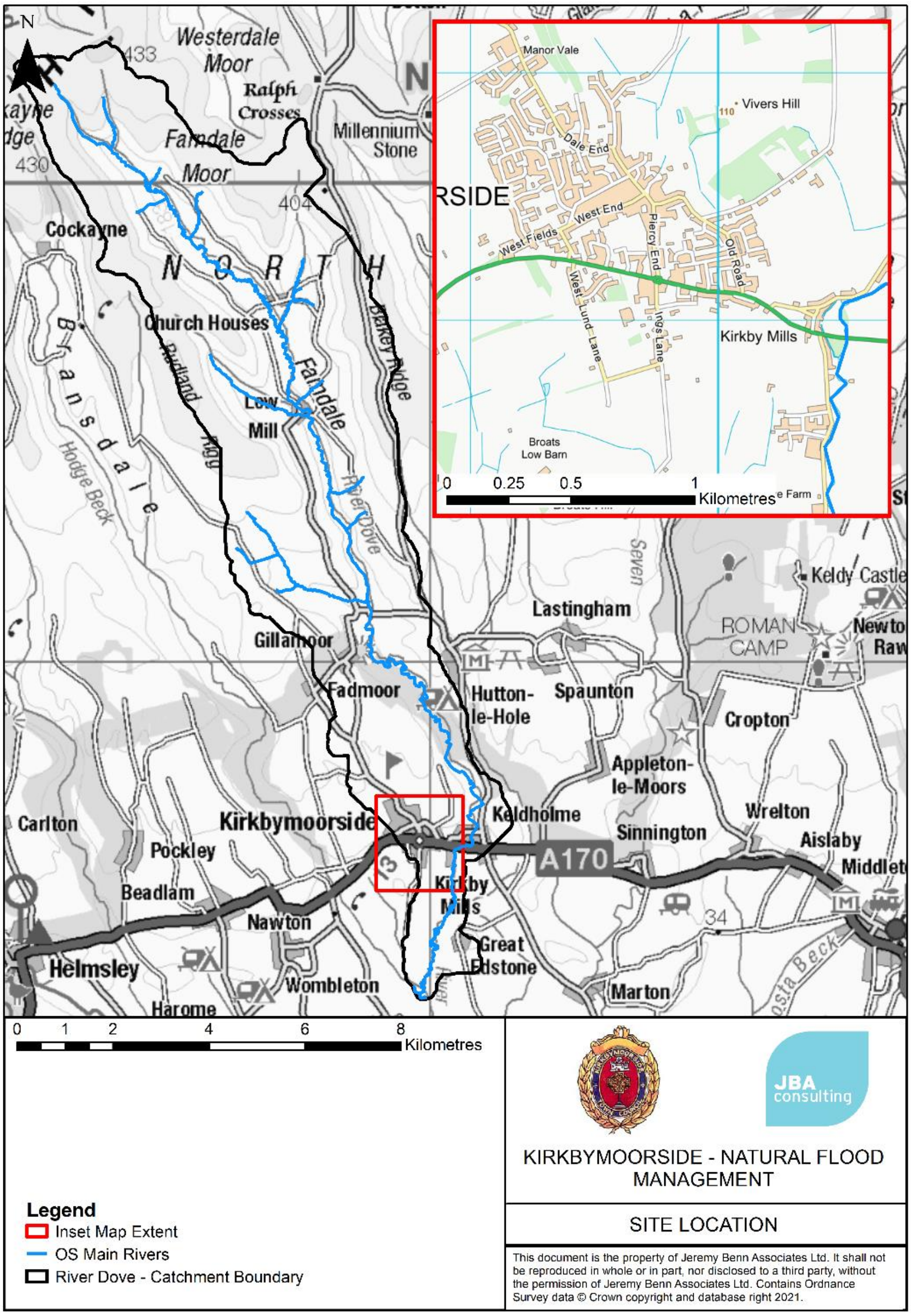


Figure 2-1: River Dove catchment to Kirkby Mills – Site Location

2.2 Current and historic land use

Farndale is an elongated valley characterised by heath and bog headwaters and a steep sided valley, comprising of improved grassland for livestock, with areas of woodland and arable farming. The proportion of arable farming increases greatly downstream of Lowna (Figure 2-2). The majority of the headwater moorland is protected as a Site of Special Scientific Interest (SSSI).

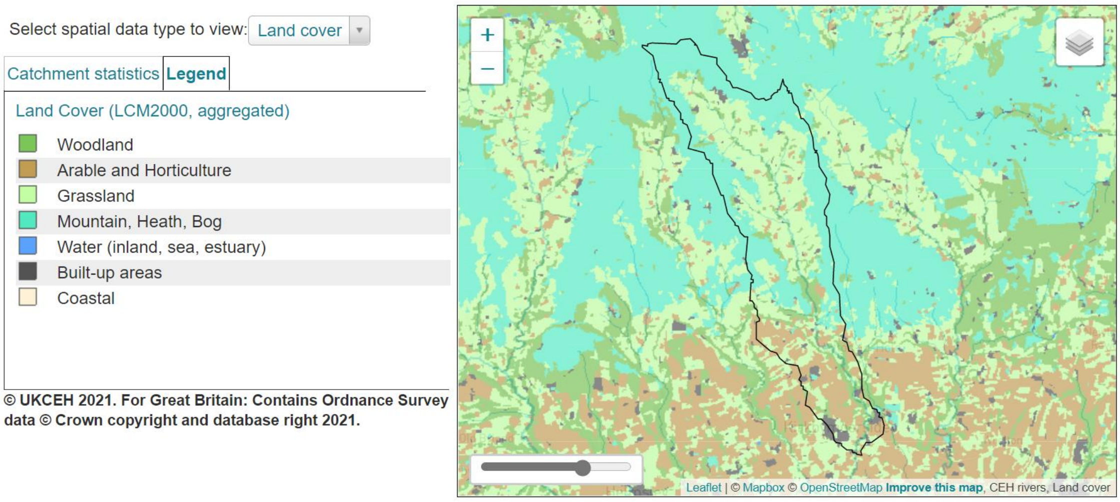


Figure 2-2 Land cover in the River Dove catchment

2.2.1 Historic Map Analysis

The One Inch 7th series 1955-61 mapping was compared to current freely available online Ordnance Survey (OS) Maps. A total of 73 km of additional drainage was identified in the current map compared to the 1955-61 map (Figure 2-3). This increase in land drainage is likely the result of the increase in recreational moorland activities. Moorlands have been historically drained to provide habitat for grouse. These drains provide a quick and efficient pathway for rainfall, which would be typically stored within the soils, to move down the valley. Local anecdotal understanding is that the additional drains have caused an increase in surface water runoff from the moors and a reduction in moorland water storage[3], which has been attributed to the flood risk within Kirkbymoorside.

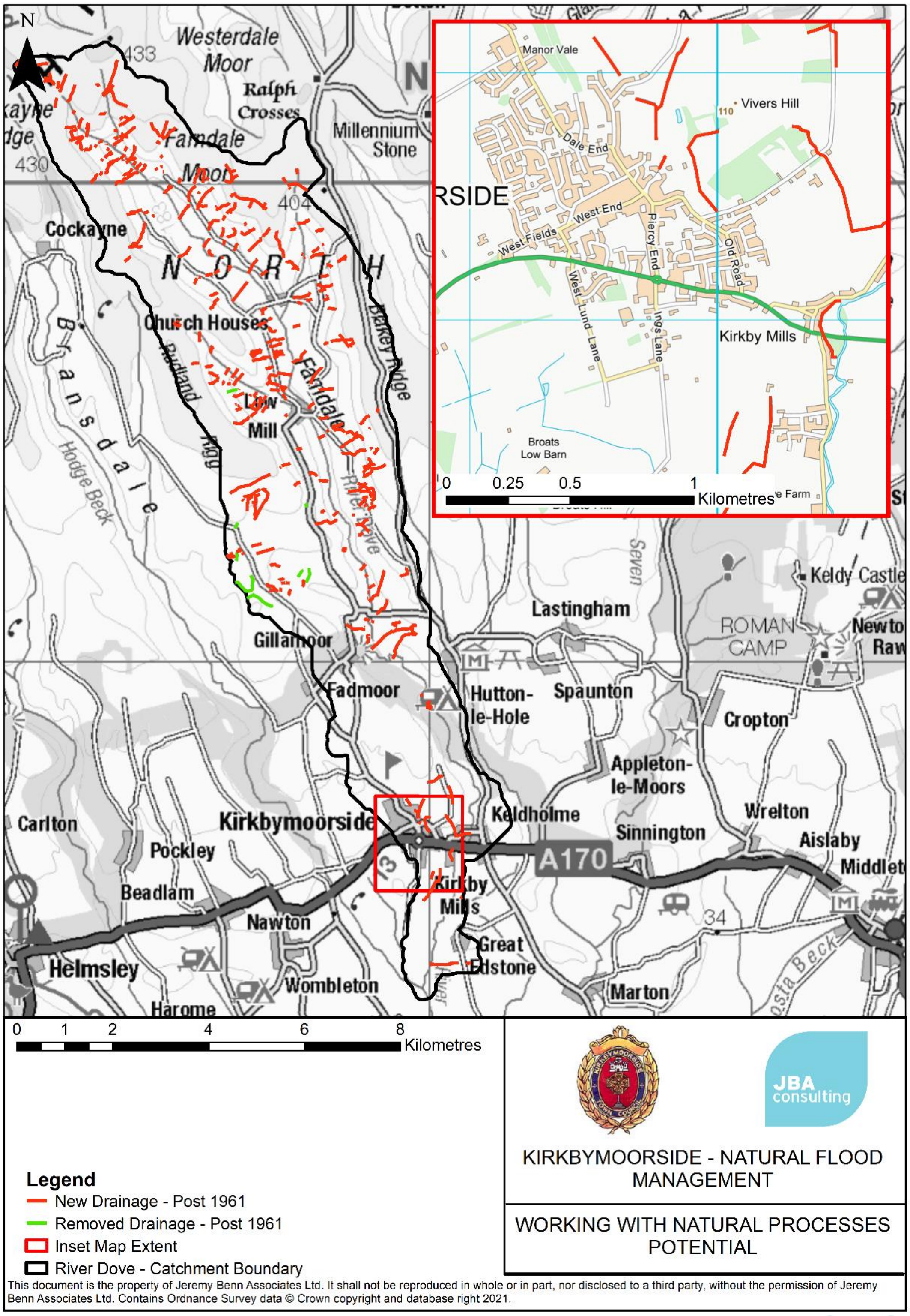


Figure 2-3: New drainage apparent in mapping between 1961 and present day

2.3 Flooding mechanisms – review of previous studies

2.3.1 Introduction

A number of previous studies[1,2,3,4] were supplied by the client to JBA. Studies primarily focused on flood mechanisms based on the three main flood receptor areas: Kirkbymoorside, Kirkby Mills and Keldholme. These reports should be read in connection to this new study which aim to analyse potential further influences and further mitigation options upstream within the catchment. This additional report focuses on surface water contributions to the flood risk in these locations and within the upstream catchment area. JBA has reviewed the reports in relation to the 0.1% AEP Risk of Flooding from Surface Water (RoFSW) Maximum Depths Map and Risk of Flooding from Rivers and Sea (RoFRS) map to identify the most likely routes surface water is taking to the three receptor areas.

2.3.2 Kirkbymoorside

Photographic evidence shows historic flooding (1980s) of the High Street, and flooding of West End occurred in 2010[1]. The flooding in Kirkbymoorside arises from surface water flow pathways and natural springs upstream of Manor Vale and Castlegate[1].

Neglected land drains (Figure 2-3) increased surface water runoff flowing into the valley and down Manor Vale Lane and Manor Vale Wood[1]. Properties around Park Lane and Castlegate are occasionally flooded due to adjacent agricultural field surface water runoff[1]. Above Kirkbymoorside, Natural England and North Yorkshire County Council have worked together to improve farming practices, including the reintroduction of ditches and land drains, reducing the runoff rates to Manor Vale but increasing them to the north of Park Lane and High Street[1].

Inspections of the ditch system north of Park Lane and Manor Vale have shown poor conditions, including overgrown vegetation, culvert blockages and potential under sizing, which are likely to be exacerbating the flooding issues for residents particularly on Park Lane and Castlegate[1].

A summary of the properties at risk from previous studies[4] includes:

- 4 properties alongside Park Lane and Castlegate;
- 5 properties along Manor Vale Lane, Manor Close and Dale End;
- 16 properties along West End and Tinley Garth; and
- 10 properties adjacent to the church yard.

2.3.3 Keldholme

Previous studies[4] suggest some flooding in Keldholme, downstream of Keldholme bridge, is due to rising levels in the River Dove. The flooding mechanisms are, however, complicated by surface water flow from highways (particularly Gray Lane) and adjacent fields[4]. In the Autumn 2000 flood, a summary[4] of the properties inundated included:

- 6 properties (including Priory Lodge)

2.3.4 Kirkby Mills and Mill Race

Within Kirkby Mills, flooding issues are primarily the result of backing up of water from the River Dove into Mill Race. Flooding is exacerbated by a storm drain which discharges into the Mill Race (bringing runoff from Kirkbymoorside), channel constriction from a bridge and pipe crossing and poor channel maintenance[2]. Flood risk is of much greater significance once the River Dove breaches to the north of the A170, flowing across the paddock at The Cornmill and joining the Mill Race flood waters[2]. Evidence for the flooding in Kirkby Mills is supported by the RoFRS map (Figure 2-4). A summary of the properties at risk from previous studies[4], which were flooded in Autumn 2000, include:

- 21 properties between the area to the north and south of the A170; and
- 6 industrial units at risk.

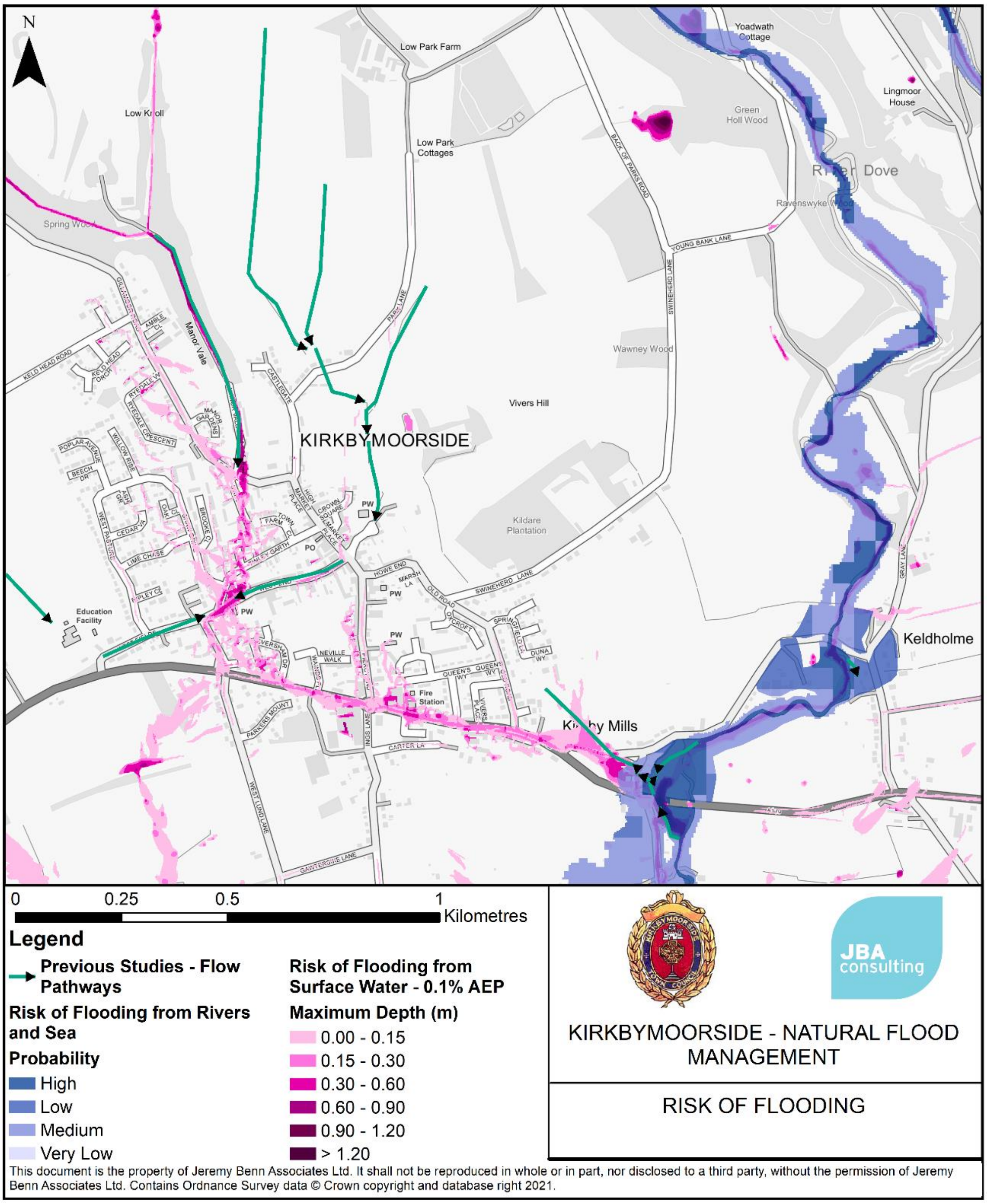


Figure 2-4 Risk of Flooding from Rivers and Seas and Surface Water

It was noted more generally in some reports that an increase in activity on the moorland has seemingly caused a reduction in land cover quality (and condition) and thus a reduction in water storage[3].

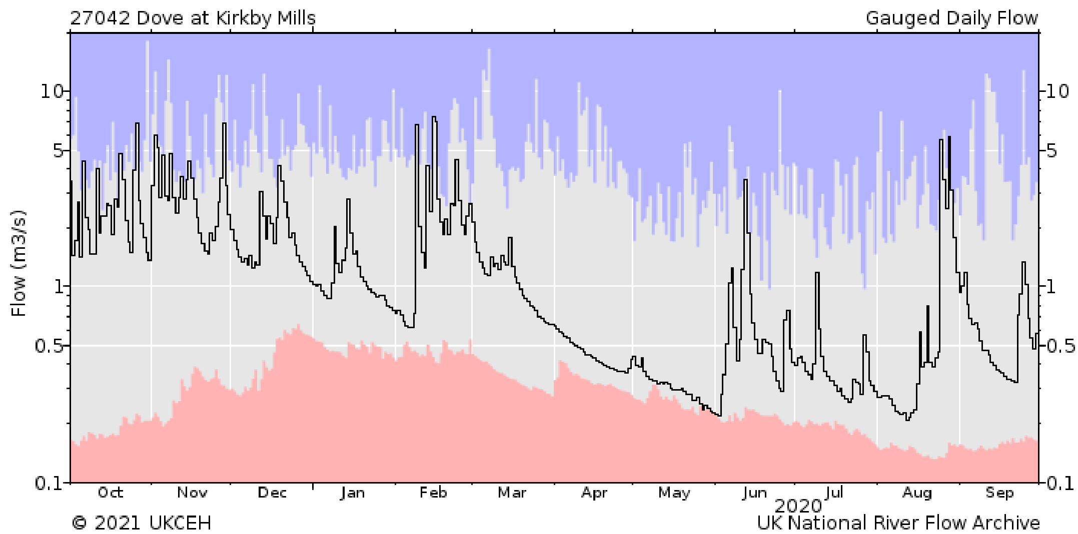
The previous studies provide several suggestions, of which none are currently implemented, to improve flood risk in the areas, including:

- Clearance/improvements of current drainage systems[1];
- Improved channel maintenance (and clarification of who is responsible for maintenance)[1];
- Sustainable Urban Drainage Systems (SuDS)[1,4]; and

* NFM upstream of Manor Vale – bund in field adjacent to golf course, swales in woodland adjacent to golf course[1].

2.4 Gauged data analysis

Analysis of the National River Flow Archive (NRFA) archived flows data of the River Dove flow gauge at Kirkby Mills (27042[5]) shows a mean flow of 1 m^3/s with general peak flows of between 5-10m^3/s at a maximum since 2014 (Figure 2-5). This suggests that the quantity of flood flows within the River Dove is generally fairly low on average and therefore with substantial NFM measures be implemented within the catchment, there is potential for significant flood peak reduction. The gauge record also indicates that subsurface inflow from the River Seven catchment (27057[6]) to the east may represent a significant proportion of summer baseflow.



Key: Red and blue envelopes represent lowest and highest flows on each day over the period of record. Underlying data supplied by the Environment Agency

Figure 2-5: 27042 - Dove at Kirkby Mills flow data for water year 2020

2.5 Catchment hydrogeological controls

The bedrock geology[7] underlying the upper part of the study catchment comprises strata of the Middle Jurassic Ravenscar Group, which consists of sandstones and mudstones. In the lower half of the study area catchment (approximately south of Boonhill Common) the catchment geology comprises strata of the Upper Jurassic Corallian Series which consists of sandstones and limestones with occasional shales and mudstones, and is more complex. The Corallian strata comprise the lower slopes of the North York Moors and extend west to east within the middle/upper catchment of the River Derwent tributaries, including the River Dove (Figure 2-6).

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[5] https://nrfa.ceh.ac.uk/data/station/info/27042

[6] https://nrfa.ceh.ac.uk/data/station/info/27057

7 http://mapapps2.bgs.ac.uk/geoindex/home.html

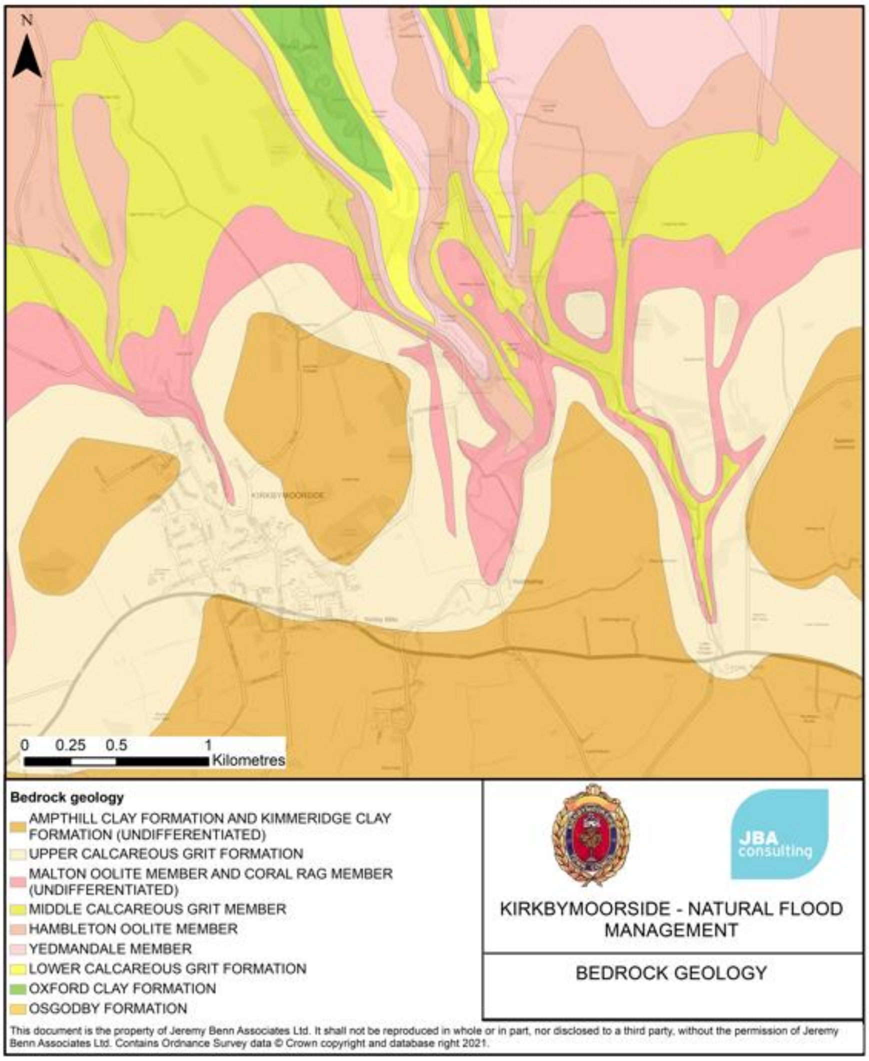


Figure 2-6: Bedrock geology at Kirkbymoorside

The Corallian rocks are of marine origin, and mainly comprise ooidal and micritic limestones and calcareous fine-grained sandstones, although minor facies also include interbeds of silts and muds. In general, the mixed geology of the catchment provides areas which are highly permeable. In addition, there is extensive karstic development, such as to support a well-documented caving network in the area[8]. This karst system has two key controls on River Dove dynamics. One is that the portion of the River Dove between the former trout farm (NGR SE 7076 8672) and Bogg Hall Rising (NGR SE 7094 8653) is ephemeral and remains largely dry between April and September. The other is that the emergence of groundwater at the spring head of Bogg Hall Rising also contributes flows from Hutton Beck to the east, where it is lost near Ox Close (NGR SE 7092 8883).

There are significant proportions of the catchment downgradient of Kirkby Mills where superficial clay allows for a highly impermeable sub surface and therefore encourages quick runoff generation from rainfall. This combined with a saturated permeable sub surface can allow for substantial rainfall-runoff contributions to the River Dove. However, within the study catchment area itself, there are little or no mapped superficial deposits, limited only to peat in the headwater zones. As such, river flow receives a high proportion of baseflow from groundwater (baseflow index (BFI) is 0.46 (CEH, 2009)). The Flood Estimation Handbook (FEH) gives the Standard Percentage Runoff (SPR) for the catchment containing the site as being ~40%. The SPR is the percentage of rainfall responsible for the short-term increase in

[8] https://yorkcavingclub.org.uk/publications/

river flow during and/or following a rainfall event. Surface runoff will occur in places where pathways into the karstic bedrock are limited by the fracture network of the Corallian Limestone to transport groundwater. However, other parts of the Limestone units are more permeable.

Immediately upgradient of Kirkbymoorside, several springs are mapped to the north of Castlegate. Given the historic evidence for flooding in this area discussed above, it is likely that this occurs when the groundwater table in this area is high, and the springs reflect the surface expression of this water table being elevated above ground level. Currently, the proportion of groundwater contribution to flooding events is not known (i.e. quantity, timing and duration), but could be quantified following a consideration of the likely groundwater catchment, and a water balance. Nonetheless, given the extensive linear pathways of the karstic network are unknown, this would comprise a high-level assessment only.

NFM options throughout the catchment would aim to hold and slow any rapid surface runoff before it reaches the River Dove. This in turn would aid water retention and groundwater recharge during the summer, and provide flood risk benefits throughout the larger rainfall events. NFM would also add additional benefit to alter the timing and shape of the hydrograph (a longer, lower flood peak), and provide a valuable contribution to reducing flood risk.

3 Natural Flood Management Potential

3.1 Desk-based Assessment - Working with Natural Processes

JBA has previously worked with the EA to develop the new national Working with Natural Processes (WwNP) Evidence Base in 2017.

(https://www.gov.uk/government/publications/working-with-natural-processes-to-reduce-flood-risk)

As part of this project the WwNP potential maps were developed for England. These maps were designed to signpost all stakeholders in the more likely or more effective areas for WwNP, focusing on:

- Runoff Attenuation Features (RAFs);
- Gully-blocking opportunities;
- Floodplain reconnection;
- Tree-planting in three categories:
    - Floodplain;
    - Riparian; and
    - Wider catchment on Slowly Permeable Soils.

JBA used its previously developed national uFMfSW maps for the EA which provides information on predicted surface water flood risk and depths, at a 2 m resolution for the whole of England and Wales (EA, 2013) to aid the subsequent development of the WwNP potential maps in 2017, which can be viewed at:

(https://naturalprocesses.jbahosting.com/)

These maps are used as a starting point to view the different types of NFM interventions and their potential locations within the catchment in a completely unconstrained manner. Once this overview assessment has been analysed then local knowledge and constraints (derived from stakeholder engagement activities, etc.), together with specific NFM interventions, can add to/limit these potential NFM opportunities.

Within the River Dove catchment, a number of potential WwNP locations can be identified, including tree planting and runoff attenuation features (Table 3-1). Opportunities cover the entirety of the catchment (Figure 3-1). Around Kirkbymoorside, there is potential for increased riparian planting on surface water flow pathways (Figure 3-1). On the River Dove at Keldholme and Kirkby Mills, there are opportunities for floodplain reconnection and planting.

Table 3-1 Opportunities for NFM as identified in the WwNP Maps

Intervention Type	Area of Potential Opportunity (m^2)
RAFs 1% - Gully Blocking	56,904
RAFs 1% - RAFs	87,460
RAFs 3.3% - Gully Blocking	35,004
RAFs 3.3% - RAFs	78,144
Floodplain Reconnection	293,394
Floodplain Planting	1,618,019
Riparian Planting	10,425,369

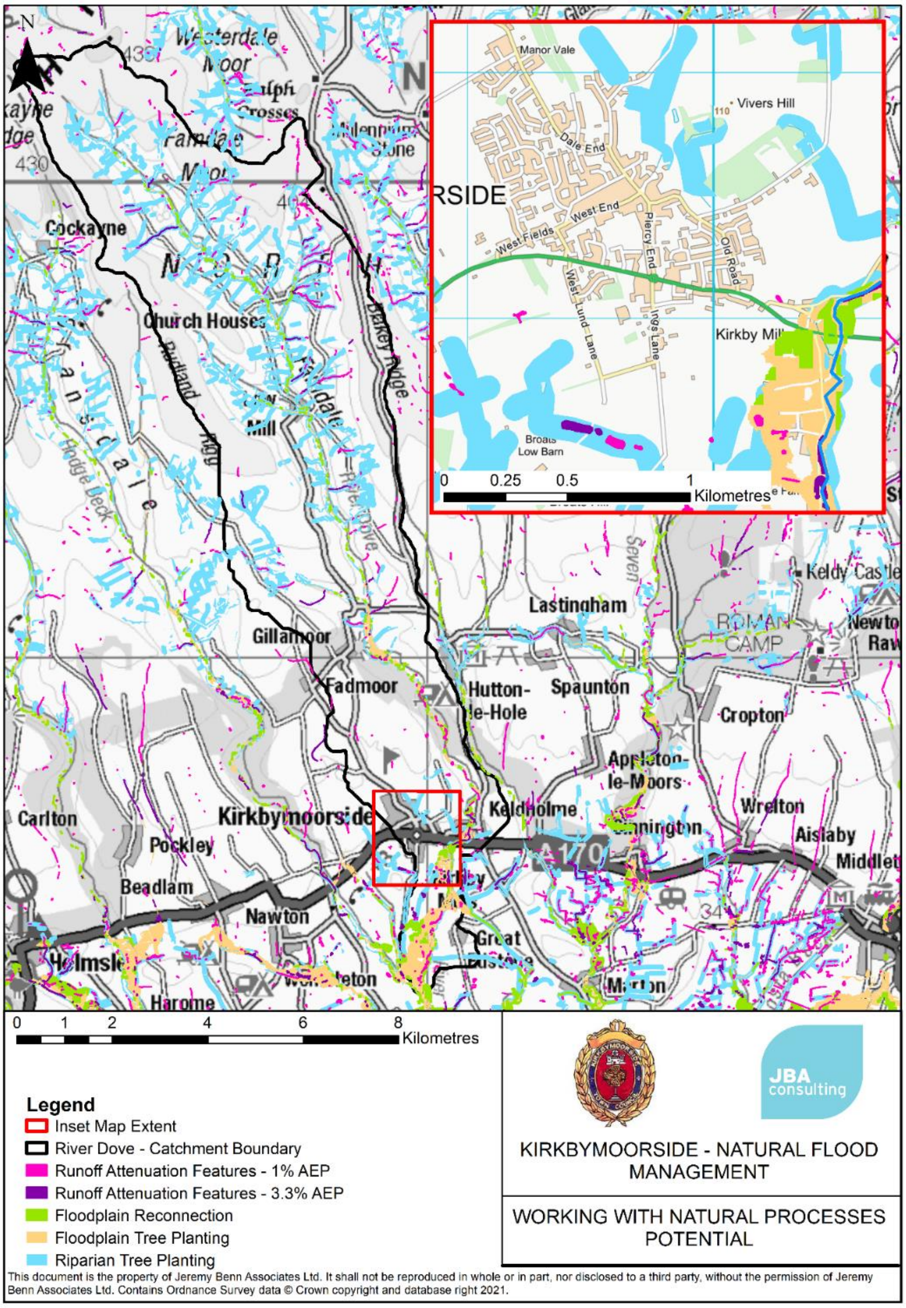


Figure 3-1 Working with Natural Processes Opportunities within the River Dove catchment

3.2 Site Walkover

A site walkover was undertaken by NFM specialists from JBA Consulting on September 1st and 2nd 2021. The walkover was used to check the feasibility of proposed NFM interventions from the desk-based assessment. The weather was dry on both days, with no heavy rainfall on previous days.

The morning of the 1st September was spent around Kirkbymoorside and Kirkby Mills, before moving up into the larger River Dove catchment for the remaining time on site.

3.2.1 Opportunities identified around Kirkbymoorside and Kirkby Mills

In summary, the NFM potential identified around Kirkbymoorside included (Figure 3-2):

- Offline storage in the arable and grass fields upstream and east of the golf course and on floodplain at Ravenswick Hall;

- Leaky barriers in Spring Wood to the south west of the golf club (subject to confirmation of channel/depression character), and in the springs area upstream of the churchyard and on the River Dove at Ravenswick;
- Woody debris in smaller spring-fed ditches near Neville Castle; and
- Riparian planting fenced off from livestock on banks of the River Dove at Keldholme.

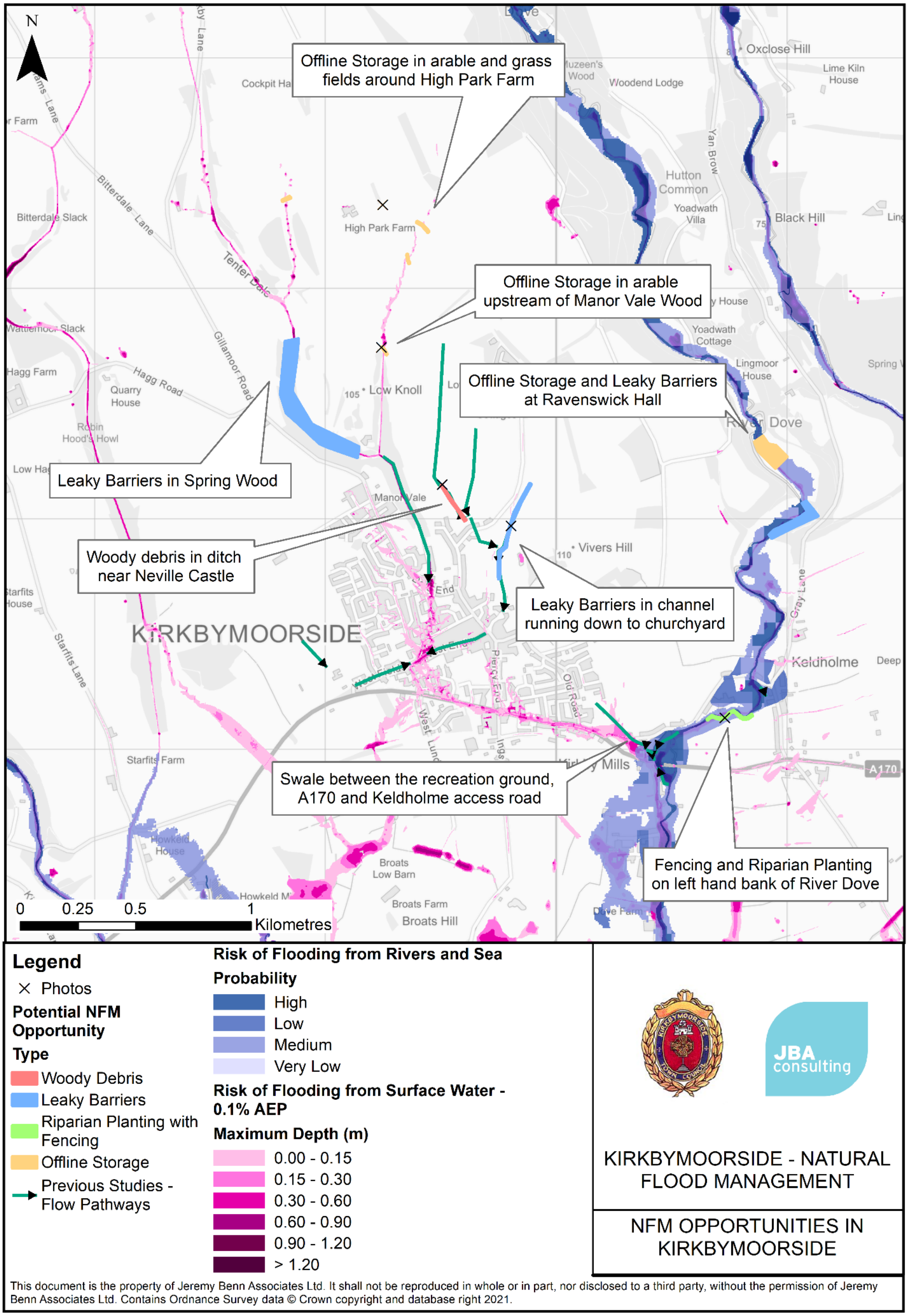
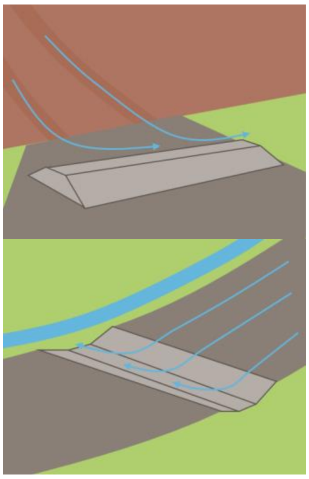


Figure 3-2: Summary of NFM Potential around Kirkbymoorside

The site visit started by walking up through Manor Vale Wood. Here, the footpath and then the road both appear to act as channels to quickly and effectively convey surface and drainage water from the surrounding agricultural fields down into Kirkbymoorside. The vegetation adjacent to both the path and Manor Vale itself is coarse. However, the path, and subsequently the road, are very smooth, providing little obstruction to flow. Without significant modifications to the path and road, for example through adding in speedbump type features (example image right) to push water into the adjacent coarser vegetation, there is little opportunity to slow the flow here. Although it was not visited during the site visit due to lack of public access, it is assumed that there is potential in Spring Wood (Figure 3-2) to the south west of the golf course for leaky barriers, if it is of a similar character to Manor Vale Wood but with a channel as opposed to a public right of way. Given the lack of access, this would need confirming by the landowner. With respect to the golf club some general advice would be to ensure that all the grassed areas, natural surfaces and soakaways within the entire golf course area are maintained to maximise the potential for the infiltration of direct rainfall and/or any surface runoff that is generated into the underlying soil.



The footpath through Manor Vale Wood then follows the edges of several, currently, arable fields. The gradient of the fields highlights the movement of water into the woods, and there are opportunities for earthen bunds (Table 4-1) to be added to create offline storage features in a number of places (Figure 3-2). When first leaving the woods, there is an opportunity to add a bund and create offline storage by taking advantage of the steeply sided fields (Figure 3-3). At the time of the site visit, arable crops had been present in this location which could be a potential constraint to a scheme. However, the feature could be designed to only be wet in times of flood and therefore maximise the potential for continued arable use. Further upstream, the gradient of the land is shallower. However, there is an opportunity to raise the track (Figure 3-2), where the surface naturally dips, to act as a bund feature and create a similarly low-level bund at the field boundary (Figure 3-3). Although there was no access closer, the gradient of the land in the improved grassland field immediately upstream of the golf course may also provide potential for offline storage (Figure 3-4). Given the dry weather conditions during the site visit, there is a need to ground truth the surface water flood maps to confirm surface water is apparent in the previously mentioned areas in periods of heavy rainfall to increase the optimum use of NFM.

As there have been potential storage opportunities identified within arable fields, there may be a need for compensation to the landowner for loss of crops if a flood were to occur. This is therefore a potential constraint to the opportunities identified here.

Figure 3-3: Arable field suitable for creation of offline storage upstream of Manor Vale woods (Left), Potential for offline storage by raising farm track and creating small bund along field boundary (Right)

Figure 3-4: Potential for bunded offline storage immediately upstream of the golf course.

A number of smaller springs arise within the catchment which are controlled by the local geological complexity, and also contribute to the flooding in Kirkbymoorside. Although it was difficult on the site visit to identify where these contributed to flooding in town directly, it is thought they contribute to the flow within the ditch running through the churchyard. These flow pathways are not represented on the surface water flood maps (Figure 3-2), due to the catchment's geology. However, the previous flood risk studies provide some understanding as to their origin and route into town[1]. The first was a small ditch in, what appeared to be an unused field near Neville Castle (Figure 3-2). This ditch could be filled with woody debris or leaky boards (Table 4-1) to slow and store water within the ditch. The second spring has a more substantial channel, where leaky barriers could be installed which utilised the floodplain which sits below the general level of the adjacent field. The riparian vegetation is generally coarse. There was, however, evidence of poaching due to the livestock having direct access to the watercourse causing degradation and erosion of bankside material. This material will reduce the water quality and has the potential to increase the risk of blockage to downstream infrastructure, including the culvert running under the churchyard. It is therefore advised that the watercourse be fenced off to reduce the risk of damage of measures implemented.

Figure 3-5: Ditch running through field adjacent to Neville Castle, suitable for woody debris or leaky boards

Figure 3-6: Spring running into the churchyard channel, suitable for leaky barriers extended onto the small floodplain

At Kirkbymoorside recreation ground and sports field, the gradient is very shallow. Therefore, there is limited capacity for storage and the watercourse is currently piped under the recreation ground[4]. Measures here would likely need to target excess overland flow which bypasses the drainage system (Figure 3-2). General advice for the recreation ground and sports field would be for all the grassed areas and natural surfaces to be maintained to maximise the potential for the infiltration of direct rainfall and/or any surface runoff that is generated into the underlying soil. The footpath appears to have a small depression which is assumed to store some water, although this would need to be verified given the dry conditions on the site visit. There is the potential to add a swale in the triangle of grass that sits between the access road to Keldholme, the A170 and the footpath parallel to the recreation ground. This ground, however, currently slopes downwards from the A170 to the footpath and, therefore, a significant amount of excavation would likely be required to route water a feature here. There are few other opportunities for SuDS in Kirkbymoorside due to the narrow streets.

The flood risk in the immediately vicinity of Mill Race at Kirkby Mills presents a challenge far greater than that which using NFM alone could solve. The much larger quantity of water coupled with the notably deep channel of the River Dove suggests a more engineered approach would likely be required here to increase floodplain connection and utilisation. Consideration may be given to flood embankments to protect the houses around Kirkby Mills. However, the Mill Race would still provide a conduit for water to reach the properties. A second consideration may be to remove the weir at Mill Race and at Keldholme to greatly increase the conveyance and capacity of the channel in addition to improving overall longitudinal connectivity of the River Dove geomorphologically and ecologically (especially for fish passage). Weir removal and re-introduction of natural river processes may also decrease the concern regarding debris and silt accumulation at the weir[2]. Property level flood protection should also be maximised. Himalayan Balsam was however present in the Mill Race. Himalayan Balsam is a non-native invasive species (NNIS) as it prevents the native species from growing. It easily spreads both upstream and downstream due to the explosive seed release. Due to its prolonged pollen season, it is thought to cause a decrease in pollination of native plants[9]. Therefore, any remedial works within the Mill Race would require additional care to reduce the risk of further spread of this NNIS.

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[9] https://www.plantlife.org.uk/uk/discover-wild-plants-nature/plant-fungi-species/himalayan-balsam

Figure 3-7: Mill Race weir, which could be removed to increase channel capacity and conveyance (Left). Improved grassland on riverbank which could be excluded from grazing (Right).

At Keldholme, the channel is too wide for any in-channel NFM measures. The majority of the floodplain is set far above the channel. However, in areas where the floodplain level is lower, fencing could be erected to exclude currently grazing livestock, which currently keeps the existing grass very short, and would allow for easy passage of water over the floodplain. Excluding livestock will encourage the natural re-growth of rougher vegetation to increase the potential for out-of-bank flow attenuation. This can be aided by the planting of a riparian buffer strip of rougher vegetation (Figure 3-7).

The River Dove floodplain upstream of Keldholme shows potential for large scale floodplain storage near to Ravenswick Hall (Figure 3-8). Similar to the private artificial lake constructed recently within the grounds of Ravenswick Hall, a feature could be designed to activate within flood flows and temporarily store water until the peak flow has passed. In this location flood debris has been noted on the floodplain and therefore is currently active, even if the river channel is dry within low flows. Landowner engagement would be required in this location. In addition, large scale woody debris could be encouraged within the channels to improve water retention and slow the flow.

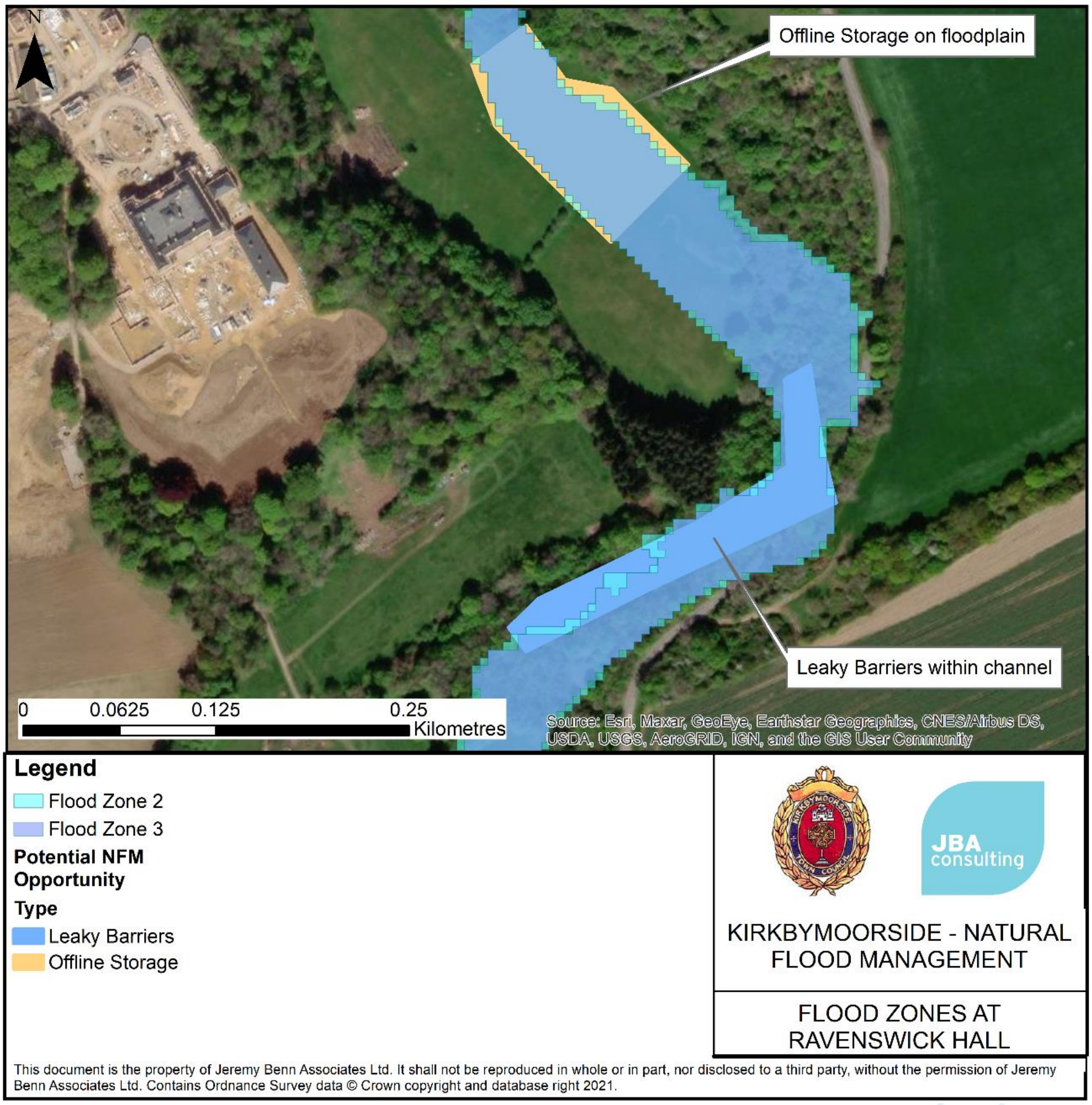

Figure 3-8: Flood zones and NFM opportunity at Ravenswick Hall

3.2.2 Opportunities identified in the wider River Dove catchment

In summary, the potential for NFM in the wider River Dove catchment (Figure 3-9, Figure 3-10) includes:

- Leaky barriers in tributaries of the River Dove, where channel width and depth are conducive to the addition of large woody debris (i.e. narrower than the height of riparian trees), including Harland Beck, West Gill Beck and Fish Beck;
- Riparian planting with fencing to exclude livestock along Fish Beck, although additional opportunity is likely in the upper reaches of the River Dove but would require landowner engagement to assess riparian character;
- Grip/drainage blocking along the disused Rosedale railway;
- Online storage using the disused railway embankment as an existing bund on Blakey Gill; and
- Clough planting in moorland gullies.

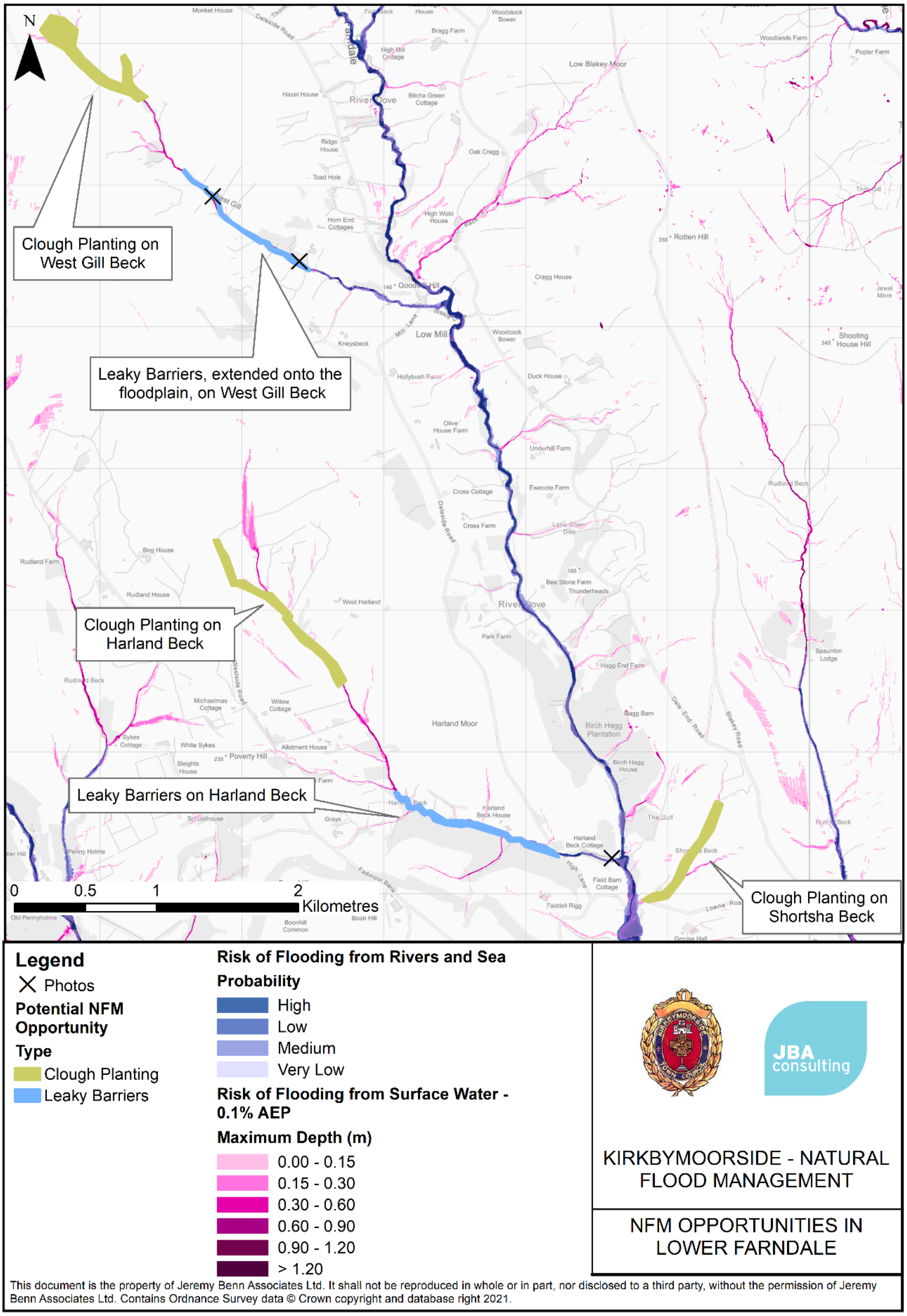

Figure 3-9: NFM Potential in Lower Farndale

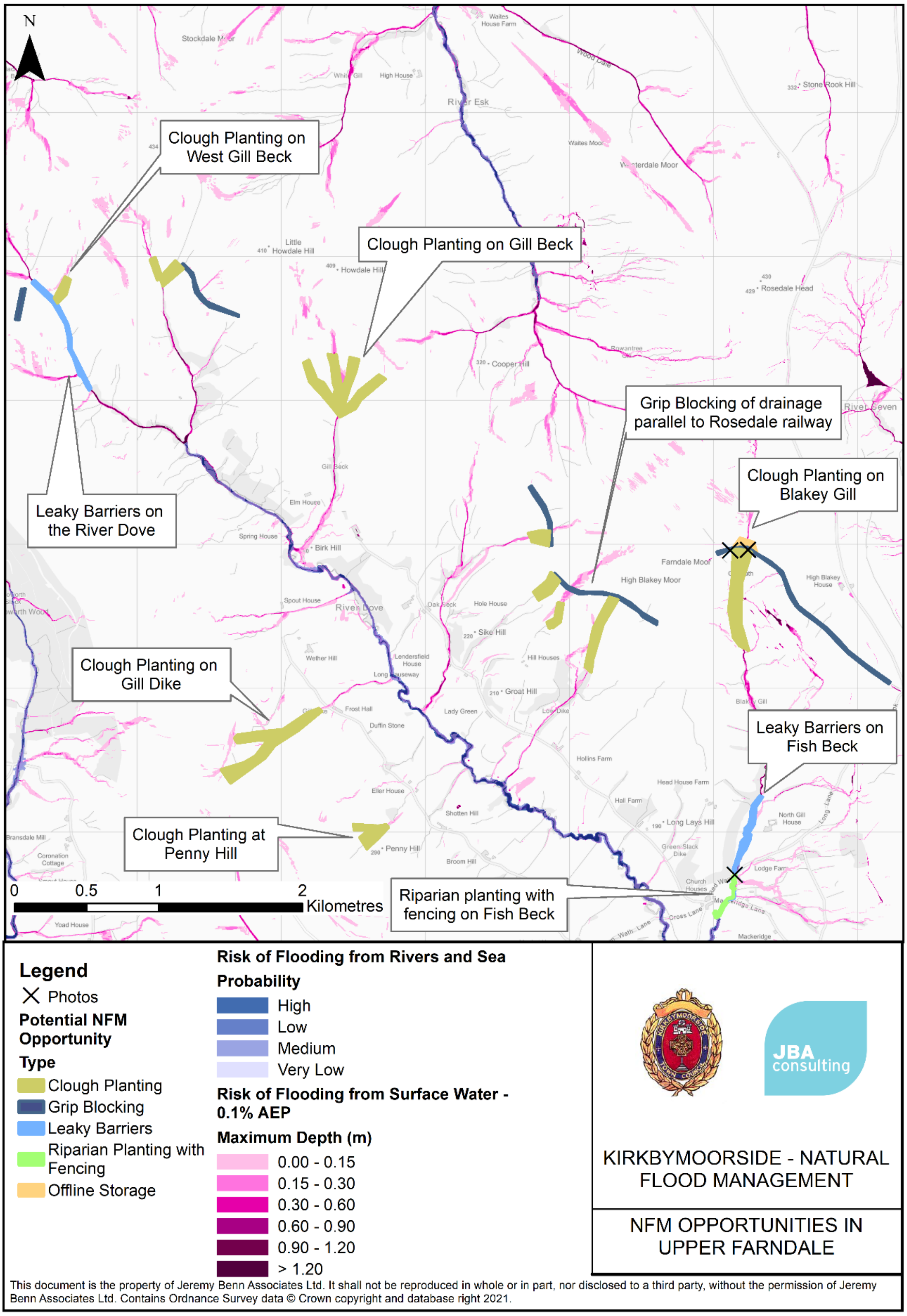

Figure 3-10: NFM Potential in Upper Farndale

The main channel of the River Dove for the majority of its length was observed to be too deep and wide for in-channel NFM opportunities. Given the depths of the channel, it also means floodplain reconnection would require a significantly engineered approach. However, of the reaches accessible via public rights of way, the riparian zones were often densely vegetation and excluded from grazing areas, increasing the likelihood of attenuation of out-of-bank flows. Accessibility via public rights of way limited the scope for identifying opportunities on the main channel upstream of High Mill, however we expect the channel to decrease in size to a point where in-channel NFM, such as leaky barriers, would be appropriate and therefore landowner engagement within the western side of Farndale would be advantageous (Figure 3-10).

The tributaries of the River Dove provide greater opportunity for in-channel NFM measures due to their smaller size. Although Harland Beck, at the confluence with the River Dove, is too deep and wide for in-channel NFM measures (Figure 3-11), the channel further up will likely be more suitable, although it would be beneficial to try and gain access to the channel further upstream to confirm this.


Figure 3-11: Channel character at the confluence of Harland Beck and River Dove (Left). Existing, naturally occurring large woody debris in West Gill Beck (Right).

On West Gill Beck (Figure 3-9), there is existing naturally occurring large woody debris, from decaying and living trees, blocking the channel (Figure 3-11). These blockages have collected additional smaller debris increasing water storage upstream. There is evidence on low lying floodplains that inundation and ponding of water occurs at higher flows, with debris and sediment collecting at the hillslope edge of the floodplain. Where the public footpath crosses the channel upstream of High Barn, a large dead tree trunk rests on the hillslope (Figure 3-12), this could be pulled down onto the floodplain to act as a blockage to high flows and increase storage on the floodplain.


Figure 3-12: Evidence of floodplain inundation (top) and potential material which could be used to increase floodplain storage (bottom) on West Gill Beck

The channel of Fish Beck is suitable for within channel NFM, such as leaky barriers, at Church Houses (Figure 3-13). Leaky barriers here and further upstream should be designed to take advantage of any floodplain which sits below the typical elevation of the adjacent fields. There was also evidence of poaching of the banks, therefore it would be advantageous for fencing to be erected in the riparian zone to exclude livestock and allow for the growth of rougher vegetation to increase the potential for attenuation of higher flows. We assume the channel is of a similar character upstream of Church Houses and would therefore be suitable for leaky barriers, however access is likely to become an issue within the more remote headwater areas.

Figure 3-13: Fish Beck at Church Houses, leaky barriers could be implemented here to utilise the floodplain

Upstream of Fish Beck is Blakey Gill, on the moorland plateau, there are opportunities to block the existing drains that runs parallel to the old Rosedale Iron Ore railway (Figure 3-14). Where Blakey Gill crosses the old railway embankment, there is an opportunity to utilise the existing embankment as a bund feature and sensitively modify the existing infrastructure (culvert/pipe), to allow for water to be stored upstream of the embankment in heavy rainfall (Figure 3-15).

Figure 3-14: Smaller drainage ditches parallel to railway embankment which could be blocked to create pool features

Figure 3-15: Large potential storage opportunity upstream of the disused railway embankment

4 Benefits of and constraints to Natural Flood Management

NFM is known to have a variety of additional benefits, other than reductions in flood risk.

Magic Map (Magic Map Application (defra.gov.uk)) provides a platform to explore authoritative geographic information from across government. Data that Magic Map provides can be used to identify additional benefits NFM may bring for biodiversity or water quality, for example, and may highlight potential funding streams through with NFM can be implemented, including Countryside Stewardship. This section identifies some of the benefits which may be realised from implementation of NFM measures for this catchment.

4.1.1 Biodiversity

Within the River Dove catchment, there are opportunities for Countryside Stewardship Scheme (CSS) agreements for management of rough grazing for birds[10], with a number of priority areas for measures addressing habitat issues for particular species including Lapwing, Curlew and Willow Tit. There are also areas of high spatial priority for woodland priority habitat networks and woodland improvement. The forthcoming Environmental Land Management Scheme (ELMS) that will replace CSS is another suitable funding stream to explore in due course to provide biodiversity and other benefits, including NFM.

The majority of the moorland headwaters of the River Dove catchment are protected as Sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC) and Special Protection Areas (SPA). The majority of the catchment is also covered by Priority Habitats, including lowland meadows, purple moor grass, lowland dry acid grassland, upland heathland, blanket bog and lowland fens. Such protections do not inhibit the implementation of NFM, however additional permissions will be required if measures are intended within protected areas.

4.1.2 Water

The whole catchment is under high priority for Countryside Stewardship agreements which target water quality, where incentives are offered to adopt agricultural practices which safeguard areas. Particular water quality issues within the catchment relate to sediment and phosphate. The catchment between Hutton le Hole and Kirkby Mills is a designated Nitrate Vulnerable Zone, where water is at risk from agricultural nitrate pollution.

The catchment is covered under both high and medium priority Countryside Stewardship agreements for flood risk management, with high priority areas focused primarily along the watercourses and medium priority areas in the headwaters. Priority areas for woodland (both for water quality and flood risk management) are also present.

A number of existing Countryside Stewardship agreements are present within the catchment, suggesting landowners may be receptive to NFM measures. The catchment is under the Less Favoured Areas designation, with areas of disadvantaged and severely disadvantaged and Agricultural Land Classification between Grade 3 and 5. Typically, NFM would be avoided on the most productive land (Grade 1 and 2).

The overall classification for the River Dove under the Water Framework Directive (WFD) is “Moderate”, reasons for not achieving “Good” status include point source - sewage discharge, physical modification – flood protection and physical modification - barriers (ecological discontinuity)[11]. Flood risk mitigation (either engineered or natural) should seek to improve the WFD status of the River Dove.

4.1.3 Site-specific NFM measures and benefits

Table 4-1 provides an overview of the benefits of the NFM measures proposed for the River Dove catchment.

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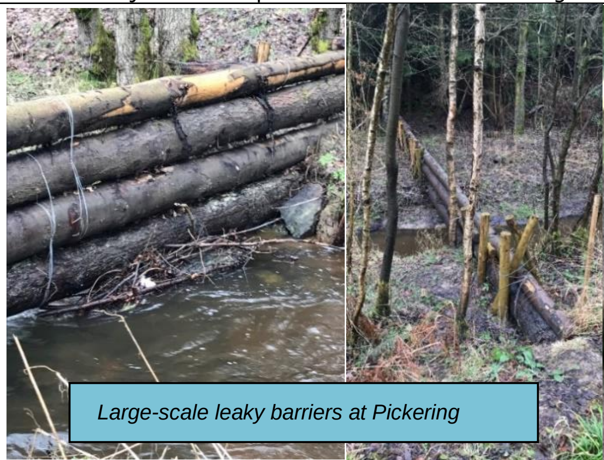
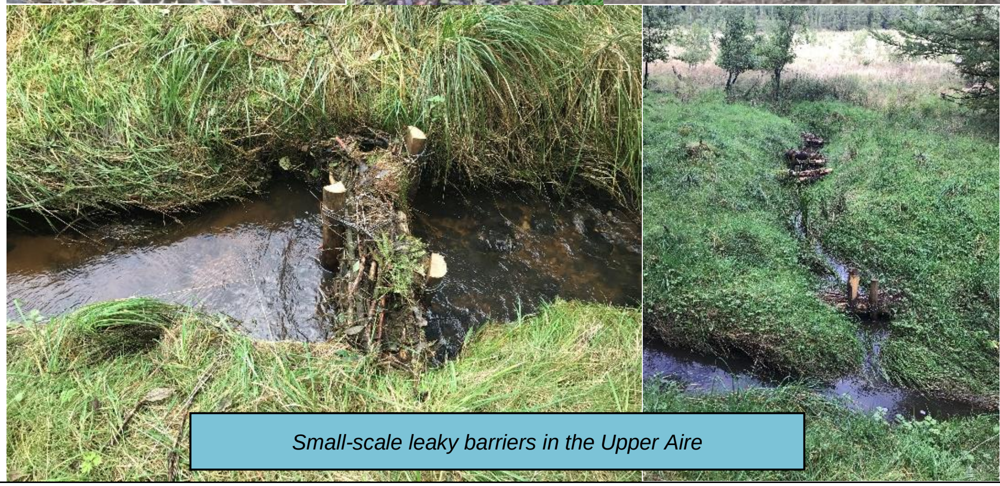
[10] UP2: Management of rough grazing for birds - GOV.UK (www.gov.uk)

[11] Environment Agency - Catchment Data Explorer

Table 4-1: Identified potential NFM measures within the River Dove catchment

Leaky Barriers and Woody Debris	
Description	Leaky barriers involve using natural on-site materials to block/slow the flood flows within streams and gullies. The dams are constructed above normal stream water level, allowing baseflow through/under each barrier before the flood flow starts to back up behind them prior to spilling over. During the rainfall event each individual barrier fills and spills in turn in a downstream direction. Once the storm peak has passed the leaky barriers use their "leakiness" to slowly drain away the stored flood flows. Where site conditions are suitable (i.e. where the channel is not overly incised), these interventions can also encourage the flood flows to flow out of bank and onto the adjacent floodplain areas for further storage.
Examples	 *Large-scale leaky barriers at Pickering*  *More 'natural' looking leaky barrier in Upper Frome*  *Small-scale leaky barriers in the Upper Aire*
Benefits	**Flooding** Each individual barrier in turn will not have significant impacts on any hydrograph peak. Multiple barriers within a system are needed to significantly reduce and slow any flood flows.

	Sediment As the barrier slows and temporarily stores flood water, it encourages sediment carried with the water to settle out and be deposited on the channel bed. Localised scour to the bed and banks may occur as water flows underneath the barrier and over the top of the barrier (during flood events).
	Habitat The sediment deposition and scour will aid the development of improved in-channel features such as the development of pool, riffle, and bar formations, therefore increasing the channel morphology diversity and providing improved hydraulic habitat variability for wildlife. The use of bankside timber may reduce channel overshading if tree cover is currently dense.
Design considerations	Leaky barriers should be implemented at reasonably regular intervals every 5-20m (or 7-10 times the channel width) depending on site characteristics (e.g. channel gradient, channel bed/bank composition, bankside tree anchoring opportunities), available resources and accessibility. At a minimum, the top of the downstream barrier must be lower than the bed elevation of the upstream barrier. Barriers should be no more than approximately 1.5m high even if this limits possible utilisation of the floodplain and subsequent additional benefits. Requires acquisition of significant timber (e.g. tree trunks and large branches). This can include locally sourced timber, however decomposition rates (which vary with tree species) of wood will affect the lifetime of the barriers. Leaky barriers can be created by laying two large stacks of tree trunks in a cross formation across the channel. Wherever possible, every single tree trunk/branch used to create a leaky barrier should be long enough to fully span the whole channel width, plus extend a further 1-2m (into the bank) and be securely anchored in position, (e.g. using vertical stakes and pins or lashing fixing them to other trees). Smaller timbers can be placed in-between larger ones. The horizontal logs are normally secured together to avoid the top logs floating off during flood events. The method of anchoring is very site specific (bed and bank characteristics). If site conditions allow, then two trees either side of the channel can provide additional anchor points. All other vertical anchors (not supported by bankside rooted trees) should be driven into the banks and not into the stream bed (where they will be more susceptible to local scouring action). Bank conditions should be frequently monitored as disturbing the bank during installation can cause accelerated future erosion. Typically, the top of the opening underneath the barrier is set at about 30cm above the normal baseflow level, though local site characteristics may influence this setting. The 'look' of the leaky barrier can be made to mimic woody barriers that would naturally form in watercourses flowing through mature woodlands, though sometimes this can add complexity and extra cost to the construction. Exact location, design and size of leaky barriers should be done on a barrier by barrier basis.
Maintenance	Following high flow events, each leaky barrier should be inspected for: Any debris trapped behind the barrier Integrity of the structure and the component parts Condition of the wood and materials
Permissions, consents, surveys	**Consents** Main River – Consent from Natural Resources Wales Other watercourses – Ordinary Watercourse Consent from Lead Local Flood Authority
	Ecology An ecologist should walkover the proposed reach to help inform the specific locations of each leaky barrier, identifying opportunities for habitat enhancement
Monitoring approaches	Record the location (OS Grid reference of every barrier) and store data in a GIS format. Photograph the channel at each barrier location (looking both upstream and downstream) before the barrier is implemented (in low flow conditions) and immediately after implementation (incl. photo of upstream and downstream faces of barrier). Photographs will also permit an assessment of the effect of the leaky barrier structure on the local in-channel hydromorphological conditions. Repeat photography from the same (fixed) position during low flow and flood flow conditions. Install and maintain time lapse cameras (with night vision), set up to obliquely view the leaky barrier from a nearby post or tree. Install graduated water level staff boards both upstream and downstream of the leaky barrier (with the top of staffs set at exactly the same absolute level) within the field of view of the time lapse camera. Install and maintain water level recorders both upstream and downstream of the leaky barrier (and ensure logger clocks are set identically and with the same recording timestep). Install and maintain a water level recorder downstream of a cascade (series) of 5-10 leaky barriers (and ensure logger clock is set identically and with same recording timestep as any other logger within the cascade).

Riparian Planting	
Description	Riparian woodlands could be described as a particular type of wide coarse buffer strip, in between the watercourse and adjacent land, which allows the maximum amount of contact between the trees and flood water. Buffer strips slow the flow in flood events as surface runoff must flow through a zone of rougher vegetation. Buffer strips also provide storage potential on the floodplain through improving the infiltration rate, helping to restrict the transfer of fine sediment and pollutants into the watercourse via overland flows. They can be used in both arable and grass fields and give the same result. Riparian vegetation can range from rough grasses/semi-natural vegetation to woodland. Low levels of vegetation maintenance might be required to control the vegetated area specially to control any invasive species. Additionally, they provide an area that is shaded with a moderate temperature providing an area of refuge, for both terrestrial and aquatic life. By building a small mound down the in-field buffer strip, a beetle bank can be created, further benefiting the wildlife, and encouraging natural predators of crop-eating insects, providing biodiversity enhancements and better habitat connectivity for wildlife to exploit.
Examples	 *Vegetated buffer strip along edge of arable field in Wharfe catchment*
Benefits	**Flooding** A well-managed woodland cover can increase the capture and evaporation of rainfall by interception. This can reduce the amount of rainfall reaching the ground by as much as 45%, or more for some types of woodland. A reduction of even half of this amount could therefore make a major contribution to flood control.
	Sediment Buffer strips can provide a physical barrier that helps restrict the flow of flood water, carrying sediment and nutrients, and prevents them from being washed from the field into the watercourse. The further development of the vegetated buffer strip will aid the improvement of bank stability and reduce the erosion risk through an increased root network within the soil substrate.
	Habitat Buffer strips help create wildlife corridors and sites for ground nesting birds, small mammals, and beneficial insects. Buffer strips can also provide support for more foraging pollinators. They also improve woodland connectivity to the wider landscape for mammals and birds and additionally provide areas of shelter for livestock.
Design considerations	Riparian buffer strips should be 5-10m wide and may require fencing to exclude livestock from the riverbanks. This allows the natural vegetation within this zone to grow producing a rough vegetated surface. These planted areas can be further enhanced into hedgerows or woodland planting which are natural weather barriers, protecting crops, soils, and livestock. They provide ideal habitat for farmland birds and wildlife species, and also perform a natural flood management function by trapping and slowing water flow.

	Consideration should be given for access to the vegetated buffer strip for maintenance of the vegetation and any in stream features. There could be a designated narrow access route from one side of the stream only where larger woody material (e.g. trees/shrubs) is excluded. Therefore, access is available for powered machinery and/or delivery of tree trunks/branches for restoration/re-creation of leaky barriers.
Maintenance	Dependent on the land use. Fertilisers and manures should not be used. If fencing is required, it should be inspected and repaired following large flood events.
Permissions, consents, surveys	Unlikely to be required. Fencing can be used along watercourses without need for a permit if it is post and rail or post and wire (strands of at least 100mm spaced mesh).
Monitoring	Undertake repeat habitat surveys to monitoring change in habitat type and extent. Hand draw habitat extents on a map and digitise using GIS.

Land and soil management	
Description	Land management measures across the catchment that seek to improve and maintain good soil structure and increase infiltration rates will contribute to an overall reduction the generation of surface runoff. In many cases, such practices will also help to improve productivity and yields. Management can include winter cover crops, cross slope soil cultivation, soil aeration and sub-soiling. Good farm management reduces the risk of soil damage by matching crop production to land capability with particular reference to the inherent wetness of land and soil. For example, late-harvested crops are unsuited to soils with seasonal waterlogging in high rainfall areas. Winter cover crop is a non-cash crop grown primarily for the purpose of protecting or improving the soil in between periods of regular crop growth. Especially through the winter months, a cover crop (e.g. rye-grass, clovers, black oats, forage rye, mustards, radishes, turnips, vetch), often sown as a mixture, that is grown to provide cover rather than leave bare soil reduces surface runoff and soil erosion, elevates organic matter content, helps weed and pest management and maintains soil structure and fertility. Soils that have been subjected to serious compaction during wet seasons need to be restored by deep cultivation and/or subsoil loosening during the next suitably dry periods. Compaction dramatically reduces the volume of coarse pores (drainable pore space) in upper soil layers. Compressed and compact soil has few pores and low air capacity. The formation of thin unnaturally impermeable layers can cause perched water tables and surface saturation. This generates enhanced surface runoff even though the soil below the induced impermeable layer is unsaturated and permeable. Reducing the impact of agricultural machinery on soil capping and soil compaction, for example, by increasing tramline spacing, using flexible low ground pressure tyres, decreasing loads, and using the correct tyre pressure can also increase infiltration and reduce runoff, particularly on wet soils. The use of a soil aerator (mechanical lifting or spiking of the soil), subsoiler and tramline management techniques (if undertaken at an appropriate time of the year and when the soil wetness condition is most suitable (i.e. reasonably dry) for these operations) can also improve infiltration in compacted soils in arable and grass fields while also benefiting crop/grass growth by increasing the amount of oxygen reaching the roots.
Examples	 *Cross-slope tramlines across field in Trent catchment* 

Benefits	**Flooding** Winter cover crops provides cover rather than leave bare soil thereby it reduces surface runoff. Reducing soil compaction increases the amount of water held in the soil over a wide area, reducing the amount of surface runoff and lowering flood risk.
	Sediment Winter cover crops provides cover rather than leave bare soil thereby it reduces soil erosion and runoff of sediment and nutrients. Reducing soil compaction reduces soil loss and poaching, improving water quality. Undertaking soil cultivations along contours (where it can be done safely), rather than straight up and down field slopes, can be particularly effective in reducing surface runoff and soil erosion.
	Habitat Winter cover crops used consistently over the years will improve soil structure and nutrient content, providing improved soil health and therefore habitat. They also reduce the need for herbicides and other pesticides.
Design considerations	The 2007 'think soils' manual (http://adlib.everysite.co.uk/adlib/defra/content.aspx?id=263233) is a practical guide to soil assessment which aims to help farmers and land managers to recognise problems with erosion and runoff from agricultural land. Compaction Look for signs of waterlogging – pooling water, algae growth, yellowing of crop/pasture. Dig a hole up to 40cm deep to look at the soil condition and depth of compaction in topsoil and subsoil. Undertake a soil test to identify pH, if under 6, add lime which encourages separation of soil particles, creating air pockets. Mechanically aerate soils using spiked aerators, subsoilers or sward lifters (depending on depth of compaction) – sub-surface and surface historic features can be damaged by mechanical treatment, particularly where these treatments have not been carried out before. Minimal tillage for arable crops or when reseeding. Crop and livestock rotation can reduce compaction whilst improving soil fertility and yield. Avoid using heavy machinery on wet soils. The 2017 publication "Soils and Natural Flood Management" (https://wrt.org.uk/wp-content/uploads/2017/12/soils-and-nfm.pdf) provides detailed guidance on identifying, remediating, and avoiding soil capping and soil compaction problems in various soil types. Winter cover crops Sow any plant with the ability to grow through winter. Leaving crop residues throughout winter can also protect the soil surface. Do not destroy until immediately before establishment of spring crop. Deep-rooted plants provide additional benefits to reduce soil compaction. May require altering of arable rotation away from winter drilling towards spring.
Maintenance	Requires use of suitable well-maintained machinery by an appropriately trained/skilled operator following best farming practices.
Permissions, consents, surveys	Consent generally not required for works aimed at reducing soil compaction. Use of sward lifers and subsoilers requires consultation with County Council or National Park historic environment team. Consent unlikely to be required for works to establish winter cover crops.
Monitoring	Regular soil assessment (typically either in autumn or spring) is recommended across both arable and grass fields for the early identification of potential soil degradation problems and the implementation of an appropriate remediation technique. An example of a simple and rapid visual evaluation of soil structure (VESS) has been developed by Scotland's Rural College (https://www.sruc.ac.uk/info/120625/visual_evaluation_of_soil_structure).

Offline Storage Areas	
Description	Offline storage areas are floodplain areas that have been adapted to retain and attenuate floodwater in a managed way. They usually require the construction of a containment bund which increases the amount of water that can be stored on a floodplain and may also require an inlet, outlet and potentially a spillway mechanism. Many different terms are used internationally to describe offline storage areas. However, the important difference between these definitions is the size and amount of engineering involved in the design. For example, the terms washlands (larger scale) and run-off attenuation features (smaller scale) are frequently used.
Examples	 *Runoff Attenuation Feature at Belford – Larger storage structure* 
Benefits	**Flooding** Dependent on the scale of the feature with more engineered options providing greater flood storage potential. Large woody debris structures can provide ample flood storage and encourage slowing flow. These features are leaky by nature and therefore attenuation benefits are reduced compared to engineered options.
	Sediment As water is held behind the barrier on the floodplain, deposition of sediment is encouraged. As sediment is deposited, nutrients and pollutants are retained in the field.
	Habitat Provide an area of terrestrial and aquatic habitats depending on the flow conditions of the river. This new habitat feature will develop a wide range of habitat niches at different inundation periods suitable for numerous of species including but not limited to, invertebrates, birds, reptiles and amphibians. The connection of the swale to the wetland habitat via the river will create an area of slower velocities and suitable area for fish to take shelter, once the flood event has passed this may cause fish stranding's.
Design considerations	Smaller scale floodplain storage through the use of large woody debris will require much less engineering with similar design considerations as specified in the leaky barrier section above. For larger features: Dimensions are entirely site dependent and will needed detailed specialist advice. Pre-works assessments and surveys will be required to ensure that works do not increase flood risk downstream. The careful construction of robust broad and shallow earthen bunds (with clay core) is needed using suitable soil/substrate and outlet piped culvert. Any bare soil would need to be revegetated. A slow-release culvert would be implemented through the base of the bund to allow the storage area to drain slowly after the peak of the storm event has passed. This outlet piped culvert would be sized according to storage volume and required discharge rate to ensure that the storage area can drain out completely (from full) within 24-48 hours. Slopes of the bunds will be designed to allow safe machine access for mowing or other land management, as well as safe grazing and allowing better blending with the wider landscape.

	However, by doing this it is recognised that this would sacrifice some storage volume, as well as increasing the bund material requirement.
Maintenance	Check for damage – particularly scour at inlet and outlet features - regularly but at least after significant rainfall events. Check outlet pipe for blockages and remove as necessary. Can be left to fill with sediment and revegetate, but at this point no more flood risk benefits will be provided. Management of vegetation may also be required.
Permissions, consents, surveys	Larger features may require planning permission. Permanent pond features on the floodplain of a main river requires a flood risk activity environmental permit from the Environment Agency. Land drainage consent from Lead Local Flood Authority if storage area alters flow on ordinary watercourse.
Monitoring	Record location (OS Grid reference of every offline storage) and store data in GIS format. Photograph channel at the location of where water exits onto floodplain and into the offline storage, the offline storage area and where water re-enters channel (design dependent) both upstream and downstream, before the offline storage area is implemented (in low flow conditions) and immediately after implementation. Photographs will also permit an assessment of the effect of the offline storage area structure on the local hydromorphological conditions. Repeat photography from same (fixed) position during low flow and flood flow conditions. Install and maintain a time lapse camera (with night vision) set up to obliquely view offline storage area from nearby post or tree. Install graduated water level staff boards where water exits the channel to enter the offline storage, within the offline storage area and where water re-enters the channel (with top of staffs set at exactly the same absolute level) within the field of view of the time lapse camera. Install and maintain water level recorders where water exits the channel to enter the offline storage, within the offline storage area and where water re-enters the channel (and ensure logger clocks set identically and with same recording timestep). Undertake topographic surveying prior to offline storage construction. Repeat survey following construction and after large flood events to measure levels of sedimentation. Observe and take notes of scour where water exits onto the floodplain, at inlet and outlet infrastructure of the offline storage area (if applicable) and where water re-enters channel. Undertake repeat habitat surveys to monitoring change in habitat type and extent. Hand draw habitat extents on a map and digitise using GIS.

Grip and Gully Blocking	
Description	Grip and Gully blocking[12] involves the construction of dams across gullies or grips to block the flow pathway and slow the flow of water. Sediment and vegetation accumulate behind the dam restoring the eroded gully. It can also involve completely infilling the gully.
Examples	  Moors for the future – gully blocking
Benefits	**Flooding** Similar to a leaky barrier, each individual barrier in turn will not have significant impacts on any hydrograph peak. Multiple barriers within a system are needed to significantly reduce and slow any flood flows.
	Sediment Gully blocking has been shown to decrease erosion and encourage fine sediment accumulation. In addition, flood velocities are decreased downstream to aid further erosion.
	Habitat Small pools of stored water are created which can enhance local wildlife. In addition, the higher water table encourages restabilisation and filling in of the gully, revegetation will occur, increasing carbon sequestration and habitat availability.
Design considerations	Dams should be wider than the grip or gully they are blocking, with a lower section in the middle to reduce the risk of erosion at the edges. Completely infilling the gullies will create wetter areas, allowing water to dissipate over the moor. Variety of materials can be used (timber, stones, heather) which vary in cost and permeability. Built in succession, dams should not overtop as this may impact the integrity of the dam itself and cause erosion downstream. Timber dams are built in a similar fashion to leaky boards (see below), where the retaining posts are knocked into the ground and trenches dug into the sides of the gully to slot the timber boards in. The size of gaps between each board will alter the amount of water ponding that will occur.
Maintenance	Check for damage, including erosion, after significant rainfall events.
Permissions, consents, surveys	Planning permission may be required for moorland restoration.
Monitoring	Repeat surveys to note geomorphological change (particularly erosion), water storage and revegetation. Ecological surveys, including vegetation, habitat and species change.

[12] Moorsforthefuture - Grip and Gully Blocking - https://www.moorsforthefuture.org.uk/__data/assets/pdf_file/0022/87430/Grip-and-gully-blocking-Factsheet.pdf

Clough Planting	
Description	Small blocks of broadleaf tree planting in areas of steep-sided valleys on the edges of open moorland[13]. Native species include Oak, Birch, Rowan, Aspen, Alder, Willow, Hawthorn and Holly and clough woodlands often have varied structures. Benefits may include contribution to bracken control, shade and shelter for livestock and a source of timber.
Examples	 Clough woodland – Moors for the Future
Benefits	**Flooding** Increase roughness of the surface in areas where flow is usually very fast, encouraging water to slow down on steep slopes
	Sediment Planting trees can improve the soil structure and resilience, reducing erosion and improving water quality
	Habitat Clough woodland connects moorland to high value habitat in the valley, providing a corridor for wildlife movement. Trees provide food and shelter for both moorland species and livestock.
Design considerations	Trees should be planted in accordance with UK Forestry Standard, aiming to achieve National Vegetation Classification. Each block should consist of 40% open ground and 60% varied density tree planting (~1,600 trees per hectare). Fencing may be required, particularly during initial woodland establishment.
Maintenance	Monitoring to ensure quality is maintained (removal of broken stakes and tree guards) Some removal may be required
Permissions, consents, surveys	Discussions with Environment Agency, Natural England and Forestry Commission to create a woodland management plan. Land drainage consent, flood defence consent and herbicide consent may be required.
Monitoring	Monitoring to determine if additional bracken control would be required Habitat monitoring if the site is designated

[13] Clough Woodland Project | Moors for the Future

5 Conclusions

5.1 Summary

The River Dove catchment and the flooding issues occurring downstream at Keldholme, Kirkbymoorside and Kirkby Mills provide an interesting mitigation challenge. Historic features such as the urban drainage system in Kirkbymoorside, and natural features such as the hydrogeological controls, increase the complexity of any given possible solution.

JBA Consulting has identified, and ground-truthed a number of opportunities for NFM, both within the vicinity of Kirkbymoorside and within the wider River Dove catchment. Opportunities include: the addition of leaky barriers in channels which are suitably narrow and shallow for their construction; riparian planting particularly where livestock is currently allowed on the riverbanks; offline storage in natural depressions in the topography or on readily accessible floodplain; grip/drainage blocking in the moorland headwaters; and clough planting in the steep-sided valleys running down from the moorland headwaters.

It should, however, be acknowledged that the quantity of water causing the flooding issues particularly at Kirkby Mills (in larger flood events) is greater than that which could feasibly be reduced using NFM measures alone, particularly when accounting for geological influences. Therefore, JBA suggests that a combined approach is investigated, where NFM in the wider River Dove catchment is combined with a more engineered approach at/around Kirkby Mills to attain greater certainty in the reduction to flood risk. A greater understanding of the geological influences will enable quantification of the volume of storage required for any given level of protection. Removing the weirs at Kirkby Mills and Keldholme may increase the capacity and conveyance of the channel in times of flood, as well as increase the wider ecological and geomorphological connectivity, further restoring the natural functioning of the river. NFM could be targeted at especially lower magnitude flooding issues within the local area.

5.2 Recommended next stages

Further to the recognition of NFM opportunities across the catchment, additional opportunities may be identifiable on private land that could not be investigated during the site visit. It is therefore advised that landowner engagement is increased to further identify additional opportunities and increase awareness of the benefits of NFM in the catchment as a whole. Local authorities, such as the North York Moors National Park Authority, may be able to help with this as well as provide information to landowners on potential funding streams (current, new and future), such as the Farming in Protected Landscapes Programme[14]. For moorland specific NFM and restoration, the Yorkshire Peat Partnership[15] has vast experience in regeneration of moorland across North Yorkshire.

As discussed previously, investigating the potential for a more engineered approach to flood risk mitigation, particularly at Kirkby Mills would be advantageous, alongside an assessment to quantify the influences groundwater has on flooding in the area. Recommendations from the EA's 2002 report[4] should also be added to the options proposed in this current study.

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[14] Farming in Protected Landscapes (northyorkmoors.org.uk)

[15] Home | Yorkshire Peat Partnership (yppartnership.org.uk)

Our services

Our skilled and interdisciplinary team has extensive experience in WWNP/NFM. We have a strong foundation in surface water, fluvial and coastal flooding processes.

Our team brings further knowledge and skills in land and soil management, understanding the landscape, clear communication, and appreciation of the wide range of benefits to people and society that WWNP/NFM can bring.

We can work with you and your catchment partners to understand and implement NFM within your catchment to help reduce flood risk, improve water quality and biodiversity, and deliver health and well being benefits.

- NFM assessment
- NFM potential mapping
- NFM modelling and visualisation
- NFM benefits quantification
- NFM implementation
- NFM monitoring
- NFM training
- NFM knowledge transfer and engagement

https://www.jbaconsulting.com/what-we-do/environmental-services/natural-flood-management/

In terms of the Mill race weir removal potential option. JBA's Catchment and River Restoration Team (#CRRTeam) has a wealth of experience carrying out baseline ecological, fisheries and geomorphological assessments, developing concept options and developing river restoration schemes through to construction.

Our approach would be to follow the below steps:

Project step	Outline costs
High level feasibility/inception stage including: - Site visit - Understanding of constraints such as services, heritage assets, flood risk, nearby properties etc - Data collection of any available model/flow data The aim of this study is to determine at a high level whether removal of the weir is feasible. The reporting would detail the works required in future stages and the costs in more detail.	£3k
Outline design: - Detailed modelling of weir removal, with a focus on: o Flood risk o Bank stability upstream - Working with a contractor to plan works to minimise risk to environment	£5k to 15k
Detailed design - Engineering drawings suitable for construction - Designers Risk Assessment	£5k to 15k
Permitting and planning - Flood Risk Activity Permit (from EA) - Impoundment licence (from EA) - Planning permission	£5k to 15k

Appendices

A.1 Full sized NFM opportunity maps

A3 sized maps of Figure 3-2, Figure 3-9 and Figure 3-10 available as separate PDFs.

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