Opportunity mapping for natural flood management: a case study of the Don Hidden Heritage Secret Stream Project

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Contents

Note of caution

Mapping and modelling is limited by the resolution of data used, the methods and process in this report are meant to help guide practitioners to areas of interest in a catchment where interventions may be required. The exact location of these interventions will need to be ground truthed in order to assess the overall impacts of the intervention. Throughout this report, further reading is suggested.

Abbreviations used in this report:

BAP – Biodiversity Action Plan

CEH – Centre for Ecology and Hydrology

DCRT – Don Catchment Rivers Trust

FEH – Flood Elevation Handbook

GIS – Geographic Information System

HHSS – Hidden Heritage Secret Streams

HLF – Heritage Lottery Fund

LNR – Local nature reserve

LWS – Local Wildlife sites

NFM – Natural Flood Management

SAC – Special areas of conservation

SPA – Special Protection areas

SSSI – Sites of special scientific interest

Executive Summary

In 2018 the Don Catchment Rivers Trust (DCRT) were awarded a grant from the Heritage Lottery Fund for 'Hidden Heritage Secret Streams', a project based on the Upper Rother catchment. One of the aims of the project is to implement volunteer-led natural flood management interventions, with the aim to slow the flow, decrease diffuse pollution and increase landscape habitat connectivity. Prior to this iCASP project, the DCRT did not have access to a consolidated dataset to inform where the interventions should be placed. This project has mapped open source datasets to identify where problem areas are within the catchment, related to overland flow and diffuse pollution. Further, areas where habitat connectivity could be improved have been mapped. Habitat connectivity is often not incorporated in NFM modelling, this work has shown that freely available models can be used to investigate potential locations to increase connectivity. Combining the datasets allows interventions to be placed and prioritised. The placement of interventions has been informed by an expert advice workshop, attended by people from local authorities, statutory agencies and universities.

This report outlines the processes undertaken to produce opportunity maps for the Don Catchment Rivers Trust.

1. Introduction

Natural flood management (NFM) is a technique that aims to work with natural catchment processes such as planting trees and the addition of large woody dams. Flood risk and environmental benefits include, but are not limited to: slowing flood peaks, reducing the depth and duration of flooding, reducing soil erosion and sediment risk, increasing carbon storage, improving water quality and increasing habitat connectivity. Natural flood management is increasingly being used for catchment management in the UK, as catchment-wide approaches have been championed, further, NFM offers sustainability benefits and can provide additional protection against climate change.

Although a range of models exist that can be used to assess where interventions should be placed and their impacts (including hydrological and hydraulic models), this project is based on a GIS mapping approach. Hotspot maps can be produced to assess the variation in a key parameter of interest to show where the greatest risk or potential is. Opportunity mapping uses hotspot maps, associated data and catchment knowledge to produce a targeted map of key locations within a catchment where interventions should be placed for maximum benefits.

The Don Catchment Rivers Trust (DCRT) has been awarded a Heritage Lottery Fund grant for a project entitled: Hidden Heritage Secret Streams (HHSS). One element of the project is related to implementing volunteer-led natural flood management with the aim to: 1) reduce diffuse agricultural pollution, mainly related to sediment; 2) slowing overland flow and; 3) increase the ecological connectivity of the landscape. One of the aims of the iCASP project is to understand where NFM interventions can have multiple benefits, for example where can interventions that slow the flow / decrease diffuse pollution also be used to increase habitat connectivity. The DCRT have a number of interventions that could be utilised (Appendix 1), however, this list has not been prioritised from a volunteer friendly point of view nor on the potential impacts the interventions could have. In order to better understand the catchment, hotspot and opportunity maps were produced to inform management options. The hotspot mapping only relates to the three aims above, as these are the focus of the HLF bid. However, NFM has a range of benefits that have not been mapped in this project.

This work has been informed by a workshop, hosted at the University of Sheffield by iCASP universities (University of Leeds, York and Sheffield) and the Don Catchment Rivers Trust held in January 2019. The workshop included experts on Natural Flood Management from the iCASP universities, and stakeholder organisations such as Derbyshire County Council, Derbyshire Wildlife Trust, Environment Agency and Sheffield and Rotherham Wildlife Trust. In total, 19 people attended. The aim of the workshop was to understand how organisations currently implement NFM measures, how different maps could be used to implement NFM, what NFM measures are volunteer friendly and how the effectiveness of NFM can be monitored. Information gathered from the workshops has fed into this report, for example by assessing which NFM interventions (Appendix 1) are volunteer friendly.

The main purpose of this report is to showcase the steps taken to produce opportunity maps for volunteer led interventions using freely available datasets, in order to highlight key areas to prioritise when implementing NFM interventions at a sub-catchment scale.

Key words:

Hotspot mapping: The process of identifying key areas of interest within a catchment e.g., areas of increased erosion risk.

Opportunity mapping: The process of mapping where interventions can be placed within a catchment.

Further reading:

Forbes, H., Ball, K., and McLay, F., 2015. Natural Flood Management Handbook. Scottish Environment Protection Agency.

Burgess-Gamble, L, Ngai, R., Wilkinson, M., Nisbet, T., Pontee, N., Harvey, R., Kipling, K., Addy, S., Rose, S., Maslen, S., Jay, H., Nicholson, A., Page, T., Jonczyk, J., and Quinn, P. 2018. Working with Natural Processes – Evidence Directory. Environment Agency.

Currently, several iCASP projects are looking at NFM from different viewpoints:

Monitoring – 'Natural Flood Management': Link to NFM project on iCASP website

Modelling – 'Natural Flood Management': Link to NFM project on iCASP website and 'Calderdale NFM': Link to Calderdale NFM project on iCASP website

Payment for Outcomes (PfO) – 'Payment for outcomes': Link to PfO project on iCASP website

Community of practice (COP) - Link to NFM COP on iCASP website

Future projects, which may have an NFM aspect, will be posted here: Link to projects on iCASP website

2. Catchment overview

The study area for the HHSS project is the Upper Rother, which is a main tributary of the River Don. The Upper Rother contains the following major rivers: The Moss; River Drone; Barlow Brook; Holme Brook; River Hipper; Redleadmill Brook; Spital Brook and River Rother (Fig. 2.1). Under the Water Framework Directive (WFD), the study area can be divided into 10 waterbodies (Fig. 2.1); of these 10 waterbodies 4 failed to reach 'good' ecological status, for cycle 2, due to sediment (Appendix 2).

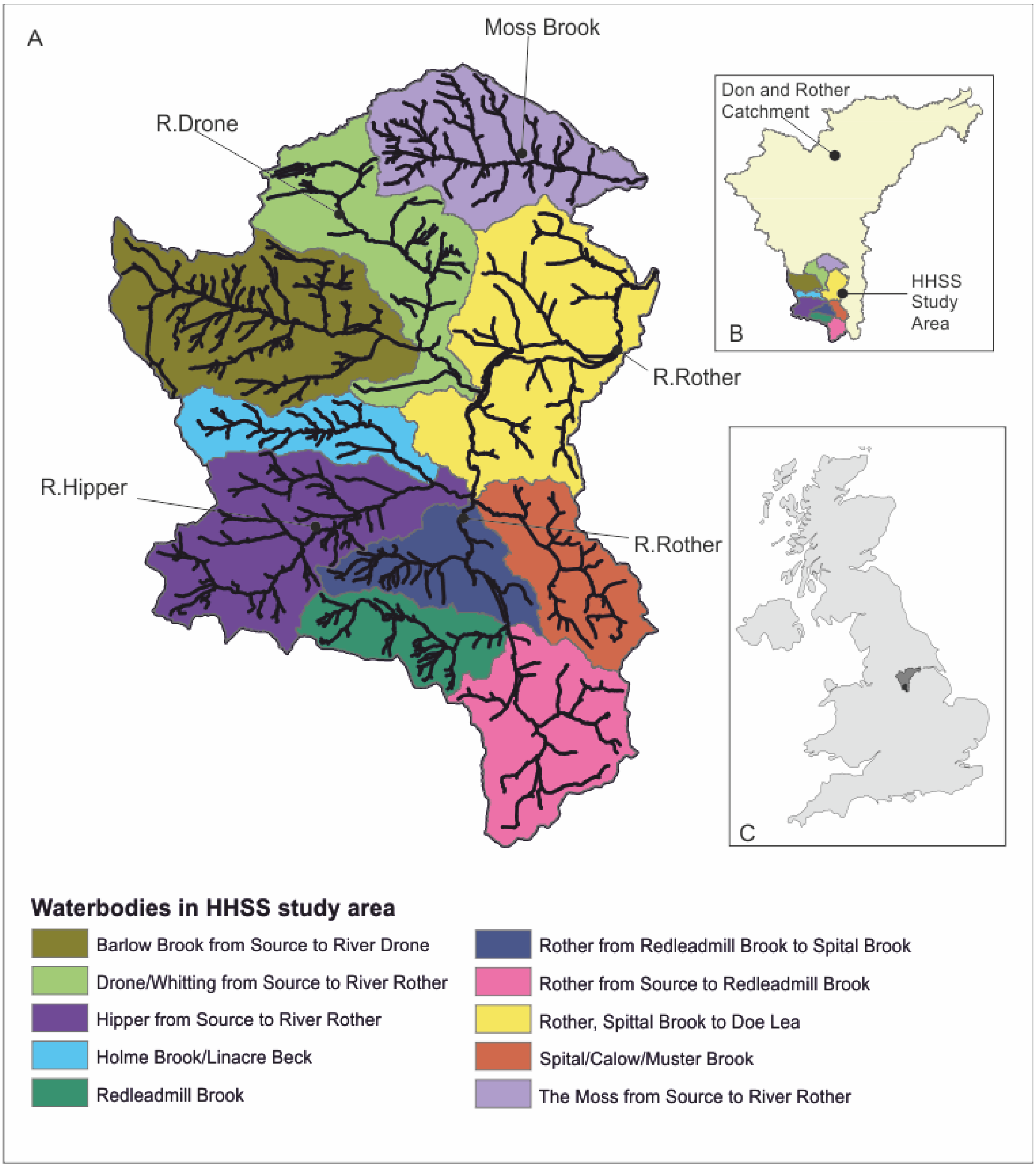

Figure 2.1 *– A) Location of HHSS study areas and Water Framework Directive waterbodies. The rivers shown are main rivers, as depicted by the Ordnance Survey. Inserts show the study area within the B) Don and Rother catchment and C) the UK.*

The study area is 215.75 km^2, and ranges in elevation between 40 and 400 m (Fig. 2.2A), slopes range from 0º to 55º with steep areas found within the upland areas of the catchment, most noticeably in the Moss Brook sub-catchment (Fig. 2.2B).

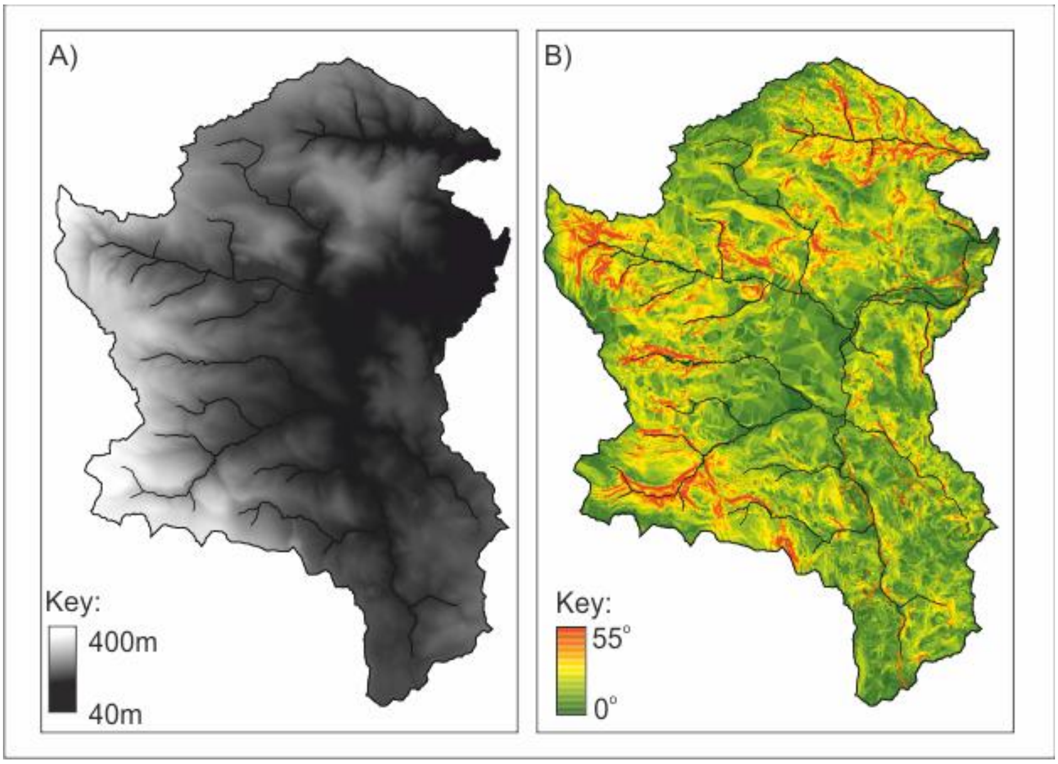

Figure 2.2 – HHSS study area maps showing: A) topography of the HHSS study area and; B) slope.

2.1 Catchment issues

As previously outlined, the HHSS project aims to use NFM to: 1) reduce diffuse pollution; 2) slow the flow and; 3) increase landscape connectivity. For that reason, this report focuses on these three aims. The following chapter, sets the scene for the opportunity mapping.

NFM has multiple benefits and can improve the following issues, but is not limited to only these: carbon sequestration; air quality; biodiversity; health, cultural value etc. For more information read:

Burgess-Gamble, L, Ngai, R., Wilkinson, M., Nisbet, T., Pontee, N., Harvey, R., Kipling, K., Addy, S., Rose, S., Maslen, S., Jay, H., Nicholson, A., Page, T., Jonczyk, J., and Quinn, P. 2018. Working with Natural Processes – Evidence Directory. Environment Agency.

2.1.1 Diffuse pollution

Diffuse rural pollution can relate to a range of pollutants deriving from agricultural runoff such as phosphate, nitrates and sediment. This work has focused on fine grained sediment as a diffuse pollutant, as this is a good indicator of agricultural run-off including phosphates and nitrates. Hereafter, diffuse pollution when discussed in the report refers to fine-grained sediment (silt or sand carried in suspension in a river).

Fine-grained sediment, as a diffuse pollutant, can cause multiple issues within a catchment such as; increased water treatment costs due to removing sediment from water; reduced ecological diversity (e.g., due to clogging gravels and reducing spawning areas); increased flood risks (e.g., around bridges and culverts, where sediment reduces storage capacity) and reduced recreational areas[1]. Of the four waterbodies within the study area which failed to reach good ecological status due to sediment, one was confirmed (by site visit) to have a significant fine sediment load, however the other three are not confirmed.

2.1.2 Hydrological overview

There is a long history of flooding within the entire Don Catchment, with recent large floods in 2019, 2015, 2007 and 2000. The Flood Management Plan for the Don (Environment Agency, 2010)[2], states that '*within the Don catchment there are 16587 properties at risk from a one per cent (1 in 100 year flood) probability flood from rivers, without taking into account flood defences*' (pg. 6). The risk in the catchment is likely to change due to climate change resulting in more frequent and intense storms and the increased amounts of winter rainfall. Within the HHSS study area, currently there are 1,731 properties at risk of flooding during a one in 100 year flood assuming no defences. This may rise to 1,899 in the future (Environment Agency, 2010[2]). When any flood management is placed in a catchment, the synchronisation of tributaries needs to be investigated and planned for to ensure that the interventions do not synchronise the flood peak and therefore exacerbate flooding.

Figure 2.3 highlights the areas at risk of a 1 in 30 year and 1 in 100 year flood (Figure 2.3A), and areas of risk within the catchment (Figure 2.3B). Figure 2.3B is a combination of local water level and flood defence data, which has been used to model flood risk over 40 different categories. The main rivers and largest tributaries have been highlighted to have the highest flood risk.

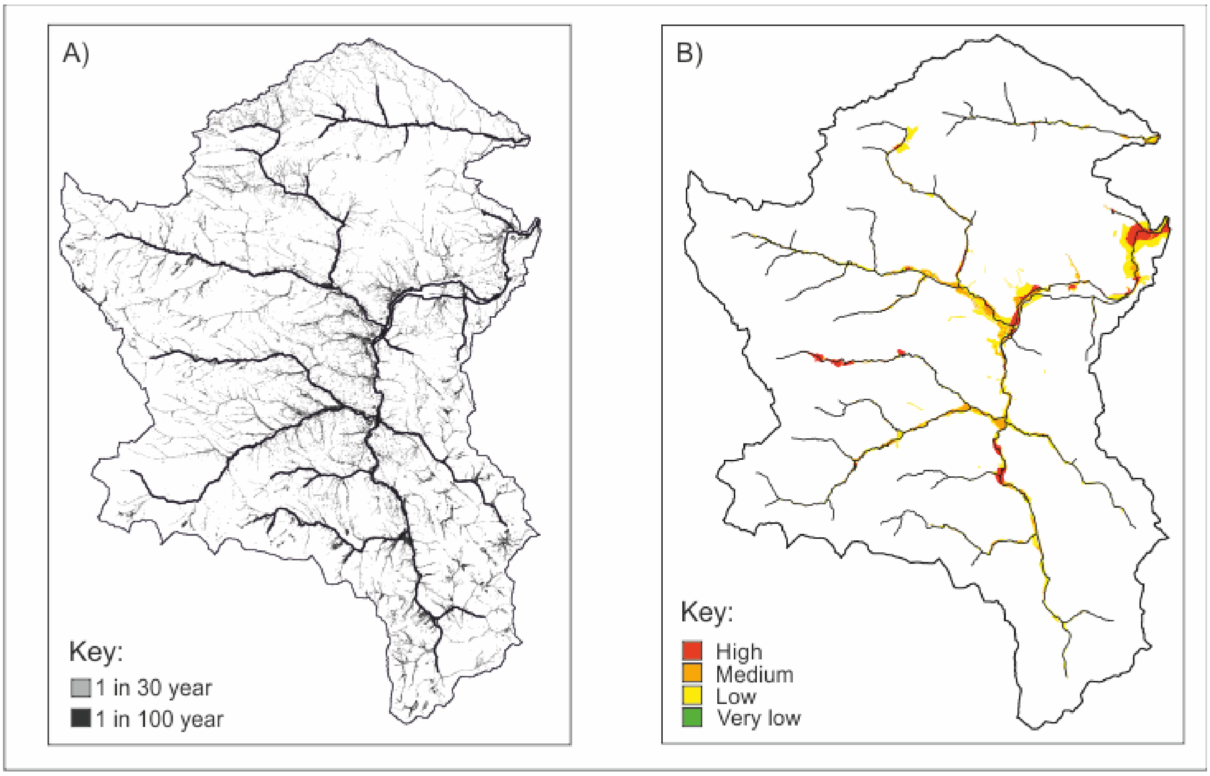

***Figure 2. 3** – Flood risk within the catchment; A) map showing 1 in 30 year and 1 in 100 year flood extents and; B) flood risk ranging from very low to high. High flood risk relates to a 1/30*

[1] For example: Holmes, 1988; Owens et al., 2005; Reaney et al., 2011; Rickson, 2014

[2] Environment Agency. (2010). Don Catchment Flood Management Plan, Summary Report: Managing Flood Risk. [Don Catchment Flood Management Plan](#) accessed June 20th 2019].

year flood, medium risk relates to a flood risk of between 1/30 year to 1/100 year flood, low flood risk relates to 1/100 year to 1/1000 year flood and very low where there is a greater than a 1/1000 year flood.

2.1.3 Habitat overview

There are several designated sites within the catchment (Fig 2.4), including statutory designations such as sites of Special Scientific Interest (SSSI), Special Areas of Conservation (SAC), Special Protection Areas (SPA), and Local Nature Reserves (LNR). Additionally there are non-statutory sites such as country parks, ancient woodlands and local wildlife sites (LWS).

Figure 2.4 shows designations that are held under different statutory legislation. SACs and SPAs are designated under European Law and represent internationally important habitats; SSSIs are designated under UK law, and represent the UKs best sites for nature and geology; LNRs are designated by local authorities and are important for wildlife, geology, education and public enjoyment. Non-statutory sites, are not designated under law, for example local wildlife sites (Fig. 2.4). LWS are sites with substantive nature conservation value, and can be based on distinctive and threatened habitats and species. Many of the sites contain habitats and species that are priorities under the county or UK Biodiversity Action Plan (BAP). LWS play a critical role in refuge areas and can provide stepping stones between other protected sites[3]. For this work, local wildlife sites have been used to investigate habitat connectivity (Fig. 2.4; Section 3).

Appendix 3 details the BAP priority species and designated citation species present within the catchment; when assessing habitat connectivity at a species level different design elements may be required than when looking at connectivity at a landscape scale.

> For further information on the habitats within the catchment read:
>
> Lowland Derbyshire Biodiversity Partnership, Derbyshire Wildlife Trust (2017). Lowland Derbyshire Biodiversity Action Plan. Summer 2017. Available: Lowland Derbyshire Biodiversity Action Plan

[3] Wildlife Trust – Descriptions of different types of protected wildlife sites in the UK [accessed 26/07/2019]

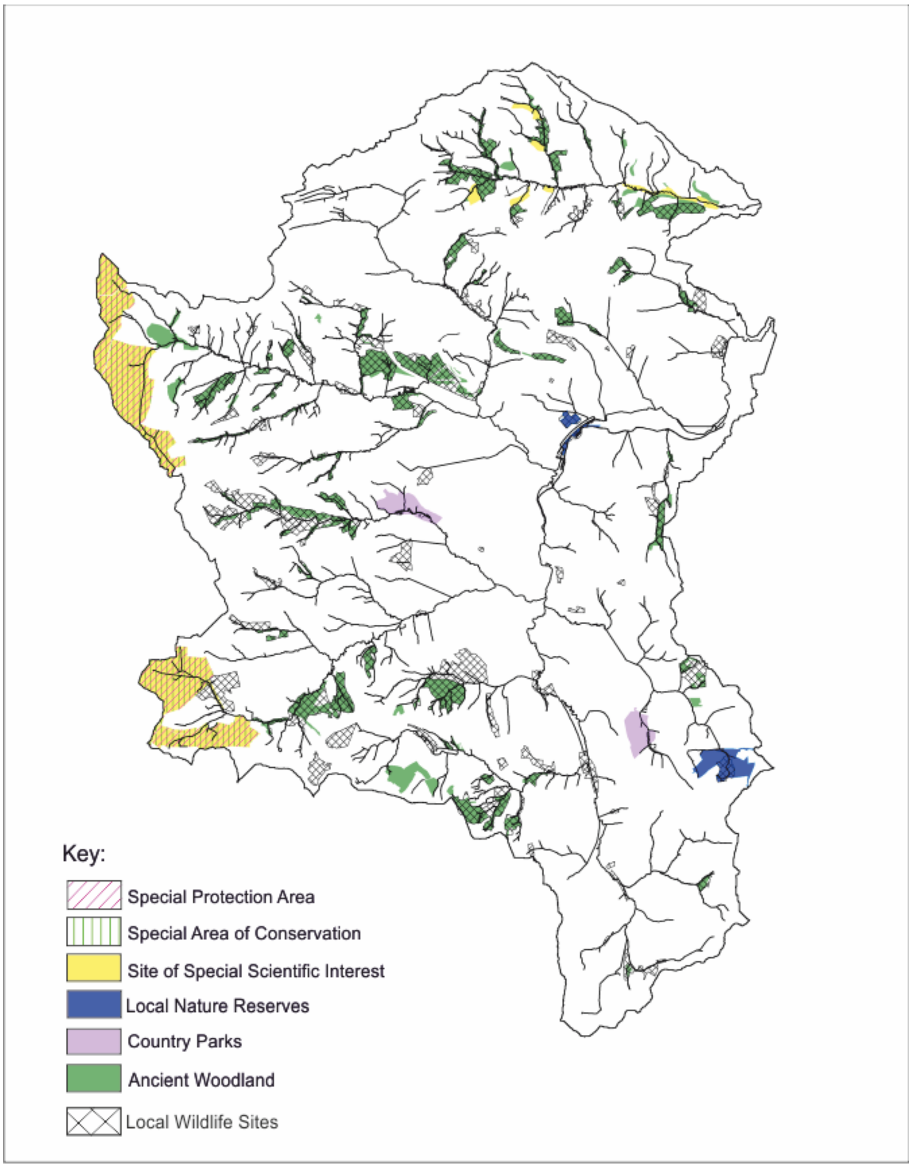

Figure 2.4 *–Statutory and non-statutory sites within the catchment area.*

3. Method

Hotspot and opportunities for flood reduction, diffuse pollution reducing and habitat were mapped using a Geographical Information System (GIS). Figure 3.1 shows a conceptual figure of the steps taken to create the maps, with relevant data input. For more detailed information please read the GIS method report[4].

Diffuse pollution: SCIMAP[5] was used to assess erosion risk within the catchment. SCIMAP is open source and is freely available to use, it needs the following information: topography, rainfall and land use. SCIMAP assesses relative risk within a catchment, and therefore does

[4] Link to GIS method report on iCASP website
[5] Link to SCIMAP website

not produce absolute volumes of sediment produced. SCIMAP produces three output datasets of relevance to this work. Each dataset is described below:

1. Erosion Risk: This grid shows erosion risk across the catchment and ranges from 0 (lowest risk) to 1 (highest risk)[6].
2. Erosion Risk in Channel Concentration: This output shows the concentration risk of the sediment in the channel, which is a cumulative value of all the inputs upstream related to erosion risk.
3. Network Index: This grid shows the hydrological connectivity of the catchment, the data ranges from 0 (lowest connectivity) to 1 (high connectivity). This grid can be used to look at overland flow connection within the catchment.

The erosion risk data (1 and 2) can be used to understand where interventions can be placed in order to decrease diffuse pollution, in this case related to input of fine grained sediment into the river channel.

Slow the flow: The network index from SCIMAP was used to look at overland flow pathways within the study area. This information is used to assess placement of NFM interventions that slow overland flow. The synchronisation of tributaries was assessed using the EA's NFM storage calculator[7]; this assesses which sub-catchment is the most effective at reducing flood flows downstream by: 1) delaying the timing of flood peak and; 2) delaying the flood peak by storage of flood water (e.g., placing ponds in the sub-catchments; for modelling the storage was kept the same across the sub-catchment with the only variable to change the threshold in which the storage starts to fill). Information on the synchronisation of flow within tributaries can be used to prioritise interventions in sub-catchments which have the biggest impact on reducing flood peaks. Figure 3.2 shows the study area modelled for tributary synchronisation. The Upper Rother, River Hipper and River Drone were chosen in order to assess flood risk to the city of Chesterfield which has one of the highest population densities within the study area and Chesterfield constituency (noting the River Drone joins the River Rother downstream of Chesterfield)[8].

[6] Risk defined here is related to the chance of a parcel of land producing sediment, 1 indicates that erosion is high in this area and likely to produce diffuse pollution.
[7] This is an excel spreadsheet that can be used to delay flow from different sub-catchments to understand the impact downstream. For further information please download the GIS method report.
[8] The Moss Valley was excluded from the modelling as it does not impact flooding in Chesterfield.

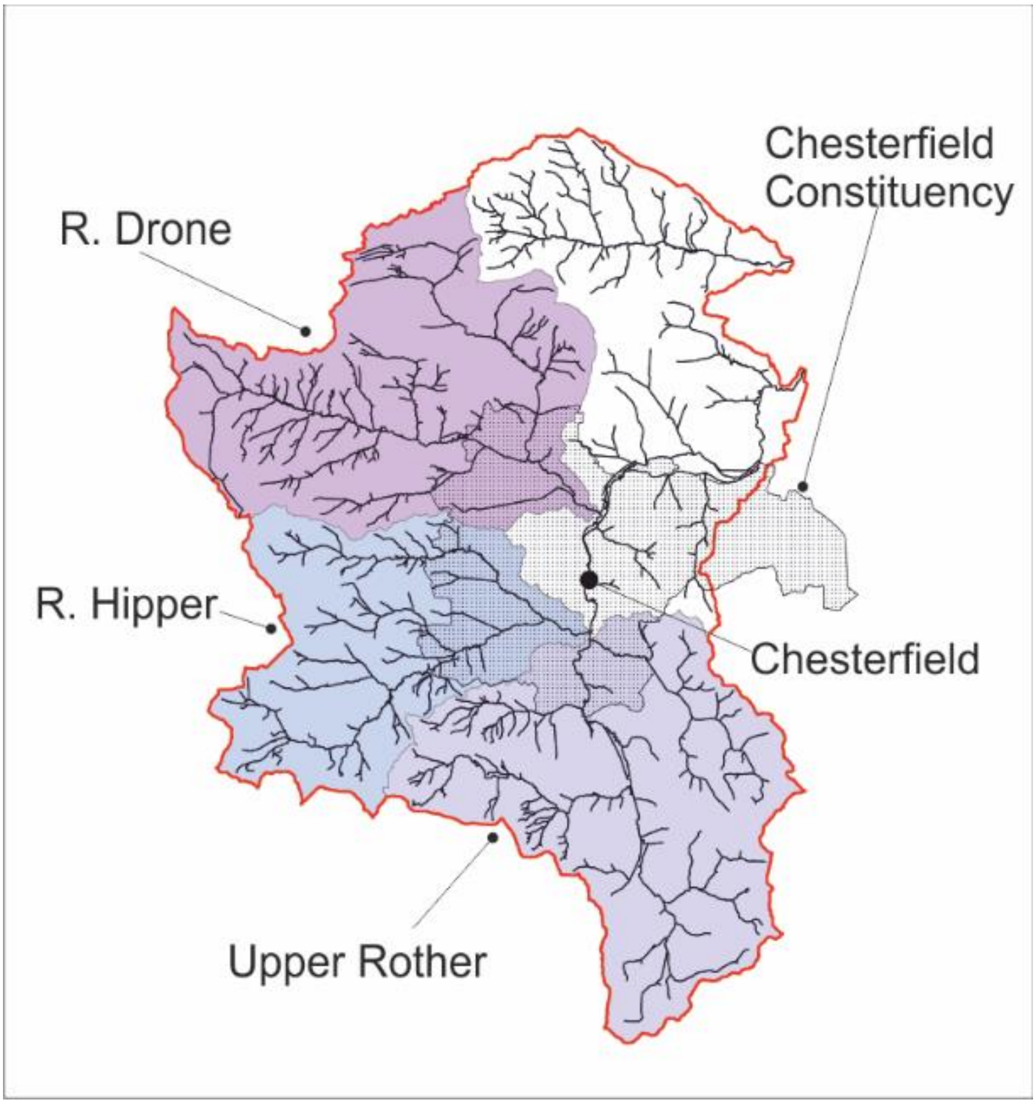

***Figure 3.2** – Sub-catchments used for modelling tributary synchronisation.*

Habitat Connectivity: Linkage Mapper[9] was used to assess habitat connectivity. This is an open source GIS plugin. Habitat connectivity was modelled using local wildlife sites as target habitats, and a resistance map based on underlying land use. Linkage mapper produces the following datasets:

1. Corridor map – This map shows the resistance[10] between different target habitats which can be used to asses which target habitats are easiest to connect. Low values of resistance indicate easier habitat pockets to connect e.g., connecting these pockets will have a greater ecological uptake. The map is created using the resistance map of underlying land use[11] and the potential pathways between the habitat pockets.

[9] McRae, B.H. and D.M. Kavanagh. 2011. Linkage Mapper Connectivity Analysis Software. The Nature Conservancy, Seattle WA. Available at: http://www.circuitscape.org/linkagemapper.
[10] Resistance is related to underlying land use, urban areas for example have a high resistance and it is therefore harder for different habitats to become established. Resistance value are recorded from academic literature. More information is available in the GIS method report.
[11] This work used CORINE land use maps, however CEH land use maps could also be used.

2. Target habitat lines – these connect target habitats[12], which are used to create the corridor map. The target lines represent the shortest route to connect target habitats. Not all the target habitats are connected directly, this is because in some cases, the corridor is through multiple target habitats.

These datasets can be used to inform where interventions placed for slowing the flow or decreasing diffuse pollution can also be used to increase habitat connectivity.

[12] Target habitats are the habitats of interest, in this case, the local wildlife sites.

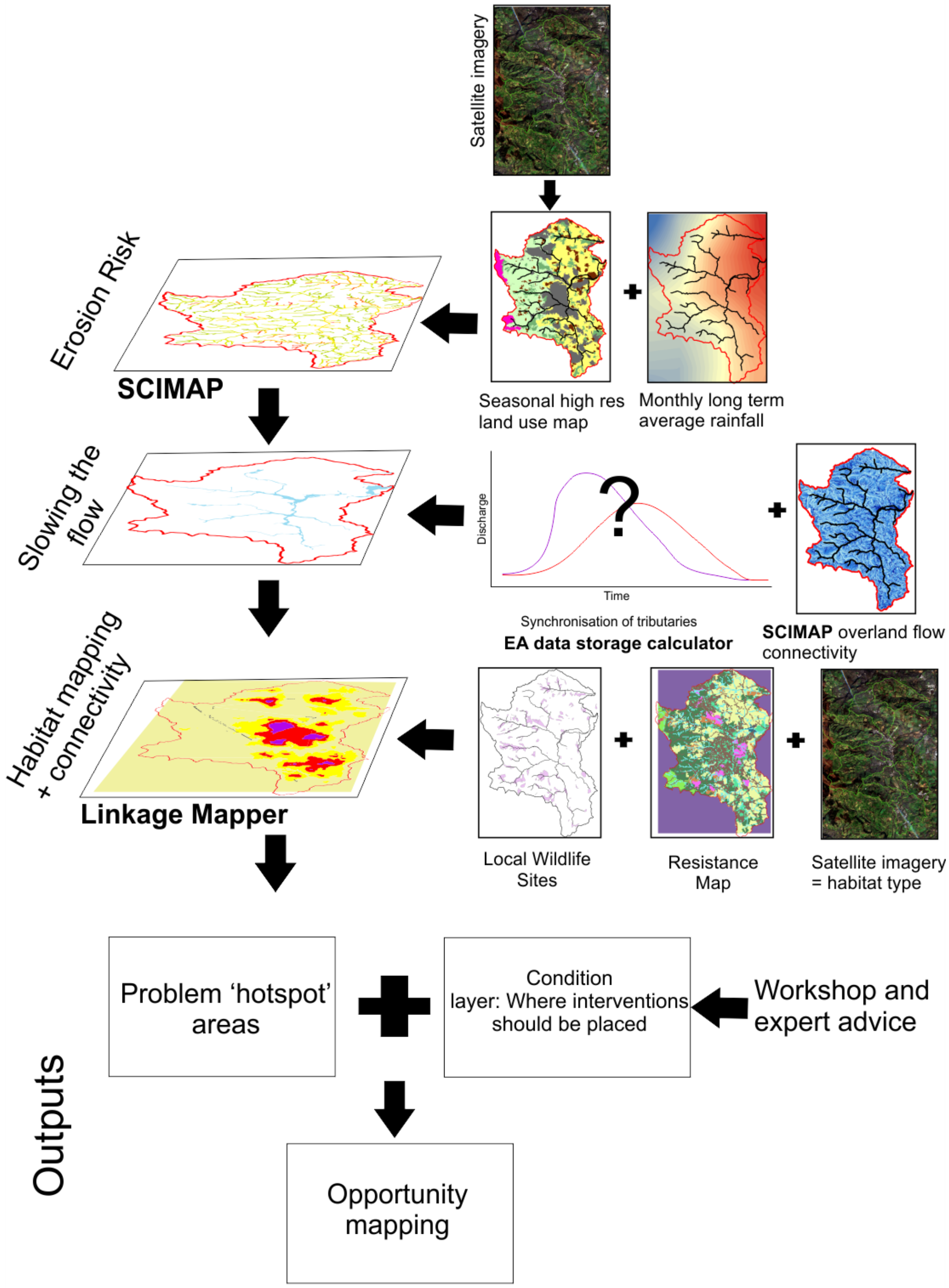

***Figure 3.1** – Conceptual method followed in this report. Programs / plugins (software component that add a specific feature to an existing computer program) used are in bold. For further information on data sources and methods followed, download the GIS Method report.*

3.1 Future work

Modelling and mapping are limited by the resolution of data that is used and the processes used in this report are not the only way to look at erosion risk, hydrological connectivity or landscape connectivity. The tools used in this report, represent a quick and effective way to assess catchment opportunities, which could lead to further, more detailed investigation.

Erosion risk – SCIMAP was used in this project as it is used by a range of stakeholders, and is a quick and effective way to analyse source areas within a catchment. More detailed mapping processes such as the 'revised universal soil loss equation' (RUSLE), which can integrate information on soil and geological variation, could be used to increase the detail of the erosion risk maps.

Hydrological connectivity – SCIMAP was used to assess overland flow in this project, which is a quick and effective way to understand flow pathways. However, more detailed modelling (SD-TOPMODEL) can be undertaken to assesses hillslope hydrology (overland flow, throughflow) and incorporates soil data information, which can then be used to model the effects of placing NFM in a catchment at higher resolution.

For further information on the SD-TOPMODEL Calderdale NFM project visit: Link to Calderdale NFM project on iCASP website

Landscape connectivity – Linkage mapper was used in this work due to its usability. However, a range of GIS plugins / models exist that can be used to model connectivity e.g., Fragstats[13]; GRAPHAB[14] etc. This work has used local wildlife sites in this work, however, more detailed habitat quality mapping will indicate what target habitats should be connected to not only increase connectivity but also improve habitat quality.

[13] Link to fragstats website
[14] Link to GRAPHAB website

4. Interventions

This section provides an overview of volunteer-friendly interventions and their impacts on the key aims and wider benefits. These interventions were identified within the workshop and assessed in terms of those interventions that can be utilised in the HHSS study area. It should be noted that both land management and gate relocation were also discussed at the workshop. Land management could be used across the entirety of the HHSS study area and has therefore has not been mapped. Resolution of data did not allow for the identification of current gate locations.

The following section summarises information from EA[15] and SEPA[16]. It is not extensive and represents the state of science at time of publication.

4.1 Buffer strips

Buffer strips, comprised of planting vegetation, can be classified as run-off control features and can be placed in various locations across the catchment including riparian zones and should be placed in a location that intercepts the pathways of concentrated flows.

4.1.1 Impact on project aims

Diffuse pollution - Buffer strips can intercept overland flow, reducing suspended matter, pesticides and herbicides reaching the watercourse by increasing the hydraulic roughness of the landscape[17]. Somma (2013) reported that 5 m buffer strips in a steep area reduced suspended sediment by 55–97%.

Slow the flow - As buffer strips increase roughness, they can slow the flow by decreasing the velocity of overland flow. Buffer strips can also increase infiltration. A 10 m buffer strip has been shown to reduce run-off rates by at least 50%[18]. A modelling study by Gao *et al*. (2016) also found that buffer strips reduce the rate and amount of run-off though the extent varied depending on their location and size. Riparian buffer strips, for example, were shown to have the greatest impact on peak flows compared to those placed midslope and in headwater locations. Furthermore, narrower buffer strips surrounding both upstream and downstream channels had a greater effect than a wider buffer strip of the same total area but placed only around the downstream channel network. Buffer strips can also stabilise flow and therefore aid in periods of low flow[19].

Landscape connectivity - Buffer strips managed for biodiversity have been shown to double the number of invertebrates compared with normal cropped margins[20]. They also increase plant diversity, and provide wildlife corridors and habitat connectivity[21].

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15 Website link to the EAS NFM WWNP guide
16 Website link to SEPA NFM guide
17 Dillaha et al. 1986, Vought et al. 1995, Hansen et al. 1999, Kamphorst et al. 2000, Planchon et al. 2001, Zheng et al. 2012
18 CORPEN 2007
19 Christen and Dalgaard 2013
20 Meek et al 2002
21 Constanza et al. 1997, Boutin et al. 2003

4.1.1.1 Extent of impact

Although there is evidence of land-use change having an impact on localised flooding, effects are less palpable at a catchment scale. There is limited evidence to demonstrate that buffer strips reduce run-off at both the plot and catchment scale[22].

4.1.1.2 Design

In general, the longer and steeper the slope and the less free draining the adjacent field is, the wider the grass strip or riparian buffer that is needed to slow and intercept runoff.

> Important consideration is needed within the design of buffer strips if the aim is to increase landscape habitat connectivity. As a general rule, native plant species should be planted, mimicking the composition of similar, more natural habitats in the area.
>
> Further, catchment specific information can be found from the Derbyshire Wildlife Trust.

4.1.2 Multiple benefits

Water quality: Somma's (2013) study also found the 5 m buffer strips reduced inputs of phosphorous by 42–96%, nitrogen by 27–81% and organic matter by 83–90%.

Climate regulation: vegetated buffer strips have a cooling effect on local rivers.

Health access: Benefits will only be realised if projects are designed with public access in mind, providing footpaths and other amenities e.g., a buffer zone on the River Avon, disabled access via a gate in fencing.

Aesthetics: Buffer strips usually resemble natural scenery associated with 'peaceful' landscapes and may thus meet the criteria of acceptability for the wider public[23].

4.1.3 Applicability to HHSS study area

Buffer strips can be placed in a number of locations across a catchment and are not land-use specific. Buffer strips therefore are highly relevant to the HHSS study area.

4.2 Leaky woody dam

Leaky woody dams are comprised of one or multiple logs placed instream; the level of engineering can vary depending on the site location.

4.2.1 Impact on project aims

Diffuse pollution – Leaky barriers can trap fine sediment, reduce sediment transport[24] and encourage the formation of channel features[25], for example pool and riffle sequences[26]. However, sedimentation upstream of a barrier could reduce its water storage capacity and potentially reduce the effectiveness of the measure. However, retaining sediment could be needed in a catchment dominated by diffuse pollution; a study in Belgium found that over 7 years, 1,710 m^3 of sediment was deposited behind beaver dams[27]. However, in restored

[22] Lane et al. 2007
[23] Christen, 2013
[24] Jeffries et al. 2003, Dixon, 2013
[25] e.g., Kali et al. 2007
[26] e.g., Gregory et al., 1994
[27] De Visscher et al. 2013

sections of the Highland Water in the New Forest[28], in channelised (unrestored) streams with large woody dams added, the resulting scour due to the dams, led to the transfer of fine sediments downstream with no deposition behind the large woody dam.

Slow the flow – The introduction of woody material or boulders to a natural channel to slow the flow[29] increase instream water levels during moderate to high flows, and thereby increase water storage on the floodplain. The effects of leaky barriers are site-specific but generally show a positive flood risk effect[30]. Leaky barriers can: reduce flood risk locally for small events; increase hydraulic roughness; reduce flow velocities; increase the travel time of the flood wave; create temporary storage (e.g., upstream of Pickering, 104 barriers provide a total of ~1,020m^3 of potential flood storage[31]) and attenuate flood flows and increase floodplain connectivity[32]. Wenzel et al. (2014), used an artificial flood wave for a 3.5 year return period event and showed a significant delay of the flood wave propagation over the local reach as a result of increased channel roughness and a small decrease in peak discharge (2.2%). There is limited evidence of how these measures perform during extreme flood events and if they could also result in synchronisation the flood peak between tributaries and/ or the main river. Further, if the storage is full when the flood arrives, they may act as an area of run-off due to overflowing. In times of low flow, the water ponding induced by woody barriers can store water and regulate low flows during dry periods[33].

Landscape Connectivity - Habitat surveys will be required prior to placement of structures in watercourses in order to establish that no important habitat is being damaged (e.g. otter and water vole habitat). The installation of woody barriers increases habitat diversity by increasing channel morphology diversity. Leaky woody dams support a range of fauna including fish, macroinvertebrates, reptiles and birds, for example wood placement in a stream in the New Forest increased biodiversity by 46%[34]. However, during low flows, the pools created are refuge areas for fauna.

Caution: As leaky woody dams are in the watercourse, a clear understanding of the hydromorphology and flow regime of the watercourse is needed, including water levels, the direction of flow, channel dynamics (including the sediment regime) and distance to downstream features; there is a lack of information on whether leaky woody dams can synchronise the flood peak. Maintenance is important, as woody debris can have a negative impact on flood risk if they wash out and cause a blockage further downstream in a problematic location.

4.2.1.1 Extent of impact

Studies at the reach scale have shown leaky woody dams to be effective at slowing the flood wave locally and delaying the flood peak; however they may not reduce the magnitude of the

[28] Sear et al., 2006
[29] Hygelund and Manga 2003
[30] e.g., Shields and Gippel 1995, Sear et al. 2010, Kitts 2010, Thomas and Nisbet 2012, Dixon et al. 2016
[31] Nisbet et al. 2015
[32] Nisbet et al. 2011a
[33] Booth et al. 1997, Gurnell 2013
[34] Kitts 2010

flood as water that is diverted onto the floodplain from the barrier may re-enter downstream[35]. Benefits of leaky woody dams are localised and confined to small or medium rainfall events. There is a lack of information on the effect of leaky woody dams in extreme flood events, or how they affect the larger catchment hydrology.

4.2.1.2 Design

Leaky woody dams can range in style and complexity from more 'natural' to engineered, and from single wooden structures to stacked logs. Woody dams should not be placed upstream of pinch points (e.g., bridges), and are more likely to wash out in steeper gradient reaches. A trash screen may be needed downstream if there is doubt about how secure the structure is. Leaky woody dams can be pinned to the bank to secure the structure. There is currently little information on the longevity of these interventions, however wood will naturally decay in a channel setting and therefore will need to be replaced. **Caution is needed when installing leaky barriers to ensure they do not become detached and cause a downstream blockage with consequent impacts on public safety.**

Leaky woody debris design guidance has been produced by the Woodland Trust (website link to the leaky woody debris guide)

Leaky debris dams may affect the connectivity of migratory fish if they are not placed at the correct level.

4.2.2 Multiple benefits

Water quality: Leaky barriers improve nutrient cycling this is particularly apparent in lowland streams[36]. Further, leaky barriers are successful at retaining and breaking down organic matter[37].

Climate regulation: submerged wood creates a carbon sink[38]

Cultural activities: May improve recreational opportunities, e.g., due to the increase of fish for angling. One study valued the ecosystem services provided by wood placement projects at €1·08 to €1·81 per metre of river per year[39].

4.2.1 Applicability to HHSS study area

Leaky woody dams have a wide applicability to the HHSS study area and function well in smaller headwater tributaries, common in the HHSS study area.

4.3 Hedgerow and tree planting

Planting of hedgerows and trees across different catchment locations.

35 Kitts 2010, Thomas and Nisbet 2012, Dixon et al. 2016
36 Krause et al. 2014
37 Acuña et al. 2013
38 Guyette et al., 2002
39 Acuña et al. 2013

4.3.1 Impact on project aims

Diffuse pollution – Both hedgerows and cross slope woodland can be used to intercept overland flow, and can be used to reduce diffuse pollution due to the increase in resistance and soil infiltration[40]. Floodplain woodland can cause backwater effect and increase channel roughness, which allows for deposition of sediment within the riparian zone[41].

Slow the flow – Hedgerows are run off control features, which are very effective if planted in a natural gully or along the contour of a field. Hedgerows and trees increase roughness, and slow flow down, which increases the chance of infiltration, interception and evapotranspiration[42]. A study at Pontbren in Mid Wales, for example, found that soil infiltration rates were up to 60 times higher where young native cross slope woodlands were present compared to adjacent heavily grazed pasture[43]. Floodplain woodlands slow down and hold back flood flows within the floodplain by increasing hydraulic roughness. During periods of low flow, woodlands generally help regulate flow; floodplain woodlands are effective in low flows by increasing flow levels by the slow release of water stored in pools, side channels and floodplain soils[44]. Due to slowing the flow, floodplain woodlands could synchronise flow and exacerbate flood levels.

Floodplain woodland can create a backwater effect, which can extend for 300 to 400 m or more upstream, depending on the channel gradient (Thomas and Nisbet, 2006).

Landscape connectivity – Cross slope woodland, floodplain woodlands and hedgerows can increase habitat connectivity in agricultural dominated landscapes, supporting a wide range of fauna. Further specialist habitats can be formed in the microclimates of cross-slope woodlands.

4.3.1.1 Extent of impact

The impact of hedgerows and cross-slope woodlands on a catchment scale is difficult to measure, there is a low to medium confidence in the ability of cross-slope woodland to reduce small to moderate flood flows in small catchments (<10 km^2). As floodplain widths increase downstream, the scope for floodplain woodlands to have an impact on flood flows is usually greatest in the middle and lower river reaches, and therefore medium to large catchments. The magnitude of effect on flood flows of floodplain woodlands may be relatively small, unless the woodland is in the right place and the right size to maximise the desynchronization of the sub-catchments.

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[40] Kamphorst et al. 2000, Planchon et al. 2001, Harris et al. 2004, Nisbet et al. 2011a, Zheng et al. 2012
[41] Piégay and Bravard 1996
[42] Hansen et al. 1999, Kamphorst et al. 2000, Planchon et al. 2001, Harris et al. 2004, Zheng et al. 2012
[43] Carroll et al., 2006
[44] McGlothlin et al. 1988

4.3.1.2 Design

Woodlands and hedgerows can be planted in a range of locations in a catchment. The design and planting of woodland must comply with the UK Forestry Standard and the associated guidelines on water, soil, biodiversity, landscape, people, historic environment and climate change. Tree planting may require maintenance such as: replacing trees that have failed to establish; protecting trees from pests, disease and browsing; making repairs to infrastructure such as fences and gates and eventually replanting harvested trees.

Planting on floodplains may more commonly lend itself to conifer or mixed species, or to short rotation coppicing/ short rotation woodland which is planted to provide wood fuel for fossil fuel substitution.

When planting trees, consideration of tree types is needed to ensure there is ecological diversity, especially when considering birds. Further information can be found by the Woodland Trust, who can help offer tailored advice: website link to tree planting advice

4.3.2 Multiple benefits

Water quality – Hedgerows and woodland can remove phosphates, nitrates and fix toxic metals, improving water quality.

Climate – Trees have a cooling effect on their local climate and increase carbon sequestration. However, their impact is limited by their small footprint.

Health – depending on the accessibility, and if designed for public use, woodlands can have positive impacts on physical and mental health.

Air quality – woodland helps prevent windblown soil erosion, improving air quality and is more effective at this than shorter vegetation.

4.3.1 Applicability to HHSS study area

Hedgerows and trees can be planted in a range of locations across the HHSS study area, these NFM interventions are very applicable to the study area.

4.4 Ponds and Wetland Scrapes

Ponds and wetland scrapes refers to a range of designs that have various levels of engineering, and spillways may be needed depending on the structures size.

4.4.1 Impact on project aims

Diffuse pollution – Wetland scrapes increase resistance and act a sediment sink, which can decrease diffuse pollution within the main river channel. Offline ponds and ponds also trap sediment, however, the rate of sedimentation depends on how frequently the pond is inundated.

Slow the flow - Ponds and wetland scrapes can regulate flow by providing extra storage during high rainfall events, which can attenuate the flood peak; this can help reduce flood risk locally. A 120,000 m^3 storage pond created in the Pickering catchment aims to reduce the risk of flooding by anything between 4% to 25% in any one year depending on the flow volume[45].

[45] Nisbet et al. 2011a

During low flow periods, these features can help regulate water flow and can recharge aquifers during flooding.

Caution: The impact of multiple storage distributed across a catchment compared against one large storage area is unknown. There is also limited evidence on how these features perform under extreme flood events.

Landscape Connectivity – Ponds and woodland scrapes can create new habitat for species, however the potential for habitat depends on how the features are managed. The inundation rate will impact what species of flora and fauna will develop in the feature. Ponds and woodland scrapes may increase connectivity at a localised level.

4.4.1.1 Extent of impact

The extent of impact will depend on the location of the feature within the catchment, generally, the effectiveness of these features increases with size. The number of features required to have an impact increases with catchment size.

4.4.1.2 Design

Depending on the scale of intervention and the level of engineering, a great deal of caution is needed when designing them to ensure that any associated infrastructure (e.g. containment bunds, inlets, outlets and spillways) are robustly designed and do not impact public safety. Further, maintenance may be required to remove the sediment and maintain storage capacity.

4.4.2 Multiple benefits

Water quality – Ponds can cycle nutrients and pollutants, however, during flooding phosphorous can leak into drainage downstream and cause pollution issues.

Climate – Ponds and wetlands have the ability to store carbon.

4.4.1 Applicability to HHSS study area

Ponds and scrapes can be placed in a range of locations across the HHSS study area.

4.5 Grip Blocking

Large drains were historically placed on peatlands for drainage, or may have developed due to erosion. Drain blocking is normally carried out using peat, however can be undertaken using other materials including wooden structures.

4.5.1 Impact on project aims

Diffuse pollution – Grip blocking can reduce erosion, and help trap sediment; this will decrease the transport of sediment to the local drainage network.

Slow the flow –Evidence related to the effectiveness of grip blocking is not consistent[46]. At a hill slope scale, grip blocking can increase or decrease discharge rates due to local catchment and drainage characteristics and the orientation of the grips; these impacts are therefore site specific. There are limited studies on the impact on run-off rates, however modelling suggests that once established there could be long term flood attenuation. Nonetheless, grip blocking restores the natural drainage patterns, often raising the water table; impacts on flood risk may be more localised and there is little evidence to show a significant impact downstream[47].

[46] Shepard et al. 2013
[47] Lane and Milledge, 2013

Behind each dam, the pools created may not have significant storage attenuation especially during storm events due to the water table rising. Further, the effectiveness of restoration may decrease over time in response to the restoration as soil properties change[48]. As restoration of ditches can help the water table recover, during low flows, grip blocking can reduce variations in groundwater level close to rivers[49].

Landscape connectivity – Peatland is a crucially important ecosystem (Bonn *et al*., 2009). Drought sensitive species, in particular, such as aquatic invertebrate will benefit from higher water tables. However, when removing ditches by blocking; habitat can be lost and these areas are often rich in biodiversity[50].

4.5.1.1 Extent of impact

Lane and Milledge (2013) modelled the impacts of grips on flow hydrographs and found that the benefits of grip blocking may not translate into catchment-wide impacts. The impacts of grips is site specific, depending on the orientation of the grip, the density and the topographic setting.

4.5.1.2 Design

Grip blocking can be achieved by using compacted peat dams or on steeper slopes and for larger grips (>0.7 m^2), wooden or plastic dams may be required. The crest level of the dams should be slightly higher than the surrounding area to encourage excess water to redistribute on the surrounding bank area. Consideration of the site location and access may be required if mechanical machinery is needed to install the dams.

> Technical guidance is available from the Yorkshire Peat Partnership:
>
> Yorkshire Peat Partnership (2012). Technical guidance notes 1-4 on peat blocking. York: Yorkshire Peat Partnership.
>
> Available: website link to the YPP technical guidance on restoration

4.5.2 Multiple benefits

Water quality – Grip blocking reduces levels of organic carbon, nitrates and sulphates, and decreases raw water colour production[51]. In restored peatlands, due to the increased water table, phosphorous can be released into the soil and cause pollution downstream and eutrophication[52].

Climate - Peatlands are the largest carbon reserve in the UK, storing around 3 billion tonnes of carbon[53]. Peatland restoration can help to store carbon within the soil however, rewetted peat can also increase the emissions of methane. Further it may increase or decrease nitrous oxide emissions. Restoring peatlands has less of an impact on global warming than degraded peatland and therefore it is beneficial to restore[54].

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48 Holden et al., 2016
49 Krause et al., 2007
50 Marja and Herzon 2012
51 Holden et al. 2007, Woltemade and Woodward 2008, Armstrong et al. 2010, Ross and Hammond 2015
52 Baum et al., 2003
53 Worrall and Evans 2007
54 Further information can be found here: website link to Natural England resources

Health access – Uplands are popular tourist destinations and restoration can increase their value.

Air quality – Management to reverse land and headwater drainage can significantly improve air quality through carbon sequestration. Restoring uplands also reduces the risk of uncontrolled moorland fires, which are sources of localised air pollution.

Aesthetics - Moorlands are highly valued aesthetically for their 'wildness' and as sources of inspiration.

An iCASP project has assessed Optimal Peatland Restoration (OPR), more information can be found here: link to OPR project on iCASP website and outputs here: iCASP website resources on peat

4.5.1 Applicability to HHSS study area

Less than 5% of the study area contains land use applicable to grip blocking. This intervention is focused in the upland regions to the west of the HHSS study area.

5. Opportunity mapping: volunteer friendly interventions

This chapter focuses on the sub-catchments discussed at the workshop; hotspot and opportunity maps for the remaining sub-catchments have been produced and should be requested by contacting the iCASP office. The maps produced for this chapter follow the method discussed in Chapter 3[55]. Case study sheets have also been produced, which explain

How to interpret the hotspot maps:

Erosion Risk: Erosion risk varies from green (very low risk) to red (high risk). Interventions that are focused on reducing diffuse pollution are best placed in areas of higher risk (oranges and reds).

Overland Flow: Connectivity varies from low (white) to high (dark blue). The darker the blue, the more connected the overland flow is to the main channel. If interventions are used to slow the flow, they are best placed in areas of high connectivity (dark blue).

Habitat connectivity: Resistance of connecting target habitats ranges from low (beige) to high (blue); the higher the resistance, the harder it will be to connect the target habitats. Interventions based on increasing habitat connectivity should be placed between target habitat pockets that are connected by low resistance areas to make the interventions more effective. The lines shown are target habitat lines which connect the target habitats. Woodlands were assessed on a sub-catchment scale and therefore the lines are contained within the sub-catchment presented. This is due to the prevalence of woodlands in the HHSS study area which crashed the connectivity modelling. Whereas for grasslands and meadows the HHSS study area scale was used and therefore the lines may extend out of the sub-catchment to connect target habitats to a neighbouring target habitat in a different sub-catchment.

[55] A more detailed method can be found here: GIS methods report on iCASP website

how to use the hotspot maps in more detail, they can be downloaded from the Don Catchment project resources area of the iCASP website.

5.1 Results: Hotspot maps

5.1.1 Upper Rother

Erosion risk mapping: Output from SCIMAP (Fig. 5.1) indicates that erosion risk is higher in January, than September. Most of the catchment has medium to high risk areas in January, with the higher risk areas decreasing in September. Overall, the east of the sub-catchment has greater risk.

NB. All the erosion maps produced in Section 5 are comparable and have been scaled with the same erosion risk bands.

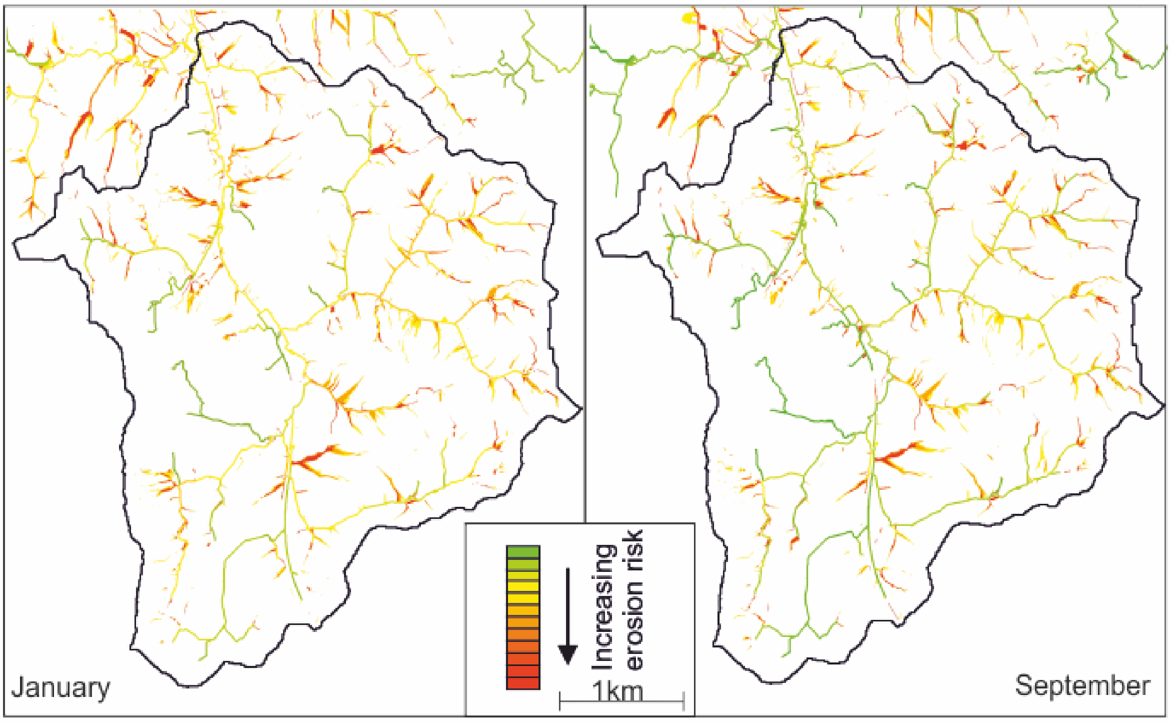

Figure 5.1 *– Erosion Risk Mapping data for the Upper Rother for January and September 2018. Erosion risk varies from green (very low risk) to red (high risk). Interventions that are focused on reducing diffuse pollution are best placed in areas of higher risk (oranges and reds).*

Overland flow: Overland flow map output (Fig. 5.2) indicates that there are several potential routes for overland flow to reach the main channel. Along the river channels, there are several areas where overland flow is pooling, this is shown by the deep blue areas.

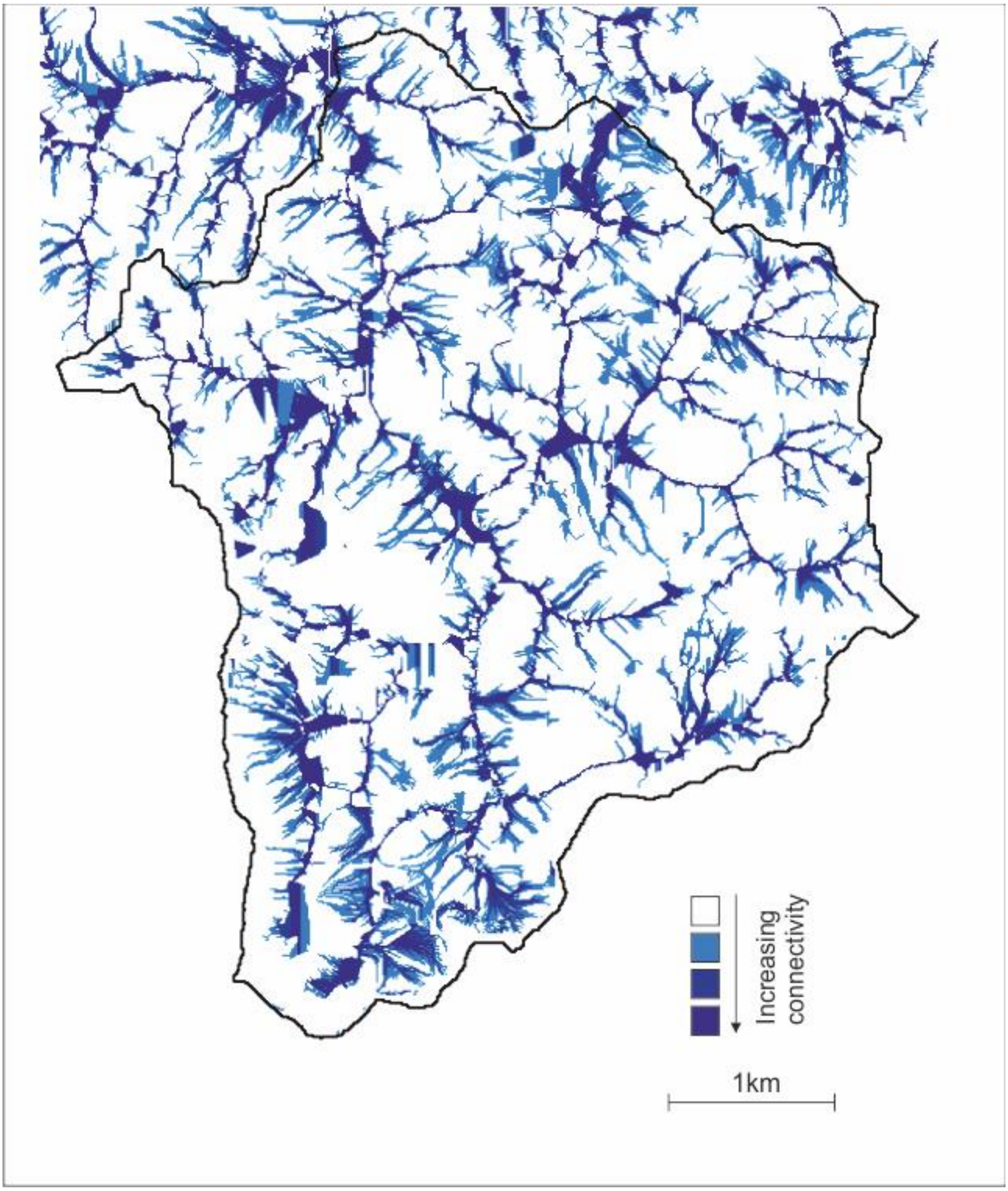

Figure 5.2 *– Overland flow data for Upper Rother. Connectivity varies from low (white) to high (dark blue). The darker the blue, the more connected the overland flow is to the main channel. Interventions used to slow the flow are best placed in areas of high connectivity (dark blue).*

Habitat Connectivity: Figure 5.3 shows the connectivity maps for the Upper Rother. There are three pockets of LWS woodlands in the Upper Rother catchment (~5 km apart, Figure 5.3A), most of the Upper Rother has a low resistance to connectivity, however to the south west of the catchment there is an area of higher resistance that can impact the connectivity between two target habitats.

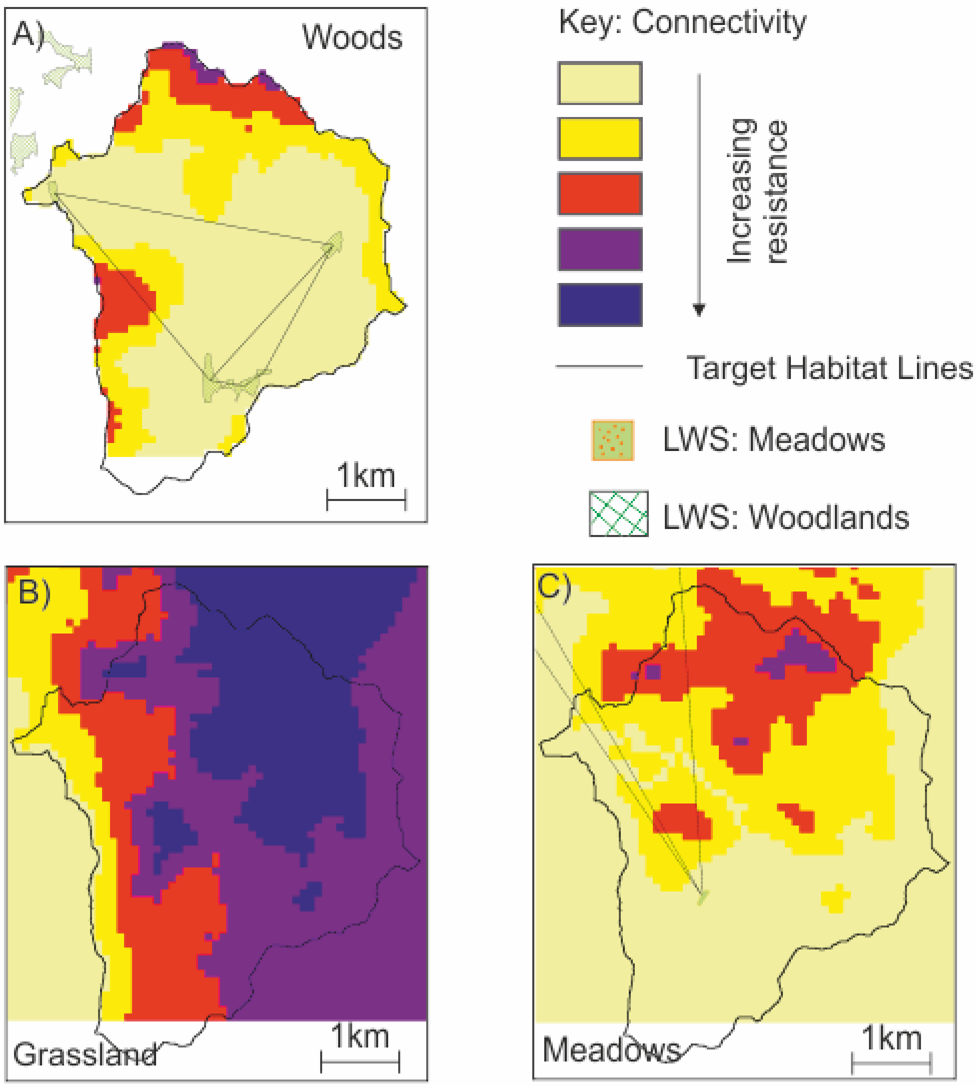

***Figure 5.3** – Habitat connectivity maps for the Upper Rother: A) connectivity of LWS woodlands; B) connectivity of LWS grasslands and; C) connectivity of LWS meadows. Resistance of connecting target habitats ranges from low (beige) to high (blue); the higher the resistance, the harder it will be to connect the target habitats. Interventions based on increasing habitat connectivity should be placed between target habitat pockets that are connected by low resistance areas, this will make the interventions more effective. The lines shown are target habitat lines which connect the target habitats. Woodlands were assessed on a sub-catchment scale and therefore the lines are contained within the sub-catchment, whereas for grasslands and meadows the HHSS study area scale was used and therefore the lines may extend out of the sub-catchment to connect target habitats to a neighbouring target habitat in a different sub-catchment.*

There are no designated LWS grasslands in the Upper Rother (Fig 5.3B), due to this there are areas of high resistance in the sub-catchment (a combination of resistance related to land use e.g., urban areas and the distance to the other LWS grassland areas in neighbouring sub-catchments). There is one pocket of LWS meadow within the Upper Rother (Fig 5.3C); the headwaters of the catchment have low resistance to connect surrounding meadow vegetation. However, in order to connect to other LWS meadow pockets, areas of high resistance (e.g., urban areas) need to be breached.

The target habitat lines connect neighbouring habitat pockets. For the analysis of connectivity of woodlands each sub-catchment was assessed individually[56], so for Figure 5.3A, the target habitat lines are contained within the sub-catchment. The LWS for grasslands and meadows were analysed at the HHSS study catchment scale. There are no examples of LWS grasslands in the Upper Rother (Fig 5.3B), so no target habitat lines are visible. In Figure 5.3C, the target habitat lines extend out of the sub-catchment, this is because the target habitat line is connecting to a LWS meadow in a neighbouring sub-catchment.

5.1.1 Lower Rother

Erosion risk mapping: Figure 5.4 shows the SCIMAP output for the Lower Rother. Again, January has a higher level of risk than September. The northern part of the sub-catchment has the greatest level of risk; this area is dominated by agricultural land.

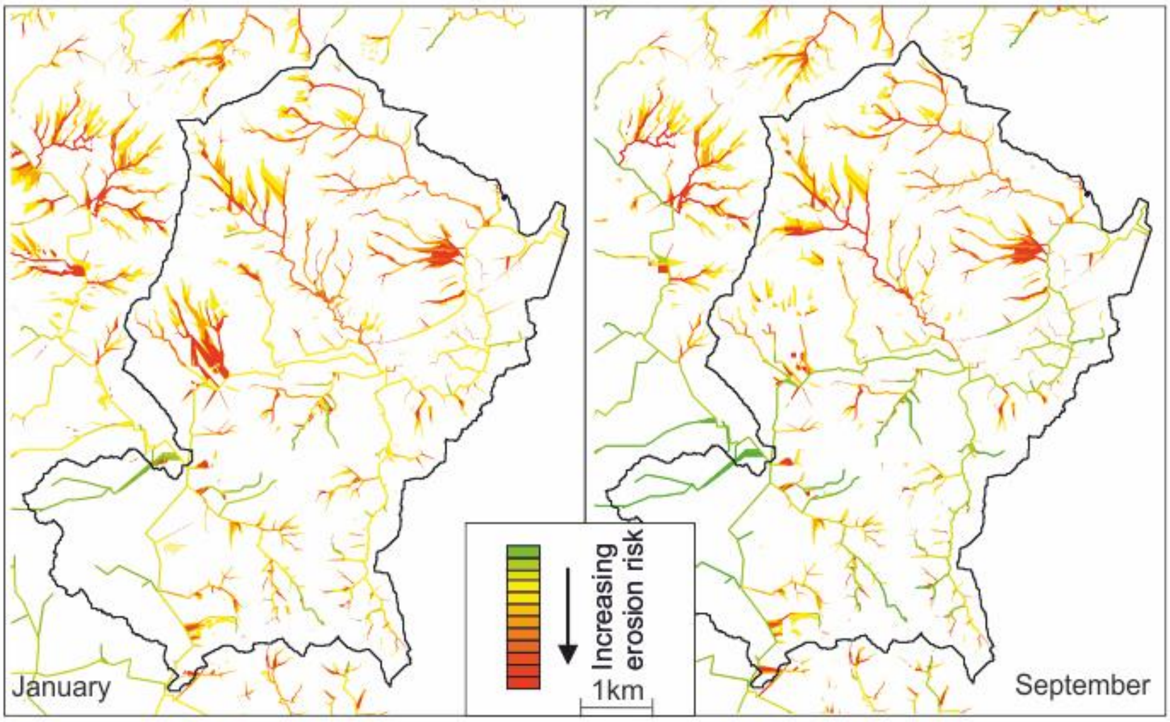

Figure 5.4 *- Erosion Risk Mapping data for the Lower Rother for January and September 2018. Erosion risk varies from green (very low risk) to red (high risk). Interventions that are focused on reducing diffuse pollution are best placed in areas of higher risk (oranges and reds).*

Overland flow: Overland flow map output (Fig. 5.5) indicates there are large areas for potential storage within the catchment, particularly within the middle of the catchment near the River Rother channel.

[56] This was due to the prevalence of woodland areas in the catchment, which crashed the ArcGIS plugin when run at the HHSS study area scale. Therefore, each sub-catchment was run individually.

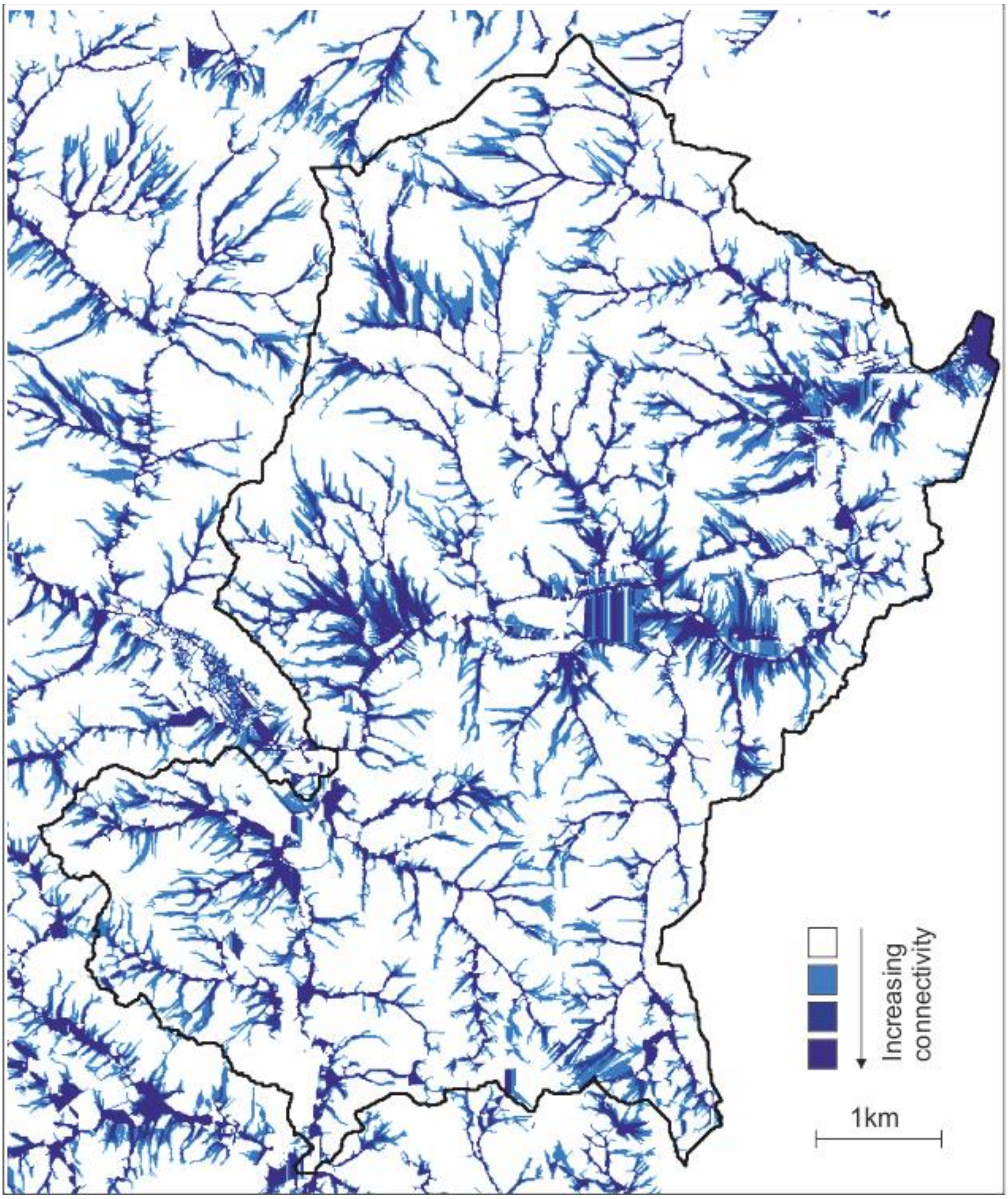

Figure 5.5 *- Overland flow data for Lower Rother. Connectivity varies from low (white) to high (dark blue). The darker the blue, the more connected the overland flow is to the main channel. Interventions used to slow the flow are best placed in areas of high connectivity (dark blue).*

Habitat Connectivity: Figure 5.6 shows the connectivity maps for the Lower Rother. There are 8 LWS woodland areas in the Lower Rother, resistance across most of the catchment is generally low, however increases towards the urban areas in the south west of the sub-catchment. There are no LWS grasslands in the Lower Rother (Fig. 5.6B), due to this there is high resistance in the sub-catchment which is a combination of the nearest grassland site and resistance of land use types present. There is one pocket of LWS meadow (Fig. 5.6C) in the sub-catchment, most of the sub-catchment has lower resistance values, and again, notable high values of resistance represented by urban areas.

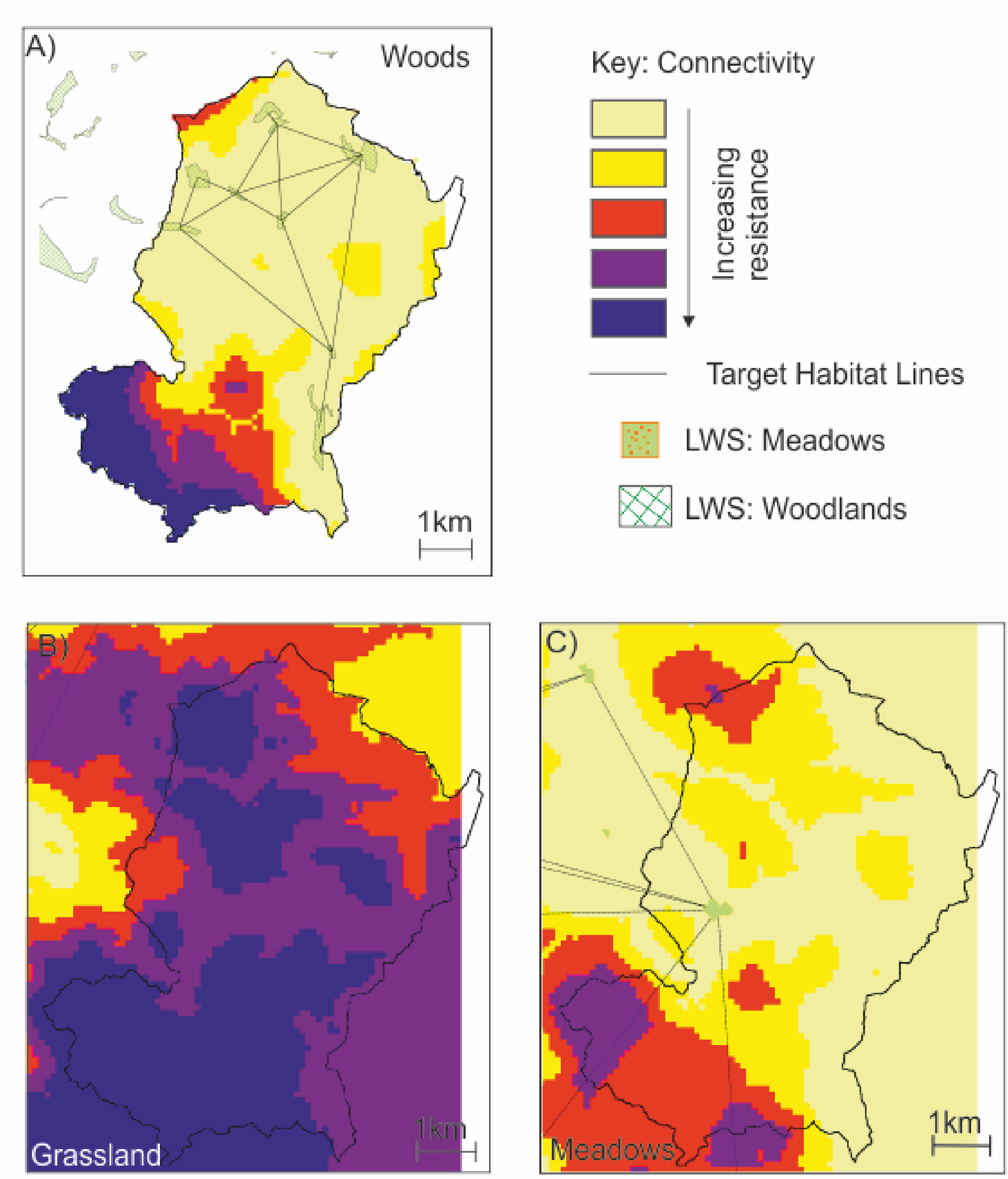

Figure 5.6 - *Habitat connectivity maps for the Lower Rother: A) Connectivity for LWS woodlands; B) connectivity of LWS grasslands and; C) connectivity of LWS meadows. Resistance of connecting target habitats ranges from low (beige) to high (blue); the higher the resistance, the harder it will be to connect the target habitats. Interventions based on increasing habitat connectivity should be placed between target habitat pockets that are connected by low resistance areas, this will make the interventions more effective. The lines shown are target habitat lines which connect the target habitats, woodlands were assessed on a sub-catchment scale and therefore the lines are contained within the sub-catchment, whereas for grasslands and meadows the HHSS study area scale was used and therefore the lines may extend out of the sub-catchment to connect target habitats to a neighbouring target habitat in a different sub-catchment.*

5.1.2 Moss Brook

Erosion risk mapping: Figure 5.7 shows the erosion risk maps for Moss Brook. Erosion risk is higher in January, which is evident in the upper part of the catchment. The middle and lower part of the sub-catchment have similar levels of erosion in both seasons.

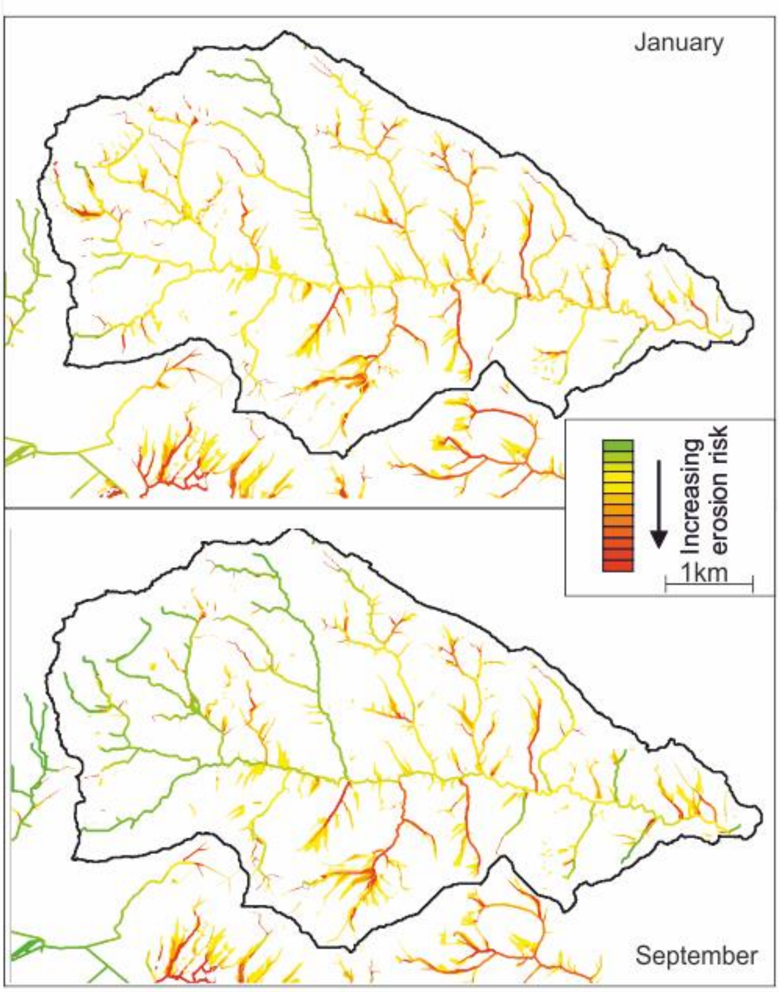

Figure 5.7 *- Erosion risk maps for Moss Brook in January and September 2018. Erosion risk varies from green (very low risk) to red (high risk). Interventions that are focused on reducing diffuse pollution are best placed in areas of higher risk (oranges and reds).*

Overland flow: Figure 5.8 shows the overland flow pathways within the sub-catchment. Concentrations of flow are evident along the main channel, with larger areas of overland flow in the headwater areas.

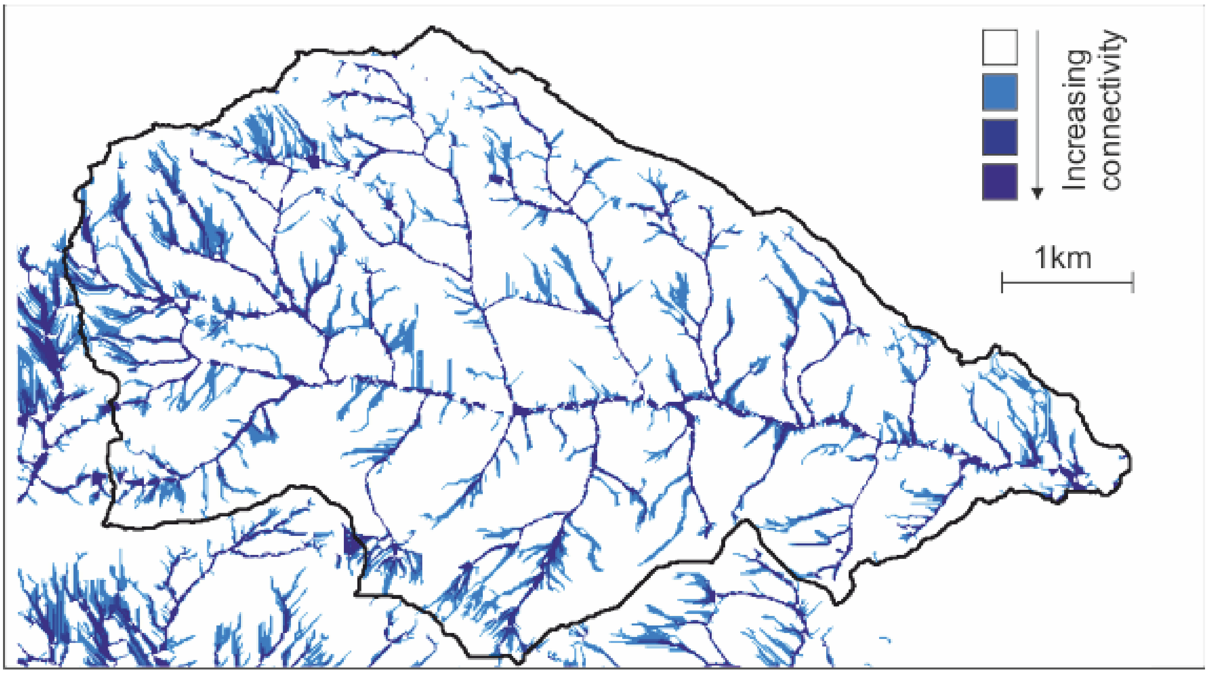

***Figure 5.8** – Overland flow within the Moss Brook. Connectivity varies from low (white) to high (dark blue). The darker the blue, the more connected the overland flow is to the main channel. Interventions used to slow the flow are best placed in areas of high connectivity (dark blue).*

Habitat Connectivity: Figure 5.9 shows the connectivity maps for the Moss Brook. There are 11 LWS woodland areas within Moss Brook, most of the catchment has low resistance between the woodland habitat pockets. The maximum distance to a woodland site is 2 km. Figure 5.9B shows the connectivity of grassland areas within Moss Brook; the north west of the catchment has the lowest resistance. There are no LWS meadows in Moss Brook, resistance values to connect meadows in this sub-catchment are overall lower than the connection of grasslands.

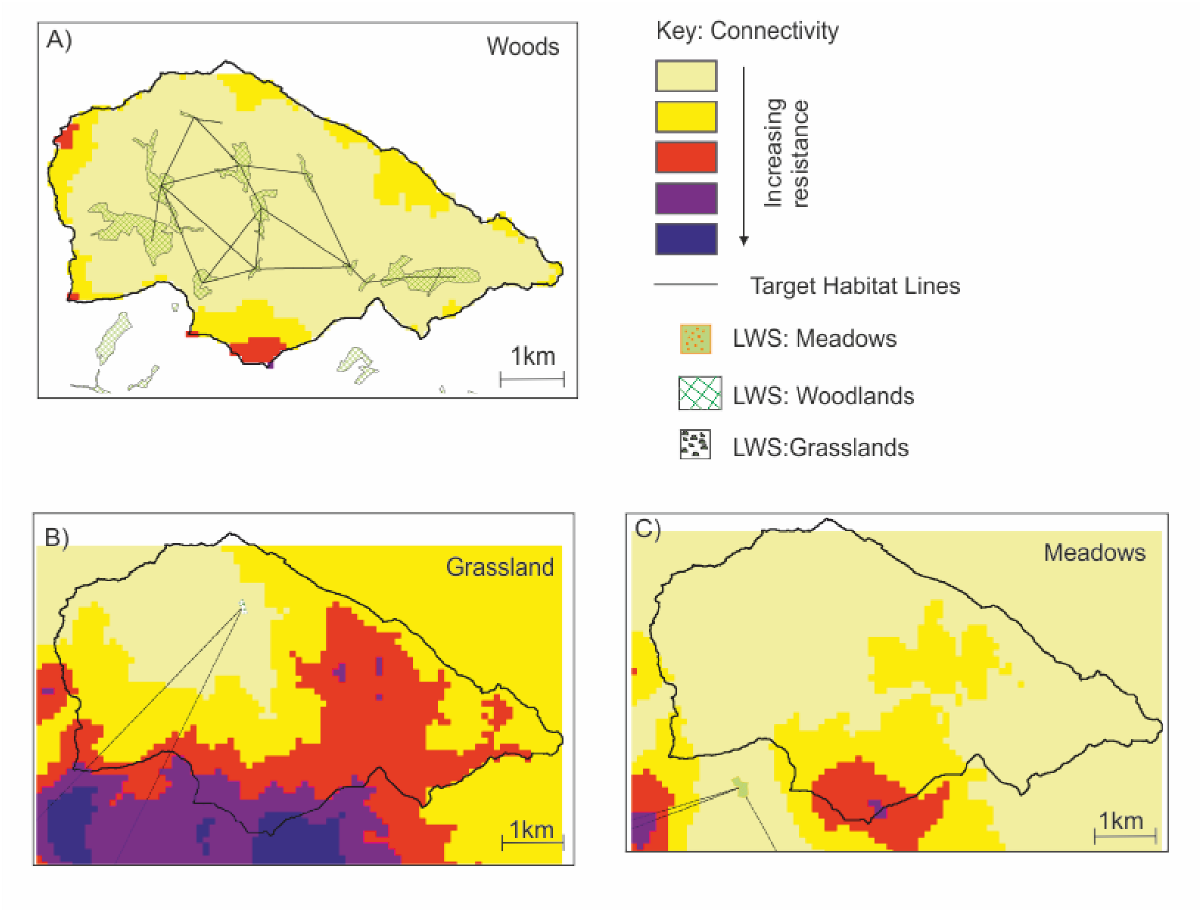

***Figure 5.9** – Habitat connectivity within Moss Brook. Resistance of connecting target habitats ranges from low (beige) to high (blue); the higher the resistance, the harder it will be to connect the target habitats. Interventions based on increasing habitat connectivity should be placed between target habitat pockets that are connected by low resistance areas, this will make the interventions more effective. The lines shown are target habitat lines which connect the target habitats, woodlands were assessed on a sub-catchment scale and therefore the lines are contained within the sub-catchment, whereas for grasslands and meadows the HHSS study area scale was used and therefore the lines may extend out of the sub-catchment to connect target habitats to a neighbouring target habitat in a different sub-catchment.*

5.1.3 River Hipper

Erosion risk mapping: Figure 5.10 shows in the River Hipper sub-catchment. Compared to the other three sub-catchments, erosion risk is generally lower in this sub-catchment. Erosion risk within the River Hipper sub-catchment is higher during January.

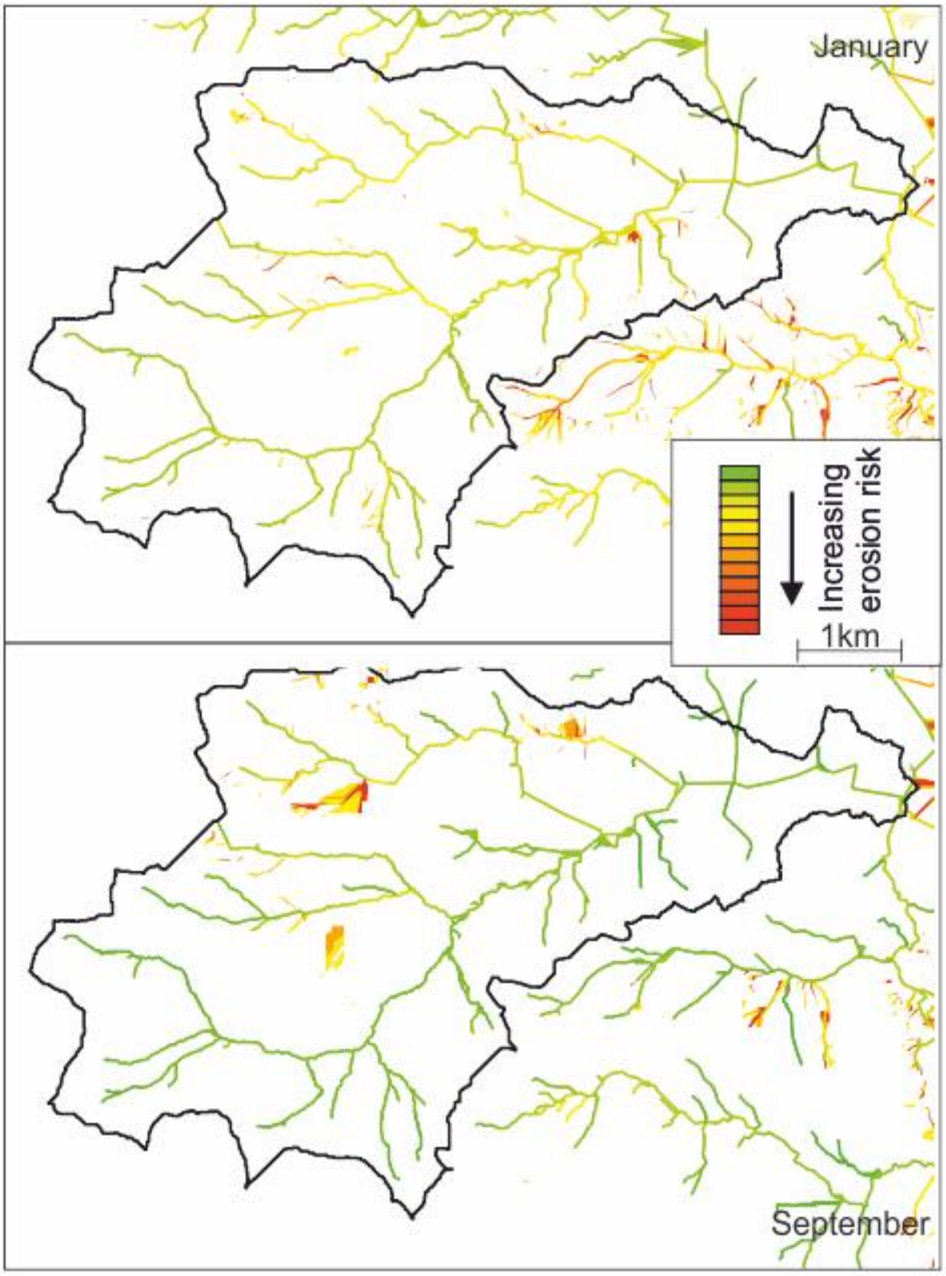

***Figure 5.10** – Erosion risk maps for the River Hipper in January and September 2018. Erosion risk varies from green (very low risk) to red (high risk). Interventions that are focused on reducing diffuse pollution are best placed in areas of higher risk (oranges and reds).*

Overland flow: Figure 5.11 shows the overland flow within the River Hipper sub-catchment. Many of the headwater tributaries have high potential for overland flow; which ponds near the main channel.

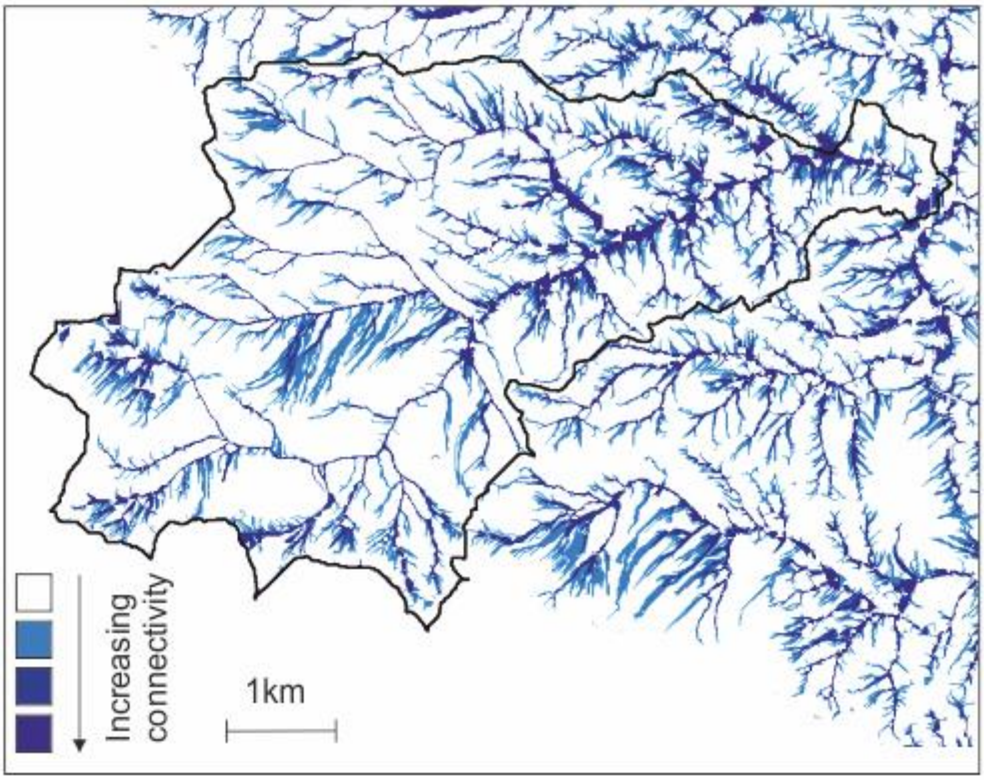

Figure 5.11 – *Overland flow in the River Hipper. Connectivity varies from low (white) to high (dark blue). The darker the blue, the more connected the overland flow is to the main channel. Interventions used to slow the flow are best placed in areas of high connectivity (dark blue).*

Habitat Connectivity: Figure 5.12 shows the connectivity maps for the River Hipper. There are 6 LWS woodland areas in the River Hipper sub-catchment. Most of the catchment has low resistance, however resistance increases towards the bottom of the sub-catchment. There are no LWS grasslands within the sub-catchment (Fig. 5.12B) and resistance values increase down the sub-catchment. The connectivity map for meadows (Fig. 5.12C) indicate low resistance values in the top of the catchment, again increasing downstream.

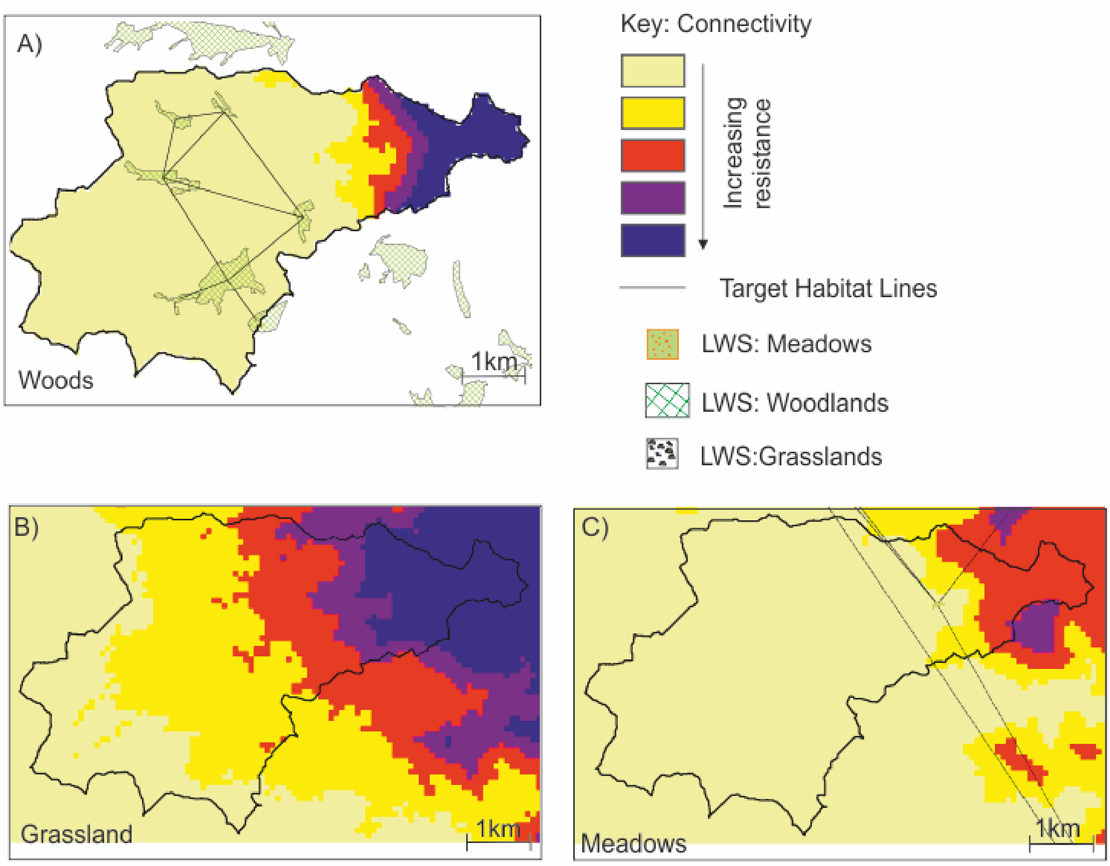

***Figure 6.12** – Habitat connectivity maps for the River Hipper. Resistance of connecting target habitats ranges from low (beige) to high (blue); the higher the resistance, the harder it will be to connect the target habitats. Interventions based on increasing habitat connectivity should be placed between target habitat pockets that are connected by low resistance areas, this will make the interventions more effective. The lines shown are target habitat lines which connect the target habitats, woodlands were assessed on a sub-catchment scale and therefore the lines are contained within the sub-catchment, whereas for grasslands and meadows the HHSS study area scale was used and therefore the lines may extend out of the sub-catchment to connect target habitats to a neighbouring target habitat in a different sub-catchment.*

5.1.4 Tributary synchronisation

For the hydrological modelling, a smaller catchment area than the HHSS study area was modelled. The Moss Brook was excluded from the tributary synchronisation modelling work, as reducing flooding in Chesterfield is an aim of the DCRT and the Moss Brook does not influence flooding in Chesterfield. The River Drone was included as it flows into the Chesterfield constituency, although the confluence with the River Rother is downstream of the town of Chesterfield.

Varying time to peak only[57]: each sub-catchment's flow was delayed by 2 hours (Table 5.1). Table 5.1 shows that modifying the flow, by placing interventions that could slow the flood

[57] This was analysed for 1 in 2, 1 in 5 and 1 in 10 year flood return periods.

peak by 2 hours in the Upper Rother will have the greatest impact on flood peaks in the study area, for example those impacting Chesterfield.

***Table 5.1** – Impact of delaying the sub-catchment flood peaks by 2 hours*

Location	Flow reduction for full catchment (%)
Upper Rother	3.3
Hipper	1.7
Drone	1.7

Table 5.1 indicates that delaying the peak flow by 2 hours in the Upper Rother will reduce flow peaks in the Chesterfield constituency by 3.3%; the lowest point modelled here is just below the tributary with the River Drone. The percentage reduction in peak flow delivered by the 2-hour delay was found to be the same for flood events with return periods of 1 in 2, 1 in 5, and 1 in 10 years.

Storage: Table 5.2 shows the local percent mitigation and full catchment mitigation of installing storage ponds in each sub-catchment for floods with a return period of 1 in 2 years, 1 in 5 years and 1 in 10 year floods. The storage modelled was 100,000 m^3 in 10 ponds[58], this is 0.17% of the Upper Rother catchment area, 0.25% of the River Hipper catchment area and 0.17% of the River Drone catchment area[59]. For the model runs, the only variable that is changed is the flow threshold; the discharge in which the storage will start to fill. The optimal flow threshold is stated in this section, which is the discharge value in which the storage will start to fill, that will have the biggest impacts on flood mitigation.

Table 5.2 shows the optimised threshold for reduction in discharge for different flood return periods, in this table the optimal threshold changes for each return period modelled. If the pond was optimised for the threshold stated in the 1 in 2 year event, the impacts stated in the table for the 1 in 5 or 1 in 10 year would not be seen (as the threshold value is optimised for a different return period). Table 5.2 shows what is possible in terms of flood reduction, as the storage has been optimised for different flood return periods. Table 5.3 shows the impact on the sub-catchments for different return periods if the storage was optimised for a 1 in 5 year flood[60]; for this model run the optimal threshold was kept the same for the different return periods.

At a 1 in 2 year flood frequency (Table 5.2), interventions that slow the flow in the Upper Rother and River Drone have a similar impact on overall flood reduction for the study area (optimal threshold for a 1 in 2 year flood is 13 m^3s^{-1} and 10 m^3s^{-1}, respectively). However, interventions in the Upper Rother will have more of an impact on Chesterfield, due to the location of the tributaries joining of the River Drone to the River Rother. Interventions in the Upper Rother will also have more of a localised effect in the sub-catchment reducing flow peaks by 25%.

58 Following the guidance in the EA storage calculator. The location of the storage in the sub-catchment is not defined, and the storage calculator works as a mass balance approach. The local percent mitigation shows the impact of delaying the flow peak on the sub-catchment modelled only and is modelled using the design hydrograph, with a delayed peak showing the difference between 'normal' conditions and conditions that slow the flow (e.g., storage).

59 100,000 m^3 is split between 10 ponds in the sub-catchments, each pond holds 10,000 m^3 – which could be a pond 100m in length, 100 m in width and 1 m in depth for example.

60 The 1 in 5 year return period was chosen arbitrarily to show the impact of keeping the optimal threshold the same for different flood return periods.

At a 1 in 5 year flood frequency (Table 5.2), interventions in the Upper Rother will decrease the flow peaks in the full catchment by 10% (optimal threshold for a 1 in 5 year flood is 17 m^3s^{-1}), having a wider catchment impact than the Hipper or Drone. However, interventions in the River Hipper (7.7%,optimal threshold for a 1 in 5 year flood is 10 m^3s^{-1}) and River Drone (9.1%, optimal threshold for a 1 in 5 year flood is 14 m^3s^{-1}) will have a larger localised impact on their respective sub-catchments.

When modelling a 1 in 10 year event (Table 5.2), interventions in the Upper Rother will have a bigger impact on the whole catchment (9%, optimal threshold for a 1 in 10 year flood is 21 m^3s^{-1}), whereas interventions in the River Hipper (optimal threshold for a 1 in 10 year flood is 12 m^3s^{-1}) and River Drone (optimal threshold for a 1 in 10 year flood is 17 m^3s^{-1}) have an impact of 7.5% and 8.5% respectively[61].

Overall, Table 5.2 shows that the Upper Rother will have the largest impacts on reducing flooding at the catchment scale.

When optimising the threshold flow for a 1 in 5 year flood (Table 5.3), during the 1 in 2 year flood event, the River Drone storage (optimal threshold for 1 in 5 year event is 14 m^3s^{-1}) has the biggest impact on the whole catchment (4.4%); however this is closely followed by the other two sub-catchments modelled (4.2%). Localised mitigation is highest in the River Hipper catchment (16.2%, optimal threshold for 1 in 5 year event is 10 m^3s^{-1}). At a 1 in 5 year flood frequency, interventions in the Upper Rother will decrease the flow peaks in the full catchment by 10% (optimal threshold for 1 in 5 year event is 17 m^3s^{-1}), having a wider catchment impact than the Hipper or Drone. However, interventions in the River Hipper (7.7%) and River Drone (9.1%) will have a larger localised impact on their respective sub-catchments. During a 1 in 10 year event, when the threshold is optimised to the 1 in 5 year event threshold, impacts are greater for the whole catchment in the River Hipper (2.6%), and localised impacts here are 3.3%.

Table 5.3 shows that the most effective sub-catchment changes with the flood return period when the optimal threshold is kept for the 1 in 5 year event. The River Drone has the biggest catchment impacts for a 1 in 2 event (closely followed by the other sub-catchments, although the River Hipper has greatest localised effects); the Upper Rother for the 1 in 5 event (again greatest localised impacts in River Hipper sub-catchment) and the River Hipper sub-catchment will have the biggest impacts for the 1 in 10 (n.b. these results could be different if the storage was optimised for the 1 in 2 or 1 in 10 threshold).

Table 5.2 *– Impact of storage in each sub-catchment for different flood frequencies (n.b the optimal threshold is varied for each flood return period)*

Flood return period	**Storage: 100,000 m^3 in 10 ponds.**	**Upper Rother sub-catchment**	**River Hipper sub-catchment**	**River Drone sub-catchment**
1 in 2 year	Optimal threshold Flow (m^3s^{-1})	13	7	10
	Local mitigation (%)	25.4	33.3	19.4
	Full catchment mitigation (%)	10.2	8.7	10.3
1 in 5 years	Optimal threshold Flow (m^3s^{-1})	17	10	14
	Local mitigation (%)	9.8	27	15.3

[61] This is a simplistic approach to modelling the impact of NFM in the sub-catchments chosen. As increments of 1m^3s^{-1}, the true mathematical optimum was not distinguished, this could impact the ranking effect on how each sub-catchment responds at different flooding return periods.

Flood return period	**Storage: 100,000 m^3 in 10 ponds.**	**Upper Rother sub-catchment**	**River Hipper sub-catchment**	**River Drone sub-catchment**
	Full catchment mitigation (%)	10.0	7.7	9.1
1 in 10 years	Optimal threshold Flow (m^3s^{-1})	21	12	17
	Local mitigation (%)	9.6	15.0	11.4
	Full catchment mitigation (%)	9.0	7.5	8.5

Table 5.3 – *Impact on sub-catchment performance during different flood frequencies when optimising the storage to the 1 in 5 year optimal threshold.*

Flood return period	**Storage: 100,000 m^3 in 10 ponds.**	**Upper Rother sub-catchment**	**River Hipper sub-catchment**	**River Drone sub-catchment**
1 in 2 year	Optimal threshold Flow (m^3s^{-1})	17	10	14
	Local mitigation (%)	10.6	16.2	12.8
	Full catchment mitigation (%)	4.2	4.2	4.4
1 in 5 years	Optimal threshold Flow (m^3s^{-1})	17	10	14
	Local mitigation (%)	9.8	27	15.3
	Full catchment mitigation (%)	10.0	7.7	9.1
1 in 10 years	Optimal threshold Flow (m^3s^{-1})	17	10	14
	Local mitigation (%)	0.3	3.3	1.4
	Full catchment mitigation (%)	0.8	2.6	0.8

5.2 Opportunity maps produced

The opportunity maps displayed below combine the hotspot maps and conditions developed from the expert advice workshop (e.g., where they would be most effective etc.). These conditions relate to where the biggest problem in the catchment area is (e.g., areas of high erosion risk) and what intervention would be most effective to reduce this (e.g., buffer strips, Chapter 4). Producing opportunity maps therefore requires analysis of the hotspot maps and knowledge of the different types of interventions possible. Figures 5.13 – 5.16 show the recommended volunteer-led opportunities within the Upper Rother, Lower Rother, Moss Brook and River Hipper respectively. The types of volunteer-led opportunities mapped were determined through an expert advice workshop. Figure 5.17 shows the underlying hotspot maps and opportunities for Moss Brook; highlighting the main problem areas that have been targeted by interventions. The annotations also highlight the impacts of each intervention chosen. Not all of the opportunities have been highlighted and the maps show where two or more of the aims of the HHSS can be met (noting, habitat connectivity is often not modelled when focusing on slowing the flow or reducing diffuse pollution). The shapefiles produced for the DCRT showed a scoring system to help prioritise interventions (a score out of 3 for each intervention related to the aims).

The opportunity areas map represent the areas where interventions could be placed to: 1) decrease diffuse pollution; 2) slow the flow; and 3) increase landscape connectivity[62,63].

[62] In the workshop, habitat maps were used instead of the connectivity maps.
[63] Each shapefile produced indicates how these goals could be met.

5.2.1 Advantages and limitations of opportunity mapping

The opportunity maps produced in this report are based on GIS modelling of hotspots, or problem areas in the catchment. This information can be used to prioritise the areas and interventions used that will have the biggest impacts e.g., that can slow the flow, reduce diffuse pollution and increase landscape connectivity. They therefore act as a time saving activity that reduce the need for extensive catchment wide fieldwork. The modelling methods can also be used to test problem areas under different conditions and can be used to see how different interventions will perform under different climate change scenarios.

Benefits of mapping using GIS:

- Quick and repeatable methodology.
- Saves time by prioritising areas and interventions that can be used.
- Can test whether interventions can be used for multiple benefits.
- Can be used to model different scenarios to see how problem areas change (e.g., using seasonal land use maps for mapping erosion risk or different flood return periods for tributary synchronisation work).

Nonetheless, the outputs need to be ground truthed and only show the general area of where interventions should be placed due to the resolution of the data used (5 m). Further, the GIS methodology is comprised of simplified models based on a limited set of equations which simplify the complexities experienced in catchments. When placing in-stream interventions a detailed understanding of the hydrology and hydromorphology of the reach is needed.

Limitations of opportunity modelling:

- Mapping is limited by the resolution of data and simplified equations used and therefore the outputs need to be ground truthed.
- Any in-stream work requires further detailed modelling to understand the hydrology and hydromorphology of the reach.

It is also important to note, if interventions are being placed to increase landscape connectivity different species may need to be considered than for those used to slow the flow or reduce erosion risk

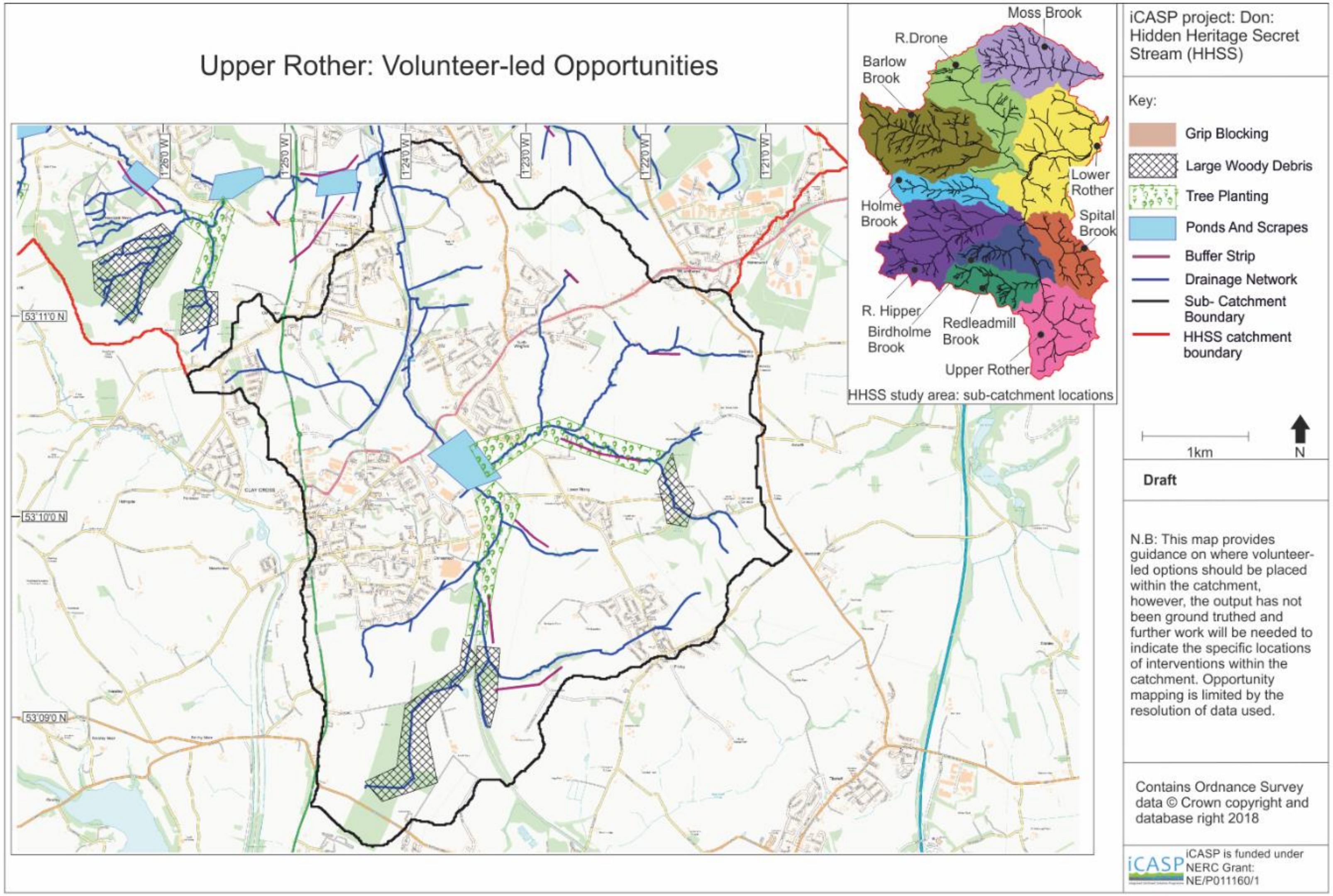

Figure 5.13 *– Opportunity map for the Upper Rother.*

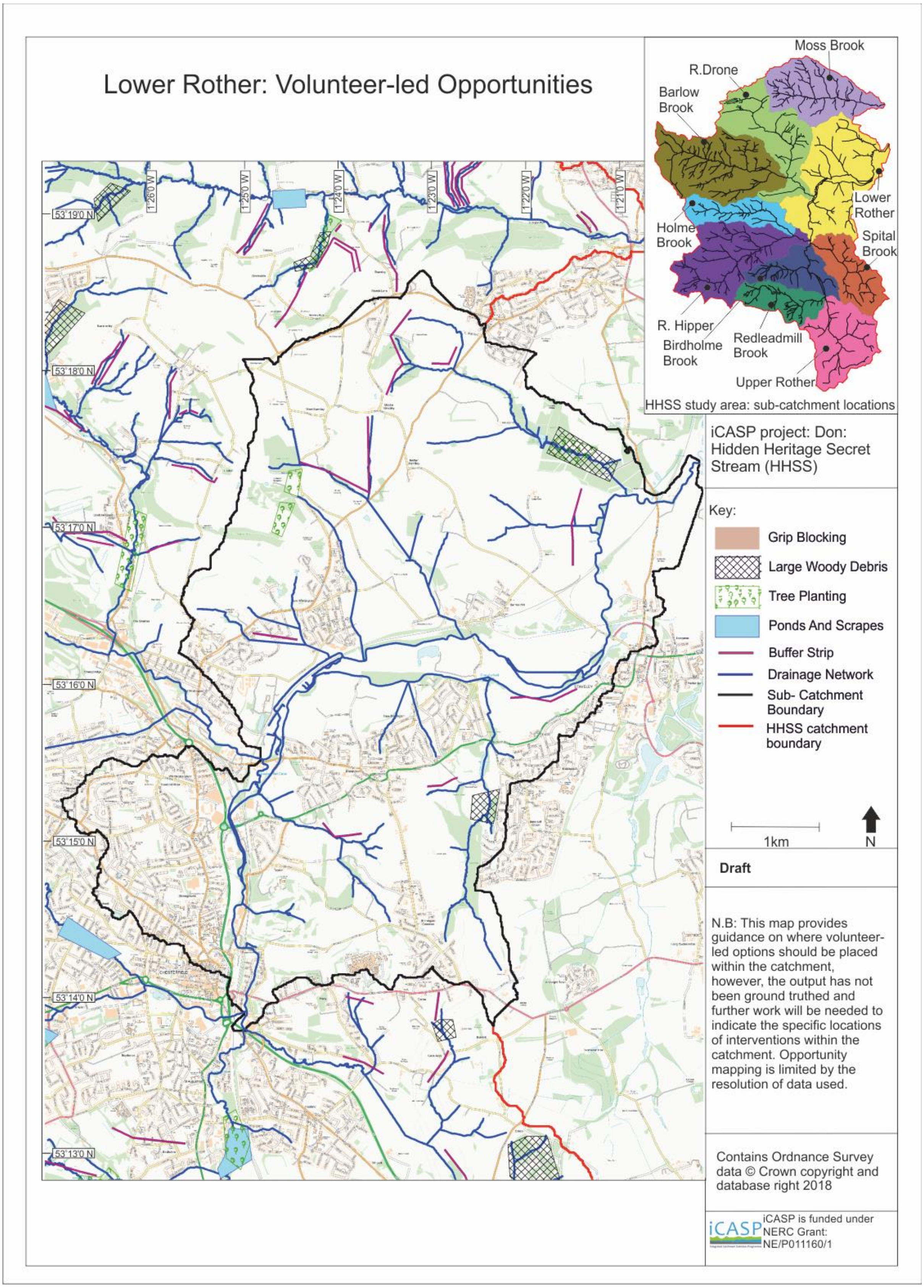

***Figure 5.14** – Opportunity map for the Lower Rother.*

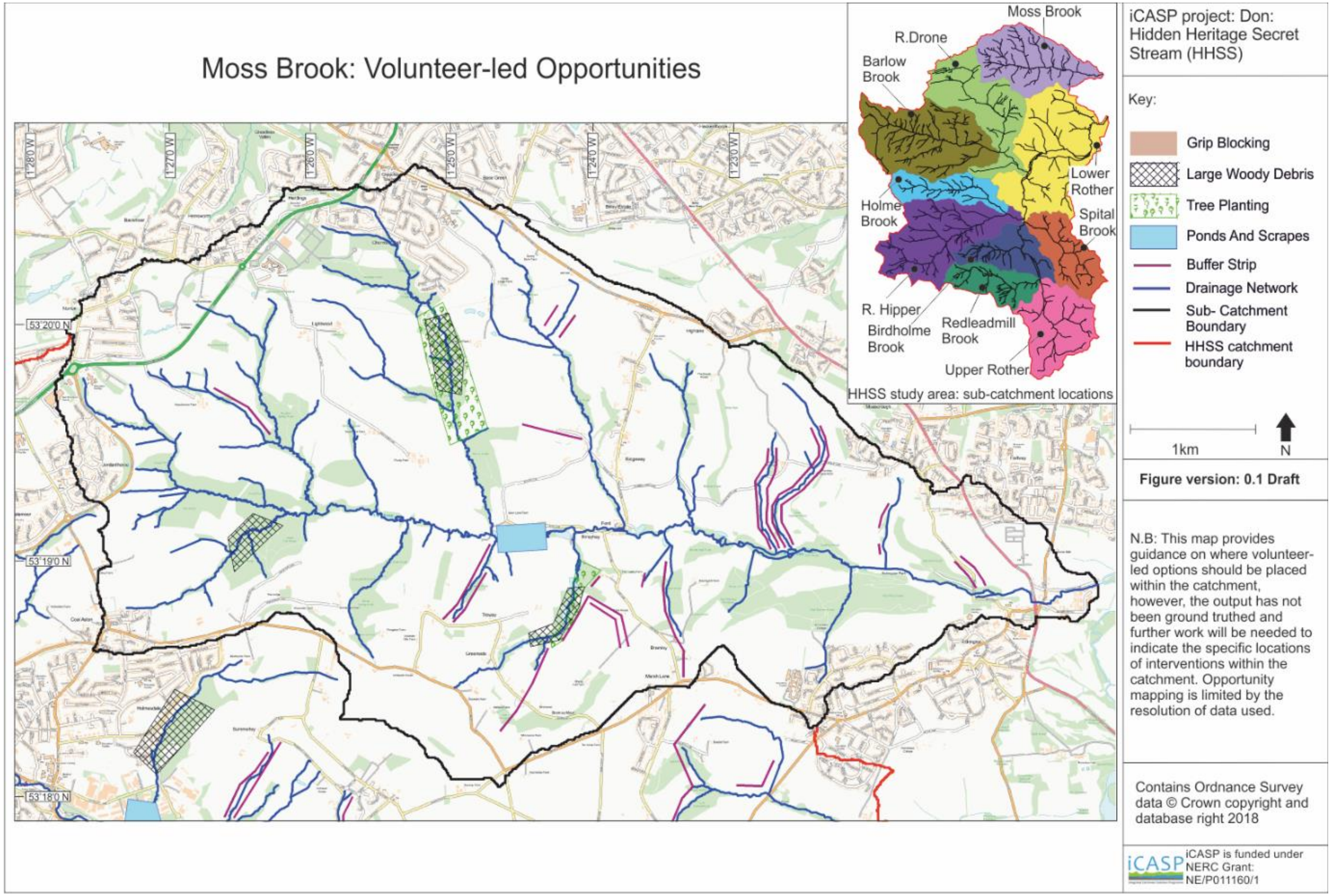

***Figure 5.15** – Opportunity map for Moss Brook.*

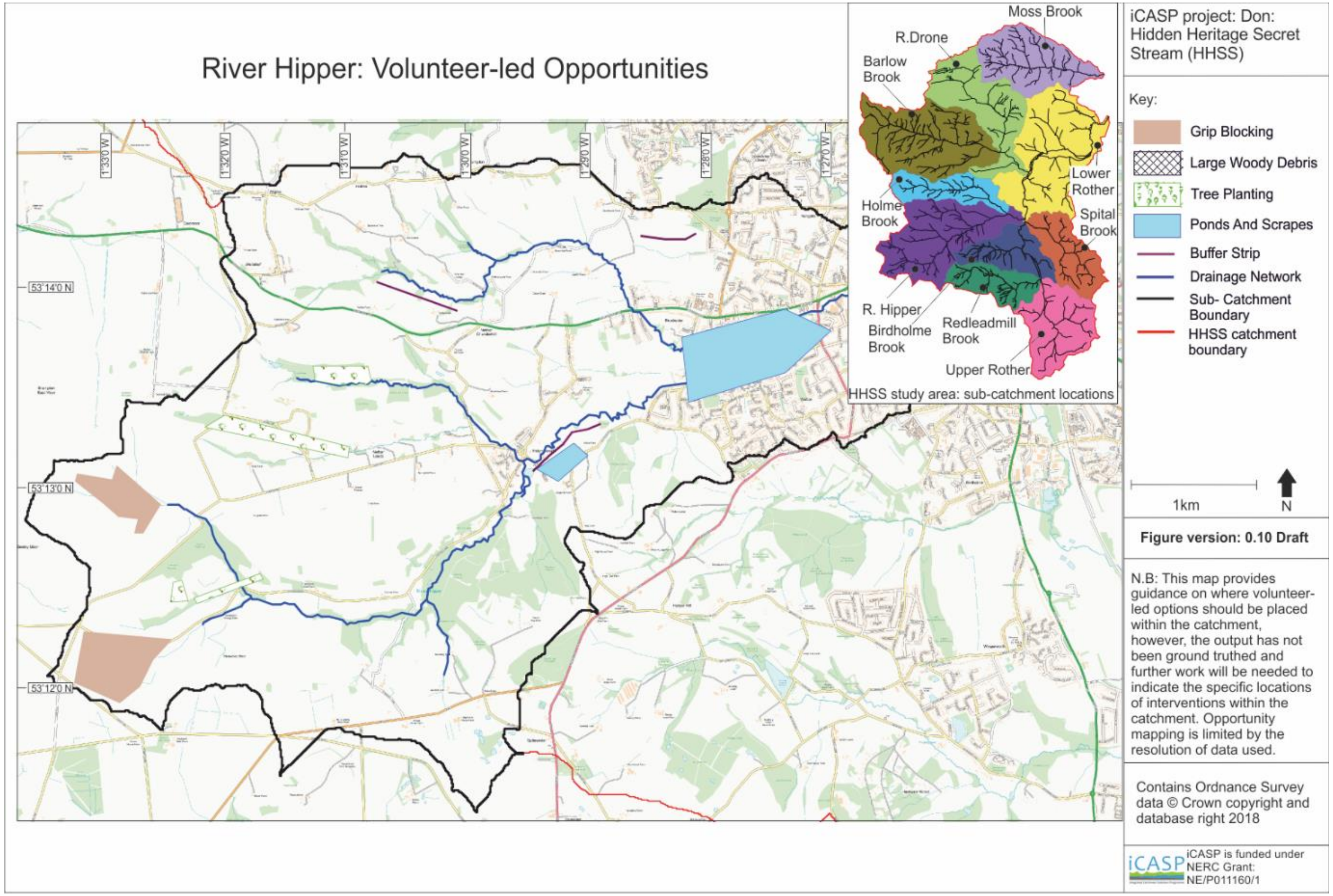

***Figure 5.16** – Opportunity map for River Hipper.*

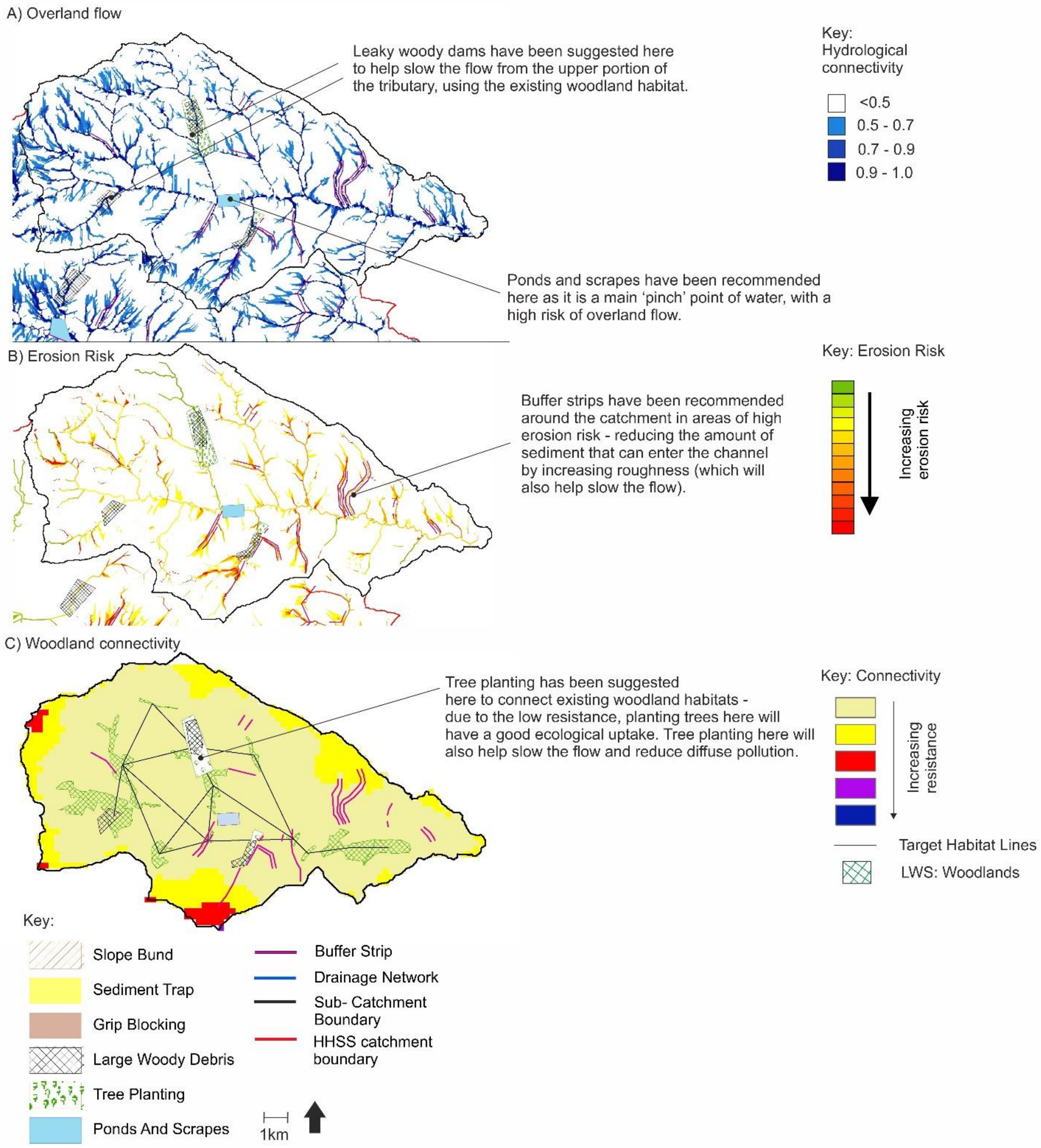

Figure 5.17 *– Comparison of hotspot maps for Moss Brook and opportunities. Some annotations have been added to explain the intervention choices and their impacts.*

6. Monitoring of interventions

This section has been compiled from the expert workshop, and relates to volunteer-led monitoring activities only. The top four interventions: buffer strips, tree planting, leaky woody debris and ponds were discussed in detail.

Ideally, monitoring data would be collected before an intervention is put in place to have a baseline dataset that could be compared against. In the best case situation at least 3 – 4 years of baseline data are required, to show the variation of events in the catchment including different flow events and conditions of the catchment (e.g., soil moisture content, number of days of rainfall, rainfall amounts). Baseline information is especially important where in-channel interventions are required e.g., leaky woody debris. However, extreme events are unpredictable and infrequent, and therefore the baseline period may not include the whole range of events that a catchment can experience. Furthermore, in practice, baseline data is normally not available at the resolution needed to compare before and after an intervention. Existing data sets could be used to inform the baseline e.g., ecological data. In situations where no baseline data is available, comparative sites (where interventions are / are not present) could be used to assess the effectiveness of the interventions. Examples of existing data include the Environment Agency's Water Quality data, the Environment Agency's Ecological Data (e.g. macrophytes and macroinvertebrates) and the National River Flow Archive's Flow data.

Some NFM interventions have a timeframe of impact longer than the HHSS project duration, a clear continuation policy is required in case the volunteer team disbands. Data collected needs to be uploaded to the most appropriate database e.g., Joint Nature Conservation Committee (JNCC) for ecology data. It may be more effective to have a framework or tick sheet for volunteers to work to; this will allow data to be comparable if collected by different people.

It may be better to focus on demonstrator sub-catchments or pilot areas, than monitor the entire HHSS study area. For monitoring, ongoing permission will be needed for land access. If volunteers repeatedly monitor one site consistently, there may be more of an effective monitoring with consistent data collected. Additionally, it is important when working with volunteers to show how the data will be used, for example, will there be a science fair?

An iCASP project on monitoring of NFM is underway, information on this project can be found here: Website link to iCASP NFM website.

Table 6.2 shows the range of monitoring that can be undertaken for volunteers in the HHSS study area, focused on the interventions that have been mapped through opportunity mapping.

Further reading:

Defra guidance on monitoring is available here: website link to Defra guidance.

Monitoring information can also be found in chapter 6 of: Burgess-Gamble, L, Ngai, R., Wilkinson, M., Nisbet, T., Pontee, N., Harvey, R., Kipling, K., Addy, S., Rose, S., Maslen, S., Jay, H., Nicholson, A., Page, T., Jonczyk, J., and Quinn, P. 2018. Working with Natural Processes – Evidence Directory. Environment Agency

Monitoring information can also be found in chapter 9 of: Forbes, H., Ball, K., and McLay, F., 2015. Natural Flood Management Handbook. Scottish Environment Protection Agency.

JNCC (September 2016) common standards monitoring guidance for rivers. ISSN 1743-8160

Table 6.2 *- Monitoring of volunteer-led NFM interventions.*

Intervention	What can be monitored?	Who will monitor (e.g., land owners, weekend helpers etc.)	When should the monitoring occur?	How often does monitoring need to happen?	What kit is required?
Before interventions are placed	Ground truthing of model outputs	Volunteers	Before interventions is implemented		Camera for recording potential problem locations
	Walkovers to gather site specific information	Volunteers	To shortlist interventions		Camera
All interventions	Checking of damage to NFM structures	Volunteers		Annual	Camera for recording potential problem locations
Hedgerows	Hedgerows	Landowner or volunteer	Lifespan of hedge	Before hedge is planted, then annually (just after storm event)	Visual inspection
Pond	Off-line pond and leaky dams or anything where water is held back (water level monitoring)	Volunteer or landowner	HHSS duration	Every five minutes (monthly trip to downloNad)	Timelapse camera
Leaky woody debris	Flow	Landowner, volunteer, Auditor/instructor	Before, during and after life of the asset.	Baseline and before and after an event.	Cameras, gauge boards.
	Level	Landowner, volunteer, Auditor/instructor	Before, during and after life of the asset	Baseline and before and after an event.	Cameras, gauge boards.
	Asset performance	Landowner, volunteer, Auditor/instructor	Life time of the asset	For the lifecycle of the asset	Pre-defined criteria, photographic record from a fixed point.
	Baseline	Landowner, volunteer, Auditor/instructor	A full season - 1 year at least. Range	For a period before but including a storm event	Same kit as all the other but need to

Intervention	What can be monitored?	Who will monitor (e.g., land owners, weekend helpers etc.)	When should the monitoring occur?	How often does monitoring need to happen?	What kit is required?
			of conditions.		be done before.
	Ecological (macro invertebrates)	Landowner, volunteer, Auditor/instructor	Baseline and then once the intervention has been in place to establish effect - at the same time of year.		Net, tray, river fly ID key
	Sediment - bed composition	Landowner, volunteer, Auditor/instructor	Baseline and then once the intervention has been in place to establish effect - at the same time of year.		Tape measure / visual inspection.
Tree planting	The base line Infiltration rates Bank erosion Sediment reduction Soil structure Flow reduction	Project volunteers Landowners / farmers	To fully assess the impact it was thought 30 years could be needed	Preferably seasonally, but at least once per year At the end of the 3 year project for funders reporting requirements	Observation (tick sheet): • Sandbanks • Size of sediment points • Bank erosion • Drains • Collapsed trees • How close arable gets to river • Is a buffer present? Volunteers would need: • Camera for photos

Intervention	**What can be monitored?**	**Who will monitor (e.g., land owners, weekend helpers etc.)**	**When should the monitoring occur?**	**How often does monitoring need to happen?**	**What kit is required?**
					• GPS / mobile phone for co-ordinates If enough budget available an app could be designed to gather data in the field.
Buffer strips	Sediment load and phosphate levels Turbidity	Both	Before, during lifetime of the asset	Seasonally and after a storm event.	Sediment maps /white tile – how quickly it silts up (sediment disk) – very easy to do – (the tiles need to be numbered) Phosphate dipstick – level in buffer strip – across difference distances form the river. Turbidity: river logger – ruler or could use cameras. *Stage what number can you read down to?* *What colour is the water?*

Intervention	What can be monitored?	Who will monitor (e.g., land owners, weekend helpers etc.)	When should the monitoring occur?	How often does monitoring need to happen?	What kit is required?
	Rack marks / trash line – size of inundation of buffer strip after an event	Both, weekend walkers	During lifetime of the asset	Try and get different flow events / rainfall events. Roughness and therefore efficiency would change seasonally (e.g., grazing will have an impact)	GPS location
	Size of habitat / species present	Both, weekend walkers	Pre intervention data is needed - biodiversity – need a few surveys throughout the year (existing data may be helpful) and during lifetime of the asset	Seasonally	Volunteer – presence of key species – co-ordinate with the wildlife trust Follow: national butterfly transect or Phase 1 habitat survey protocols
General	Fishing club – otter monitoring	Volunteer or landowner	HHSS duration		
	Invert monitoring Riverfly = PSI possible	Volunteer or landowner	HHSS duration		Could pull EA data - / map where monitoring is.
	Camera traps for wildlife corridor – e.g., otters going through the area	Volunteer or landowner	HHSS duration		

Intervention	What can be monitored?	Who will monitor (e.g., land owners, weekend helpers etc.)	When should the monitoring occur?	How often does monitoring need to happen?	What kit is required?
	Water quality testing	Volunteer or landowner	HHSS duration	As frequently as possible	People's Ponds and Water Freshwater Habitats Trust See publications. OPAL – citizen science in urban environment
	Outfall safari – app Trent rivers trust / CaBA	Volunteer or landowner	HHSS duration	As frequently as possible	Guides on 'outfall safari' – identification of pollution sources: website link to outfall safari guide.

7. Framework

The method used in this project can be adapted to involve other benefits NFM provides such as water quality, air quality, carbon sequestration etc. Mapping is limited by data resolution, however the advances in satellite imagery allow for high resolution data to be used that is freely available. Nonetheless, smaller pathways for water and sediment such as farm tracks or small gullies will need to be mapped via fieldwork. The mapping here represents a first step in prioritising sub-catchments and specific areas for further fieldwork investigation for ground truthing or more in depth modelling (e.g., hydrological modelling via SD-TOPMODEL).

Habitat connectivity is often not incorporated in NFM modelling, this work has shown that freely available plugins can be used to investigate potential locations to increase habitat connectivity without the need for extensive ecological surveys.

Figure 7.1 summarises the method and framework followed for this project to allow for prioritising sub-catchment and sites for volunteer-lead interventions.

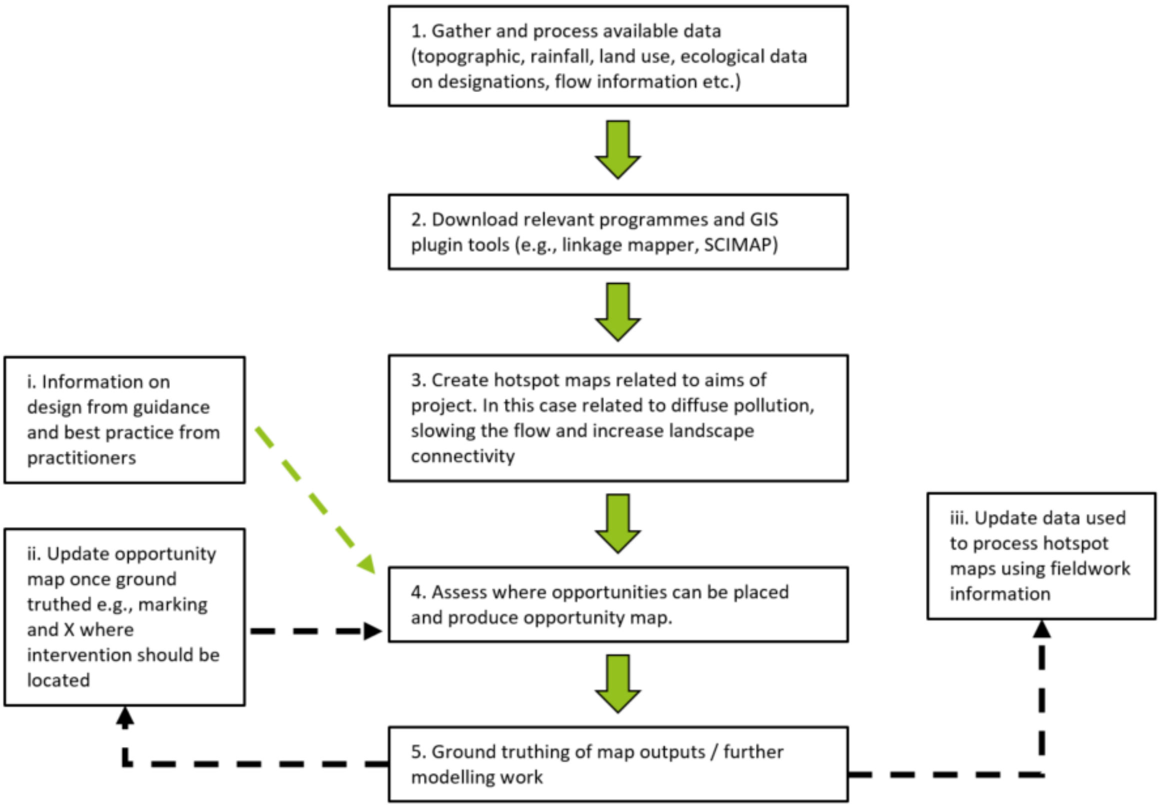

Figure 7.1 *– Framework followed for this work.*

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Appendices

Appendix 1 – Natural Flood Management Options Under Consideration for the HHSS project

Source: DCRT Hidden Heritage Secret Streams Phase 2 Application to the Heritage Lottery Fund. Submitted August 2018.

1. Basic sediment trap

A sediment trap is a containment area where sediment-laden runoff is temporarily detained, allowing sediment to settle out before the run-off is discharged.

2. Swales

Swales are broad and shallow vegetated open channels, designed to convey runoff, reducing its volume and velocity and removing pollutants.

3. Infiltration trench

A narrow trench filled with stone or a commercial drainage material one to two meters deep with no outlet which encourages slow infiltration into the subsoil through the creation of an underground reservoir

4. Filter/French drains

A method to move run-off water slowly towards a receiving watercourse. Provides some storage and some treatment.

5. Barriers/traps within ditches & swales

Barrier/traps cause ditch water to pond inducing sedimentation and increased filtration. Sometimes the measure includes material which encourages further removal of pollutant from the water e.g. ochre traps.

6. Wetlands within ditches

Creation of a small linear wetland feature within a ditch, increasing sedimentation, denitrification and nutrient utilisation.

7. Detention basin/pond

Normally dry basins designed to temporally store and slowly release runoff water.

8. Infiltration basin

A depression designed to store runoff and infiltrate it into the ground.

9. Retention pond

Wet ponds, designed to permanently retain some water at all times and provide temporary storage above it, through an allowance for large variations in level during storms.

10. Riparian tree planting

Riparian woodlands are usually planted as buffer zones the watercourse and adjacent land, which allows the maximum amount of contact between the trees and water.

11. Floodplain tree planting

Floodplain woodland is thought to offer the greatest potential for downstream flood mitigation

12. Woodland shelter belts

Planting mixed woodland to produce a belt which primarily reduces wind speeds, but also encourages infiltration and prevents soils erosion.

13. Hedgerow planting/management

Plant hedges and maintain them across slopes in erosion vulnerable areas.

14. Stone wall laying

Build dry stone dykes and maintain them across slopes in erosion vulnerable areas.

15. Dry grass buffer strips

Broad, gently sloping area of grass or other dense vegetation that can be placed on slopes around the farm to intercept run-off around vulnerable areas.

16. Riparian buffer strips (dry)

Medium width, dry, bands of natural or naturalised vegetation situated alongside waterbodies.

17. Riparian buffer strips (wet)

A broad, strip of natural or naturalized wetland vegetation or wet woodland alongside a water body.

18. Berms and water diversions

Low ridges or banks to redirect runoff.

19. Wetland creation

Wetlands (CWs) are a habitat type with natural processes that can remove contaminants via a combination of physical (filtration, sedimentation), biological (microbial processes, plant uptake) and chemical (precipitation, adsorption mechanisms.

20. Rainwater harvesting and diversion

Rainwater is collected from roofs and impervious hard standing areas and diverted from surface waters. It can be stored and used around properties and farms or to be diverted to soak-away

21. Green roofs

A multi-layered system covering the roof of a building with vegetation cover or landscaping over a drainage layer. They are designed to intercept and retain precipitation, reducing runoff volume and attenuating peak flows.

22. Pervious surfaces

Pavement or hard standing constructions or other pervious surfaces that allow rainwater or run-off to infiltrate through the surface to an underlying temporary storage area.

23. Cross drains

A cross drain is a system to convey water across a path or route. A cut-off drain is a more durable form of cross-drain and can also be used to collect run-off from a vulnerable area. For example, tracks, which provide a significant transport pathway for water and sediment.

24. Biobeds

Biobeds are intended to collect, retain and degrade pesticide residues arising from agricultural pesticide handling activities e.g. handling/diluting pesticides and washing of equipment and have the potential to reduce pollution of surface waters.

25. Sedimentation boxes

Sedimentation boxes, also known as baffle boxes, are tanks with a permeable base, connected to tile drains.

26. Soak-away

An infiltration drain. Often square or circular excavations (may also be trenches, see infiltration trenches) filled with rubble, lined with brickwork, pre-cast concrete rings or similar where rainwater and run-off is collected and infiltrates directly into the ground.

27. Grip (gully) blocking

Blocking off of grips (drainage ditches) in peatlands.

28. Re-site gateways away

Move field entrances away from high risk areas

29. Livestock bridges

Construct small bridges for livestock to cross over waterbodies rather than fording them

30. Riparian fencing

Prevent livestock from entering waterbodies by erecting fences along their perimeters

31. Loosen compacted soils

Loosen compacted soil layers in grassland fields

32. Path improvements

Improve the condition of paths that are significant sources of sediment

33. River bank restoration

Restore degraded river banks

34. Instream structures

Create woody dams or similar to attenuate the flow of water within the waterbody

35. Washland and offline storage pond creation

Create areas where water can be stored on the floodplain

Appendix 2 – Water Framework Directive, reasons for not achieving good status

Waterbody	Element	Cycle 2 year	Activity	Activity certainty	Pressure
Barlow Brook	Fish	2014	Poor soil management	Suspected	**Sediment**
		2014	Urbanisation - urban development	Confirmed	Morphology
		2014	Barriers - ecological discontinuity	Confirmed	Morphology
		2014	Sewage discharge (continuous)	Confirmed	Dissolved oxygen
		2014	Trade/Industry discharge	Confirmed	Organic pollution
		2014	Incidents	Probable	**Sediment**
Drone and Whitting	Ammonia (Phys-Chem)	2014	Sewage discharge (continuous)	Confirmed	
	Invertebrates	2014	Sewage discharge (continuous)	Confirmed	Ammonia
	Phosphate	2014	Sewage discharge (continuous)	Confirmed	
	Mitigation Measures Assessment	2013	Other (not in list, must add details in comments)	Confirmed	Urbanisation
	Mitigation Measures Assessment	2013	Other (not in list, must add details in comments)	Confirmed	Flood protection
	Invertebrates	2014	Urbanisation - urban development	Confirmed	Morphology
	Macrophytes and Phytobenthos Combined	2015	Sewage discharge (continuous)	Confirmed	Nutrients
Hipper		2013	Physical modification	Confirmed	Urbanisation
Holme Brook	Invertebrates	2014	Sewage discharge (intermittent)	Suspected	Ammonia
	Fish	2014	Urbanisation - urban development	Confirmed	Morphology
	Invertebrates	2014	Septic Tanks	Confirmed	Dissolved oxygen

Waterbody	**Element**	**Cycle 2 year**	**Activity**	**Activity certainty**	**Pressure**
	Mitigation Measures Assessment	2013	Other (not in list, must add details in comments)	Confirmed	Urbanisation
	Fish	2014	Septic Tanks	Probable	Dissolved oxygen
	Ammonia (Phys-Chem)	2016	Not applicable	Not applicable	
Redleadmill	Macrophytes and Phytobenthos Combined	2015	Poor nutrient management	Suspected	Nutrients
	Macrophytes and Phytobenthos Combined	2015	Sewage discharge (continuous)	Probable	Nutrients
	Fish	2015	Other (not in list, must add details in comments)	Suspected	Morphology
Rother from Redleadmill Brook to Spital Brook	Phosphate	2014	Sewage discharge (continuous)	Confirmed	
	Macrophytes and Phytobenthos Combined	2015	Sewage discharge (continuous)	Confirmed	Nutrients
	Mitigation Measures Assessment	2013	Other (not in list, must add details in comments)	Confirmed	Flood protection
	Fish	2015	Contaminated water body bed sediments	Confirmed	**Sediment**
	Invertebrates	2015	Sewage discharge (continuous)	Probable	Ammonia
	Macrophytes and Phytobenthos Combined	2015	Sewage discharge (intermittent)	Confirmed	Nutrients
Rother from Source to Redleadmill Brook	Ammonia (Phys-Chem)	2016	Sewage discharge (intermittent)	Confirmed	
	Phosphate	2016	Sewage discharge (continuous)	Confirmed	
	Invertebrates	2014	Sewage discharge (intermittent)	Probable	Dissolved oxygen
	Invertebrates	2014	Sewage discharge (intermittent)	Probable	BOD

Waterbody	**Element**	**Cycle 2 year**	**Activity**	**Activity certainty**	**Pressure**
	Fish	2014	Sewage discharge (continuous)	Confirmed	Ammonia
	Macrophytes and Phytobenthos Combined	2014	Sewage discharge (continuous)	Confirmed	Nutrients
	Fish	2014	Sewage discharge (intermittent)	Probable	Ammonia
	Invertebrates	2014	Sewage discharge (intermittent)	Probable	Ammonia
	Invertebrates	2014	Sewage discharge (continuous)	Confirmed	Dissolved oxygen
	Invertebrates	2014	Sewage discharge (continuous)	Confirmed	BOD
	Invertebrates	2014	Sewage discharge (continuous)	Confirmed	Ammonia
Rother, Spittal Brook to Doe Lea	Fish	2016	Sewage discharge (intermittent)	Confirmed	Ammonia
	Invertebrates	2015	Sewage discharge (intermittent)	Confirmed	Ammonia
	Biochemical Oxygen Demand (BOD)	2016	Sewage discharge (intermittent)	Suspected	
	Macrophytes and Phytobenthos Combined	2015	Sewage discharge (continuous)	Confirmed	Nutrients
	Invertebrates	2015	Sewage discharge (continuous)	Probable	Organic pollution
	Phosphate	2015	Sewage discharge (continuous)	Confirmed	
	Fish	2016	Sewage discharge (continuous)	Confirmed	Ammonia
	Fish	2016	Sewage discharge (continuous)	Probable	Organic pollution
	Fish	2016	Incidents	Probable	Not applicable
	Fish	2016	Barriers - ecological discontinuity	Confirmed	Morphology
Spital/Calow/Muster Brook	Fish	2014	Poor soil management	Probable	**Sediment**

Waterbody	Element	Cycle 2 year	Activity	Activity certainty	Pressure
	Phosphate	2014	Poor soil management	Probable	
	Nickel and Its Compounds	2015	Contaminated land	Probable	
	Phosphate	2014	Sewage discharge (continuous)	Probable	
	Invertebrates	2015	Abandoned mine	Probable	Other (not in list)
	Fish	2014	Urbanisation - urban development	Confirmed	Morphology
	Invertebrates	2015	Poor soil management	Probable	**Sediment**
	Fish	2014	Poor soil management	Probable	**Sediment**
The Moss	Fish	2014	Barriers - ecological discontinuity	Confirmed	Morphology
	Fish	2014	Poor soil management	Confirmed	**Sediment**
	Macrophytes and Phytobenthos Combined	2013	Poor nutrient management	Suspected	Nutrients
	Fish	2014	Barriers - ecological discontinuity	Confirmed	**Sediment**

Appendix 3 - Species present within the study area

SSSI, SAC and SPA Citation species

Moss Valley Woods SSSI

- Hoverfly species, Sphegina elegans and Criorhina berberina
- The white-letterhairstreak butterfly, Strymonidia w-album

Moss Valley Meadows SSSI

- Common blue butterfly, Polyomnatus Icarus
- Rare hoverfly species, Xylota florum and Syrphus torvus

Moss Valley SSSI

- Net-winged beetle, Pyropterus nigroruber
- Ship timber beetle, Hylecoetus dermestoides
- Hoverfly species, Melangyna guttata and Xylota florum
- Cranefly, Prionocera pubescens
- Digger wasp, Lindenius albilabris
- Grass snakes, Natrix natrix
- Great crested newts, Triturus cristatus
- British freshwater crayfish, Austropotamobius pallipes
- Green woodpecker Picus viridus
- Great spotted woodpecker Dendrocopos major
- Tawny owl Strix aluco
- Kingfisher Alcedo atthis
- Grey wagtail Motacilla cinerea

Eastern Peak District Moors, SSSI

- Golden plover, Pluvialis apricaria
- Curlew, Numenius arquata
- Dunlin, Calidris alpine
- Redshank, Tringa totanus
    - Meadow pipits, Anthus pratensis
    - Merlin, Falco columbarius
    - Short-eared owl, Asio flammeus
- Stonechat, Saxicola torquata
- Snipe, Gallinago gallinago
- Lapwing, Vanellus vanellus
- Reed bunting, Emberiza schoeniclus
- Twite, Carduelis flavirostris
- Wheatear, Oenanthe oenanthe
- Ring ouzel, Turdus torquatus
- Whinchat, Saxicola rubetra
- Tree pipit Anthus trivialis
- Redstart, Phoenicurus phoenicurus
- Nightjars, Caprimulgus europaeus
- Grey wagtail, Motacilla cinerea
- Common sandpiper, Actitis hypoleucos
- Little ringed plover, Charadrius dubius
- Teal, Anus crecca
- Hen harrier, Circus cyaneus
- Snow bunting, Plectrophenax nivalis
- Dotterel, Charadrius morinellus
- Goosander, Mergus merganser
- Adders, Vipera berus
- Golden-ringed dragonfly, Cordulegaster boltonii

Peak District Moors SPA

- Merlin, Falco columbarius
- Golden Plover, Pluvialis apricaria
- Short-eared Owl, Asio flammeus
- Peregrine, Falco peregrinus
- Lapwing, Vanellus vanellus
- Dunlin, Calidris alpina schinzii
- Snipe, Gallinago gallinago
- Curlew, Numenius arquata
- Redshank, Tringa tetanus
- Common Sandpiper, Actitis hypoleucos
- Whinchat, Saxicola rubetra
- Wheatear, Oenanthe oenanthe
- Ring Ouzel, Turdus torquatus
- Twite, Carduelis flavirostris

BAP Species present in Rother and Doe Lea catchments:

Ref: Lowland Derbyshire LBAP, Biodiversity Action Plan 2011-2020

Amphibians

- Great Crested Newt
- Common Toad

Reptiles

- Adder
- Grass Snake
- Slow Worm

Fish

- Eel

Birds

- Bullfinch
- Corn bunting
- Cuckoo
- Curlew
- Dunnock
- Grasshopper warbler
- Grey Partridge
- Hawfinch
- Herring Gull
- House Sparrow
- Lapwing
- Lesser Redpoll
- Lesser spotted woodpecker
- Linnet
- Marsh tit
- Reed bunting
- Skylark
- Song thrush
- Spotted flycatcher
- Starling
- Tee pipit
- Tee sparrow
- Turtle dove
- Willow tit
- Yellowhammer
- Yellow wagtail

Mammals

- Brown hare
- Brown long –eared bat
- Harvest mouse
- Hedgehog
- Noctule
- Polecat
- Soprano pipistrelle
- Water vole

Invertebrates

Butterflies

- Dingy skipper
- Small heath
- Wall
- White letter hairstreak

Crustaceans

- White-clawed crayfish

Moths

- August thorn
- Autumnal rustic
- Beaded chesnut
- Blood-vein
- Brindled beauty
- Broom moth
- Brown-spot pinion
- Buff ermine
- Centre-barred sallow
- Dot moth
- Dusky brocade
- Dusky thorn
- Dusky-lemon sallow
- Feathered gothic
- Figure of eight
- Flounced chestnut
- Garden dart
- Garden tiger
- Ghost moth
- Green-brindled crescent
- Heath rustic
- Latticed heath
- Minor shoulder-knot

- Mottled rustic
- Mouse moth
- Oak hook-tip
- Powdered quaker
- Rosy minor
- Rosy rustic
- Shaded broad-bar
- Shoulder-striped wainscot
- Small phoenix
- Small square-spot
- The cinnabar
- The sallow
- White ermine

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