Mapping the potential for Working with Natural Processes – technical report

SC150005

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This report is the result of research commissioned by the Environment Agency's FCRM Directorate and funded by the joint Flood and Coastal Erosion Risk Management Research and Development Programme.

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This report is the result of research commissioned by the Environment Agency's FCRM Directorate and funded by the Joint Flood and Coastal Erosion Risk Management Research and Development Programme. The programme is a joint collaboration between the Environment Agency, Defra, Natural Resources Wales and the Welsh Government. It conducts, manages and promotes flood and coastal erosion risk management research and development.

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Professor Doug Wilson
Director, Research, Analysis and Evaluation

Executive summary

This report provides the technical background behind an updated set of strategic maps that identify potential locations for Working with Natural Processes (WWNP) across England. The maps are indicative, and signpost a range of locations where there is the potential for managing flood risk by protecting, restoring and emulating the natural regulating function of catchments and rivers.

The maps, user guide and this technical report form part of the wider WWNP Evidence Base project (SC150005), where users can find further evidence for the effectiveness of the different WWNP measures as well as information on wider environmental, social and cultural benefits.

The updated maps are based entirely open data, and have been made into a suite of interactive and georeferenced PDFs and web maps, allowing for wide accessibility. They highlight the potential for WWNP derived from national datasets such as the Environment Agency's Risk of Flooding from River and Sea, and Risk of Flooding from Surface Water datasets. They have been used to target areas where rivers have been disconnected from their floodplain, or areas of high flow accumulations where it would be effective to temporarily store and hold back water to reduce flood peaks further downstream. The maps introduce new science on characterising slowly permeable soils, based on geological datasets, where tree planting could increase hydrological losses and reduce surface run-off. Geographical information system (GIS) shapefiles of the new data layers created as part of this project are also available.

The maps do not cover a comprehensive list of WWNP measures and they are not prescriptive as to how these measures could be designed. Wider environmental and societal benefits are not included in the maps, but need to be considered in addition to flood risk mitigation. Care should be taken to seek out experts to help understanding of catchment processes and to select the appropriate solution as a result.

The maps identify potential areas for:

- floodplain reconnection
- run-off attenuation features and gully blocking
- woodland planting covering floodplain planting, riparian planting and wider catchment woodland

A new constraints dataset based on open data aims to help users further refine potential locations for WWNP. This dataset includes roads and rail, urban areas, existing woodland, peat and water bodies, which may restrict the potential for some interventions (in particular woodland planting).

This technical guide includes:

- an overview of the maps
- details of the data behind the maps
- the methodologies behind identifying the different kinds of WWNP

The published data and online maps contain the same information, they are all directly comparable.

The maps are intended to be used for reference during and after landowner engagement on natural flood management (NFM). They do not oblige landowners and occupiers to become involved in NFM schemes. Practical or farm business reasons may exist which prevent NFM implementation being possible in locations highlighted on the maps.

Acknowledgements

Many thanks are given to Andrew Fielding of JBA for generating the thousands of interactive maps.

We are grateful for the suggestions and advice from the multi-agency steering group, our user testers, and to Mike Waters for his advice on making the maps IP-free. We are also very grateful for the inputs and proactive data-sharing by the British Geological Survey, and especially the advice and guidance from Holger Kessler and Russell Lawley. Finally, thanks to Sim Reaney, our external peer reviewer for his helpful comments and suggestions.

This evidence base is dedicated to the memory of our friend and colleague Duncan Huggett, whose pioneering work and dedication to the field of Natural Flood Management has had a significant impact on the development of the policy, science and practice which underpins this report.

Duncan Huggett addressing the Flood and Coast Conference 2017 (Source: Flood and Coast Conference 2017)

Contents

List of tables and figures

1 Introduction

1.1 Purpose and scope of project

Working with Natural Processes (WWNP) aims to protect, restore and emulate the natural functions of catchments, floodplains, rivers and the coast. It takes many different forms and can be applied in urban and rural areas, and on rivers, estuaries and coasts. Globally, many different terms are used to refer to this form of flood and coastal risk management (FCRM). In the UK context, WWNP and natural flood management (NFM) are the most commonly used; these 2 terms are used interchangeably throughout this report.

A suite of interactive maps called the National Strategic NFM Opportunity Maps were developed for the Environment Agency in 2016 to help understand the extent of the potential for WWNP in England. Two versions were made:

1. For internal use only within the Environment Agency due to intellectual property right restrictions on some of the datasets
2. An external version containing only open data

The maps were produced pragmatically and in time to include the 2016 flood and coastal erosion risk management (FCERM) schemes, the location of which were included on the maps.

The Woodlands for Water layer can be accessed under conditional licence, but cannot be released as open data and is therefore not on the new maps.

The purpose of this project has been to update the first generation of maps so that they contain a wider range of WWNP measures, and can also be shared as open data, to ensure the widest possible audience.

The maps can be accessed in a number of ways, including interactive PDFs and through ArcGIS Online. The user guide provides further details on accessing the maps and accompanying data, and a web portal provides links to view and download them.

Note that the maps remain strategic in nature. They aim to signpost areas for WWNP that are considered more likely to be effective at reducing flood hazards. It is anticipated that the maps will be improved further through time, especially as more evidence gaps are filled and as the quality of open data improves.

This project has 4 outputs:

- this technical guide
- a suite of maps, including Interactive georeferenced PDF maps (geoPDFs) that visualise and tabulate the potential extent of WWNP measures and online web maps
- an updated user guide to the maps
- the geographical information system (GIS) data behind the maps

The maps cover those WWNP measures that have been prioritised – based on the need for mapping – in consultations with Environment Agency staff and external partners. These WWNP measures include:

- floodplain reconnection

- run-off attenuation features
- gully blocking as a subset of run-off attenuation features on steeper ground
- tree planting in 3 categories:
  - floodplain
  - riparian
  - wider catchment woodland

Further information on the WWNP interventions excluded from this project is provided in Section 3 of the user guide.

A constraints layer has also been developed. This brings together national open data on where the potential locations for WWNP are not likely to function, such as in urban areas, or to avoid targeting tree planting where there is already woodland (using the latest Forestry Commission Woodland Inventory). For urban areas it may be more appropriate to target green infrastructure such as sustainable urban drainage systems (SUDS) for which there are, for example, British Geological Survey (BGS) layers (see Appendix 3 of the user guide).

The maps do not cover all aspects of WWNP, however, and should be used alongside all other sources of relevant information, where available, to focus more detailed investigations. Advice should be sought when interpreting the maps to ensure that measures are in the most appropriate location for the most effective flood attenuation benefits and to help deliver the potential wider environmental and societal benefits of WWNP. Further guidance on the ecosystem services provided by WWNP can be found in the Evidence Directory, and tools also exist to maps and model these.[1]

Efforts should be made to look for connectivity within a catchment to:

- understand processes
- identify appropriate interventions
- assess whether no active interventions or assisted recovery is the best option

Landowner considerations are also paramount. Effective engagement and an understanding of local knowledge should be established before considering any indicative locations for WWNP presented by the maps.

The maps identify locations and extents of different WWNP measures and quantify additional capacity for flood storage at a water body catchment scale (average area 30km^2 nationally). This information can be incorporated into modelling to assess the potential changes to flood risk.

There is guidance on a range of modelling tools for different catchment processes (Environment Agency 2016), and a report called ‘Using the Evidence Base’ provides further guidance on modelling. There are a wide range of strategies for mapping and modelling WWNP (see Hankin et al. 2017); these are highly dependent on the assumptions and uncertainties involved in setting model parameter changes to reflect the influence of WWNP measures.

[1] For example: InVEST (https://www.naturalcapitalproject.org/invest/) and LUCI (http://lucitools.org).

1.2 WWNP evidence base projects

The maps discussed here are one part of 3 interlinked projects (Figure 1.1), which together form an evidence base for WWNP.

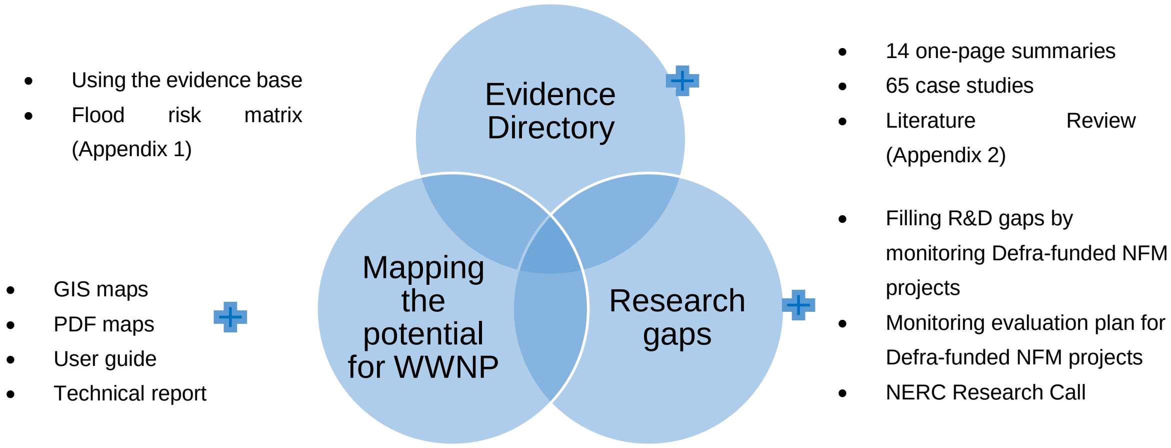

Figure 1.1 Three interconnected projects making up the WWNP evidence base

1.2.1 Evidence Directory

The Evidence Directory summarises what we know about the effectiveness of different measures from a flood risk and ecosystem services perspective. It is underpinned by a detailed Literature Review and links to real-world examples through 65 standalone case studies. (River and floodplain case studies; Woodland case studies; Runoff from hills case studies; and Coast and estuary case studies). In addition, 14 one-page summaries of the different types of WWNP measures – have been produced.

The Evidence Directory is a useful resource intended to help you think about which FCRM measures may potentially work best in your catchment.

1.2.2 WWNP potential maps

The maps are intended to be used alongside the Evidence Directory to help you think about the types of measure which may work in your catchment, and potentially the best place to locate them. They are a useful tool to help start conversations with key partners. The maps and underlying data are provided in a number of formats, and they are supported by a user guide and this technical report.

1.2.3 Research gaps

Research gaps that need to be addressed to move this form of FCRM into the mainstream are listed at the end of each chapter in the Evidence Directory. The Environment Agency has worked with the Natural Environment Research Council (NERC) to develop a Research Call to help address some of these gaps and with many of the Principal Investigators to inform their proposals. The funded projects will be announced in autumn 2017 and the Environment Agency will work in partnership with them to continue to address priority areas of research.

The list of research gaps has also been shared with Defra-funded NFM projects, so that these can address research gaps through long-term monitoring. As part of this project, an evaluation plan is being developed to capture the outcomes of this monitoring, so that the outcomes of this research can be shared across the WWNP community.

1.3 First set of strategic WWNP potential maps

A suite of nationally consistent, strategic NFM opportunity maps were produced for the Environment Agency in 2016 to act as a screening tool to support the identification and development of ways to work better with natural processes and to supplement FCRM schemes in the 2016 programme. The maps were in the form of interlinking, indexed, interactive PDFs.

Three core categories of were included on the original maps but, because they included some conditional licences, they could not be shared with all partners. The 3 categories were as follows:

- Potential for **tree planting** using the Woodlands for Water dataset (Broadmeadow et al. 2014). This encompasses 3 types of tree planting:
  - riparian
  - floodplain
  - areas of high natural run-off potential – this layer contained embedded intellectual property rights (IPR) because of the use of Hydrology of Soil Types (HOST) data

  Potential locations for WWNP were masked by a 'constraints' layer, which also contained restricted IPR because of a peat layer. This mapping was used by Forestry Commission England to target Countryside Stewardship grants for woodland creation to reduce flood risk.

- **Run-off attenuation features** based on areas identified as sites of high natural flow accumulation in the Risk of Flooding from Surface Water dataset. JBA Consulting developed a GIS tool called JRAFF (JBA Run-off Attenuation Feature Finder), which identifies these areas based on different constraints, including restrictions on size (100–5,000m^2) and location (for example, avoiding urban areas).

- **Soil structure improvement.** Here the maps simply showed the composition of land cover using Land Cover Map 2007 (LCM2007). So if local opportunities were identified such as 'allow all acid grassland to return to a much rougher semi-natural habitat', then the fraction of each water body catchment for this change could be estimated, and the approximate additional soil storage estimated. LCM2007 also has embedded IPR, and has therefore been replaced in the new set of strategic maps with a combination of CORINE Land Cover data and some Ordnance Survey (OS) Open Data layers such as woodland.

1.4 New measures mapped with open data

This project has updated the first suite of WWNP maps using open data, Open Government Licence (OGL V3.0) and IPR-free datasets, and incorporated additional measures prioritised by the Environment Agency.

The maps consist of a suite of interlinking, indexed geoPDFs and online web maps that cover every water body in England (Figure 1.2). The changes and updates include:

- floodplain reconnection potential based on the Risk of Flooding from Rivers and Sea dataset which is licensed as OGL
- classification of run-off attenuation features on steep slopes as gully blocking potential (the run-off attenuation features have been released under OGL)

The Woodlands for Water layer (Broadmeadow et al. 2014) cannot be included as open data (although it provides a useful additional resource).

The maps and data contain IPR-free datasets and some new science based on identifying slowly permeable soils.

- Riparian and floodplain planting are the same as in the previous maps, but have been masked using a new open data ‘constraints’ layer detailed in Section 2, which includes a more up-to-date forest inventory than Woodlands for Water.
- Tree planting in areas of high percentage run-off has been replaced with areas of slowly permeable soils, based on new analysis of superficial and bedrock geologies in the British Geological Survey (BGS) Geology 1:50,000 dataset, and a 100m gridded dataset free of intellectual property (IP) has been developed. Each grid square represents 1ha of tree planting, considered a sensible unit for targeting meaningful changes to run-off generation at the water body catchment scale. The same set of open data constraints has been applied to the grid of slowly permeable soils.

The area of each of these WWNP measures per water body catchment is provided explicitly in the PDF maps, giving a measure of the relative level potential compared with other water bodies. The maps do not cover coastal or estuarine (transitional) waters, or cover the specifics of floodplain connectivity and wetland creation or restoration, although they can be used as pointers to identify the potential for in-channel and floodplain storage.

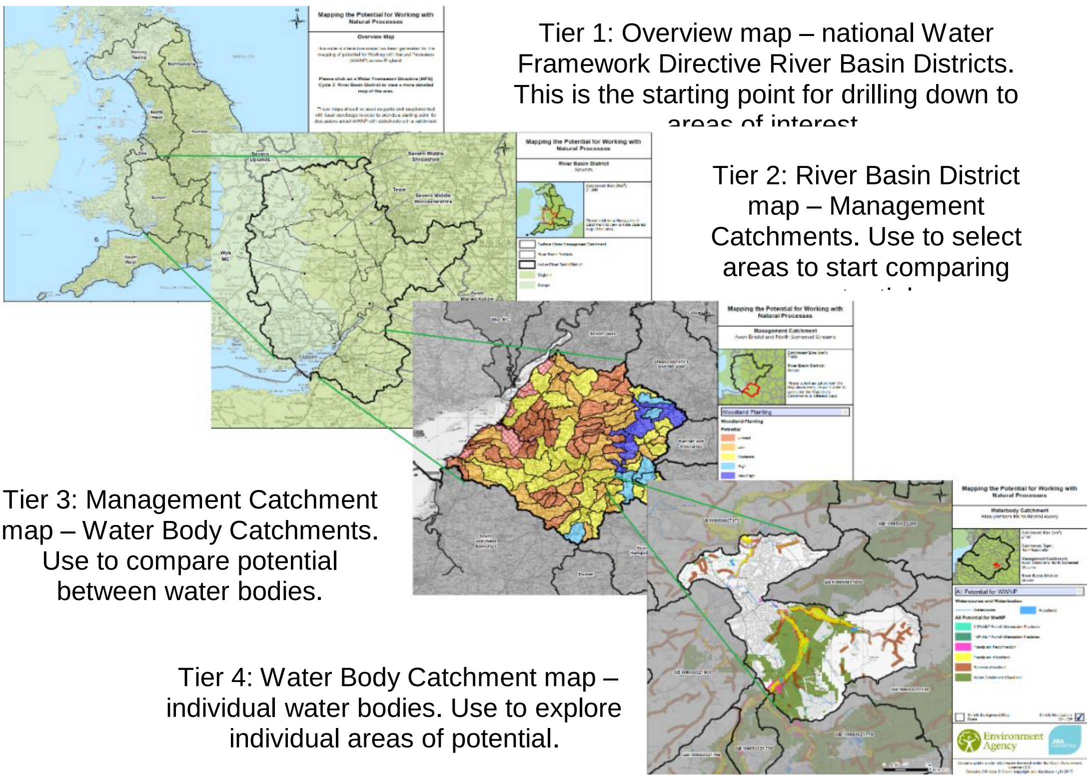

Figure 1.2 New suite of WWNP maps

1.5 How to use this report

This report is intended for users who are interested in understanding the results produced by the WWNP potential mapping project. The detailed description of data and methodology should also help those who wish to manipulate and extend the datasets released as part of this project. The report also provides a useful reference point for future NFM mapping projects looking to use solely open data.

Chapter 2 provides details of the data used for the background mapping, the WWNP interventions and the constraints layer. It also lists datasets that were excluded for licensing, quality or consistency reasons. The data shortlist is given in a table in Appendix 1.

Chapters 3–6 focus on each of the WWNP measures covered in the project. They summarise the science behind the methodologies, which is covered in more detail in the Evidence Directory. These sections also detail the data used, how each model was created and tested, and the outputs produced as part of the mapping product. Concept summaries and process diagrams are provided for each intervention, enabling a clear understanding of what was done and why. Chapter 4, on wider catchment woodland, is supplemented by Appendix 2, which provides a detailed rationale for the new science used to create this dataset.

Chapter 7 concludes the report with a summary of the project and its outputs, and provides a series of recommendations for future research.

2 Data

2.1 Introduction

This chapter outlines the data used in the mapping. This includes:

- background data
- the data used for each WWNP intervention
- the data that make up the new constraints layer

There is also a brief discussion of licensing and data that were not used due to IP or quality restrictions.

The updated maps have been commissioned to be based entirely on open data or layers released under OGL. This means that, at times, the datasets may be inferior to data available under conditional licence; however, they are still fit for purpose. Efforts have been made to use the best available open data and to negotiate new derived open data.

Appendix 1 provides a complete list of the data that has been used, in addition to shortlisted data that was not used in the final outputs. Appendix 2 of the user guide suggests additional data sources that could help users to refine their investigations and further target areas of interest.

2.2 Background data

2.2.1 Background mapping open data

The following OS open data background mapping has been used (2016 release):

- OS MiniScale™ (January 2016)
- OS 1:250,000 (June 2016)
- OS VectorMap® District (raster) (September 2016)
- OS Open Map Local (vector) (October 2016)

2.2.2 Catchment boundary data

The OGL Water Framework Directive datasets (September 2015 release) used are:

- River Basin Districts (Cycle 2)
- Surface Water Management Catchments (Cycle 2)
- River Waterbody Catchments (Cycle 2)

2.2.3 Water feature data

The following OS open data has been used for display purposes (October 2016 release). Some conditional licensed data (the Detailed River Network) were used to develop the maps, but the data is not displayed.

- OS Open Map – Local: Surface Water Line
- OS Open Map – Local: Surface Water Area
- OS Open Rivers ('WatercourseLink_openrivers')

2.3 WWNP data

The following WWNP measures are shown on the maps and the relevant open data licence details are listed in Table 2.1. The different features are all polygons.

Table 2.1 WWNP measures and data

WWNP Type	Open data licence details
Floodplain reconnection	• Risk of Flooding from Rivers and Seas (April 2017) • Data derived from the Detailed River Network, which is not displayed, rescinding the licence requirements for displaying the dataset (to be superseded by OS Water Network but not available for project in time). • Constraints data
Run-off attenuation features	• Data derived from Risk of Flooding from Surface Water (Depth 1 percent annual chance and Depth 3.3 percent annual chance) (October 2013). The original data is not displayed, due to licensing restrictions.[2] • Constraints data • Gully blocking potential (a subset of run-off attenuation features on steeper ground) • Data derived from OS Terrain 50 (2016) to classify each run-off attenuation feature based on median slope.
Tree planting (3 categories)	• Floodplain: Flood Zone 2 from Flood Map for Planning (April 2016) and new constraints layer • Riparian: 50m buffer OS water features from Section 2.2.3 with constraints layer • Wider catchment woodland: - Based on slowly permeable soils. - BGS Geology 50,000 Superficial and Bedrock layers (both V8, 2017). Used with new science to derive new 100m gridded open data. This new layer can be used to signpost areas of SLOWLY PERMEABLE SOILS and can be checked in more detail on the BGS portal. - To the north of the line of Anglian glaciation, the presence of till-diamicton has been shown to be a strong predictor of slowly permeable soils. - To the south of this line, particular bedrock geologies have shown a similarly strong spatial relationship to the presence of slowly permeable soils.

[2] Data provided by East Riding of Yorkshire and Hull Local Authorities in the Risk of Flooding from Surface Water was removed from the dataset, due to additional licensing restrictions

The area of potential for WWNP per water body catchment was also computed as follows:

- area of tree planting potential (combined)
- area of floodplain reconnection potential
- capacity of run-off attenuation features for 3.3% and 1% annual exceedance probability (AEP) return

These are shown on a scale on the map legends ranging from 'limited' to 'very high', with the corresponding values listed in Appendix 1 of the user guide.

The total catchment area is also provided for each water body.

2.4 Constraints data

The 2 types of constraints data used in this project fall broadly into:

- open data that can be displayed on the maps
- IP restricted data that has been used for important screening, but which cannot be provided under OGL

Each type of WWNP measure has specific constraints data. Open access data were assessed before incorporation, and some datasets were excluded on quality or consistency grounds. The open constraints data provided as a layer in the interactive maps was used to erase areas of potential for tree planting.

Users may want to consider additional datasets provided on the PDF maps, such as Protected Habitats and Agricultural Land Classification, when thinking about constraints. For example, a Site of Special Scientific Interest could act as a constraint or an added opportunity to undertake a WWNP scheme, depending on the intervention proposed and the nature of the site. High grade agricultural land could also provide a constraint to WWNP, although this would depend on local landowner considerations.

2.4.1 Open constraints data displayed on maps

This combines the following open data:

- OS Open Map – Local: Railways (October 2016)
- OS Open Roads (November 2016)
- Forestry Commission National Forest Inventory woodland maps (2015)
- OS Open Map – Local: Woodland (October 2016)
- OS Open Map – Local: Surface Water Line (October 2016)
- OS Open Map – Local: Surface Water Area (October 2016)
- OS Open Rivers (October 2016)
- CORINE Land Cover Urban Areas (2012)
- CORINE Land Cover peat layer (2012)

Figure 2.1 shows an example map with this layer, which is provided on the interactive maps and in the GIS data.

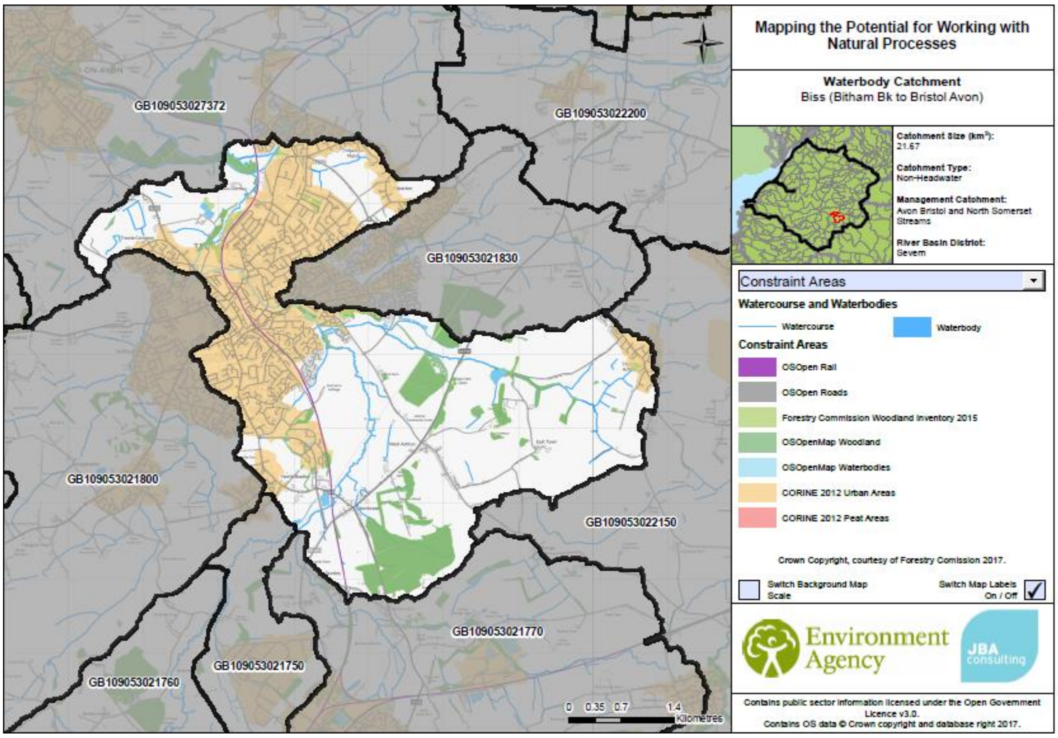

Figure 2.1 Example map showing constraints layer

2.4.2 IP restricted constraints data used in processing

The following datasets were used in the derivation of the open datasets that are included in the maps, but are not shown in the final products:

- Detailed River Network (2013)
- National Receptors Database (2014)
- BGS 50,000 Superficial Geology (V8, 2017)
- BGS 50,000 Bedrock Geology (V8, 2017)

2.5 Data excluded owing to IPR or quality restrictions

The following datasets were considered but could not be included with the maps as they have conditional licences:

- Woodlands for Water
- full resolution BGS 50,000 geology maps
- Wetland Vision

Some open data were not included on the grounds of inconsistency nationally or data quality. Those investigated and not included were:

- Areas Benefiting from Flood Defences (part of Flood Map)

- Flood Storage Areas (part of Flood Map) – these were used for assessing the performance of floodplain reconnection

2.6 Licensing

The licensing for all datasets on the maps is open or OGL, and is recorded in the table in Appendix 1.

2.7 Where to find the data

The geodata are available in ESRI File Geodatabase format.

3 Riparian and floodplain tree planting potential

3.1 Introduction

Three types of tree planting types are considered, as in the original Woodlands for Water dataset, although the areas of high run-off (high standard percentage run-off (SPR) HOST) have been excluded owing to IPR restrictions. A new dataset based on identifying areas of slowly permeable soils was derived from IPR-free geology datasets, this is described in more detail in Chapter 4. This chapter focuses on the methods used to identify the potential for riparian and floodplain tree planting.

Figure 3.1 shows how the 3 types of tree planting were processed. There are overlaps between the 3 measures which have been left in the spatial data, but the maps report the area of new tree planting without overlap and so there is no double-counting.

The areas of potential for tree planting have also been masked using the new open data constraints layer (Section 2.2.3) to replace that used in the Woodlands for Water dataset, which had embedded IPR. The constraints mask includes urban areas, roads, rails and existing woodland based on the most recent inventory from the Forestry Commission. The 3 categories of tree planting are:

- Floodplain – Flood Zone 2 (0.1% AEP Flood Map for Planning) with the open data constraints mask
- Riparian – a 50m buffer on the open data features that represent areas of open water (OS Open Water Lines, Water Areas and Open Rivers) with constraints applied
- Wider catchment woodland – a new set of 100m grids based on superficial and bedrock geologies indicative of slowly permeable soils and therefore fast run-off areas, with constraints applied

These are displayed as a single layer in the PDF maps.

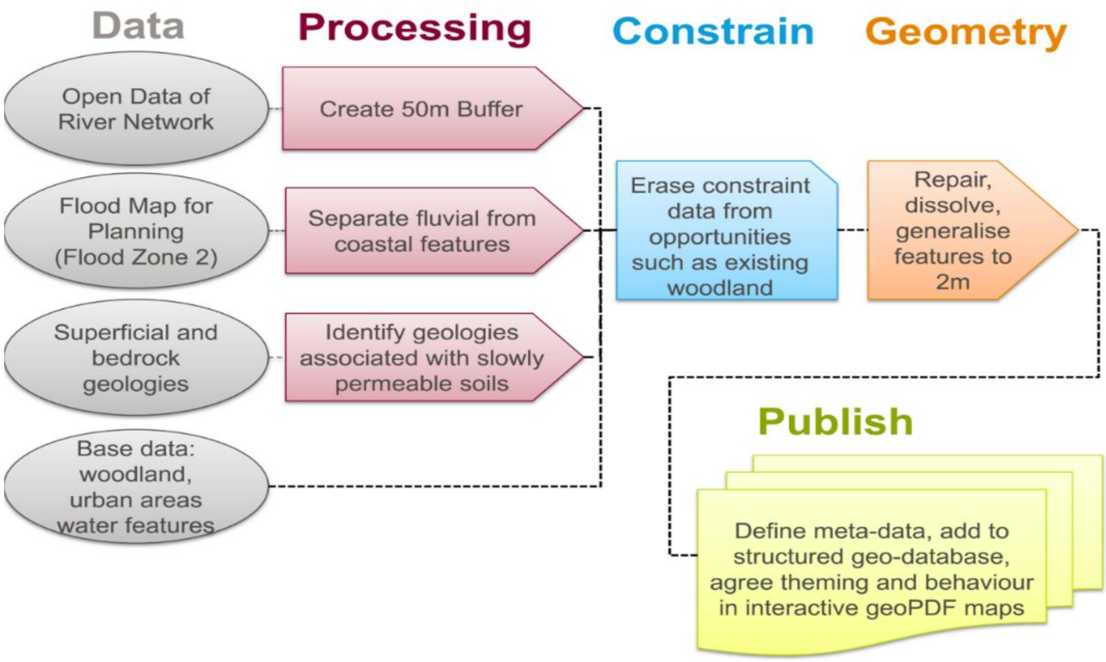

Figure 3.1 Processing the 3 different types of woodland or tree planting

3.2 Science

Interventions involving tree planting seek to:

- slow overland flow through the development of rougher ground surfaces
- largely eliminate overland flow through enhanced infiltration rates via increased topsoil permeability and enhanced soil drying from enhanced evapotranspiration
- remove water from the streamflow generating system via enhanced wet canopy evaporation (‘interception loss’) and enhanced transpiration

Floodplain forests provide ‘floodplain roughness’ which dissipates flood energy (Dadson et al. 2017), although there is some debate over how much conveyance can be reduced in floodplain areas that are already slow-flowing. Additional floodwater storage may also be provided from the multiple water channels and backwater pools associated with the presence of trees, shrubs and deadwood.

The riparian zone is considered an effective location for woodland planting to aid flood risk management, as well as providing other significant water benefits. An important attribute is the formation of large woody debris dams from fallen trees and the input and collection of dead wood. These dams impede water flow and promote out of bank flows, increasing flood storage and delaying flood flows (Broadmeadow et al. 2014). Riparian woodland can buffer sediment delivery from the adjacent land and protect riverbanks, reducing downstream siltation (which may contain excess nutrients), keep water temperatures cooler, and help to maintain the flood storage capacity of river channels.

Given the physical impact of increasing friction, along with other benefits of wet woodland, floodplain and riparian areas have been identified in addition to wider catchment woodland. However, increased friction can create backwater effects and so it is important to investigate upstream and downstream risks. Different approaches are described for different levels of modelling in the Using the Evidence Base report.

Figure 3.2 Lower Woodsford, River Frome, Dorset

Source: Environment Agency

3.3 Mapping or modelling concept

The methodology for identifying riparian and floodplain tree planting is based on consistent, quality assured national open data. It follows that used in Woodlands for Water, but updates the different datasets, including the constraints identified in Chapter 2.

Key concept: riparian and floodplain woodland

Woodland provides enhanced floodplain roughness that can dissipate the energy and momentum of a flood wave if planted to obstruct significant flow pathways. Riparian and floodplain tree planting are likely to be most effective if close to the watercourse in the floodplain, which is taken to be the 0.1% AEP flood extent, or Flood Zone 2, and within a buffer of 50m of smaller watercourses where there is no flood mapping. There is a constraints dataset that includes existing woodland.

Figure 3.1 provides an overview of the data and processing undertaken in implementing this concept.

3.4 Data

3.4.1 Floodplain woodland

- Environment Agency Flood Map for Planning (2014) – Flood Zone 2 (0.1% AEP)
- Constraints data

3.4.2 Riparian woodland

- OS Open Map – Local: Surface Water Line
- OS Open Map – Local: Surface Water Area
- OS Open Rivers
- Constraints data

3.4.3 Licensing

All data in the mapping are either open data or OGL. Individual licences are indicated in Appendix 1 and shown on the maps.

3.5 Method

3.5.1 Floodplain woodland

The approach here followed that used in the original Woodlands for Water project (Broadmeadow et al. 2014). The Flood Map data are classified according to the information source; the flood zone being a composite of detailed modelling of fluvial, tidal and fluvial/tidal hydrological responses, and the recorded extent of fluvial, tidal and coastal flood events. The floodplain TYPE field was used to select areas representing the fluvial floodplain [‘Fluvial Model’, ‘Fluvial Event’, ‘Fluvial Model and Fluvial Event’, ‘Undefined Event’, ‘Fluvial/Undefined Event’, ‘Fluvial Model and Fluvial /Undefined Event’, ‘Fluvial Model and Undefined Event’].

The selected features were then masked using the new open data constraints layer (Section 2.2.3) to avoid locations where tree planting would not be possible or appropriate. These include:

- open water
- urban areas
- existing woodland
- areas of deep peat soil

3.5.2 Riparian woodland

A 50m riparian buffer was applied to the 3 OS Open Water Layers described in Section 2.4, and masked using the new open data constraints layer (Section 2.2.3). The original Woodlands for Water dataset used a buffer of the Detailed River Network, which has a conditional licence, and is being superseded by the OS Water Network Layer, which was not available for this project. Tests identified that the 3 OS Open Water Layers, used in combination, recover much of the Detailed River Network (some very small or separated areas are not included).

One final difference between these new datasets and their Woodlands for Water equivalent is that they were not merged with the areas of high run-off, giving greater transparency to each layer’s provenance.

3.6 Outputs

The final dataset represents areas suitable for potential floodplain woodland (yellow in Figure 3.3) and riparian woodland (brown in Figure 3.3). These are shown alongside potential locations for tree planting on slowly permeable soils, which are covered in the next chapter.

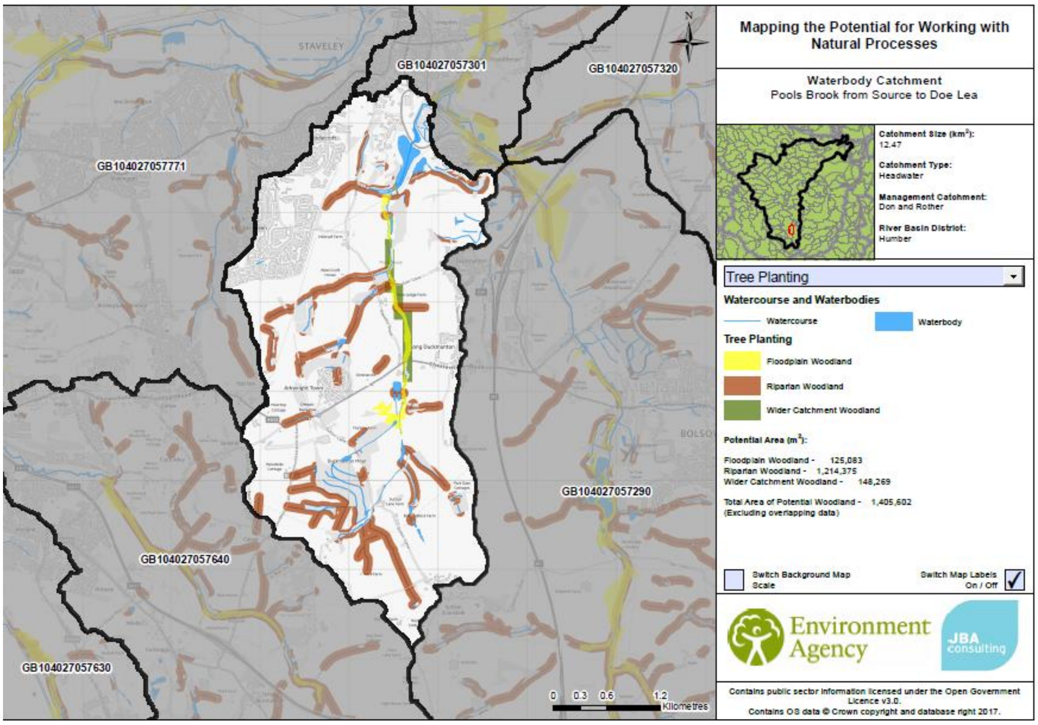

Figure 3.3 Example map showing tree planting layer

4 Wider catchment woodland potential

4.1 Introduction

This chapter introduces a new open dataset, which has been derived based on new science stemming from this project, based on the BGS's 50,000 geology maps. It explains the science behind the mapping concept, before outlining the data and methods used to produce the model. Model outputs were tested using qualitative and quantitative comparisons at 6 test sites and the results are presented in the final section. A more detailed description of the rationale behind the methodology used to identify wider catchment woodland potential can be found in Appendix 2.

This new dataset does not aim to replace the Woodlands for Water layer, which cannot be included under open data licence, but is based on a new concept of targeting areas where the soil characteristics are particularly impermeable. These may be different to those identified in Woodlands for Water as that is based on SPRHOST classification, which is ultimately founded on more general empirical relationships characterising hydrograph response.

4.2 Science

The greatest hydrological impact of woodland planting is often found in areas of slowly permeable soil where the soil is likely to produce overland flow due to infiltration-excess and/or saturation. These areas have been surveyed and locally mapped in detail as soil types broadly classified as the Major Soil Groups of 'Surface-Water Gley soils' and 'Peat soils' by the Soil Survey of England and Wales (Avery 1980).

The research hypothesis was that the location of subgroups of slowly permeable soils within the Major Soil Groups of Surface-Water Gley and Peat are closely linked to the presence of the underlying glacial till – with its slowly permeable matrix – in those parts of the UK that have been glaciated in the past 2 million years (Figure 4.1). In this period, ice and subsequently glacial till deposits, probably reached their maximum extent in the Anglian glaciation – extending south to the Bristol Channel in the west and to Brentwood, north-east of London in the east (see, for example, Scheib et al. 2011). As peat soils (Avery 1980) with an organic layer exceeding 50cm in depth are not considered suitable for tree planting given the potential for negative impacts on carbon sequestration, this study focuses on the mapping of Surface-Water Gley soils.

BGS maps separately areas of superficial geology covered by peat. If the detailed BGS 1:50,000 scale mapping of glacial till (class TILLD-DMTN; Smith 2013) is a good representation of the extent of the Surface-Water Gley Soil Subgroups within the 1:25,000 scale locally mapped areas, then the BGS till data might be considered a good basis for mapping slowly permeable mineral soils across the UK within the area of the Anglian glaciation. Beyond the extent of the Anglian glaciation, BGS data on the solid geology may be used to estimate the extent of slowly permeable Surface-Water Gley Soil Subgroups in a similar way to its use in the production of Soil Series of England and Wales maps.

Figure 4.1 A slowly permeable cambic stagnohumic gley soil subgroup (Wilcocks Series) in the valley of the Gwy headwater catchment in Wales developed from the fine matrix of glacial till

Photo: © N.A. Chappell

4.3 Mapping or modelling concept

The methodology for wider catchment woodland potential is founded on identifying slowly permeable soils. This is based on the following simple concept:

Key concept: wider catchment woodland

Slowly permeable soils have a higher probability of generating 'infiltration-excess overland flow' and 'saturation overland flow'. These are best characterised by gleyed soils, so tree planting can open up the soil and lead to higher infiltration and reduction of overland flow production.

It was hypothesised that the presence of till-diamicton north of Bristol/London along the Anglian glaciation line is a strong indicator of gleyed soils. South of this line, specific bedrock types are used to characterise slowly permeable soils. A more detailed rationale is provided in Appendix 2, and the high-level method is shown in Figure 3.1.

4.4 Data

- BGS 50,000 bedrock and superficial geologies
  - Digital Geological Map of Great Britain 1:50 000 scale (DiGMapGB-50) data, Version 7.22, Tile EW150_Dinas Mawddwy, published by BGS on 15 April 2013
  - BGS has given permission for the project's 100m × 100m gridded version of these data to be realised publicly (see Figure 4.5 for example of the final output)
- Constraints layer (Section 2.4)
- Evaluation data – the detailed Soil Series of England and Wales maps were used for evaluation (referred to as the 'gold standard')

Licensing

The new slowly permeable soils dataset provided on a 100m gridded basis have been licensed as OGL V3.0.

4.5 Method

The 6 stage process devised for evaluating and testing the new model of slowly permeable soils is described below. An overview of the processes used to create the model is provided in Figure 3.1.

4.5.1 Stage 1: Selection of 6 test areas

To test the ability of the new model using BGS data to predict the location of subgroups of slowly permeable soils (excluding peat), six 10km × 10km test areas were used. These are selected 1:25,000 maps developed from detailed field surveys by Soil Series of England and Wales.

Most areas of slowly permeable soils are located north of the southern extent of the Anglian glaciation, with a particularly high coverage in north-west England. As a consequence, 3 of the 6 selected test areas are in north-west England. Different parent materials may be responsible for the presence of slowly permeable soils in eastern England and so a test area in this region was included. South of the southern extent of the Anglian glaciation, the extent of slowly permeable soils is more likely to be associated with the solid geology given a more limited extent of slowly permeable superficial deposits. Two further test areas were therefore selected beyond the extent of the Anglian glaciation – in south-west England. Table 4.1 gives details of the selected test sites.

Table 4.1 Location of test areas

Location	Details
North-west England	• Test Area 1: NY56 Brampton (Cumbria III) 1:25,000 Soil Series Map • Test Area 2: NY53 Penrith (Cumbria I) 1:25,000 Soil Series Map • Test Area 3: SD58 Sedgwick (Westmorland I) 1:25,000 Soil Series Map
Eastern England	• Test Area 4: SK99 Kirton in Lindsey (Lincolnshire VI) 1:25,000 Soil Series Map
Below extent of Anglian glaciation (south-west England)	• Test Area 5: SU03 Wilton (Wiltshire I) 1:25,000 Soil Series Map • Test Area 6: SS30 Holsworthy (Devon IV) 1:25,000 Soil Series Map

4.5.2 Stage 2: Digitisation of the areas of slowly permeable soils within the 6 test areas

All of the subgroups of slowly permeable soils within each test area were identified. The boundary of these areas with soils not within this category were digitised.

4.5.3 Stage 3: Qualitative comparison of model in each test area

The initial visual comparisons of model versus observed data for the 6 test areas were later expanded in southern England to involve other visual comparisons. In southern England, 5 additional Soil Series of England and Wales Soil Series maps were examined with reference to the solid geology (see Appendix 2).

4.5.4 Stage 4: Discretisation of each test area

To provide a grid for quantitative comparison of the model based on BGS data with the observed extent of slowly permeable soils, each test area was divided into 100m × 100m squares (giving 10,000 cells per test area). The agreed spatial resolution for the new layer of slowly permeable soils was 100m^2.

4.5.5 Stage 5: Quantitative comparison

Quantitative evaluation of the predictive capability of the models was conducted for the 6 test sites. For each of the 10,000 cells associated with each test area, the intersected area associated with slowly permeable soils was calculated using ArcGIS for both the selected soil subgroups and the modelled BGS data. These 2 map layers associated with each test area were compared as follows:

- Stage 5.1: Calculate the percentage capture of the presence of slowly permeable soils by the model
- Stage 5.2: Calculate the percentage capture of the absence of slowly permeable soils by the model

- Stage 5.3: Calculate the total capture (presence and absence)

The capture is the percentage match by test area between the model and observed data.

For these percentages to be calculated, it was assumed that for a cell to be labelled as containing slowly permeable soils at least 5% of any 100m × 100m cell must be classified as slowly permeable. To take into account the uncertainty in the prediction of slowly permeable soils and to investigate the optimal predictive capability for the model, these steps were repeated using different degrees of predicted (modelled) presence; that is, for each 100m × 100m square, the threshold area used in a binary sense to represent presence of modelled slowly permeable soils was varied from 1% to 95%. This allowed investigation of the percentage of modelled slowly permeable soils whose presence gives the best fit to the observed data. Separate treatment of presence and absence was required to prevent spurious results where test areas had very high coverage of slowly permeable soils (or in contrast a very high coverage of well-drained soils) that could allow a poor model to achieve a high overall percentage capture.

4.5.6 Stage 6: Comparative evaluation of the SPR>50 model

Applications for the Countryside Stewardship woodland creation grant are assessed against a scoring criteria to ensure appropriate design in the best location. The Forestry Commission used the Woodlands for Water mapping to identify priority areas for woodland creation; the high priority area for flood risk management are soil associations with a revised SPR value of >50% (Broadmeadow et al, 2014). The selection of the 50% threshold for Countryside Stewardship was a pragmatic decision to target the wettest soils (26.8% of England) for grant aid. It is expected that woodland creation on the many soil associations with revised SPR values of <50% would also contribute to reducing flood risk management as a result of improved soil texture and enhanced soil infiltration. As a comparison to the fit of the models, the degree of fit of the SPR>50 model to the soil subgroups classified as slowly permeable was calculated. This was carried out for all test areas in the same way as the calculations in Stage 5 above. A qualitative comparison of the SPR>50 model predictions with the observed data was also made for the additional Soil Series of England and Wales areas of Stage 3.

4.6 Results and outputs

Model performance for Test Areas 1–4 combined and 5–6 combined

The model capture of the slowly permeable soils present in all northern test areas is approximately 68% (Figure 4.2). The optimal overall model – in terms of predicting presence and absence – captures 68% of the area of slowly permeable soils using a threshold for till presence of 40%.

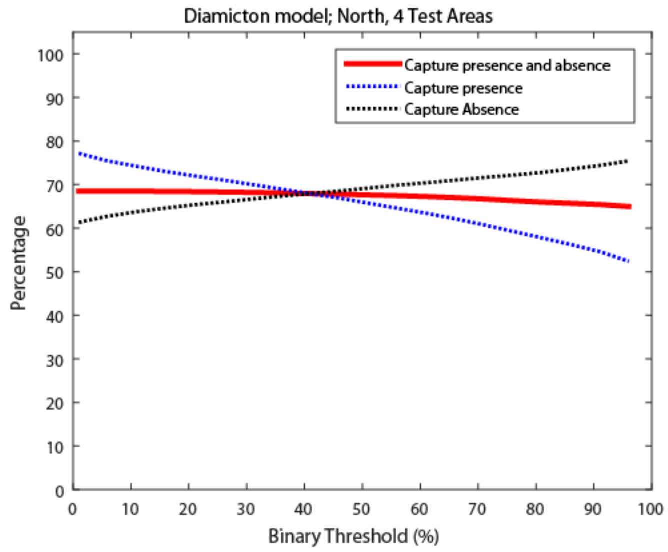

Figure 4.2 Till model capture of slowly permeable soils covering combined Test Areas 1–4

The model capture of the slowly permeable soils present in the 2 southern test areas is approximately 70–75% (Figure 4.3). The optimal overall model – in terms of predicting presence and absence – captures 75% of the area of slowly permeable soils, using a threshold for the presence of the specific geology classes present at very low percentages reflecting the under-prediction associated with the Wilton test area.

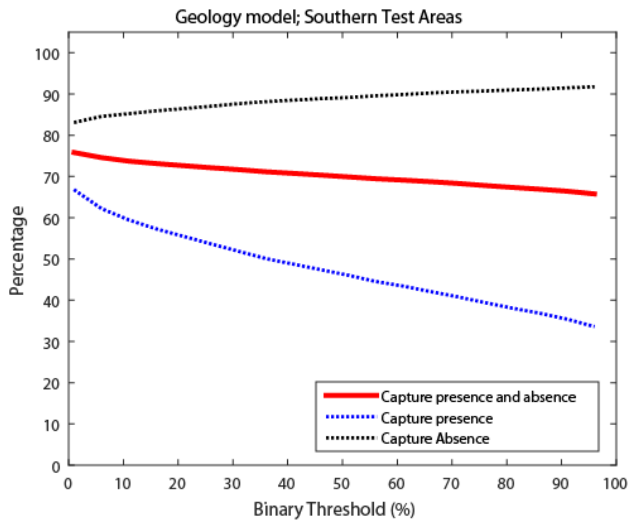

Figure 4.3 Solid geology model capture of slowly permeable soils covering combined Test Areas 5–6

Table A.2.1 in Appendix 2 provides a summary of all the test areas, plus the combined performance across all northern and southern test areas.

Figure 4.4 applies the new model of slowly permeable soils based on superficial geology in the north and specific bedrock geologies in the south of the UK.

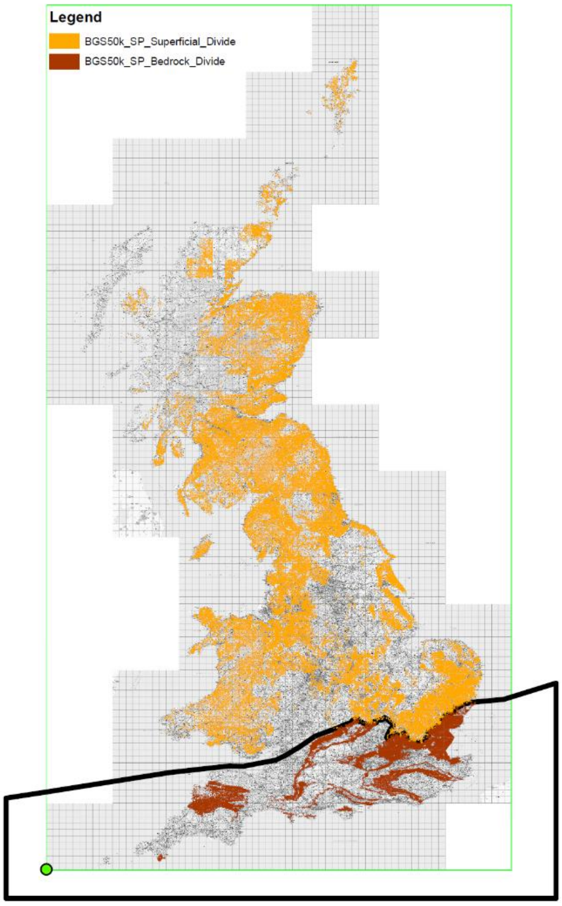

Figure 4.4 National map of slowly permeable soils based on the new model

Figure 4.5 shows how the new layer appears on the new interactive PDFs described in the accompanying user guide. The 100m grid cells are classified as either slowly permeable soils or not (based on area intersected), and have been masked or clipped by a new open data constraints layer (Section 2.4).

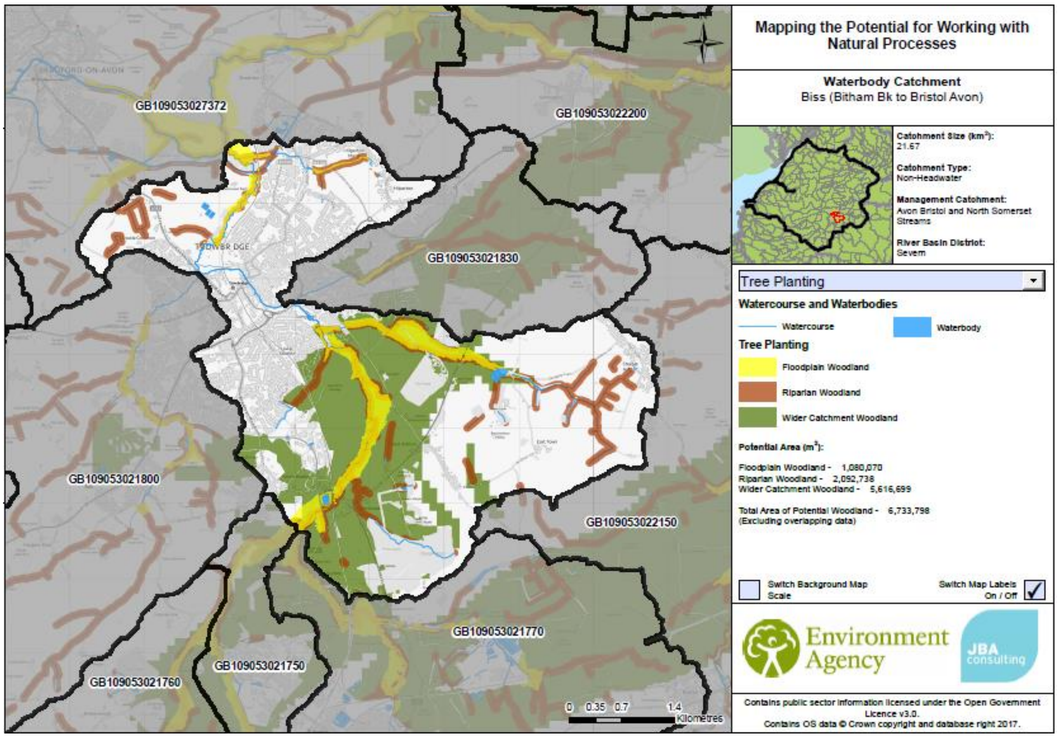

Figure 4.5 Example map showing potential for tree planting on slowly permeable soils (green)

5 Floodplain reconnection potential

5.1 Introduction

Rivers and their floodplains have been physically modified through a variety of means for the purposes of navigation, drainage and industrial development. The purpose of these maps was to identify areas of floodplain which have become disconnected from their river and as a result are either no longer capable of or have a reduced ability to store water during times of flood.

This chapter describes how we mapped the potential to reconnect rivers with their floodplains. It involved an assessment of existing OGL datasets (described in Chapter 2) which were then used these alongside information on slope and topography to develop a method for identifying potential places where floodplain connectivity could potentially be restored.

We also used existing flood modelling outputs which looked at the hydraulic interaction of flood flows in relation to topography and defences. The Risk of Flooding from Rivers and Sea dataset met these criteria and was used to identify areas where watercourses have limited connectivity to the floodplain.

5.2 Science

Floodplains can be restored to store large volumes of water for flood risk, potentially also creating ecological benefits. Floodplain restoration aims to restore the hydrological connection between rivers and floodplains, so that floodwaters inundate the floodplains and store water during times of high flows. This can involve removing flood embankments and other barriers to floodplain connectivity.

Figure 5.1 Padgate Brook floodplain restoration 2016

Source: Environment Agency

5.3 Mapping or modelling concept

The methodology for identifying floodplain reconnection potential is based on consistent, quality assured national open data that takes into consideration the interaction of hydraulics with topography and defences.

Key concept: floodplain reconnection

Areas of low or very low probability based on the Risk of Flooding from Rivers and Sea dataset, which are in close proximity to a watercourse and that do not contain properties, are possible locations for floodplain reconnection. It may be that higher risk areas can be merged, depending on the local circumstances.

Figure 5.2 provides an overview of the data and processing carried out in implementing this concept.

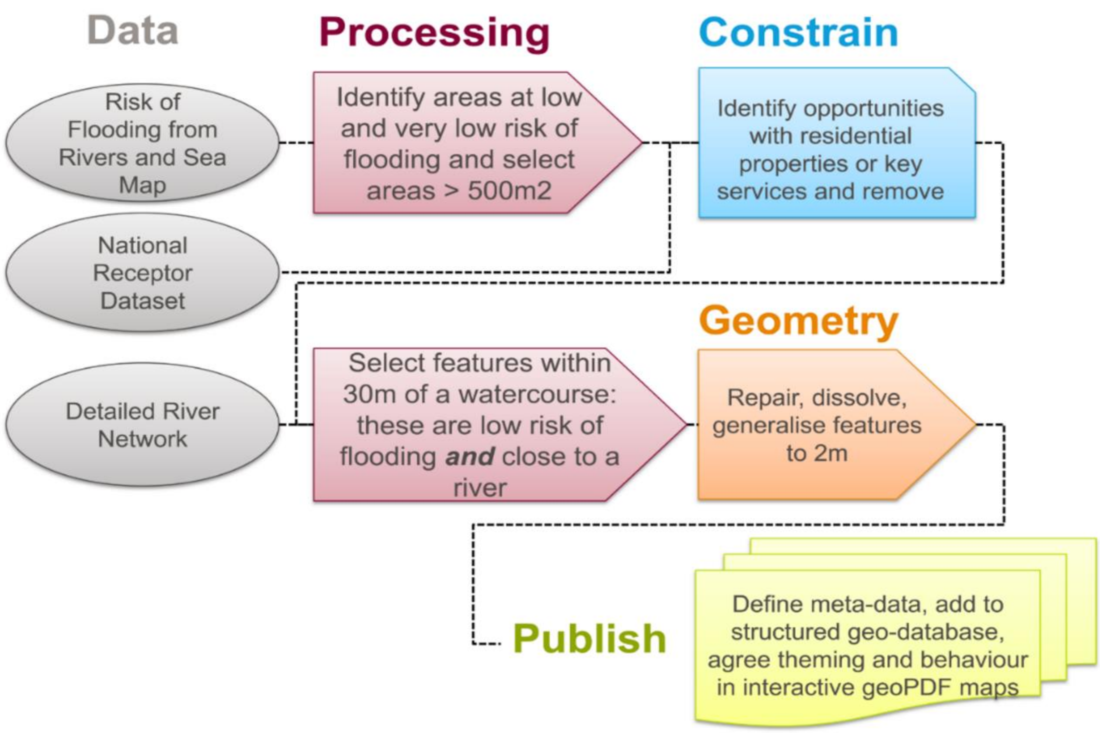

Figure 5.2 Processing of floodplain reconnection potential

5.4 Datasets

5.4.1 Open data used in the mapping

The following open datasets are used or displayed in the maps:

- Risk of Flooding from Rivers and Sea
- OS Open Map – Local: Surface Water Line
- OS Open Map – Local: Surface Water Area
- OS Open Rivers

In testing, the OS open datasets compare well with the Detailed River Network. This is about to be superseded by the OS Water Network Layer, but this is not open data and was not ready to be used for this project.

5.4.2 Constraints data

The following constraints data was used:

- Detailed River Network
- National Receptors Dataset property points

These data are **not** displayed on the maps.

5.4.3 Data excluded from maps owing to IP or quality restrictions

The following datasets were not included/displayed:

- National Receptors Dataset – this cannot be shown as it has conditional licensing, but the background OS open data mapping shows the presence of buildings
- Detailed River Network – these data are being superseded and the Environment Agency will not be able to re-license for mapping
- OS Water Network Layer – these data will supersede the Detailed River Network; they are not open data and so cannot be shown on the maps
- Areas Benefiting from Flood Defences (Flood Map) – these data were excluded because they were considered not nationally consistent by the project team
- Flood Storage Areas (Flood Map) – manmade and natural flood storage areas were excluded because they were not considered nationally consistent

5.4.4 Licensing

All data displayed in the mapping are OGL. Individual licences are indicated in Appendix 1 and shown on the maps.

5.5 Method

The Risk of Flooding from Rivers and Sea dataset was chosen to identify floodplain reconnection potential. It is nationally consistent, has been extensively quality controlled, and is published online under OGL. It was developed for the National Flood Risk Assessment (NaFRA) (Environment Agency 2008) and is based on the Risk Assessment for Strategic Planning (RASP) approach (see Hall et al. 2003, Environment Agency 2005), which estimates residual risk having considered the presence and performance of flood defences.

The Risk of Flooding from Rivers and Seas dataset shows bands of probabilities of flooding on a 50m resolution grid that takes into account spatial defence datasets. Where the Risk of Flooding from Rivers and Seas data show low (0.1–1% AEP) or very low (<0.1% AEP) probability of flooding but closeness to a watercourse, it is argued that this is indicative of poor floodplain connectivity.

The potential for floodplain reconnection also needed to be constrained by factors including the distance to watercourses and the presence of properties. The Detailed River Network was used as the most accurate, available data to derive the proximity of the watercourses to the floodplain. These data were used in place of the new OS Water Network Layer, which is not yet available. The National Receptors Dataset 2014 property points were used to screen out locations where residential property and important services were present. Non-residential buildings were left in so as not to rule out potential locations such as playing fields and unused land.

The project analysis aimed to identify where watercourses are poorly connected to their floodplain, excluding residential areas where barriers to connectivity may be serving a flood defence purpose.

Having defined the method for identifying potential locations for floodplain reconnection, these were processed in a simple series of GIS queries and quality controlled based on the more detailed process diagram shown in Figure 5.3, which expands on Figure 5.2.

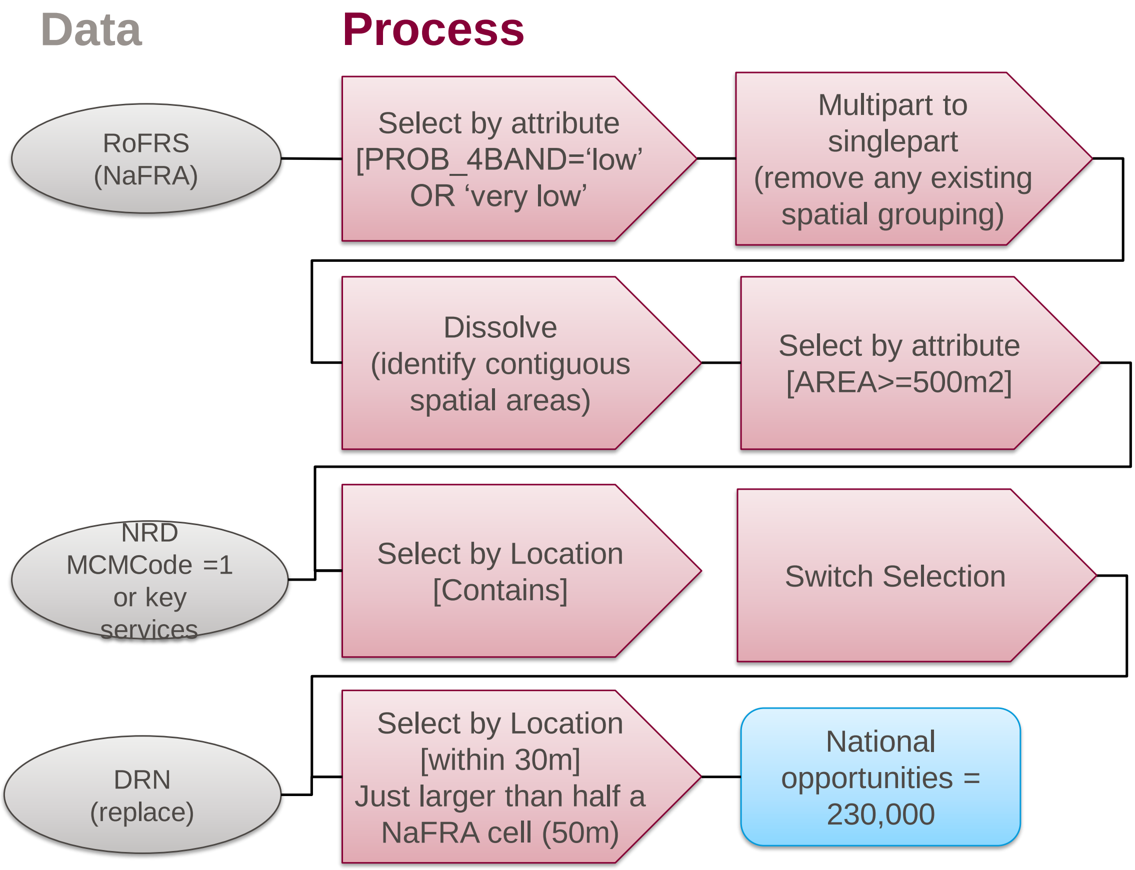

Figure 5.3 Processing of floodplain reconnection potential

Notes: DRN = Detailed River Network; NRD = National Receptors Dataset; RoFRS = Risk of Flooding from Rivers and Sea

5.6 Results and outputs

A sample of the resulting 230,000 floodplain reconnection opportunities were analysed (see example in Figure 5.4) and compared with other datasets including the most similar data – Flood Storage Areas. This dataset is believed to be inconsistent nationally at present, but was used here to assess capture by the floodplain reconnection layer. Formally there are 494 flood storage areas features across England, and with a search radius of 50m (the resolution of Risk of Flooding from Rivers and Seas), the new features captured 79% of them. The processing was repeated twice to ensure that the method presented in Figure 5.3 was robust.

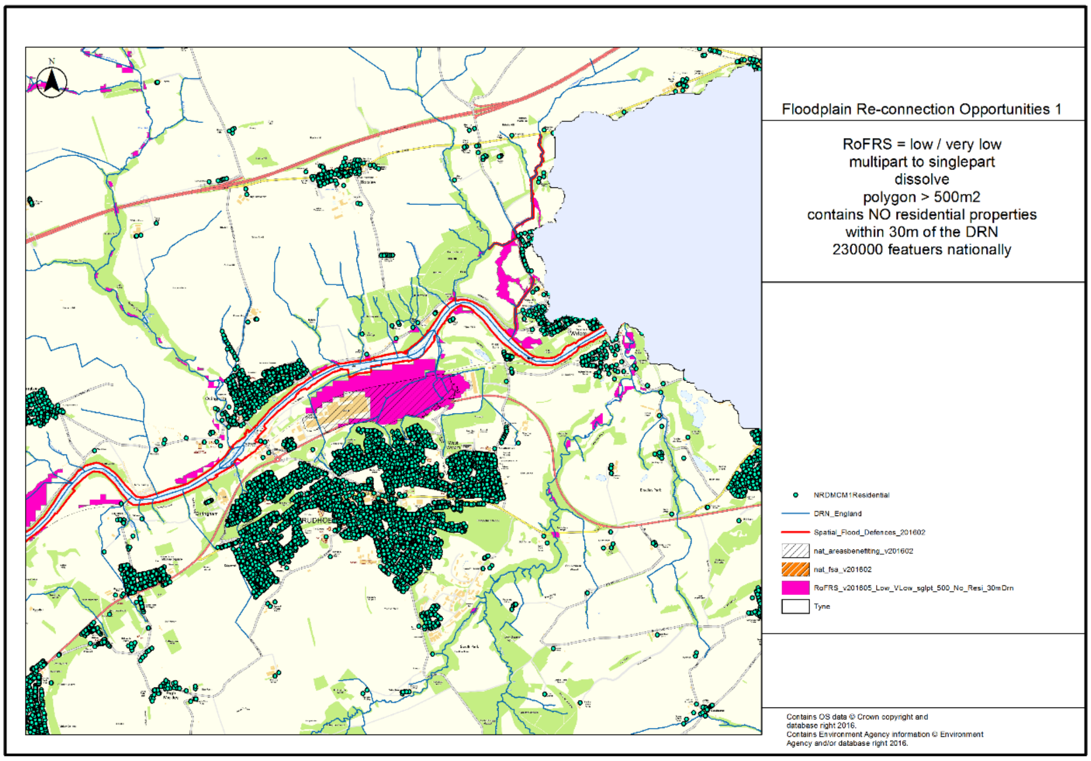

Figure 5.4 Sample floodplain reconnection potential identifying existing flood storage areas (brown/cross-hatched)

Some of the potential locations for floodplain reconnection are very small or thin, but they act as useful signposts of where further investigation may be useful, such as adjoining higher risk floodplain, multiple disconnected areas, or areas unnecessarily screened out of the final dataset.

The potential floodplain reconnection locations were not masked using the constraints layer described in Chapter 2 since, for example, this would exclude potential for reconnecting a wooded area of floodplain. However, residential properties and important services were excluded from the analysis. Examples of outputs for floodplain reconnection can be seen in Figures 5.5 and 5.6.

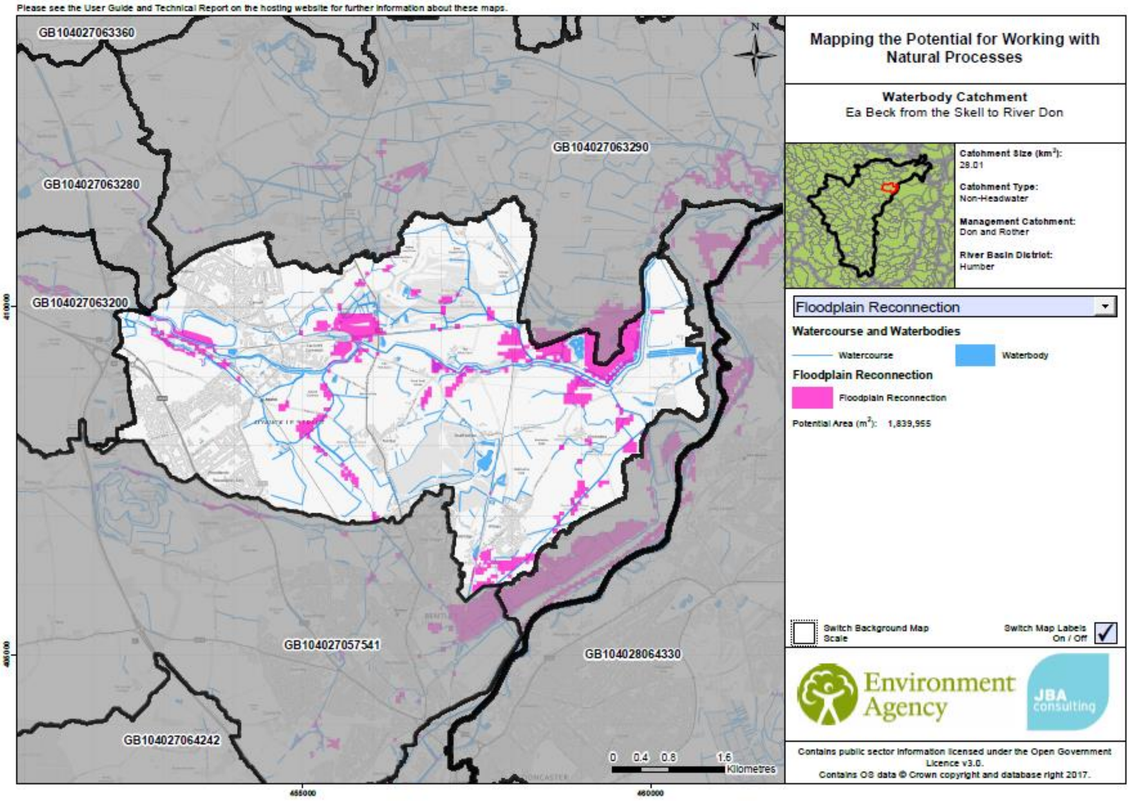

Figure 5.5 Example map showing floodplain reconnection potential for a semi-urban area

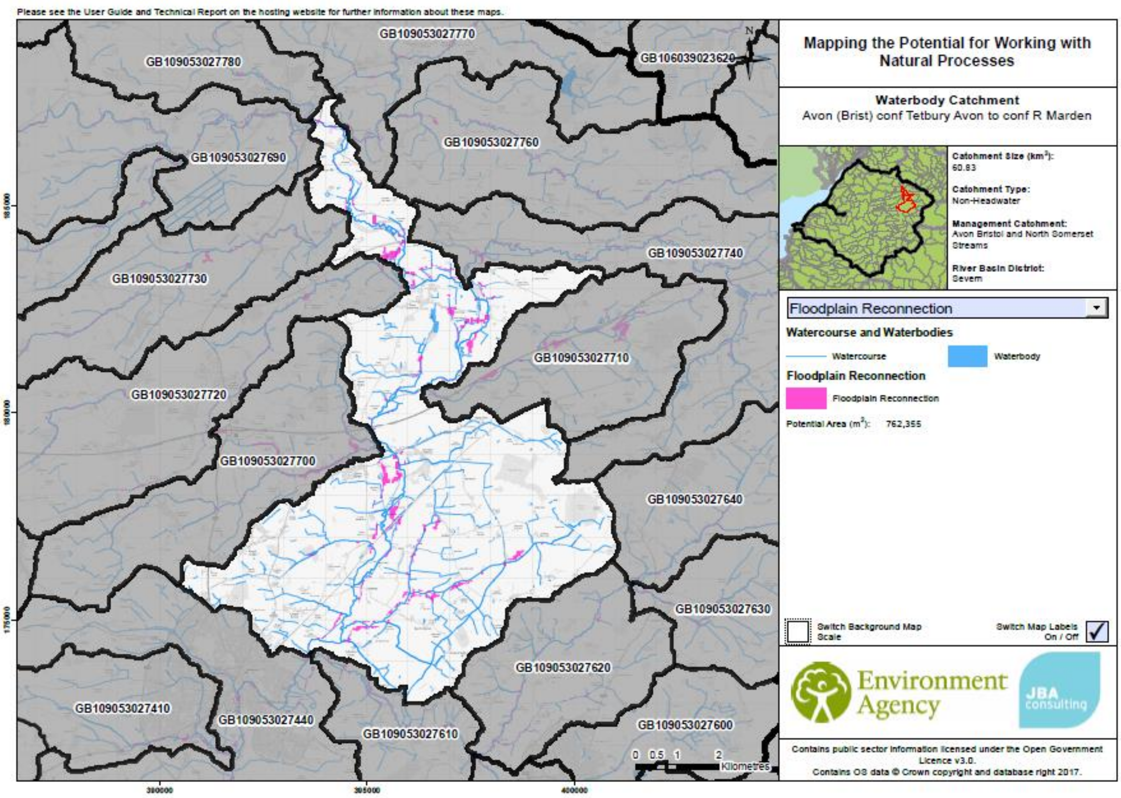

Figure 5.6 Example map showing floodplain reconnection potential for a more rural area

6 Run-off attenuation feature and gully blocking potential

6.1 Introduction

This chapter covers the data and methods used to map potential locations for run-off attenuation features and gully blocking. The first generation of NFM maps used data mining techniques to identify areas of high flow accumulation in the Risk of Flooding from Surface Water maps (Environment Agency 2013). A similar method was used to produce the run-off attenuation features data for this project. Gully blocking potential has additionally been identified as a subset of run-off attenuation features on steep slopes where leaky barriers may be most effective.

Two mapping layers have been produced based on the potential for a 3.3% AEP (or a 1 in 30 year flood event) and a 1% AEP (or a 1 in 100 year flood event). Both run-off attenuation features and gully blocking potential are displayed on these layers.

6.2 Science

Run-off attenuation features are areas of high run-off accumulation in the landscape where water can temporarily be held back in additional storage, such as ponds or in-channel features, and released more slowly following storms. They can consist of farm ponds in areas of overland flow accumulation – termed ‘overland flow disconnection ponds’ by Nicholson et al. (2012) and Barber and Quinn (2012) – and need to be designed to intercept and store overland flow until after a flood peak in the river. Run-off attenuation features require a large upslope contributing area and suitable local topography for the formation of storage areas. The model used for identifying run-off attenuation features locates areas with high natural flow accumulation, potentially providing ideal sites for temporary storage of floodwater.

Figure 6.1 Belford Burn run-off attenuation features

Source: Newcastle University

Gully blocking can increase the travel time of floodwater and cause other flow paths to develop during rainfall events. This technique creates pools of water behind the features, which can contribute to additional temporary flood storage space (if the pools are able to drain down between each event). Gullies naturally occur on slopes or where artificial drainage features have been eroded. Gully blocking may therefore be more appropriate than run-off attenuation features on steeper land. The project analysis used data on slope gradient to differentiate potential for gully blocking from run-off attenuation features.

6.3 Mapping or modelling concept

Mapping of run-off attenuation features was based on the following concept:

Key concept: run-off attention features

Run-off attenuation features are based on the premise that areas of high flow accumulation in the Risk of Flooding from Surface Water maps are areas where the run-off hydrograph may be influenced by temporary storage if designed correctly.

Identifying gully blocking potential provides an extension of this concept:

Key concept: gully blocking

Gully blocking potential is based on run-off attenuation features on steeper ground, with a gradient >6%, where leaky barriers may be more beneficial than a deepened pond, raised bund or grip blocking.

6.4 Data

The following data and constraints were applied to the run-off attenuation features; these are different from those applied to the other maps. Existing woodland and water networks (with the exception of canals) are not excluded since additional water can be stored in or out of channel, and can be stored within woodland.

6.4.1 Constraints data

- Constraint on size (100–5,000m^2)
- CORINE Land Cover Urban Areas
- OS Open Map Local – railway and building layers
- OS Open Roads
- OS Open Rivers – canal layer

6.4.2 Data excluded owing to IP or quality restrictions

The full Risk of Flooding from Surface Water map was not included in the updated suite of maps owing to the need for a conditional licence, though users should try to look at these in more detail to understand other flow pathways.

6.4.3 Open data used

- OS Terrain 50m grid used to assign slope in every run-off attenuation feature
- Run-off attenuation feature polygons data mined from Risk of Flooding from Surface Water maps

6.4.4 Licensing

The data for run-off attenuation features and gully blocking potential produced by JRAFF have been approved as open access. The Risk of Flooding from Surface Water dataset, from which the data are derived, is available from the Environment Agency under conditional licence.

6.5 Method

Before describing the generation of run-off attenuation features, it is first necessary to understand how the Risk of Flooding from Surface Water maps were generated.

The maps were produced in 2012 by applying blanket rainfall over the best available merged 2m LiDAR (light detection and ranging) product[3] and using a fast two-dimensional (2D) flood inundation model, JFLOW (Lamb et al. 2009) to route the water across the landscape to understand flow paths and accumulations. A Revitalised Flood Hydrograph (ReFH) hydrological losses model (Kjeldson 2007) was applied to different rainfall events with different probabilities (3.3%, 1% and 0.1% AEP) and durations (1, 3 and 6 hours). ReFH considers local soil storage properties based on empirical relationships with Flood Estimation Handbook catchment descriptors, and allows for different rates of wetting up through each event. The resulting maps are the maximum depth of flooding at any time over the rainfall event, as a composite across the 1, 3 and 6 hour events.

JRAFF was used to analyse potential for run-off attenuation features. This identifies areas of high flow accumulation from surface water depth grids within the Risk of Flooding from Surface Water outlines that could be targeted as locations for enhanced temporary storage. The tool is able to:

- define upstream catchment areas draining to a point
- identify areas of ponded water within the 3.3% AEP, 1% AEP and 0.1% AEP year Risk of Flooding from Surface Water depth grids
- calculate the existing volume of storage within ponding surface water and the additional volume if these ponds are deepened by a default of 1m
- stamp these deepened ponds onto a digital terrain model (DTM) ready for modelling

Since it is known from the modelling that these areas are where water channels go through or accumulate, they are natural locations to try and hold back the flow temporarily using soft engineering approaches.

Figure 6.2 provides an overview of the datasets and processing involved in the production of the potential locations for run-off attenuation features.

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[3] 2012 DTM containing LiDAR and interferometric synthetic aperture radar (ifSAR) data

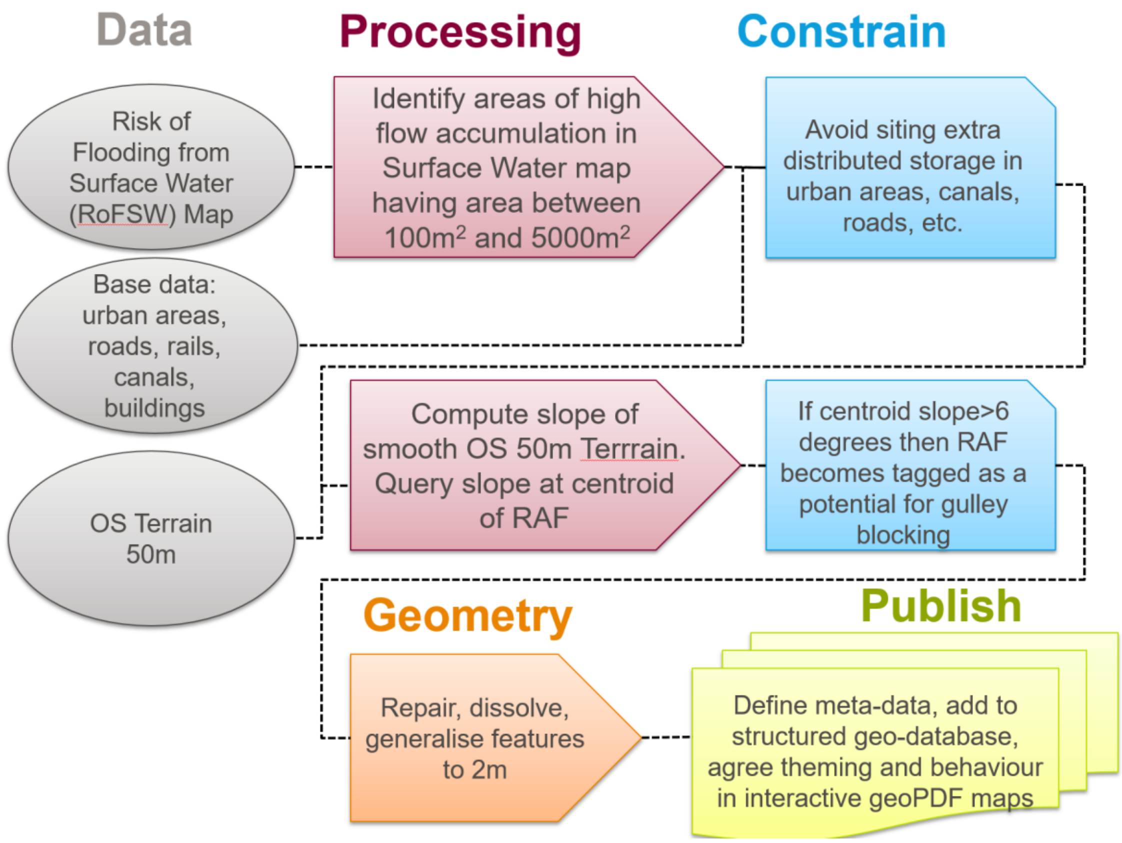

Figure 6.2 Processing of potential for run-off attenuation features

In the first generation of NFM maps, the run-off attenuation features were plotted in the same way independent of slope. Run-off attenuation features on steeper ground for updated maps have been reclassified using the slope based on the OS Open Terrain 50 DTM as 'gully blocking potential' and colour coded accordingly. For each run-off attenuation feature, the slope value was assigned from the OS 50m Terrain slope directly underneath the internal-centroid of the RAF polygon.

6.5.1 Identification of run-off attenuation features

GIS software (JRAFF) was used to undertake spatial queries on the Risk of Flooding from Surface Water maps to identify areas of natural depressions or in-channel areas where water is predicted to accumulate. The model proceeds to select areas of high flow accumulation within a user-specified size range,[4] before calculating the existing volume of storage based on predicted flood depths together with the predicted increase in storage volume should these storage features be deepened by up to 1m or bunded with low bunds up to 1m in height. Exclusions were applied to remove urban areas, roads, railways and canals.

[4] Here 100–5,000m^2 was used with the intention of avoiding large areas that, if improved, might come under the Reservoirs Act (which affects capacities >10,000m^3).

6.5.2 Reclassification of run-off attenuation features on steep ground as gully blocking

On steeper ground, potential for run-off attenuation features were reclassified as gully blocking. A threshold of >6 degrees (10%) was used (Figure 6.3), based on the following 2 criteria.

- Different typological classifications suggest slopes >5% are ‘steep’, have high energy and can cause braiding (Schumm and Khan 1972).
- Above 6 degrees (10%), restoring peatland vegetation becomes unviable (Evans et al. 2005) and so grip blocking becomes less effective as a form of run-off attenuation. Therefore, it has been argued that other methods such as gully blocking to hold back flows are more viable.

Local investigations may highlight additional areas that are suitable for gully blocking, such as ditches in low topographic relief areas.

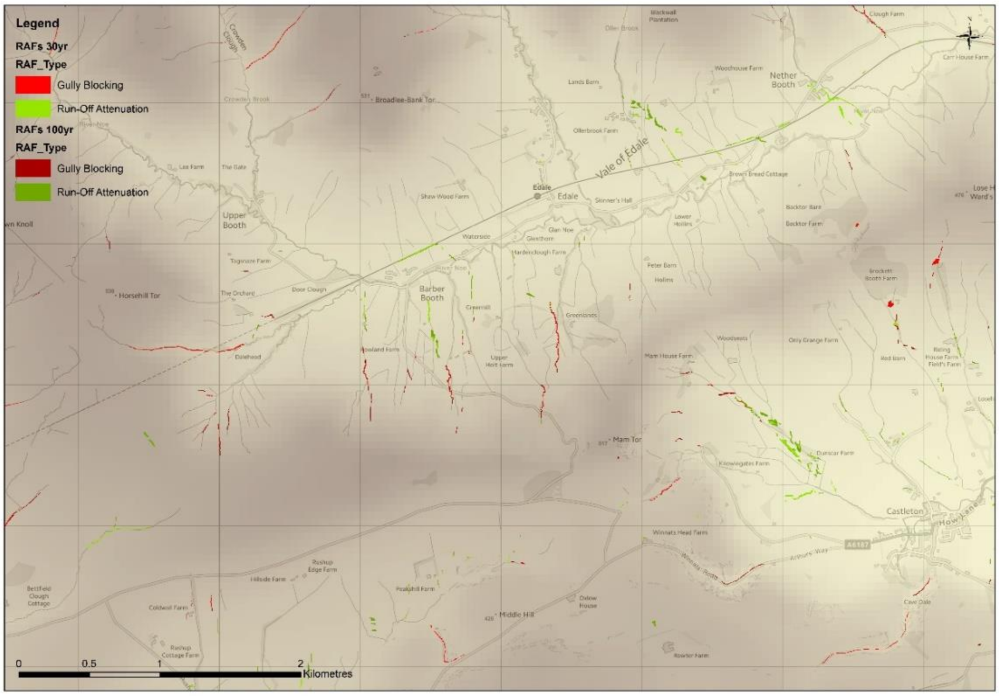

Figure 6.3 Run-off attenuation features classified by slope into gully blocking potential where internal-centroid slope >6 degrees

6.6 Results and outputs

Two layers have been produced for run-off attenuation features, based on a 3.3% AEP (Figure 6.4) and 1% AEP (Figure 6.5). Gully blocking is shown on the same layer, coloured brown.

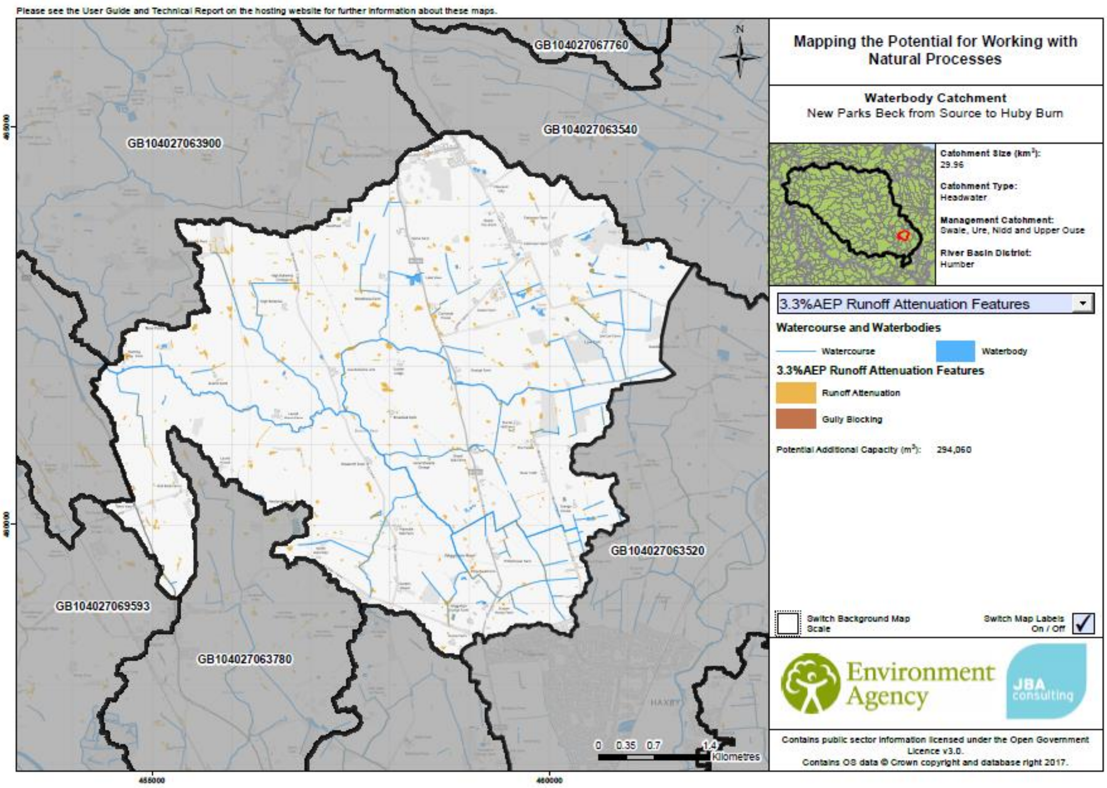

Figure 6.4 Example map showing run-off attenuation features and gully blocking potential based on 3.3% AEP mapping

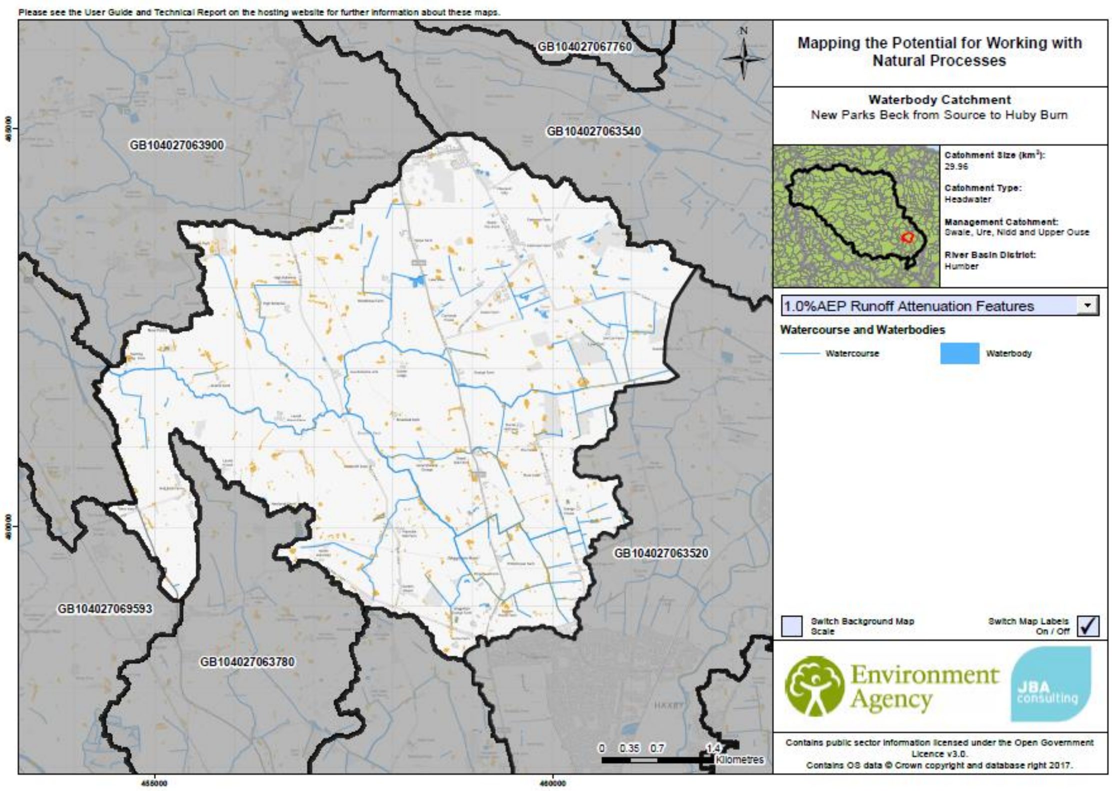

Figure 6.5 Example map showing run-off attenuation features and gully blocking potential based on 1% AEP mapping

7 Conclusions

7.1 Introduction

This report provides the technical background behind an updated set of strategic maps that identify the potential for WWNP across England. It has described the processes, methods and data used to create a nationally consistent, open access product. While a number of the mapped interventions were based on 'tried and tested' methodologies, the project has introduced new science on using slowly permeable soils to identify woodland planting potential, and created a new method for classifying floodplain reconnection potential.

The report highlights how decisions were made on using the best available open data, such as the Environment Agency maps showing the risk of flooding from rivers, sea and surface water, to produce a national picture of the potential for WWNP. The project also involved negotiating access to data including the BGS 1:50,000 geological maps, from which the wider catchment woodland potential maps were derived. This proved higher quality than the open access soils data that had been identified, enabling the more accurate targeting of areas where woodlands could increase hydrological losses and reduce surface run-off.

The maps identify locations and size of features that may enhance the natural capital of whole catchments to improve resilience to flooding, in combination with established flood risk management measures. The extent of the potential for WWNP has been quantified at the water body catchment scale (average $30km^2$), and can be incorporated into modelling to assess upstream and downstream risks. The maps therefore provide a resource for identifying, sizing and then modelling risks, although they do not specify engineering design.

The methodologies for identifying the potential for WWNP has been peer-reviewed, and the outputs have been edited based on feedback from the project steering group and user testers. The maps are available as a suite of interactive and georeferenced PDFs, and are also hosted online to ensure the widest possible audience.

7.2 Outputs

This project has 4 main outputs:

- this technical guide
- a suite of interactive geoPDF maps and online web maps that visualise and tabulate the extent of the potential WWNP measures
- an updated user guide to the maps
- the GIS data behind the maps

The WWNP measures prioritised for mapping in this project include:

- tree planting across 3 categories:
  - floodplain
  - riparian
  - slowly permeable soils

- floodplain reconnection
- run-off attenuation features
- gully blocking potential

7.3 Recommendations

It is recommended that the new WWNP maps and the accompanying user guide are used strategically as a screening tool to signpost areas of greater potential for slowing, storing or infiltrating flows to help reduce flood risks. Any kind of intervention comes with its own risks and uncertainties, which should be fully explored as part of the decision-making process. Landowner and land occupier considerations also need to be taken into account.

It is essential to seek expert advice in interpretation of these maps to:

- identify any further constraints
- pinpoint appropriate locations to ensure the long-term sustainability of catchment processes to achieve maximum flood risk and other benefits

Users should seek additional guidance and information from government bodies including the Environment Agency, the Forestry Commission and Natural England where appropriate. Care should be taken to look at a catchment scale and to locate interventions where these work with the catchment processes. It should also be acknowledged that a decision of no active intervention or small actions to assist natural recovery is as valid as active interventions.

Users should also check whether there is a model available to assess and quantify upstream and downstream risk with any significant changes. There are a wide range of strategies for mapping and modelling WWNP (see Hankin et al. 2017); these are highly dependent on the assumptions and uncertainties involved in setting model parameter changes to reflect the influence of WWNP measures. The Evidence Base includes a report called 'Using the Evidence Base' which explains how different models can be adapted to represent changes to catchment processes resulting from WWNP measures, while a previous report, 'How to model and map catchment processes' (Environment Agency 2016) provides some further guidance and case studies.

It is important to investigate upstream and downstream risks. Increased friction due to riparian planting, for example, could theoretically give rise to backwater effects that increase flood extents upstream. Modelling can also be a powerful tool to identify potential changes to the relative timing of flood waves along adjacent tributaries, since these can synchronise, or more helpfully desynchronise flood peaks under different circumstances.

It is recommended that the new slowly permeable soils dataset and evidence provided here and in the appendices are published to gain further peer review. The model could also be field tested and further analysed to evaluate its performance in relation to a range of factors such as slope gradient, rainfall and geology.

Some important datasets that are currently available only under conditional licences have not been included in the maps. It would, for example, be especially useful to show the Risk of Flooding from Surface Water layer to help identify other major flow pathways at 2m resolution.

Although this project identifies the potential for a number of key WWNP interventions, the range of measures covered by mapping could be usefully expanded at a national scale. Interventions such as river restoration, woody dams and land management are also an important part of WWNP, as are coastal measures and interventions in urban areas. These additional layers and datasets would complement the existing maps.

References

AVERY, B.W., 1980. *Soil classification for England and Wales (higher categories).* Soil Survey Technical Monograph No. 14. Harpenden: Rothamsted Experimental Station.

BARBER, N.J. AND QUINN, P.F., 2012. Mitigating diffuse water pollution from agriculture using soft-engineered runoff attenuation features. *Area*, 44 (4), 454-462.

BOORMAN, D.B., HOLLIS, J.M. AND LILLY, A., 1995. *Hydrology of Soil Types: a hydrologically based classification of the soils of the United Kingdom. Wallingford:* Institute of Hydrology Report No. 126.

BROADMEADOW, S.B.; THOMAS, H., AND NISBET, T.R., 2014. *Opportunity mapping for woodland creation to reduce diffuse water pollution and flood risk in England and Wales*. Farnham, Surrey: Forest Research.

BRUTSAERT, W., 2005. *Hydrology: An Introduction*. Cambridge: Cambridge University Press.

BURNHAM, C.P., AVERY, B.W., FINDLAY, D.C. AND MACKNEY, D., 1980. The soils of England and Wales. *Field Studies*, 5 (2), 349-363.

CHAPPELL, N.A. AND TERNAN, J.L., 1992. Flow-path dimensionality and hydrological modelling. *Hydrological Processes*, 6 (3), 327-345.

CRANFIELD SOIL AND AGRIFOOD INSTITUTE, 2015. *Soil maps, books and information resources: publications list.* Cranfield, Bedfordshire: Cranfield University.

DADSON S.J., HALL, J.W., MURGATROYD, A., ACREMAN, M., BATES, P., BEVEN, K., HEATHWAITE, L., HOLDEN, J., HOLMAN, I.P., LANE, S.N., O'CONNELL, E., PENNING-ROWSELL, E., REYNARD, N., SEAR, D., THORNE, C. AND WILBY, R., 2017. A restatement of the natural science evidence concerning catchment-based 'natural' flood management in the UK. *Proceedings of the Royal Society A*, 473 (2199), 20160706; DOI: 10.1098/rspa.2016.0706

ENVIRONMENT AGENCY, 2005. *Risk assessment of flood and coastal defence systems for strategic planning (RASP).* R&D Technical Report W5B-030/TR. Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2008. *National Assessment of Flood Risk (NaFRA): RASP methodology.* Bristol: Environment Agency

ENVIRONMENT AGENCY, 2013. *What is the updated Flood Map for Surface Water?* Bristol: Environment Agency.

ENVIRONMENT AGENCY, 2016. *How to model and map catchment processes when flood risk management planning.* Bristol: Environment Agency.

EVANS, M., ALLOTT, T., HOLDEN, J., FLITCROFT, C. AND BONN, A., 2005. *Understanding gully blocking in deep peat.* Moors for the Future Report No 4. Castleton, Derbyshire: Moors for the Future. Available from: http://www.moorsforthefuture.org.uk/research-publications [Accessed 7 July 2017].

FAO-UNESCO, 1990. *Soil map of the world,* revised legend. Soils Bulletin 66. Rome: Food and Agricultural Organization of the United Nations.

FINDLAY, D.C., COLBORNE, G.J.N., COPE, D.W., HARROD, T.R., HOGAN, D.V. AND STAINS, S.J., 1984. *Soils and their use in south west England.* Soil Survey of England and Wales Bulletin 14. Harpenden: Rothamsted Experimental Station.

HALL J.W., DAWSON R.J., SAYERS, P., ROSU, C., CHATTERTON, J. AND DEAKIN, R., 2003. A methodology for national-scale flood risk assessment. *Proceedings of the Institution of Civil Engineers – Water & Maritime Engineering*, 156 (3), 235-247.

HANKIN, B., METCALFE, P., CRAIGEN, I., PAGE, T., CHAPPELL, N., LAMB, R., BEVEN, K. AND JOHNSON, D., 2017. Strategies for testing the impact of natural flood risk management measures. In *Flood Risk Management* (ed. T. Hromadka and P. Rao), Chapter 1. InTech. DOI: 10.5772/intechopen.68677. Available from: https://www.intechopen.com/books/flood-risk-management/strategies-for-testing-the-impact-of-natural-flood-risk-management-measures [Accessed 18 September 2017].

JARVIS, R.A., BENDELOW, V.C., BRADLEY, R.I., CARROLL, D.M., FURNESS, R.R. KILGOUR, I.N.L. AND KING, S.J., 1984. Soils and their use in northern England. Soil Survey of England and Wales Bulletin 10. Harpenden: Rothamsted Experimental Station.

KJELDSON, T., 2007. *The revitalised FSR/FEH rainfall-run-off method*. Flood Estimation Handbook Supplementary Report No. 1. Wallingford: Centre for Ecology and Hydrology.

LAMB, R., CROSSLEY, A. AND WALLER, S., 2009. A fast 2D floodplain inundation model. *Proceedings of the Institution of Civil Engineers– Water Management*, 162 (6), 363-370.

MILNE, G., 1947. A soil reconnaissance journey through part of Tanganyika Territory December 1935 to February 1936. *Journal of Ecology*, 35 (12), 192-265.

MURPHY C.P., 1984. The morphology and genesis of eight Surface-Water Gley soils developed in till in England and Wales, UK. *Journal of Soil Science*, 35 (2), 251-272.

NICHOLSON, A.R., WILKINSON, M.E., O'DONNELL, G.M. AND QUINN, P.F., 2012. Runoff attenuation features: a sustainable flood mitigation strategy in the Belford catchment, UK. *Area*, 44 (4), 463-469.

PACKMAN, J.C., QUINN, P.F., HOLLIS, J. AND O'CONNELL P.E., 2004. *Review of impacts of rural land use and management on flood generation. Short-term improvement to the FEH rainfall-runoff model: technical background*. R&D Project Record FD2114/PR3. London: Department for Environment, Food and Rural Affairs.

SCHEIB, A.J., LEE, J.R., BREWARD, N. AND RIDING, J.B., 2011. Reconstructing flow paths of the middle Pleistocene British ice sheet in central-eastern England: The application of regional soil geochemical data. *Proceedings of the Geologists' Association*, 122 (3), 432-444.

SCHUMM, S.A. AND KHAN, H.R., 1972. Experimental study of channel patterns. *Geological Society of America Bulletin*, 83 (6), 1755-1770.

SHAW, E.M., BEVEN, K.J., CHAPPELL, N.A. AND LAMB, R., 2010. *Hydrology in Practice*, 4th edition. Abingdon: Taylor and Francis.

SMITH, A. 2013. *Digital Geological Map of Great Britain: information notes*. British Geological Survey Open Report OR/13/007. Keyworth, Nottingham: British Geological Survey.

List of abbreviations

AEP	annual exceedance probability
BGS	British Geological Survey
DTM	Digital Terrain Model
FCRM	flood and coastal risk management
GIS	geographical information system
HOST	Hydrology of Soil Types
IP	intellectual property
IPR	intellectual property rights
JRAFF	JBA Run-off Attenuation Feature Finder
LiDAR	light detection and ranging
NaFRA	National Flood Risk Assessment
NFM	natural flood management
OGL	Open Government Licence
OS	Ordnance Survey
ReFH	Revitalised Flood Hydrograph
SPR	standard percentage run-off
WWNP	Working with Natural Processes

Glossary of terms

Annual exceedance probability (AEP)	This is a term for expressing flood frequency. The 100-year return period flood can be expressed as the 1% AEP flood, which has a 1% chance of being exceeded in any year. A 20% AEP event has a 20% chance of being exceeded in any one year, and is equivalent to the 5-year return period flood. The return period of a flood is the average period of time expected to elapse between the occurrence of a flood event of a certain size at a given site. The actual number of years between consecutive floods varies considerably because of the naturally changing climate. A 100-year event is an extreme flood event of such size that, over a long period of time, the average time between flood events of equal or greater magnitude is 100 years.
Floodplain restoration	Floodplain restoration aims to restore the hydrological connection between rivers and floodplains so that floodwaters inundate the floodplains and store water during times of high flows. This can involve removing flood embankments and other barriers to floodplain connectivity.
Floodplain woodland	Floodplain woodland refers to all woodland lying within the fluvial floodplain that is subject to an intermittent, regular planned, or natural flooding regime. It typically comprises broadleaved woodland, and can range from productive woodland on drier, intermittently flooded areas to unmanaged, native wet woodland in wetter areas. The degree of benefit provided by this range of types can vary depending on the woodland.
GIS (geographical information system)	A geographical information system is a system designed to capture, store, manipulate, analyse, manage and present spatial or geographic data.
Gully blocking	Gullies are naturally occurring features of peatlands, where blanket peats spread to the heads of valleys, but they also form where artificial drainage features become eroded. They can be blocked using a variety of materials including wood, plastic, stone and heather. They can create temporary flood storage space.
Infiltration-excess overland flow	This type of flow is formed when the rainfall intensity exceeds the soil infiltration capacity in an area. Water then accumulates on the soil and starts moving downslope, due to gravity, towards the hydrographic network.
Management catchment	This is the unit of geography for which action plans are drafted in implementing the Water Framework Directive.
Measures and interventions	The terms 'measures' and 'interventions' of Working with Natural Processes have been used interchangeably throughout this report. Measures and interventions are the change to a landscape or management regime with an intention to reduce flood risk. Examples include a change in a land management practice, construction of a run-off

	attenuation feature, planting of a new woodland and managed realignment on the coast.
Riparian woodland	Riparian woodland is woodland located within the riparian zone, defined here as the land immediately adjoining a watercourse or standing water and influenced by it. The riparian zone is usually relatively narrow. It typically comprises native broadleaved woodland and is often unmanaged. The main role of riparian woodland from a natural flood management perspective is to slow down and hold back flood flows within watercourses, as well as to reduce sediment delivery and bankside erosion.
River Basin District	The Water Framework Directive defines a river basin district as ‘the area of land and sea, made up of one or more neighbouring river basins together with their associated groundwaters and coastal waters’.
Run-off	Runoff, is the quantity of water discharged in surface streams. Runoff includes not only the waters that travel over the land surface and through channels to reach a stream but also interflow, the water that infiltrates the soil surface and travels by means of gravity toward a stream channel (always above the main groundwater level) and eventually empties into the channel. Runoff also includes groundwater that is discharged into a stream. Total runoff is equal to the total precipitation less the losses caused by evapotranspiration (loss to the atmosphere from soil surfaces and plant leaves), storage (as in temporary ponds), and other such abstractions.
Run-off attenuation features	Run-off attenuation features are intended to mimic natural hydrological regimes to minimise the impact of human activity on surface water drainage discharge, reducing flooding and pollution of waterways and groundwater. They include measures such as swales, ponds and sediment traps.
Saturation overland flow	This type of occurs when the soil profile becomes saturated and any additional precipitation or irrigation causes surface run-off.
Slowly permeable soils	These are soils through which water passes slowly. These types of soils are more likely to generate infiltration-excess overland flow. Planting woodland on these naturally impermeable soils could break up them up, enabling greater infiltration and reducing surface run-off.
Till–diamicton	Till describes a group of sediments laid down by the direct action of glacial ice. These are usually sandy, silty clay (potentially chalky in south-east England) with pebbles, but can contain gravel-rich or laminated sand layers. Diamicton refers to poorly sorted sediment with a wide size range and undefined composition.

Water body catchment	The Water Framework Directive defines a water body catchment as 'an area of land from which all surface run-off flows through a series of streams, rivers and, possibly, lakes to a particular point in the water course such as a river confluence'.
Wider catchment woodland	Wider catchment woodland is defined as the total area of all woodland within a catchment. The term 'woodland' is used to describe land predominantly covered in trees (with a canopy cover of at least 20%), whether in large tracts (generally called forests) or smaller areas known by a variety of terms, including woods, copses, spinneys or shelterbelts. Catchment woodland is likely to affect: • the generation and conveyance of flood flows by the water use by trees • the related effects on snow accumulation and melting • soil infiltration beneath woodland • the hydraulic roughness exerted by woodland • the impact of woodland on soil erosion and sediment delivery
Working with Natural Processes	Working with Natural Process is taking action to manage fluvial and coastal flood and coastal erosion risk by protecting, restoring and emulating the natural regulating function of catchments, rivers, floodplains and coasts.

Appendix 1: Data shortlist

The first stage of this project was to identify suitable datasets that were nationally consistent, open access and fit for purpose. This table presents a shortlist of the data considered, their owner and licence type, and their use in the project. The shortlist was narrowed down further to the data which were used to create each mapping layer – discussed in further detail in Chapter 2. An extensive list of additional datasets that could be used to complement the data provided by this project is given in Appendix 2 of the user guide.

Data reference	Title	Owner	Licence type	Link	Use in project
2017s5679-1	National Receptors Dataset 2014	Environment Agency	Conditional licence – not published	https://data.gov.uk/dataset/national-receptor-dataset-afa171	Derivation data – not displayed on maps
2017s5679-2	OS OpenMap Local (Vector) – used SurfaceWater_Line_openmap and SurfaceWater_Area_openmap	OS	Open data	https://www.ordnancesurvey.co.uk/business-and-government/products/os-open-map-local.html	Displayed in background mapping
2017s5679-3	Detailed River Network	Environment Agency	Conditional licence – not published	https://data.gov.uk/dataset/detailed-river-network--offline-drainage-afa036	Derivation data – not displayed on maps
2017s5679-4	Cycle 2 Water Framework Directive River Basin Districts	Environment Agency	OGL	https://data.gov.uk/dataset/wfd-river-waterbody-catchments-cycle-2	Displayed on maps – catchment boundaries
2017s5679-5	Cycle 2 Water Framework Directive Water Body Catchments	Environment Agency	OGL	https://data.gov.uk/dataset/wfd-river-waterbody-catchments-cycle-2	Displayed on maps – catchment boundaries
2017s5679-6	Agricultural Land Classification	Natural England	OGL	http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/	Displayed as additional layer
2017s5679-7	CORINE Land Cover – peat and urban layers	European Environment Agency	OGL	https://data.gov.uk/dataset/corine-land-cover-2012-for-the-uk-jersey-and-guernsey	Displayed as additional layer and used in constraints layer

Data reference	Title	Owner	Licence type	Link	Use in project
2017s5679-8	European Soils Database	European Soil Data Centre	Open data	http://esdac.jrc.ec.europa.eu/content/european-soil-database-v20-vector-and-attribute-data#tabs-0-description=1	Not used
2017s5679-8	BGS Superficial Geology 625,000	BGS	OGL	http://www.nationalarchives.gov.uk/doc/open-government-licence/version/3/	Not used
2017s5679-10	Flood Map for Planning (Rivers and Seas)	Environment Agency	OGL	https://data.gov.uk/dataset/flood-map-for-planning-rivers-and-sea-flood-zone-2	Displayed as additional layer and used in floodplain woodland layer
2017s5679-11	Risk of Flooding from Rivers and Sea	Environment Agency	OGL	https://data.gov.uk/dataset/risk-of-flooding-from-rivers-and-sea1	Displayed as additional layer and used in floodplain reconnection layer
2017s5679-13	Run-off Attenuation Features	JBA/ Environment Agency	OGL	https://data.gov.uk/dataset/wwnp-runoff-attenuation-features-3-3-aep	Used in run-off attenuation features layer
2017s5679-14	Upland Blanket Bog	Natural England	OGL	https://data.gov.uk/dataset/priority-habitat-inventory-england2	Not used
2017s5679-15	Lowland Fens / Raised Bogs	Natural England	OGL	https://data.gov.uk/dataset/priority-habitat-inventory-england2	Not used
2017s5679-17	SPRHOST	CEH/ Cranfield	Licence required	https://www.ceh.ac.uk/services/hydrology-soil-types-1km-grid	Not used
2017s5679-18	Standard average annual rainfall (SAAR)	CEH	Licence required	https://www.ceh.ac.uk/services/flood-estimation-handbook	Not used
2017s5679-19	BGS 50,000 geology maps	BGS	Licence required	http://www.bgs.ac.uk/products/digitalmaps/	Derivation data – not displayed on maps
2017s5679-20	OS Terrain 50	OS	Open data	https://www.ordnancesurvey.co.uk/business-and-government/products/terrain-50.html	Derivation data used in gully blocking
2017s5679-23	Spatial Defence Layers with Attributes	Environment Agency	OGL	http://environment.data.gov.uk/ds/catalogue/#/b07dc5b5-f382-4dc1-be4b-464f1e64f12b	Displayed as additional layer

Data reference	Title	Owner	Licence type	Link	Use in project
2017s5679-24	Priority Habitat layers from Natural England for peat	Natural England	OGL	http://environment.data.gov.uk/ds/catalogue/#/catalogue	Not used

Notes: All links accessed 18 September 2017.
CEH = Centre for Ecology and Hydrology

Appendix 2: Evaluation of the slowly permeable soils model

A.2.1 Identification of new national IP-free map of slowly permeable soils for prioritising tree planting for NFM benefit

A.2.1.1 Rationale

Processes that the new map needs to represent

Most interventions harnessing nature to reduce flood peaks in rivers (NFM interventions) are designed to achieve this, in part, by reducing the velocity and amount of ‘overland flow’ on slopes. ‘Surface flow’ is a more ambiguous term that includes overland flow on slopes, and channel flow derived from a combination of subsurface flow and overland flow on slopes.

Overland flow on slopes is produced where the rainfall intensity, measured over sub-daily periods, exceeds the local permeability of the ground surface (also called the infiltration capacity or saturated hydraulic conductivity of the topsoil) to give **infiltration-excess overland flow**.

Surface soils in valley bottoms or hillslope hollows may also experience overland flow, even if the local permeability of the ground surface is very high. This is because the rates of percolation from upslope areas towards the local streams may exceed the rate at which the downslope soils can deliver the water into the channel, and so levels of saturation build up during a rainstorm in valley bottoms and hillslope hollows. This build-up of soil moisture may result in saturation at the soil surface. Where this occurs, further rainfall onto these saturated soils produces **saturation overland flow**. Indeed, the downslope accumulation may be so great that water leaves the ground before reaching the channel (this is called return flow) to produce another source of saturation overland flow (see, for example: Brutsaert 2005, Chapter 5 or Shaw et al. 2010, Chapter 1).

Interventions involving tree planting seek to:

- slow overland flow through the development of rougher ground surfaces
- largely eliminate overland through enhanced infiltration rates (via increased topsoil permeability and enhanced soil drying from enhanced evapotranspiration)
- remove water from the streamflow generating system via enhanced wet canopy evaporation (‘interception loss’) and enhanced transpiration

Interventions involving changed soil management on agricultural land are similarly designed to reduce overland flow through enhanced infiltration rates (via increased topsoil permeability and enhanced soil drying from better subsoil drainage). Interventions involving the introduction of farm ponds in areas of overland flow accumulation – called overland flow disconnection ponds by Nicholson et al. (2012) (or a type of run-off attenuation feature) – are designed to intercept and store overland flow until after a flood peak in the river. The exceptions are interventions involving enhanced in-channel storage within headwaters (via channel remeandering or the introduction of leaky dams using semi-natural materials), where a component of the total water flow rather than just overland flow is stored until after a flood peak in the river.

As a direct consequence, the greatest hydrological impact of the interventions that directly affect overland flow velocity and amount will be in areas where the soils are likely to produce significant overland flow amounts (by the infiltration-excess and/or saturation mechanisms). Areas most likely to generate infiltration-excess overland flow will be areas of slowly permeable soil. Here the term 'soil' is used according to its strictest definition of the 'solum' comprising the 'A soil horizon' and 'B soil horizon'. Areas most likely to generate saturation overland flow will be areas either where shallow subsurface flow returns towards the surface (which needs to be defined by very detailed topographic analysis) or where deep groundwater flow from rock aquifers returns to the surface (which needs to be defined by detailed hydrogeological mapping and modelling). However, the effects of both factors may be influenced by the presence of slowly permeable soil.

UK soils developed from slowly permeable parent materials (that is, the surficial geology where present, or the solid geology, where absent; see, for example, Murphy 1984) tend to be naturally poorly drained. The parent materials and resultant waterlogging near the surface give rise to hydromorphic (or hydric) soils with either gleying near the ground surface or the development of peat. These areas have been surveyed and locally mapped in detail as soil types broadly classified as the Major Soil Groups of 'Surface-Water Gley soils' and 'Peat soils' by the Soil Survey of England and Wales (Avery 1980).

Hydrologically distinct soil types with slow permeability

The most precise definition of a soil type with distinct hydrological characteristics is the 'Soil Subgroup' of the Soil Series of England and Wales classification (for example, 7.2 stagnohumic gley soil; Avery 1980) or the Level 2 Soil Units of the international FAO-UNESCO classification (for example, Gn Humic gleysol; FAO-UNESCO 1990).

The Soil Subgroup of, for example, a 7.2 stagnohumic gley soil consists of several 'Soil Series' (for example, Wilcocks Series). These Soil Series have been field surveyed and then mapped at 1:25,000 scale for the Soil Series of England and Wales for local areas of England and Wales, typically covering approximately 10km × 10km rural areas, for example, NY53 Soils of Cumbria I (Penrith).

In the UK (and elsewhere), the Soil Subgroups of the 2 Major Soil Groups highlighted here tend to be associated with low permeability topsoil (see, for example, Chappell and Ternan 1992) and hence are those soils with the greatest likelihood of experiencing infiltration-excess overland flow.

For other Major Soil Groups, there is little evidence that the majority of the component Soil Subgroups are associated with slowly permeable topsoil and subsoil. For example, the ironpan stagnopodzol Soil Subgroup (for example, Hiraethog Soil Series) is associated with shallow peat and gleyed E horizons above the ironpan, and a slowly permeable profile. However, the ferric stagnopodzol (for example, Hafren Soil Series) and brown podzolic soil (for example, Manod Soil Series) of the same Major Soil Group of Podzol are not (see, for example, Burnham et al. 1980, Chappell and Ternan 1992).

Grouping slowly permeable Soil Subgroups with limited spatial extent with the more extensive permeable Soil Subgroups of the same Major Soil Group would produce a high risk of prioritising soils that do not have a high likelihood of generating significant infiltration-excess overland flow. Thus, the focus for identifying areas of soils with a significant likelihood of generating infiltration-excess overland flow is based on specific Soil Subgroups with a high likelihood of experiencing infiltration-excess overland flow, and those Major Soil Groups where the majority of the Soil Subgroups have a similarly high likelihood of generating such flow, based on published experimental research (see, for example, Chappell and Ternan 1992), that is, Surface-Water Gley soils and Peat soils.

Maps of hydrologically distinct soil types with a slow permeability

The field survey and 1:25,000 scale mapping of individual Soil Subgroups in England and Wales has taken place in 132 areas (Cranfield Soil and Agrifood Institute 2015). These individual maps typically cover approximately 10km × 10km and thus cover only 8.7% of England and Wales (13,200/151,040 × 100). However, the few areas that they are available for might be seen as the 'gold standard' of mapping hydrologically distinct Soil Subgroups.

Soil Association, HOST, SPR>50 and Woodlands for Water maps

Outside the few areas where 10km × 10km maps at 1:25,000 scale are available, no better than 1:250,000 scale soil mapping has been produced for England and Wales. Outside the areas of detailed survey, soil areas were classified based on an assumed characteristic Soil Series (and hence characteristic Soil Subgroup) with reference to other soils in the same geology and adjacent topographic settings (see, for example, the commentary in Jarvis et al. 1984).

It is long established that spatial patterns in soil types, such as the Soil Series of England and Wales Soil Subgroups, are linked to topography and geology, with the spatial linkages between the soils described by a conceptual 'topographic catena' or 'geological catena' (Milne 1947). Definition of soil areas at the national scale utilised this catena concept. Consequently, such a soil area – called a Soil Association – includes a range of spatially linked Soil Subgroups, associated with an assumed characteristic Soil Series. From a purely hydrological perspective, this means that Soil Subgroups with very different hydrological behaviours are grouped into a single Soil Association (Chappell and Ternan 1992).

The map currently used to identify areas likely to generate overland flow on slopes for NFM and other purposes is based on the 1:250,000 scale Soil Series of England and Wales Soil Association map. Strictly speaking, the Woodlands for Water layer derived from the Soil Association map shows soils likely to produce 'direct run-off', where this is typically interpreted as overland flow on slopes and is quantified by the SPR>50 index.

This SPR>50 layer is a core component of the Woodlands for Water spatial layer (Broadmeadow et al. 2014) used by the Environment Agency and others in NFM mapping. Soils categorised as having an SPR>50 value are considered to produce more than 50% of the river hydrograph by a fast response (SPR) and less than 50% via slow pathways or baseflow. The SPR>50 values for the UK were derived as part of the HOST classification (Boorman et al. 1995).

Within this model of the hydrological functioning of UK soils, the 1:250,000 scale map of Soil Associations was re-categorised into 29 different classes. River hydrograph records from 170 river stations were used in this classification, with so-called 'hydrograph separation' techniques used to determine the direct run-off and baseflow components, with rainfall and antecedent wetness values also incorporated (Boorman et al. 1995, p. 9). However, the most important predictor of the SPR value is the amount of baseflow represented by a Base Flow Index (BFI) (Boorman et al. 1995, p.

14). Changes to the derivation of the SPR values have been made since the original publication (see, for example, Packman et al. 2004).

The source Soil Series of England and Wales 1:250,000 Soil Association map, the derived HOST map, the SPR>50 map and Woodlands for Water map derived from these data are all subject to licensing restrictions.

Potential use of BGS 1:50,000 scale data for mapping of hydrologically distinct soil types with slow permeability across England (and wider)

For more than 50 years, BGS has been carrying out field surveys of solid geology and surficial geology at a 1:10,000 scale; almost all the UK is now digitally mapped at 1:50,000 scale (Smith 2013). These digital map layers are supported by a single national layer showing the exact georeferenced locations of the field survey points. The incredibly detailed spatial coverage at 1:50,000 scale for the whole of the UK (242,495km^2), except for EW118 Nefyn and EW180 Knighton, can be viewed online via the BGS's Geology of Britain viewer.[5]

The research hypothesis for this project is that the location of slowly permeable Soil Subgroups within the Surface-Water Gley and Peat Major Soil Groups are closely linked to the presence of the underlying glacial till, with its slowly permeable matrix, in parts of the UK that have been glaciated in the past 2 million years (see Figure A.2.1). In this period, ice and subsequently glacial till deposits probably reached their maximum extent in the Anglian glaciation, extending south to, for example, the Bristol Channel in the west and to Brentwood, north-east of London in the east (see, for example, Scheib et al. 2011). BGS maps areas of surficial geology covered by peat separately.

If the detailed BGS 1:50,000 scale mapping of glacial till (class TILLD-DMTN; Smith 2013) is a good representation of the extent of the Surface-Water Gley Soil Subgroups within the 1:25,000 scale locally mapped areas, then the BGS till data could be considered a good basis for mapping slowly permeable mineral soils across the UK within the area of the Anglian glaciation.

Beyond the extent of the Anglian glaciation, BGS data on the solid geology can be used to estimate the extent of slowly permeable Surface-Water Gley Soil Subgroups in a similar way to their use in the production of Soil Association maps.

An important requirement of this analysis was to:

- map those slope areas across England (that is, the non-riparian and non-floodplain areas addressed above) where tree planting is likely to give the largest hydrological benefit to flood risk mitigation, including via reduced amounts of infiltration-excess overland flow
- devise an open data layer so that the prioritisation could be made public

As peat soils (Avery 1980) with an organic layer exceeding 50cm in depth are not considered suitable for tree planting given the potential for negative impacts on carbon sequestration, this study focused on the mapping of Surface-Water Gley soils (that is, observed slowly permeable soils).

These requirements and the research hypothesis are addressed through the combination of:

[5] http://mapapps.bgs.ac.uk/geologyofbritain/home.html

- digital map data on surficial and solid geology at 1:50,000 scale developed by BGS (DiGMapGB-50; Smith 2013)
- the intellectual input of Lancaster University researchers evaluating the prediction of Soil Series comprising the Surface-Water Gley Major Soil Group in at 6 test areas of England where detailed 1:25,000 scale Soil Series mapping has taken place (emphasising regions where these soils dominate)
- the high-level spatial mapping skills and experience of JBA Consulting researchers to produce the spatial datasets for internal evaluation, and separate publically released datasets (following agreements with BGS and the Environment Agency)
- the resources of the Environment Agency's WWNP programme

The following sections discuss:

- the dataset on which the model is based
- the analytical methodology used
- the presentation and review of the model evaluation
- the implications of the new model for the location and extent of prioritised areas for woodland planting across England

A.2.1.2 Use of IPR-free data for the first time for slowly permeable soils

The spatial dataset to be used for the new model is the Digital Geological Map of Great Britain 1:50 000 scale (DiGMapGB-50) data, version 7.22, Tile EW150_Dinas Mawddwy, published by BGS on 15 April 2013. BGS has given permission for the 100m × 100m gridded version of these data to be released publicly.

A.2.1.3 Six stage experimental strategy

Stage 1: Selection of 6 test areas for evaluation of model based on BGS data

To test the model's ability using BGS data to predict the location of slowly permeable Soil Subgroups (excluding peat), 6 test areas each 10km × 10km were used. These areas are selected 1:25,000 Soil Series maps developed from detailed field survey by the Soil Series of England and Wales.

Most areas of slowly permeable soil are located north of the southern extent of the Anglian glaciation, with a particularly high coverage in north-west England. As a consequence, 3 of the 6 selected test areas are in north-west England. Different parent materials may be responsible for the presence of slowly permeable soil in eastern England, and so a test area in this region was included. South of the southern extent of the Anglian glaciation, the extent of slowly permeable soil is more likely to be associated with the solid geology, given a more limited extent of slowly permeable surficial deposits. As a result, 2 further test areas in south-west England were selected that were beyond the extent of the Anglian glaciation. The selected test sites are follows.

Test areas in north-west England

- Test Area 1: NY56 Brampton (Cumbria III) 1:25,000 Soil Series Map
- Test Area 2: NY53 Penrith (Cumbria I) 1:25,000 Soil Series Map
- Test Area 3: SD58 Sedgwick (Westmoreland I) 1:25,000 Soil Series Map

Test area in eastern England

- Test Area 4: SK99 Kirton in Lindsey (Lincolnshire VI) 1:25,000 Soil Series Map

Test areas below extent of Anglian glaciation (south-west England)

- Test Area 5: SU03 Wilton (Wiltshire I) 1:25,000 Soil Series Map
- Test Area 6: SS30 Holsworthy (Devon IV) 1:25,000 Soil Series Map

Stage 2: Digitise the areas slowly permeable soils within the 6 test areas

All the slowly permeable Soil Subgroups within each test area were identified. The boundary of these areas with soils not within this category were digitised.

Stage 3: Qualitative comparison of modelled and observed slowly permeable soils

The initial visual comparisons of model with observed data for the 6 test areas were later expanded in southern England to involve other visual comparisons. In southern England , 5 additional Soil Series of England and Wales Soil Series maps were examined with reference to the solid geology.

Stage 4: Discretisation (vector to raster conversion) of each test area prior to quantitative analysis

To provide a grid for quantitative comparison of the model based on BGS data with the observed extent of slowly permeable soil, each test area was divided into 100m × 100m squares (giving 10,000 cells per test area).

Stage 5: Quantitative comparison of modelled and observed slowly permeable soils

Quantitative evaluation of the predictive capability of the model was made for the 6 test areas. For each of the 10,000 cells associated with each test area, the area associated with slowly permeable soils was calculated using ArcGIS for both the selected Soil Subgroups and the modelled BGS data. The 2 map layers associated with each test area were compared as follows:

- Stage 5.1: Calculate the percentage capture of the **presence** of slowly permeable soil by the model.
- Stage 5.2: Calculate the percentage capture of the **absence** of slowly permeable soil by the model.
- Stage 5.3: Calculate the total capture (**presence and absence**).

The 'capture' is the percentage match by test area between the model and observed data.

For these percentages to be calculated, it was assumed that for a cell to be labelled as containing slowly permeable soil **at least 5%** of any 100m × 100m cell must be classified as slowly permeable. To take into account the uncertainty in the prediction of slowly permeable soils and to investigate the optimal predictive capability for the model, these steps were repeated using different degrees of predicted (modelled) presence; that is, for each 100m × 100m cell, the threshold area used in a binary sense to represent presence of modelled slowly permeable soils was varied from 1% to 95%. This enabled the percentage of modelled slowly permeable soil presence giving the best fit to the observed data to be determined. Separate treatment of presence and absence was required to prevent spurious results where test areas had very high coverage of slowly permeable soils (or in contrast a very high coverage of well-drained soils) that may allow a poor model to achieve a high overall percentage capture.

Stage 6: Comparative evaluation of the SPR>50 model

As a comparison to the fit of the model, the degree of fit of the SPR>50 model to the Soil Subgroups classified for the analysis as slowly permeable was made. This was carried out for all test areas in the same way as the calculations in Stage 5. A qualitative comparison of the SPR>50 model predictions with the observed data was also made for the additional Soil Series of England and Wales areas of Stage 3.

A.2.1.4 Results: Evaluation of model based on BGS data for each of the 6 test areas

Each of the 6 test areas is evaluated in turn below. For each digitised test area, the map of slowly permeable soils is presented followed by a figure showing the performance of the model in terms of percentage capture (defined under Stage 5). Finally, there is a short discussion of the measures of model performance and deficiencies in the model based on the visual comparisons of the first 2 figures.

After evaluating the results for the 6 individual test areas, the quantitative model performance for the test areas affected by glacial till was combined and presented, as were those data for the region beyond the Anglian glaciation.

A summary of the results from Stages 5 and 6 of the evaluation for each test area is presented in Table A.2.1.

Table A.2.1 Summary of results (overall performance at base)

Test site	Geology datasets relevant in model	Capture of slowly permeable soils using new model	Capture of slowly permeable soils using SPRHOST >50%	Summary of model
NY56 Brampton	Superficial 50,000, presence of till–diamicton	Up to 70%	30%, only 6.5% area	The new model based on the glacial till (TILLD-DMTN) has a percentage capture of the location of the very slowly permeable soils present in Test Area 1 of around 60–70%.
NY53 Penrith	Superficial 50,000, presence of till–diamicton	60%	0% (no areas captured)	The new model based on the glacial till (TILLD-DMTN) has a percentage capture of the location of the slowly

Test site	Geology datasets relevant in model	Capture of slowly permeable soils using new model	Capture of slowly permeable soils using SPRHOST >50%	Summary of model
				permeable soils present in Test Area 1 of around 60%.
SD58 Sedgwick	Superficial 50,000, presence of till-diamicton	60%	0.25% (but 26% area should have slowly permeable soils)	The new model based on the glacial till (TILLD-DMTN) has a percentage capture of the location of the slowly permeable soils present in Test Area 1 of around 60%.
SK99 Kirton in Lindsey	Superficial 50,000, presence of till-diamicton	80%	80% (only location where using SPR>50 comes as close as the new model)	The new model based on the glacial till (TILLD-DMTN) has a percentage overall capture of the location of the slowly permeable soils present in Test Area 1 of around 80%.
SU03 Wilton	Bedrock geologies – Wealden mudstone and Gault mudstone solid geology (W-MDST and GLT-MDST)	Up to 90%. Reduces to 50%	12% slowly permeable soils (but only 3% covered by SPR>50%)	The new model based on the Wealden mudstone and Gault mudstone solid geology (W-MDST and GLT-MDST) has a percentage overall capture of the location of the slowly permeable soils present in Test Area 1 of around 90%.
SS30 Holsworthy	Bedrock geologies – pelo-stagnogley soils (Tedburn) and cambic stagnogley soils (Brickfield, Hollacombe)	Up to 70%	25% (tends to predict the opposite of the Soil Series of England and Wales Soil Maps)	The new model based on the Crackington formation mudstone and siltstone and Bude formation mudstone and siltstone (CKF-MDSI and BF-MDSI) has a percentage capture of the location of the slowly permeable soils present in Test Area 1 of around 50-70%.
Northern sites based on superficial geology		**68%**		**Recommend threshold of 40%**
Southern sites based on bedrock geologies		**75%**		**Recommend threshold of 45%**

Test Area 1: NY56 Brampton (Cumbria III) 1:25,000 Soil Series Map

The observed slowly permeable Soil Subgroups (and related Soil Series) included in this test area are:

- stagnogley soils (Clifton)
- alluvial gley soils (Dolphenby Soil Series)
- sandy gley soils (Plumbton Soil Series and Acaster Malbis Soil Series)
- cambic gley soils (Greengill Soil Series)

Maps of the digitised observed slowly permeable soils and the till model predicted slowly permeable soils are shown in Figures A.2.1 and A.2.2 respectively.

The proportion of the test area covered by the soils listed above is 55%, and 58% of the area is covered by glacial till (TILLD-DMTN). The spatial pattern of the till and slowly permeable Soil Subgroups of the Surface-Water Gley are a remarkably similar. The model based on the 1:50,000 scale BGS data captures slightly more of the region (that is, contiguous areas of till are slightly larger than contiguous areas of slowly permeable soil); see, for example, the area to the north of Walton hamlet (Figure A.2.1). Note that the ~1km^2 area of peat soil north-east of Walton (the white area) is, correctly, not included in the model. Note also that the river terrace deposit, alluvium and glacio-fluvial deposit on the surficial geology map along King Water ('curvilinear white area' north-east of Walton) are correctly not included in the model.

The model based on the glacial till (TILLD-DMTN) has a percentage capture of the location of the slowly permeable soil present in Test Area 1 of around 60–70% (Figure A.2.4).The optimal model – in terms of predicting presence and absence – captures 65% of the area of slowly permeable soil, using a threshold for till presence of 65%.

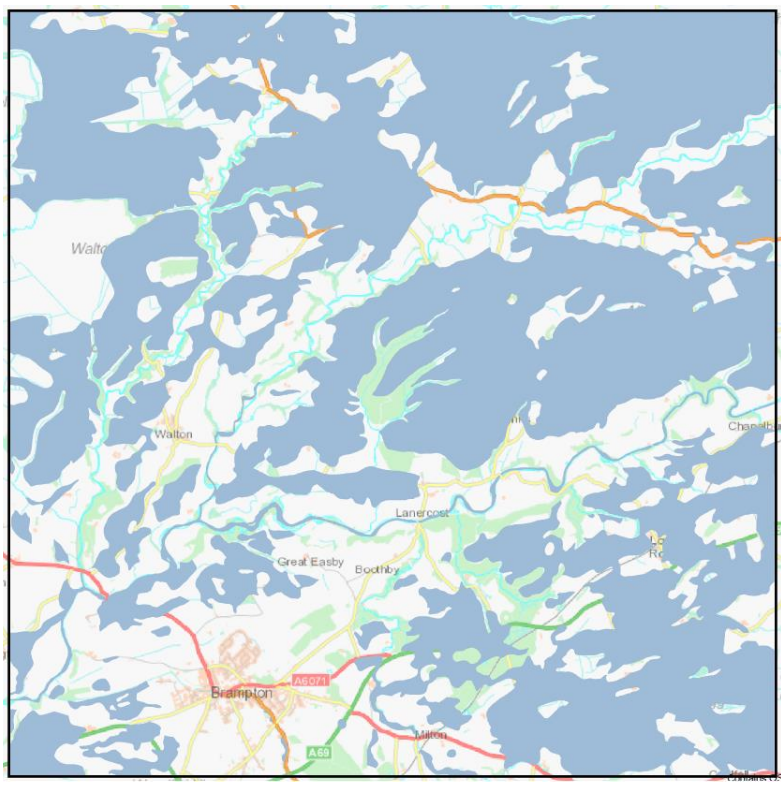

Figure A.2.1 Digitised observed slowly permeable soils – Brampton test area

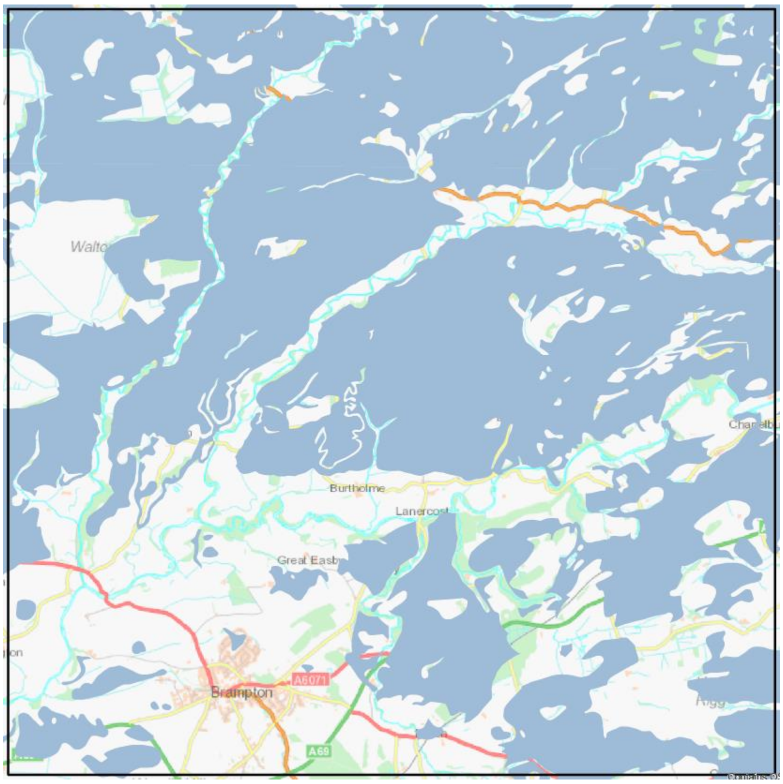

Figure A.2.2 Till model predicted slowly permeable soils – Brampton test area

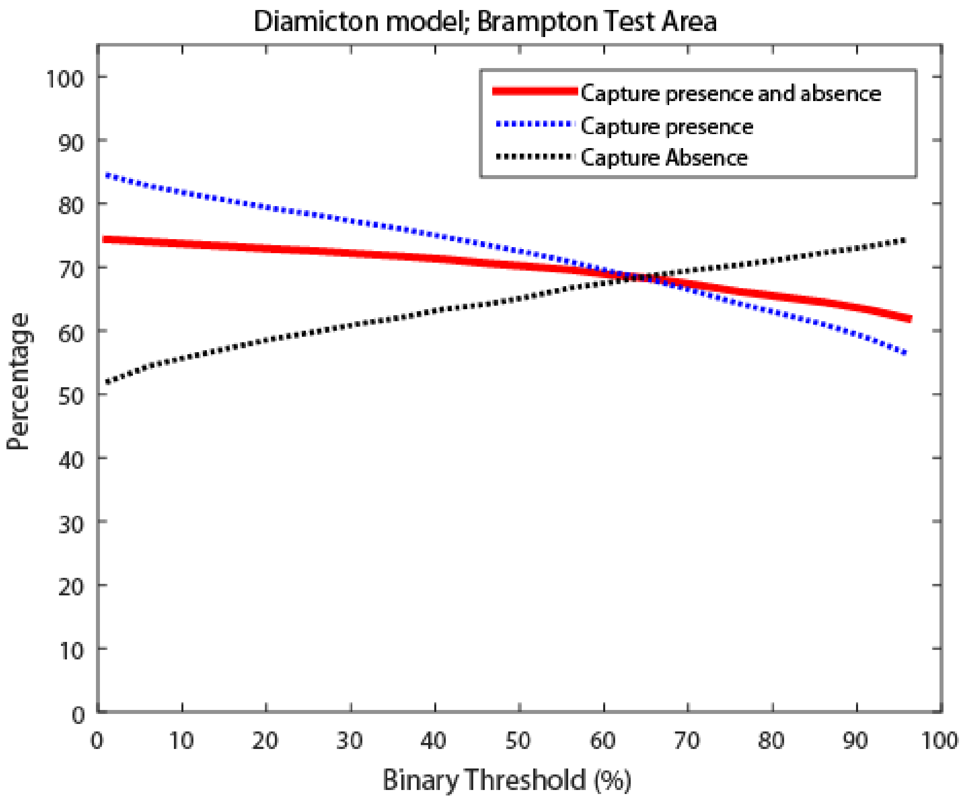

Figure A.2.3 Till model capture of slowly permeable soils for the Brampton test area

Test Area 2: NY53 Penrith (Cumbria I) 1:25,000 Soil Series Map

The slowly permeable Soil Subgroups (and Soil Series) included in this test area are:

- stagnogley soils (Clifton; Salop)
- pelo-stagnogley soils (Crewe)
- cambic stagnogley soils (Brickfield)
- cambic stagnohumic gley soils (Wilcocks)
- argillic stagnogley soils (Blackwood)
- humic sandy gley soils (Isleham)

Maps of the digitised observed slowly permeable soils and the till model predicted slowly permeable soils are shown in Figures A.2.4 and A.2.5 respectively.

The proportion of the test area covered by these soils is 27%, and 52% of the area is covered by glacial till (TILLD-DMTN). In the region north of Penrith, the till-based model captures almost all areas of slowly permeable soil, but also captures some adjacent soils (Figures A.2.4 and A.2.5); see, for example, the area south-east of Glassonby hamlet (in the top right of the maps) where areas of well-drained brown podzolic soil (Winskill Series) are also captured.

The model based on the glacial till (TILLD-DMTN) has a percentage capture of the location of the slowly permeable soil present in Test Area 1 of around 60% (Figure A.2.6). The optimal model – in terms of predicting presence and absence – captures around 60% of the area of slowly permeable soil using a threshold for till presence of around 85%. This reflects the general overestimation of spatial extent.

Figure A.2.4 Digitised observed slowly permeable soils – Penrith test area

Figure A.2.5 Till model predicted slowly permeable soils – Penrith test area

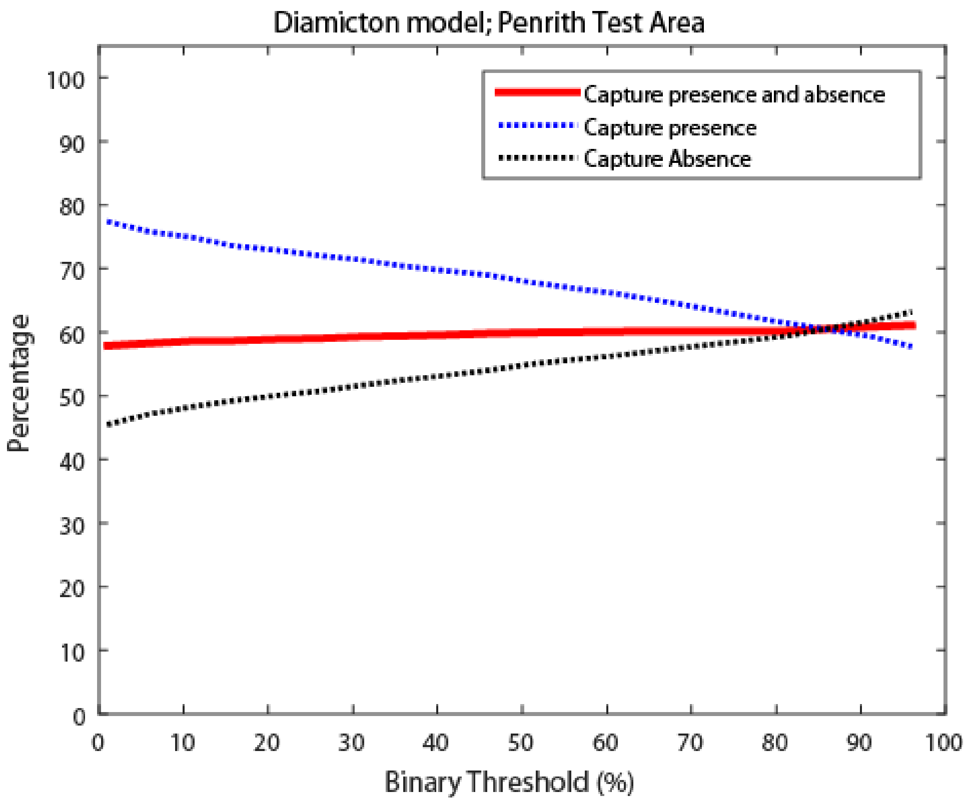

Figure A.2.6 Till model capture of slowly permeable soils for the Penrith test area

Test Area 3: SD58 Sedgwick (Westmorland I) 1:25,000 Soil Series Map

The slowly permeable Soil Subgroups (and Soil Series) included in this test area are:

- gleyed brown earths (Sannan)
- non-calcareous Surface-Water Gley soils (Cegin)
- peaty gley soils (Ynys, also called Wilcocks Series)

Maps of the digitised observed slowly permeable soils and the till model predicted slowly permeable soils are shown in Figures A.2.7 and A.2.8 respectively.

The proportion of the test area covered by these soils is 26%, while the 53% of the area is covered by glacial till (TILLD-DMTN). As with the region north of Penrith (Test Area 2), the till-based model captures almost all areas of slowly permeable soil, but also captures some adjacent soils (Figures A2.7 and A.2.8); see, for example, the area north-east of Ackenthwaite hamlet (bottom left hand corner of Figure A.2.7) where areas of well-drained acid brown earth (Denbigh Series) are developed on the till.

The model based on the glacial till (TILLD-DMTN) has a percentage capture of the location of the slowly permeable soil present in Test Area 1 of around 60% (Figure A.2.9). The optimal model – in terms of predicting presence and absence – captures around 60% of the area of slowly permeable soil, using a threshold for till presence of around 80%. This like Test Area 2 reflects the general overestimation of spatial extent.

Figure A.2.7 Digitised observed slowly permeable soils – Sedgewick test area

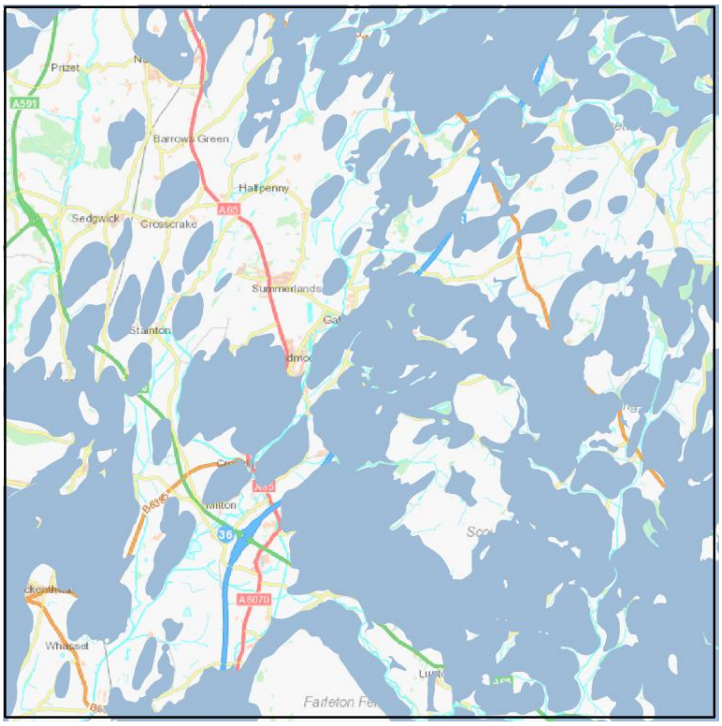

Figure A.2.8 Till model predicted slowly permeable soils – Sedgewick test area

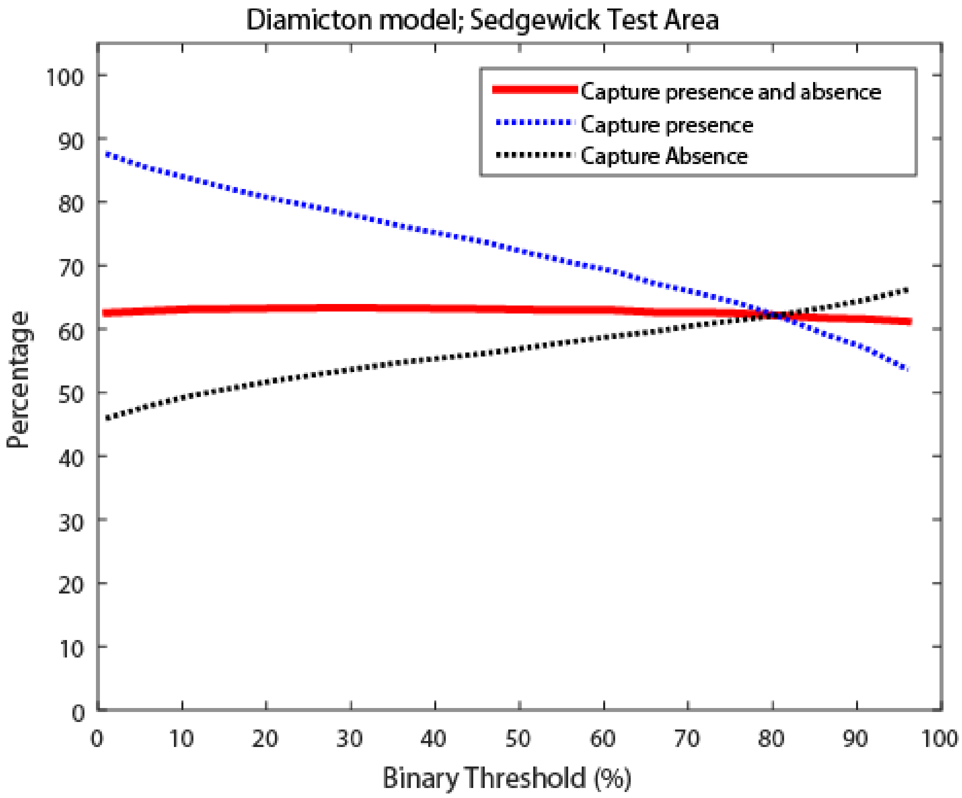

Figure A.2.9 Till model capture of slowly permeable soils for the Sedgewick test area

Test Area 4: SK99 Kirton in Lindsey (Lincolnshire VI) 1:25,000 Soil Series Map

The slowly permeable Soil Subgroups (and Soil Series) included in this test area are:

- calcareous pelosols (Haselor)
- pelo-stagnogley soils (Ragdale, Elkington, Denchworth)
- stagnogley soils (Beccles, Wickham)
- cambic stagnogley soils (Ticknall)

Maps of the digitised observed slowly permeable soils and the till model predicted slowly permeable soils are shown in Figures A.2.10 and A.2.11 respectively.

The proportion of the test area covered by these soils is 25%, while 16% of the area is covered by glacial till (TILLD-DMTN). In the south-western quarter of this test area in Lincolnshire where most slowly permeable soils are located, there is a good correspondence between model and observations. In, for example, the south-eastern quarter of the test area, pelo-stagnogley soil (Denchworth Series) has inadvertently been selected as a slowly permeable soil due to the lack of colour coding of the map. This is a Ground-Water Gley and should not have been included. Immediately south of Kirton in Lindsey, the soil map shows that stagnogley soil of the Wickham Series is developed on the steep western slopes of the Lincoln Edge. The surficial geology map shows that head deposit (HEAD-XCZSV) is developed here. Beyond this project, further analysis might explore if the soil is mapped correctly in this precise location or if head deposits should be included in the model.

Figure A.2.10 Digitised observed slowly permeable soils – Kirton in Lindsey test area

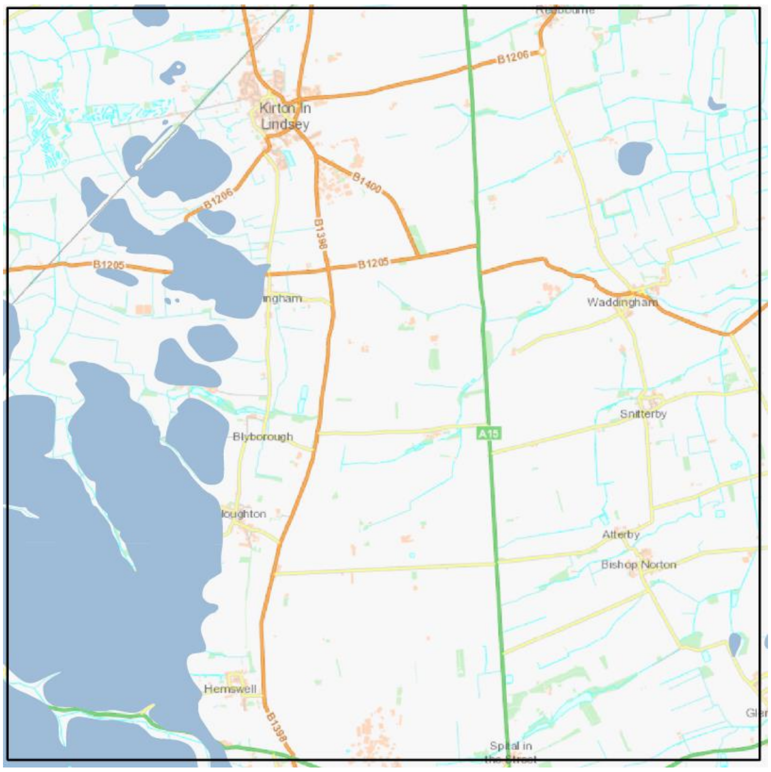

Figure A.2.11 Till model predicted slowly permeable soils – Kirton in Lindsey test area

The model based on the glacial till (TILLD-DMTN) has a percentage overall capture of the location of the slowly permeable soil present in Test Area 1 of around 80% (Figure A.2.12). This figure is primarily driven by a high capture rate for absence of slowly permeable soils which reflects their relatively low presence in the test area (25%). The optimal model – in terms of predicting presence and absence – captures around 50% of the area of slowly permeable soil, using a threshold for till presence of less than 5%. This reflects the general underestimation of spatial extent.

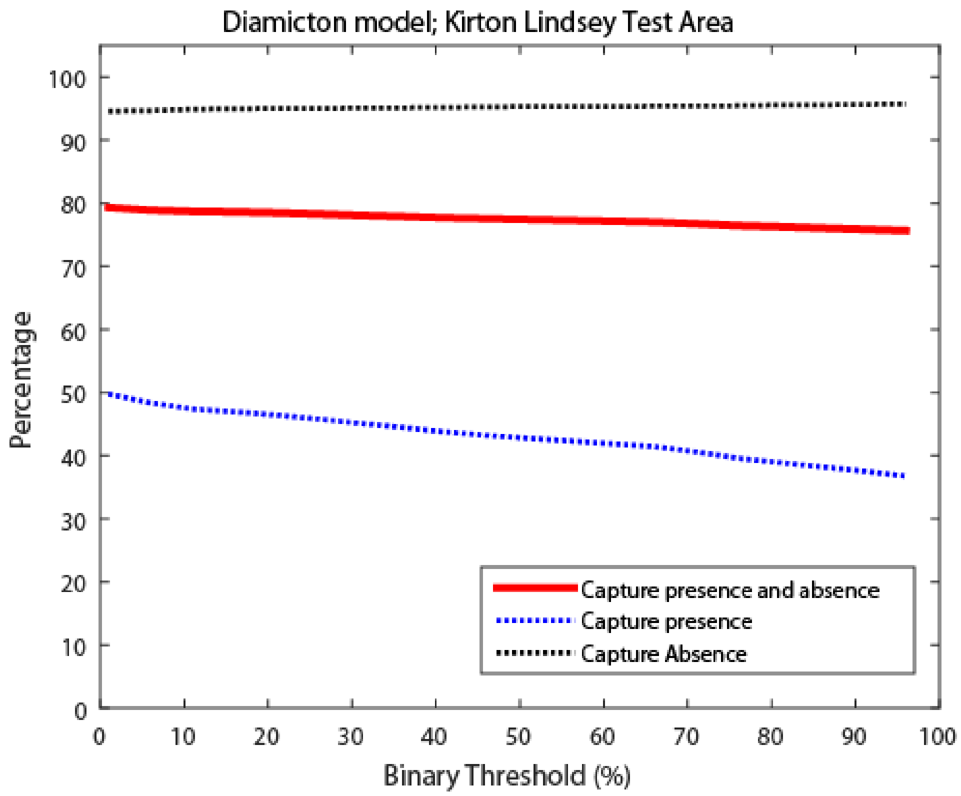

Figure A.2.12 Till model capture of slowly permeable soils for the Kirton in Lindsey test area

Test Area 5: SU03 Wilton (Wiltshire I) 1:25,000 Soil Series Map

The slowly permeable Soil Subgroups (and Soil Series) included in this test area are:

- stagnogley soils (Rowsham)
- alluvial gley soils (Wylye, Fladbury)

Maps of the digitised observed slowly permeable soils and the till model predicted slowly permeable soils are shown in Figures A.2.13 and A.2.14 respectively.

The proportion of the test area covered by these soils is 12%, while 1.2% of the area is covered by the Wealden mudstone and Gault mudstone solid geology (W-MDST and GLT-MDST). Calcareous alluvial gley soil of the Wylye Series along the river valleys was included in the classification of slowly permeable soil, in addition to the cambic stagnogley soil of the Rowsham Series (present in the south-west corner of the area). The Wylye Series was included as mottling is reported to be present at 15cm depth in the reference section (Findlay et al. 1984). This soil is, however, described as 'rendzina-like' by Findlay et al. (1984), which may mean that these soils may be very thin locally. Beyond this project, whether calcareous alluvial gley soils generate slowly permeable soils should be investigated further, as should the separate classification of clay-rich alluvial surficial deposits (present in the local valleys, but not included in the model).

There is no surprise that the W-MDST and GLT-MDST solid geology (in the south-western corner of the test region) is associated with slowly permeable soil, as the inclusion of this solid geology was based on its correspondence with these rocks and the Surface-Water Gleys on the low resolution 1:250,000 Soil Association map.

Furthermore, the extent of Surface-Water Gleys on the Soil Series of England and Wales Soil Association map was defined with reference to the underlying geology.

Figure A.2.13 Digitised observed slowly permeable soils – Wilton test area

Figure A.2.14 Solid geology predicted slowly permeable soils – Wilton test area

The model based on the Wealden mudstone and Gault mudstone solid geology (W-MDST and GLT-MDST) has a percentage overall capture of the location of the slowly permeable soil present in Test Area 1 of around 90% (Figure A.2.15). This figure is primarily driven by a high capture rate for absence of slowly permeable soils, which reflects both their low presence in the test area (12%). The optimal model – in terms of predicting presence – captures around 50% of the area of slowly permeable soil, using a threshold for the presence of the specific geology classes of less than 5%. This reflects the general underestimation of spatial extent.

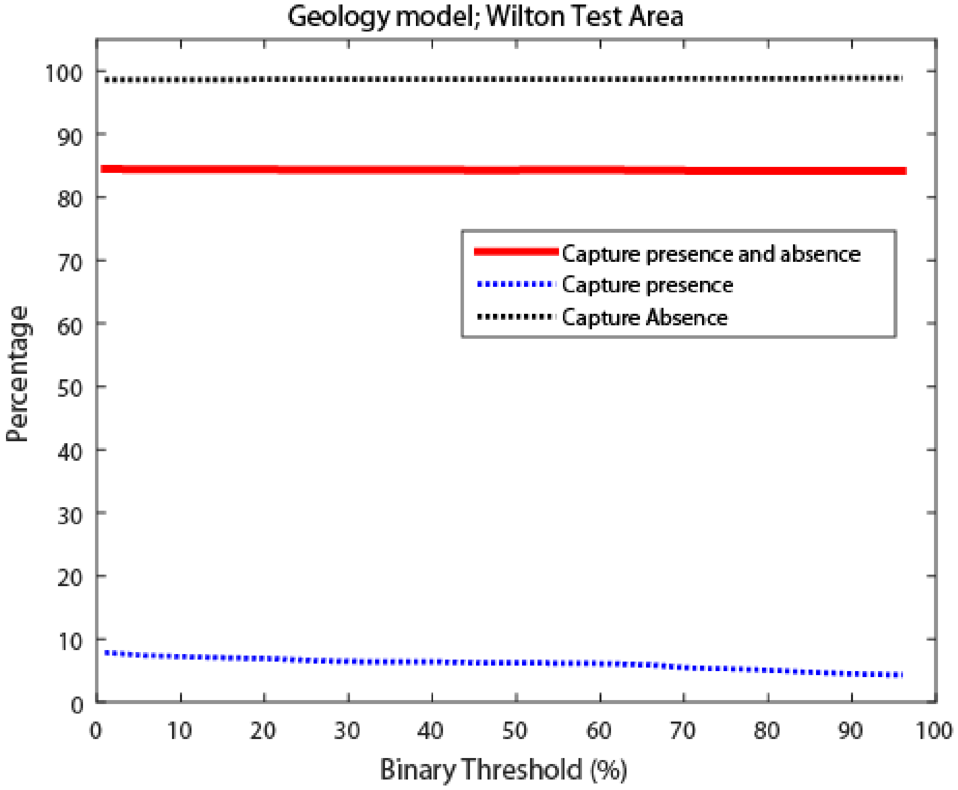

Figure A.2.15 Geology model capture of slowly permeable soils for the Wilton test area

Test Area 6: SS30 Holsworthy (Devon IV) 1:25,000 Soil Series Map

The slowly permeable Soil Subgroups (and Soil Series) included in this test area are:

- pelo-stagnogley soils (Tedburn)
- Cambic stagnogley soils (Brickfield; Hollacombe)

Maps of the digitised observed slowly permeable soils and the till model predicted slowly permeable soils are shown in Figures A.2.16 and A.2.17 respectively.

The proportion of the test area covered by these soils is 54%, while 48% of the area is covered by the Crackington formation mudstone and siltstone, and Bude formation mudstone and siltstone (CKF-MDSI and BF-MDSI). The model based on the BGS solid geology picks out the extremely patchy nature of slowly permeable soil in the Holsworthy area of Devon. It captures the large contiguous block of slowly permeable soil in the south-eastern corner of the text area.

The model based on the Crackington formation mudstone and siltstone, and Bude formation mudstone and siltstone (CKF-MDSI and BF-MDSI), has a percentage capture of the location of the slowly permeable soil present in Test Area 1 of around 50–70% (Figure A.2.18). The optimal model – in terms of predicting presence and absence – captures around 60% of the area of slowly permeable soil, using a threshold for the presence of the specific geology classes of around 45%.

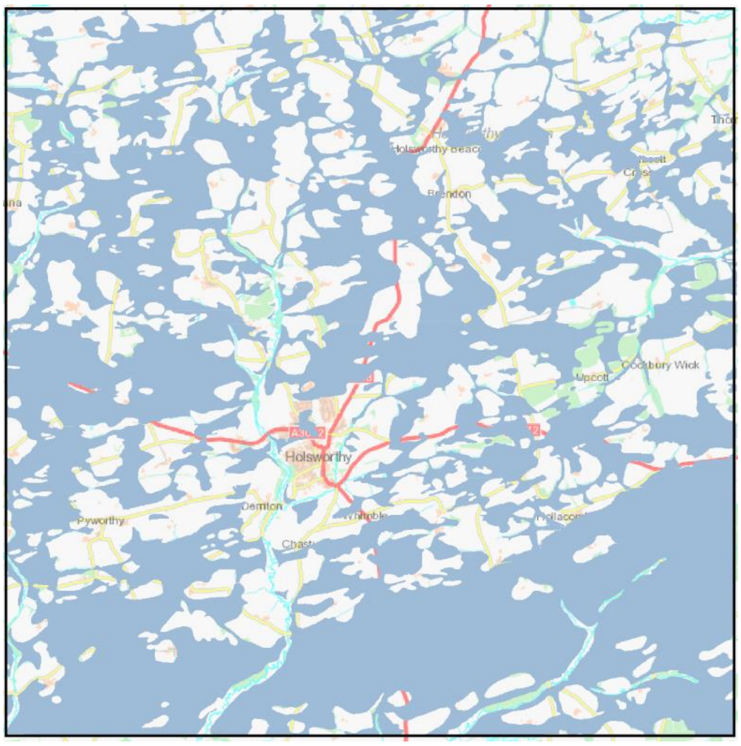

Figure A.2.16 Digitised observed slowly permeable soils – Holsworthy test area

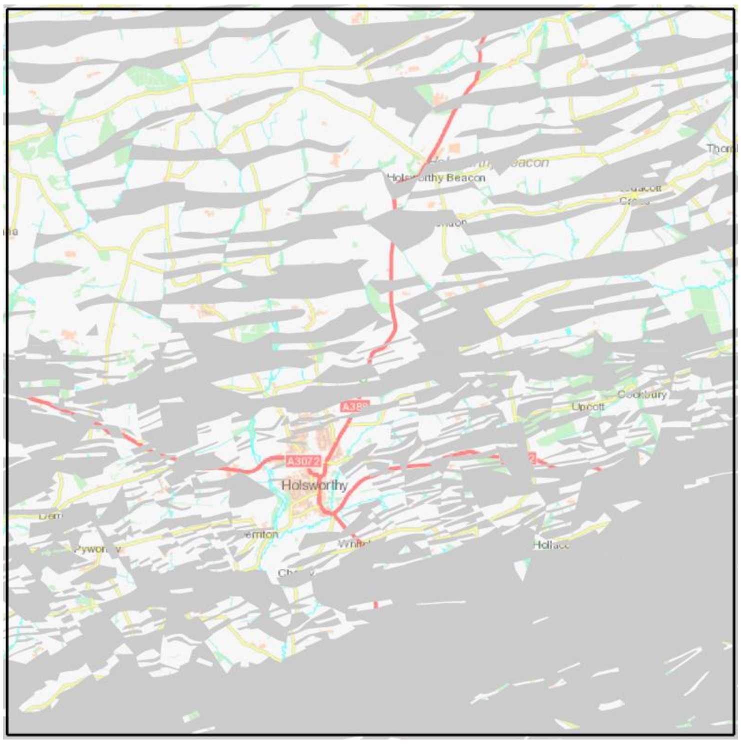

Figure A.2.17 Solid geology predicted slowly permeable soils – Holsworthy test area

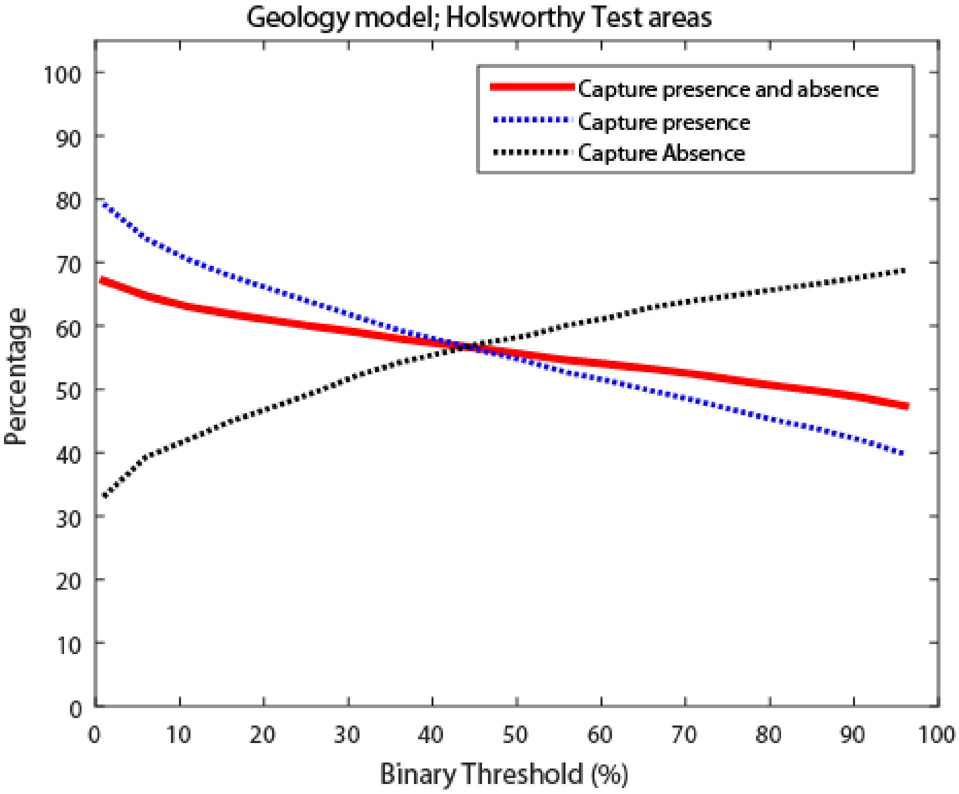

Figure A.2.18 Geology model capture of slowly permeable soils for the Holsworthy test area

A.2.2 Model performance for Test Areas 1–4 combined and 5–6 combined

The model capture of the slowly permeable soil present in all the northern test areas is approximately 68% (Figure A.2.19). The optimal overall model in terms of predicting presence and absence captures around 68% of the area of slowly permeable soil, using a threshold for till presence of around 40%.

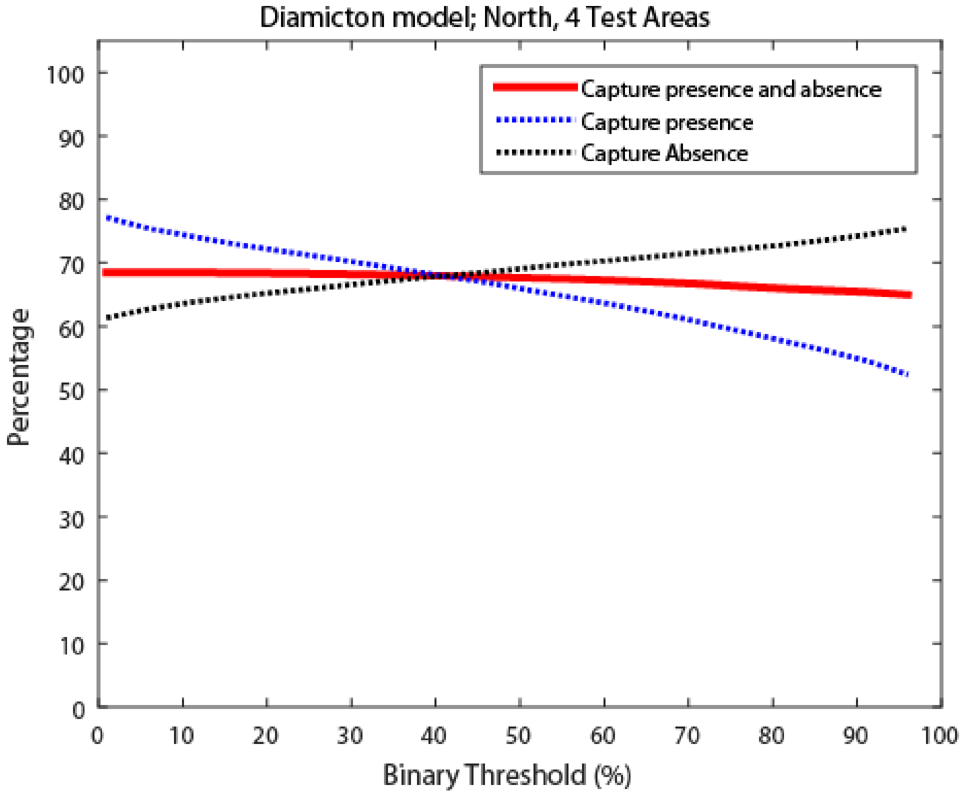

Figure A.2.19 Till model capture of slowly permeable soils covering combined Test Areas 1–4

The model capture of the slowly permeable soil present in the 2 southern test areas is approximately 70–75% (Figure A.2.20). The optimal overall model in terms of predicting presence and absence captures around 75% of the area of slowly permeable soil, using a threshold for the presence of the specific geology classes presence at very low percentages which reflects the under-prediction associated with the Wilton test area.

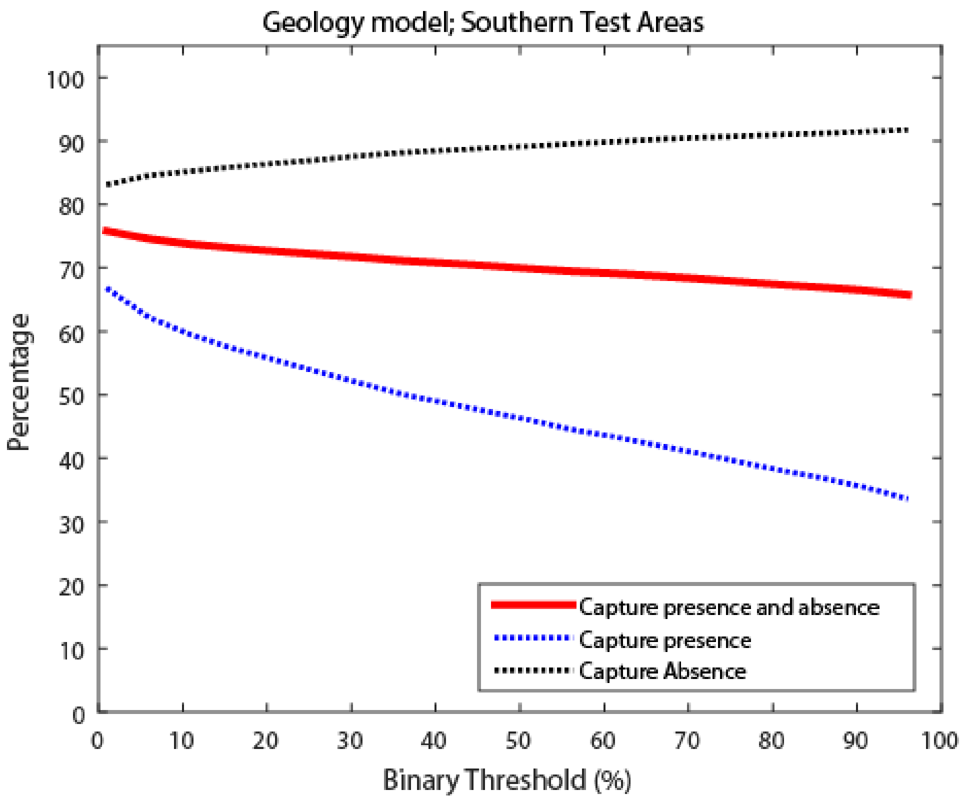

Figure A.2.20 Solid geology model capture of slowly permeable soils for covering combined Test Areas 5–6

A.2.2.1 Results: Qualitative evaluation of the solid geology model for 5 additional test areas in southern England

Additional evaluation of the model based on the selected BGS solid geology data was conducted for 5 further 1:25,000 Soil Series map areas in the area of England beyond the extent of the Anglian glaciation. These maps are:

- Bognor Regis: sheet SU90
- Farringdon: parts of sheets SU28, 29, 38 and 39
- The Lizard: parts of sheets SW 61, 62, 71, 72, 81 and 82
- Chichester: sheets SU70 and 80
- Worthing: sheets TQ00 and 10

The qualitative results for each area showed that, in general, the geology model predicted the main areas where slowly permeable Surface-Water Gleys have developed, although other soil forming factors affect the very localised distribution of these soils on those solid geologies. A few map-specific comments are as follows:

- **Bognor Regis**. There are generally consistent patterns of Surface-Water Gleys but one area is missed in the south-east corner of the map. The model correctly predicted the absence of Surface-Water Gleys where Ground-Water Gleys (that is, soils with mottling but where the upper profile is permeable) were present on the map.
- **Farringdon**. There were generally consistent patterns of the primary areas of Surface-Water Gleys, but some small areas in the central part of the

map, which are a complex mixture of Surface-Water Gleys and Ground-Water Gleys, were missing or wrongly predicted.

- **The Lizard**. Overall there was a very consistent match of the patterns of Surface-Water Gleys, but one area was missed around Penhallick village.
- **Chichester**. The main swathes of Surface-Water Gleys were captured, but there were some local patches of gleyic argillic brown earths (particularly around the Chichester urban area).
- **Worthing**. The primary strip of groundwater gleys was captured by the solid geology model.

A.2.2.2 Results: Evaluation of SPR>50 model for each test area as a comparison

As a comparison with the new model, the extent to which the national map of SPR>50 values (currently used within the Woodlands for Water layer of the original NFM maps) predicted the observed (that is, field surveyed) locations of slowly permeable Surface-Water Gleys in the 6 test areas was evaluated. Each of the 6 test areas was evaluated in turn. Below are presented the graphs showing the performance of the model in each test area. The mapped comparisons are not displayed due to licensing restrictions on the SPR>50 maps.

Test Area 1: Brampton

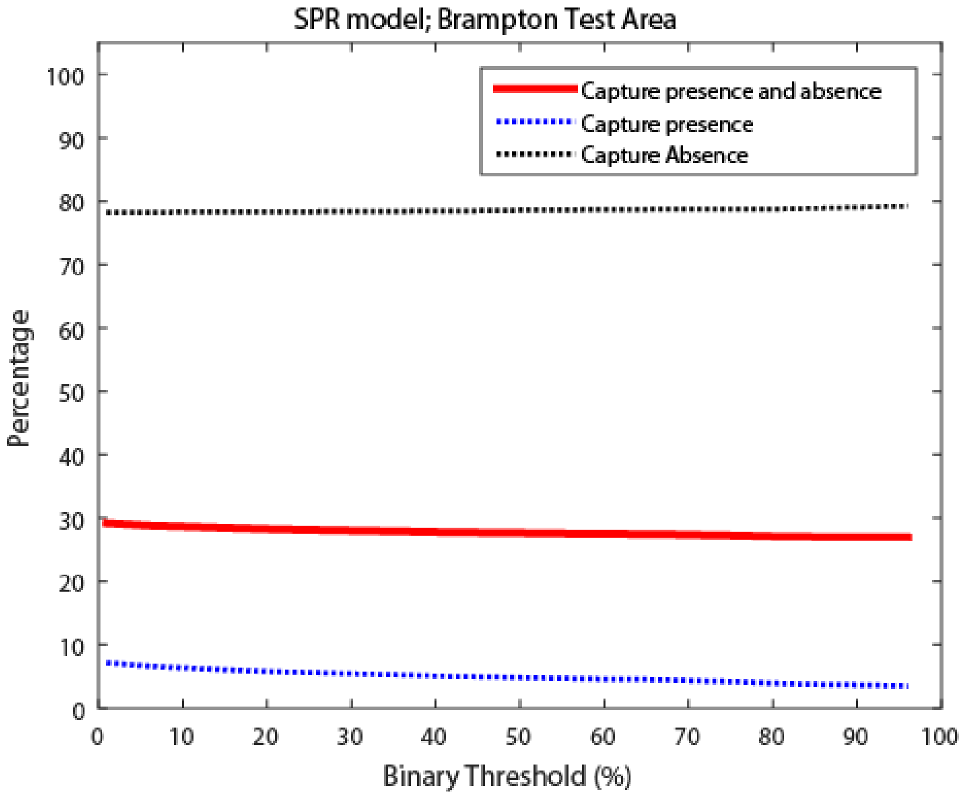

Figure A.2.21 SPR>50 model capture of slowly permeable soils for the Brampton test area

The proportion of the test area covered by these soils is 55%, while only 6.5% of the area is covered by the SPR>50 prediction. This model has a very low capture of the presence of slowly permeable soils (Figure A.2.21).

Test Area 2: Penrith

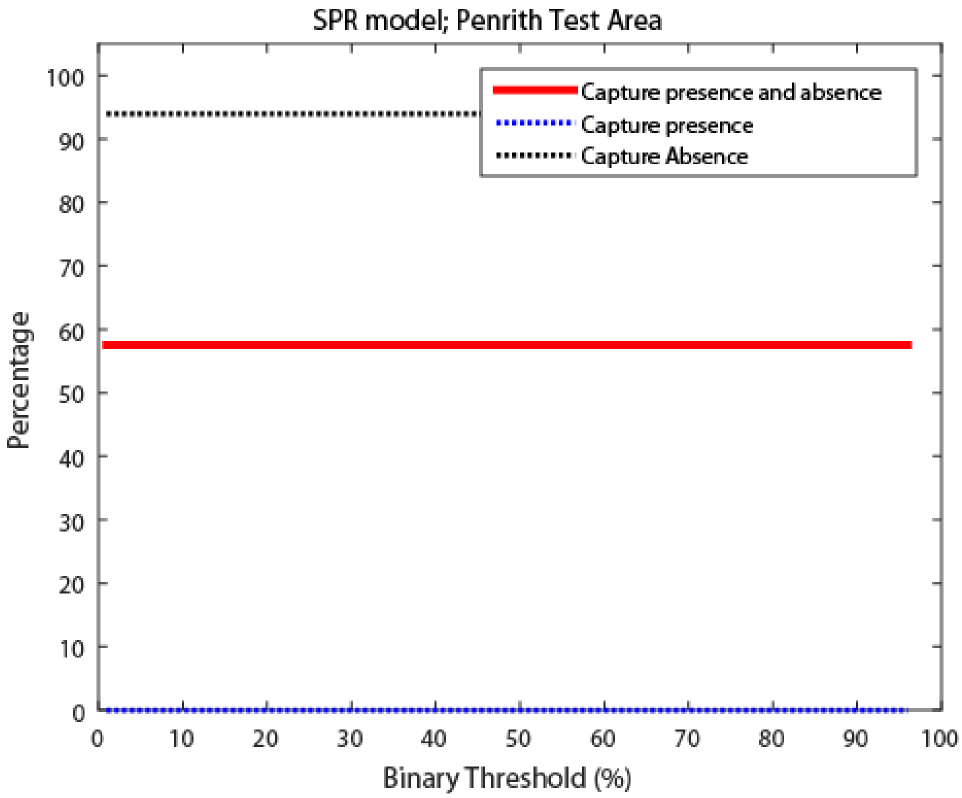

Figure A.2.22 SPR>50 model capture of slowly permeable soils for the Penrith test area

The proportion of the test area covered by these soils is 55%, while slowly permeable soils are absent using the SPR>50 prediction (Figure A.2.22).

Test Area 3: Sedgewick

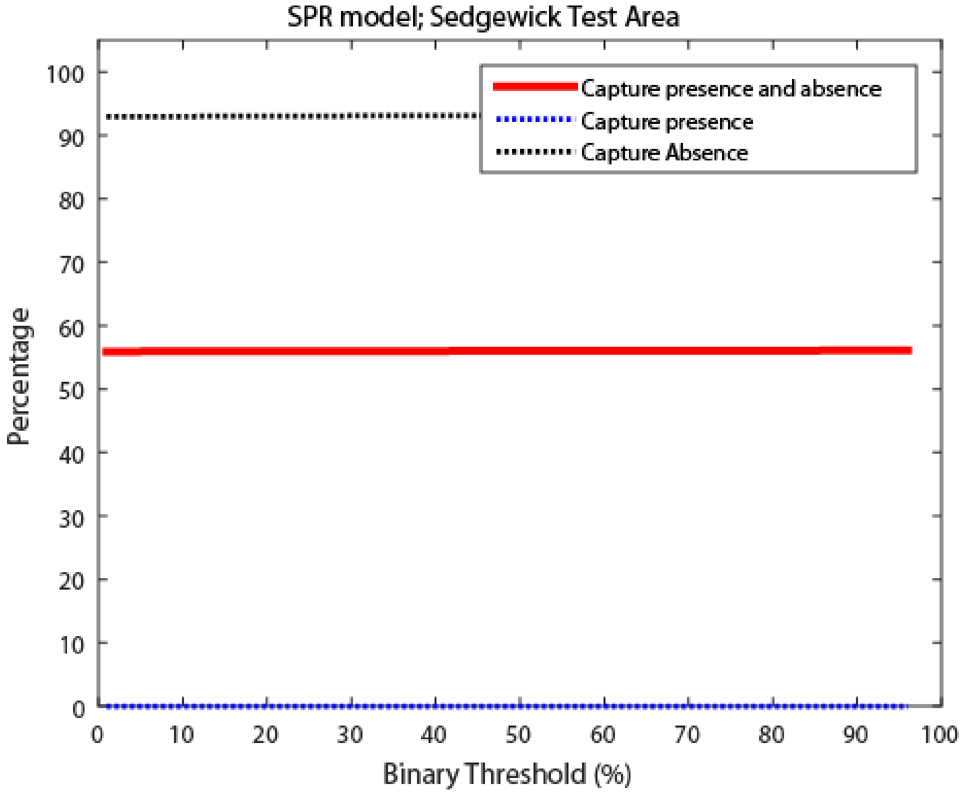

Figure A.2.23 SPR>50 model capture of slowly permeable soils for the Sedgewick test area

The proportion of the test area covered by these soils is 26%, while only 0.25 % of the area is covered by the SPR>50 prediction. This model has a very low capture of the presence of slowly permeable soils (Figure A.2.23).

Test Area 4: Kirton in Lindsey

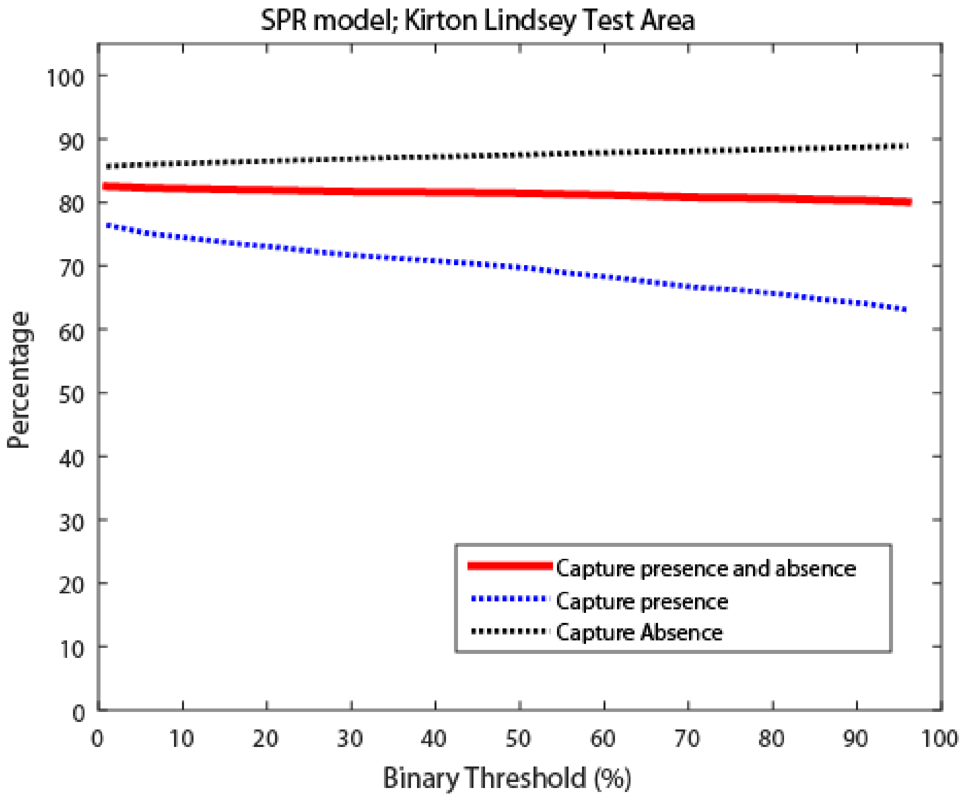

Figure A.2.24 SPR>50 model capture of slowly permeable soils for the Kirton in Lindsey test area

The proportion of the test area covered by these soils is 25%, while 30% of the area is covered by the SPR>50 prediction (Figure A.2.24).

Test Area 5: Wilton

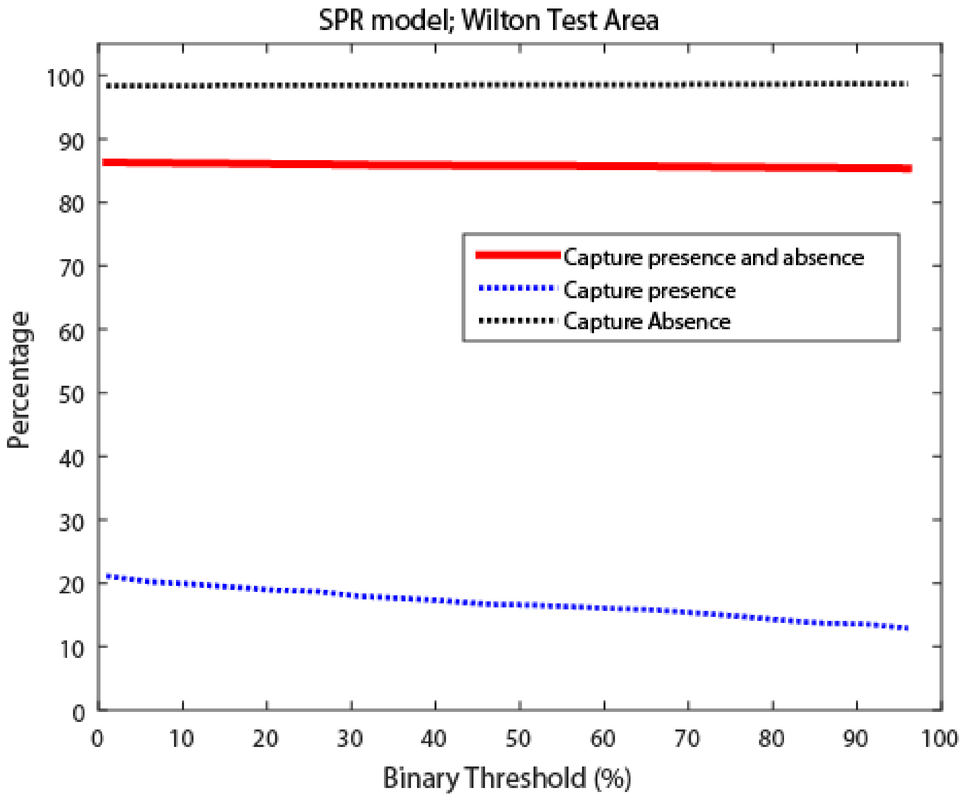

Figure A.2.25 SPR>50 model capture of slowly permeable soils for the Wilton test area

The proportion of the test area covered by these soils is 12%, while only 3% of the area is covered by the SPR>50 prediction (Figure A.2.25).

Test Area 6: Holsworthy

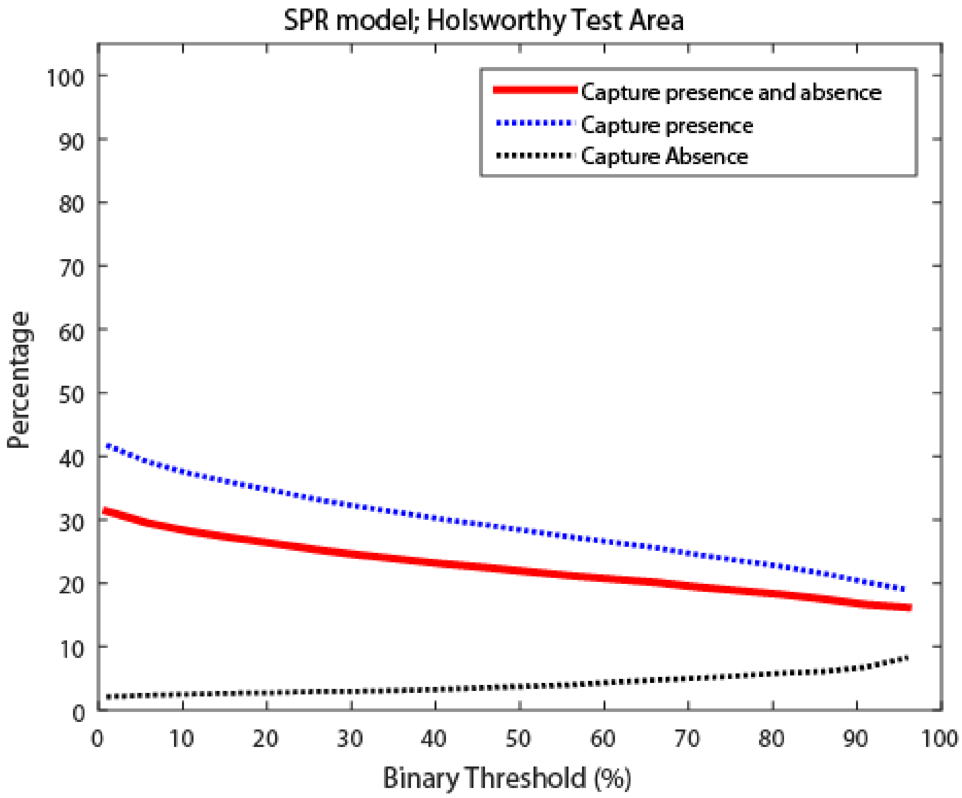

Figure A.2.26 SPR>50 model capture of slowly permeable soils for the Holsworthy test area

The proportion of the test area covered by these soils is 54%, and 45 % of the area is covered by the SPR>50 prediction. This model has a low capture of presence and absence of slowly permeable soils (Figure A.2.26), as it tends to predict the opposite pattern to the Soil Series of England and Wales Soil Series map.