Arup | SCALGO

NatureInsight

Whitepaper

Reference: Methodology, assumptions & limitations for web

| 4 July 2024

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Job number 088630-00

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1. Background

Our planet faces the existential and very real threat of a warming climate alongside a catastrophic loss of biodiversity and species. As the climate changes, so too does the frequency and intensity of extreme weather events, with costs associated with flood risk estimated to increase fifteen-fold in the UK by 2080. Simultaneously, human beings have transformed landscapes for food, energy, transport and shelter and have limited the natural capacity of landscapes to retain water, sequester carbon and enable habitats to thrive and connect to one another.

Nature-based Solutions (NbS) offer relief from these threats, with the potential to mitigate climate change, adapt to extreme events and provide restored and new habitats for plant and animal species. Planning and designing NbS can be complex and there are few established methods to enable greater uptake at the speed and scale required to combat climate change and biodiversity loss. We need proportionate and accessible tools to enable early exploration of NbS so that benefits can be identified, costs estimated, stakeholders can be brought together, landowners can be engaged, and funding can be obtained.

Arup and SCALGO have been working in collaboration to combine years of experience in designing NbS and state of the art data analysis algorithms to build a new web-based opportunity mapping and hydrological modelling software package, called NatureInsight®, that puts the design and planning of NbS in the hands of those seeking to implement schemes. NatureInsight currently covers Great Britain and allows for the assessment of ten different NbS. The tool uses several datasets in a multi-criteria analysis to assess NbS across 250m x 250m grid squares. NatureInsight can tell you how much the identified NbS will cost, how much area they will take up, and how much water they can store.

The hydrological element of NatureInsight has been designed to generate realistic design storm hydrographs within a user-defined catchment or sub-catchment area. The design storms use Parameterized eXtreme Rainfall (PXR) global data and physical catchment characteristics to produce hydrographs for design rainfall profiles. The storage volumes arising from the NbS interventions proposed in the gridded multi-criteria analysis are 'lumped' within the defined area, and where appropriate key hydraulic parameters can be dynamically adjusted to refine their design. Watersheds can be divided into sub-watersheds to explore synchronisation of peaks and to refine the output of the opportunity mapping. This process facilitates rapid optioneering to understand the potential effectiveness of a bespoke NbS scheme on reducing the flood risk at key locations, for example where there are communities at risk from flooding.

For some time, it has been known that NbS provide additional benefits when compared to traditional alternatives. NatureInsight quantifies the following benefits of implementing NbS across the analysed area:

1. Potential increase in carbon sequestration
2. Potential increase in habitat
3. Hydrological impact of increasing flood storage capacity

Accessibility, proportionality, and efficiency are the fundamentals behind this new product. It is intended to be used from early project stages right through to the outline design of schemes – at which point further tools within SCALGO can assist with increasing the detail.

2. Opportunity mapping

2.1 Introduction

The aim of NatureInsight is to produce an objective classification of the suitability of land for implementing different types of NbS intervention to mitigate flood risk, sequester carbon and enhance biodiversity. There are a range of datasets available which can help to characterise the landscape quantitatively, for example in terms of land use type or slope. A consistent spatial reference is required within which to summarise key landscape characteristics, so that areas can be objectively assessed and compared for NbS. After testing different methods, a uniform grid square with dimensions of 250m by 250m (6.25ha) was selected.

2.2 Nature-based Solutions (NbS)

The following NbS have been embedded within the tool, as described below.

2.2.1 Runoff Attenuation Features (RAFs)

Runoff attenuation features (RAFs) are man-made structures that intercept and attenuate a hydrological flow (runoff) pathway (e.g. an earth bund or machined timber 'leaky barrier'). By capturing and storing overland flow, a temporary pond or pool is formed behind the feature which then drains at a slower rate altering the peak and timing of the flood hydrograph, as demonstrated in Figure 2-1. Low bunds or other ground reprofiling can slow or divert flow to disconnect the pathways and divert them into low points, ponds, buffer zones or woodlands. Further, overland flow over bare soil or heavily poached fields can also intercept sediment and debris in the flow.

RAFs are best located in largely rural settings where the tailback of water, when full, will not affect any infrastructure. They are best suited to pasture to avoid any potential loss of crop, however, arable fields can accommodate these features near the field boundaries and within buffer strips.

Figure 2-1: Example RAFs from Belford Northumberland (© Newcastle University)

2.2.2 Floodplain Reconnection

Floodplain reconnection or offline flood storage is an approach which aims to establish a pathway between a watercourse and its natural floodplain, especially during high flows, where flood waters were previously constrained to the channel and storing additional water on the floodplain than would naturally occur.

Engineered to ensure timing of the floodplain of the intervention to benefit downstream flood impact - this could include removal/set back/breaching of embankments and excavation on the floodplain to create greater/new areas of flood storage shown in Figure 2-2. These features are therefore best located in or adjacent to the floodplain and modelled Flood Zones (in particular Flood Zone 2, between a 1 in 100 and 1 in 1000-year event), in the mid-lower catchment.

Figure 2-2: Examples of Floodplain Reconnection (left; Coatham Woods, right; Weardale) (© Environment Agency)

2.2.3 Large Woody Debris (LWD)

Placement of natural, large wood across/within the channel to slow the flow, leading to greater flow diversity and connectivity with floodplains, as shown in Figure 2-3. LWD are pieces of wood, occasionally combined with some living vegetation, that accumulate in river channels as well as on riverbanks and floodplains. LWD can occur naturally along rivers as a result of trees falling locally into watercourses through snagging of natural wood or occasionally due to beaver activity. Similar structures can also be engineered by humans to restore rivers and floodplains to slow and store flood waters. They are therefore best placed in the upper catchment, particularly through wooded areas where features such as these would more naturally occur.

Figure 2-3: Examples of Large Woody Debris (Left; Naturally arranged debris in Belford, Northumberland, photo courtesy of Newcastle University© and, right; Formalised debris dam in Pickering, North Yorkshire, photo courtesy of Arup©)

2.2.4 Soil Management

The way rural land is managed affects the pathways and speed at which rainfall enters watercourses. This is controlled by both soil health and vegetation cover. By better managing our soils, such as avoiding bare soils (including the use of over-winter stubble) or using no or low tillage cultivation methods, the macro-structure and organic matter content of soils can be improved. This results in increased infiltration and therefore reduced runoff, which may also mobilise sediments. Even simple practices such as contour ploughing, which involves ploughing and/or planting across a slope following its natural contour lines, can make a difference to runoff volumes and flow rates.

Figure 2-4: Soil management technique (left; cover crops, Bence Balla-Schottner©. Right; low tillage machinery, Visual Services-East Moline©)

These practices are generally suited to arable agricultural land but are applicable to any area of open landscape within a catchment.

2.2.5 Buffer Strips

Buffer strips are areas adjacent to rivers, which are also referred to as ditches, dykes, becks, watercourses, where woody planting or grass buffers can be created to increase roughness and slow runoff. Due to their permanent vegetation, buffer strips promote effective water infiltration and slow surface flow. They can comprise a variety of vegetation including long grasses, trees and shrubs.

Figure 2-5: Example of buffer strips (© Justin Wilkens (Unsplash))

Buffer strips are suitable in rural regions of the catchment with riparian buffer strips being located adjacent to watercourses (between 4-12 m from the bank). In-field buffer strips can also be used across fields and field boundaries in both pasture and arable fields, as shown in Figure 2-2-6. They can also contribute to sediment and nutrient management.

2.2.6 Tree Planting

Increasing tree cover has the potential to reduce flood risk by promoting soil infiltration, intercepting water on the canopy and increasing soil roughness, thus, slowing down the flow of surface runoff. The degree of benefit provided by tree planting can vary depending on the woodland, with coniferous being generally more efficient compared to broadleaved woodland. However, a mixed native woodland would provide the greatest benefits for biodiversity and carbon sequestration.

Figure 2-2-6: Example of Tree Planting ©OKrasyuk iStock

The most suitable area within a catchment is on existing pasture, where the density of planting can be between 1,100 and 2,250 trees per ha. Existing woodland and non-irrigated arable land can also be suitable as well as at a small scale or density in green urban spaces. From a runoff management perspective, tree planting is best suited to headwater catchments catchment and linking with existing woodland and hedgerows, promoting wildlife corridors and habitat connectivity, wherever possible.

2.2.7 Wet Woodland

Wet woodland is woodland located in the floodplain subject to intermittent, regular planned or natural flooding regimes. It has the capacity to slow down and hold back flood flows within the floodplain and enhances sediment deposition and thereby reduces downstream siltation. Common tree species include alder, willows and birch with sedges, ferns and mosses dominating on the ground.

It typically comprises broadleaved woodland and can range from productive woodland on drier, intermittently flooded areas to unmanaged, native, mixed wet woodland in wetter areas (as shown in Figure 2-7) and is therefore located in areas of the catchment within the fluvial floodplain or subject to surface water or groundwater flooding.

Figure 2-7: Example of wet woodland (© Kat Closon (Unsplash))

2.2.8 Peat Management

Restoring degraded peatlands to reverse the carbon emissions associated with their historic drainage. A wide variety of peat management interventions can help to restore peatlands including, converting grassland to blanket bog, converting grassland to heath, improving existing peat condition, restoration burning and cutting to reduce heather dominance, rewetting of peat, the reintroduction of blanket bog species, as well as careful management of livestock grazing, to name but a few. This also includes Grip Blocking – restoring ecological, hydrological function and the peatland carbon sink function by damming and infilling old gripping ditches.

Figure 2-8: Example of peatland management/restoration (© K Brembo (Unsplash))

This intervention is suitable in upland and lowland areas of the catchment, in areas of heath and peat as indicated in Figure 2-8.

2.2.9 Grip Blocking

Historically, areas of heath and blanket bog have been drained through the digging of ditches with the practice known as gripping. The ecological and hydrological function, as well as the peatland's carbon-sink function, can be restored by damming and infilling old gripping ditches as shown in Figure 2-9. This enables the storage of water in the headwaters and re-wets the moorland.

Grips can be blocked by creating a series of dams made from timber planks, peat, bales of heather or plastic piling. The best place for grip blocking is in the upper headwaters of a catchment, preferably along grips running in parallel to the natural slope.

Figure 2-9: Examples of grip blocking (far left © RSPB, centre © Environment Agency, far right © Moors for the Future)

2.2.10 Gully Stuffing

Erosion gullies and ravines are filled with brash (term used to describe thin upper branches) and logs to impede erosion and flow and increase infiltration see Figure 2-10. These water bodies are largely seasonal and the brash and logs reduce the impact of surface runoff and slow the flow. By positioning the brash longitudinally, sediment and debris is also captured as well as slowing the flow.

Figure 2-10: Example of Gully Stuffing (© Catherine Wright - Twitter)

This intervention is particularly useful in a steep catchment where wood extraction might be difficult as it provides some justification for management activity in areas where none might previously have been undertaken. Therefore, gully stuffing is traditionally undertaken in ditches draining woodland.

2.3 Underlying data

NatureInsight extracts key statistics from the nationally available datasets presented in Table 1, and summarises them within each 250m by 250m grid square. These 'baseline' statistics have been produced for each grid square covering the entirety of Great Britain, a total of around 3.6 million, and are analysed in a multi-criteria analysis to determine the suitability of NbS.

Table 1: Datasets used in NatureInsight

Dataset	Source	Description of use
LiDAR	Various across Great Britain (see https://scalgo.com/en-US/scalgo-live-documentation/country-specific/england-and-wales). Open data from national LiDAR programmes from the Environment Agency, Natural Resources Wales and the Scottish Environment Protection Agency are primarily used with some extensions to fill any gaps.	Elevation data is analysed to generate flow pathways, flow accumulation and slope data. Flow paths are needed to identify whether runoff-style interventions have any potential to interact with pathways. Flow accumulation is used as a 'hard-constraint' to limit the presence of interventions – too far upstream and not enough water will be generated to need certain interventions, whilst too far downstream there are certain interventions (e.g. large woody debris) that could wash away. Slope is calculated so that storage-based interventions can be ruled in if the land is flat enough for storing water.
Corine Land Cover Map (2018)	Generated using European Union's Copernicus Land Monitoring Service information; https://doi.org/10.2909/71c95a07-e296-44fc-b22b-415f42acfdf0	Land cover assessment. Each baseline land cover class is given a score based on suitability for the NbS types. Once incorporated the Copernicus Small Woody Features dataset will improve the baseline estimation of carbon sequestration from

Dataset	Source	Description of use
Small Woody Features (2018) [Due to be incorporated into NatureInsight v1.1]	Generated using European Union's Copernicus Land Monitoring Service information; https://doi.org/10.2909/7fd9d32e-8c2f-42b2-b959-c8e12b843821	woody material and will modify the suitability scoring of NbS potential – particularly over large areas of farmland where the minimum mapping unit of Corine Land Cover has failed to pick out hedgerows and small areas of woodland.
Provisional Agricultural Land Classification (ALC) (England)	Natural England	Agricultural land classification (ALC) is used to understand any limitations for the land and to help determine suitability of proposing land cover change to areas of productive farmland. The ALC characteristics of each country have been classified into a consistent approach for a Great Britain-wide assessment. Each ALC grade is scored for suitability of the various NbS interventions.
Predictive Agricultural Land Classification (ALC) Map 2	Welsh Government	
National scale land capability for agriculture	Soil Survey of Scotland Staff (1981). Land Capability for Agriculture maps of Scotland at a scale of 1:250 000. Macaulay Institute for Soil Research, Aberdeen. DOI: 10.5281/zenodo.6322683	
Priority Habitat Inventory England for North, Central and South	Natural England	Information from these datasets informs the coverage of degraded peatland across Great Britain. Openly available datasets in England, Wales and Scotland, give an indication of areas of degradation. An assumed average emissions rate is used for 'degraded' and 'non-degraded' peat across Great Britain. Any 'degraded' area of peatland is scored as higher suitability for 'Peat Management' and any areas 'non-degraded' are scored as lower suitability for 'Peat Management'
Carbon and Peatland 2016	NatureScot	
Priority Habitat Inventory Wales	Natural Resources Wales	
Flood Map for Planning (Rivers and Sea) – Flood Zone 2 and 3	Environment Agency	The coverage of flood outlines help determine suitability of different NbS interventions and helps differentiate floodplain style interventions from runoff style interventions.
Risk of Flooding from Surface Water Extent: 1 percent annual chance	Environment Agency	
River Flood Maps	Scottish Environment Protection Agency	
Surface Water Flood Maps – Medium Likelihood	Scottish Environment Protection Agency	
Flood Map for Planning Flood Zones 2 and 3	Natural Resources Wales	
Soil Texture from LUCAS	European Soils Data Centre Ballabio C., Panagos P., Montanarella L. Mapping topsoil physical properties at European scale using the LUCAS database (2016) Geoderma, 261, pp. 110-123	The Soil Texture class (from the US Department of Agriculture's soil texture triangle) is used in combination with Slope to determine suitability of Soil Management on agricultural land.
Detailed Aspect Method of Scoring (DAMS)	Forest Research (ForestGALES)	DAMS is a modelled windiness score calculated from tatter flag observations, elevation, aspect, topographic exposure, valley shape and direction. It has been used to identify areas across Great Britain where targeted tree planting would not thrive as a land cover change option.
The following datasets are not used in the multicriteria analysis, but are used for wider analysis and post-processing		

Dataset	Source	Description of use
European Soils Database v2.0	Panagos, P., Van Liedekerke, M., Borrelli, P., Köninger, J., Ballabio, C., Orgiazzi, A., Lugato, E., Liakos, L., Hervas, J., Jones, A. Montanarella, L. 2022. European Soil Data Centre 2.0: Soil data and knowledge in support of the EU policies. European Journal of Soil Science, 73(6), e13315. DOI: 10.1111/ejss.13315 Panagos P., Van Liedekerke M., Jones A., Montanarella L., "European Soil Data Centre: Response to European policy support and public data requirements"; (2012) Land Use Policy, 29 (2), pp. 329-338. doi:10.1016/j.landusepol.2011.07.003 European Soil Data Centre (ESDAC), esdac.jrc.ec.europa.eu, European Commission, Joint Research Centre	The European Soils Database is utilised to derive a high-level Hydrology Of Soil Types (HOST) dataset for the whole of Great Britain. It follows the method set out in Schneider et al. (2007) to produce a coarse representation of HOST, which is used to determine infiltration and runoff rates for watersheds within the hydrological model. (Not used for the selection of NbS features) Method paper citation: Schneider, M. K., Brunner, F., Hollis, J. M., and Stamm, C.: Towards a hydrological classification of European soils: preliminary test of its predictive power for the base flow index using river discharge data, Hydrol. Earth Syst. Sci., 11, 1501–1513, https://doi.org/10.5194/hess-11-1501-2007, 2007 (Permission obtained (June 2023) from both sets of authors to use the data and the method within NatureInsight)
Seasonal Annual Average Rainfall 2009-2019 (SAAR)	Developed by Arup using the gridded CEH GEAR rainfall dataset. Tanguy, M.; Dixon, H.; Prosdocimi, I.; Morris, D.G.; Keller, V.D.J. (2021). Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2019) [CEH-GEAR]. NERC EDS Environmental Information Data Centre. (Dataset). https://doi.org/10.5285/dbf13dd5-90cd-457a-a986-f2f9dd97e93c	SAAR 2009-2019 is used in the calculation of average baseflow for the storm hydrograph. It is a set baseflow for a given watershed and not impacted by the design storm. Baseflow is calculated as a function of SAAR and catchment area, according to the formula from FEH (1999): Houghton-Carr, H. (1999) Flood Estimation Handbook – Volume 4 – Restatement and application of the Flood Studies Report rainfall-runoff method. Available at: https://www.ceh.ac.uk/sites/default/files/2021-11/Flood-Estimation-Handbook-4-Restatement-And-Application-Of-The-Flood-Studies-Report-Rainfall-Runoff%20Method_Helen-Houghton-Carr%20version%202.pdf
Parameterized eXtreme Rainfall (PXR)	Courty, L. G., Wilby, R. L., Hillier, J. K., & Slater, L. J. (2018). Parametrized eXtreme Rainfall (PXR) (1.0.0) [Data set]. Zenodo. https://doi.org/10.5281/zenodo.1467859	Parametrized eXtreme Rain (PXR) is a dataset that simplifies the representation of extreme precipitation on a global scale. It allows the creation of Intensity-Duration-Frequency (IDF) curves. Here it has been used to determine rainfall magnitudes for any given watershed for a range of storm durations which are set to default durations of 24-hours (but can be altered) and use a Winter distribution defined by the Flood Estimation Handbook.
Living England Habitat Map (Phase 4)	Natural England	The 17 classes of habitat are matched to habitat distinctiveness classes from The Statutory Biodiversity Metric (Defra) to determine baseline habitat scores across England
Terrestrial Phase 1 Habitat Survey (Wales)	Natural Resources Wales	The 138 classes of habitat are matched to habitat distinctiveness classes from 'Phase 1 Translation Tool' within The Statutory Biodiversity Metric spreadsheet (Defra) to determine baseline habitat scores across Wales
Scotland Habitat and Land Cover Map (HLCM) 2022	Scottish Government	The 29 classes of habitat defined using EUNIS are matched to habitat distinctiveness classes from The Statutory Biodiversity Metric (Defra) to determine baseline habitat scores across Scotland – though

Dataset	Source	Description of use
		there are gaps in this dataset, which means that additional data has been used to fill any areas of missing data. The classes between EUNIS and The Statutory Biodiversity Metric are matched using: McVittie, A., Cole, L., McCarthy, J., Fisher, H., and Rudman, H. (2023) Research into Approaches to Measuring Biodiversity in Scotland, Final Report to Scottish Government.

2.4 Multi-criteria analysis

Multi-criteria analysis was undertaken by scoring the ten different NbS interventions against each of the spatial data layers in Table 1 and then applying weighting factors to derive a total score (out of 100) representing the suitability and feasibility of each intervention for any given grid cell. The higher the score, the more suitable the intervention in that specific grid square. Example lookup scores are provided in Appendix A.

These criteria enabled interventions to be evaluated against a series of spatial factors, flood risk information, typical costs and maintenance responsibilities and their contribution to ecosystem services (see Table 2). The weightings were designed to cover the most influential factors of successful NbS projects. The purpose of the weightings and lookup scores is to identify the highest-ranking NbS opportunities with, theoretically, the greatest potential to yield success and attract relevant funding sources based on the benefits likely to be achieved. The process of applying the same criteria to each of 3.6 million grid squares covering Great Britain provides an objective method of comparing different areas, which is seen as a strength of this approach.

A large proportion of the weighting factor is directed to the 'Baseline Land Cover' Criteria, as these spatial datasets provide a strong indicator for suitability of land cover change or the application of NbS interventions. 'Baseline flood potential' is the next largest weighting criteria, as the spatial movement and natural spreading of water in the landscape is what is being targeted for the potential to reduce downstream flood risk.

Financial considerations (including cost, maintenance and life expectancy), localised flooding characteristics (floodplain extent and length of runoff routes) and angle of slope (and therefore storage potential) were assigned a total Criteria Weighting based on previous work undertaken to assess appropriate weightings[1].

Table 2: Weighting parameters for the NFM Feasibility Assessment Tool

Criteria	Sub-criteria	Sub-Criteria Weighting
Storage	Slope – does the local slope restrict storage potential?	10%
Baseline flood potential	Flood extents (Flood Zone 2, 3, Risk of flooding from surface water, dry zones)	24%
	Runoff Pathway Length	6%
Economics / feasibility	Cost	1.25%
	Funding	1.25%
	Maintenance	1.25%
	Life Expectancy of intervention	1.25%
Baseline Land Cover	Land Cover	20%
	Agricultural land classification	20%

[1] River Hull Natural Flood Management Study, Hull City Council 2020.

Criteria	Sub-criteria	Sub-Criteria Weighting
Ecosystem Services – derived from the Working with Natural Processes evidence directory[2]	Flood (Fluv) – does the intervention have positive impact on fluvial flood risk reduction?	1.5%
	Flood (SW or GW) – does the intervention has positive impact on surface and/or groundwater flood risk reduction?	1.5%
	Air Quality – would the intervention lead to air quality improvement?	1.5%
	Health Access – could the intervention create greater amenity for the public thus generating improvements in terms of physical and mental health?	1.5%
	Low Flows – could intervention contribute to regulation of low flows through capture and infiltration of water?	1.5%
	Climate regulation – could intervention contribute to regulation of climate change for example through sequestration of carbon?	1.5%
	Habitat – could intervention create/enhance habitat such as wetlands and woodlands that support locally important species?	1.5%
	Water Quality – does intervention have potential to capture and/or filter our excess nutrients and sediments from farmland or other sources?	1.5%
	Cultural Activity – could intervention provide direction recreational benefit to the public such as facilitating angling by improving fish habitat?	1.5%
	Aesthetic Quality – would interventions likely provide improvement to the local landscape?	1.5%

Some parts of the multi-criteria analysis are hard constraints. For example, the DAMS layer (presented in Table 1) is used to screen-out any areas of Tree Planting where the dataset indicates a DAMS value of 16 or higher, due to the overall windiness and exposure of the site. Expert judgement has effectively hard-constrained certain NbS interventions from being selected on particular land cover types e.g. Grip Blocking will not be selected in Urban or Woodland areas (more information in Section 3.1). Flow accumulation (or upstream drainage area) reaching the NbS intervention will impact its ability to either fill with enough water (lower drainage areas) or there will simply be too much flow energy and water volume for the NbS interventions to handle given the underlying assumptions of each intervention. The rules set out in Table 3 have been developed to ensure NbS features are not selected in inappropriate areas based on upstream drainage area.

[2] EA (2017). Working with Natural Processes One-Page Summaries. https://assets.publishing.service.gov.uk/media/6036c730d3bf7f0aac939a47/Working_with_natural_processes_one_page_summaries.pdf

Table 3: Upstream drainage area-based restrictions for NbS features. Red means NbS not suitable at drainage area and green means suitable.

Area (km^2)	Runoff Attenuation Feature	Floodplain Reconnection	Large Woody Debris	Tree Plant	Wet Wood	Buffer Strip	Soil Management	Peat Management	Gully Stuffing	Grip Blocking
<0.4	Red	Red	Red	Green	Red	Green	Green	Green	Green	Green
0.4-0.6	Green	Red	Red	Green	Green	Green	Green	Green	Green	Green
0.6-1	Green	Red	Green	Green	Green	Green	Green	Green	Green	Green
1-1.5	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green
1.5-2	Green	Green	Green	Green	Green	Green	Green	Green	Red	Green
2-2.5	Green	Green	Green	Green	Green	Green	Green	Green	Red	Red
2.5-3	Green	Green	Red	Green	Green	Green	Green	Green	Red	Red
3-5	Green	Green	Red	Green	Green	Green	Green	Green	Red	Red
5-20	Red	Green	Red	Green	Green	Green	Green	Green	Red	Red
20-30	Red	Green	Red	Green	Green	Green	Green	Green	Red	Red
>30	Red	Red	Red	Green	Red	Green	Green	Green	Red	Red

Other datasets provide uplift to the scoring process where an intervention will be beneficial, for example the presence of degraded peat data within a grid square will give an uplift to the Peat Management opportunity scoring.

Soil texture data is combined with slope in grid squares to identify areas that would benefit from Soil Management interventions. The general principle of Soil Management is to increase infiltration rates into the soil where feasible i.e. where the slope is high enough to create runoff and low enough to enable hydraulic retention. Close-textured soil is more likely to generate runoff and most likely to benefit from soil management techniques such as cover crops, zero tillage farming and contour ploughing. The purpose in combining these two parameters is to help identify locations where Soil Management can have most benefit when compared alongside Buffer Strips and other NbS features.

Table 4: Score uplift (out of 100) for Soil Management for dual criteria of Slope and Soil Texture

	Slope (degrees)			
Texture (USDA)	0-2	2-5	5-9	>9
Sand	0	0	20	0
Loamy Sand	0	0	20	0
Sandy Loam	0	0	20	0
Loam	0	20	60	0
Silty Loam	0	20	60	0
Silt	0	20	60	0
Clay Loam	20	60	100	0

	Slope (degrees)			
Texture (USDA)	**0-2**	**2-5**	**5-9**	**>9**
Sandy Clay Loam	20	60	100	0
Silty Clay Loam	20	60	100	0
Sandy Clay	60	100	100	0
Silty Clay	60	100	100	0
Clay	60	100	100	0

Using lookup tables (see example in Appendix A), scores awarded to the different datasets in the multicriteria analysis, and the weighting of each criterion and percentage area of each variable, allowed NbS interventions to be ranked in priority order for each grid square. Those considered most suitable (those with the greatest score) in each grid square are then displayed as 'the Best' in NatureInsight (Figure 2-11). A score threshold can be applied within the tool to reduce or increase the number of opportunities being displayed in the map. Additionally, the top five highest scoring interventions can be explored for each grid square, if they achieve a score higher than the assigned threshold. This allows multiple options to be considered for given grid squares, which is useful in discussions with landowners or project stakeholders.

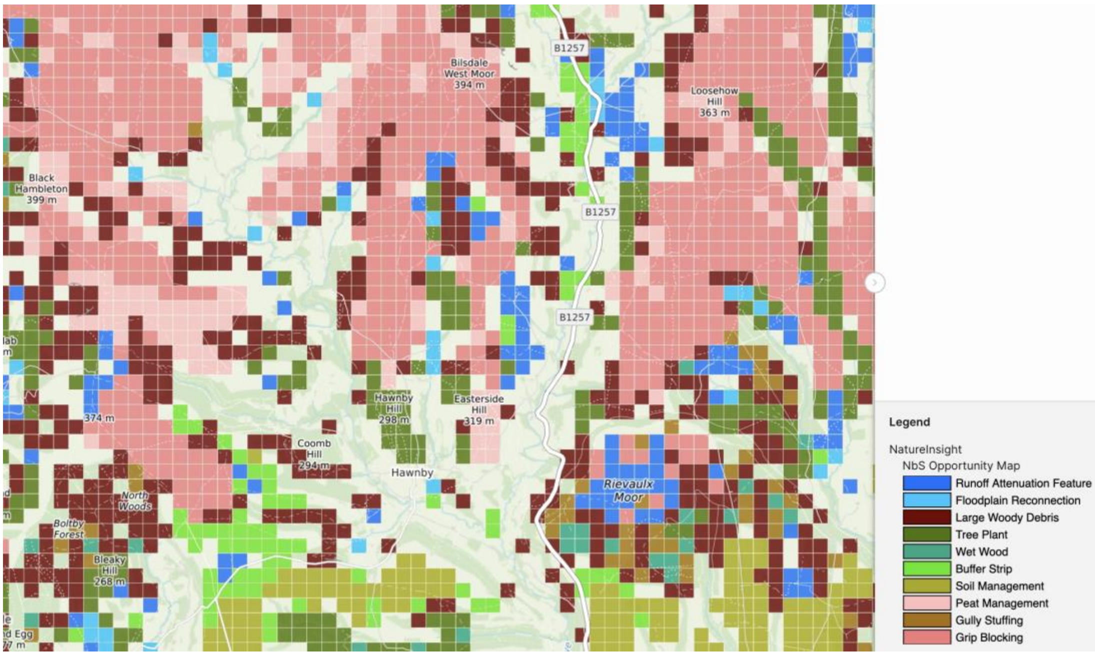

Figure 2-11: Sample NbS opportunity map in NatureInsight

Spatial data from NatureInsight is linked with carbon factors based on land use data, obtained from Natural England (2022) and habitat scores, which use part of The Statutory Biodiversity Metric from Defra (described in Section 3). This provides high-level quantitative attributes for the baseline habitats and land covers, enabling assessment of the existing condition of land and supporting informed decision-making about the impacts of future land use changes. An overview of the workflow is presented in Figure 2-12.

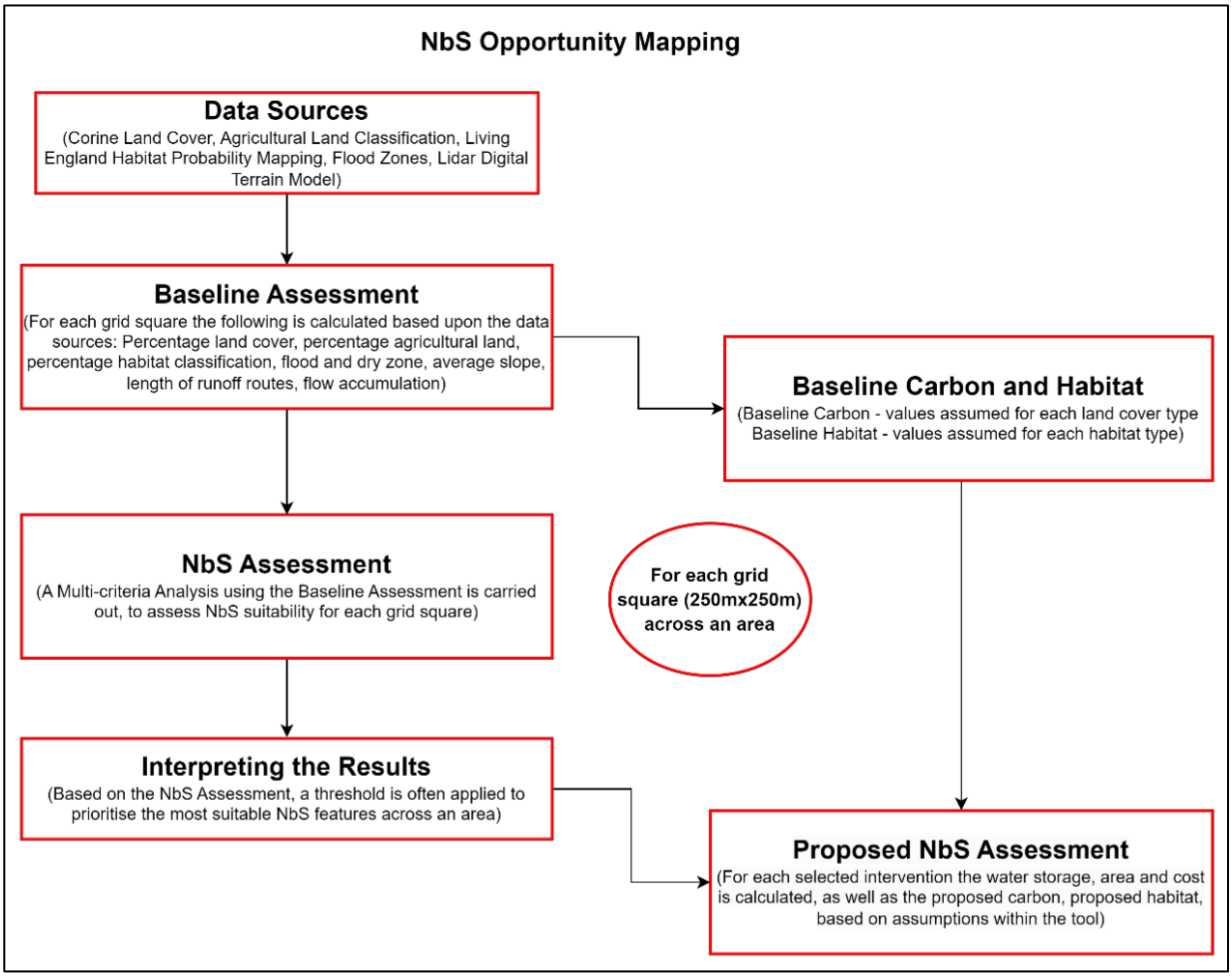

Figure 2-12: Opportunity mapping workflow used in NatureInsight

3. NbS Intervention Assumptions

High-level assumptions on intervention area, storage volume, cost, carbon sequestration potential and habitat creation potential were embedded in the assessment.

3.1 Intervention Area and Storage Volumes

The overarching assumptions for each NbS intervention are outlined in Table 5. Several of the NbS interventions (tree planting, buffer strips, soil management and wet woodland) have variable properties based on the existing land cover of a grid square. For the non-variable NbS features (RAFs, LWD, etc), the properties remain the same regardless of the existing land cover of a grid square.

Table 5: Key assumptions for each NbS at a grid square scale

Intervention type	Coverage rationale within each grid square
Runoff Attenuation Features (RAFs)	1 feature per grid square. 50m x 50m = 2,500m^2 i.e. 1 RAF is 4% of a grid square. (Average depth of 0.2m for 500m^3 per RAF).
Floodplain Reconnection	1 feature per grid square. Assuming 100m-200m of river impacted (depending on floodplain width). Assuming 1 ha (10,000m^2) of land take. Assume a single feature stores 1,000m^3.
Grip blocking	Assume 16 peat or wooden dams of 0.5m high and 10m wide to store 25m^3 in each location (400m^3 in total for grid square). Spacing approximately 15m.
Large Woody Debris (LWD)	Assume LWD have impact over area of 10m by 10m, and each dam 'stores' 10m^3 water. 100m^2 is 1% of a hectare. Assume 10 dams per grid square - so 1000m^2 total area, and 100m^3 of storage per grid.
Gully Stuffing	Assume entire ditch of 250m is managed by this practice. The multicriteria analysis limits the locations that gully stuffing can be used (in areas of low flow accumulation). Assume gully stuffing provides 10m^3 storage per grid by forcing runoff to travel longer, less efficient routes towards main rivers.
Peat management	Assume 50% of grid square being converted from 'degraded' peat to 'improved' peat. Assume 3mm more effective storage in the restored peat. Over an area of 31,250m^2 (half a grid square) this equates to 93.75m^3.
Tree Planting	Variable (see Table 7). Depends on existing land cover. Assume variable relative soil storage depending on existing land cover and assuming that soil store is provided with a density of tree planting equivalent to 1,000 trees per ha. For example, tree planting on pasture (25% of the grid at a density of 1,500 trees per ha) has the potential to provide approx. 47m^3 per grid. (15,625 x 0.002) x (1,500 / 1,000)
Buffer Strips	Variable (see Table 8). Depends on existing land cover. Assume variable relative soil storage depending on existing land cover
Soil Management	Variable (see Table 9). Depends on existing land cover. Assume variable relative soil storage depending on existing land cover
Wet Woodland	Variable (see Table 10). Same assumptions as for tree planting, however, an allocation of storage is provided assuming a runoff attenuation feature (RAF) is incorporated into the location for an intervention coverage of 50% of a grid square. So, if the intervention coverage is 25% of a grid square, the storage provided by the RAF is halved.

For certain NbS interventions there is a variability on the proposed coverage within a grid cell; this is based on the existing (baseline) land cover. Several variables can change depending on the baseline land cover, including the area of the proposed intervention, the density of planting, and the cost, more detail in Section 3.2. This variability allows for certain interventions to be considered in more locations, rather than being simply included or excluded.

The 37 Corine landcover classes identified have been summarised into 12 reclassified land codes, as illustrated by Table 6. This has been done to categorise and consolidate the assumptions across the NbS features.

Table 6: Corine Land Cover Reclassification

<table>
<tr><th>Corine Land Cover</th><th>Reclassified Land Code</th></tr>
<tr><td>Continuous urban fabric</td><td rowspan="6">Discontinuous urban fabric</td></tr>
<tr><td>Discontinuous urban fabric</td></tr>
<tr><td>Industrial or commercial units</td></tr>
<tr><td>Road and rail networks and associated land</td></tr>
<tr><td>Port areas</td></tr>
<tr><td>Airports</td></tr>
<tr><td>Mineral extraction sites</td><td rowspan="3">Dump sites</td></tr>
<tr><td>Dump sites</td></tr>
<tr><td>Construction sites</td></tr>
<tr><td>Green urban areas</td><td>Green urban areas</td></tr>
<tr><td>Sport and leisure facilities</td><td>Sports and leisure facilities</td></tr>
<tr><td>Non-irrigated arable land</td><td rowspan="4">Non-irrigated arable land</td></tr>
<tr><td>Permanently irrigated land</td></tr>
<tr><td>Fruit trees and berry plantations</td></tr>
<tr><td>Complex cultivation patterns</td></tr>
<tr><td>Pastures</td><td rowspan="4">Pasture</td></tr>
<tr><td>Land principally occupied by agriculture, with significant areas of natural vegetation</td></tr>
<tr><td>Sparsely vegetated areas</td></tr>
<tr><td>Burnt areas</td></tr>
<tr><td>Agro-forestry areas</td><td rowspan="5">Woodland</td></tr>
<tr><td>Broad-leaved forest</td></tr>
<tr><td>Coniferous forest</td></tr>
<tr><td>Mixed forest</td></tr>
<tr><td>Transitional Woodland Scrub</td></tr>
<tr><td>Natural grasslands</td><td rowspan="2">Natural grassland</td></tr>
<tr><td>Moors and heathland</td></tr>
<tr><td>Bare rocks</td><td>Bare rock</td></tr>
<tr><td>Inland marshes</td><td rowspan="2">Peat bogs</td></tr>
<tr><td>Peatbogs</td></tr>
<tr><td>Beaches Dunes and Sand Plains</td><td rowspan="3">Coastal</td></tr>
<tr><td>Salt marshes</td></tr>
<tr><td>Intertidal flats</td></tr>
<tr><td>Water courses</td><td rowspan="2">Water courses</td></tr>
<tr><td>Water bodies</td></tr>
</table>

Corine Land Cover	Reclassified Land Code
Coastal lagoons	Coastal
Estuary	
Sea and Ocean	

The variability between land cover classes is outlined for tree planting, buffer strip, soil management, and wet woodland, in Table 7, Table 8, Table 9 and Table 10 respectively. These tables also show that there are several baseline landcovers that are not considered for the individual NbS interventions e.g. Soil Management on Urban areas or Buffer Strips in Woodland areas. This is a judgement on the NbS interventions and effectively provides an additional 'hard constraint' in the opportunity mapping process.

Tree planting

Table 7: Variable coverage and cost for tree planting

Existing land cover (re-classified)	Percentage of grid square adopted by intervention	Area of intervention (m2)	Density of planting (no of trees/ha)	Cost (£/ha)	m effective soil storage (compared to baseline)
Discontinuous Urban Fabric	5	3,125	50	25,000	0.004
Dump Sites	5	3,215	250	500	0.002
Green Urban Areas	20	12,500	250	1,000	0.002
Sport Facilities	10	6,250	250	1,000	0.002
Non-irrigated Arable Land	10	6,250	500	1,000	0.003
Pasture	25	15,625	1,500	3,000	0.002
Woodland	50	31,250	500	1,000	0.001
Natural Grassland	10	6,250	1,500	3,000	0.002
Bare Rock	-	-	-	-	-
Peatbogs	5	3,125	500	1,000	0.002
Coastal	-	-	-	-	-
Water courses	-	-	-	-	-

Buffer Strips

Table 8: Variable coverage and cost for buffer strips

Existing land cover (re-classified)	Percentage of grid square adopted by intervention	Area of intervention (m2)	Cost (£/ha)	m effective soil storage (compared to baseline)
Discontinuous Urban Fabric	5	3,125	1,371	0.003
Dump Sites	10	6,250	914	0.001
Green Urban Areas	5	3,125	1,371	0.0015
Sport Facilities	5	3,125	1,371	0.001
Non-irrigated Arable Land	15	9,375	914	0.002
Pasture	15	9,375	914	0.0015
Woodland	-	-	-	-
Natural Grassland	5	3,125	914	0.001
Bare Rock	-	-	-	-
Peatbogs	-	-	-	-
Coastal	-	-	-	-
Water courses	-	-	-	-

Soil Management

Table 9: Variable coverage and cost for soil management

Existing land cover (re-classified)	Percentage of grid square adopted by intervention	Area of intervention (m2)	Cost (£/ha)	m effective soil storage (compared to baseline)
Discontinuous Urban Fabric	-	-	-	-
Dump Sites	-	-	-	-
Green Urban Areas	20	12,500	600	0.001
Sport Facilities	20	12,500	600	0.001
Non-irrigated Arable Land	80	50,000	120	0.002
Pasture	75	46,875	120	0.0015
Woodland	-	-	-	-
Natural Grassland	-	-	-	-
Bare Rock	-	-	-	-
Peatbogs	-	-	-	-
Coastal	-	-	-	-
Water courses	-	-	-	-

Wet Woodland

Table 10: Variable coverage and cost for wet woodland

Existing land cover (re-classified)	Percentage of grid square adopted by intervention	Area of intervention (m2)	Density of planting (no of trees/ha)	Cost (£/ha)	m effective soil storage (compared to baseline)
Discontinuous Urban Fabric	5	3,125	50	25,000	0.004
Dump Sites	5	3,125	250	500	0.002
Green Urban Areas	20	12,500	250	1,000	0.002
Sport Facilities	10	6,250	250	1,000	0.002
Non-irrigated Arable Land	10	6,250	500	1,000	0.003
Pasture	25	15,625	1,500	3,000	0.002
Woodland	50	31,250	500	1,000	0.001
Natural Grassland	10	6,250	1,500	3,000	0.002
Bare Rock	-	-	-	-	-
Peatbogs	5	3,125	500	1,000	0.002
Coastal	-	-	-	-	-
Water courses	-	-	-	-	-

3.2 Costs

Cost estimates have been developed based on Environment Agency's 'Cost estimation for land use and run-off – summary of evidence', review of median costs of peatland restoration and Spon's 'Civil Engineering and Highways Pricing Book (2023)'. Costs for the NFM interventions were based on unit costs, built up to determine the cost per grid. Note that no optimism bias has been included, and that mobilisation and maintenance costs have been excluded. Table 11 summarises the indicative costs associated with each intervention. Breakdowns of the variable interventions: tree planting, buffer strips, soil management, and wet woodland, can be found in Table 7, Table 8, Table 9 and Table 10 respectively.

Table 11: Indicative construction cost per grid square (£) for each NFM intervention

Intervention	Area of intervention (m^2)	No of features per grid / density of tree planting (trees/ha)	COST (£)	Per	COST per grid (£)
Grip Blocking	1,667	16	2,500	km	625
Gully Stuffing	500	1	1,000	km	250

Intervention	Area of intervention (m^2)	No of features per grid / density of tree planting (trees/ha)	COST (£)	Per	COST per grid (£)
Floodplain Reconnection	10,000	1	16,500	feature	16,500
LWD	1,000	10	575	feature	5,750
Peat Management	31,250	N/A	1,026	ha	3,206.25
RAF	2,500	1	6,500	feature	6,500
Tree Planting	3,125 – 31,250	50 – 1500	500 - 25,000	ha	156.25 – 7812.5
Wet Woodland	3,125 – 31,250	50 – 1500	500 - 25,000	ha	156.25 – 7812.5
Buffer Strip	3,125 – 9,375	N/A	40 - 300	ha	12.5 – 93.75
Soil Management	12,500 – 50,000	N/A	120 - 600	ha	562.5 - 750

Note the variability in costs for tree planting, wet woodland, buffer strips, and soil management, interventions is present due to the different baseline land covers they can be applied to, and the planting density/maturity adopted in these classifications. For the remaining of NbS interventions, the baseline land cover makes no difference to the assumed average cost per grid using the EA and Spon's estimation guidance.

3.3 Carbon sequestration assumptions

3.3.1 Baseline carbon factors

The baseline level of carbon sequestration is calculated based on the CORINE Land Cover 2018 dataset. NatureInsight calculates the percentage of each land cover type in each grid cell and uses carbon factors derived from literature to determine the baseline carbon sequestration rate of a given grid square.

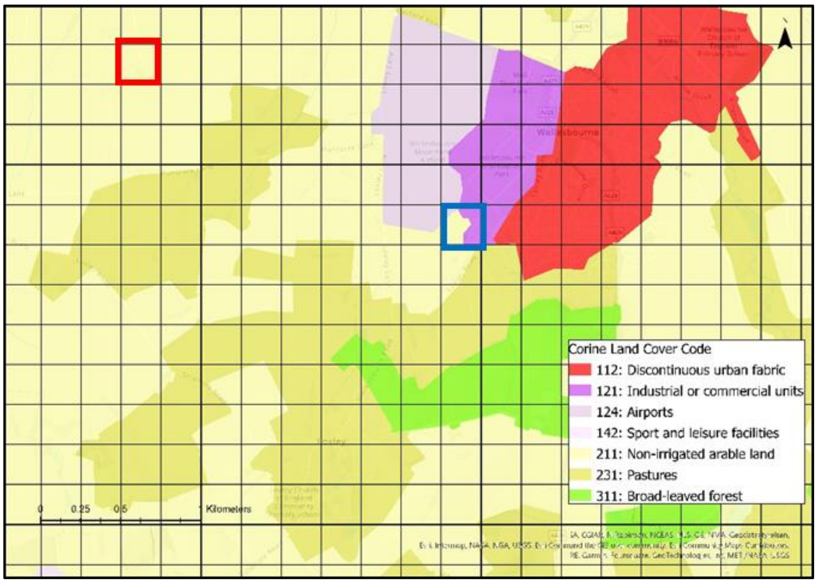

Figure 3-1: Land Cover Analysis Example

As an example, the grid square highlighted in red in Figure 3-1 is 100% 'Non-irrigated arable land,' whereas the grid square highlighted in blue will have percentage splits of 'Non-irrigated arable land,' 'Airports,' and 'Industrial or commercial units.' The land cover within each grid square adds up to 100%. The baseline carbon (in TCO_2/grid/yr) is calculated based on the land use percentages. Each land cover type has an assumed baseline carbon sequestration rate associated with it, based on a range of assumptions (see Table 12). NatureInsight uses the percentages of each land cover to calculate a baseline carbon rate for each grid square based on its land use make-up.

Proposed Carbon sequestration for the NbS interventions used the same unit values as the baseline, built up to determine the carbon sequestration per grid based on the expected number of features and expected area of each intervention (as outlined in Table 11). The baseline sequestration within each grid adopted by NbS was then subtracted proportionately to the area of proposed intervention(s).

The assumed baseline carbon sequestration potential per land-use type is defined in Table 12. The following material was used to inform the carbon sequestration assessments detailed above:

a. Natural England (2021): R Gregg, J. L. Elias, I Alonso, I.E. Crosher and P Muto and M.D. Morecroft (2021) Carbon storage and sequestration by habitat: a review of the evidence (second edition) Natural England Research Report NERR094. Natural England, York

b. Woodland Carbon Code (WCC): https://woodlandcarboncode.org.uk/standard-and-guidance/3-carbon-sequestration/3-3-project-carbon-sequestration.

Table 12: Indicative Baseline Carbon Sequestration for Corine Landcover Classifications (positive factors sequester, whilst negative factors emit)

Corine Land Cover description [and code]	Baseline Carbon Sequestration (TCO_2e/ha/yr)	Assumptions / references
Continuous urban fabric [111]	-	Assumed
Discontinuous urban fabric [112]	0.988	In line with Corine definition - "impermeable features like buildings, roads and artificially surfaced areas range from 30 to 80 % land coverage." and spot checks assume 80% land coverage. Assume 10% grassland, with natural grasslands (code 321) as a proxy 5% mixed Forest (code 313) 5% transitional scrub woodland (code 324) 80% continuous urban fabric (code 111) (CF of 0)
Industrial or commercial units [121]	-	
Road and rail networks and associated land [122]	0.338	Based on Corine land cover definition, assume 85% impermeable surfaces (CF of 0), 5% transitional scrub woodland (code 324), 10% natural grasslands (code 321)
Port areas [123]	-	Assume impermeable surfaces
Airports [124]	-	Assume impermeable surfaces
Mineral extraction sites [131]	-	Assume impermeable surfaces
Dump sites [132]	-	Assume impermeable surfaces
Construction sites [133]	-	Assume impermeable surfaces
Green urban areas [141]	2.030	Based on spot checks and Corine land cover type description, assume combination of 30% Transitional woodland scrub (code 324) (assume same as "scrub vegetation") Natural England (2022), and; 60% natural grasslands (code 321) assume same as "undisturbed semi-natural grassland", Natural

Corine Land Cover description [and code]	Baseline Carbon Sequestration (TCO_2e/ha/yr)	Assumptions / references
		England (2022); 5% continuous urban areas (code 111) assume negligible (CF 0); 5% water bodies (code 512) assume negligible or too variable (CF 0)
Sport and leisure facilities [142]	1.976	Based on spot checks, assume combination of: 10% Transitional woodland scrub 324, 10% mixed forest 313, 75% natural grasslands 321, 5% continuous urban areas 111
Non-irrigated arable land [211]	-0.29	Assume "arable land" in Natural England (2022). No differentiation given between irrigated and non-irrigated
Permanently irrigated land [212]	-0.29	Assume "arable land" in Natural England (2022). No differentiation given between irrigated and non-irrigated
Fruit trees and berry plantations [222]	3.369	Assume 50% fruit trees, 50% berry plantations for fruit trees: Assume 62% is traditional orchard (CF of 2.89) and 38% intensive (CF of 5.99) (as per Ordinance Survey Agricultural census 2006). 2.89 for traditional, 5.99 for intensive (therefore assume fruit trees CF of 4.068) For berry plantations: assume hedgerows, average of range provided (CF of 2.67)
Pastures [231]	0.36	Natural England 2022 assume same as "improved grasslands"
Complex cultivation patterns [242]	0.091	Based on Corine land cover definition, assume that this is based on the UK split of agricultural land. Assume 52% arable, 3% berry plantation and 45% pasture in line with UK agriculture split (DEFRA). Assume pasture is - "Improved grasslands" in Natural England (2022) (CF of 0.36). Assume cropped land is "land under arable" in Natural England (2022) (CF of -0.29). Assume berry plantation is equivalent to hedgerows, average of range provided (CF of 2.67)
Land principally occupied by agriculture, with significant areas of natural vegetation [243]	3.673	Based on Corine land cover definitions and spot checks assume 20% mixed forest (code 313), 15% transitional woodland scrub (code 324), 65% complex cultivation patterns (code 242) (Natural England, 2022)
Agro-forestry areas [244]	1.479	In line with the EU Agroforestry federation assume roughly 100 trees per hectare, assuming only broadleaf. Assume combination of complex cultivation patterns 90% (code 242), mixed forest 10% (code 311). Natural England (2022) and WCC
Broad-leaved forest [311]	13.966	Assume average annual sequestration over 45 years. 45 years selected based on forestry commission's statistics on age estimation of woodland in Wales. Average of highest and lowest yield class, 1.5m spacing, no thin, 40-45 years. With addition of 0.5 TCO_2/ha/yr of soil carbon. (Other than woodland ages used, assumptions here are based on those used in Natural England, 2022).
Coniferous forest [312]	12.019	Assume average annual sequestration over 35 years. 35 years selected based on forestry commission's statistics on age estimation of woodland in Wales. Average of highest and lowest yield class, 1.5m spacing, no thin, 30-35 years. With addition of 0.5 TCO_2/ha/yr of soil carbon. (Other than woodland ages used, assumptions here are based on those used in Natural England, 2022).
Mixed forest [313]	12.992	Assume 50% split of broadleaf and conifer.

Corine Land Cover description [and code]	Baseline Carbon Sequestration (TCO_2e/ha/yr)	Assumptions / references
Natural grasslands [321]	-	Natural England (2022)
Moors and heathland [322]	-0.054	Natural England (2022)
Transitional Woodland Scrub [324]	6.765	Assume average of scrub values for birch woodland and mixed ash and sycamore (7.33 TCO_2/ha/yr and 6.20 TCO_2/ha/yr) negligible. Natural England (2022)
Beaches Dunes and Sand Plains [331]	2.18	Assume same as sand dune value Natural England 2022
Bare rocks [332]	-	Assume no vegetation, therefore assume negligible
Sparsely vegetated areas [333]	0.338	Aligned with Corine land cover definition assume vegetation for 30%, assuming 25% natural grasslands (code 321), 5% transitional woodland scrub (324) and 70% bare, assume negligible
Burnt areas [334]	-	Corine land cover definition states that this is assumed to be at least a year after burning. No figures provided in Natural England for CFs post burning. Assume negligible.
Inland marshes [411]	10	Assume same as "freshwater wetlands", Environment Agency.
Peat bogs [412]	-5.566	Weighted average based on peat coverage in England, Wales and Scotland. More explanation shown below table.
Coastal salt marshes [421]	5.2	Average CF based on UK saltmarshes (Range 2.35-8.04 TCO_2/ha/yr) Beaumont et al. 2014, Natural England 2022
Intertidal Flats [423]	3.064	assume average of "natural mudflats" values (0.94-0.73 TC/ha/yr), using conversion factor of 3.67 (EPA) (3.4498-2.6791 TCO_2/ha/yr) Natural England 2022
Water courses [511]	-	Too variable and lack of scientific evidence for CFs therefore assume 0. Assumption based on Natural England paper Rivers, Lakes and wetland habitats chapter
Water bodies [512]	-	Too variable and lack of scientific evidence for CFs therefore assume 0. Assumption based on Natural England paper Rivers, Lakes and wetland habitats chapter
Coastal Lagoons [521]	-	Lack of scientific evidence for CFs therefore assume 0. Assumption based on Natural England paper section 6.2 Marine and coastal habitats.
Estuary [522]	0.3	Based on Corine land cover definition, assume same as "Estuary - subtidal deep habitat"
Sea and Ocean [523]	1.09	Assume only include sequestration rate of seafloor mud and sands (excluding possibility for seagrasses, macroalgae, reefs and other sea and ocean habitats that sequester carbon). Assume average of range (0.01-2.17TCO_2e/ha/yr)

Peatland datasets have been obtained to improve our assumptions into how peat and degraded areas of peat are dealt with in NatureInsight. Presently a single value is being assumed for all peat across England, Wales and Scotland, which will be improved using national averages for the specific parts of Great Britain, Peatlands of Wales Emissions data and assumptions on degraded peatland in Scotland and England in due course. The three sub-sections below identify what has been done at present to assume emissions/sequestration rates from Peatland in Wales, England and Scotland.

Wales:

All peat in Wales is currently assumed to have a carbon factor of **-4.67** TCO_2/ha/yr**.** This value has been calculated by using the area of Peatland by land use for each country (England, Wales and Scotland) using Table 3 (from https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapitalforpeatlands/naturalcapitalaccounts) and, using carbon factors (Table 4.3, Gregg et al., 2021[3]) for each land use type to determine sequestration/emissions rates for each land use. The national average is determined by summing the emissions and dividing by the total area of peat in the country (excluding Forest, Cropland, Domestic Fuel and Industrial Fuel land uses – to try to match the assumed Corine 412 coverage).

England:

As we do not have a breakdown of 'degraded' and 'undegraded' peat emissions for England, we will assume an average emissions rate of **-7.92** for all peat in England (calculated using the same method above).

Scotland:

As we do not have a breakdown of 'degraded' and 'undegraded' peat emissions for Scotland, we will assume an average emissions rate of **-4.97** for all peat in Scotland (calculated using the same method above).

3.3.2 Proposed Carbon Factors

The proposed carbon sequestration rate is calculated based on the baseline rates, the baseline land cover and the identified NbS intervention, see Table 13. In each case, the area changed by the intervention is proportionally subtracted from the baseline sequestration and the altered sequestration rate is added to the grid – so the proposed replaces some of the existing in most cases. In the case of new woodland planting proposed in areas of existing woodland, however, the baseline sequestration rate is simply added to by the proposed rate (as the interventions are not intended to lead to tree felling). For new tree planting on existing woodland, it is assumed that within a c. 3ha plot, thinning activities would take place to enable additional low-density planting of young trees.

As detailed in Section 3.1 some of the NbS opportunities identified have variable area coverage, dependant on the baseline land cover where the interventions are proposed. As a result, the proposed carbon sequestration potential of the interventions can vary from grid to grid (see Table 13). For the tree planting, wet woodland, buffer strips, and soil management NbS interventions, carbon sequestration estimation is based on the land cover type they are proposed on.

[3] Gregg, R., Elias J. L., Alonso, I., Crosher, I. E. and Muto, P. (2021). Carbon storage and sequestration by habitat: a review of the evidence (second edition). Natural England Research Report NERR094. Natural England, York.

Table 13: Potential carbon sequestration rates by NbS Intervention (TCO2e/grid/yr)

Corine Land Cover	RAF	Floodplain Reconnection	LWD	Tree Plant	Wet Wood	Buffer Strip	Soil Management	Peat Management	Gully Stuffing	Grip Blocking
Discontinuous urban fabric	0.174	0.697	-	0.212	0.230	0.859	-	-	-	-
Dump sites	0.174	0.697	-	1.061	1.078	1.719	-	-	-	-
Green urban	0.174	0.697	-	4.243	4.312	0.859	0.51	-	-	-
Sport facilities	0.174	0.697	-	2.121	2.156	0.859	0.51	-	-	-
Non-irrigated arable land	0.174	0.697	-	4.243	4.277	2.578	2.04	-	-	0.234
Pasture	0.174	0.697	-	31.819	31.906	2.578	1.913	-	-	0.234
Woodland	0.174	0.697	-	21.213	21.387	-	-	-	-	-
Natural grassland	0.174	0.697	-	12.728	12.763	0.859	-	-	-	0.234
Bare rock	-	-	-	-	-	-	-	-	-	-
Peatbogs	0.174	0.697	-	2.121	2.139	-	-	-12.938*	-	0.234
Water courses	-	-	-	-	-	-	-	-	-	-
Sea and Ocean	-	-	-	-	-	-	-	-	-	-

*The carbon factor for Peat Management assumes restoring from ‘Modified’ to ‘Near Natural’. The value shown above is the restoration value for all Great Britain.

[-4.14 $TCO_2/ha/yr$ x 3.125 *ha* = -12.938 $TCO_2/grid/yr$]

This value will be added to the grid square after the proportionate amount of baseline carbon sequestration (from 3.125 *ha* of the grid) has been subtracted.

3.4 Habitat assumptions

3.4.1 Baseline habitat units

The baseline habitat score is calculated in a similar way to the carbon sequestration baseline (see above). As an example, Figure 3-2 shows the grid squares over a portion of the Living England Habitat Map (Phase 4). NatureInsight calculates the percentage of each habitat in each grid cell. The calculation for each baseline habitat type is based upon an assumed distinctiveness score and an assumed condition score (explained below). These scores are multiplied together, along with the percentage cover of the habitat and the area of a grid square in hectares, to give the baseline 'habitat units' for each grid square.

Figure 3-2: Living England Habitat Map Data Output

Baseline habitat units are assessed using underlying spatial data to establish the impact to biodiversity potential interventions could have for each grid square. Several different habitat datasets have been used within the tool, based on the availability across England, Wales and Scotland. Classifications within each of these datasets have been matched to various habitat classes from The Statutory Biodiversity Metric (referenced and discussed further below), to have consistent units across the 3 countries.

The habitat units are based on The Statutory Biodiversity Metric from Defra; with distinctiveness and condition scores contributing to this metric. However, the values do not represent Biodiversity Net Gain (BNG) units, due to certain aspects of The Statutory Biodiversity Metric not being considered within the analysis (for example 'Difficulty' and 'Time to achieve condition' factors). Hence, the reference to 'habitat units' as opposed to 'BNG units.'

The habitat units have been calculated from the condition and distinctiveness scores as outlined in Equation 1.

Equation 1: Calculation of habitat units (applies for the baseline and proposed habitat scores)

$$Habitat\ Units = Baseline\ Distinctiveness\ Score\ \times Condition\ Score \times Area\ in\ hectares$$

Proposed habitat units for the NbS interventions used the same scoring metric as the baseline, built up to determine the potential habitat units per grid based on the identified NbS feature and its expected area. The baseline habitat units within each grid adopted by NbS was then subtracted proportionately to the area of proposed intervention(s).

Table 14 outlines the baseline habitat units for each habitat classification. The columns denoting each of the different habitat maps are as follows:

- (England) The ‘England A Pred Category’ column is the habitat classification as part of the Living England Habitat map.
- (Wales) The ‘Wales Phase 1 Habitat Survey code’ column is the habitat classification as part of the Phase 1 Habitat Survey Data.
- (Scotland) European Nature Information System (EUNIS) codes from Scottish Habitat and Land Cover Map (2022) have been matched to The Statutory Biodiversity Metric using the Environment and Forestry Directorate[4] for the ‘Scotland EUINS code’ column. Habitat Map of Scotland (HABMOS) data is due to be incorporated into the habitat classification for Scotland in due course.

[4] McVittie, A., Cole, L., McCarthy, J., Fisher, H., and Rudman, H. (2023) Research into Approaches to Measuring Biodiversity in Scotland, Final Report to Scottish Government (https://www.gov.scot/publications/research-approaches-measuring-biodiversity-scotland/documents/)

Table 14: Baseline habitat units for different habitat types across England, Scotland and Wales, matched with The Statutory Biodiversity Metric

The Statutory Biodiversity Metric description	Baseline Distinctiveness Score	Condition	Condition Score	Habitat Units	England A Pred Category	Wales Phase 1 Habitat Survey Code	Scotland EUNIS Code
Coastal saltmarsh - Saltmarshes and saline reedbeds	6	Moderate	2	12	Coastal Saltmarsh	H.2.6 H.2.4 H.2.3	A2
Cropland - Arable field margins tussocky	4	Condition Assessment N/A	1	1	-	J.2.3.2 J.2.3.1 J.2.2.2 J.2.2.1 J.2.1.2 J.2.1.1	-
Cropland - Cereal crops	2	Condition Assessment N/A	1	1	Arable and Horticultural	-	I1
Cropland - Horticulture	2	Condition Assessment N/A	1	1	-	J.1.1	-
Grassland - Bracken	2	Condition Assessment N/A	1	1	Bracken	C.1.2 C.1.1	-
Grassland - Floodplain wetland mosaic and CFGM	6	Moderate	2	12	-	F.2.2 F.1.1 F.1	-
Grassland - Lowland calcareous grassland	6	Moderate	2	12	-	B.3.1	-
Grassland - Lowland dry acid grassland	8	Moderate	2	16	-	B.1.1	-
Grassland - Lowland meadows	8	Moderate	2	16	-	B.2.1	-
Grassland - Modified grassland	2	Moderate	2	4	-	J.3.4 J.2.8 J.2.7 J.2.6 J.2.5 J.2.4	-
Grassland - Other lowland acid grassland	4	Moderate	2	8	-	H.8.6	-
Grassland - Other neutral grassland	4	Good	3	12	-	B.5	-
Grassland - Other neutral grassland	4	Moderate	2	8	-	J.5 B.2.2	E3 E2 NA
Grassland - Tall herb communities (H6430)	6	Moderate	2	12	-	C.3.1	E5 C.2
Grassland - Upland acid grassland	4	Good	3	12	-	-	E4 E1

The Statutory Biodiversity Metric description	Baseline Distinctiveness Score	Condition	Condition Score	Habitat Units	England A Pred Category	Wales Phase 1 Habitat Survey Code	Scotland EUNIS Code
Grassland - Upland acid grassland	4	Moderate	2	8	-	B.1.2	-
Grassland - Upland calcareous grassland	6	Moderate	2	12	-	B.3.2	-
Heathland and shrub - Bramble scrub	4	Moderate	2	8	-	-	F3
Heathland and shrub - Lowland heathland	6	Moderate	2	12	-	D.1.3 D.1.2 D.6 D.5 D.3 D.2	-
Heathland and shrub - Mixed scrub	4	Moderate	2	8	Scrub	A.2.2 A.2.1	F9
Heathland and shrub - Mountain heaths and willow scrub	8	Moderate	2	16	-	D.4	-
Heathland and shrub - Upland heathland	6	Good	3	18	-	-	F2
Heathland and shrub - Upland heathland	6	Moderate	2	12	Dwarf Shrub Heath	-	F4
Intertidal hard structures - Artificial hard structures	2	Moderate	2	4	-	J.3.5	-
Intertidal sediment - Littoral coarse sediment	4	Moderate	2	8	-	H.1.3.3 H.1.3.2 H.1.3 H.1.2.3 H.1.2.2 H.1.2.1	-
Intertidal sediment - Littoral mud	6	Moderate	2	12	-	H.1.1.3 H.1.1.2 H.1.1.1 H.1.1	-
Intertidal sediment - Littoral sand	4	Moderate	2	8	Bare Sand	-	-
Lakes - Low alkalinity lakes	6	Moderate	2	12	-	G.1.6	-
Lakes - Marl lakes	6	Moderate	2	12	-	G.2.6 G.2.5 G.2.4 G.2.3 G.2.2 G.2.1	-

The Statutory Biodiversity Metric description	Baseline Distinctiveness Score	Condition	Condition Score	Habitat Units	England A Pred Category	Wales Phase 1 Habitat Survey Code	Scotland EUNIS Code
Lakes - Moderate alkalinity lakes	6	Moderate	2	12	-	G.1.4 G.1.3 G.1.2 G.1.1 G.1	-
Lakes - Temporary lakes ponds and pools (H3170)	6	Moderate	2	12	Water	-	C
Sparsely vegetated land - Calaminarian grasslands	8	Moderate	2	16	-	H.6.5	-
Sparsely vegetated land - Coastal sand dunes	6	Moderate	2	12	Coastal Sand Dunes	H.6.8 H.6.7 H.6.6 H.6.4	B1
Sparsely vegetated land - Coastal vegetated shingle	6	Moderate	2	12	-	H.4 H.3.2 H.3.1 H.3	B2
Sparsely vegetated land - Inland rock outcrop and scree habitats	6	Moderate	2	12	-	-	H3
Sparsely vegetated land - Limestone pavement	8	Moderate	2	16	-	I.1.3	-
Sparsely vegetated land - Maritime cliff and slopes	6	Moderate	2	12	-	H.8.5 H.8.4 H.8.2 H.8.1	B3
Sparsely vegetated land - Other inland rock and scree	4	Moderate	2	8	-	I.2.4 I.2.3 I.2.2 I.2.1 I.1.5	H2
Sparsely vegetated land - Ruderal/Ephemeral	2	Moderate	2	4	-	C.3.2	-
Unclassified	0	Moderate	2	0	Unclassified	-	-
Urban - Bare ground	2	Poor	1	2	Bare Ground	-	-
Urban - Developed land; sealed surface	0	Poor	1	0	-	J.3.6	J
Urban - Vacant or derelict land	2	Poor	1	2	-	J.4 J.3.7	O
Urban - Vegetated garden	2	Condition Assessment N/A	1	1	Built-up Areas and Gardens	J.1.5	-
Wetland - Blanket bog	8	Good	3	24	-	E.1.6.2 E.1.6.1	-

The Statutory Biodiversity Metric description	Baseline Distinctiveness Score	Condition	Condition Score	Habitat Units	England A Pred Category	Wales Phase 1 Habitat Survey Code	Scotland EUNIS Code
Wetland - Blanket bog	8	Moderate	2	16	Bog	-	D1
Wetland - Blanket bog	8	Poor	1	8	-	E.4 E.1.8 E.1.7	-
Wetland - Fens (upland and lowland)	8	Moderate	2	16	-	E.3.3.1 E.3.3 E.3.2.1 E.3.2 E.3.1.1	D4
Wetland - Transition mires and quaking bogs (H7140)	8	Moderate	2	16	-	-	D2
Woodland and forest - Felled	6	Good	3	18	-	A.4.3 A.4.2 A.4.1	-
Woodland and forest - Lowland mixed deciduous woodland	6	Moderate	2	12	Broadleaved, Mixed and Yew Woodland	-	G1
Woodland and forest - Native pine woodlands	6	Moderate	2	12	-	G3.4	-
Woodland and forest - Other coniferous woodland	2	Moderate	2	4	Coniferous Woodland	A.1.2.2 A.1.2.1	G3
Woodland and forest - Other coniferous woodland	2	Poor	1	2	-	G3.F	-
Woodland and forest - Other woodland; broadleaved	4	Moderate	2	8	-	A.1.1.2 A.1.1.1	-
Woodland and forest - Other woodland; mixed	4	Moderate	2	8	-	A.1.3.2 A.1.3.1	G4
Woodland and forest - Other woodland; mixed	4	Poor	1	4	-	-	G5

The outcome of having each of the habitat scores embedded into NatureInsight is the ability to quickly understand baseline habitat units across Great Britain (see Figure 3-3). Equipped with this information, it is possible to understand the impact of the mapped NbS features upon habitat units for a given area.

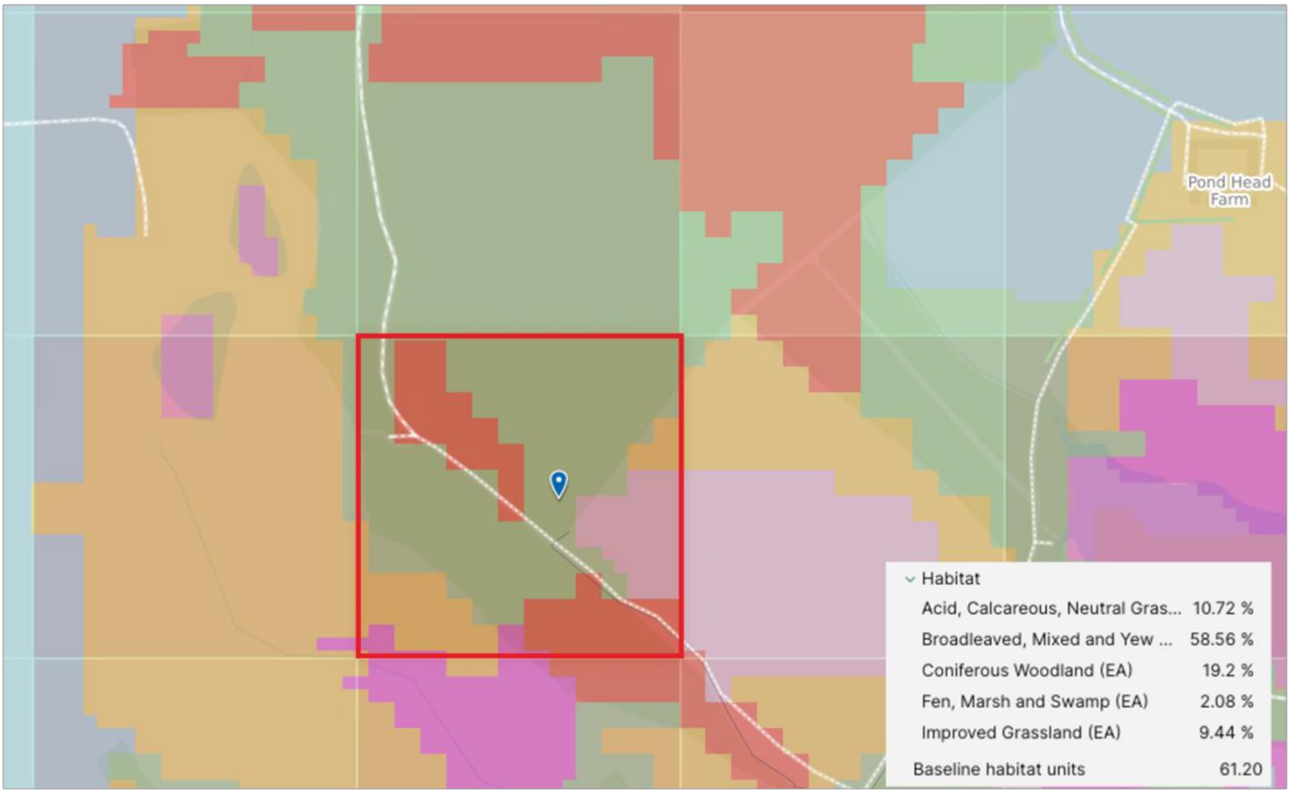

Figure 3-3: Habitat units for a grid square in NatureInsight

3.4.2 Proposed habitat units

The proposed habitat units are calculated based on the baseline habitat rate assumptions and the identified NbS intervention, see Table 15. In each case, the area changed by the intervention is proportionally subtracted from the baseline units and the altered units are added to the grid – so the proposed replaces some of the existing in most cases. There is no variability of units based upon the baseline habitat classification. The habitat score is calculated as in Equation 1.

Table 15: Potential habitat units by NbS intervention

NbS Intervention	Distinctiveness Score	Condition	Condition Score	Habitat Units (condition * distinctiveness)	Biodiversity Metric 4.0 Label
RAF	4	Fairly Good	2.5	10	Grassland – Other neutral grassland
Floodplain Reconnection	6	Fairly Good	2.5	15	Grassland - Floodplain wetland mosaic and CFGM
LWD	0	N/A	0	0	N/A
Tree Plant	6	Fairly Good	2.5	15	Woodland and forest - Lowland mixed deciduous woodland
Wet Wood	6	Fairly Good	2.5	15	Woodland and forest - Wet woodland
Buffer Strip	8	Moderate	2	16	Grassland – Other neutral grassland
Soil Management	0	N/A	0	0	N/A
Peat Management	8	Fairly Good	2.5	20	Wetland - Blanket bog
Gully Stuffing	0	N/A	0	0	N/A
Grip Blocking	8	Fairly Good	2.5	20	Wetland - Blanket bog

4. Hydrology and routing model

The rainfall-runoff approach, on which the hydrograph is based, is to be published separately by SCALGO later this year. Here, the default parameters and rainfall data used by NatureInsight are explained, so that NatureInsight users can understand the baseline assumptions behind the design hydrographs used to test water storage provided through NbS.

The aim of the hydrological component of NatureInsight is to demonstrate the effect, on river flow, of adding a selection of NbS interventions to a catchment. Each NbS intervention identified within a 250m x 250m grid square from the multi-criteria analysis is represented as a storage volume, which interacts with the hydrograph differently depending on the type of intervention. The storage assumptions for each type are described in Section 3.1. Interventions explicitly designed to store a volume of water, such as 'Runoff-type' interventions and 'Floodplain storage-type' interventions, can also be designed to interact with a hydrograph based on a set of storage parameters which users can dynamically edit within appropriate bounds. These relate to elements such as flow thresholds of the intake structures, diameters of outlet pipes, and embankment/bund height. More information on the storage model, including the three types of storage bucket and how interventions are categorised within each type, can be found in Section 4.3.

The hydrological component of NatureInsight is underpinned by the application of established (often) empirically derived methods and the use of new open spatial data, to provide a simple representation of hydrological processes within a catchment. These methods are often not industry standard in the UK, but comparisons have been made with UK industry standard techniques and individual storm events, which are presented throughout the sections that follow. This component of the tool can be used to provide a good indication of whether storage interventions installed via NbS or other types of flood storage could be useful within any ungauged user-defined catchment area, for a given storm event. Hydrographs produced using this method are not necessarily a true reflection of the hydrology in any given catchment. Currently, they may be most appropriate early in the optioneering phase of a project to develop and test ideas which may help to justify funding for further investigation and development of a business case, at which point industry standard techniques may be preferred. The hydrology tools will continue to be developed as more and better data becomes openly available.

Overall, the hydrological model deployed in NatureInsight can be described as being a spatially distributed conceptual model using simplifications based on well-known empirical formulae.

4.1 Rainfall

A rain event is specified as a depth of rain falling at a location (e.g. each raster cell) in the elevation model. In Great Britain, the SCALGO Live Digital Terrain Model (DTM) has a cell resolution of $1m^2$, with some areas having a reduced resolution (see SCALGO website[5]). The rainfall depth falling on a grid square is routed using the flow routing method described in the documentation section of the SCALGO website[6].

The calculation of peak flow at the outlet point of a catchment begins with estimation of the rainfall for a given frequency of design storm (rain) event. In the tool this is referred to as the return period of the event, where for example a 1 in 100-year event would have an Annual Exceedance Probability (AEP) of 1%. Parameters which require estimation are the total rainfall depth (mm) falling across the catchment area for the duration of the rain event, and the distribution of rainfall within the event. Rainfall is distributed both spatially and temporally. In NatureInsight, the rainfall is assumed to be distributed uniformly across the catchment area (i.e. spatially uniform) with a temporal distribution based on a design storm profile. More detail is provided on the rainfall depth, duration and temporal distribution in the sub-sections which follow.

Whilst other rainfall data has been investigated during development of NatureInsight, the following dataset has been chosen for providing the rainfall information necessary to drive the hydrological model:

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[5] https://scalgo.com/en-US/scalgo-live-documentation/country-specific/england-and-wales

[6] SCALGO (2023) *Analysis – Depression-Free Flow.* Available at: https://scalgo.com/en-US/scalgo-live-documentation/analysis/depression-free-flow (Accessed October 2023)

- Parameterised Extreme Rain (PXR)[7] – 31km resolution global dataset which allows estimation of Intensity Duration Frequency (IDF) curves

IDF curves for each grid square are readily accessible within PXR, which is the reason the PXR dataset was selected for further investigation with other, finer resolution datasets noted for future potential improvements for representing rainfall.

PXR is a global dataset which fits the extreme value distribution on the annual precipitation maxima obtained by reanalysis, to generate IDF curves for a range of 19 different event durations between 1hr and 15 days.

There are many limitations of using reanalysis rainfall data, some of which are acknowledged here:

- Climate models, from which reanalysis data are obtained, are known to be poor at representing rainfall extremes. Therefore, summer rainfall from convective storms is likely to be significantly underestimated in the PXR dataset.

- The spatial resolution of the PXR dataset (31km x 31km) is coarse compared to that of the NatureInsight grid squares (250m x 250m). This means that nuances in rainfall statistics at local scale, for example due to topography, are likely to be averaged out by the PXR dataset. The impact of this might be significant when investigating smaller catchments.

The method used to develop each of the rainfall parameters for depth, duration and temporal distribution are discussed in the following three sub-sections.

4.1.1 Rainfall Depth

The parameters of the extreme value distribution are available in the PXR dataset in 31km grid squares. IDF curves can be fitted for any grid square. The rainfall depth (mm) can be calculated by multiplying the intensity (mm/hr) by the time (hrs). Figure 4-1shows two example plots, one showing the IDF curves and the other showing the Depth-Duration-Frequency (DDF) curves for a range of return periods for a point queried at the longitude and latitude shown, where ‘T’ is the return period.

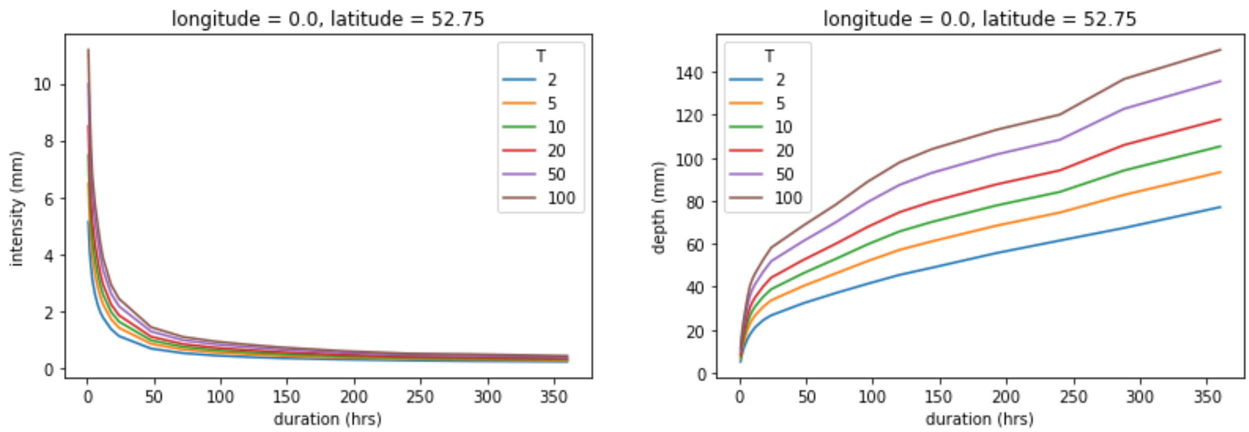

Figure 4-1: IDF curves (left) and DDF curves (right) for an example grid of the PXR dataset

In NatureInsight, a calculation is performed to produce the rainfall depth applied to a catchment area. The catchment area is defined by the user, using the Watershed tool. This calculation takes the average value of all 31km rainfall grid squares which are more than 50% within the catchment area.

The user can select the return period for which they wish to design their NbS scheme. Several methods were investigated to develop and appropriate storm duration.

[7] https://zenodo.org/records/1467859#:~:text=Parametrized%20eXtreme%20Rain%20(PXR)%20is,precipitation%20maxima%20obtained%20by%20reanalysis.

4.1.2 Recommended Rainfall Duration

The duration of the storm affects rainfall depth, with longer storms producing a greater depth for a given return period. For design, it is useful to set the rainfall duration to the minimum value which produces the highest magnitude of peak flow at the catchment outlet. This is referred to as the critical storm duration (CSD).

It is not always possible to set this *a priori* without modelling different storm durations for a given set of model parameters, but there are methods for estimating the CSD. One such method is referred to in the Flood Estimation Handbook (FEH) as the Recommended Storm Duration, where an initial value is calculated based on two catchment characteristics, and then a sensitivity test is carried out to calculate the CSD. Several iterations may be required to determine the CSD.

In the PXR dataset there are 19 possible rainfall durations. However, in our testing against industry standard methods, on average using a 24-hour duration showed a better correlation during product testing when compared to the industry standard FEH DDF model. Therefore, the default event duration has been set to 24 hours. This approach will be reviewed and improved over time. The hydrograph in SCALGO Live and NatureInsight does allow the user to edit the depth of rainfall and duration of the event, as well as import data from other sources.

4.1.3 Rainfall Distribution

The spatial distribution of rainfall within any given catchment area is assumed to be uniform. This was a simplification which may be revisited as the tool is developed to incorporate more detailed rainfall information.

The FEH methods use two industry-standard temporal rainfall profiles for generating design storm hydrology using ReFH2 in the UK, the Winter and the Summer, as shown in Figure 4-2. After product testing of different temporal rainfall distributions the FEH Winter distribution was selected as the default rainfall distribution due to better statistical alignment with industry standard hydrology approaches, but primarily due to the PXR dataset being more suitable for winter rather than summer-type storms.

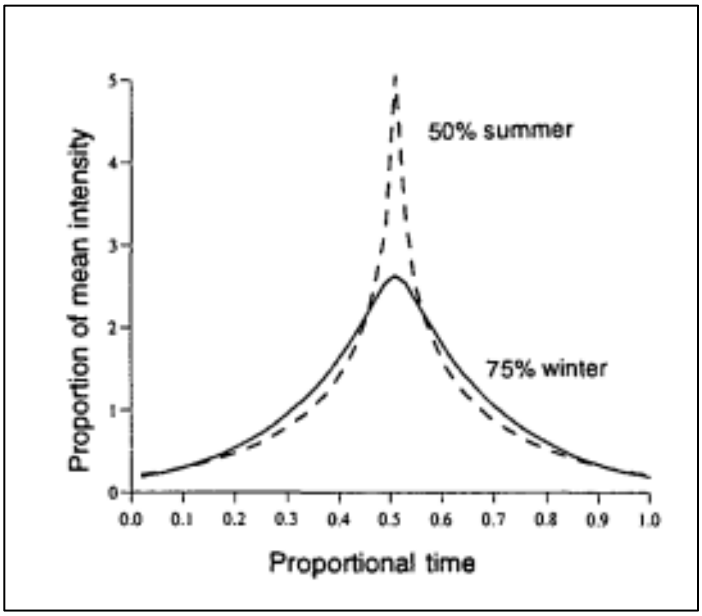

Figure 4-2: Design rainfall profiles, drawn as hyetographs from the Flood Estimation Handbook[8]

[8] Faulkner, D. S. (1999). Rainfall frequency estimation, Flood Estimation Handbook Volume 2, Institute of Hydrology, Wallingford, UK.

4.2 Rainfall-runoff response

Rainfall that hits the surface of the earth will be subject to several processes before runoff occurs, these are often referred to as hydrological losses and broadly comprise of surface wetting, canopy storage, infiltration, depression storage, drainage systems, evaporation and evapotranspiration, and snow build-up and melt. Further explanation of these processes is described by SCALGO (2023)[9]. The processes which determine how much rainfall is converted to runoff for any given rain event and catchment area are complex. Many mathematical models that predict runoff, known as Rainfall-Runoff Models, are also complex and require many user inputs. For engineering purposes, simplified Rainfall-Runoff Models have been developed. For NatureInsight, a simple and robust Rainfall-Runoff Model is required, which can make useful predictions about runoff in the context of flooding and the design of NbS interventions. In establishing a method for estimating the hydrological losses, it is necessary to strike a balance between using as much useful data as practicable, taking as many significant parameters into account as possible, while requiring few inputs from the user and being rapid and dynamic to operate.

4.2.1 HOST open-source method

A simplified adaptation of the FEH industry standard method for calculating the standard percentage runoff (SPR) using the Hydrology of Soil Types (HOST) dataset (SPRHOST) has been derived. The FEH method for calculating runoff first relies on the derivation of the HOST dataset from soil map data. The HOST classification describes dominant pathways of water movement through soil and is related to the base flow index (BFI) of a catchment (the long-term proportion of base flow on total stream flow). A method was published by Schneider, et al (2007)[10] which outlines a process for reclassifying the Soil Geographical Database of Europe (SGDBE) at 1:1 million resolution into the HOST system. We created a HOST dataset for Great Britain with this method and compared the results to the industry-standard HOST data reported in Boorman et al (1995)[11], for a selection of different catchments with variable characteristics. This dataset will be referred to as HOST_OPEN. A comparison of the two datasets is shown in Figure 4-3, where the lower resolution of HOST_OPEN can be seen, along with gaps (white colour) in the dataset where it was not possible to classify using available open information.

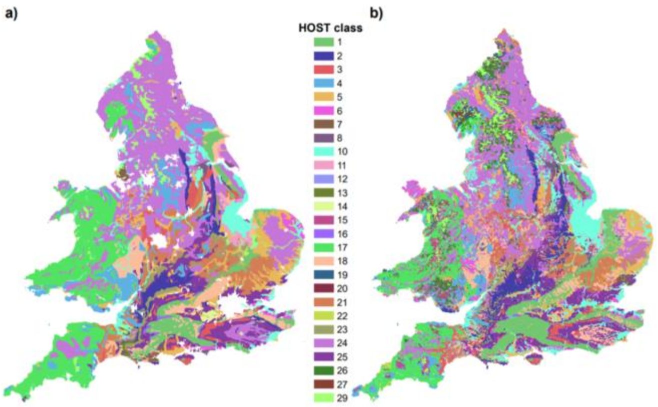

Figure 4-3: From Schneider, et al (2007). Coverage of dominant HOST classes in England and Wales (a) as reclassified from the Soil Geographical Database of Europe (SGDBE) and (b) in comparison to the original HOST map. Colours for each HOST class are given in the legend. Gaps in the reclassified SGDBE are due to missing information for urban areas. Copyrights: SGDBE polygons are copyright of the Commission of the European Community, the HOST map is copyright of National Soil Resources Institute, Cranfield University, UK and the Centre for Ecology & Hydrology, Swindon, UK

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[9] SCALGO White Paper: The Rainfall-Runoff Model in the Flash Flood Map in SCALGO Live Denmark, updated October 2023. https://scalgo.com/uploads/documentation/Whitepaper-RRM.pdf

[10] Schneider, M. K., Brunner, F., Hollis, J. M., and Stamm, C.: Towards a hydrological classification of European soils: preliminary test of its predictive power for the base flow index using river discharge data, Hydrol. Earth Syst. Sci., 11, 1501–1513, https://doi.org/10.5194/hess-11-1501-2007, 2007

[11] https://nora.nerc.ac.uk/id/eprint/7369/1/IH_126.pdf

Each of the 29 HOST classes has an SPR and BFI value assigned to it, referred to as SPRHOST and BFIHOST. For any given catchment area, the area-weighted proportion of SPRHOST and BFIHOST is calculated for each HOST class and then summated to provide the catchment-averaged value. SPR values range between 2% and 60% in the UK, and the range of BFI values is 0.209 to 0.991 (FEH, 2005)[12].

Figure 4-4: HOST map for Great Britain derived for NatureInsight using methods described in Schneider, et al (2007)

Results showing the comparison of individual catchment calculations of SPRHOST and BFIHOST using the industry-standard versus open-source method have been reported and are shown in Figure 4-5. The main limitation of this method is due to the coarse resolution of the input data from the SGDBE. This lower level of refinement may be particularly noticeable on smaller catchments and catchments with heterogeneous soil types. Moreover, in some cases it was not possible to classify the soil types. This occurs mostly in urban areas where large areas of white exist which are not accounted for in the key. For example, see the areas around London and Birmingham in the plot above. This missing data class is referred to as 'HOST0'.

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[12] Kjeldsen, T.R., Stewart, E.J., Packman, J.C., Folwell, S.S., and Bayliss, A.C. (2005) *Revitalisation of the FSR/FEH rainfall runoff method.* Available at: https://assets.publishing.service.gov.uk/media/602ba561e90e070562513e33/Revitalisation_of_the_FSRFEH_rainfall_runoff_method_technical_report.pdf (Accessed October 2023)

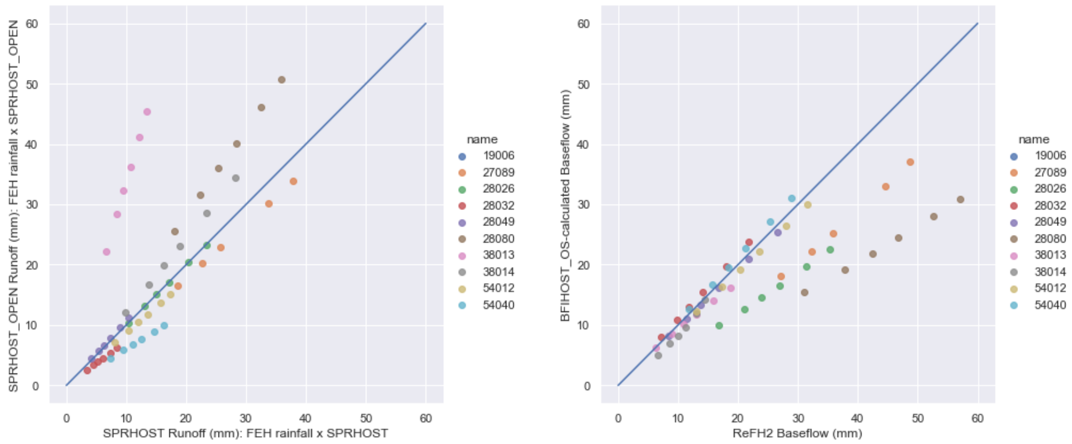

Figure 4-5: Comparison between ReFH2 and HOST open-source method for SPR(HOST) and runoff prediction (left) and BFI(HOST) and baseflow prediction (right)

4.2.2 Routing velocity

After hitting the land surface as rainfall, water moves over and through the landscape at different rates. This behaviour is extremely complex and depends on many different factors. Simplifications are often necessary to represent the rate at which water travels through the catchment to the outlet, which is the topic of this section.

As discussed in the previous section, for a particular defined storm event, some water is 'lost' to the various hydrological loss processes which occur. For the remaining runoff, the rate of travel (distance per unit time) varies depending on a range of factors such as the land surface type, slope and catchment size. In attempting to represent such a complex process conceptually, assumptions are often made to 'average out' the behaviour at the catchment scale. The way this is represented in the NatureInsight hydrological model is as an averaged velocity across a user-defined area, which is either at the catchment or at the sub-catchment scale. For example, in a small, steep urbanised catchment with many impervious surfaces, the catchment average velocity is likely to be higher than in a large, flat and predominantly rural catchment. This means that the steep urban catchment will have a faster response time than the flat rural catchment. The user can select an average velocity appropriate to a particular watershed. To help the user with this task, a method based on an individual catchment's physical characteristics is proposed for selecting a suitable default velocity value.

A simplified version of the NRCS velocity method[13] is used to calculate the 'catchment average velocity'. To do this it was first necessary to calculate the response time of the catchment. This can be referred to as the Time of concentration (T_c), which is described as 'the time required for a "water particle" to travel from the catchment boundary along the longest watercourse to the catchment outlet[14]'. It is useful to note that there are several different ways of characterising the response time of catchments, and often they overlap. This can be seen in Figure 2 of Gericke and Smithers (2014) [14], where different formulations of response time are shown. A generalised description of the time parameter might also be the 'travel time' (T). Parameters for longest flow path, catchment area and average catchment slope are extracted from the Watershed Tool in SCALGO Live and used to estimate the velocity parameter as soon as a Watershed is generated.

[13] Natural Resources Conservation Service, US Department of Agriculture. National Engineering Handbook, Part 630, Hydrology, Chapter 15 (2008). Available at: https://irrigationtoolbox.com/NEH/Part630_Hydrology/NEH630-ch15draft.pdf

[14] Gericke and Smithers (2014), Hydrological Sciences Journal. Available at: Full article: Review of methods used to estimate catchment response time for the purpose of peak discharge estimation (tandfonline.com)

According to Perdikaris et al (2018)[15], after around 30m sheet flow usually becomes a shallow concentrated flow, which may be considered negligible, particularly for larger basins. Therefore, $L = L_c + L_{shallow}$. L can be calculated from the watershed analysis tool in SCALGO Live, which automatically reports the length of the longest flow pathway in a catchment. There is an implicit assumption that the longest flow pathway is also the same as the hydraulically most distant point. Therefore, it is necessary only to calculate either L_c or $L_{shallow}$.

At this point, methods of calculating each of the different parameters were investigated to understand the sensitivity of each parameter. The sensitivity of the flow path length on the calculation of $T_{channel}$ was found to be low, compared to the Mannings' roughness coefficient 'n'. Moreover, methods of accurately deriving n for any given catchment area are known to be challenging without high quality catchment and watercourse data. Therefore, a series of pragmatic simplifications were taken. These are described as follows:

- Only the channel component of the equation was used, i.e. the equation for $T_{channel}$ (see below) was used to estimate the travel time (time of concentration T_c) for the whole catchment. This is a more reasonable assumption in medium to large catchments, where channel flow is more likely to dominate

Equation 2: Description of the $T_{channel}$ component of the NRCS method, adapted from Perdikaris et al (2018)

$$T_{channel} = \frac{0.44\ L_c\ n^{0.75}}{i^{0.25}\ A^{0.125}\ S_c^{0.375}}$$

- The total length of the longest flow path in the catchment (L) was used, rather than only the length of the main river channel L_c. Again, in medium to large catchments the channel length is likely to represent a significant majority of the total channel length
- A constant value of **n = 0.3** was applied uniformly and as such is intrinsically linked to the velocity parameter. Therefore, it is possible to simulate the effect of different sub-catchment-averaged surface roughness conditions by altering the velocity.

It is recognised that these represent significant simplifying assumptions. However, they were a necessary pragmatic solution to produce a dynamic tool capable of making instantaneous assessments. Continuing efforts are ongoing to improve the representation of the time-component and all other elements of NatureInsight. One significant challenge currently is lack of availability of high-resolution open datasets such as soil and land cover maps.

The remaining parameters in the $T_{channel}$ term of the travel time equation, see Equation 2, can be calculated using the following techniques.

- The parameter 'i' is the 1 in 2-year 24-hour rainfall (mm) and is calculated using the PXR dataset for any given catchment area, using the method described in Section 4.1.
- The parameter 'A' is the catchment area in km^2 and is calculated using the Watershed Tool in SCALGO Live directly from the DEM.
- The parameter S_c is the average slope of the main river channel. As we are using L instead of L_c as the length parameter, then the average slope is calculated for L, i.e., we calculate S instead of S_c. This can also be done in the Watershed Tool.

4.2.3 Baseflow

Conceptually, streamflow can be separated into runoff and baseflow. Runoff is the component which 'runs off' over land and into rivers during the current storm event. Baseflow is generally defined as the portion of

[15] Perdikaris, J., Gharabaghi, B. and Rudra, R.P. (2018) *Reference Time of Concentration Estimation for Ungauged Catchments.* Available at: https://www.researchgate.net/publication/325272547_Reference_Time_of_Concentration_Estimation_for_Ungauged_Catchments (Accessed October 2023)

streamflow that is sustained between precipitation events. It can also include the delayed subsurface runoff from the current storm. Therefore, baseflow can either be represented as constant within an event, or it can fluctuate over the course of the event. In the industry-standard FEH methods, typically the design storms implemented in the ReFH2 rainfall-runoff model use the latter formulation. Figure 4-6 (left) shows a 'total' flow hydrograph which has been separated into runoff and baseflow. Conversely, an example of a constant baseflow hydrograph is also shown in Figure 4-6.

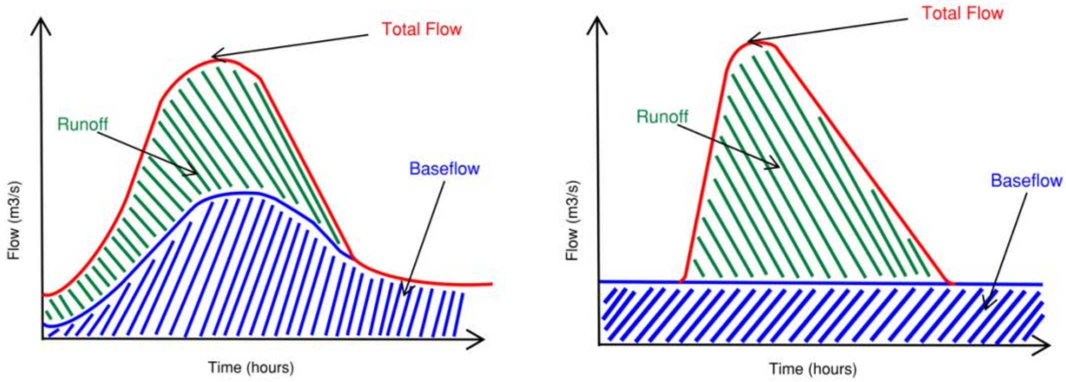

Figure 4-6: Flow components of the runoff hydrograph as used in the industry-standard ReFH2 model (left), and an example of a constant baseflow (right).

It is important to estimate the baseflow in NatureInsight because, whereas runoff-type storage buckets interact only with runoff-type interventions, floodplain reconnection-type storage interacts also with main watercourses i.e., incorporating the total flow, which is runoff plus baseflow.

The chosen method for calculating baseflow was to use a formula from FEH (1999) Volume 4, section 2.4.3[16] for estimating a constant baseflow. This estimates baseflow from catchment descriptors using a generalised model derived by regression analysis. The formula uses three parameters, the Standard-period Annual Average Rainfall (SAAR, mm), Catchment Area (km^2) and the Catchment Wetness Index (CWI, mm). The CWI is determined directly from SAAR using a graphical relationship, however no data or equations underpinning the graph (shown in Figure 4-7) were reported in FEH (1999)[16]. The period for which SAAR was calculated was 2009 to 2019, using data from the CEH GEAR dataset[17].

[16] Houghton-Carr (1999), Restatement and application of the Flood Studies Report rainfall runoff method. https://www.ceh.ac.uk/sites/default/files/2021-11/Flood-Estimation-Handbook-4-Restatement-And-Application-Of-The-Flood-Studies-Report-Rainfall-Runoff%20Method_Helen-Houghton-Carr%20version%202.pdf

[17] Tanguy, M.; Dixon, H.; Prosdocimi, I.; Morris, D.G.; Keller, V.D.J. (2021). Gridded estimates of daily and monthly areal rainfall for the United Kingdom (1890-2019) [CEH-GEAR]. NERC EDS Environmental Information Data Centre. (Dataset). https://doi.org/10.5285/dbf13dd5-90cd-457a-a986-f2f9dd97e93c

Figure 4-7: Graphical representation linking Standard-period Annual Averaged Rainfall (SAAR) to CWI, reproduced from FEH (1999)[16]

The baseflow formula from FEH (1999) can be written as:

Equation 3: Baseflow formula from FEH (1999)

$$Baseflow = (33 * (CWI - 125) + 3 * SAAR + 5.5) \ x\ 10^{-5} \ x\ Area$$

A mathematical function was created to describe the CWI in terms of SAAR (Figure 4-7).

The revitalised flood hydrograph methods (2005)[18] replaced the steady-state baseflow with a model based on the linear reservoir concept, where the storage in the baseflow reservoir is assumed to be linearly related to baseflow rate by a time parameter equivalent to the mean lag time between inflow (recharge) and outflow (baseflow) and is thus denoted as baseflow lag (BL)[18]. The equations produced for baseflow in FEH (2005) are more complicated to implement due to the addition of several parameters, such as the initial soil moisture content ($C_{ini,\ mm}$), maximum soil moisture capacity (C_{max}, mm) and proportion of time when the soil moisture deficit was below 6 mm during the period 1961-90 (PROPWET). There has also been a more recent technical report developed for Scotland which adapts the baseflow equations to better fit Scottish catchments[19].

As a pragmatic solution, the formula from the FEH (1999) publications was used to apply a baseflow. It is accepted that there are limitations with this approach, as detailed in the FEH (2005) technical report[18]. For

[18] https://assets.publishing.service.gov.uk/media/602ba561e90e070562513e33/Revitalisation_of_the_FSRFEH_rainfall_runoff_method_technical_report.pdf

[19] https://www.hydrosolutions.co.uk/app/uploads/2019/10/ReFH2-Science-Report-Model-Parameters-and-Initial-Conditions-for-Ungauged-Catchments.pdf

example, the concept of CWI incorporates theoretical and practical concerns (see page 11 and 17 of FEH 2005[18]).

4.3 Storage model

The aim of the storage component of NatureInsight is to interact with and alter with hydrological flows in a way that can realistically represent the behaviour of storage within the catchment, if it was implemented as well designed NbS interventions. The storage component in NatureInsight is based on the Aggregate Storage Model (ASM). The ASM was developed (by Arup) to assess the synchronicity of flows from each of the sub-catchments in a wider catchment area and is based the Pond Network Model[20].

The ASM allows the user to allocate a total (or aggregate) storage volume to each of the sub-catchments to assess the impact of storage on both the selected sub-catchment and the total downstream flow at the point of interest. The total storage may be made up of a number of feasibly sized 'ponds' (or pond objects), which are identified in the opportunity mapping. The ponds are an essential component of the storage unit as the number of attenuation features dictates how rapidly the storage unit can drain. Mass-balance is conserved with the ASM. Figure 4-8 shows a conceptual schematic, similar to a linear storage (bucket) model[21], which demonstrates the role of storage units within the tool.

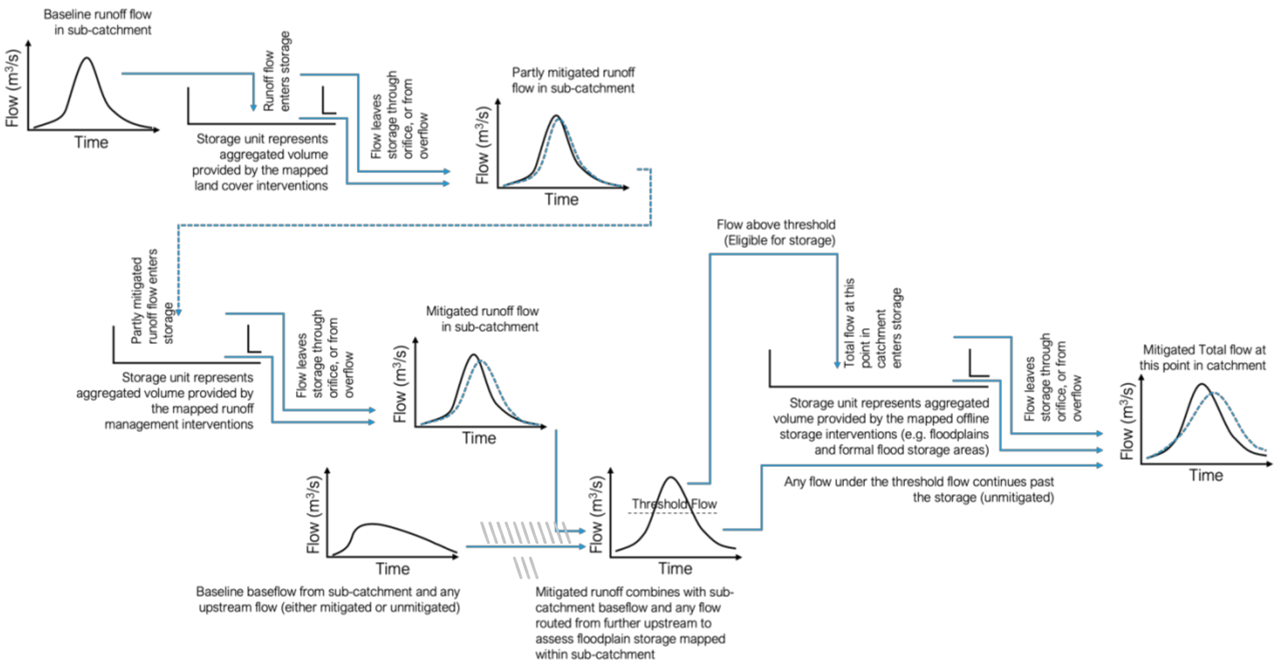

Figure 4-8: Conceptual model schematic of storage units in the ASM

The ASM assesses the aggregate effects of new storage being added to sub-catchments in three forms of attenuation: Land cover change, Runoff mitigation, and Floodplain storage. Default parameters for each of these storage buckets are defined by NatureInsight, but the user can alter any of the defaults if they desire. The default parameters are discussed in Section 4.4.

4.3.1 Inflow condition

The threshold flow is a defined flow rate at which water will 'enter' an NbS intervention. The threshold flow is either set to the baseflow magnitude, e.g. land-use and runoff storage, or it can be adjusted e.g. for floodplain

[20] Nicholson AR, O'Donnell GM, Wilkinson ME, Quinn PF. The potential of runoff attenuation features as a Natural Flood Management approach. J Flood Risk Management. 2019; e12565. https://doi.org/10.1111/jfr3.12565

[21] Nash, J. E. (1957). "The form of instantaneous unit hydrograph." Int. Assn. Sci. Hydro. Publ. No. 51, 546-557, IAHS, Gentbrugge, Belgium.

features. The inflow condition is such that once flow in the upstream channel exceeds the threshold, anything above the threshold is eligible to enter the storage unit using the following equation.

$$Q_{in} = C_d.(Q_{max} - Q_{threshold})$$

where C_d is a coefficient of discharge for flow entering the storage area (and is based on the proportion of the catchment or sub-catchment draining to the collection of storage features being modelled), Q_{max} is the peak flow from the upstream ReFH2 unit, and $Q_{threshold}$ is the flow at which, once exceeded, water is able to enter the storage unit.

4.3.2 Storage unit

Assumptions are laid out for the storage allocated to each group of NbS, as described in Section 4.4. The storage is aggregated into the buckets based on what type of flow the intervention is targeting and the number of interventions is summed for each type.

4.3.3 Outflow condition

The outflow condition from the storage unit is simulated using a generic formula, which is based on hydrostatic flow through a small orifice to ensure model transferability to similar storage types. It assumes that the water inside the storage unit is static; a similar assumption is made in engineering studies on lakes and reservoirs despite discharge currents being present in the water body (Figure 4-9).

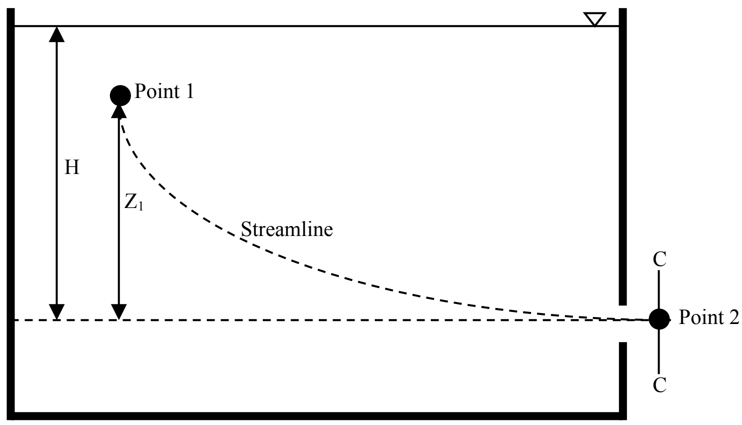

Figure 4-9: Diagram showing flow through a small orifice

The equation for outflow[22] is given by Equation 4,

Equation 4: Equation for outflow

$$Q_{out} = C_d.a\sqrt{2gH}$$

where a is the cross-sectional area of the orifice (m^2), H is the depth of water in the storage unit (m), g is acceleration due to gravity (m/s^2), and C_d, the coefficient of discharge through the outlet pipe is given by:

$$C_d = C_c C_v$$

and C_v, the coefficient of velocity, is given by:

[22] Marriot, M. J., Featherstone, R. E., & Nalluri, C. (2009). *Nalluri & Featherstone's civil engineering hydraulics: essential theory with worked examples* (Vol. 5). Chichester, West Sussex, United Kingdom: John Wiley & Sons Ltd.

$$C_v = \frac{actual\ velocity\ at\ vena\ contracta}{ideal\ velocity\ at\ vena\ contracta}$$

Sample values of C_d for a negligible approach velocity for a bevelled small orifice and a Borda's (re-entrant) mouthpiece are shown in Figure 4-9. Typically, C_d can range between 0.61 and 0.75.

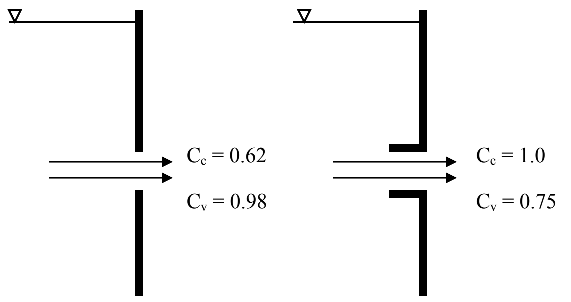

Figure 4-10: Diagram showing typical values for Cd: Left – Bevelled orifice; Right – Borda's (re-entrant) mouthpiece

For the storage model, the outflow from the storage bucket is multiplied by the number of ponds within the sub-catchment (based on the opportunity map), as the greater the number of ponds, the faster the water will drain from the storage unit (and vice versa).

$$Q_{out} = C_d . a\sqrt{2gH}\ x\ n_{ponds}$$

The mitigated (Q_{mit}) flow for the sub-catchments is determined using the following equation:

$$Q_{mit} = Q_{Cal} - Q_{in} + Q_{out}$$

4.4 Storage model defaults in NatureInsight

To enable the storage assessment within NatureInsight, default parameters for each bucket are available within the tool. These are defined in the following sub-sections for each bucket type: Land use, Floodplain and Runoff. When adding storage in NatureInsight, a bucket schematic is displayed to help the user understand the function of the different parameters. This schematic is the same for all three bucket types and can be seen in Figure 4-11, followed by definitions of the key parameters.

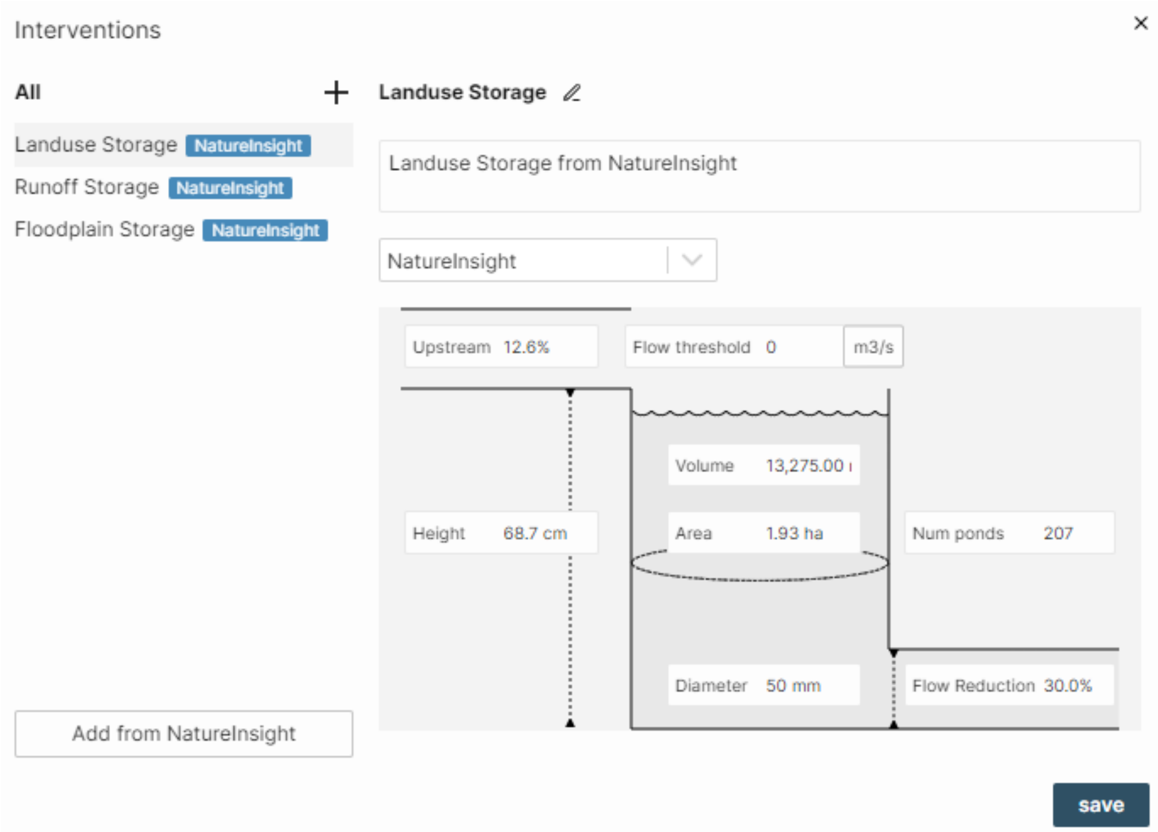

Figure 4-11: The bucket schematic displayed when adding storage in NatureInsight

NbS intervention type is a list of the NbS intervention types included within this bucket type.

For each bucket type the following parameters are defined:

'Diameter' (Pipe diameter) – the size of the pipe diameter exiting the bucket in the storage model.

'Volume' (Storage volume) – how much storage is defined in the bucket type.

'Num ponds' (Number of ponds) – how pond number is defined for each bucket type. This is generally represented as the number of NbS interventions from the NatureInsight map, according to the assumptions from Section 2.

Flow threshold – the threshold above which water will flow into the bucket type, see Section 4.3.1 for further detail.

'Height' (Storage height) – is a representation of how the new storage behaves compared to a baseline condition of 'no storage'. This is derived for both above-ground features such as RAFs, as well as for features where below ground level storage is assumed (assumed depth). This is defined for each bucket type.

'Upstream' (Cd_{in}) – represents the percentage of the total flow which interacts directly with the bucket-type. i.e. RAFs may only cover 20% of the catchment area, in which case this would be set to 20%, because 80% of the runoff generated cannot interact with these interventions. This is also referred to as the coefficient of discharge into the storage bucket (Cd_{in}).

'Flow Reduction'– This is a pipe efficiency factor indicating by how much the actual flow rate is less than the theoretical maximum flow rate through the pipe. This is also an efficiency factor, which is the inverse of the coefficient of discharge out of the storage bucket (Cd_{out}).

The default parameters for each bucket type are outlined in the Sections below.

4.4.1 Land use bucket

This bucket will include the following interventions:

- Soil Management
- Buffer strip
- Tree planting
- Peat Management

The default parameters for the Land Use bucket are as follows:

Pipe diameter = 5cm

Storage Volume = sum of volume from interventions displayed in the current opportunity map

Number of 'ponds' (# Ponds) = sum of the number of interventions (Tree Planting, Buffer Strip, Soil Management and Peat Management)

Flow Threshold = the value of the default baseflow

C_d out = 0.7 (from Toricelli's formula for the pipe being assumed)

Storage Height = The Storage Height is a representation of how the new storage behaves compared to a baseline condition of 'no storage'. Where soil is being managed, the assumption is that the depth of the additional storage is limited to 60cm, meaning the maximum water pressure through the pipe is limited and storage fills up quicker compared to, say, a vegetated buffer or tree planting. For Peat Management, water is assumed to be stored to a greater depth, which has the effect of driving more flow through the conceptual outflow pipe and being a slower intervention to 'fill'. The assumptions for the various forms of land cover change are shown below an illustrated in Figure 4-12:

- Soil Management = 0.6m
- Buffer strip = 0.8m
- Tree planting = 1.0m
- Peat Management = 1.2m

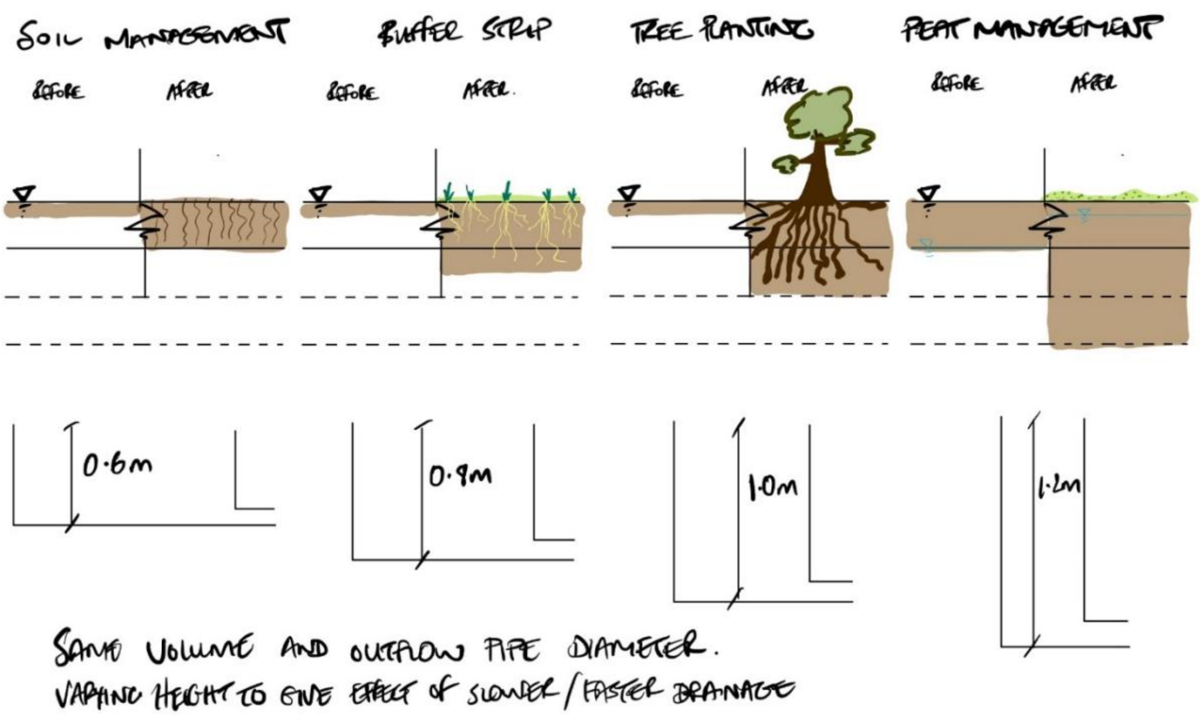

Figure 4-12: Relative storage depths for land use interventions

A weighted average of the volumes and pond heights across the interventions identified in the map is calculated to apply a single 'Storage Height' automatically.

'Upstream' - (Inverse of the coefficient of discharge into Storage ($1 / C_d$in): This factor controls the proportion of water flowing into the storage buckets. For land cover change we predominantly assume the measures interact with the rainfall directly. This means we can assume the measures do not interact with the runoff in locations of the map where they do not exist. To calculate this parameter the proportion of their coverage compared to the area of the watershed being assessed is determined. The calculation is as follows:

$C_d$in = (Number of Land use grid squares displayed x 0.0625) / (Area of watershed in km^2)

where 0.0625 is the area of a grid square in km^2.

4.4.2 Floodplain bucket

The default parameters for the Floodplain bucket are as follows:

NbS Intervention Types: Floodplain reconnection, Wet Wood

Pipe diameter = 30cm (but can be user defined)

Storage Volume = sum of volume from interventions

Number of 'ponds' (# Ponds) = sum of the number of interventions (Floodplain Reconnection and Wet Wood)

Flow Threshold = This is automatically set to 75% of the peak flow. It can be adjusted both in terms of the percentage of the peak flow, or in the units of m^3/s.

Storage Height = 1.5m (but can be user defined)

$C_d$in (Coefficient of discharge into Storage): This factor controls the proportion of water flowing into the Storage buckets. For Floodplain Reconnection and Wet Wood we can simply extract the maximum flow accumulation (watershed area) draining to the grid squares and calculate a weighted average, and proportionate area compared to the total watershed area. In the case of the watershed below the watershed area is $3.94km^2$. The average 'Flow Network Detail' draining to the two floodplain reconnection opportunities is $1.675km^2$ ((1.15+2.25)/2). 1.675/3.94 gives 0.43; meaning a $C_d$in value of 0.43 can be set for the Floodplain bucket.

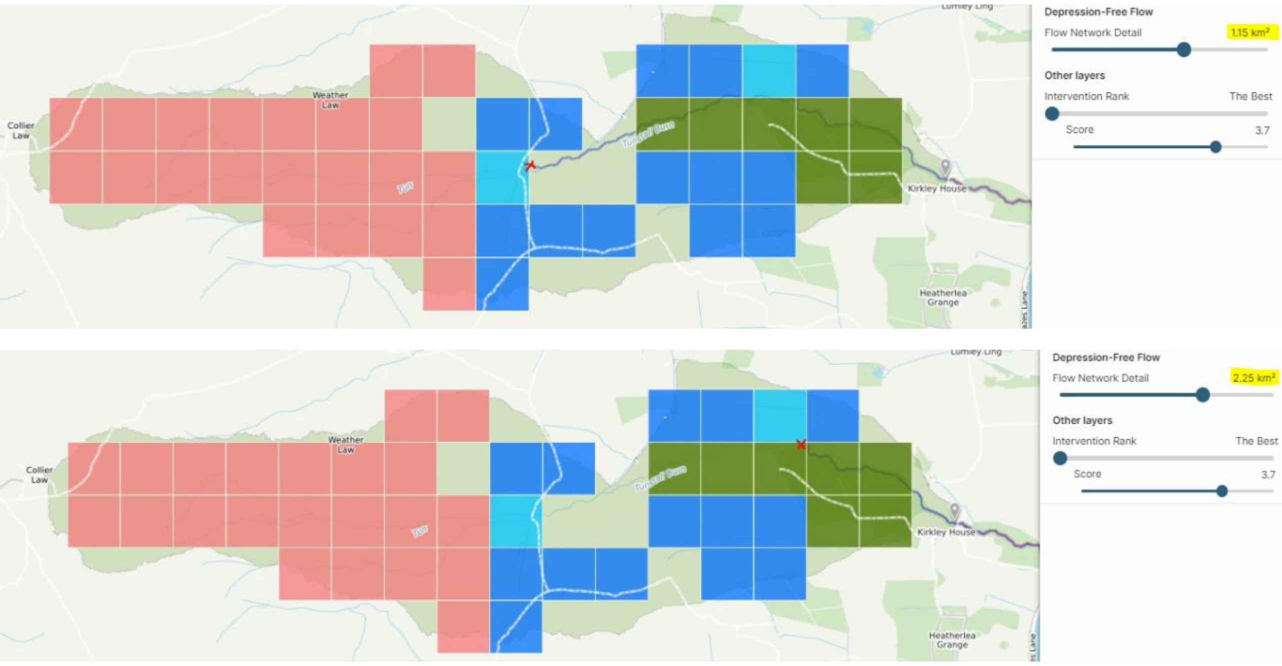

Figure 4-13: Maximum upstream area of the flow network for two floodplain opportunities

'Upstream' - (Inverse of the coefficient of discharge into Storage ($1 / C_d in$): This factor controls the proportion of water flowing into the storage buckets.

4.4.3 Runoff bucket

The default parameters for the Runoff bucket are as follows:

NbS Intervention Types: Runoff Attenuation Feature (RAF), Grip Blocking, LWD, Gully Stuffing

Pipe diameter = 30cm (but can be user defined)

Storage Volume = sum of volume from interventions

Number of 'ponds' (# Ponds) = sum of the number of interventions (Runoff Attenuation Feature, Grip Blocking, LWD and Gully Stuffing)

Flow Threshold = the value of the default baseflow 'SAAR (Baseflow)'

Storage Height = 1m (but can be user defined)

$C_d in$ (Coefficient of discharge into Storage): This factor controls the proportion of water flowing into the Storage buckets and is determined automatically by calculating the weighted average flow accumulation reaching runoff ponds on flow pathways throughout the watershed (compared to the total watershed or sub-watershed size). SCALGO Live algorithms can determine the connection between identified runoff-style NbS opportunities and whether any other runoff-style NbS lie upstream on the same flow pathway. The purpose of this is to understand what proportion of the runoff flow in the watershed/sub-watershed is passing through or interacting with runoff-style NbS, so that it can be fairly represented in the routing model.

'Upstream' - (Inverse of the coefficient of discharge into Storage ($1 / C_d in$): This factor controls the proportion of water flowing into the storage buckets

Appendix A

Multicriteria analysis

A.1 Lookup table examples

The opportunity mapping process takes a series of spatial datasets and applies 'lookup scores' for each type of land cover change or NFM intervention. For all spatial datasets with areal coverage, a percentage cover is multiplied by the Weighting for that dataset (Table 2) and then multiplied by the score for the intervention being assessed. This assessment is performed for each grid and for all interventions. Table 16 shows an extract of the lookup scores awarded to the various interventions when applied to the Land Cover dataset.

Table 16: Sample lookup scores, by intervention, awarded to classes from the Corine Landcover (2018) dataset

Land cover	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
Continuous Urban Fabric	0	0	0	0	0	0	0	0	0	0	0
Discontinuous Urban Fabric	0	0	0	40	0	0	0	0	0	0	0
Industrial or commercial units	0	0	0	20	0	0	0	0	0	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Green Urban Areas	60	60	20	80	40	20	40	0	60	0	0
Sport and leisure facilities	40	60	20	20	20	40	0	0	60	0	0
Non-irrigated arable land	60	40	60	60	40	100	100	0	40	60	0
…	…	…	…	…	…	…	…	…	…	…	…
Pastures	100	100	80	60	60	80	0	0	100	60	0
Broad-leaved forest	60	100	100	60	100	0	0	0	80	100	0
Coniferous forest	60	60	100	60	60	0	0	0	40	100	0
Mixed forest	60	80	100	60	100	0	0	0	80	100	0
Natural grassland	100	80	60	80	80	20	40	0	80	40	0
Moors and heathland	100	80	100	20	20	60	20	100	80	100	100
…	…	…	…	…	…	…	…	…	…	…	…
Peatbogs	80	60	100	20	20	20	20	100	60	60	100

Land cover	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
…	…	…	…	…	…	…	…	…	…	…	…
Water courses	0	0	0	0	0	0	0	0	0	0	0
Water bodies	0	0	0	0	0	0	0	0	0	0	0
…	…	…	…	…	…	…	…	…	…	…	…
Sea and Ocean	0	0	0	0	0	0	0	0	0	0	0

Table 17: Sample lookup scores, by intervention, awarded to classes from the Agricultural Land Classification dataset

Agricultural land classification	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
Grade 1	80	20	20	20	20	80	80	0	20	20	0
…	…	…	…	…	…	…	…	…	…	…	…
Grade 4	100	80	80	80	80	100	60	60	100	80	60
…	…	…	…	…	…	…	…	…	…	…	…
Urban	20	0	40	40	0	0	0	0	0	40	0

Table 18: Sample lookup scores, by intervention, awarded to sums of the linear distance of runoff routes derived from the topographic data

Runoff pathway length	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
0 – 500m	0	20	0	60	60	60	60	40	0	0	20
…	…	…	…	…	…	…	…	…	…	…	…
1000-1500m	60	60	60	60	60	60	60	40	60	80	80
…	…	…	…	…	…	…	…	…	…	…	…

Table 19: Sample lookup scores, by intervention, awarded to the average slope within the grid cell derived from topographic data

Slope range (degrees)	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
0-2	100	100	100	80	100	20	40	80	100	100	100
…	…	…	…	…	…	…	…	…	…	…	…
4-6	60	60	80	80	60	80	100	80	60	60	60
…	…	…	…	…	…	…	…	…	…	…	…
>8	20	20	60	80	20	20	20	80	20	20	20

Table 20: Lookup scores, by intervention, awarded to the presence of flood extent datasets

Flood extent (presence)	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
Flood zone 2	20	100	60	60	100	60	60	60	100	20	20
Flood zone 3	20	100	40	60	100	60	60	60	100	20	20
Risk of Flooding from Surface Water (RoFfSW)	100	100	100	100	60	100	80	100	100	80	100

Table 21: Lookup scores, by intervention, awarded for the provision of ecosystem services and other non-spatial considerations related to ecosystem services, cost and durability

Land cover	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
Cost	60	20	80	40	100	80	80	40	20	80	80
Funding	40	60	60	80	60	100	100	80	60	60	80
Maintenance	100	60	60	80	80	100	60	100	60	80	40
Life Expectancy	60	80	20	100	100	100	100	100	80	20	60
Flood (Fluv)	80	100	80	40	80	40	20	40	100	40	40
Flood (SW or GW)	100	80	80	60	80	40	60	40	80	60	60
Air Quality	20	40	20	100	60	40	0	40	40	20	40
Health Access	20	100	20	80	40	40	0	80	100	20	60

Land cover	RUNOFF ATTENUATION FEATURE	FLOODPLAIN RECONNECTION	LARGE WOODY DEBRIS	TREE PLANT	WET WOOD	BUFFER STRIP	SOIL MANAGEMENT	PEAT MANAGEMENT	RIVER RESTORATION	GULLY STUFFING	GRIP BLOCKING
Low Flows	40	40	60	60	80	20	20	100	40	80	100
Climate regulation	60	100	60	100	100	40	40	100	100	40	100
Habitat	60	100	80	100	100	40	40	100	100	80	80
Water Quality	80	60	100	80	80	100	100	100	60	100	100
Cultural Activity	20	60	40	80	60	40	40	60	60	40	60
Aesthetic Quality	20	100	80	100	100	40	40	80	100	40	60