01 - Putting the design of Nature based Solutions into your hands

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Abstract

Our planet faces the existential threat of combined global climate warming 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, humans have transformed and degraded landscapes for food, energy, transport and shelter and have significantly reduced the natural capacity to retain water, sequester carbon and enable habitats to thrive and connect.

Nature-based Solutions (NbS) offer some relief from these threats, with the potential to mitigate climate change, adapt to extreme events and provide improved, 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. Proportionate and accessible tools to enable early exploration of NbS are needed, 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 with state of the art data analysis algorithms to build a new web-based opportunity mapping and hydrological modelling software package that will put the design and planning of NbS in the hands of those seeking to implement schemes. The software is called NatureInsight; its extent currently includes the island of Britain and allows for the assessment of ten different types of NbS. NatureInsight uses several datasets in a multi-criteria analysis to assess NbS across 250m x 250m grid squares. The software informs the user how much the identified NbS will cost, how much area the NbS will take up, and how much water they can store in real time. A process that would usually take weeks is now possible in minutes.

The hydrological element of the software has been designed to generate realistic design storm hydrographs in 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 peak flows 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.

NbS provide additional benefits when compared to traditional alternatives. NatureInsight quantifies the following benefits of implementing NbS in any user-defined catchment area in Great Britain:

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

Accessibility, proportionality, and efficiency are the fundamental benefits of this new product. This paper presents the functions of the tool and explains some use cases for developing business cases for NbS and engaging with stakeholders. The paper also includes examples of where the underpinning

methodology has already been applied on schemes in Ireland and Britain, and will discuss how these analyses contributed to developing business cases for including NbS on flood schemes of various scales.

1. INTRODUCTION

Earth is facing the interlinked emergencies of human-induced climate change and the loss of biodiversity as outlined in the 2022 WFF Living Planet Report, with both emergencies threatening the well-being of current and future generations. A strong body of international scientific literature provides evidence that climate change and its impacts are real, with the Intergovernmental Panel on Climate Change's (IPCC) Sixth Assessment Report summarising that global warming reaching 1.5°C in the near term, would cause unavoidable increases in multiple climate hazards and present multiple risks to ecosystems and humans (IPCC, 2023). It has become clear that failing to tackle these interconnected challenges will jeopardise future wellbeing and the ability to keep climate change within limits that can reasonably be adapted to, with the IPCC stating with high confidence that climate resilient development prospects are increasingly limited if current greenhouse gas emissions do not rapidly decline (IPCC, 2023).

The impacts of climate change are becoming increasingly evident (Met Office, 2023a). The autumn of 2023 produced several exceptional storms impact the UK. In October, Storm Babet brought very strong winds and heavy, persistent, and widespread rainfall to Scotland and much of Northern England (Met Office, 2023b). Storm Babet brought heavy rain and severe flooding to Midleton, County Cork in Ireland, damaging hundreds of properties. Storm Ciarán in November 2023 was exceptional for the time of year, bringing damaging winds to northern France and the Channel Islands (Met Office, 2023c). Setting this against the context of the numerous unprecedented floods globally in recent years, such as the flooding in Belgium, the Netherlands, and Luxembourg in 2021, and the devastating Pakistan floods in 2022, indicates the widespread impacts felt from flooding disasters.

Currently, the world is in the middle of a biodiversity crisis. There are over one million plants and animals that are threatened with extinction, with the Living Planet Index (LPI) showing an average 69% decline in monitored populations between 1970 and 2018 (WWF, 2022). A big driver behind the biodiversity crisis is land use change and decreasing habitats. The 2019 Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) report outlined that since the Industrial Revolution 75% of the world's land surface is significantly altered, and over 85% of wetland areas have been lost (IPBES, 2019). Ireland is one of the worst affected countries for wetland and peatland loss, with 90% disappearing from the landscape since 1700 (Fluet-Chouinard, et al., 2023), some of which can be attributed to the Arterial Drainage Act (1925).

One of the ways to build resilience to the emergencies is through Nature-based Solutions (NbS). The IUCN defines NbS as actions to protect, sustainably manage, and restore natural and modified ecosystems that address societal challenges effectively and adaptively, simultaneously benefiting people and nature (IUNC, 2023). NbS enable and provide benefits that flow from healthy ecosystems. The benefits of NbS are being increasingly recognised by governments, in particular within the pre-2020 Nationally Determined Contributions (NDCs), where at least 66% of Paris Agreement signatories included NbS in some form to help to achieve their climate mitigation and/or adaptation goals (Seddon, et al., 2019). This suggests that the strategic direction is towards greater uptake of NbS as a technique for addressing climate change mitigation and adaptation.

NbS that are focused on flood risk reduction are commonly referred to as Natural Flood Management (NFM) or Natural Water Retention Measures ((NWRM) and involve implementing features or making land use alterations to restore or mimic the natural functions of rivers, floodplains, and the wider catchment to reduce flood risk downstream (Yorkshire Dales National Park Authority, et al., 2018). Traditional methods of reducing flood risk often involve large concrete and metal structures in and around towns, often including walls and embankments which create a divide between communities and natural watercourses. Moreover, the benefit they offer to society is generally one dimensional, being focussed solely on flood risk, and the reality is that such infrastructure can have a large carbon footprint. However, there is an increasing demand to look at the wider landscape to manage flood risk, by slowing water down before it reaches towns and cities, and temporarily storing it within the landscape elsewhere during times of flood. Example NbS features could be reconnecting the river to the floodplain, features that can intercept runoff pathways and land use changes such as native ecosystem improvement through planting, or promotion of natural recovery through management alterations. NbS for flood risk reduction provides additional benefits when compared to traditional alternatives, with the potential to sequester carbon dioxide and improve habitat conditions for enhancing biodiversity. Demonstrating and recognising the multiple benefits provided is challenging, and this is one of the key barriers to their implementation.

2. BARRIERS TO NATURE-BASED SOLUTIONS

Depending on the type of flooding, Flood Relief Schemes (FRS) are typically funded either by local authorities or by national agencies responsible for risk management, such as the Office of Public Works (OPW) in the Republic of Ireland and the Environment Agency (EA) in England. Demonstrating the reduction in flood risk to properties is the primary driver in the development of business cases for unlocking such public funding. This is typically realised by detailed hydraulic modelling that can demonstrate how properties move between flood risk zones as a consequence of implementing a particular scheme design, for example moving from 0.02% to 0.01% Annual Exceedance Probability (AEP), and also economic modelling which forecasts the reduction in damages. Many skills exist across the industry for designing traditional flood risk management infrastructure, such as flood walls and embankments. However, skills in assessing the potential effectiveness of nature-based solutions, and designing them, are not currently widespread.

The entire FRM process from design to implementation can be time-intensive, for example due to the complexity of the modelling required and the number of stakeholders involved. It is generally a rigid and prescriptive process that may effectively pre-determine the type of solution that can be delivered by unintentionally ruling out alternative solutions due to their perceived complexity to investigate and implement. The degree of rigour is understandable, with the need to demonstrate value for the expenditure of public funds underpinned by robust quantification of the costs and benefits in terms of flood risk reduction. However, this rigidity can stifle innovation because the risks of introducing less well-established types of intervention, such as NbS that can have multiple additional benefits, are considered unacceptable. It also points towards a need to improve the tools available for assessing the effectiveness of NbS.

Policy mechanisms that recognise the value of the multiple benefits of NbS, like carbon sequestration and habitat enhancement, are not typically well developed. Therefore, when an NbS scheme is costed and compared to a traditional scheme, it is on a cost-benefit analysis based on flood risk reduction only, often resulting in an unfavourable outcome for purely NbS schemes. Moreover, schemes which include NbS may be less likely to get beyond initial assessment, because they are typically overlooked early in the optioneering process, often due to a skills deficit and a lack of high-level tools which enable proportionate assessment. It is argued that the future of flood risk management is not to utilise one or other type of established solution in isolation, but rather to embrace a portfolio of measures deployed holistically to realise the full potential impact in terms of demonstrating multiple benefits. There is general need for society to become more resilient to the impacts of a changing climate and NbS can help with this. Therefore, it is necessary to address some of the barriers which are preventing NbS from being fully appraised and implemented, and to improve confidence and understanding in assessing their potential effectiveness. Concurrently, a strategic commitment is required in terms of ensuring policy-level instruments are aligned with the general desire to increase uptake of NbS, so that organisations such as the OPW can be better equipped and empowered with the necessary training and resources to investigate different solutions to problems.

It is only by approaching these challenges from different levels that it will be possible to ensure the effective implementation of NbS in the landscape as part of the overall solution to address multiple problems, from flooding to the biodiversity crisis. For instance, one policy instrument to explore is building capacity and empowering relevant risk management authorities to engage with landowners and adequately remunerate the latter for the ecosystem services provided by periodic strategic flooding of their land. One example of this in England is the Environmental Land Management (ELM) scheme to support the rural economy while achieving the goals of the strategic long-term environmental plan (UK Government, 2023). Moreover, one of the key factors in developing options for NbS is maintaining flexibility in how the solution could be delivered, and the speed at which new insights can be generated. For instance, if a previously engaged landowner suffers a change of circumstances and can no longer be part of the process, it is important to be able to pivot quickly and efficiently towards alternative solutions.

Whilst there may be a general desire to embrace NbS where possible within scheme designs, the impact of the barriers described above is that often they are disregarded. One of the ways in which some of these barriers can be reduced is through rapid and proportionate investigation at an early initial assessment or optioneering phase. There is also a need for upskilling and empowering people working on such projects to use such tools. This paper presents the development and application of one such tool for high-level mapping and modelling of NbS, 'NatureInsight'.

Since there are relatively few examples of NbS applied to flood schemes, particularly at larger catchment scales, the evidence base is less well established. Due to the complexity of the interconnected processes which occur as a result of implementing NbS in the landscape, their behaviour is not well understood or represented, even by the most complex physically-based models used in the research community, such as SHETRAN (Ewan et al., 2000). Without implementing such schemes at scale and monitoring them, before and after, it is difficult to improve and validate this understanding. Complex processes which may be qualitatively described as 'slowing the flow' or 'increasing the surface roughness' are extremely difficult to quantify with confidence without experimental evidence to enhance modelling efforts. Therefore, the focus of the methods developed and presented in the following section is around the provision of storage through NbS, because the effect of storage to reduce peak flows is more readily quantifiable than some of the other more complex processes.

3. METHOD DEVELOPMENT

Methods for assessing NbS have gradually developed over the past two decades, primarily in the context of NFM/NWR for reducing flood risk. Different researchers and practitioners have contributed to expanding collective understanding. The methods developed as part of this tool incorporated available research, but were predominantly informed and validated where possible by experience gained through involvement with a number of different projects, gradually increasing in catchment scale. The most relevant projects which informed methodological developments are shown in Figure 1.

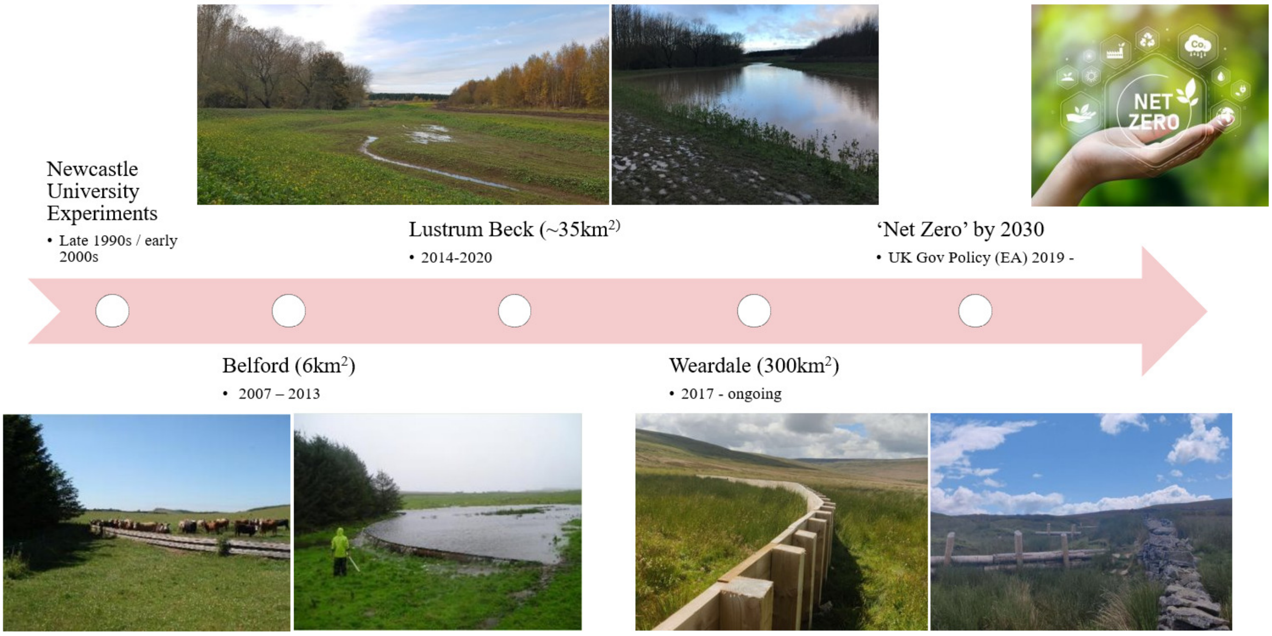

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***Figure 1:** Timeline of the evolution of NbS for flood risk management (NFM) in the context of the authors' experience*

Many of the projects up to 2019 were borne out of research-led initiatives supported by risk management authorities and councils, such as the Belford NFM project (Nicholson et al., 2020), which was supported by local levy funding. Since 2019, the EA's strategic commitment to achieving 'Net Zero' by 2030 has led to increased focus on NbS. The methods and tools developed over many years were consolidated into an overarching methodology used by Arup, broadly outlined in Figure 2, where the 'NbS Toolkit' refers to a suite of ten interventions, each one comprising a set of ascribed assumptions. These are outlined in Figure 6*: Opportunity map from NatureInsight showing a proposed NbS scheme in the 180km2 River Wansbeck catchment* in Section 5. For example, a Runoff Attenuation Feature (RAF) is assigned a fixed area, a bund height, a diameter of outlet pipe and a fixed volume of $500m^3$.

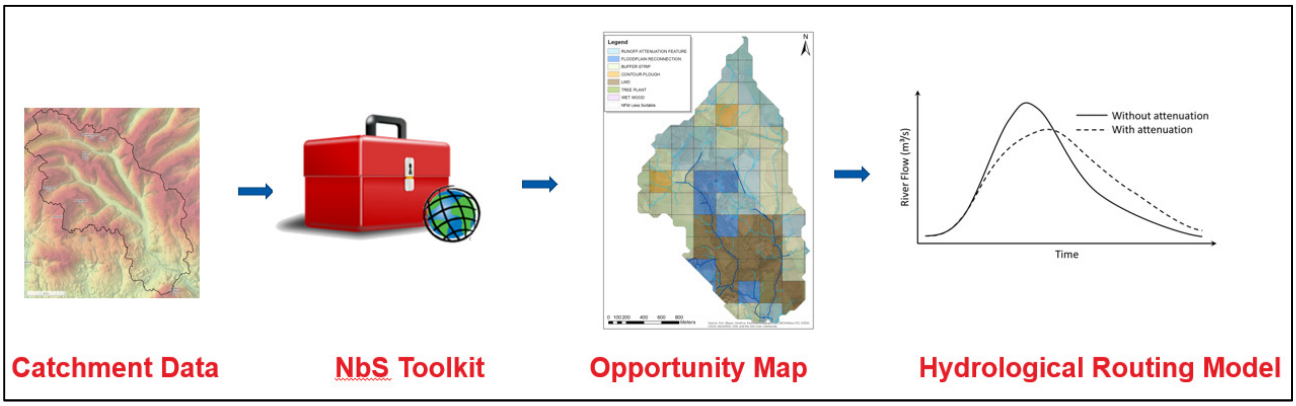

***Figure 2:** General workflow used by Arup for the strategic assessment of NbS at the catchment scale*

Through a scoring system refined and validated on projects over several years, a multi-criteria analysis was developed to determine suitability scores for each of the ten types of NbS intervention. Geospatial data relating to the study area are critical for this process, such as land use information, agricultural soil classification, habitat and topographical data. This analysis was implemented on a gridded basis, with different size of grid squares being tested ranging from 50m to 1km. After various iterations and engagement with stakeholders and landowners, a grid resolution of 250m was selected as being a reasonable trade-off between providing enough resolution to be useful versus too much detail leading to be off-putting in terms of proportionality for the early assessment stage.

An example output map is shown in Figure 3 below for a study area around Midleton comprising multiple sub-catchments. Aggregated values derived from the opportunity mapping link through to the hydrological modelling element of the method. This comprises a simple conceptual 'bucket' model for routing flows through a catchment. The model can either be lumped at the catchment scale or semi-distributed, where the catchment is split into sub-catchment. The current 'Aggregate Storage Model' was based on the pond network model (Nicholson et al., 2020), developed for modelling the hydrological impacts of the interventions installed as part of the Belford NFM project. Figure 5 in Section 4 shows a conceptual representation of the model. In the case of Midleton, while the opportunity mapping showed good potential for implementing NbS, the storage modelling showed that a very large volume of storage would be required to have a significant impact on peak flows (Arup, 2021). Moreover, the NbS proposed in the catchment would only address the fluvial flood risk and not the coastal risk, which is also high.

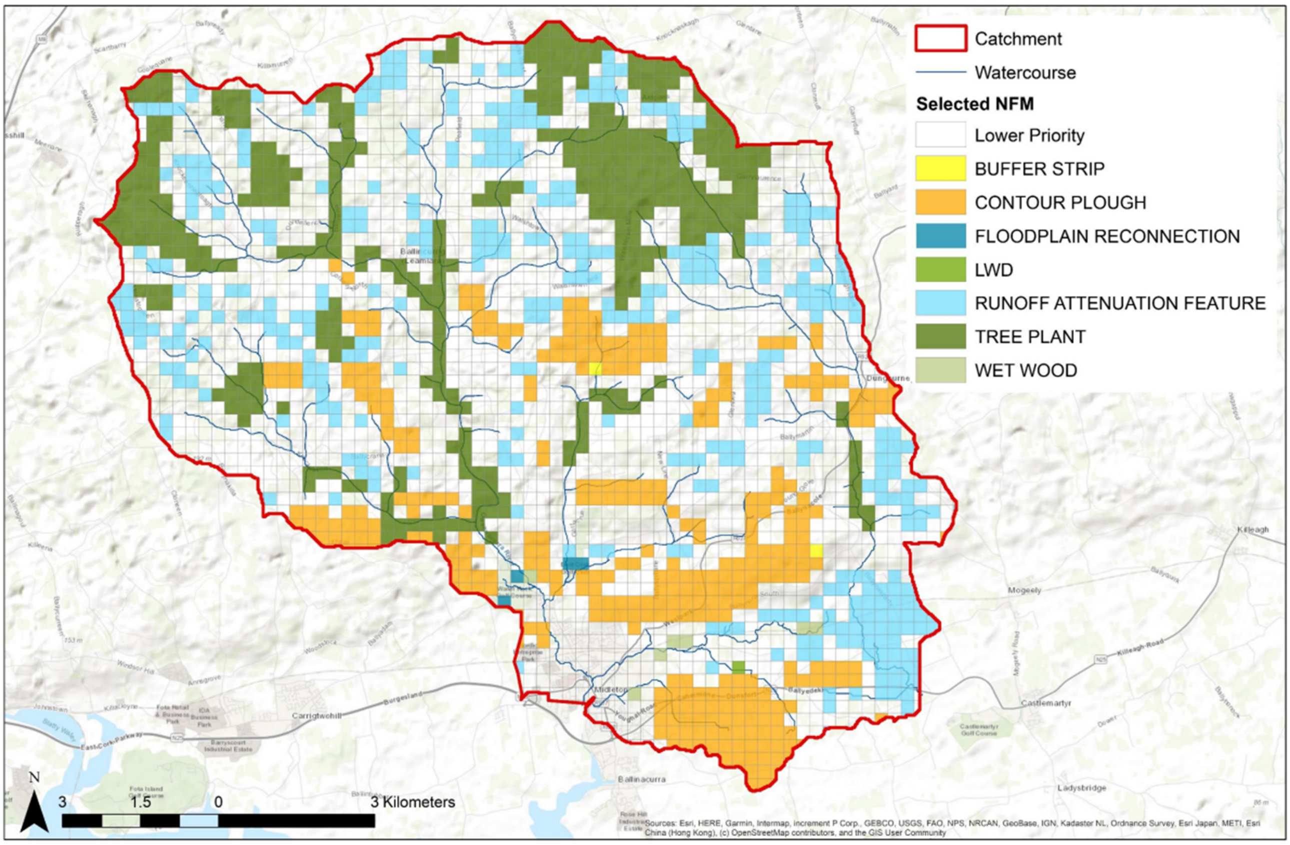

Figure 3: *Opportunity mapping assessment from the fluvial catchment draining to Midleton, Co. Cork (2021)*

As these components were developed and refined over time, it became clear that automating elements of the process within a framework, and making it more interactive, would improve the ability to map and model NbS at scale. This led to discussions around how such a product could be created to operationalise the process and make it more accessible for as many people as possible. Through a partnership with data algorithm specialists SCALGO, a new tool was developed which brought together the mapping and modelling methods within the SCALGO Live platform to produce the new module, NatureInsight.

4. NATUREINSIGHT

NatureInsight is a web-based mapping and modelling software application co-developed by Arup and SCALGO. It was designed to instantaneously produce interactive mapping of NbS opportunities within any user-defined catchment area in Great Britain. It also provides high-level quantitative estimation of the impact of NbS interventions in terms of reducing peak flows, sequestering carbon dioxide, and enhancing habitat. NatureInsight has three distinct capabilities for aiding NbS assessments:

1. Catchment Descriptions: summary of key high-level statistics and attributes for a catchment.
2. Opportunity Mapping: mapping the potential suitability for NbS across a catchment. Attached to this is the functionality of summarising key outputs for a catchment area, such as the types of interventions or the potential carbon sequestration.
3. Hydrology – Assessing Peak Flow Reduction: A built-in hydrological model that can calculate the peak flow reduction from increased storage in a catchment.

4.1 Catchment Descriptions

NatureInsight has the functionality to describe the baseline characteristics and attributes within a catchment. SCALGO Live has the existing capability for users to define watershed (catchment) areas. This tool routes water between cells based on the elevation from a Digital Elevation Model (DEM). Flow pathways are created from this, referred to as the ‘flow accumulation’ layer, which can readily be queried to dynamically create user-defined watersheds (catchment boundaries) (SCALGO, 2023a). The depression-free flow in SCALGO Live shows how water flows without taking active depressions into account (all are treated as full), and the water will keep flowing until it reaches the sea (SCALGO, 2023a).

For any defined watershed the tool makes calculations for a range of catchment characteristics, predominantly based on the percentage area of different datasets. For example, land use is described by the percentages of CORINE Land Cover (CLC) (Cole et al., 2021) and Agricultural Land Classification (Natural England, 2019). Similar descriptors are generated for slope, Standard Average Annual Rainfall (SAAR), Degraded peat, flood zone percentages, as well as several other parameters. Baseline habitat and carbon dioxide sequestration are also calculated. Baseline carbon dioxide sequestration is derived from the percentage of CORINE (2018) land use cover, with baseline rates attributed to each land use type after extensive literature review. The baseline carbon dioxide sequestration rates have been derived from the 'Carbon storage and sequestration by habitat’ study (Gregg et al., 2021) and from the Woodland Carbon Code (2019).

A similar approach is taken with the baseline habitat units, which represent part of the Environment Agency’s (England) Biodiversity Net Gain (BNG) Habitat Units calculation. Equation 1 outlines how baseline habitat units have been calculated. For England the ‘Living England Habitat Map’ (Natural England, 2023) has been used to attribute assumed values for distinctiveness, with Wales being based on the ‘Phase 1 Habitat Survey Data’ (Natural Resources Wales, 2023), and Scotland using the ‘Scottish Habitat and Land Cover Map’ to repeat this process across Great Britain. Condition is assumed to be moderate across all habitat types.

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

$$Habitat\ Units = Baseline\ Distinctivness\ Score\ x\ Condition\ Score$$

4.2 Opportunity Mapping

As described in Section 3, the Opportunity Mapping process is an Arup-developed method for scoring the suitability of NbS across a catchment or study area. The method is a multicriteria analysis that determines the suitability scores for ten types of NbS in 250m (6.25ha) grid squares. The ten NbS assessed within the tool have been selected in the context of flood risk reduction, and are described as follows: runoff attenuation features, floodplain reconnection, tree planting, buffer strips, peat management, grip blocking, soil management, large woody debris (LWD), wet woodland, and gully stuffing. The method suggests one type of intervention per grid square, which may be a conservative assumption in some locations. Importantly, the assumptions are consistent across Great Britain, which means an objective classification is possible.

Each grid square contains statistics derived from datasets representing land cover, slope, runoff pathway length, agricultural land classification and flood risk. A score is allocated to each intervention for each dataset, depending on its suitability. For example, a runoff attenuation feature (RAF) would receive a high score in an area with a low slope and a low score in very steep area (due to the limits that would impose on water storage in the RAF). The multicriteria analysis produces one output score for each intervention type in every grid cell. Other datasets such as soil texture, detailed aspect method of scoring (DAMS) and peat degradation are then used to refine the scoring for particular intervention types. The highest-scoring intervention type per grid cell is then displayed on the map by default. More or less NbS can be instantly displayed on the map by adjusting the threshold score slider, with all interventions (ranked out of 5) displayed when the threshold score is set to zero. As the threshold score is increased, the displayed interventions are refined.

Each NbS intervention then has a suite of assumptions relating to construction cost, storage volume, potential for carbon sequestration, change in habitat and the area occupied by the intervention. For some interventions, these variables are a function of the existing land cover, e.g., tree planting or soil management. These assumptions are calculated and available within any grid square in NatureInsight, as well as summarised for any catchment area of interest.

The default interactive map displays the most suitable NbS intervention when flood risk mitigation is prioritised. It is also possible to change what is prioritised with the aim of maximising the potential for either carbon sequestration or habitat enhancement. Carbon sequestration is calculated by assigning baseline sequestration rates to different intervention types. The net sequestration rate is calculated as the baseline rate subtracted from the baseline-with-intervention, also ensuring removal of potential double counting arising from the change of prior land cover to the proposed land cover. Habitat units are calculated by using habitat distinctiveness and assuming a condition of moderate for the baseline habitat. Net habitat units are calculated in a similar way to carbon sequestration. Note that both carbon sequestration rate and habitat units can be negative when an intervention has been applied in a grid square. It is also possible to interact with the map by adjusting the score at which interventions are displayed and by selecting the first, second, third (etc.) ranked intervention.

4.3 Hydrology – Generating Design Storm Hydrographs and Assessing Peak Flow Reduction

The hydrological element of the software has been designed to generate realistic design storm hydrographs within a user-defined catchment or sub-catchment area. It is underpinned by the application of established methods (often empirically derived) to provide a simple representation of hydrological processes within a catchment. These methods are often not industry standard within the UK and the hydrographs produced in the tool are not always an accurate reflection of the hydrology in any given catchment when compared to industry standard methods. However, this component of the tool can be used to provide a good indication of whether storage interventions installed via NbS or other storage infrastructure could be useful, in any ungauged user-defined catchment area, for a given storm event AEP.

The hydrological model structure contains conceptual elements derived from widely cited empirical methods, but at its core, it is fundamentally a spatially distributed model. The different elements of the hydrological model are described in the schematic in Figure 4, which shows that four key components comprise river flow: rainfall, runoff, routing and baseflow. NatureInsight has been developed with methods to estimate each of these for any user defined catchment area. Default parameters for any catchment can be automatically set using an underlying hydrology of soil types dataset and other formulae. These have been have been compared against industry standard methods. All parameters can be adjusted dynamically to account for local data or knowledge and the impact on the hydrograph can be seen instantaneously. This produces a final hydrograph for a given rainfall return period (AEP).

4.3.1 Rainfall

A rain event is specified as a depth of rain falling at a location. In SCALGO this is defined across the elevation model (e.g., each raster cell), with the rain events aggregated from the raster cell scale to the catchment scale. The rainfall depth falling on a grid square is routed using the SCALGO Live flow routing model.

The design storms use Parameterized eXtreme Rainfall (PXR) data for a range of AEPs, which are based on Intensity-Duration-Frequency curves at a global scale (Courty et al., 2019). In the model, the rainfall is made up of three components, depth, duration, and temporal distribution. The rainfall depth is derived from the 24hr PXR dataset for all catchment areas. The distribution is assumed to be spatially uniform, and a winter temporal distribution (as defined in the Flood Estimation Handbook (FEH) (Faulkner, 1999)) is used as a default. The duration of the storm within NatureInsight will be 24 hours as a default for any user defined catchment.

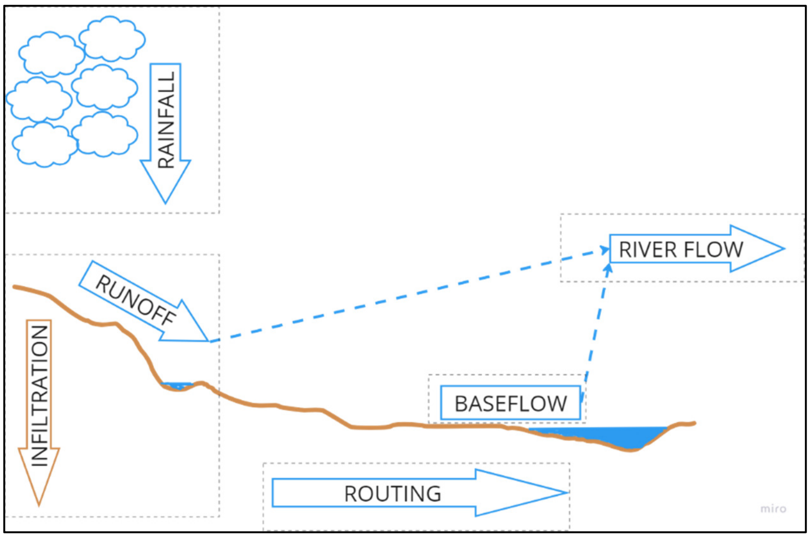

Figure 4: *Schematic of the NatureInsight hydrological model structure*

4.3.2 Runoff (or Infiltration Percentage)

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 across the literature, including SCALGO's White Paper for the Rainfall-Runoff Model (SCALGO, 2023b). In the development of NatureInsight two methods were tested for calculating the runoff (or infiltration percentage, which is the inverse of runoff) from design storm rainfall. One method is the well-established Curve Number (CN) method developed by the US Soil Conservation Service (now Natural Resources Conservation Service (NRCS)), which is an empirically based relationship between rainfall and runoff. A global curve number (GCN) that was published in 2019 and known as GCN2050 (Jaafar, Ahmad, and Beyrouthy, 2019), was used test the CN method.

The second method considered used a simplified adaptation of the FEH industry standard method for calculating the standard percentage runoff (SPR) that traditionally uses the Hydrology of Soil Types

(HOST) dataset from soil map data. A method published in 2007 (Schneider et al., 2007), outlines a process for reclassifying the Soil Geographical Database of Europe (SGDBE) at 1:1 million resolution into the HOST system, from which an ‘open’ HOST dataset for Great Britain was created to generate ‘open’ standard percentage runoff values for the catchment areas.

The ‘open’ HOST method was selected in preference over the global curve number NRCS method for calculating runoff, based on its ease of implementation and in general the prediction of the runoff coefficient being closer to that of industry standard results, on average across a range of different types of catchment area.

4.3.3 Routing

The routing element introduces a time component into the model, as after landing on the surface as rainfall, water moves over and through the landscape at different rates. As discussed above, some rainfall is ‘lost’ to various processes before runoff occurs. For the remaining runoff, the rate of travel (distance per unit time) is dependent on a range of catchment factors such as slope, catchment size, and land use. This is a complex process, which is affected by multiple factors. To represent this process conceptually, assumptions were made to ‘average out’ the behaviour at the catchment scale. In NatureInsight this is represented as an averaged velocity across a user-defined area, which is either at the catchment or at the sub-catchment scale.

The averaged velocity has been calculated using an adapted version of the NRCS velocity method, which is a method developed by NRCS. The concept of the NRCS method is that travel time is a function of runoff flow length and flow velocity (Fang et al., 2007). Conceptually, the velocity (V), the length of longest flow pathway from catchment outlet to source (L) and the travel time (T) are related such that V = L / T. But, to calculate the ‘catchment average velocity’, it is first necessary to calculate the response time of a catchment. One measure of this is 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’ (Gericke and Smithers, 2014). There are multiple ways to estimate the time component, NatureInsight uses an adapted version of the NRCS method. This is based on the Perdikaris et al. (2018) process for implementing the method using SI Units. Equation 2 outlines the components for T_c, which describes the different components of flow represented by sheet, shallow and channel.

Equation 2: *Summary of formulae used in NRCS method, adapted from Perdikaris et al. (2018)*

$$T_C = T_{sheet} + T_{shallow} + T_{channel}$$

NatureInsight calculates T_c by only considering the $T_{channel}$ part of the equation, which is represent by Equation 3. 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. Efforts are ongoing to improve the representation of the time-component and all other elements of NatureInsight. Equation 3 is then used to calculate an average velocity across a user defined catchment area.

Equation 3: *Description of the $T_{channel}$ component of the NRCS method, adapted from Perdikaris et al. (2018)*

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

Where:

L – in NatureInsight this represents the length of the longest flow path in a catchment (in the original method this is Lc which is the length of channel flow),

n – is the Manning’s’ roughness coefficient which is defined as a constant value of 0.3 in NatureInsight,

i – *represents the 2-year 24-hour rainfall (mm) derived from PXR dataset,*
A – *in NatureInsight this represents the catchment area (km2) calculated from SCALGO's Watershed Tool,*
Sc – *the main channel slope, which in NatureInsight is calculated as the average slope of the longest flow pathway in the catchment*

4.3.4 Baseflow

Conceptually, streamflow can be separated into runoff and baseflow. Runoff is described in 4.3.2 and represents the component of flow that occurs as a direct result of a storm event, and baseflow is generally defined as the portion of streamflow that is sustained between precipitation events, which can include the delayed subsurface runoff from the current storm. Therefore, baseflow can either be represented as constant, or it can fluctuate over time. Two methods of evaluating the baseflow were investigated, one using the derived HOST method described in 4.3.2, and the second using the FEH formula for baseflow.

The FEH (1999) method, from Section 2.4.3 (Houghton-Carr, 1999) for estimating constant baseflow, was found to be produce a better estimate. It is estimated from catchment descriptors using a generalised model derived by regression analysis. This formula uses three parameters, the Standard Annual Average Rainfall (SAAR, mm), catchment Area (km^2) and the Catchment Wetness Index (CWI, mm). The baseflow formula can be written as:

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

In FEH (1999), the CWI is determined directly from SAAR using a graphical relationship, which was converted into a simple function. The revitalised flood hydrograph methods (FEH, 2005) 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. The equations produced for baseflow in FEH (2005) are more complex to implement due to several additional parameters. So as a pragmatic solution for the NatureInsight model, the formula from the FEH (1999) publications was used to apply a uniform baseflow. It is accepted that there are limitations with this approach, it is noted that the concept of CWI incorporates theoretical and practical concerns, as outlined by Young (2019).

4.3.5 Storage Assessment

The aim of the storage component within NatureInsight is to interact with and alter the hydrological flows in a way that can realistically represent the behaviour of well-designed NbS and the storage they provide within a catchment. This is a methodology that has developed over time and is based on the Arup developed Aggregate Storage Model (ASM), which utilises the Pond Network Model (Nicholson, O'Donnell and Wilkinson, 2019). A schematic of the ASM is shown in Figure 5.

Storage volumes can be allocated to a catchment, or sub-catchments within a wider catchment, with the impact of storage on hydrographs being assessed. The impact of storage on the hydrograph can be examined both at the sub-catchment outflows and at the overall downstream flow point of interest. The storage in a sub-catchment (or catchment) can be comprised of a number of 'ponds' (or pond objects), which can be identified by the opportunity mapping. This allows, for example, a sub-catchment with 7 identified floodplain reconnection features, to represent the total storage across seven 'ponds'. The number of ponds are an essential component of the storage unit as the number of attenuation features dictates how rapidly the overall storage unit can drain.

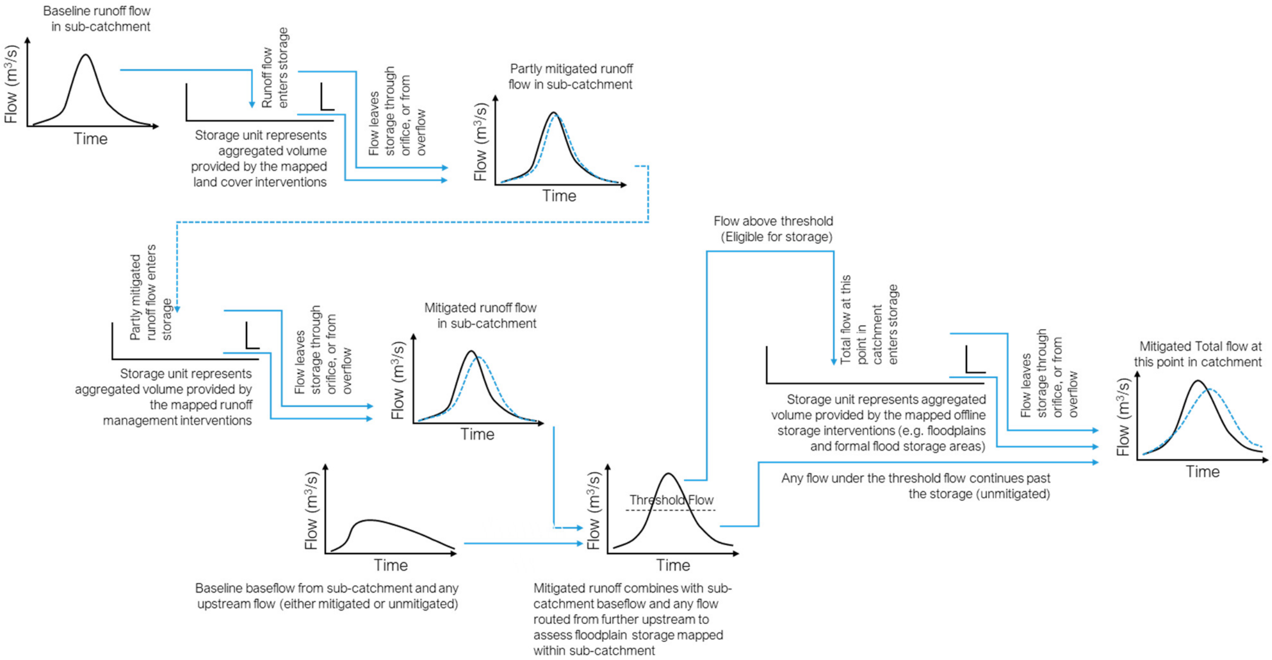

Figure 5: *Conceptual schematic of the storage model used in NatureInsight*

The ten NbS interventions are categorised into three different 'bucket' types, to represent the different ways that different storage types interact with the hydrograph. The three forms are land use, runoff, and floodplain. Each type has a range of assumptions associated with it. Storage values can be imported directly into the hydrograph from the NbS opportunity mapping for a catchment, along with default storage parameters based on knowledge of the types of interventions and the catchment baseline information. The potential impact on the peak flow hydrograph at the downstream point of interest is displayed with a mitigated and non-mitigated hydrograph, and the storage parameters can be adjusted within acceptable bounds to maximise their impact on reducing the peak flows.

5. NATUREINSIGHT RESULTS – RIVER WANSBECK CATCHMENT CASE STUDY

NatureInsight can be used to assess the NbS potential in any user-defined watershed/catchment in Great Britain. An example case study for the River Wansbeck catchment upstream of its confluence with the River Font near to the village of Mitford in Northumberland, is presented. This will be called the River Wansbeck catchment in this paper.

The River Wansbeck catchment is in the north east of England, north of Newcastle upon Tyne and west of Morpeth. The two main watercourses in the catchment are the River Wansbeck and the Hart Burn. NatureInsight summarises the baseline characteristics of a defined catchment, of which a selection are summarised in

. The River Wansbeck catchment is approximately 180km^2, with its predominant land cover according to CORINE (2018) being pastures, with significant areas of non-irrigated arable land and natural grasslands. The ability to summarise these high-level statistics at this scale is a process that traditionally would have required a multi-step geospatial assessment and access to a software capable of undertaking the analysis. The web-based NatureInsight module on the SCALGO Live platform facilitates instantaneous high-level understanding about any study area of interest, summarising catchment statistics as in

.

Table 1: *Baseline Characteristics for the Wansbeck Catchment*

Baseline Catchment Characteristics	
Downstream Outlet (British National Grid)	417339, 585899
Catchment Area (km^2)	179.74
Length of Longest Watercourse (km)	46.1
Baseline Habitat Units	120,000
Baseline Carbon Sequestration (TCO^{2}e/yr)	26,500
Corine (2018) Land Cover	Industrial or commercial units - 0.09 % Sport and leisure facilities - 0.06 % Non-irrigated arable land - 25.75 % Pastures - 45.89 % Land principally occupied by agriculture, with significant areas of natural vegetation - 0.3 % Broad-leaved forest - 0.57 % Coniferous forest - 6.12 % Mixed forest - 0.79 % Natural grasslands - 9.98 % Moors and heathland - 7.3 % Transitional Woodland Scrub - 2.37 % Peat bogs - 0.63 % Water bodies - 0.15 %
Agricultural Land Classification	Grade 3 - 49.92 % Grade 4 - 17.91 % Grade 5 - 27 % Non-agricultural - 5.17 %
Texture	Clay -15.28 % Silty Clay Loam - 86.31 % Silty Loam - 0.02 %

An NbS scheme was designed for the River Wansbeck catchment in NatureInsight, shown in Figure 6, where a range of NbS features have scored well, predominantly RAFs (dark blue) across the upstream catchment area and soil management (yellow) in the downstream.

This mapped NbS scheme was then assessed in the hydrological component of NatureInsight. A design storm hydrograph was generated for a 1 in 20-year event, with the default parameters within the tool being used to generate this for the River Wansbeck Catchment. More detail on each aspect can be found in *4.3 Hydrology*. Each of the calculations for the following four parameters are embedded within NatureInsight.

Rainfall – The distribution used was a temporal winter distribution (as defined in the Flood Estimation Handbook (FEH) (Faulkner, 1999)) and a uniform spatial distribution. A 46mm depth of rainfall was derived for the 24hr PXR rainfall dataset (Courty et al., 2019), and a storm duration of 24 hours was used.

Runoff – A standard percentage runoff (SPR) of 35.3% was calculated for the catchment, derived from the 'open' Host mapping that has been developed (using the method from Schneider et al., 2007). Therefore, an infiltration rate of 64.7% was used for this catchment.

Routing – The adapted version of the NCRS method (based on the Perdikaris et al. (2018) process) was used to determine the velocity in the catchment. This uses an adapted version of the $T_{channel}$ component. For the River Wansbeck the catchment average velocity was estimated to be 1.04m/s.

Baseflow – The catchment baseflow was calculated as 4.24m^3/s, using the formula from FEH (1999).

A storage assessment was carried out on the 1 in 20-year event design hydrograph that was generated. This was done by applying the storage volumes calculated as part of the opportunity mapping, distributed across the three 'bucket' types (land use, runoff and floodplain). NatureInsight has the functionality to adjust certain storage parameters. For example, the flow threshold at which interventions become active in the case of floodplain reconnection-type features, or the outlet pipe diameter which controls the rate of flow discharged from the interventions. Figure 7 shows results of the hydrological storage assessment for the River Wansbeck catchment for a 1 in 20-year return period. These indicate that a potential peak flow reduction of 8.4% could be achieved based on the proposed NbS scheme from Figure 6. This is a high-level estimation and could likely be further optimised.

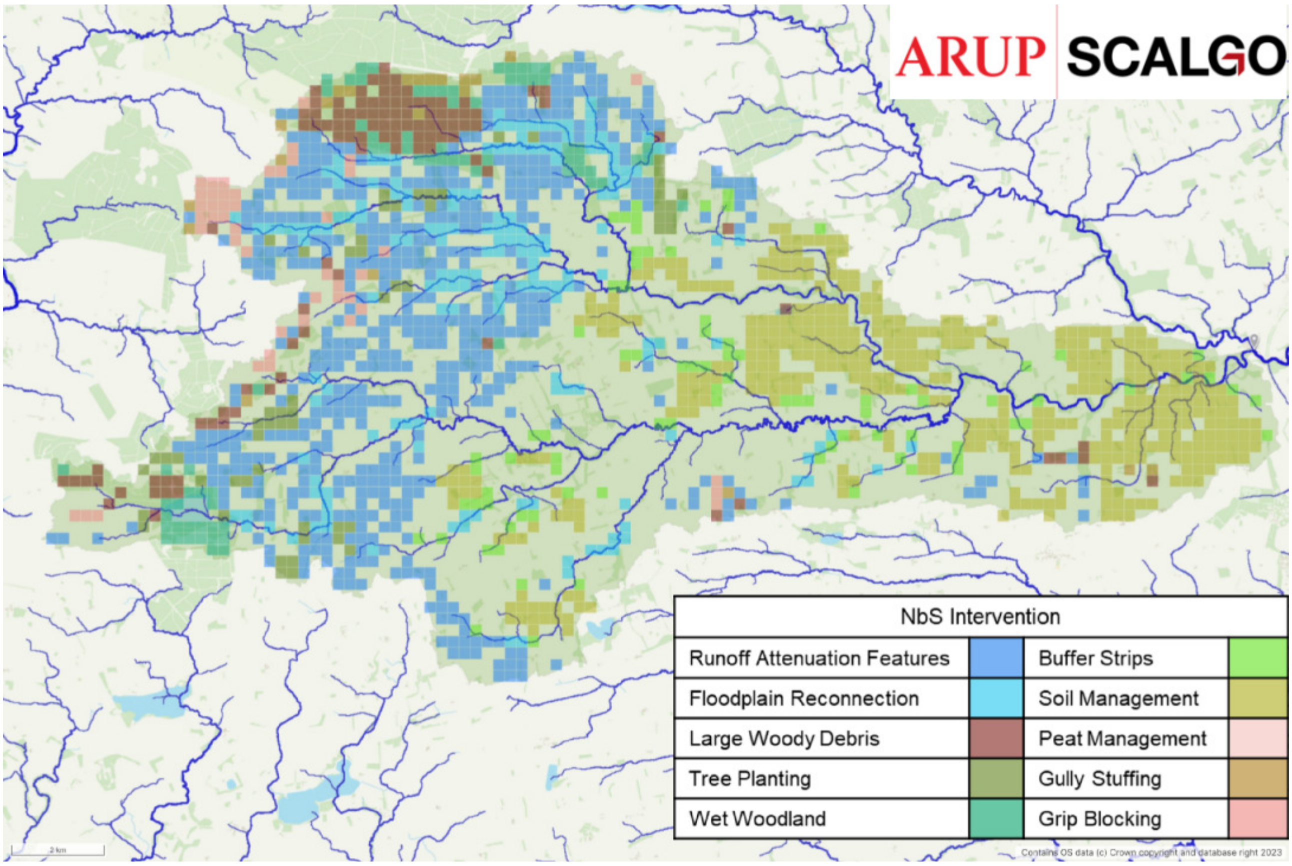

Figure 6: *Opportunity map from NatureInsight showing a proposed NbS scheme in the 180km^2 River Wansbeck catchment*

The results show that alongside the observed reduction in peak flow, the time to peak has also increased, slowing the flow in the River Wansbeck catchment. This storage assessment has considered the whole catchment, but NatureInsight has the functionality to split a catchment into multiple sub-catchments and assess the impact of the storage on individual sub-catchments as well as at a downstream location, which is useful if there are flood risk receptors at multiple locations in the catchment. Assessing the impact in this way allows for any potential synchronicity to be identified and provides the ability to assess whether flood peaks might increase in other parts of the catchment due to the designed NbS scheme.

Key functionality of NatureInsight has been demonstrated for the River Wansbeck catchment. This would take an experienced user around 15 minutes to produce. NatureInsight is designed to be a tool which minimises the key barriers stalling uptake of NbS in flood risk reduction on schemes. The level of detail that can be gained from the tool could feed into the business case process and be used to generate catchment summaries, gauging quickly how feasible NbS could be for any catchment in Great Britain.

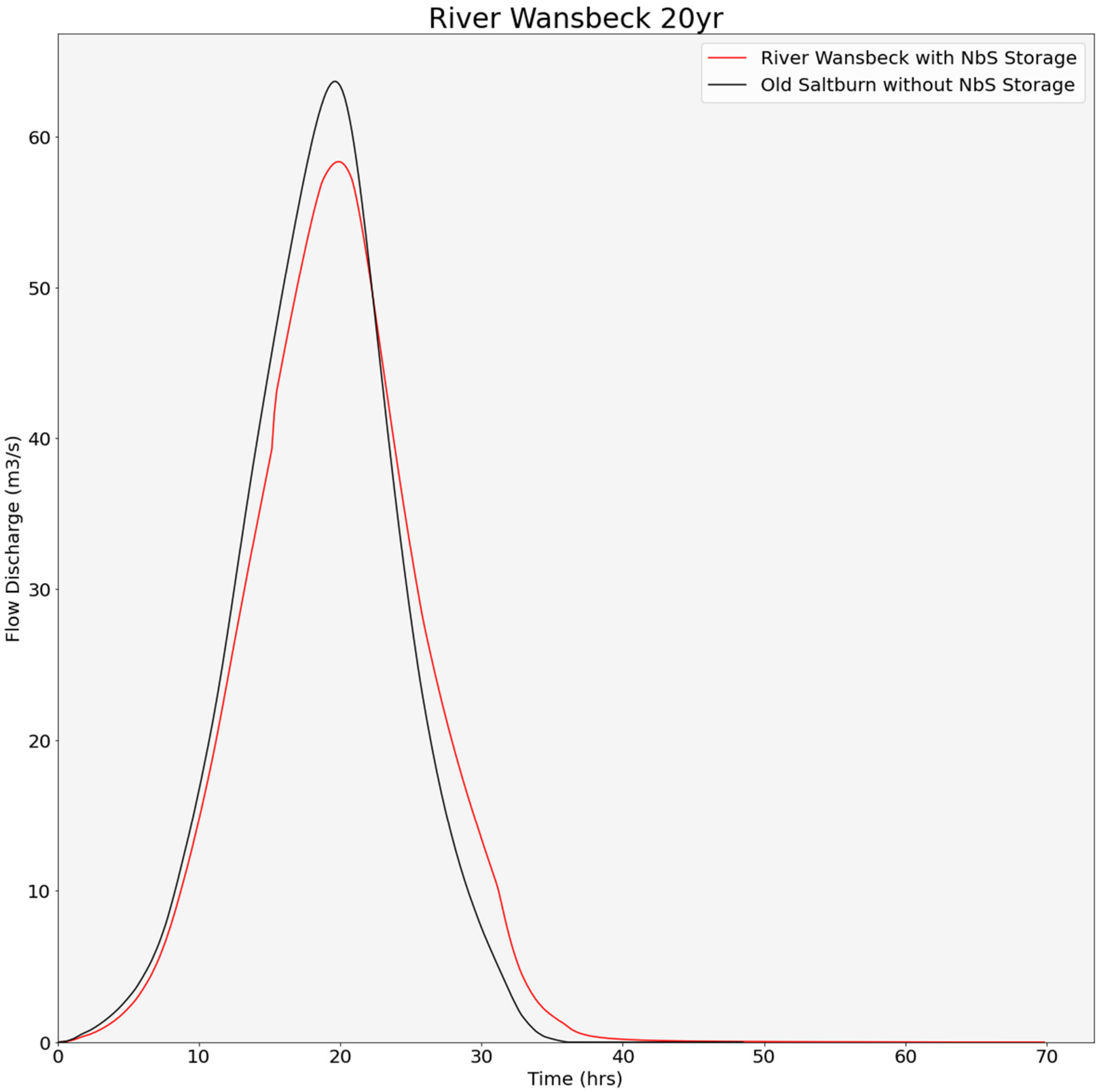

Figure 7: *Mitigated (red) and unmitigated (black) hydrographs from NatureInsight, showing an 8.4% reduction in peak flow at the outlet of the 180km^2 River Wansbeck catchment*

6. DISCUSSION AND CONCLUSIONS

Arup has co-developed a module with SCALGO called NatureInsight, which is contained within the SCALGO Live platform. It is an intuitive tool that applies knowledge developed over many years of methodological refinement within an architectural framework which uses cutting edge data processing algorithms. The end product is designed to be accessible even for non-technical users, although some technical knowledge will enhance the usefulness of the tool and provide greater understanding of and confidence in the outputs. NatureInsight is designed to break down some of the barriers, which prevent NbS from being implemented at scale, particularly in flood risk management projects.

NatureInsight is available for any location or catchment area in Britain, with multiple outputs being instantaneously available to subscribers. These outputs include baseline information such as physical catchment characteristics, carbon sequestration rates and habitat units. Next, a fully adjustable NbS scheme can be developed and implemented in the platform, with summary information available to view and download in an array of different formats. Report-quality maps can be produced, geospatial and time series data can be downloaded to inform business cases, including hydrographs demonstrating the extent of reduction in peak flows as a result of the scheme, for a variety of AEPs. The selected NbS scheme can be optimised, accounting for storage within different catchment areas, with sub-catchment-averaged statistical summaries available to inform any future more detailed modelling efforts.

It is envisaged that this tool will prove useful for a range of different organisations of different scales, from local wildlife and rivers trusts, through local councils to national scale organisations such as flood risk management authorities. Use cases will vary depending on the priorities of the user, but this tool will prove useful not only in the context of flood risk reduction, but also for example to those interested in climate change, biodiversity net gain and carbon sequestration. Outputs from the tool have already proven to be useful for nutrient management, nature markets and green financing projects.

Fundamentally, this platform provided a desk-based method by which a user can build an intuition around any catchment area rapidly. It is currently being used in industry as an efficiency-driving solution that allows much more to be done with the same resources, with the expectation that this will lead to greater implementation of projects on the ground. For example, the insights provided by a one-hour catchment analysis using NatureInsight can replace 2-weeks of full-time geospatial and hydrological analysis, and allows the user to be much more dynamic and flexible with changing circumstances.

NatureInsight provides a high-level evidence-based proportionate assessment of the potential for NbS to influence flood risk, carbon sequestration and biodiversity enhancement. It is most suitable at early stages of projects such as initial assessment and optioneering. More detailed methods should be used beyond these stages, to validate and refine the solutions developed by NatureInsight. There are many assumptions which underpin the tool, some of which are documented in this paper. These can always be refined to produce better results, for example, when more detailed datasets or methods are published. The process of continuous updating and refinement of the tool is one which Arup and SCALGO are committed to.

While the value of NatureInsight is being demonstrated in Great Britain, there is significant opportunity to expand the tool to other geographical regions. Depending on the climate, topography and nature of challenges present in different geographies, the type of NbS may need to be adjusted. The process of deciding which countries to prioritise expansion into is being led by the extent of the opportunity to implement NbS, by strategic commitments from relevant governmental and local organisations and authorities, and by the availability of high-quality data.

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