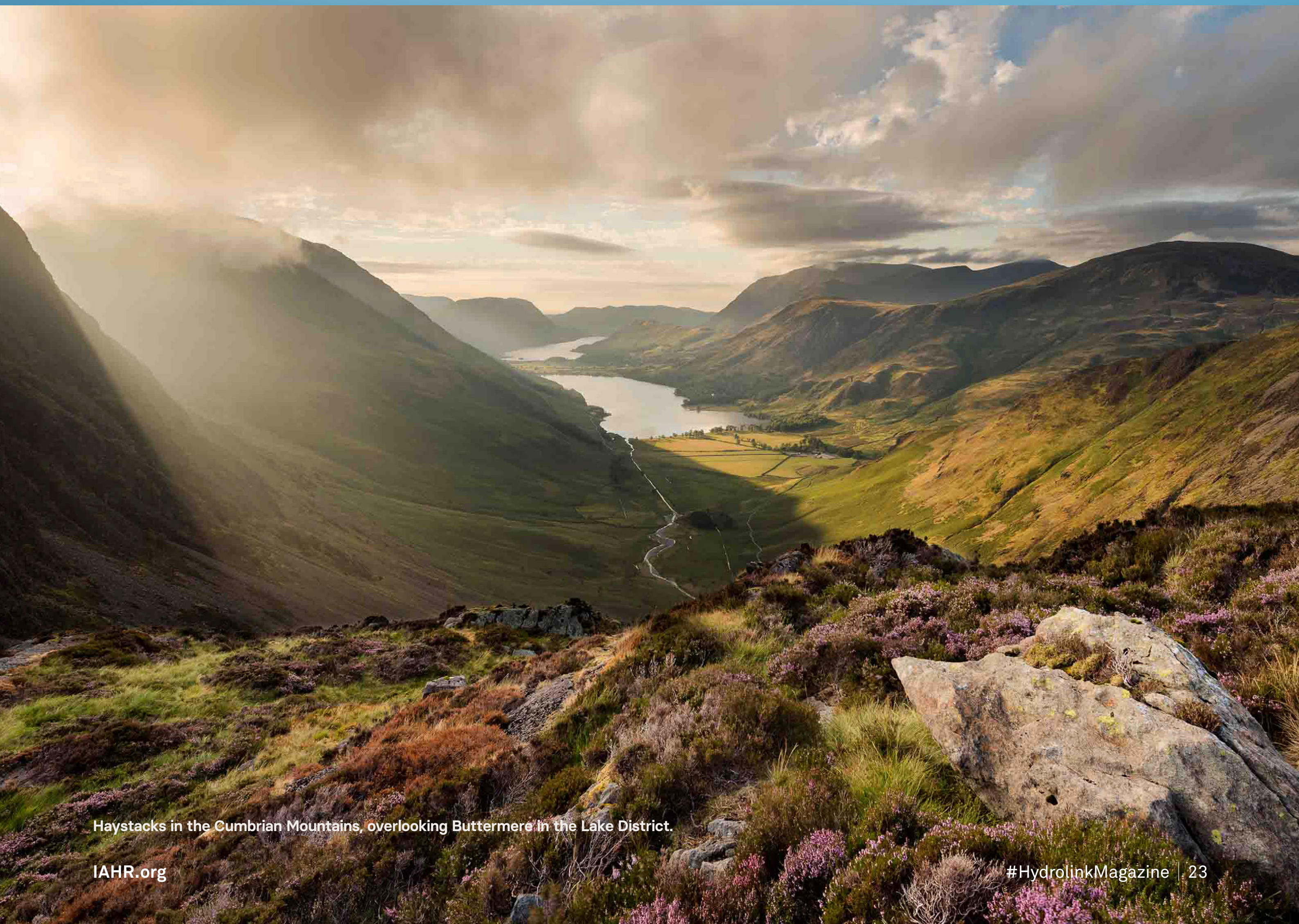
Pastureland interventions and farmer co-delivery for effective flood mitigation by NbS: Tebay case study, UK

By Nick A Chapell

Floodwater entering a person's home and fear of repeat flood incidents is a major social and economic problem across the world. This article illustrates a methodology for assessing the effectiveness of multiple types of Nature-based Solution (NbS) for flood mitigation applied to the same small catchment in UK. Farmer co-delivery proved invaluable to this pilot NbS scheme.



Haystacks in the Cumbrian Mountains, overlooking Buttermere in the Lake District.

Reducing the future risk of a home flooding requires that interventions are hydrologically effective. When the flows in a river or small stream overwhelm the channel capacity to cause flooding of homes, the volumes of water involved may be very large. Preventing the exceedance of channel capacity often involves enhancing temporary floodwater storage in the contributory area to the overtopping point. Alternative mitigation measures include diverting channel flows away from communities at risk, or by protecting homes behind local channel embankments or enhancing in-storm evaporative losses by tree planting. In recent years, interventions that do not rely on 'grey infrastructure' (features built from concrete, steel or plastics) increasingly are used to reduce this overtopping risk. Such interventions are called Nature-based Solutions, Natural Infrastructure, Blue-Green Infrastructure, and in the UK - Natural Flood Management (NFM). Those designing flood mitigation works based on NbS do however, ask scientists - What directly observed evidence do you have that shows the effectiveness of NbS at reducing flood peaks (that overwhelm channel capacity near homes)?

A team of scientists at Lancaster University (LU) in the UK have been working on this question since 2016, and using the evidence to inform models of rain-events that have flooded homes[1]. This research has focused on the 7000 km^2 Cumbrian Mountains in northern England. The majority of this region comprises of managed pastureland, farmed for lamb, beef and dairy products. The public sector (local government and agencies of national government), environmental charities (and their engineering contractors) and farmers have designed and installed these interventions on the pastureland. LU scientists have worked in partnership with these groups to measure and then model the local and regional effectiveness of the interventions. Representing the flood hydrograph reductions by the correct hydrological processes has been a core objective. Consequently, the hydrological process altered rather than NbS features (e.g., a woodland block) is the basis for classifying the interventions.

The core process shifts studied were: (I) enhanced wet-canopy evaporation by trees (EWE), (II) enhanced hillslope (surface) storage (EHS). including temporary storage ponds and features in eroded peatland, (III) enhanced in-channel storage (EIS) behind so called 'leaky dams', (IV) enhanced soil infiltration (ESI), and (V) enhanced floodplain storage (EFS). Note that (I) and (IV) are changes to a water-flux (m^3/s), while (II), (III) and (V) are changes to surface water storage (m^3).

A key finding from the Cumbria-wide measurement and modelling research was the very large volumes of temporary storage (or water-flux as 'equivalent storage') needed to reduce overbank flows during those flood events that affect homes in the region. In his region events of different return periods (from twice every year to 1-in-500 yr events) are primarily responsible for the risk that is being managed in specific communities. This is equivalent to over 10,000 m^3 of temporary storage for every square kilometre of catchment upstream of the flood-affected community. Given that the interventions need to work at times when channels are about to overtop, the equivalent volume may be better focused on a period of say 2 hours before and after flood-generating hydrographs. This gives an alternative target measure of 1,000 $m^3/km^2 \pm 2$ hrs of peaks[2]. It can be difficult to find the locations for this amount of equivalent storage using only one type of intervention (e.g., enhanced in-channel storage). Thus schemes using NbS to sufficiently reduce channel flows to prevent overtopping (for at least some events that flood homes), may require the cumulative, equivalent volumes to be achieved from a mix of different types of intervention. One example of where such 'stacking' of interventions has begun to be studied is the 5 km^2 Tebay Gill catchment, upstream of flood-affected homes in Old Tebay village, Cumbria (Lat. 54.439; Long.-2.593).

The types of NbS flood mitigation intervention installed in the Tebay catchment were firstly 'log-dams' to give enhanced in-channel storage, with some (e.g., Figure 1a) also delivering

Figure 1 | (A) Log-dam No. 16 including continuous level monitoring (B), and plank-dam No. 1 with continuous level monitoring and a discharge flume at the Tebay NbS scheme, Cumbrian Mountains, UK

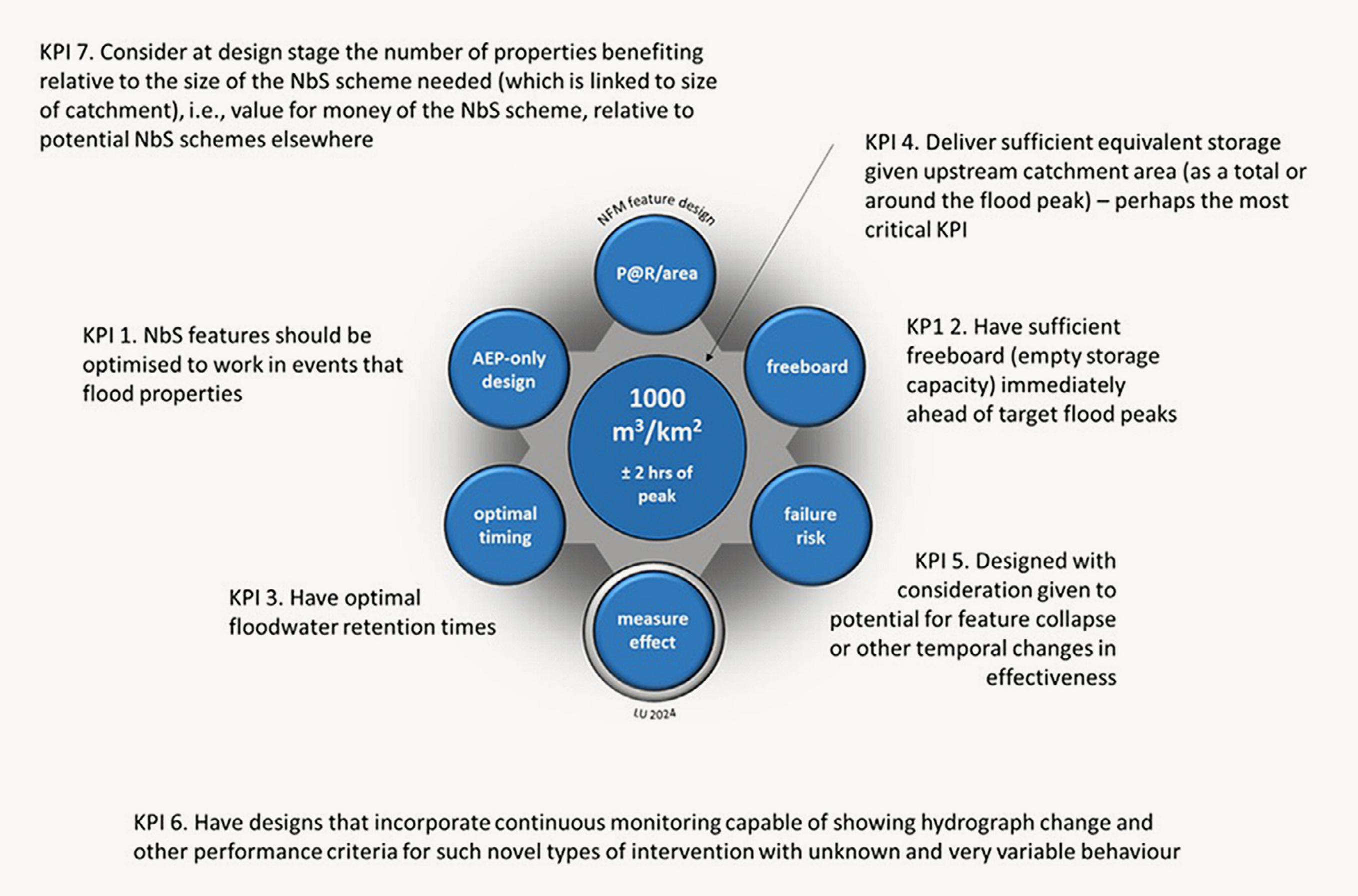


Figure 2 | Infographic for summarising Key Performance Indicators (KPIs) of NbS for flood hydrograph reductions developed by Chappell and Beven[2].

enhanced floodplain storage. A group of farmers (funded by the UK government via an environmental charity) designed and installed 77 such dams on the stream. Second, eroded gullies in the headwater peat soils were re-profiled and over 100 wooden 'plank-dams' were installed by a contractor working for another environmental charity to give enhanced hillslope storage (e.g., Figure 1b). Third, native trees were planted in specific areas. These were fenced off to prevent damage by livestock. To offset the loss of income to their businesses, farmers with grazing rights in the newly fenced areas were compensated. Delivery of enhanced soil infiltration comes as tree roots grow. As the tree canopies develop, enhanced wet-canopy evaporation will reduce the amount of storm rainfall reaching the ground. All of these interventions were installed in the upper 2.4 km^2 of the Tebay Gill catchment. Further downstream, one of the most proactive of the local farmers installed a bund to cut-off a key pathway of flood-water from the overtopping stream to the Old Tebay community. This NbS earth embankment was localised along a 170 m reach of the channel.

The LU scientists undertook measurements of the first three types of intervention at Tebay, but not of the fourth intervention. For interventions in Cumbria that involved surface storage, water-level in example storage features was measured continuously at a 5-minute resolution (e.g., Figure 1) and an instrument with an electronic theodolite combined with Electronic Distance Measurement was are used to transform level into volume time-series (of multi-year duration). This was combined with a continuous measurement of channel discharge using a pre-calibrated flume (e.g., Figure 1b) installed on the same channel. Incorporation of a channel discharge station into the experimental design allowed two key elements of storage-feature performance to be evaluated. First, comparison of the volume held at any instant with the frequency of recurrence of the discharge is possible. Second, by taking the first derivative of volume of water being added (or lost) to the temporary store (m^3/5-mins), these values may be directly equated with the measured channel discharge (m^3/5-mins). Thus, a direct observational evaluation of feature effectiveness was possible.

The findings from the Tebay measurements and analyses were, by design, pooled with those gained from very different sites across the Cumbrian Mountains.

While these sites contributed to the evaluation of the 'effectiveness criteria' of 10,000 m^3/km^2 and 1,000 m^3/km^2 ± 2 hrs of the flood peak, Chappell and Beven[2] identified other Key Performance Indicators, KPIs (Figure 2) to be summarised within a new infographic. This new, semi-quantitative infographic is presented for the first time for a single research site ('Tebay NbS pilot') with four very different NbS types (Figure 3). Scoring each of the seven KPIs, according to a 'traffic light' system of green (criterion met), orange (partially met) or red (failed), while based on quantitative monitoring[3] does involve considerable expert judgement.

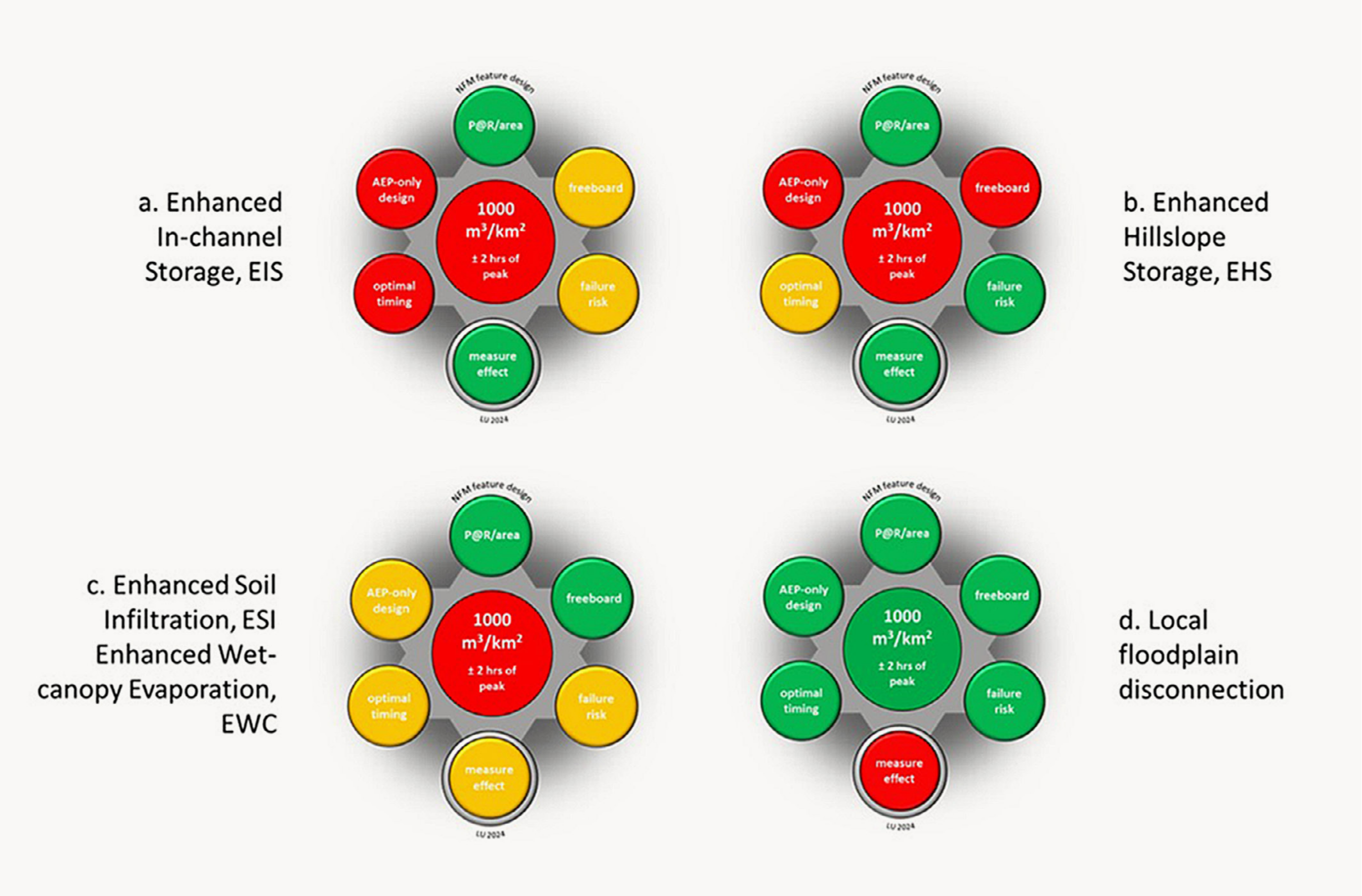


Figure 3 | Estimates of the performance of the different types of NbS at the Tebay NbS pilot, Cumbrian Mountains, UK.

Such expert judgement is needed because of the relatively small number of replicates of each intervention and less than five years of continuous monitoring for most interventions. The scoring is based on the design and extent of deployment of the particular type of intervention at the particular locality. Each type of process intervention may in principle, meet all criteria (green traffic lights) provided design is prioritised and extent of deployment is sufficient. Where a site (such as the Tebay NbS pilot) does not meet all criteria for all interventions (Figure 3) – it may meet the criteria in the future, if some features are redesigned or greater deployment of NbS is undertaken locally.

The central message is that each type of intervention installed at a particular locality may have some well-met criteria (notably the farmer-designed and built 170 m embankment that likely meets the central 1,000 m^3/km^2 ± 2 hrs of the flood peak criterion) it may have shortcomings on other issues. For some localities, certain NbS intervention types and some design teams, it may be difficult to predict those feature/network designs that pass all criteria prior to the direct measurements. This may be an additional argument in favour of using a range of different NbS types to reduce flooding in each community-based scheme.

The final 'take home' messages are summarised in Figure 4.

Value of multiple types of NbS in a single scheme:

- For emphasis, if performance of nature-based infrastructure is difficult to predict with accuracy prior to direct measurement, having a range of NbS types where some turn out to be more suited to the environmental conditions of the locality, may **reduce overall risk** of 'scheme failure'. Scheme failure is defined narrowly in this example as a scheme that does not reduce exposure of some homes to a known (historic) flood risk.

- For research pilots, it may be possible to define an alternative measure of scheme success. Where direct measurements of feature effectiveness are incorporated (KPI 6), and the findings shared with partners (farmers, engineers and funders), then a scheme may be judged to not have failed given that **learning** has been gained. Use this learning to retrofit additional or modified interventions at an evaluated site, or improve designs for other NbS schemes, then even greater success may be attributed to such a NbS pilot research.

Farmer co-delivery of NbS flood mitigation:

- All of the interventions incorporated and studied at Tebay were on pastureland. The approval of the local farmers for these NbS interventions was therefore essential given the potential for negative (as well as positive) impacts on farm businesses. In the case of the livestock exclosures for tree planting or for peatland restoration (including NbS 'plank-dams'), the farmers co-developed the NbS funding bid. The enhanced in-channel storage features, the farmers both designed and installed in the form of 'log-dams', with funding from an environmental charity. In the case of potentially the most effective flood mitigation measure of the 170 m flood embankment, one farmer designed, built, maintained and self-funded.

- The Tebay NbS pilot is a clear example of the value of farmer co-delivery of Nature-based Solutions to reduce flood peaks and so incidence of overbank flows that flood homes. Always consider local farmers as core to the effectiveness of NbS for flood mitigation. This applies equally to flooding within small urban areas, where flood-waters may originate from farmland in peri-urban areas.

Figure 4 | Take home messages.

References

1 | Beven, K. *et al.*, 2022. Hydrological Processes 36: e14752.

2 | Chappell, N.A. and Beven, K. 2024. Environmental Research Letters, 19(7): 074006. doi.org/10.1088/1748-9326/ad4fa2.

3 | Follett, E., *et al.* 2024. Proc. IAHS, 385: 197-201.

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Some of the outputs from this research is given on: www.es.lancs.ac.uk/people/nickc/npub.htm.

Panoramic view of Derwentwater in the Lake District.