



# Measuring NFM effectiveness

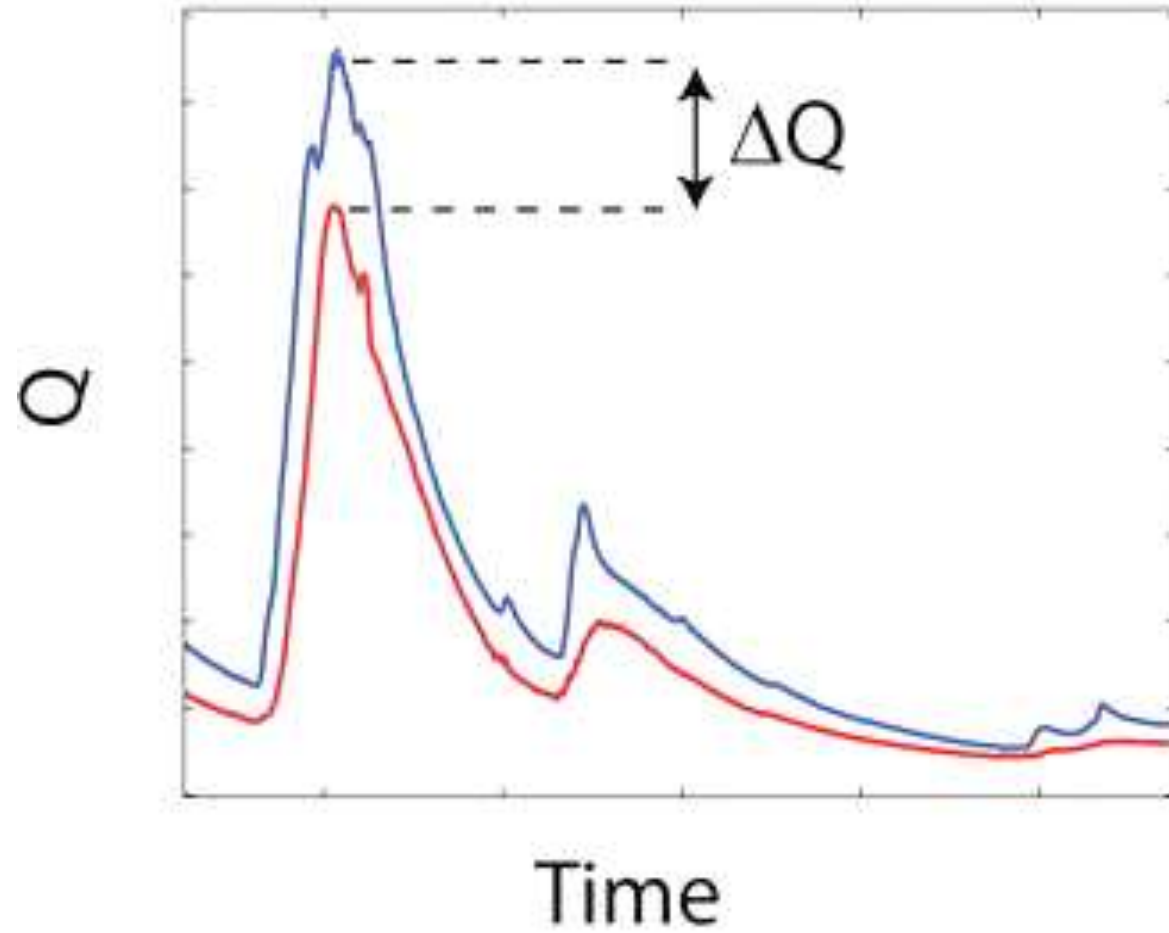
Nick Chappell with Trev Page

Image © NA Chappell: Towards Shap summit from Tebay peatland NFM site

- 1 What is NFM **effectiveness**?
- 2 Researchers and partners
- 3 Why are we undertaking **local hydrological observations**
- 4 Importance of **accurate streamflow** measurements
- 5 How we are **measuring hydrological changes** in flood events
- 6 **Scale-up**: How many such features needed
- 7 Key monitoring **messages**



- 1 What is NFM **effectiveness**?
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Hankin et al. (2017) 10.5772/intechopen.68677

## 1 What is NFM effectiveness?

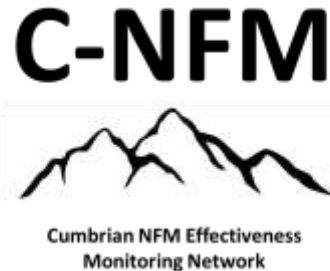


## Cumbria-focused research



With Keith Beven, Trev Page, John Quinton, Phil Haygarth, Barry Hankin  
Rob Lamb, David Johnson, Ann Kretzschmar, David Mindham & end-user partners

**Primarily physics-based modelling (with some field monitoring)**



With Dave Kennedy (EA), David Mindham and end-user partners

**Primarily field monitoring (with some dynamic systems modelling)**

## 2 Researchers and partners

# NERC Q-NFM | Investigator team



Trev Page (T1, 2, 3, 4)



David Mindham (T2)



John Quinton (T2)



Keith Beven (T3, 4)



Ann Kretzshmar (T3, 4)



Barry Hankin (T5, 6)



Rob Lamb (T6)



Nick Chappell



Phil Haygarth (T7)



David Johnson (T7)



Q-NFM

Protect NFM

Landwise

Farmer partners



Gauging station partners



Government partners



Industry partners



Environmental NGO partners



Programme Executive Board

**Wider Cumbrian Stakeholders**

Flood-affected communities  
Farmers/landowners  
Flood-affected business



**Wider UK & international Stakeholders**

Academic community  
Flood-affected communities  
Farmers/landowners  
Flood-affected business





Image © NA Chappell

Quantify effect of individual features for the **network of EA NFM pilots across Cumbria**

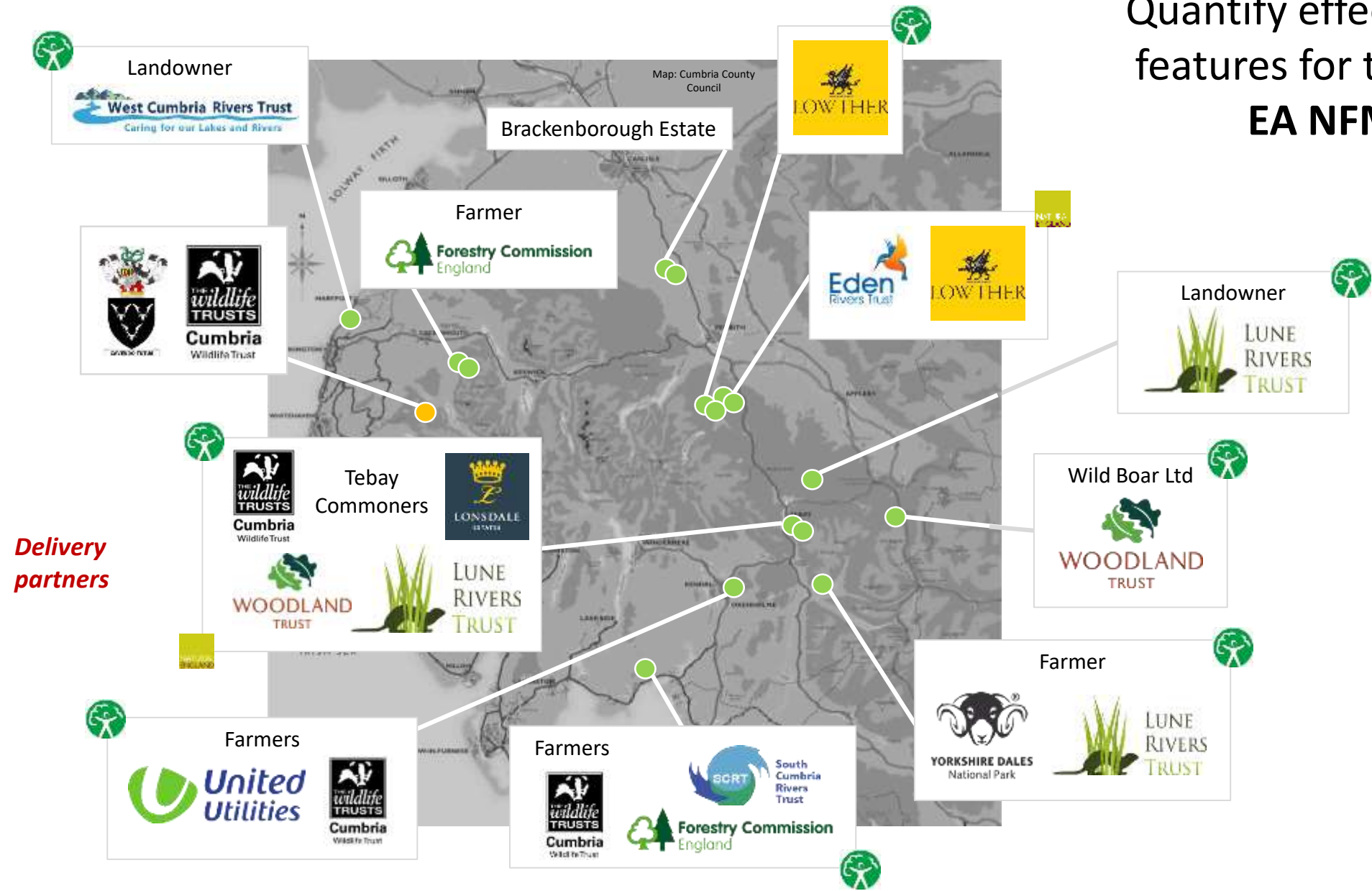
Constrain the **NFM-related shifts in parameters** of our catchment-scale models

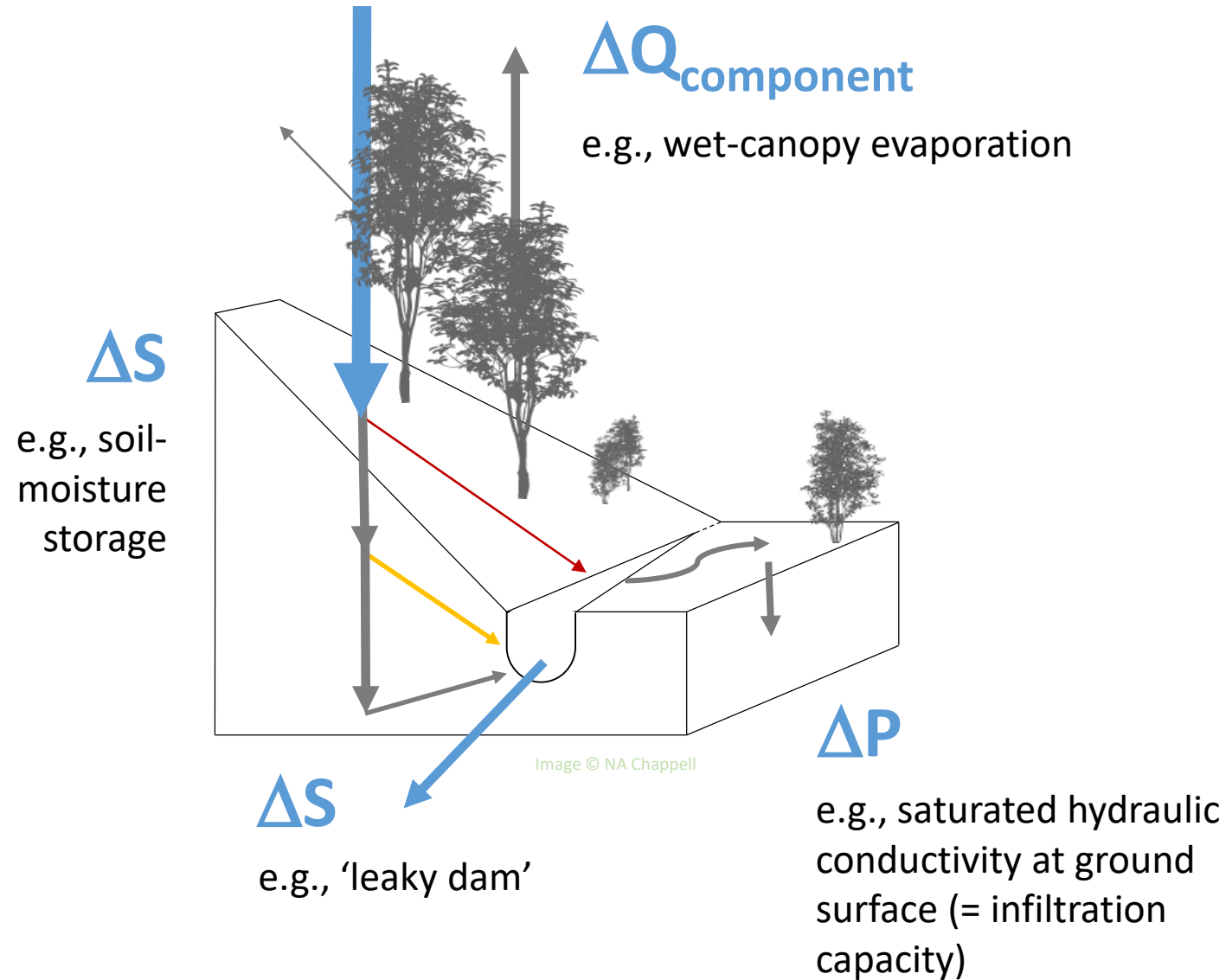
Evaluate **process representation**, locally, in our catchment-scale models

e.g., Sware Gill (left) & Darling How paired-catchment NFM sites

**3 Why are we undertaking *local* hydrological observations**

Quantify effect of individual features for the **network of EA NFM pilots across Cumbria**



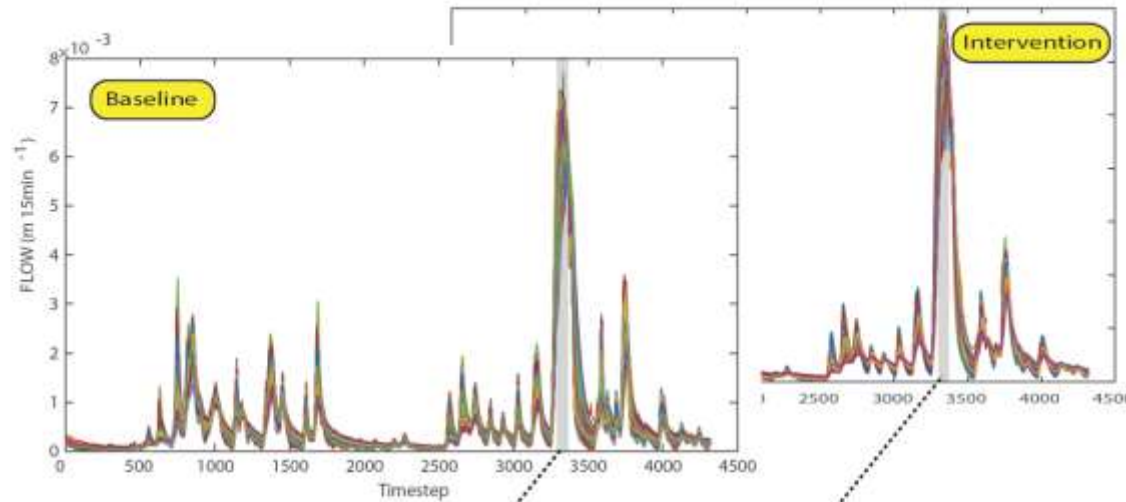


Constrain the **NFM-**  
**related shifts in**  
**parameters of our**  
**catchment-scale**  
**models**

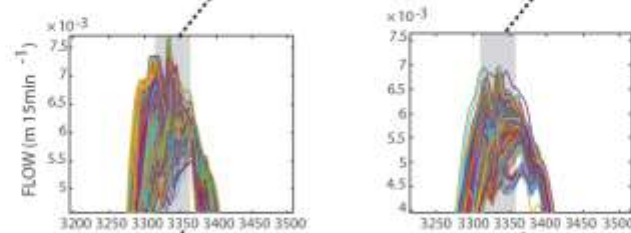
*Note for example:  
roughness change  
( $\Delta P$ ) to reproduce  
observed storage  
change ( $\Delta S$ )*



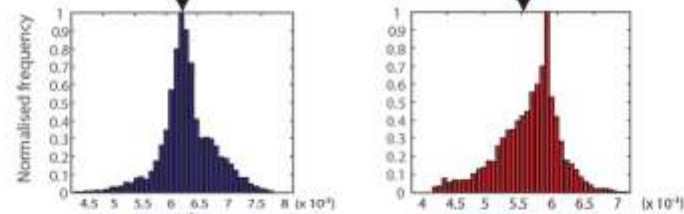
(a) Acceptable simulations



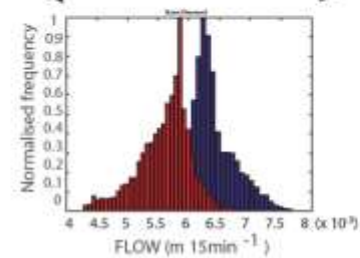
(b) Zoom to timesteps 3330 to 3358



(c) Histogram of flows for timesteps 3330 to 3358 from all acceptable simulations



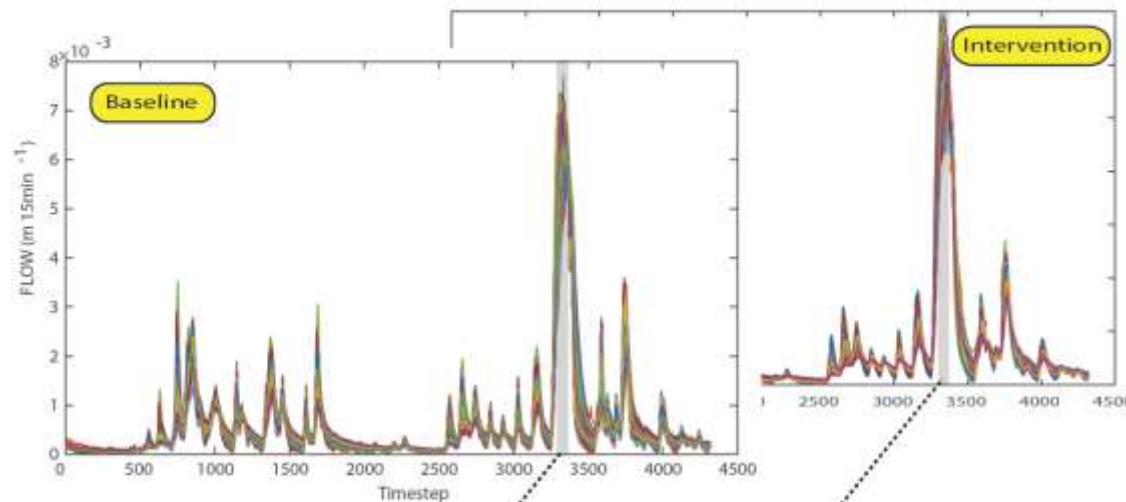
(d) Comparison of histograms for baseline and intervention



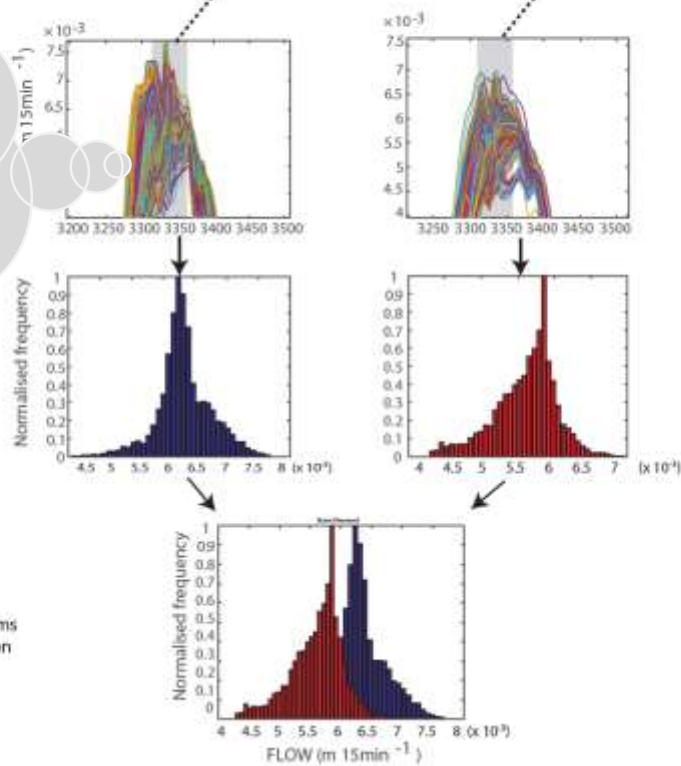
<https://naturalcourse.co.uk/uploads/2017/04/2016s4667-Rivers-Trust-Life-IP-NFM-Opportunities-Technical-Report-v8.0.pdf>

Constrain the **NFM-related shifts in parameters** of our catchment-scale models

(a) Acceptable simulations



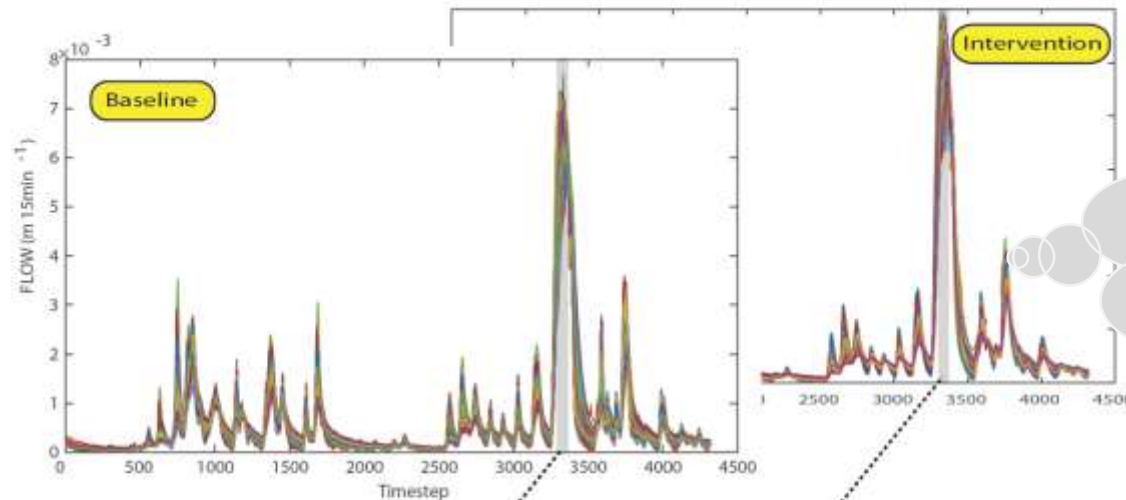
Uncertainty in  
representing  
processes in  
baseline  
simulations



(d) Comparison of histograms  
for baseline and intervention

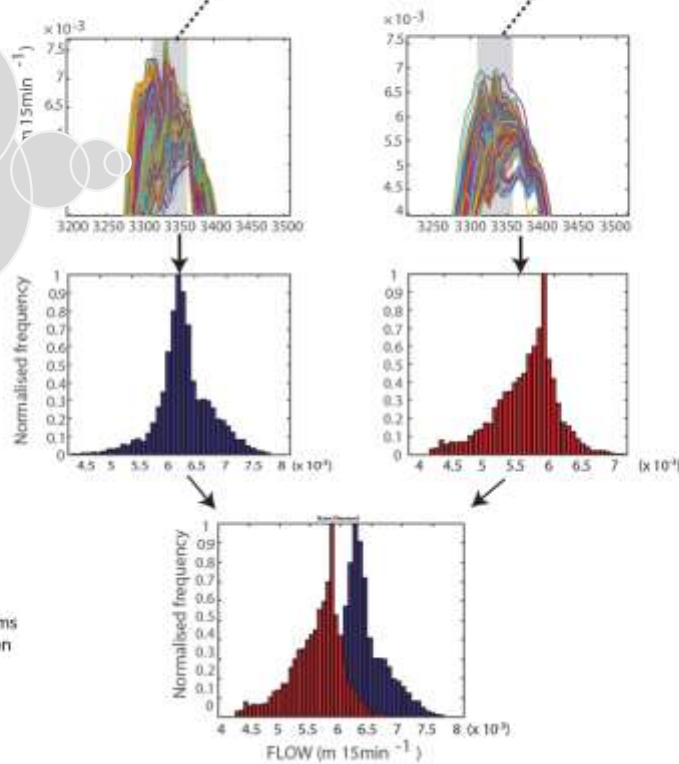
Constrain the **NFM-**  
**related shifts in**  
**parameters of our**  
catchment-scale  
models

(a) Acceptable simulations



Additional uncertainty  
from **variability in NFM-  
related parameter shifts**

Uncertainty in  
representing  
processes in  
baseline  
simulations



(d) Comparison of histograms  
for baseline and intervention

Constrain the **NFM-  
related shifts in  
parameters** of our  
catchment-scale  
models



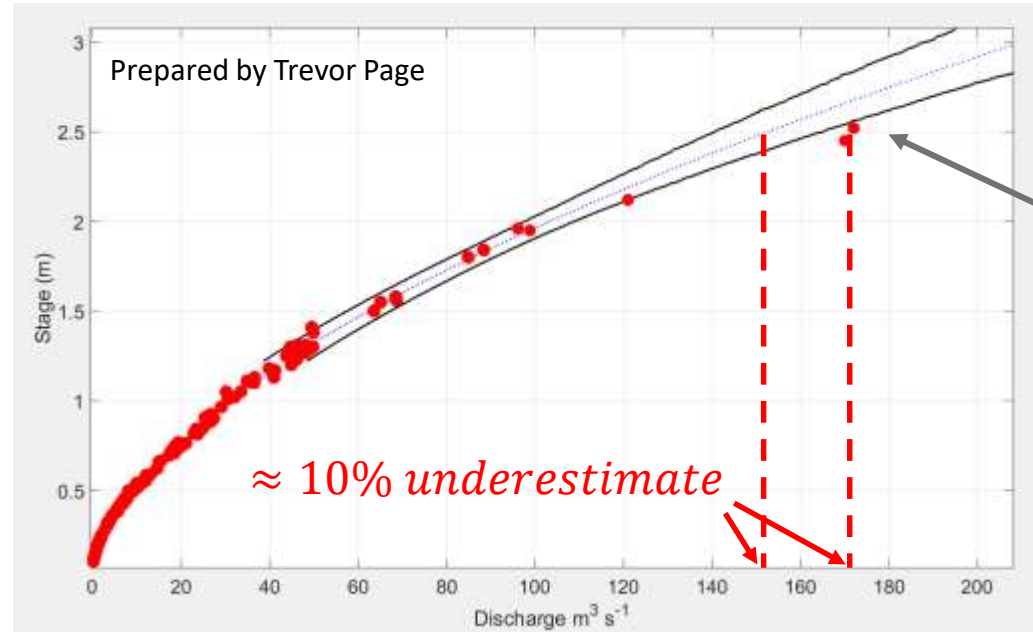
Evaluate **process representation**,  
locally, in our  
catchment-scale  
models



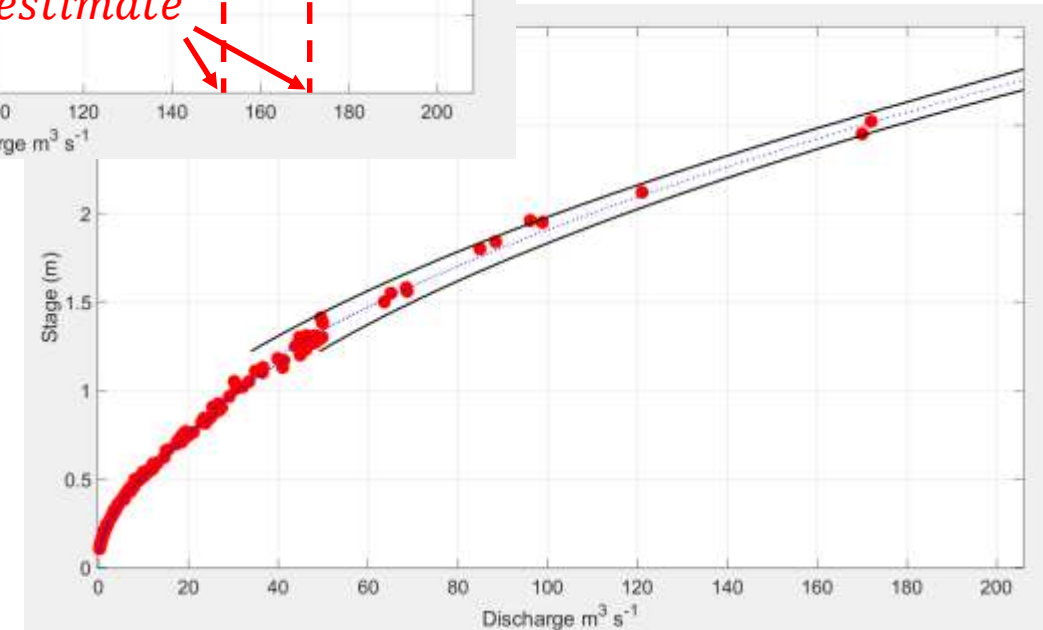
Sedbergh flume

Image © NA Chappell





EA gauging  
during Storm  
Desmond



EA Bowston weir,  
Kent basin

see also Holloway *et al.*  
(2018) 10.1002/hyp.13217

## 4 Importance of *accurate* streamflow measurements

*Equally important at micro-catchment scale (< 1 km<sup>2</sup>)*

**Why do we need accurate streamflow at micro-catchment scale?**

1. **Scale of NFM pilots** (at many places)
2. At scale of 1 km<sup>2</sup> - catchments **behave very differently**
3. **Reference for behaviour** of individual NFM interventions



At scale of 1 km<sup>2</sup>  
catchments **behave**  
**very differently**

e.g., Tebay Gill micro-basin vs Sedbergh micro-basin (both largely draining Conistone Group sandstones etc)

1:50,000 OS map







Tebay Gill micro-basin

**Dynamic response characteristics (DRCs) of  
rainfall to streamflow (5-min data)**

Rainfall nonlinearity  $\tau$  :

Pure time delay  $\delta$  :

Residence time TC :

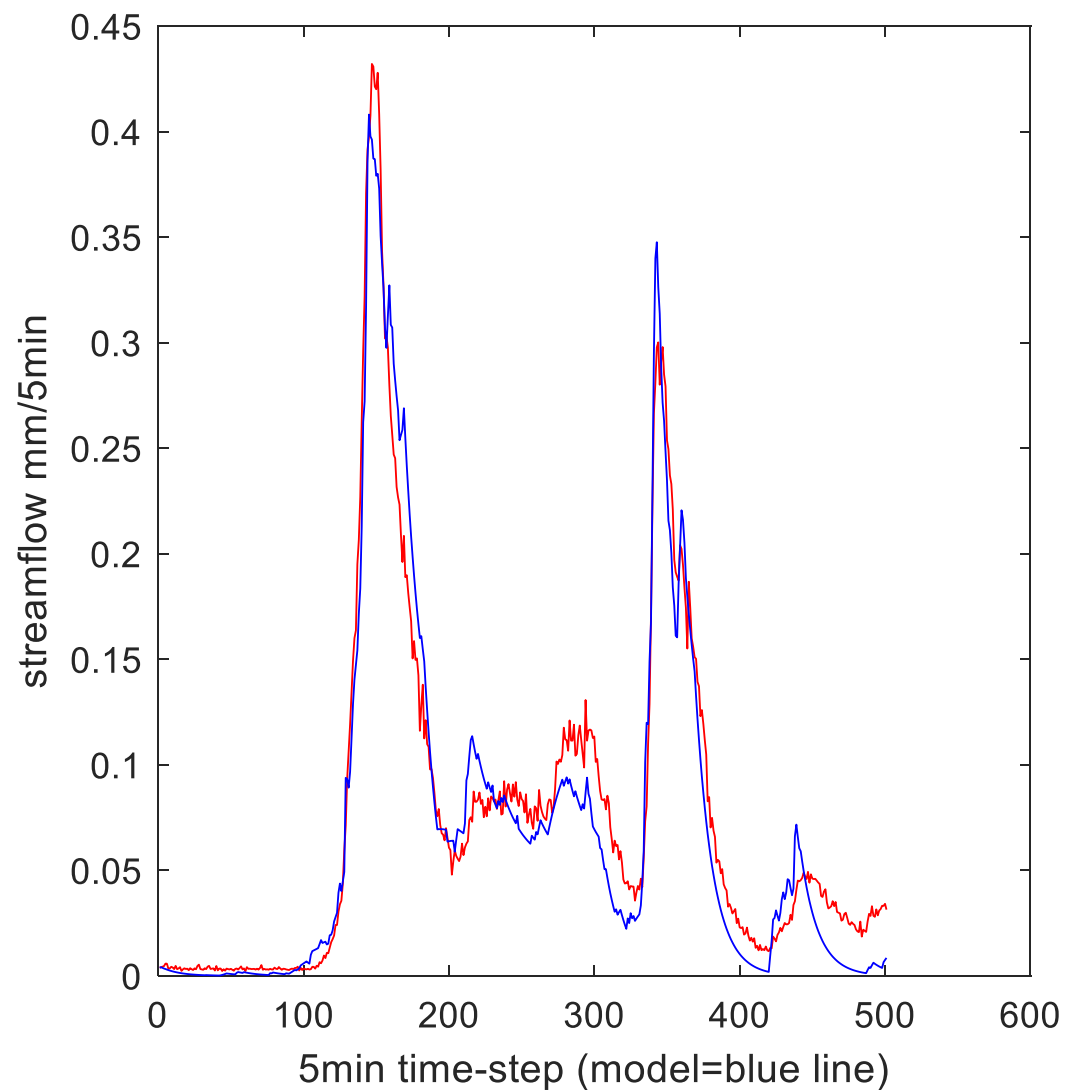
Steady-State Gain C :

---

*from first-order BOSM CAPTAIN RIV model*

Efficiency ( $R_t^2$ ) :

YIC :



Tebay Gill micro-basin

**Dynamic response characteristics (DRCs) of  
rainfall to streamflow (5-min data)**

Rainfall nonlinearity  $\tau$  : 275 min (4.58 hr)

Pure time delay  $\delta$  : 5 min (0.08 hr)

Residence time TC : 59 min (0.98 hr)

Steady-State Gain C : 0.30

---

*from first-order BOSM CAPTAIN RIV model*

Efficiency ( $R_t^2$ ): 0.9501      YIC : -10.893

\tebg1.m 12-13 Oct 2018





## Sedbergh micro-basin

### Dynamic response characteristics (DRCs) of rainfall to streamflow (5-min data)

Rainfall nonlinearity  $\tau$  : 850 min (14.2 hr)

Pure time delay  $\delta$  : 480 min (8.00 hr)

Residence time TC : 2265 min (37.7 hr)

Steady-State Gain C : 0.17

---

*from first-order BOSM CAPTAIN RIV model*

Efficiency ( $R_t^2$ ): 0.9204      YIC : -12.769

\sedb1.m



## Why is *accuracy* a critical issue for us?

1. **Stage-discharge rating** difficulty at high flows
2. **Quantifying hydrological change** (from different experimental designs) requires excellent streamflow quality
3. Our modelling is undertaken within an explicit **uncertainty framework**

# Stage-discharge rating difficulty at high flows



Mini-video of flume at Beaver NFM site (EA floodplain project)

## Pre-calibrated FRPB flume

*If installed at correct location*

Allow passage of sediment  
& macroinvertebrates

Just requires checking  
calibration (dilution gauging)  
**not building the rating curve**  
for a complex channel  
geometry (that also may not  
generate *critical flow*)

Quantifying  
hydrological  
change from  
different  
*experimental*  
designs requires  
excellent  
streamflow  
quality

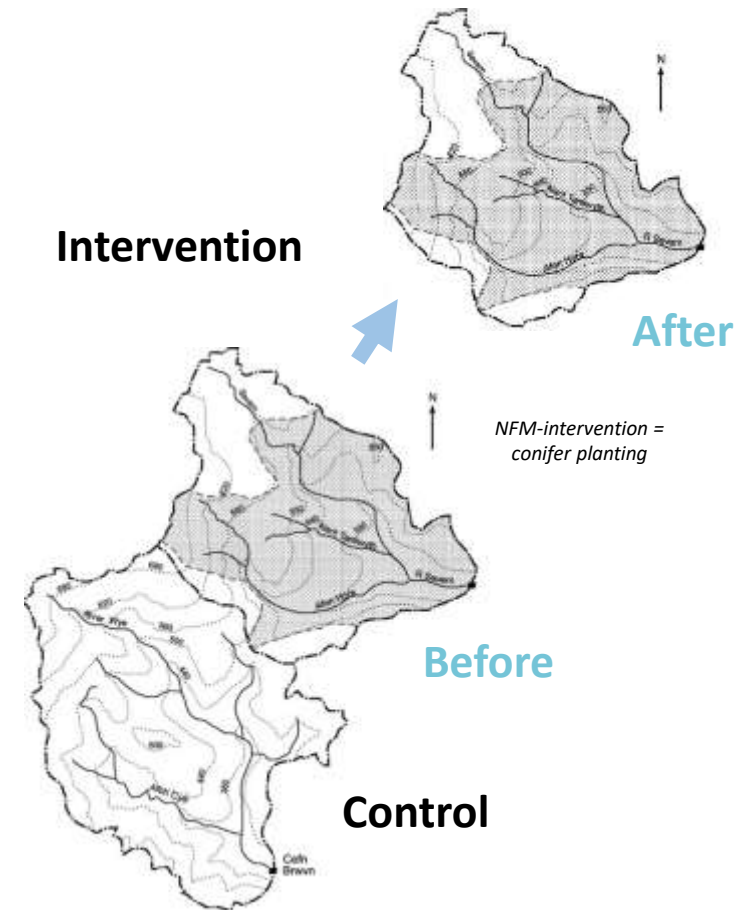
For example...

**Type 1:** Gauging station **immediately upstream and downstream** (with no major channel flows entering) eg bracketing a series of in-channel woody dams

**Type 2:** An **adjacent basin** (also gauged) lacking the extensive NFM features (eg reference moorland basin next to forested basin – emulating optimal state after tree planting)

**Type 3:** A **single reference gauging station** eg where change in storage during storm ( $\text{m}^3/\text{hr}$ ) is a significant proportion of peak channel flow ( $\text{m}^3/\text{hr}$ )

**Type 4:** A single gauging station monitored **before and after** an intervention added (*if not surface storage - requires exceptional Time Series Analysis to capture changing rain-flow dynamics with minimal uncertainty*)



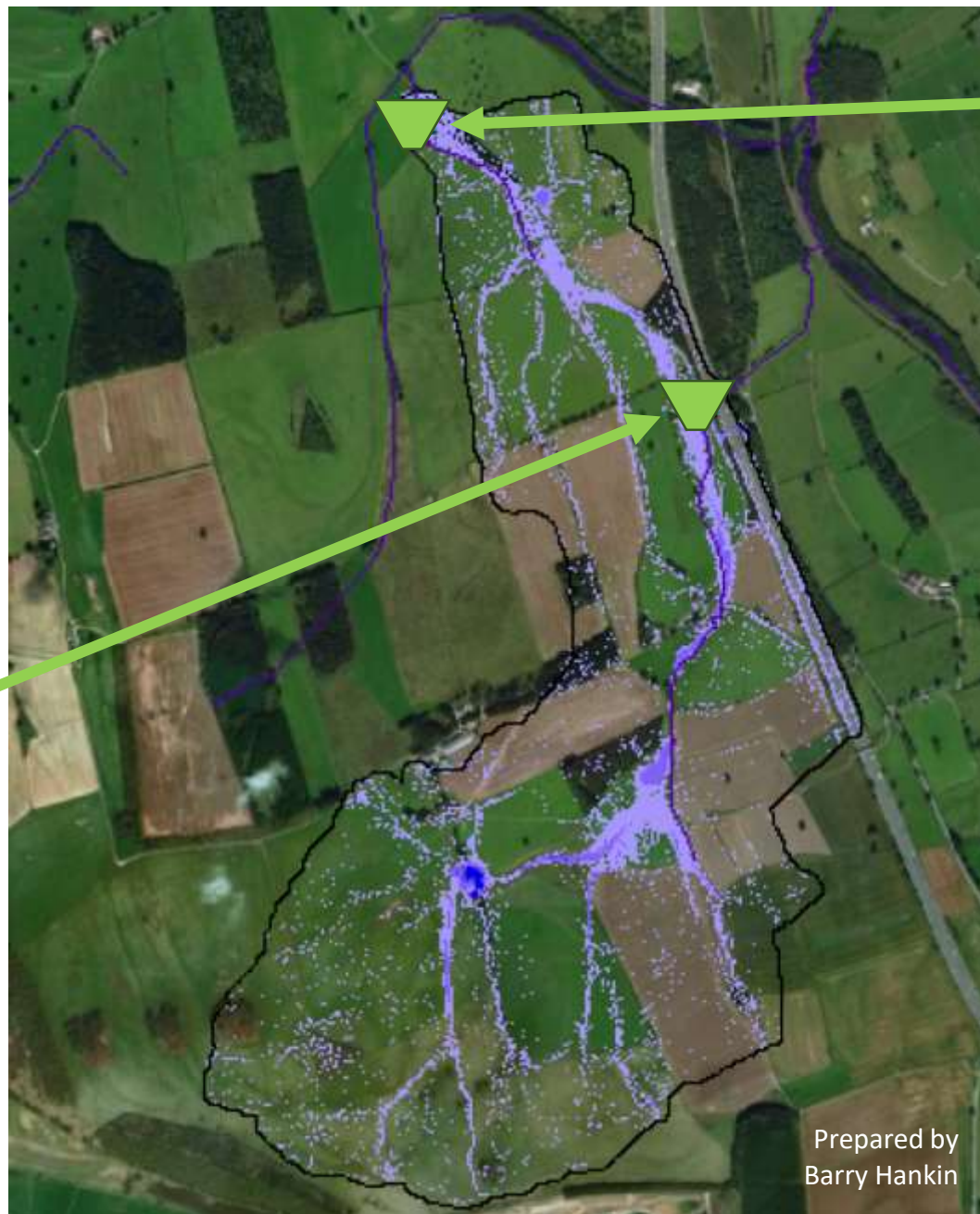
Combining 2 & 4 = BACI design  
(Before-After Control-Intervention)



e.g., Bessy Gill NFM by  
channel realignment

*and commercial  
afforestation of 0.17  
km<sup>2</sup> of former sheep  
pasture (213,000  
trees)*

Upstream  
**Control**



Downstream

**Before-and-After**



Type 1, 2 & 4  
BACI design



[illegible]

## Type 1-4 Experimental Designs

# Hydrological processes changed by NFM measures we are modelling for large floods

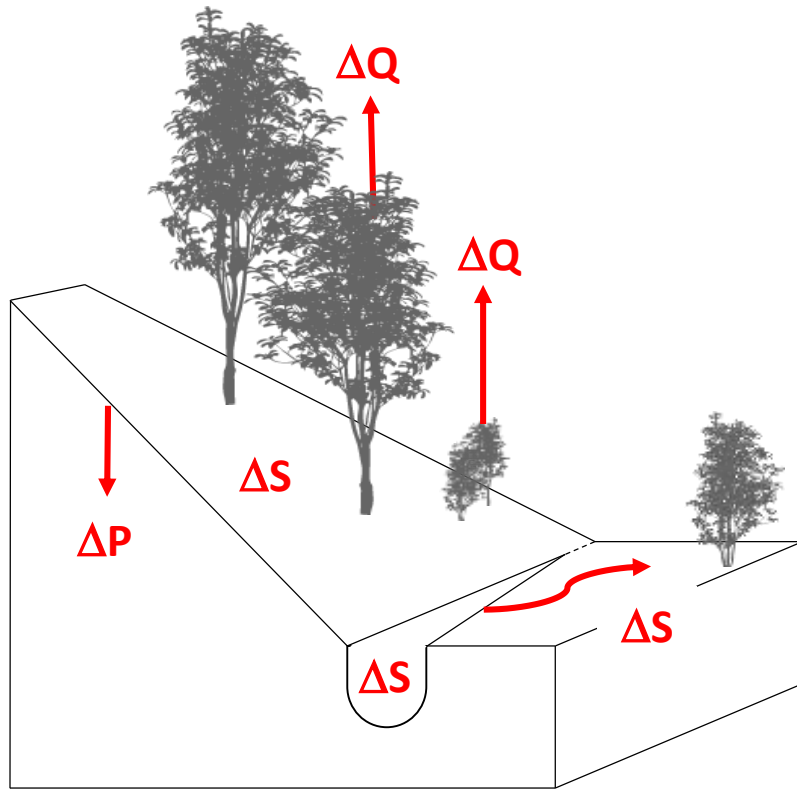
A. Enhanced wet-canopy evaporation

B. Enhanced surface storage

- on slopes
- in permanent channels
- on floodplains

C. Enhanced infiltration due to enhanced topsoil permeability

## 5 How we are measuring hydrological changes in flood events



1. Enhanced **hillslope surface storage**
2. **In-channel leaky dam storage** on streams draining less than 10 km<sup>2</sup>
3. Enhanced **floodplain surface storage**
4. **Infiltration enhancement** on slowly permeable soils
5. Enhanced **wet-canopy evaporation** from extensive woodland planting
6. Enhanced **wet-canopy evaporation** from other vegetation changes

## 5 How we are measuring hydrological changes in flood events





# 1. Enhanced hillslope surface storage

bunds, swales, kests, walls and peatland restoration; including zero-order channels



Tebay NFM peatland restoration monitoring

Image © NA Chappell





Tebay Dams flume

Tebay Gill flume

Linking storage  
dynamics ( $\text{m}^3$ )  
with local stream  
discharge ( $\text{m}^3/\text{s}$  or  
 $\text{L/s}$ )

e.g., Peatland dams  
on Tebay Fell

Dam 5

Level recorder

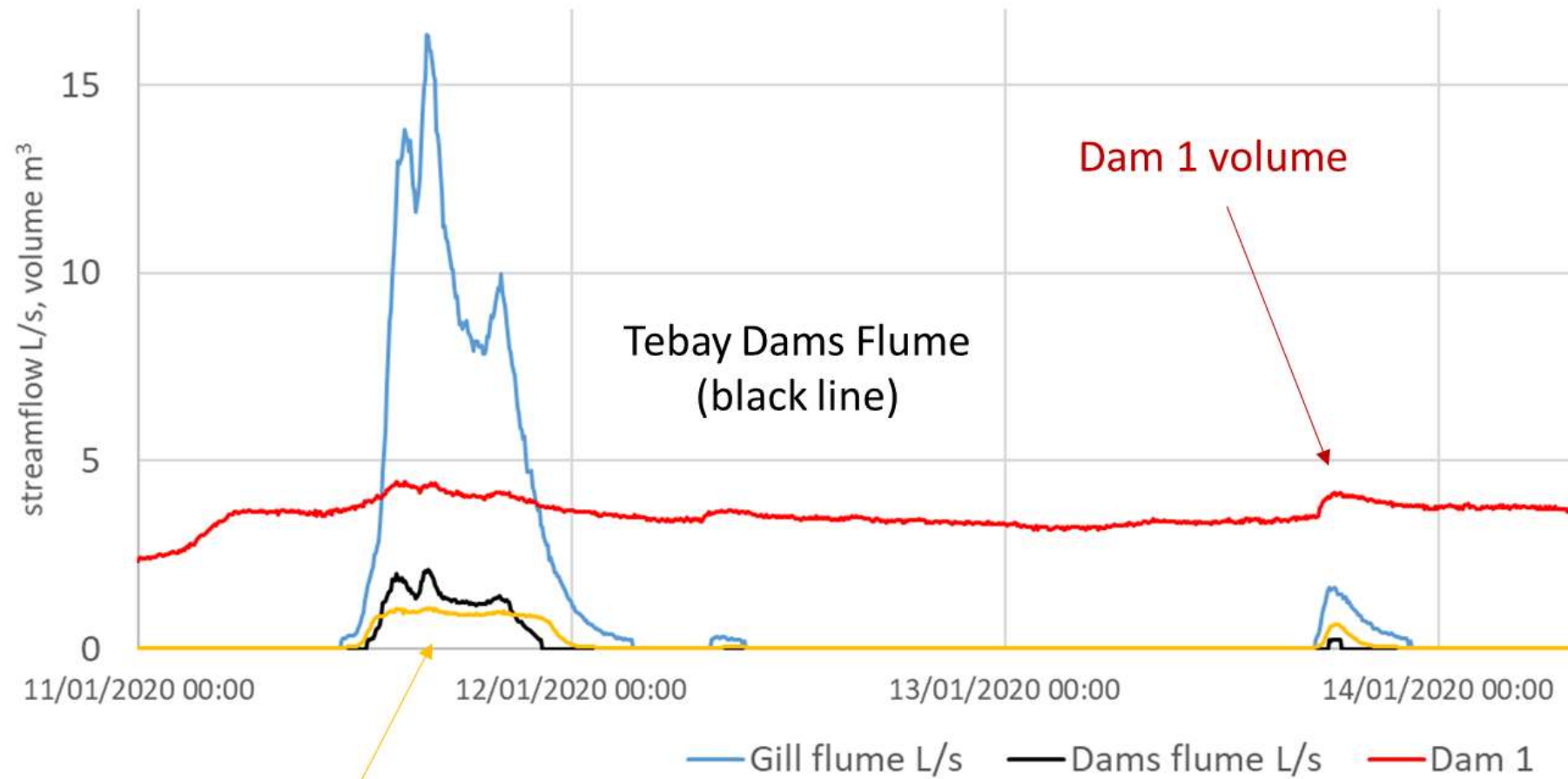
Dam 6

**Tebay NFM peatland  
restoration monitoring**

Image © NA Chappell



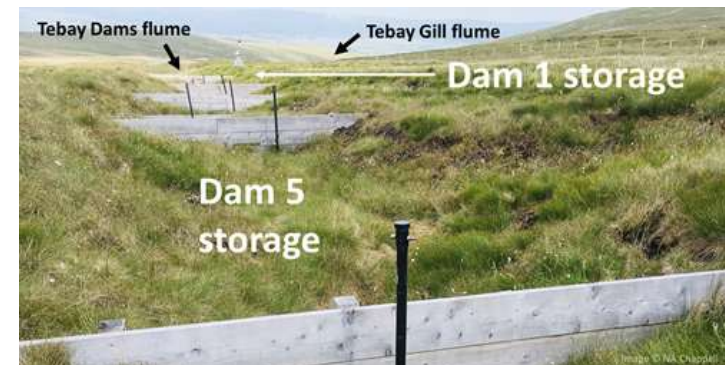
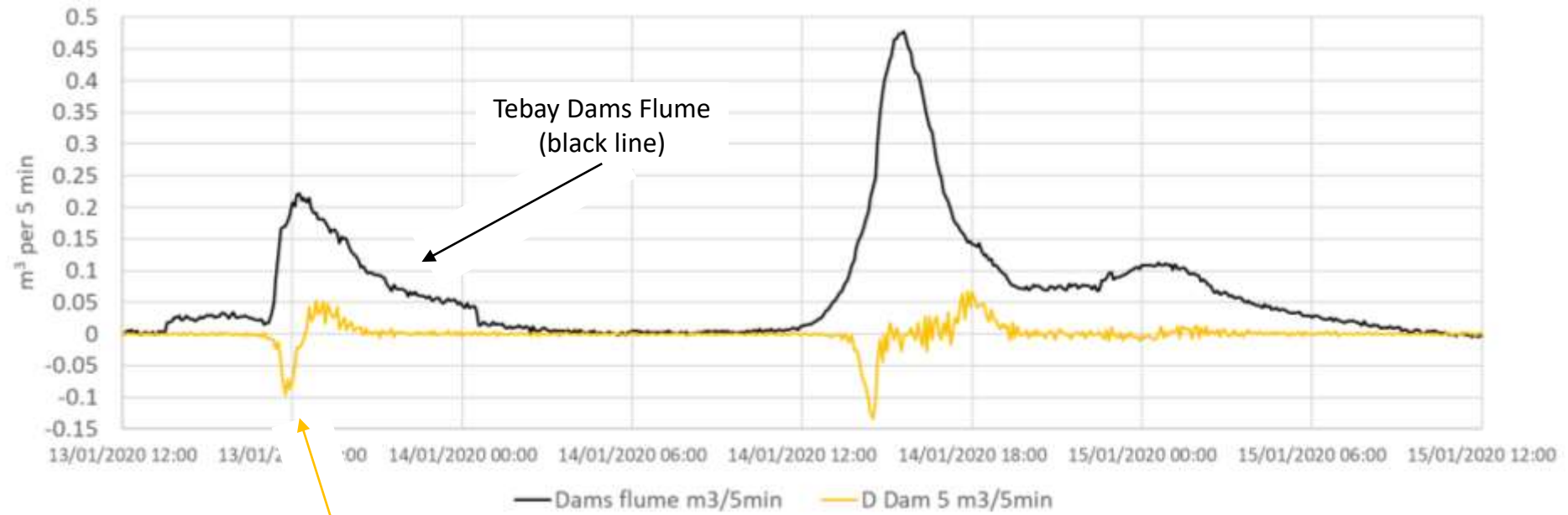
## Tebay Gill Flume



Dam 5 volume  
(orange line)







and storage gain,  $\Delta S$  ( $\text{m}^3$  per 5min)  
 directly with local stream discharge ( $\text{m}^3$  per 5min)





## 2. In-channel leaky dam storage on streams draining less than 10 km<sup>2</sup> contributory area



Sedbergh NFM site 'branch piles'









Tebay NFM log-dam demonstration site

Image © NA Chappell



A landscape photograph of a stream in a grassy field. A log dam is built across the stream, with a level recorder installed. The background shows rolling green hills under a cloudy sky.

Level recorder

Tebay NFM log-dam monitoring

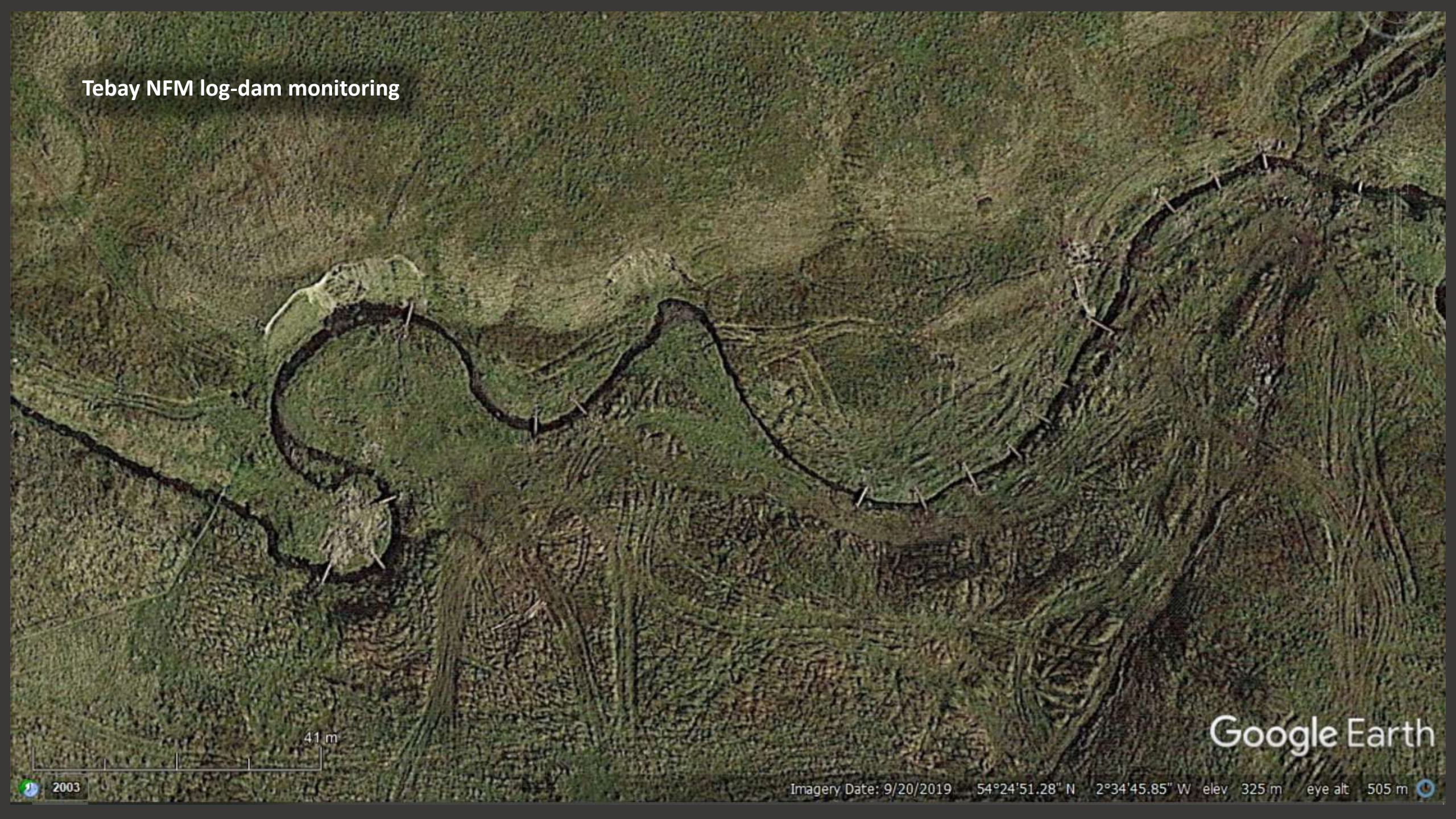
77 log dams installed on main  
channel by 28/11/2020







# Tebay NFM log-dam monitoring



41 m

Google Earth

2003

Imagery Date: 9/20/2019 54°24'51.28" N 2°34'45.85" W elev 325 m eye alt 505 m





### **3. Enhanced floodplain surface storage**

swales, bunds and floodplain reconnection





Bessy Gill NFM micro-catchment









Image © NA Chappell

**Whale NFM floodplain monitoring**

Image © NA Chappell & DPP-LU





Setterah NFM floodplain monitoring





Low Moor Farm NFM  
sward lifting monitoring

## 4. Infiltration enhancement on slowly permeable soils

by extensive woodland tree planting or soil management

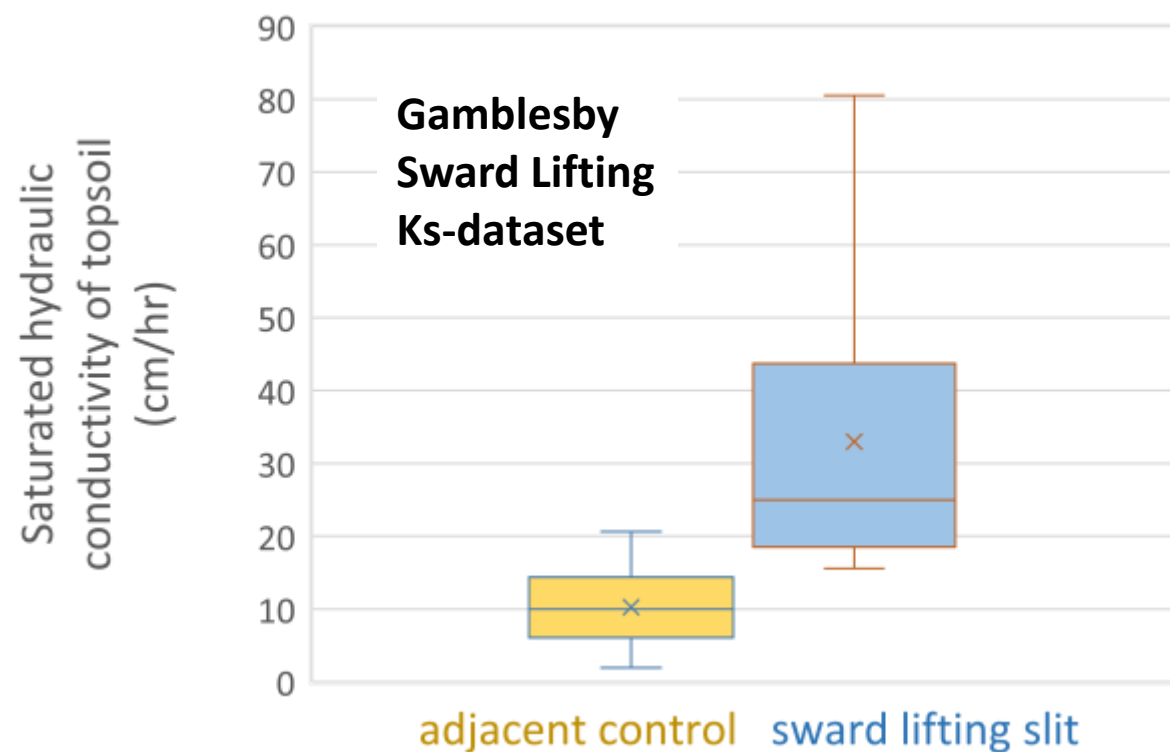




Image © NA Chappell



Ring Permeametry  
(Chappell & Ternan, 1997 ESP&L)



Sward lifting (e.g., above – as yet all sets unpublished)

Blade aeration (next page – published)



## Blade Aeration Effects on Near-Surface Permeability and Overland Flow Likelihood on Two Stagnosol Pastures in Cumbria, UK

Ethan E. Wallace\* and Nick A. Chappell

## Abstract

Overland flow (OF) from permanent pastures is believed to be a rapid pathway to the drainage network and potentially contributes to flooding across numerous grassland regions of the world. Studies investigating whether aeration can reduce observed OF have revealed mixed findings. To improve process interpretation within these studies, topsoil saturated hydraulic conductivity ( $K_s$ ) and penetration resistance (PR) were measured at two permanent Stagnated (Stag) and (P) pastures (P1 and P2) within Carleton, IA. After blade aeration to 10 cm, results were measured at 6, 13, and 21 wk post-aeration and compared with the latest rainfall record to measure the impact of an additional event on rainfall loss (RCF) threshold when spatial intensity accounts and infiltration capacity. When P1, aeration significantly increased  $K_s$  by up to a factor of 7.3 and caused seven significant reductions in PR between 3 and 15 cm. Aeration decreased the RCF threshold between the 13- and 21 wk sampling dates, reducing RCF threshold from up to 11.4% of rainfall at pasture dates, to 0.0264% of rainfall periods post-aeration. Aeration within P2 revealed no significant increases in  $K_s$  and no PR change between a significant increase at 10 cm. The RCF threshold was elevated between the 13- and 21 wk sampling dates and remained within P2. The study highlights that aeration can significantly improve  $K_s$  and PR, as well as substantially reduce the threshold of RCF generation, although benefits can be site specific.

### Core Ideas

- Aeration can significantly increase topsoil permeability and reduce compaction.
- Aeration can substantially lower the likelihood of infiltration excess runoff flow.
- Aeration may be ineffective on impermeable subsoils or highly compacted sites.
- Ex situ permeability results may have limited application within aeration research.
- Combined RAC and gained-skin approaches are advised for future aeration studies.

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© 2000 Blackwell Science Ltd, *Journal of Internal Medicine* 247: 399–406

© 2000 Blackwell Science Ltd, *Journal of Internal Medicine* 247: 399–406

Suggesting instead a possible ceiling for this price.

Received 2 May 2013

Received 11 July 2018

© 2004 Blackwell Publishing Ltd *Journal of Internal Medicine* 255: 229–236

**E**XTENSIVE SOIL COMPACTION is hypothesized to increase flood risk across numerous regions of the globe (Alam et al., 2010). Within the United Kingdom, 60% of managed pasture in England and Wales exhibits signs of topsoil compaction and/or surface crusting (AFHD, 2010). Topsoil compaction can severely impede water infiltration and drainage due to reduced soil pore volume, thereby altering the distribution, frequency, and continuity of water-transmitting macropores within the soil matrix (Kamari et al., 2014). This pore network restructuring can increase the likelihood of infiltration excess overland flow (IEOF) during precipitation events. Infiltration excess overland flow is generated when rainfall intensity exceeds soil infiltration capacity. Infiltration capacity is the flow of water into saturated soil under unit cross-sectional area and unit hydraulic gradient. Infiltration excess overland flow is often a rapid drainage pathway and increases the likelihood of channel capacity being exceeded, creating flooding (see Horton, 1933).

Topsail compaction reduces pasture productivity by restricting sward root aeration (Davies *et al.* 1989; Douglas *et al.* 1995). This compaction is often caused by livestock grazing in wet conditions (see Deeney *et al.* 2000a), as well as farm malpractice (see Bhagel *et al.* 2011). Soil aeration to 10 to 15 cm using a blade aerator is a practice commonly adopted by UK livestock farmers to aerate pastures for increased sward production (Davies *et al.* 1989; Bhagel *et al.* 2011). This practice has the potential to benefit of enhancing topsail permeability (Davies *et al.* 1989; Connell and Douglas, 1993; Douglas *et al.* 1993). Enhanced permeability (infiltration capacity) within pastures can potentially minimise EDCs, thus reducing the soil drainage pathway (YConnell *et al.* 2007), alongside reducing agrochemical losses carried within surface flows (Van Vleet *et al.* 2006).

Mechanical slit aeration (blades or stirs) has been paired with changes to overflow flow (OF) within the United States (Shah et al. 2004; Franklin et al. 2006, 2007; Buxley et al. 2009; De Koff et al. 2011) and Canada (Van Vleet et al. 2006) with mixed results (Table 1). Shah et al. (2004) found aeration did not significantly reduce rainfall-induced OF, although significant reductions were found when combined with lipid dairy manure application. Franklin et al. (2006) found no significant OF reduction after aeration when incorporating inorganic

Lancaster Commercial Centre, Lancaster LA1 1YQ UK. Assigned to Assistant Office Ray Kershaw.

**Abbreviations:** DAC, before-after control impact; ECR, infiltration rates; constant flow MCM, Main-Milney-Wilcox; MCM, maximum observed rainfall intensity; IM, organic matter; CR, constant flow; P, Total P; P<sub>1</sub> (P), P<sub>2</sub> (P) P<sub>3</sub> (P), and penetration resistance.



Image © Gareth McShane





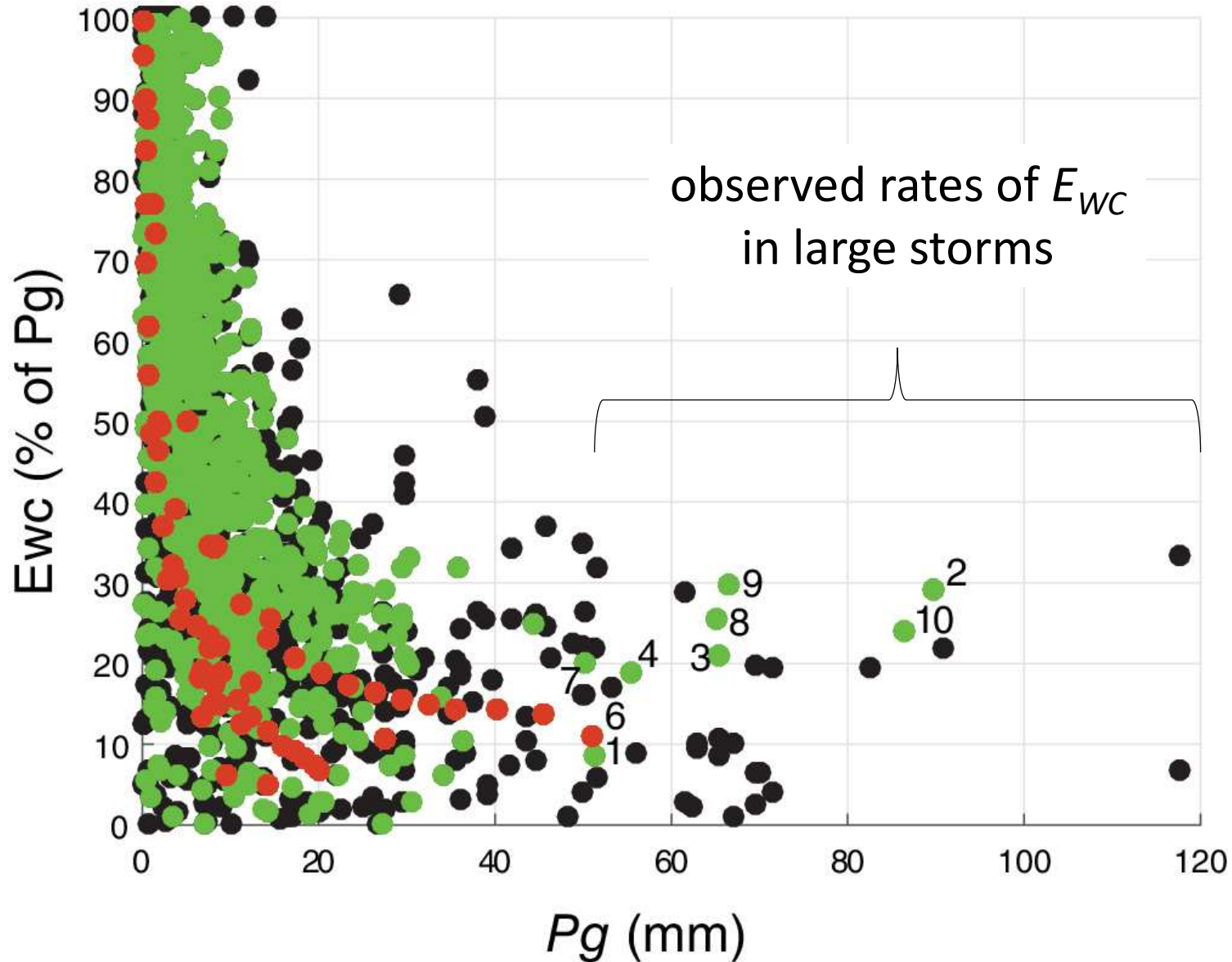
NFM evaporation plot, Bessy Gill

## 5. Enhanced wet-canopy evaporation from extensive woodland planting

‘interception loss’



New observed data assimilation : for storm-only measurements



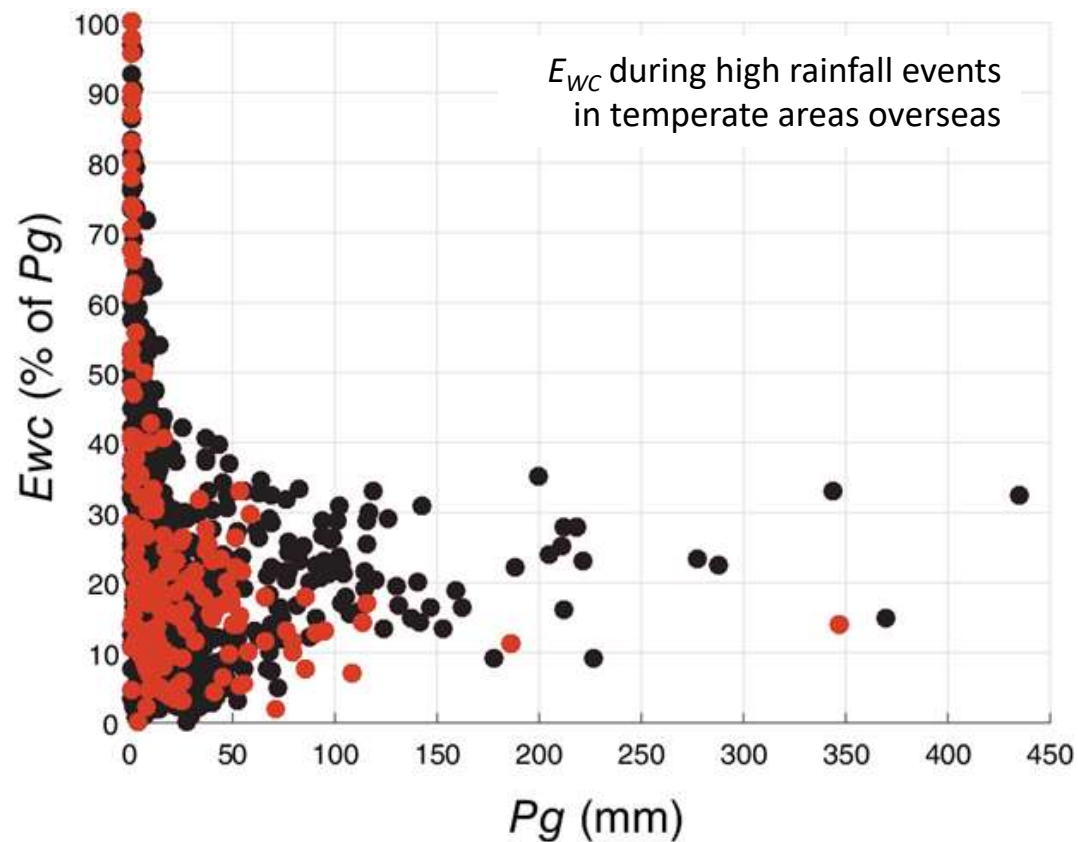
## CCD

**Catchment Change Database**  
of observed measurements  
(published & own) for each  
intervention

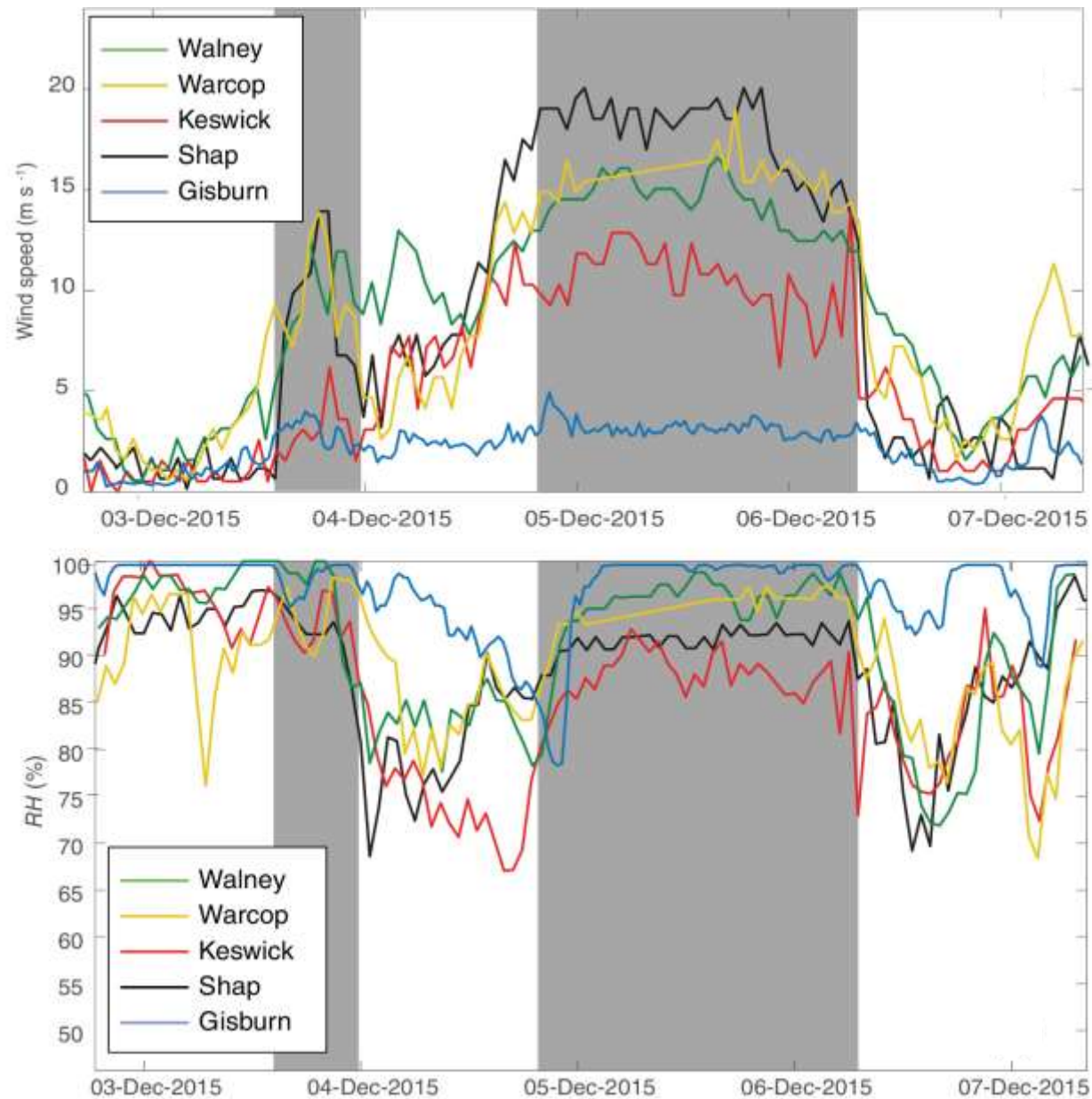
e.g., wet-canopy evaporation  
enhancement by woodland

Page, T., Chappell, N.A., Beven, K.J., Hankin, B. & Kretzschmar, A. 2020. Assessing the significance of wet-canopy evaporation from forests during extreme rainfall events for flood mitigation in mountainous regions of the United Kingdom. *Hydrological Processes* 34: 4740-4754. [10.1002/hyp.13895](https://doi.org/10.1002/hyp.13895)



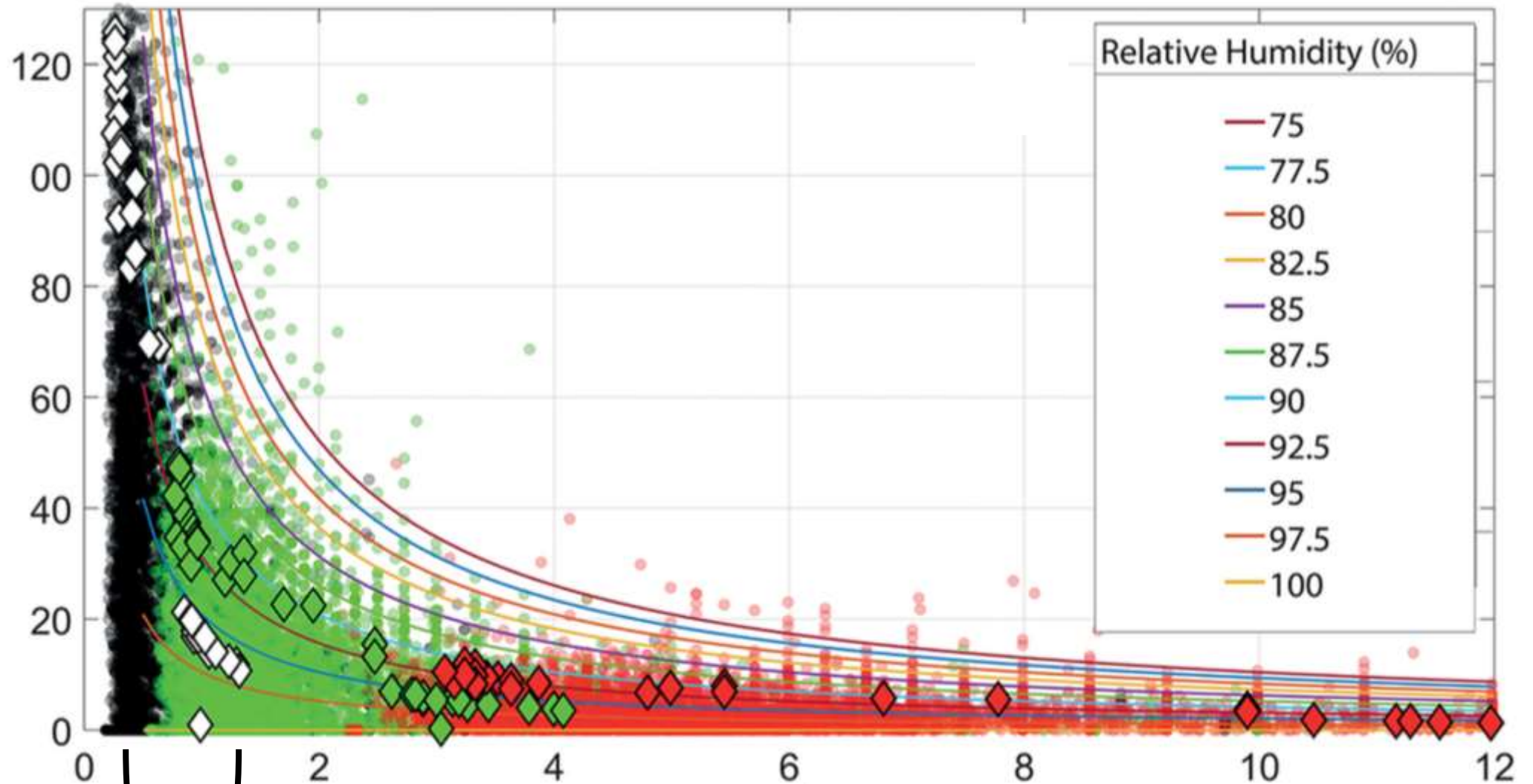


Extreme flood events –  
atmospheric capacity permits  
high  $E_{WC}$  in many places





Simulated  $E_{WC}$  (mm/d) using Cumbrian conditions



High winds give low aerodynamic resistance (s/m) using Cumbrian conditions





during 100 mm/d extreme rainfall event  
conservative 10 mm  $E_{wc}$   
feasible on leeward slopes in Cumbrian mountains  
if complete, mature woodland cover  
**10,000 m<sup>3</sup> per 1 km<sup>2</sup> loss in such rain-events**





## Small number of plots for *local* $E_{WC}$ measurements

Measurements only in large rainstorms (serviced just before & just after)

e.g., Bessy Gill NFM conifer plot



Sanity check:

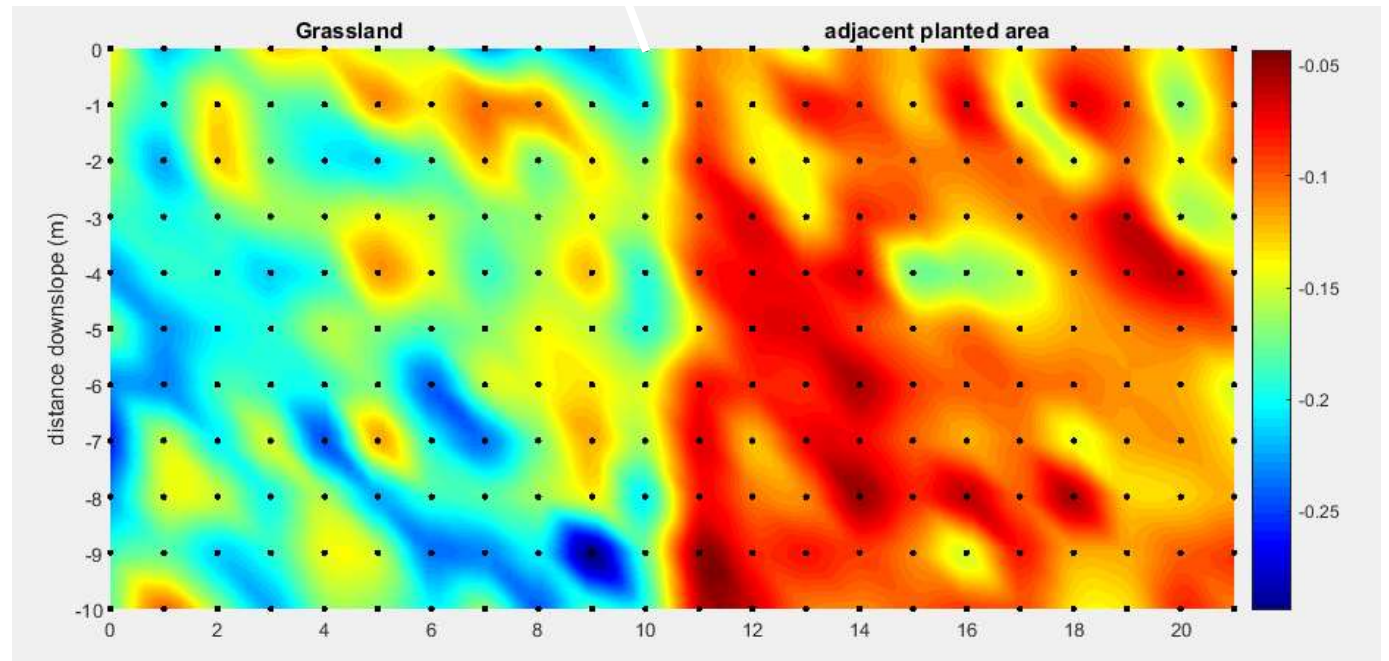
Combined  
effect of  $E_{WC}$   
& infiltration  
enhancement  
on **topsoil**  
**wetness**



TDR350 (to be  
checked with a  
CT100 TDR)




**Plot-pairs**



*Volumetric wetness ( $m^3 m^{-3}$ ) Eggerslack plot-pair #1, 9 July 2019 by Gareth McShane*





## **6. Enhanced wet-canopy evaporation from scrub planting, re-wilding, shelterbelts, hedgerow restoration and agroforestry**







**Mallerstang NFM scrub  
planting measurements**

**flume installation video**

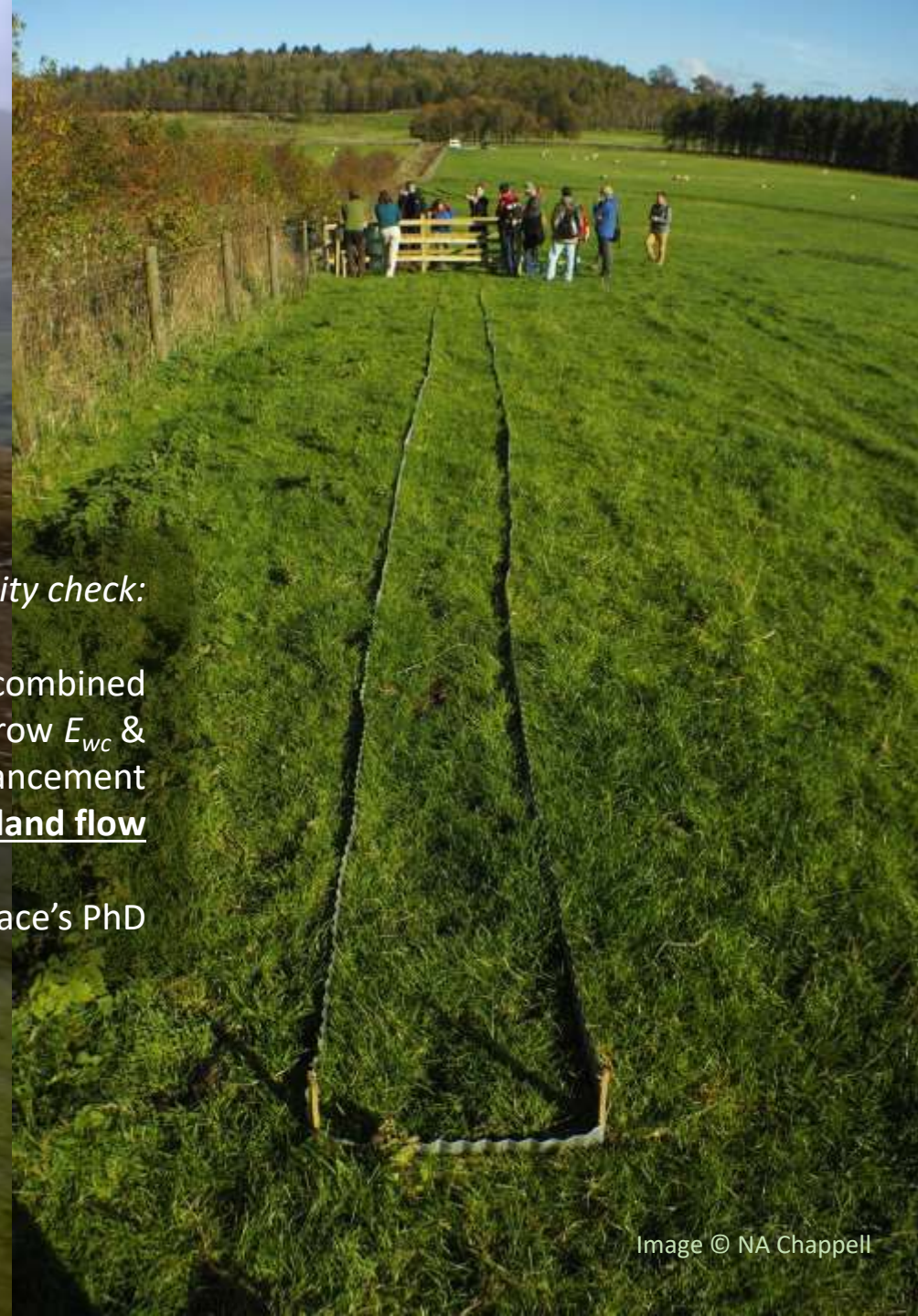
[www.lancaster.ac.uk  
/lec/sites/qnfm/t2.htm](http://www.lancaster.ac.uk/lec/sites/qnfm/t2.htm)





Visible overland flow  
(22 Jan 2018 Sedbergh NFM site)

Image © NA Chappell



*Sanity check:*

Measuring combined  
effects of hedgerow  $E_{wc}$  &  
infiltration enhancement  
on overland flow

Part of Ethan Wallace's PhD

Image © NA Chappell





Thank you to... <https://twitter.com/DaveThornhill2/status/1324143468894191616?s=20>

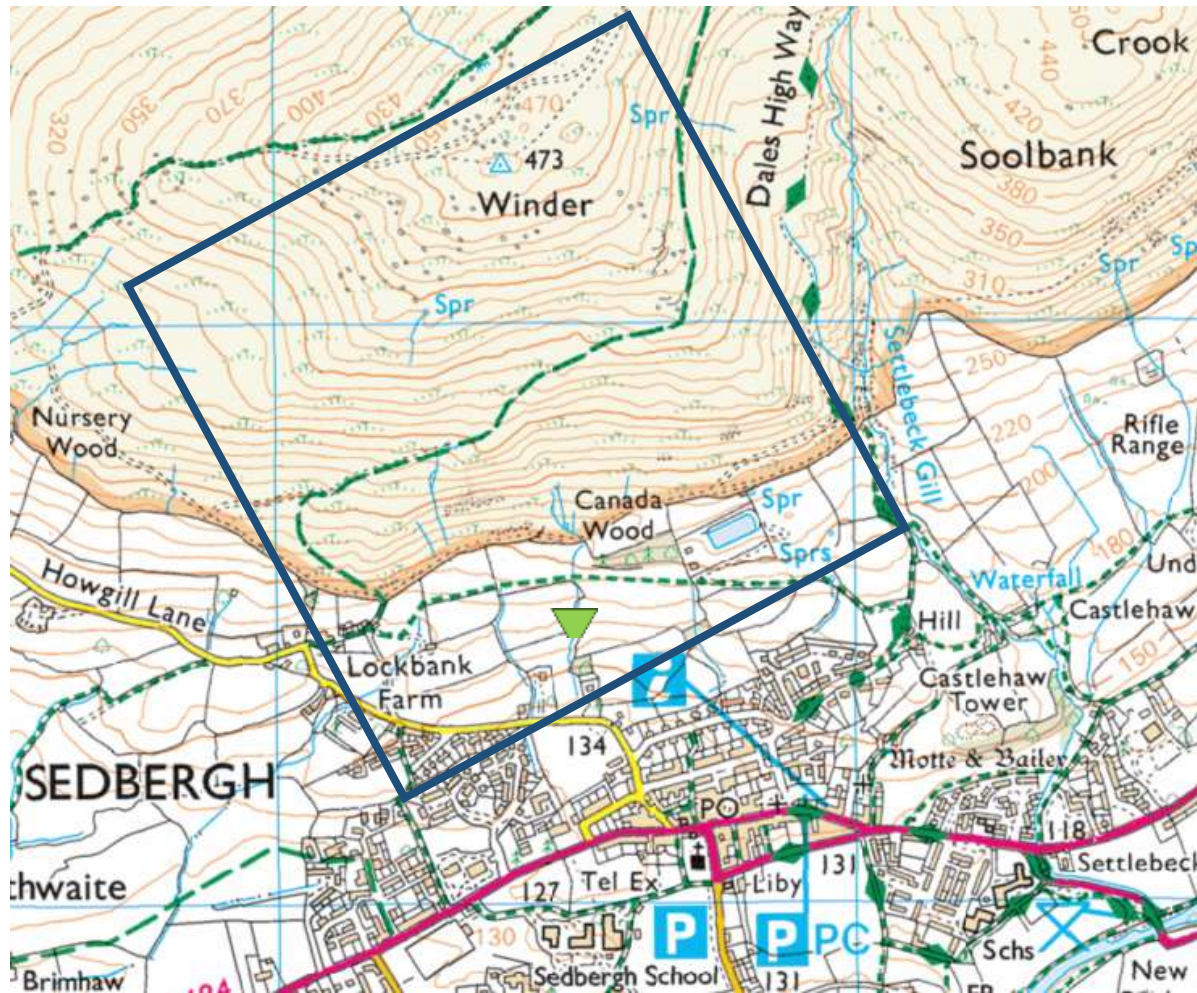
e.g., 1,300,000 m<sup>3</sup>  
Garstang flood basin  
downstream of 114 km<sup>2</sup>  
catchment (11,400 m<sup>3</sup> per 1 km<sup>2</sup>)

Note: Rydal Water 1.6M m<sup>3</sup>

For a traditional flood mitigation scheme  
**1,000,000 m<sup>3</sup> per 100 km<sup>2</sup> contributory area**

**6 Scale-up: How many such features needed**





**10,000 m<sup>3</sup> per every 1 km<sup>2</sup>  
of contributory area**

one blue square  
on OS 1:25,000 map

100 x 100 x 1 m  
total storage

8900 gallons per acre

**substantial investment  
of public money**

If former reservoir 2.5 m deep (x100x40) = 10,000 m<sup>3</sup>



1. Attempt to incorporate **accurate streamflow measurement** (NFM about hydrograph change) in the experimental design
2. Attempt to capture the **large variability in volume response of same type of feature**
3. Use observed *volume change* in floods to estimate **number of features** of a particular type needed to deliver **10,000 m<sup>3</sup> of additional flood storage per km<sup>2</sup>** upstream of a flood-affected community

## 7 Our key monitoring messages





# Thank you

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@NERC\_QNFM