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**

Lancaster University

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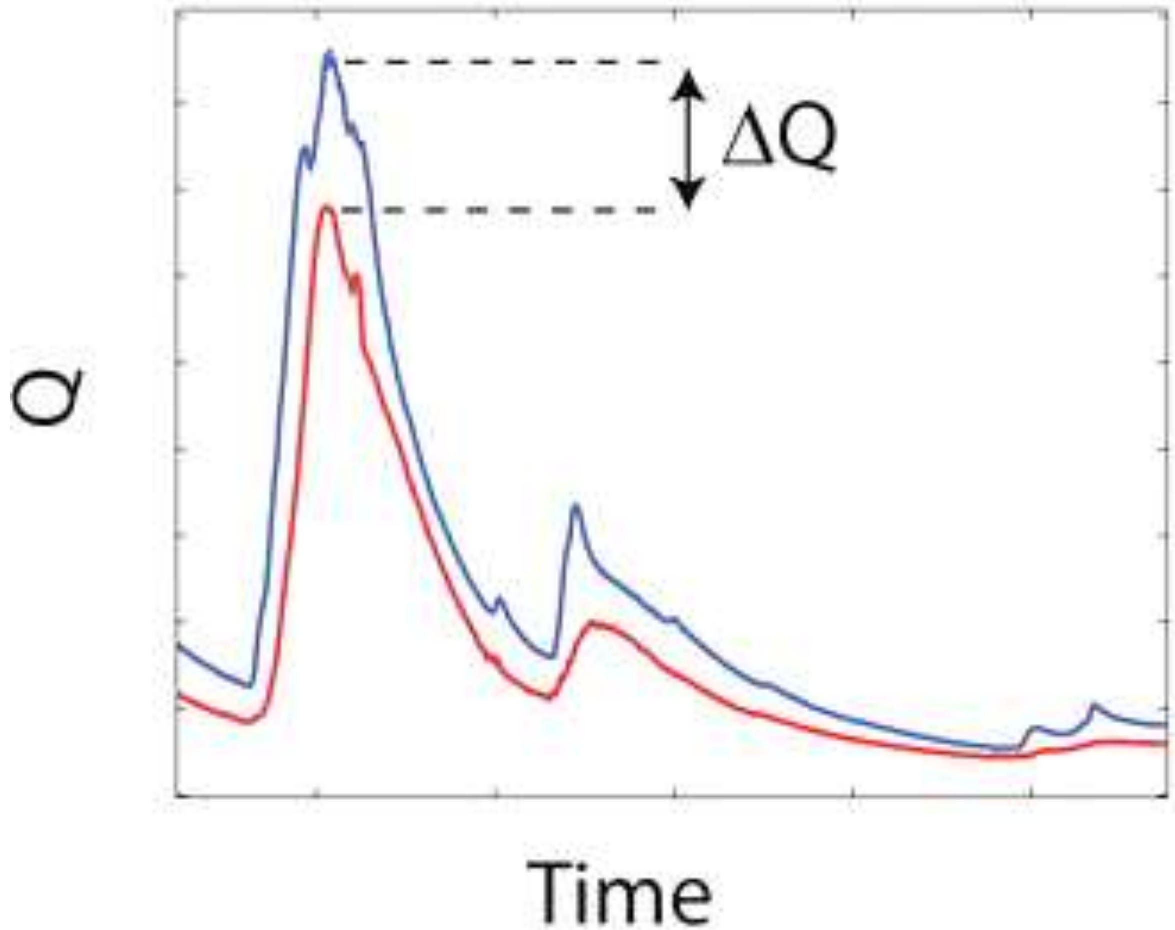
Lancaster University



Hankin et al. (2017) 10.5772/intechopen.68677

1 What is NFM effectiveness?

Cumbria-focused research

Q-NFM

NATURAL FLOOD MANAGEMENT RESEARCH PROGRAMME

UKRI Natural Environment Research Council

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)

C-NFM

Cumbrian NFM Effectiveness Monitoring Network

defra Department for Environment Food & Rural Affairs

Environment Agency

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

Primarily field monitoring (with some dynamic systems modelling)

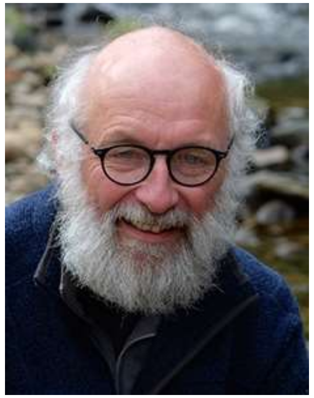
2 Researchers and partners

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)

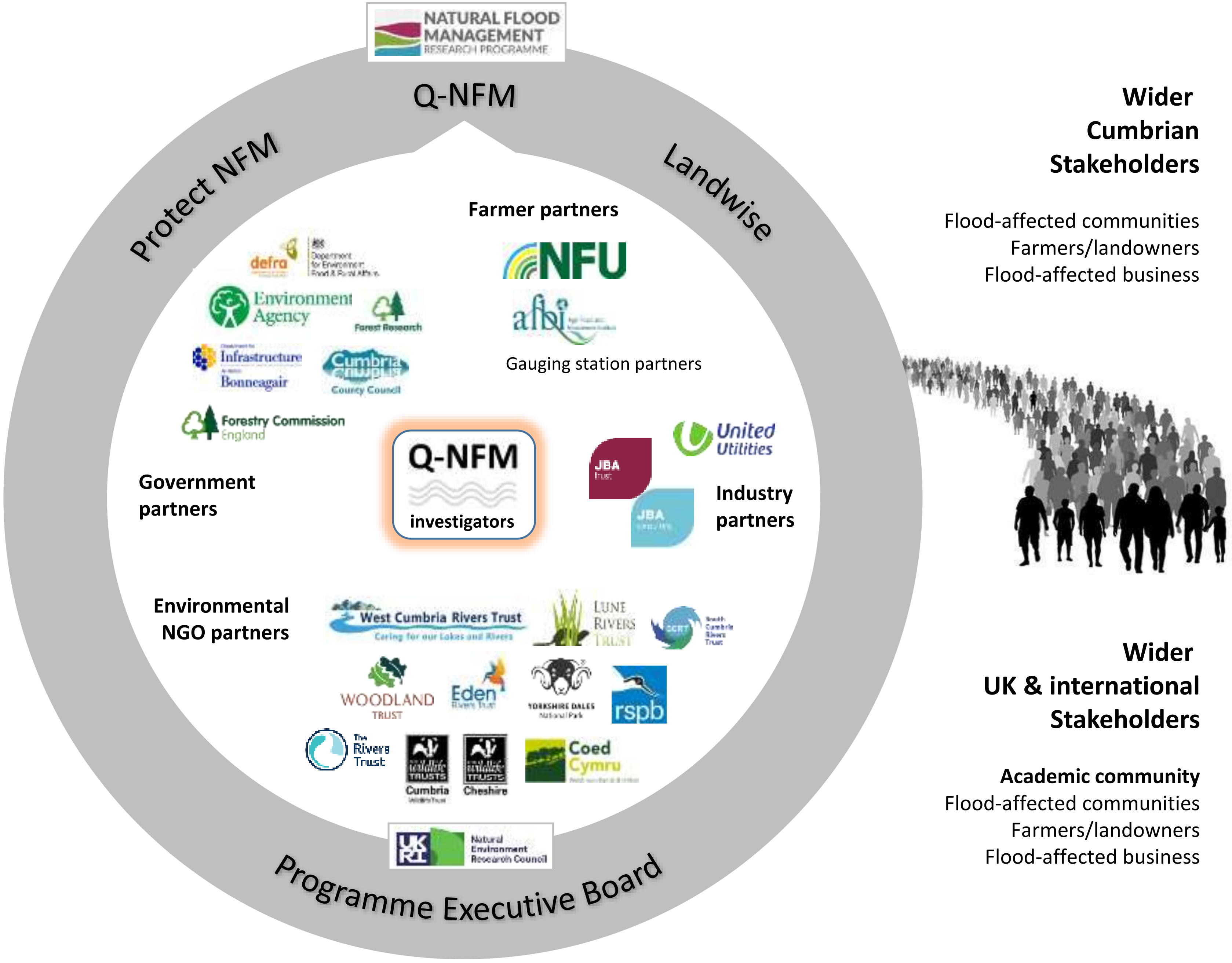
Barry Hankin (T5, 6)

Rob Lamb (T6)

Nick Chappell

Phil Haygarth (T7)

David Johnson (T7)


NATURAL FLOOD MANAGEMENT RESEARCH PROGRAMME
Q-NFM
Protect NFM
Landwise
Farmer partners
NFU
Gauging station partners
Government partners
Q-NFM investigators
Industry partners
United Utilities
Environmental NGO partners
Programme Executive Board
Natural Environment Research Council
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

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

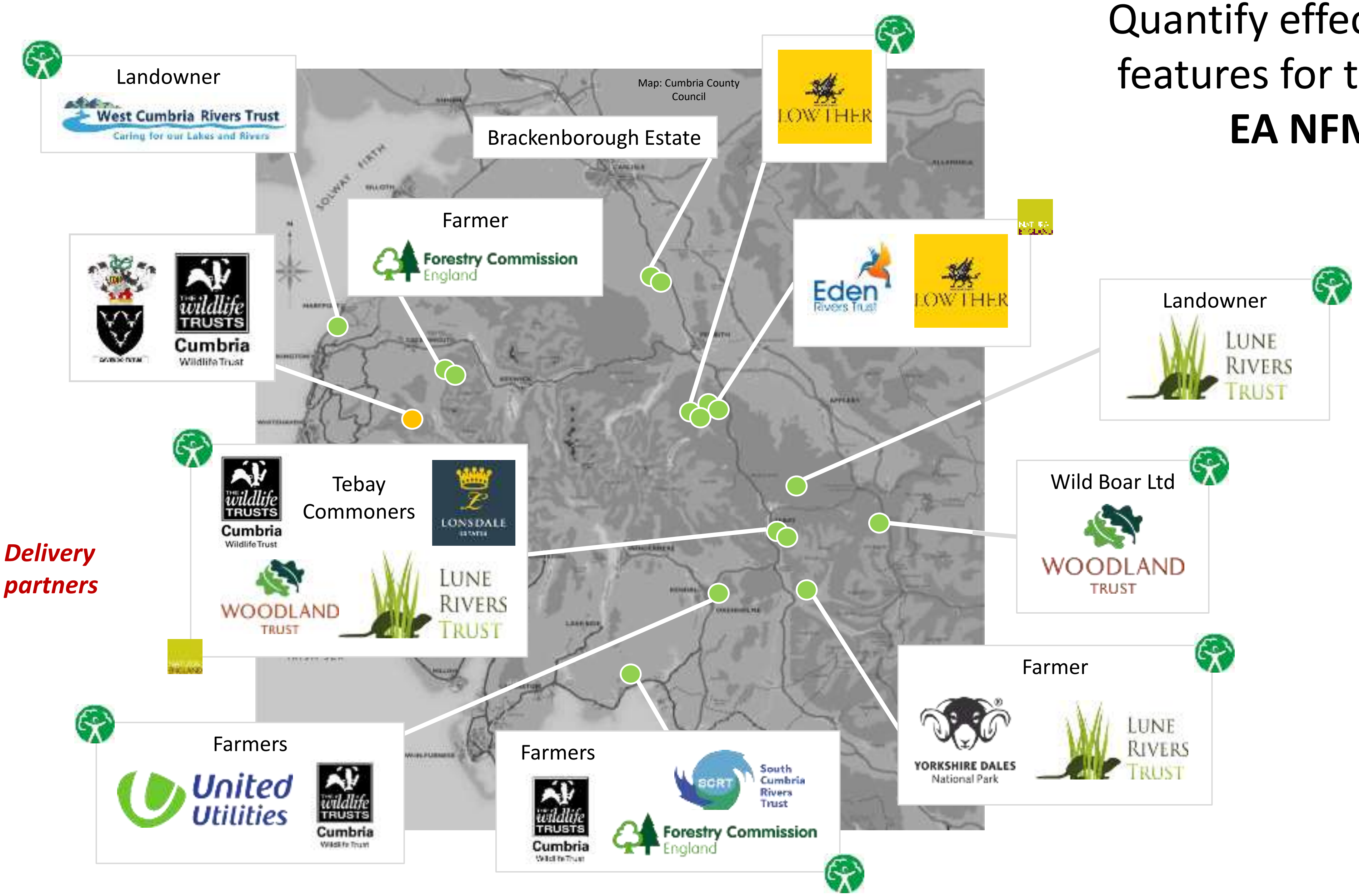
Evaluate **process representation**, locally, in our catchment-scale models

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**

Delivery partners

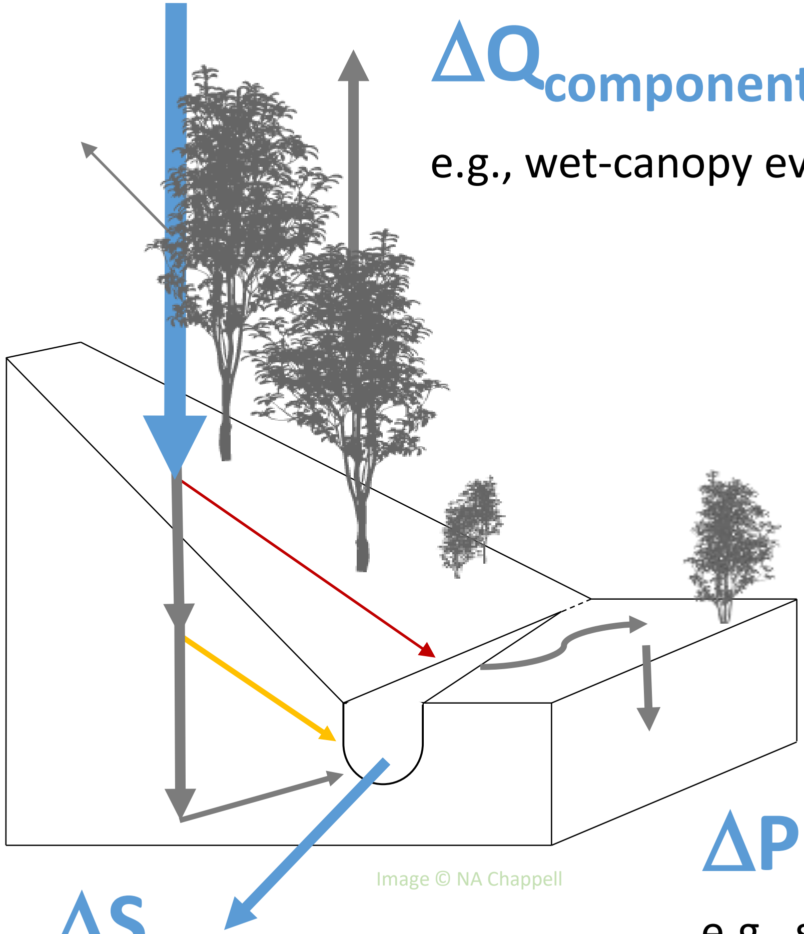


$\Delta Q_{component}$

e.g., wet-canopy evaporation

ΔS

e.g., soil-moisture storage



ΔS

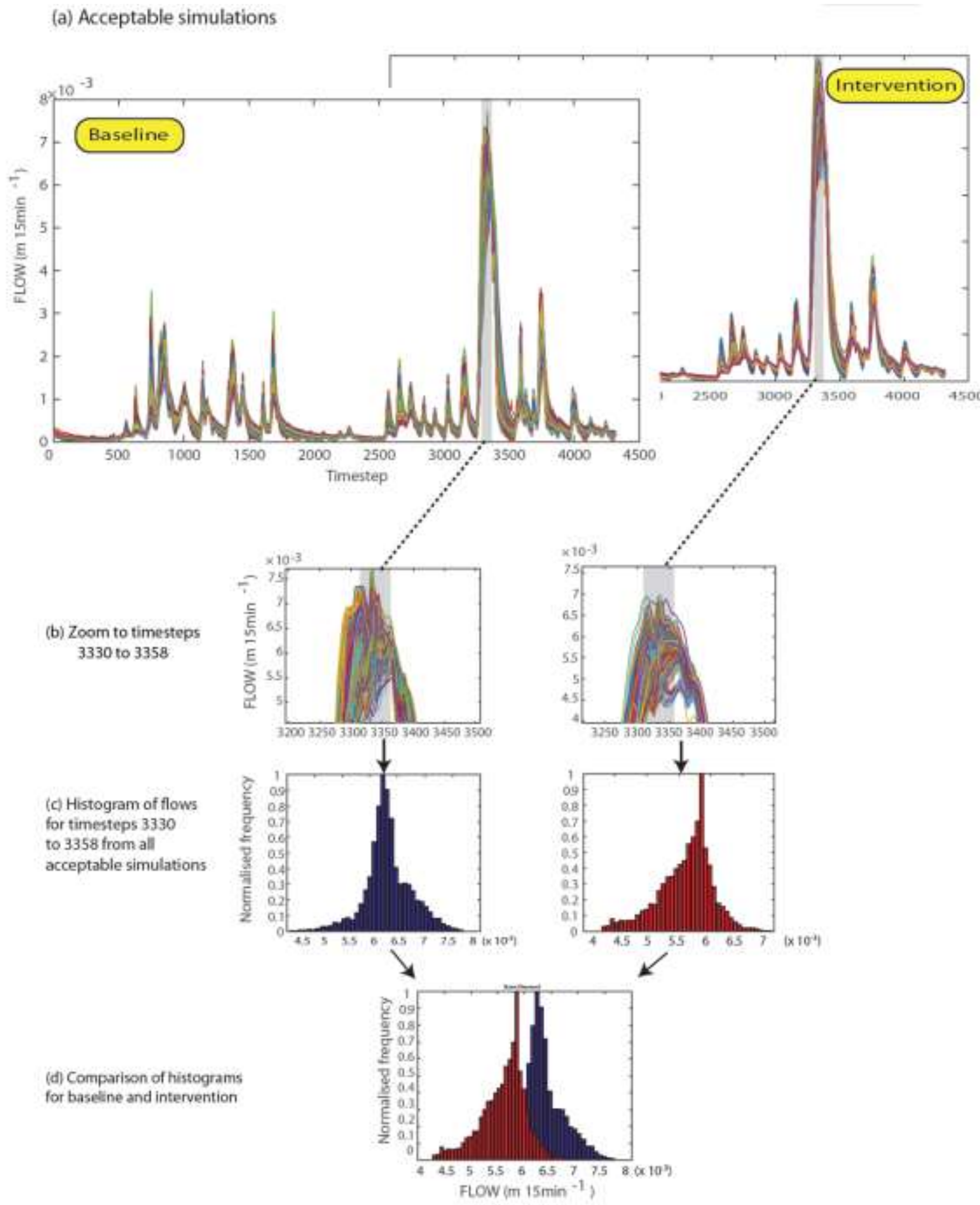
e.g., 'leaky dam'

ΔP

e.g., saturated hydraulic conductivity at ground surface (= infiltration capacity)

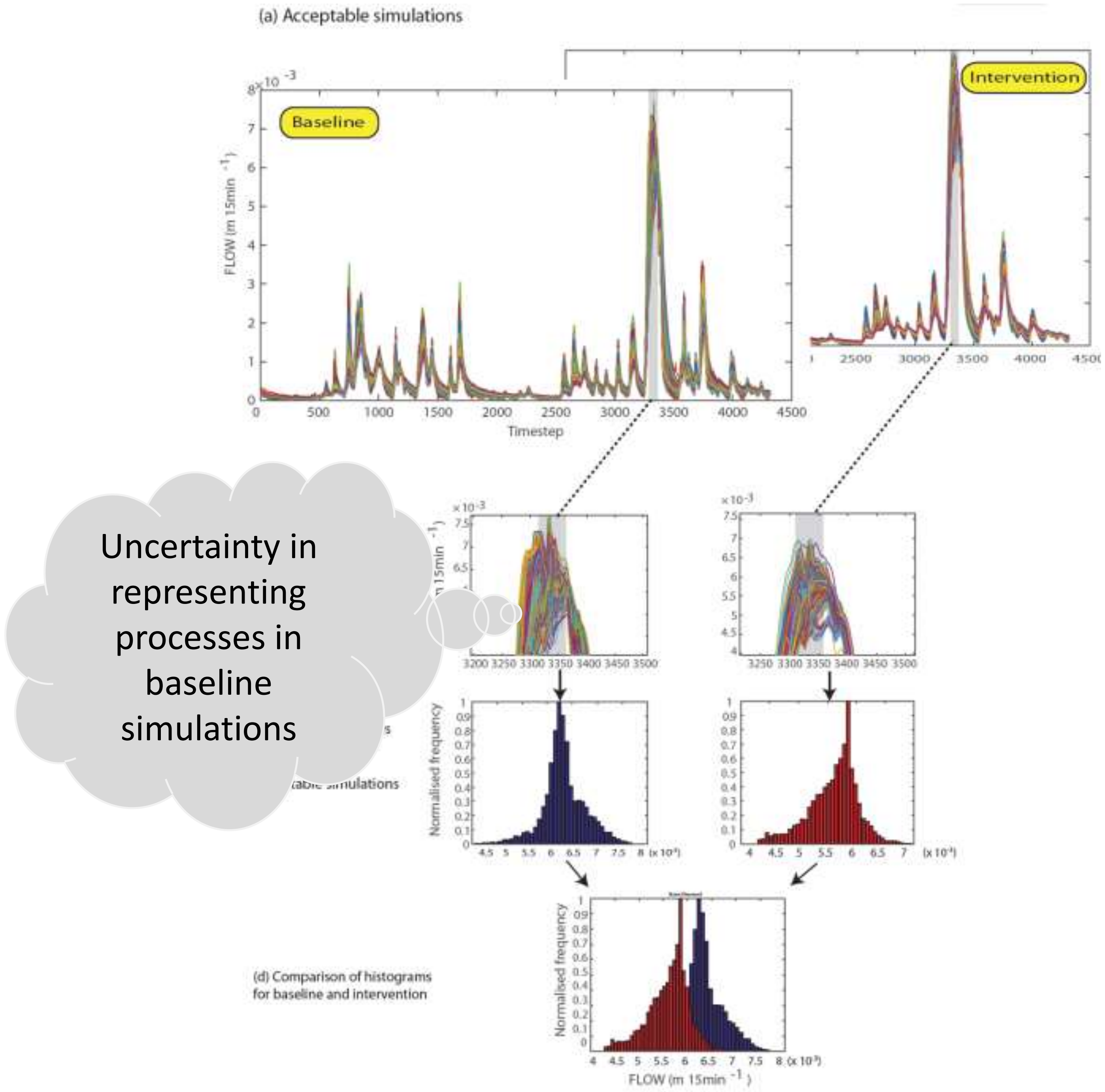
Constrain the **NFM-related shifts in parameters** of our catchment-scale models

Note for example: roughness change (ΔP) to reproduce observed storage change (ΔS)

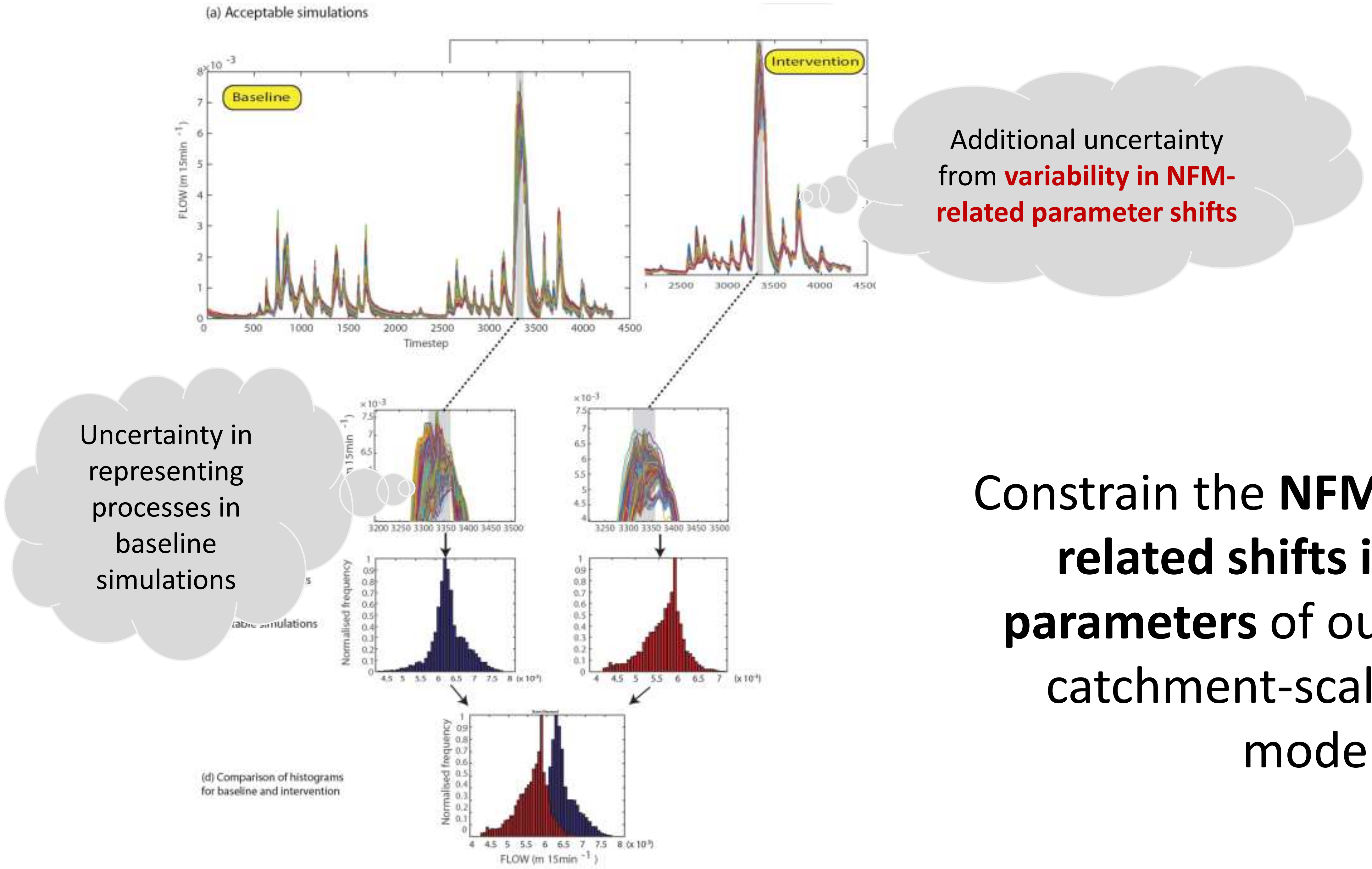


https://naturalcourse.co.uk/uploads/2017/04/2016s4667-Rivers-Trust-Life-IP-NFM-Opportunities-Technical-Report-v8.0.pdf

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

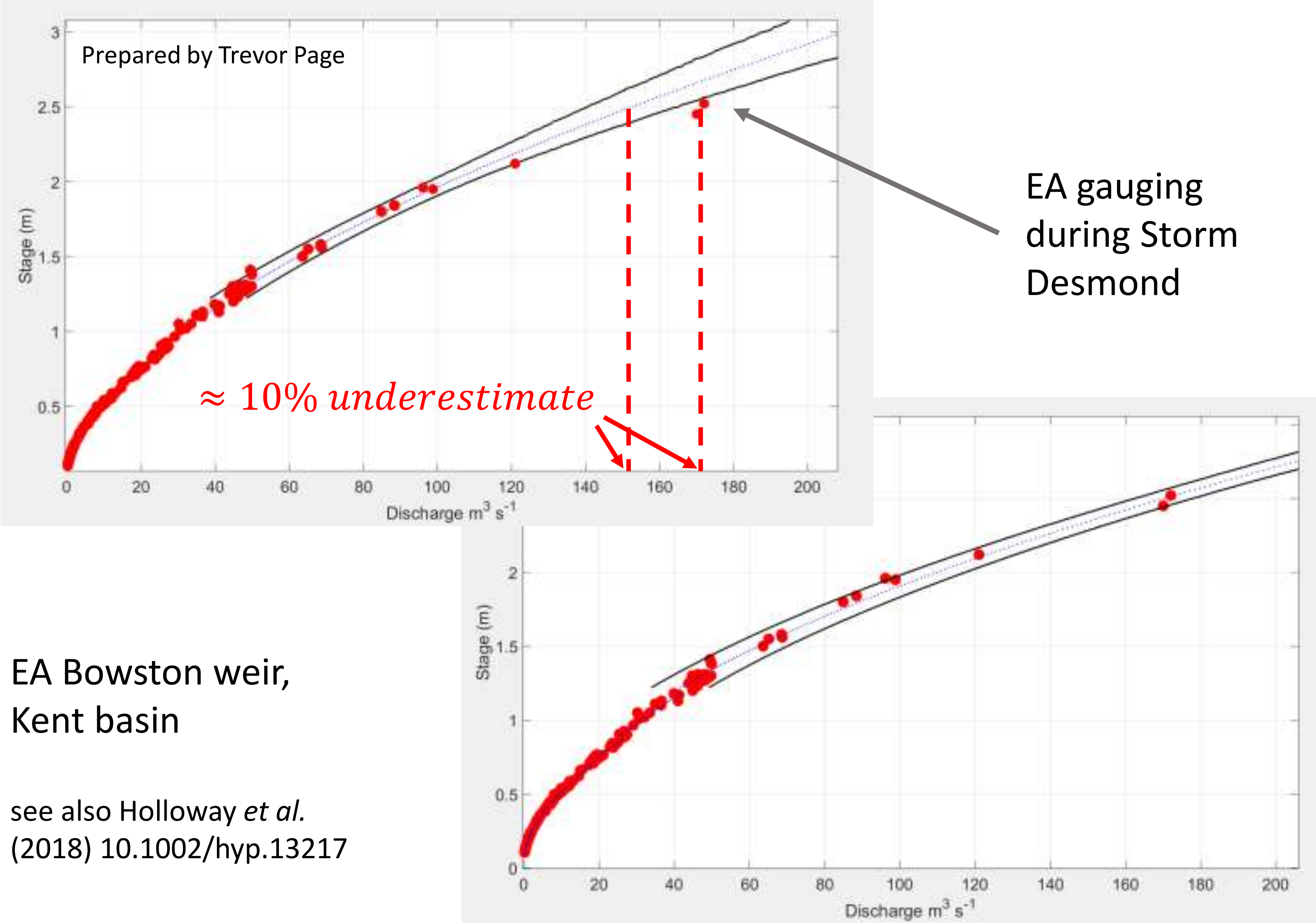


Constrain the **NFM-related shifts in parameters** of our catchment-scale models



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

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



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^2)

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

1. **Scale of NFM pilots** (at many places)

2. At scale of 1 km^2 - catchments **behave very differently**

3. **Reference for behaviour** of individual NFM interventions

At scale of 1 km^2

catchments **behave very differently**

e.g., Tebay Gill micro-basin vs Sedbergh micro-basin (both largely draining Coniston 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 τ :

Pure time delay δ :

Residence time TC :

Steady-State Gain C :

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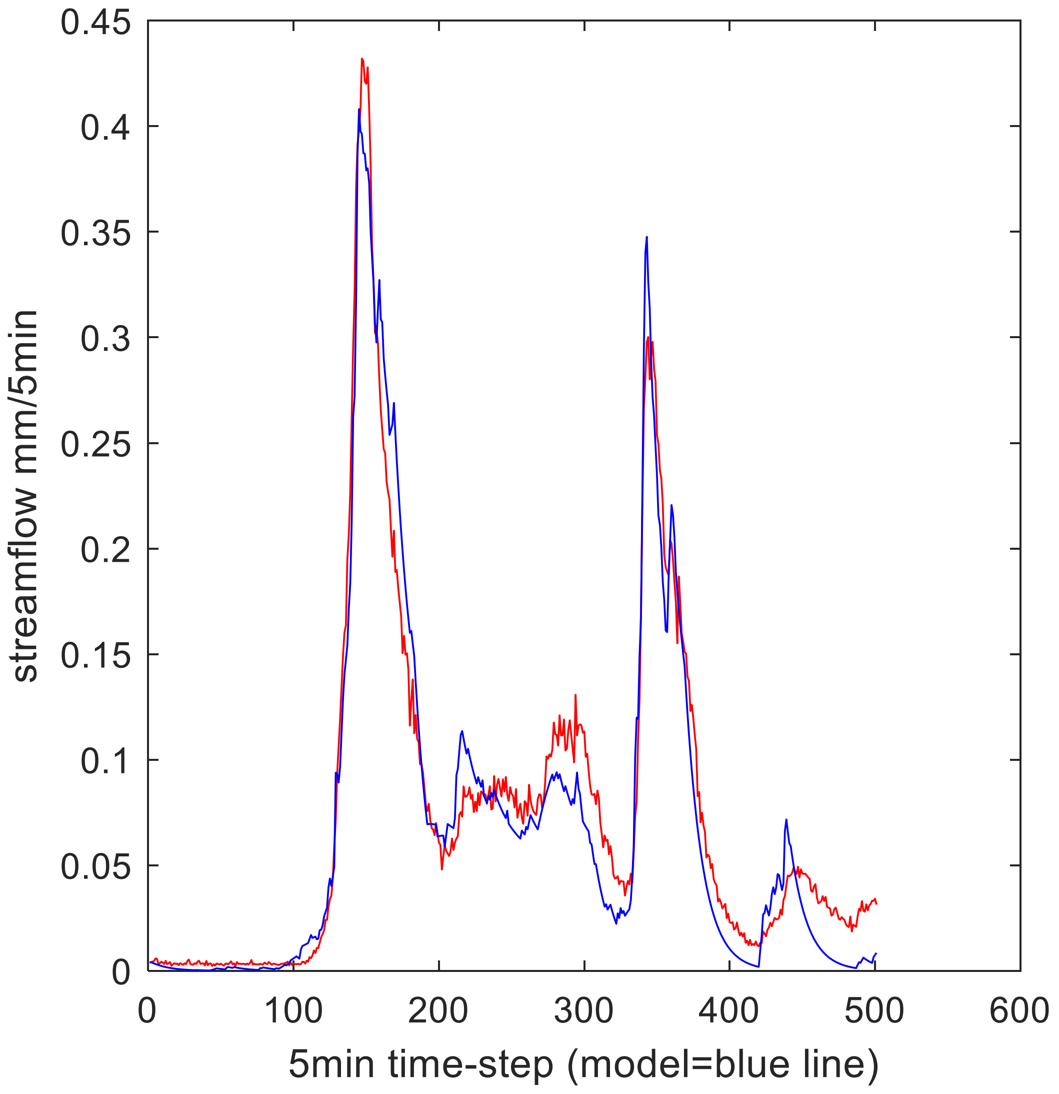
from first-order BOSM CAPTAIN RIV model

Efficiency (R_t^2) : YIC :



Tebay Gill micro-basin

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

Rainfall nonlinearity τ : 275 min (4.58 hr)

Pure time delay δ : 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 τ : 850 min (14.2 hr)

Pure time delay δ : 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*)

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

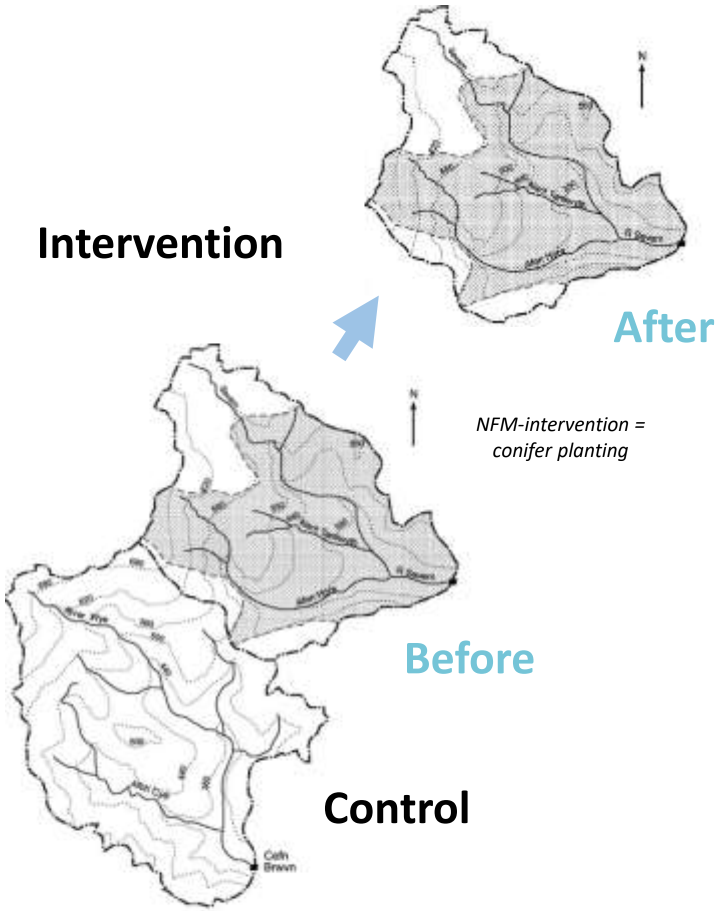
For example…

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 (m^3 /hr) is a significant proportion of peak channel flow (m^3/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)*



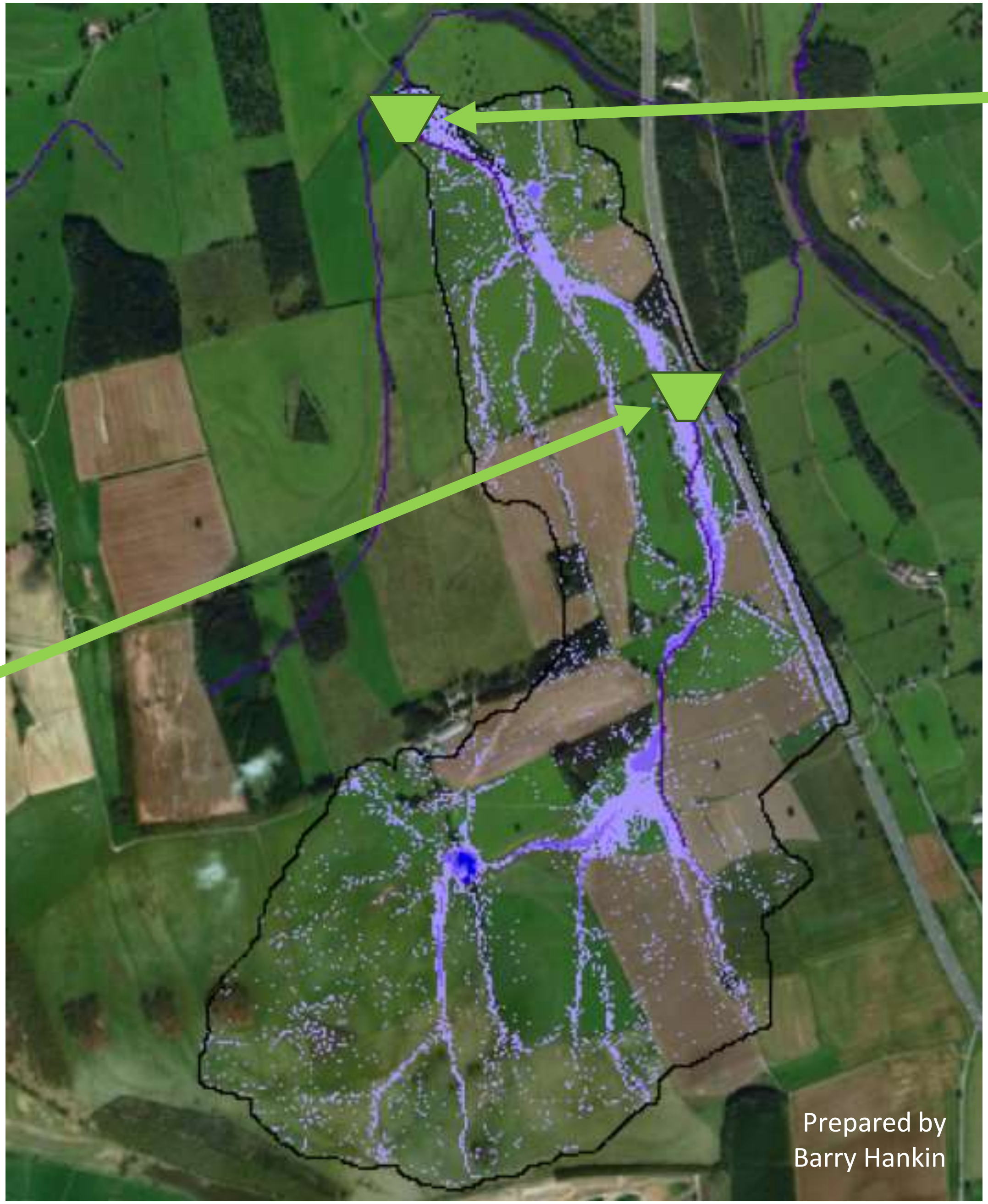
Combining 2 & 4 = BACI design
(Before-After Control-Intervention)

e.g., Bessy Gill NFM by channel realignment

and commercial afforestation of 0.17 km² of former sheep pasture (213,000 trees)

Upstream

Control

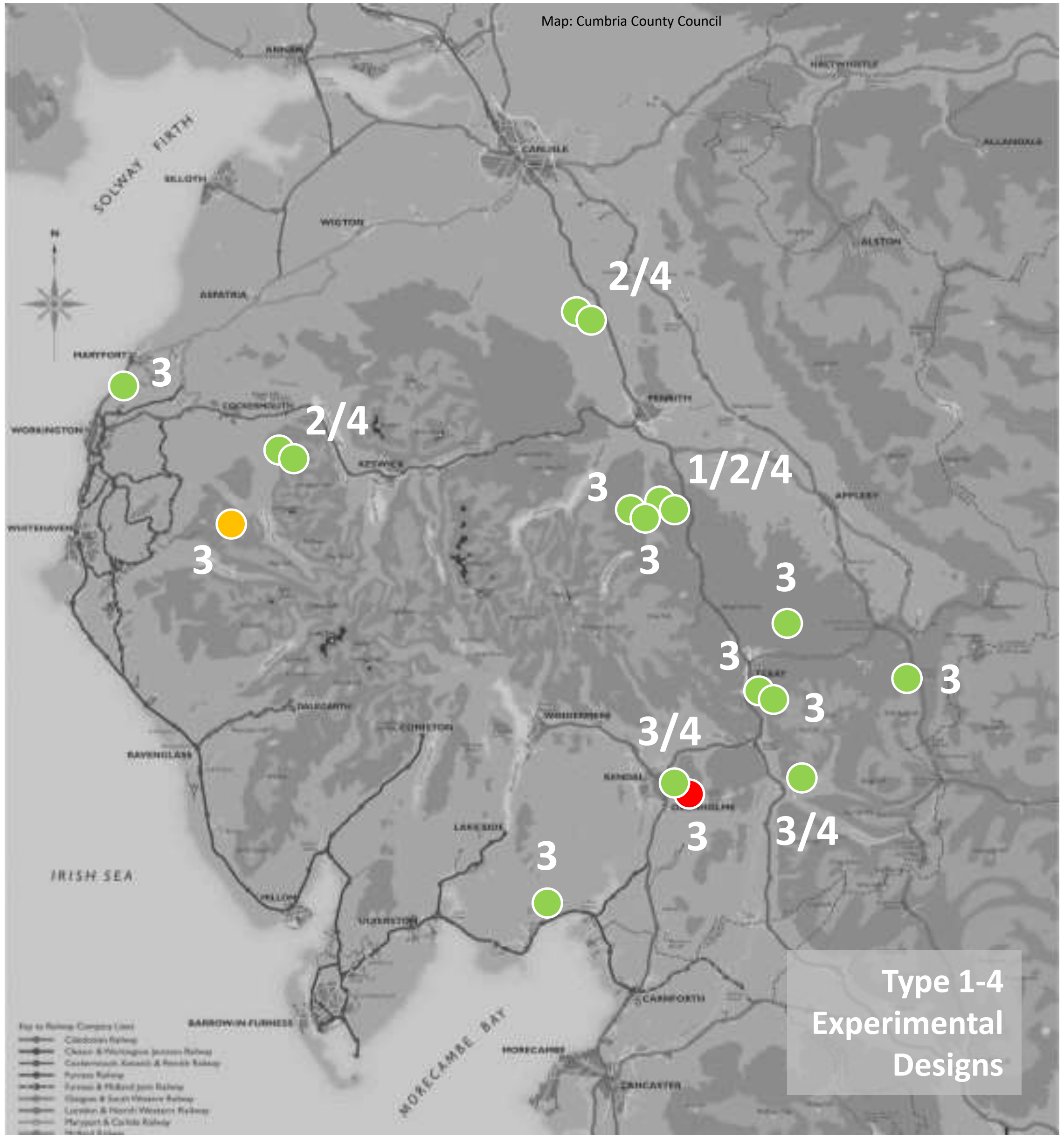


Downstream

Before-and-After

Type 1, 2 & 4
BACI design

Micro-basins (< 1 km²)



Operational status (30 Nov 2020):
fully (green), structure present
(orange), to be installed (red)

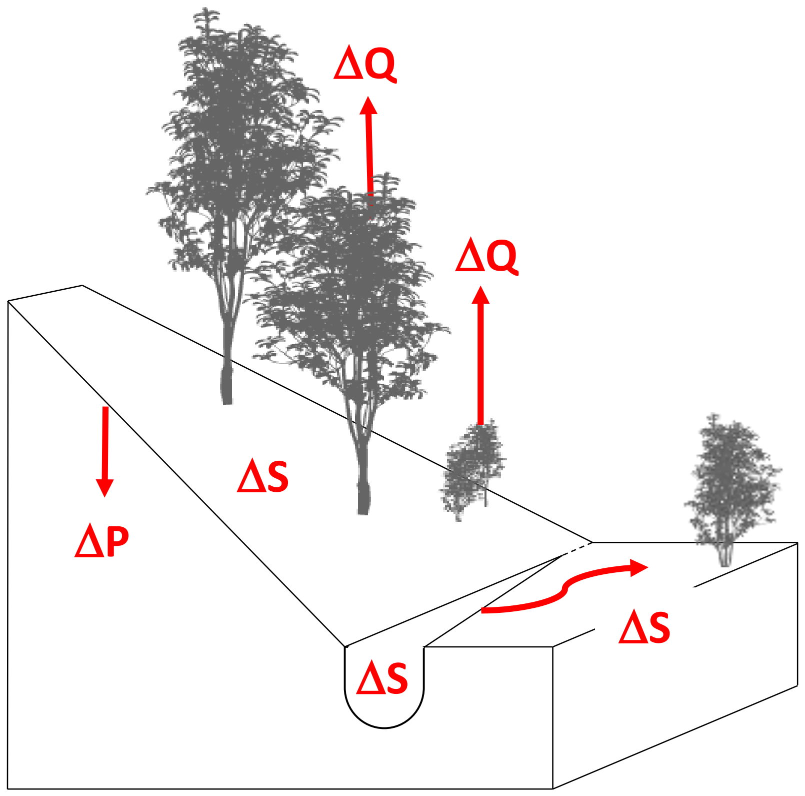
Hydrological processes changed by NFM measures we are modelling for large floods

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^2

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

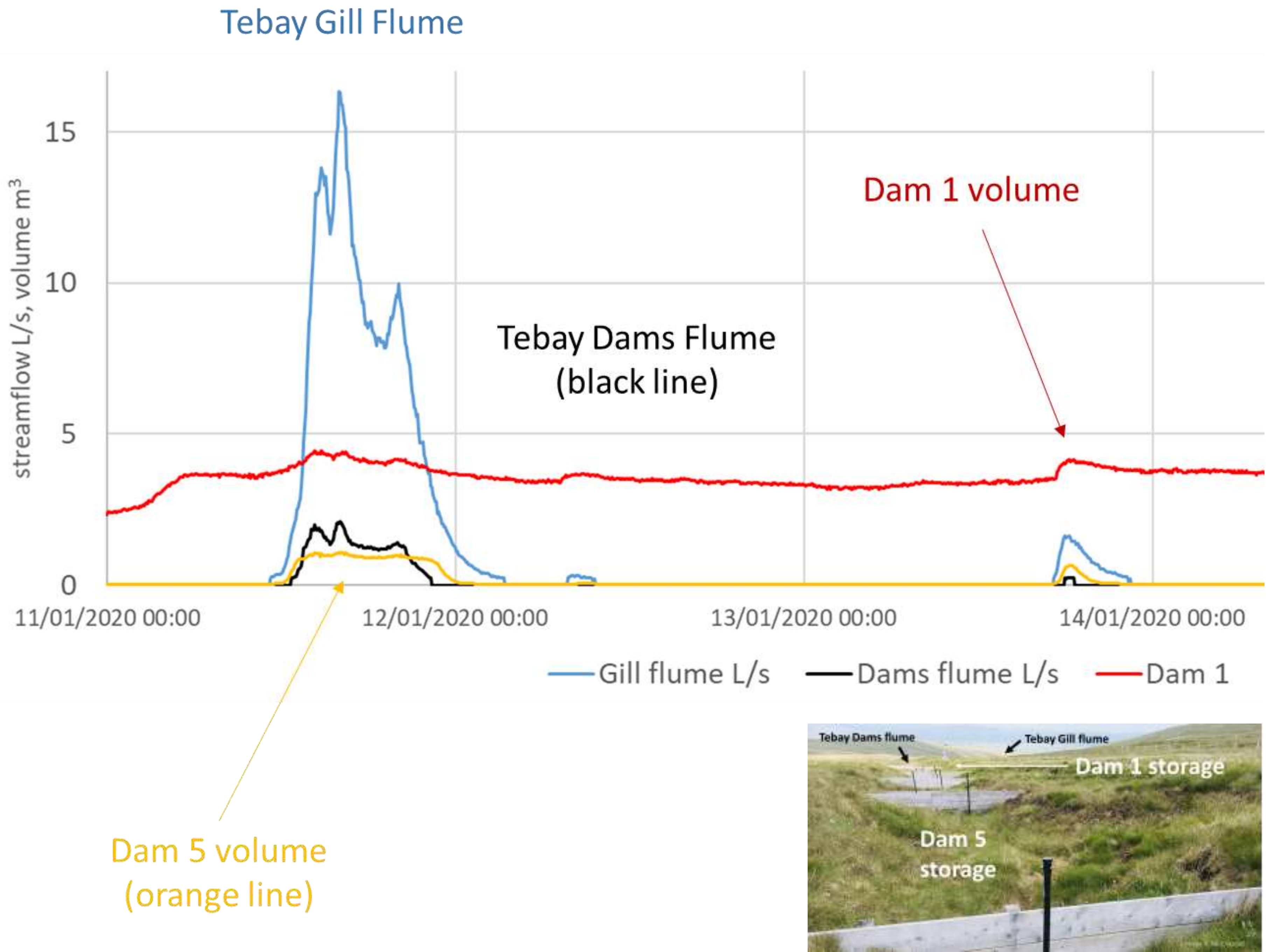
5 How we are measuring hydrological changes in flood events

1. Enhanced hillslope surface storage

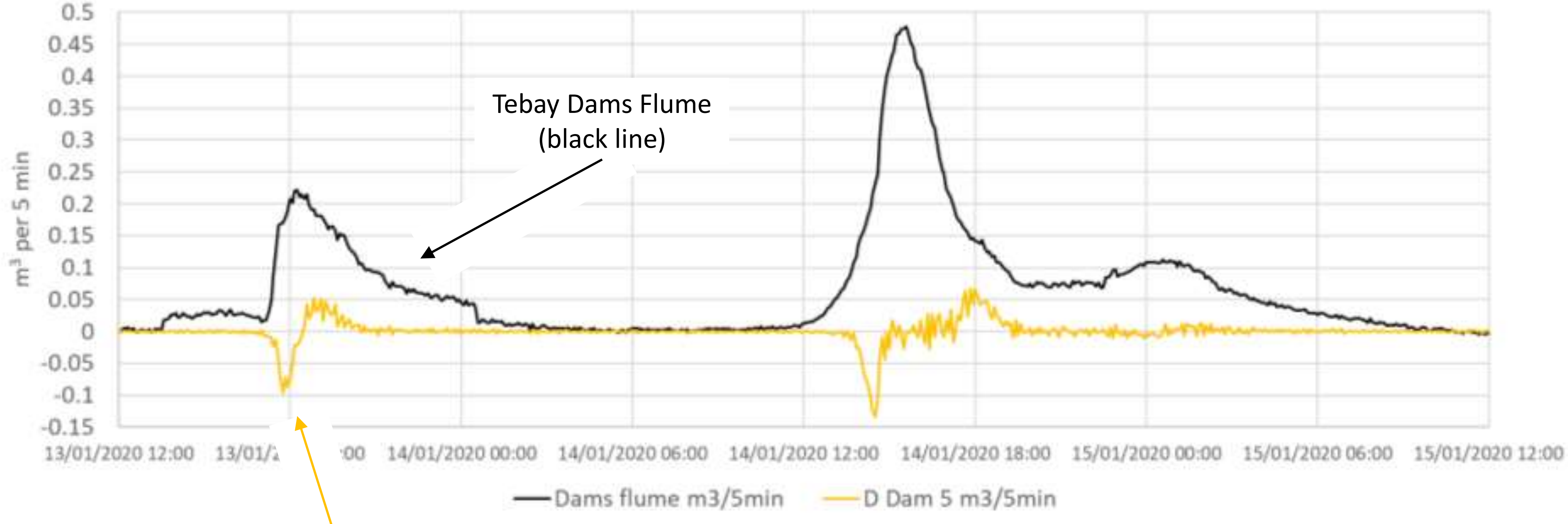
bunds, swales, kests, walls and peatland restoration; including zero-order channels

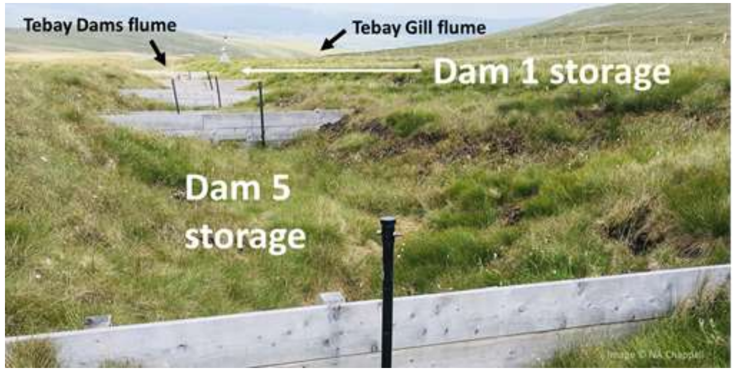
Tebay NFM peatland restoration monitoring


Tebay Dams flume
Tebay Gill flume
1
2
3
4
Dam 5
Level recorder
Dam 6
Linking storage dynamics (m3) with local stream discharge (m3/s or L/s)
e.g., Peatland dams on Tebay Fell
Tebay NFM peatland restoration monitoring
Image © NA Chappell



Tebay Gill Flume
Dam 1 volume
Tebay Dams Flume (black line)
Dam 5 volume (orange line)
streamflow L/s, volume m3
0
5
10
15
11/01/2020 00:00
12/01/2020 00:00
13/01/2020 00:00
14/01/2020 00:00
Gill flume L/s
Dams flume L/s
Dam 1
Tebay Dams flume
Tebay Gill flume
Dam 1 storage
Dam 5 storage





and storage gain, ΔS (m^3 per 5min)
directly with local stream discharge (m^3 per 5min)

2. In-channel leaky dam storage on streams draining less than 10 km^2 contributory area


Flimby flume micro-catchment
© Dave Kennedy, EA 31 Jan 2020
West Cumbria Rivers Trust
Caring for our Lakes and Rivers
Flimby NFM site
‘horse jumps’

Tebay NFM log-dam demonstration site


Level recorder
Tebay NFM log-dam monitoring
77 log dams installed on main channel by 28/11/2020

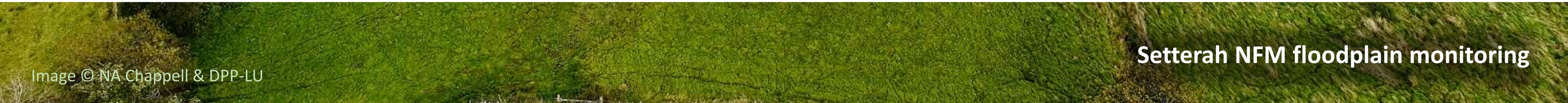

Level recorder


© Tim Winder
16:06 11 Jan 2020
Level
recorder
Tebay NFM log-dam monitoring

Tebay NFM log-dam monitoring

3. Enhanced floodplain surface storage

swales, bunds and floodplain reconnection




Bessy Gill NFM micro-catchment
Image @NERC_QNFM

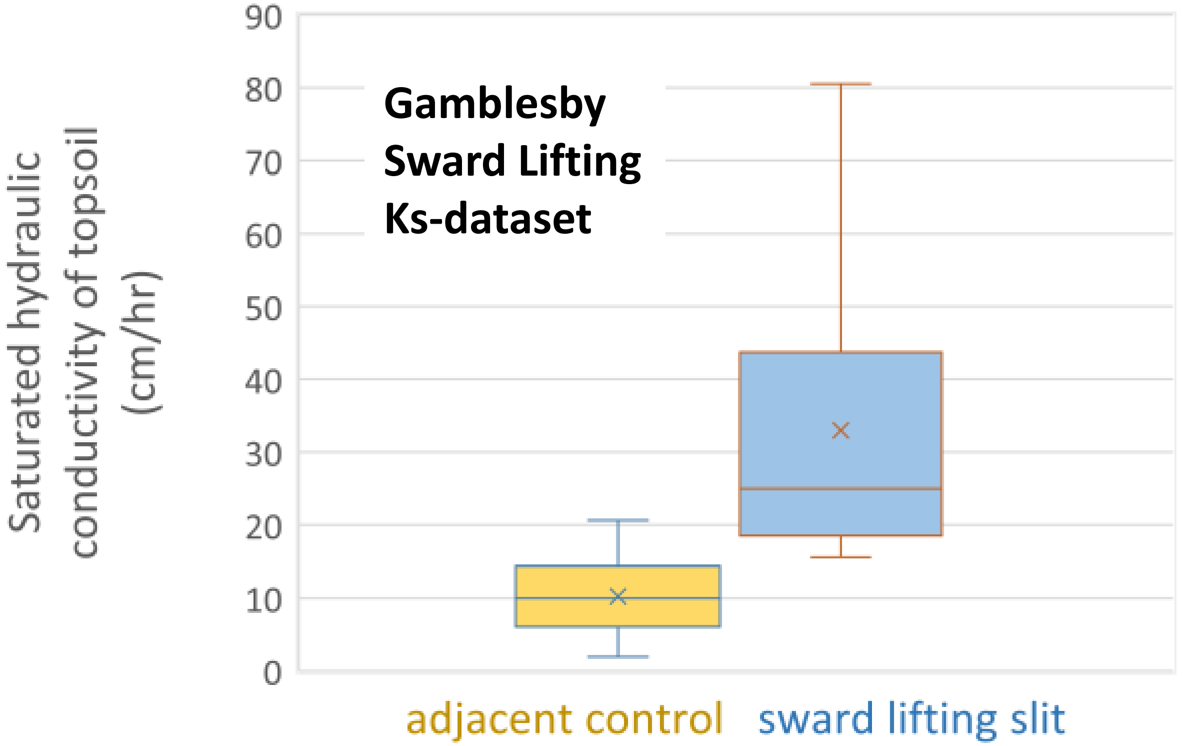

Image © NA Chappell & DPP-LU


Image © NA Chappell
Whale NFM floodplain monitoring
Image © NA Chappell & DPP-LU


Setterah NFM floodplain monitoring
Image © NA Chappell & DPP-LU

4. Infiltration enhancement on slowly permeable soils

by extensive woodland tree planting or soil management



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

Blade aeration (next page – published)

Published September 26, 2019

Journal of Environmental Quality — TECHNICAL REPORTS

LANDSCAPE AND WATERSHED PROCESSES

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

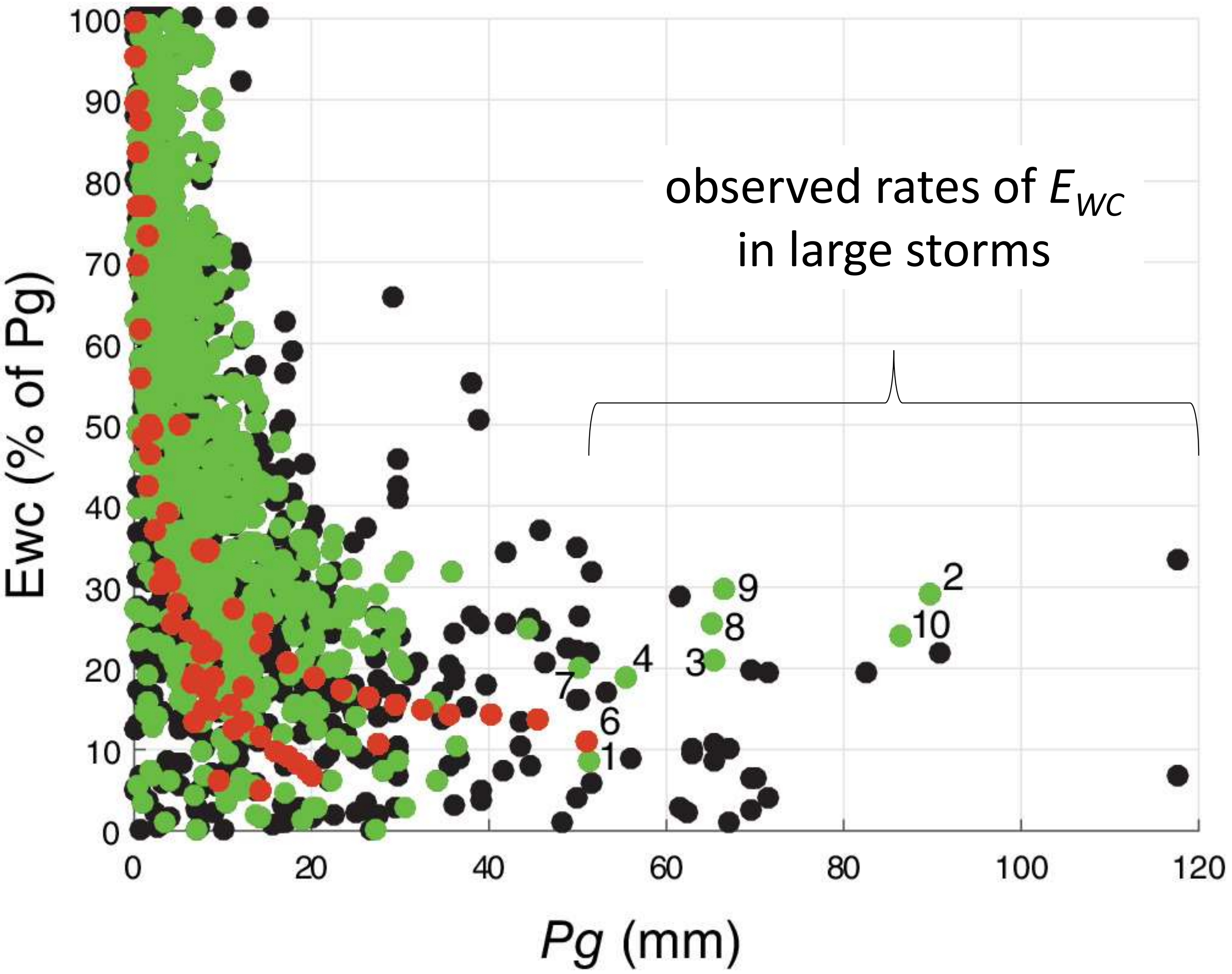
Ethan E. Wallace* and Nick A. Chappell

Abstract

Core Ideas

5. Enhanced wet-canopy evaporation from extensive woodland planting

New observed data assimilation : for storm-only measurements



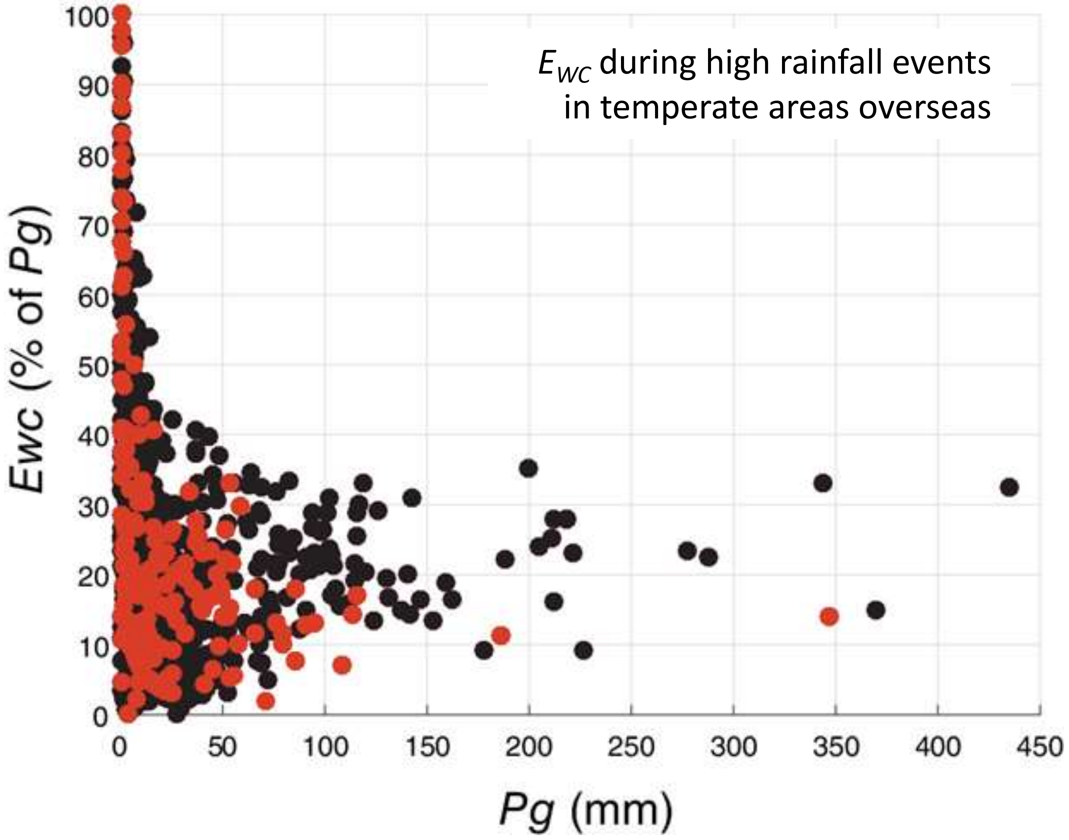
CCD

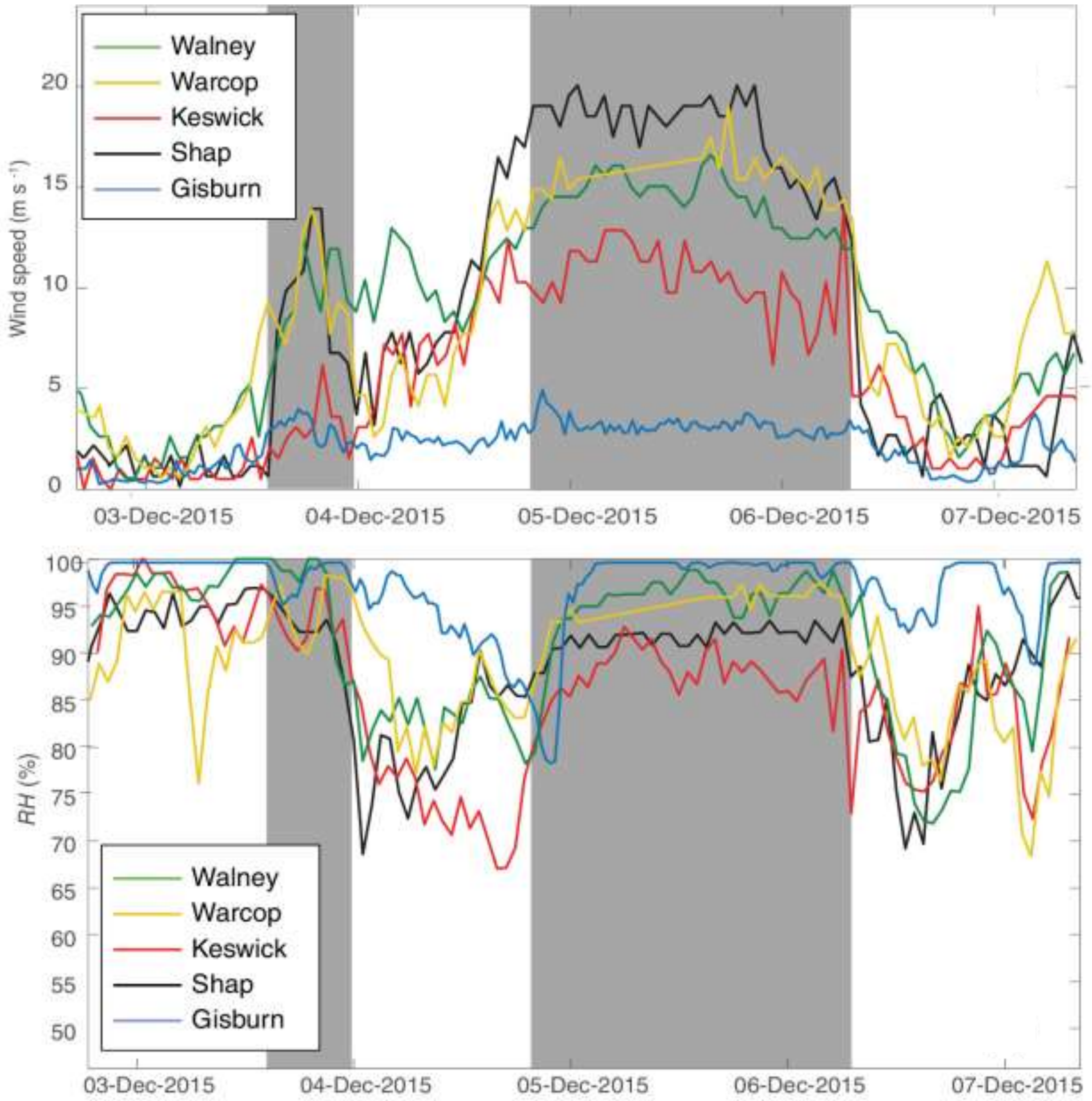
Catchment Change Database

of observed measurements (published & own) for each intervention

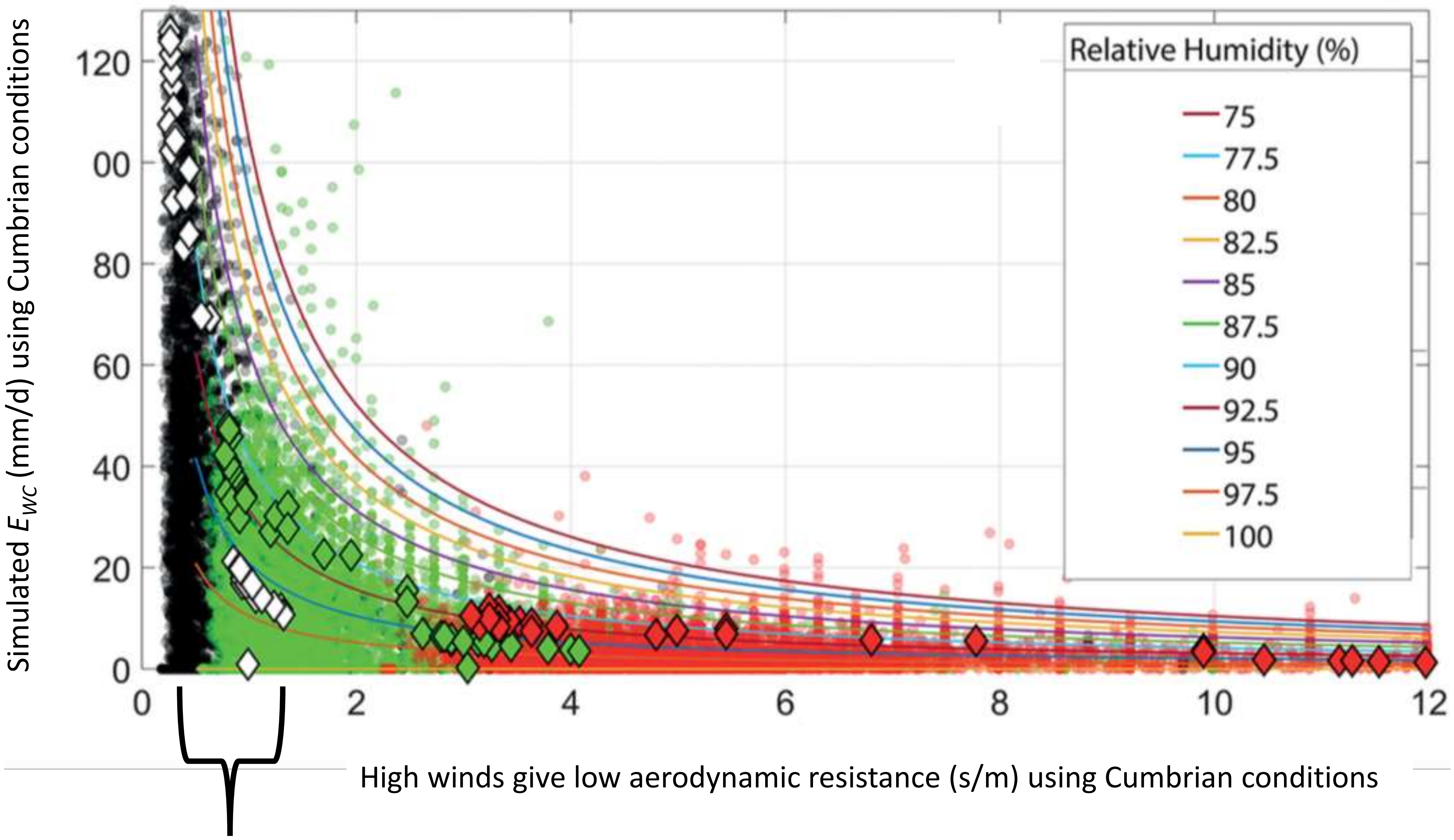
e.g., wet-canopy evaporation enhancement by woodland

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





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


Simulated E_{WC} (mm/d) using Cumbrian conditions
120
00
80
60
40
20
0
0
2
4
6
8
10
12
Relative Humidity (%)
75
77.5
80
82.5
85
87.5
90
92.5
95
97.5
100
High winds give low aerodynamic resistance (s/m) using Cumbrian conditions

BORDER

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^3 per 1 km^2 loss in such rain-events

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

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

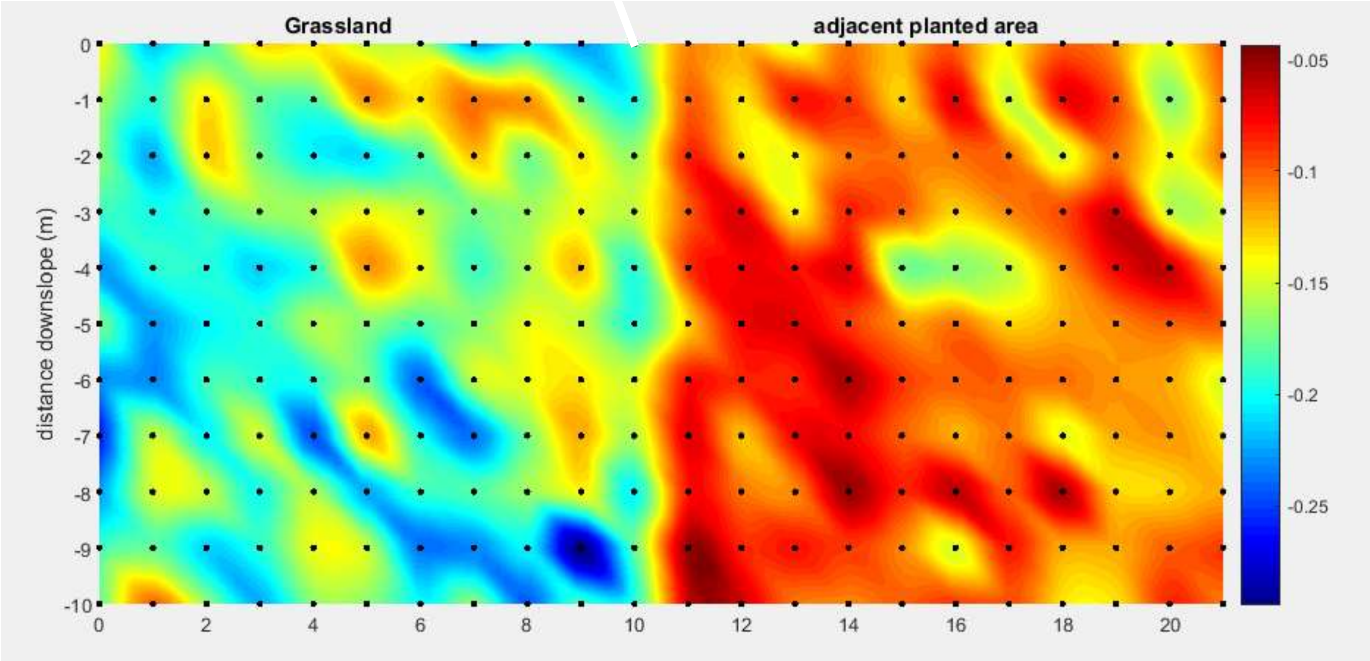
e.g., Bessy Gill NFM conifer plot

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
Image © NA Chappell

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

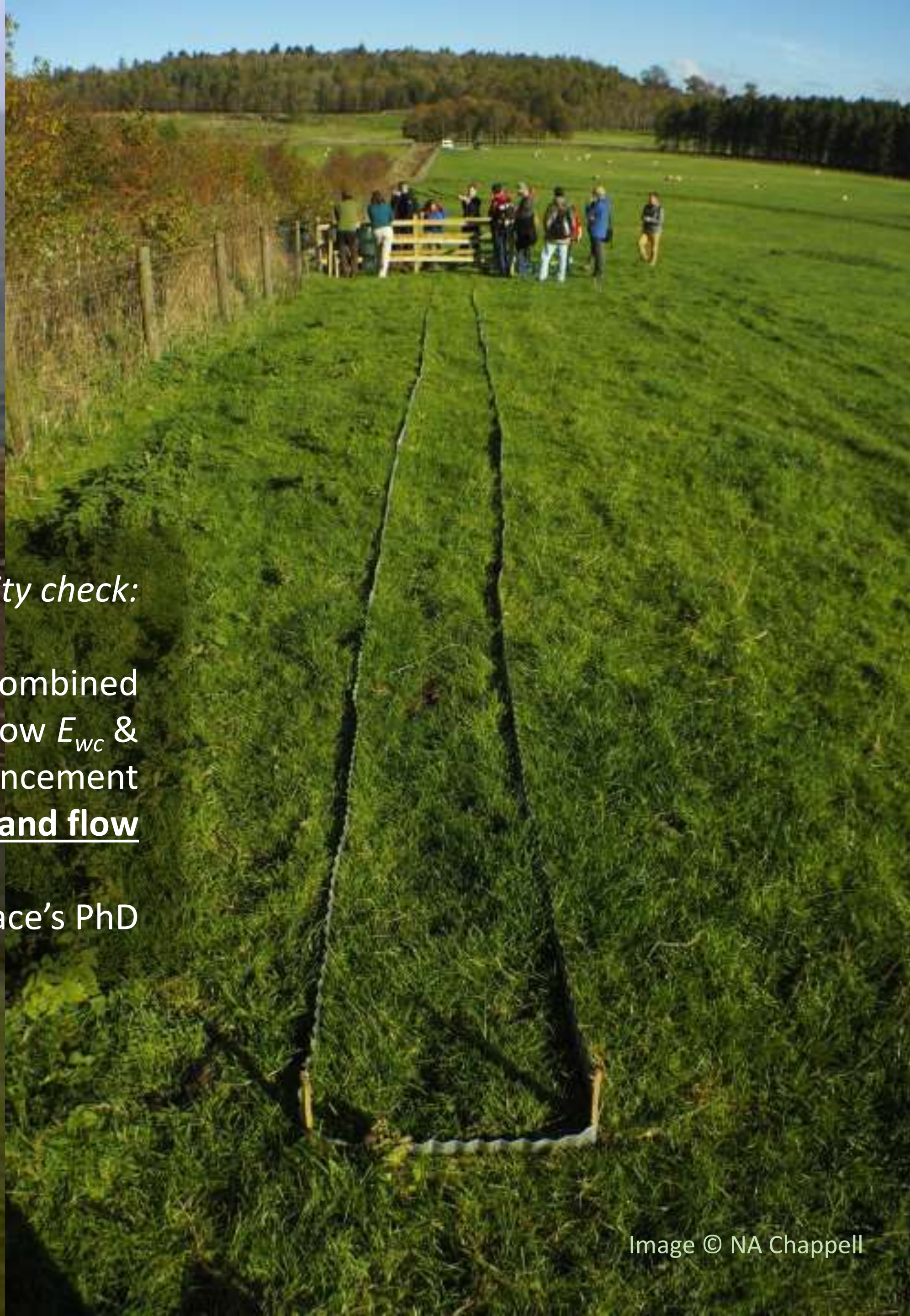


Image © NA Chappell

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

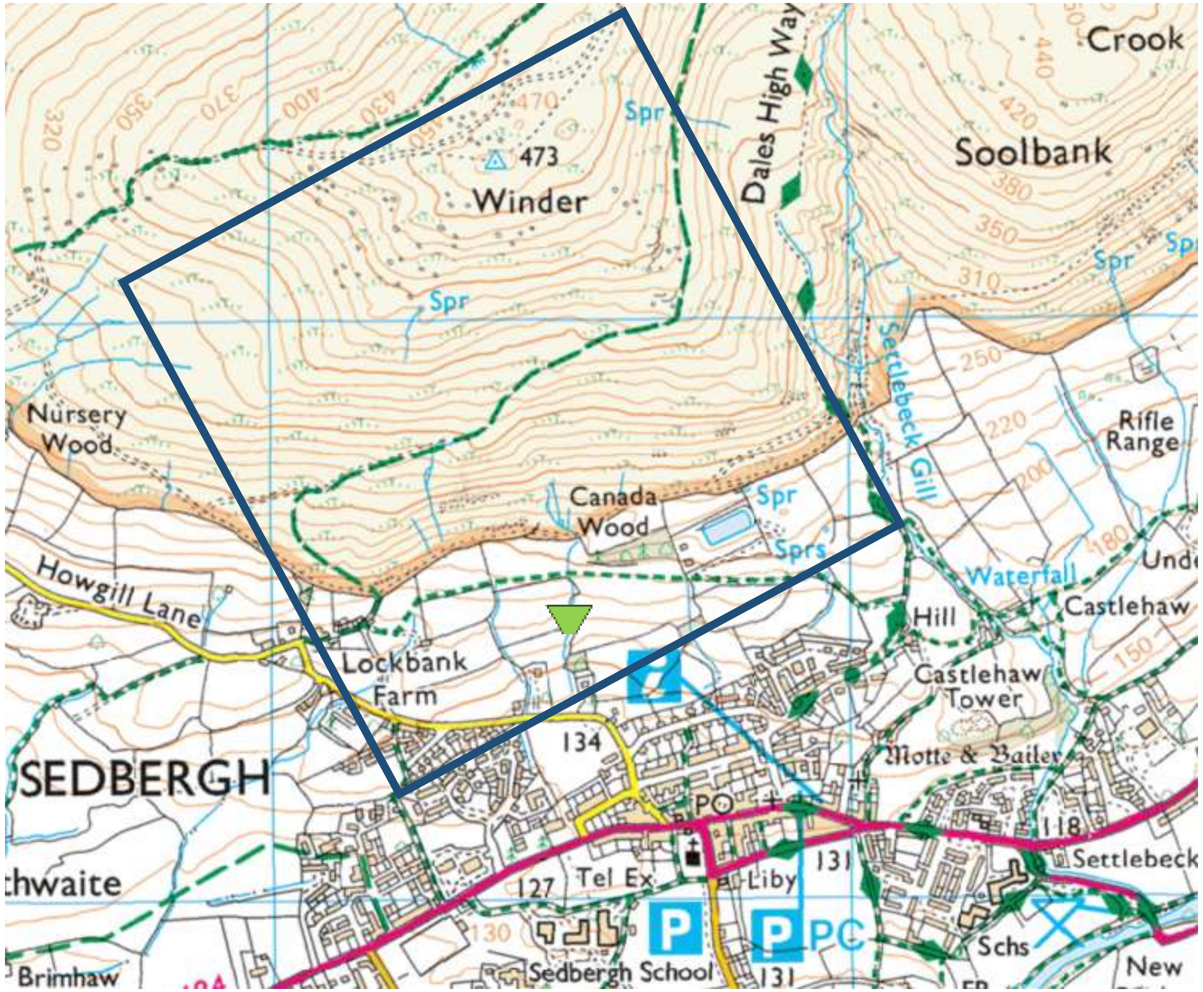
e.g., 1,300,000 m^3
Garstang flood basin
downstream of 114 km^2
catchment (11,400 m^3 per 1 km^2)

Note: Rydal Water 1.6M m^3

For a traditional flood mitigation scheme

1,000,000 m^3 per 100 km^2 contributory area

6 Scale-up: How many such features needed



Sedbergh NFM flume

If former reservoir 2.5 m deep (x100x40) = 10,000 m^3

10,000 m^3 per every 1 km^2 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

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^3 of additional flood storage per km^2** upstream of a flood-effected community

7 Our key monitoring messages

WCRT Row End NFM

Thank you

n.chappell@lancaster.ac.uk

@NERC_QNFM

Image © NA Chappell