The Eddleston Water Project – *10 years of implementing, monitoring and empirical analysis of catchment scale NFM measures*

Chris Spray & Andrew Black (University of Dundee), Barry Hankin (JBA Consulting)

NERC Natural Flood Management (NFM) Research Programme
Webinar Series - 25th August 2021

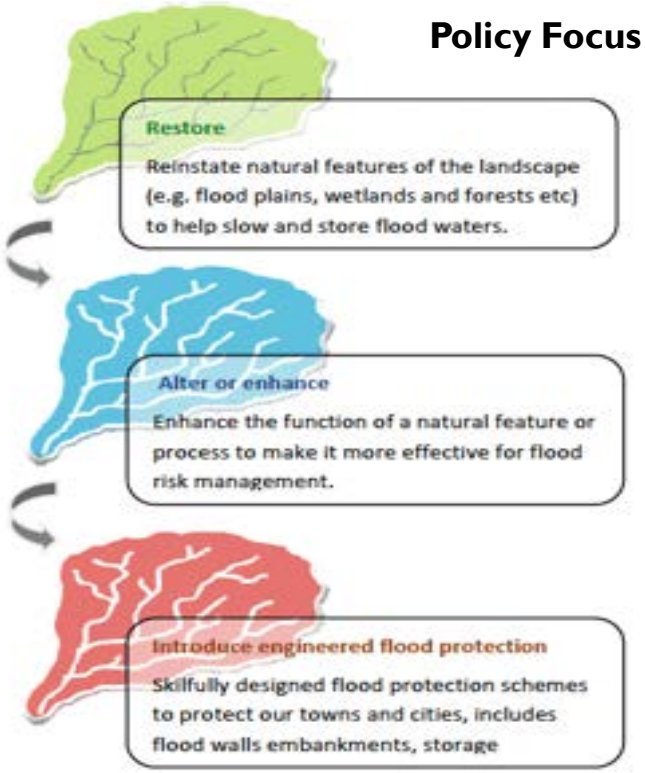
The why and the what of the Eddleston Water project?

Scottish Government's long-term empirically-based NFM study

Scottish policy framework:

***NFM* is part of the Vision for Flood Risk Management within a wider policy approach to Flooding**

- A risk-based, sustainable and plan-led approach - delivered at the **catchment scale**
- Manages **sources** and **pathways**
- Improve public investment to protect people and property
- Close **partnership** working
- NFM part of sustainable flood risk management, **alongside structural** measures
- Part of **climate change adaptation** response



Encapsulated within the ***Flood Risk Management (Scotland) Act 2009***

Recognises and responds to key Scientific challenges for putting NFM into Policy & Practice

FRM Act (section 20) *requires* '**natural characteristics**' of a catchment to be assessed as to their capacity, costs and benefits to reduce flood risk

BUT recognise that we need better Scientific information on:

- **What is the effectiveness of different NFM measures**
- **How to assess the cost/benefits of NFM measures, including other multiple benefits delivered alongside flood damages avoided**
- **How to integrate NFM within major Flood Defence Schemes**
- **How to work with land managers, and how to influence their willingness to implement NFM**

Eddleston one of a number of initiatives from Scottish Government & SEPA looking to provide the hydrological, ecological and social science evidence base for NFM

Eddleston Focus:

to answer these national policy questions on effectiveness, costs and benefits of using NFM to reduce flood risk and restore catchments for people and wildlife

Empirical and Modelled evidence of NFM at the catchment scale

PROJECT AIMS

a) To assess the ***effectiveness of NFM measures*** to **reduce flood risk**

b) To assess the ***impact of NFM restoration*** on **habitats and species**

c) Work with landowners and communities to maximise the benefits to them, **while sustaining farm businesses**

'learning by doing'

- Long-term study ***2009 Scoping…. 2010*** →
- Scottish Government & EU funding, with public & private sector support
- Managed by Tweed Forum, with Scottish Government, SEPA & University of Dundee
- Typical catchment 69 km
- **Very detailed *Hydrological* & *Ecological* monitoring network**

Massive partnership programme

http://www.tweedforum.org/projects/current-projects/eddleston

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Began with Scoping Study 2009/10

University of Dundee | cbec eco engineering | BGS British Geological Survey

Comprehensive Monitoring network installed *before* NFM measures implemented

Scoping Study looked at whole catchment, not just flooding and habitats along river

Output proposals - science led

- Locations and plans for physical restoration of channel and floodplain
- Locations and plans for interventions to achieve flood risk reductions
- Priorities for action
- Community consultation
- Detailed monitoring strategy

Monitoring

Rainfall and weather stations

River flow and flood gauges

Ground water surveys and boreholes

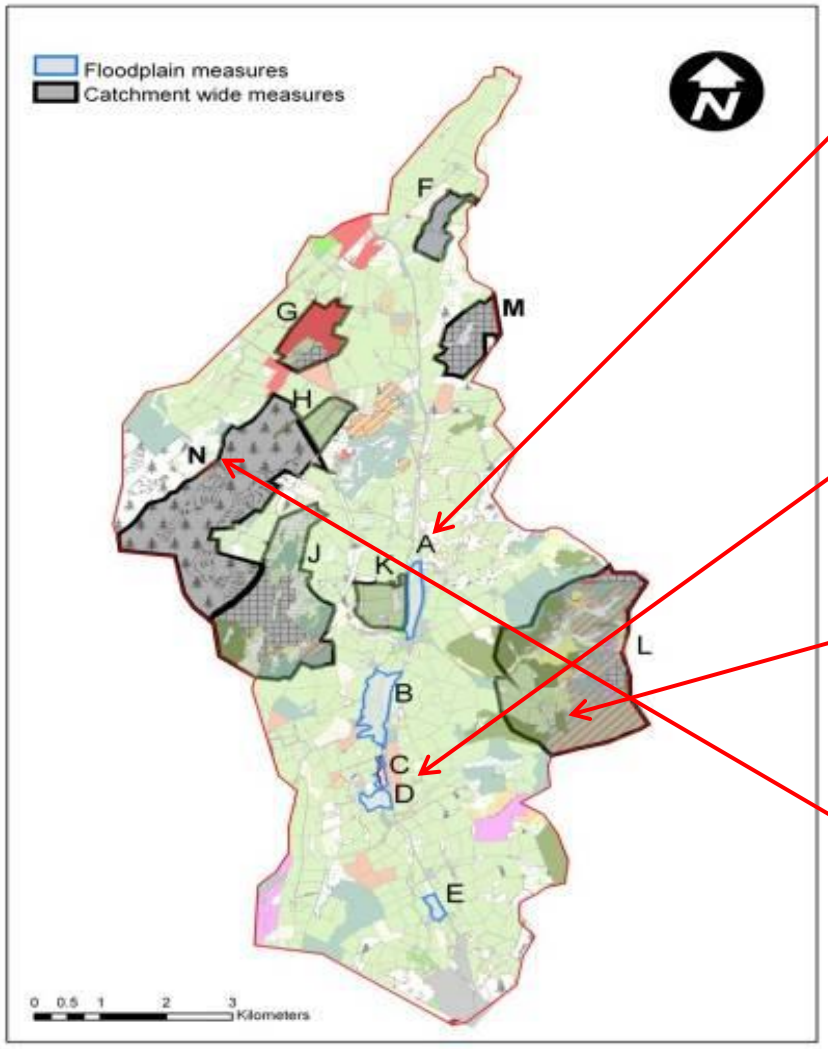
River habitats and hydro-morphology

River ecology – Aquatic macroinvertebrates, fish, plants

Land-owner & community engagement

Ecosystem services – past & present

Scoped *potential* options to *reduce flood risk* and *restore the river* across the *whole* catchment



Potential options/measures:

A: breach/set back embankments, new fence margins, riparian & wet woodland

C: **re-meander channel**

L: Reduced stocking density, **tributary woodland, floodplain forest**

N: **create ponds**, wetlands, riparian woodland block ditches, **engineered log jams**

Target list of potential restoration opportunities – from *policy-makers*, *researchers* and local desires

Trusted intermediary

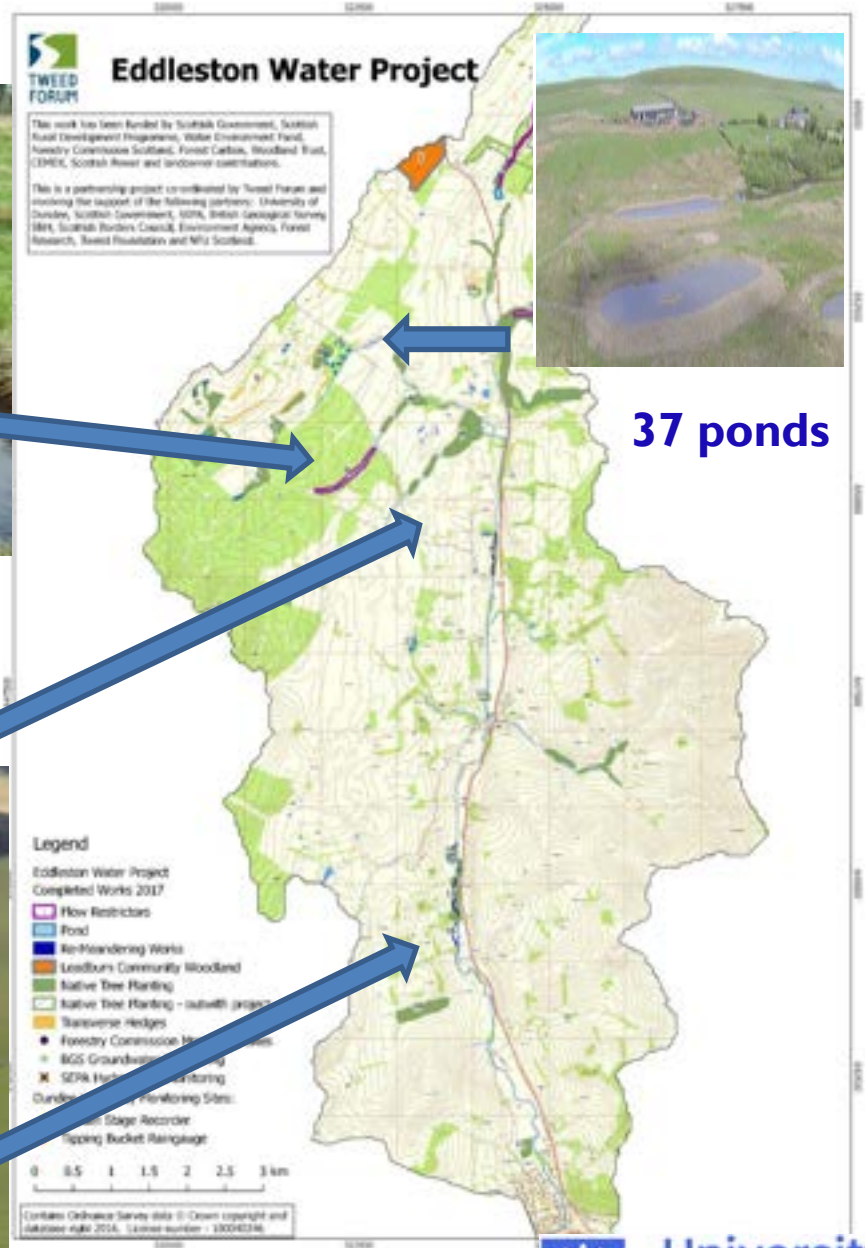
Land Managers - Changes on the ground

NFM measures implemented so far

136 debris dams

330,000 trees

3.5km remeandering



37 ponds

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

University of Dundee

Hydrometric monitoring

TWEED FORUM

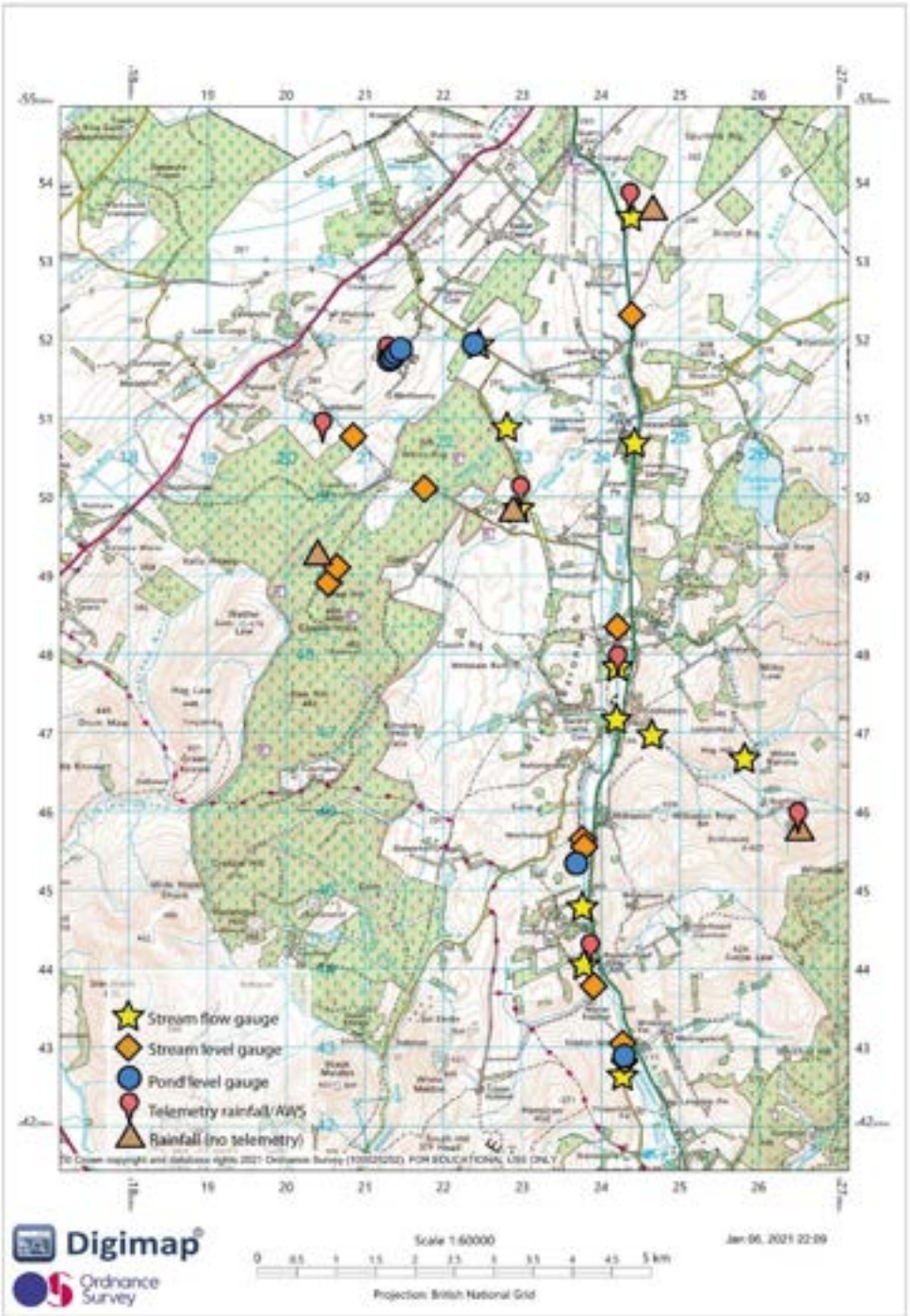
The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

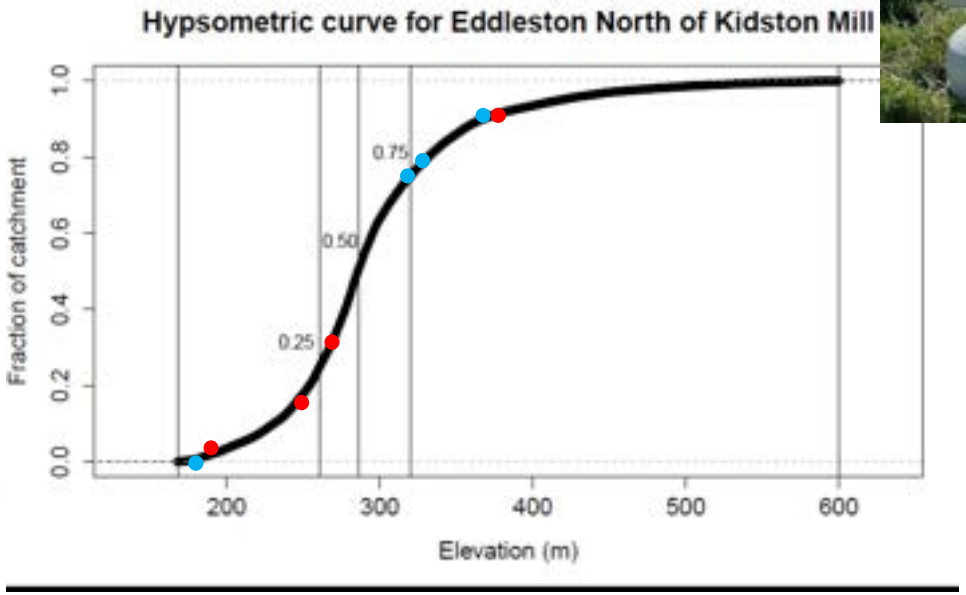
Interreg
North Sea Region
Building with Nature

University of Dundee

Network map


Stream flow gauge
Stream level gauge
Pond level gauge
Telemetry rainfall/ AWS
Rainfall (no telemetry)
Digimap
Ordnance Survey
Scale 1:60000
Projection: British National Grid

Rainfall recording



L Peskett PhD, U of Edinburgh

Rain gauges, not snow gauges

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

University of Dundee

Stream flow gauging

TWEED FORUM

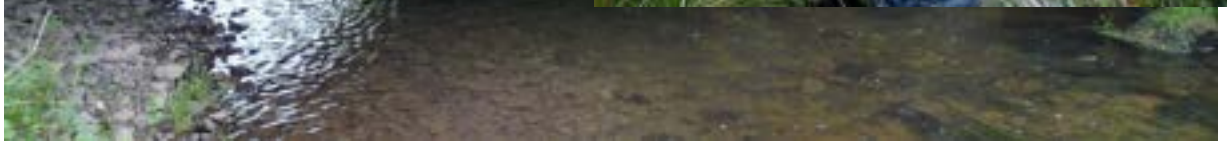
The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

University of Dundee

Stream flow gauging



TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

University of Dundee

TWEED FORUM

Changing riparian vegetation

University of Dundee

Changing riparian vegetation

Interreg North Sea Region Building with Nature

University of Dundee

Pond level monitoring

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

University of Dundee

Groundwater & soil moisture monitoring

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

BGS British Geological Survey

UNIVERSITY OF WINCHESTER

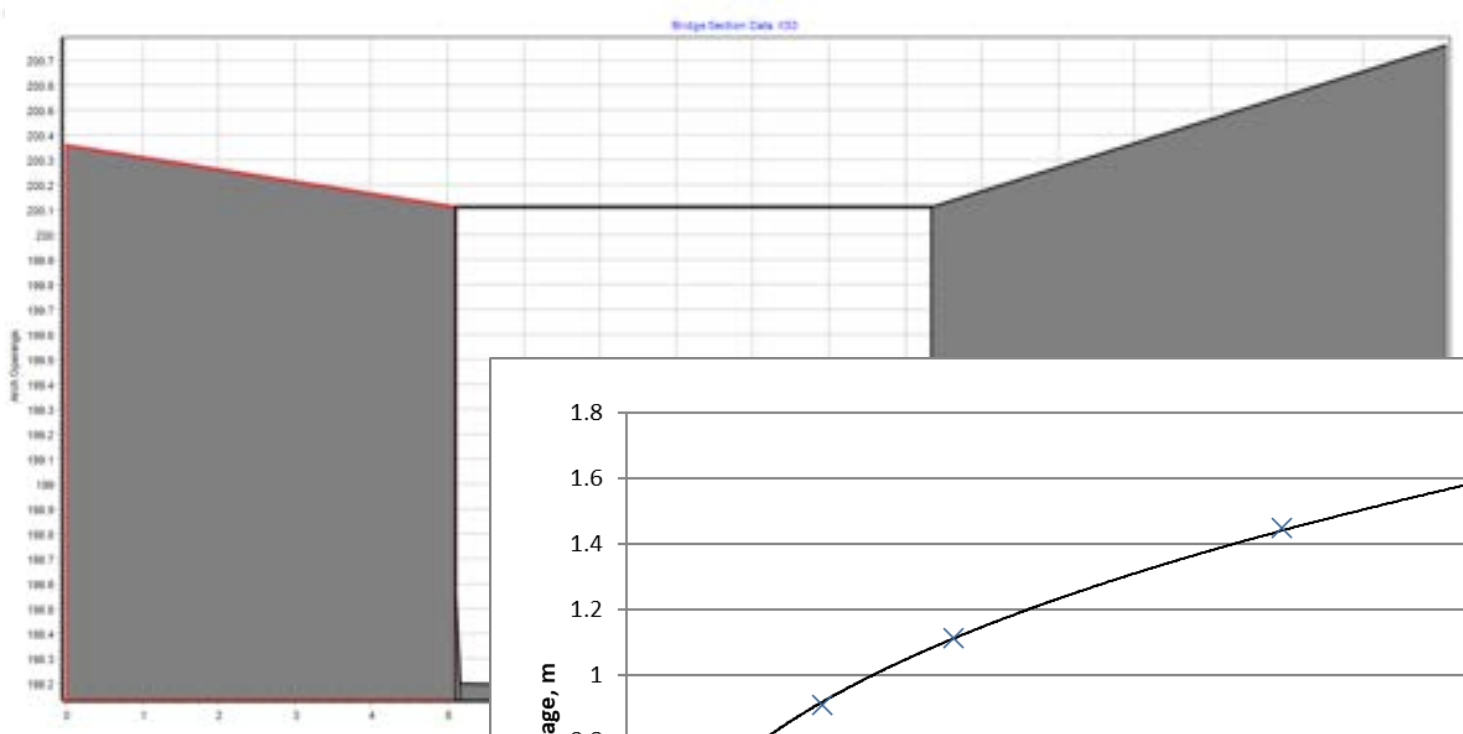
University of Dundee

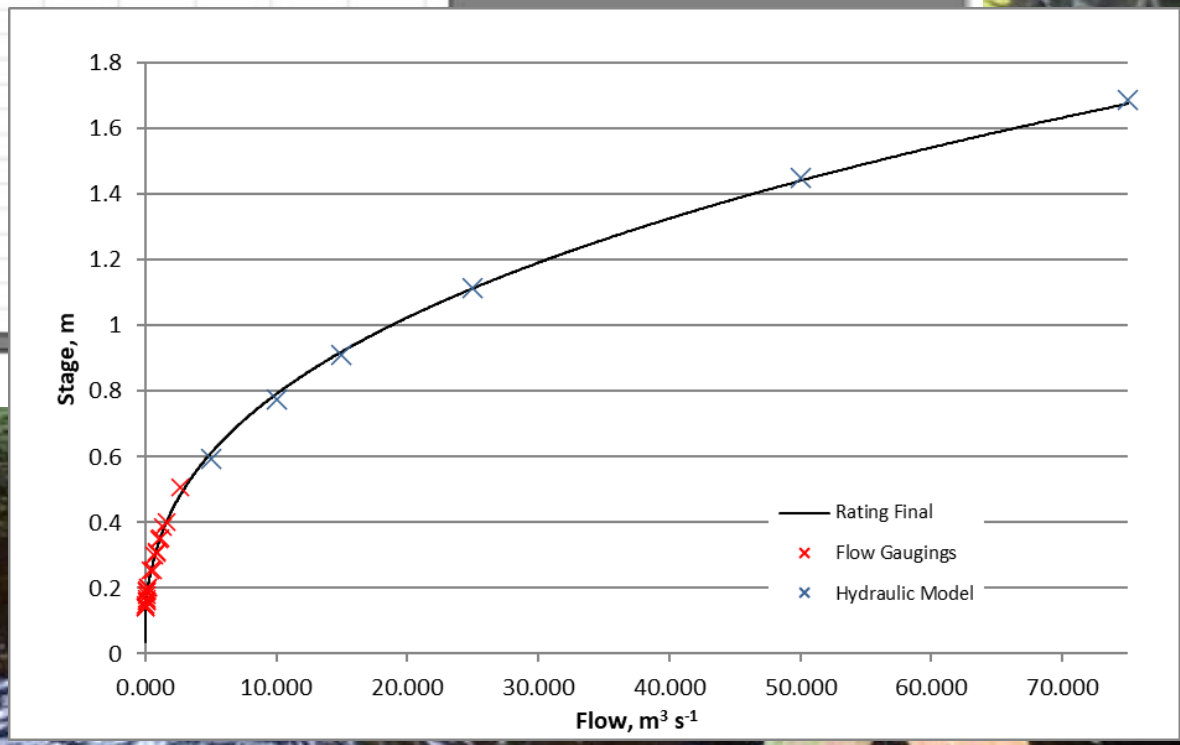
Flow gauging results

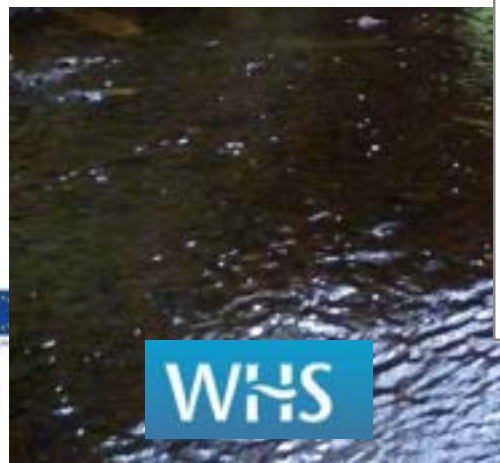
							Gaugings (m3/s)		Runoff equiv (mm/day)		Max
	Area (km2)	Records from	Completeness	Mean flow (m3/s)	BFI	# gaugings	Min	Max	Min	Max	gauging as % QMED
Craigburn*	4.34	09/02/2011	99.99%	0.066	0.44	72	0.001	0.73	0.001	0.9	52%
Cowieslinn Burn	5.09	31/10/2014	97.78%	0.121	0.36	59	0.003	0.88	0.004	1.3	51%
Middle Burn*	2.30	21/03/2011	99.91%	0.051	0.30	68	0.001	1.67	0.001	2.1	85%
Shiplaw Burn	3.14	27/01/2011	96.66%	0.052	0.25	78	0.000	1.26	0.000	1.4	98%
Earlyvale*	25.64	09/02/2011	85.53%	0.476	0.36	45	0.031	3.45	0.059	6.6	28%
Darnhall Mains	35.16	28/03/2011	99.99%	0.648	0.39	57	0.041	43.17	0.062	65.4	196%
Eddleston Village	36.69	03/03/2011	100.00%	0.645	0.50	56	0.052	15.54	0.080	24.0	142%
Middle Longcote	2.75	09/02/2011	97.69%	0.059	0.53	50	0.005	0.54	0.008	0.9	101%
School	6.89	27/01/2011	97.13%	0.152	0.51	82	0.020	1.38	0.021	1.5	60%
Milkieston Toll/Cringletie*	53.56	09/02/2011	87.39%	1.062	0.43	52	0.107	2.60	0.178	4.3	10%
Nether Kidston	54.84	04/03/2011	96.89%	1.112	0.49	63	0.098	15.14	0.135	20.8	67%
Kidston Mill	64.27	03/03/2011	98.19%	1.219	0.47	67	0.127	24.00	0.163	30.9	132%

* indicates HEC-RAS modelling used to extend calibration

Ratings defined by gauging data & extended by use of topo survey & HEC-RAS model







TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

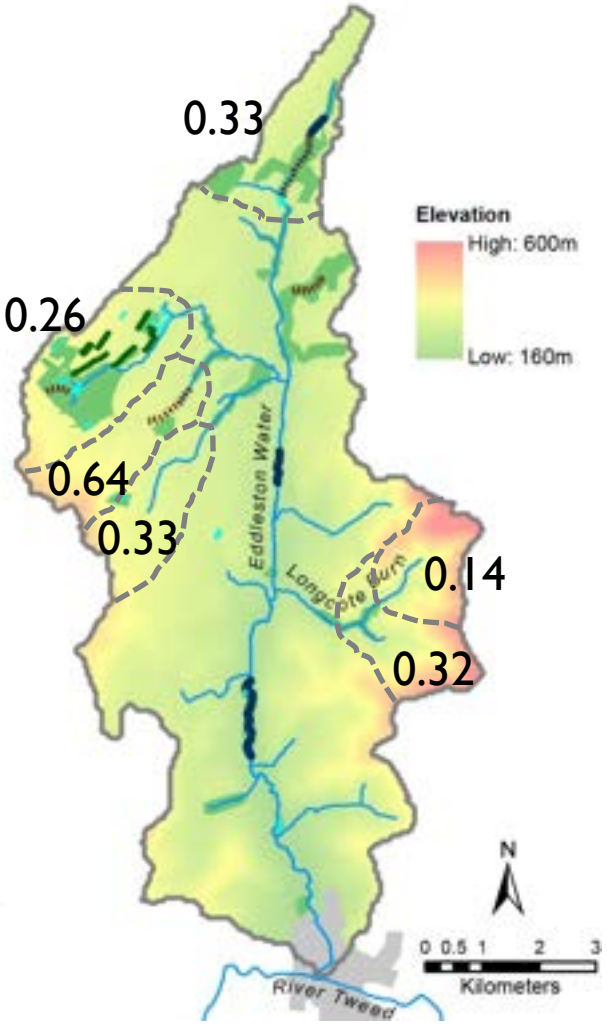
SEPA
Scottish Environment Protection Agency

Interreg
North Sea Region
Building with Nature

WHS

University of Dundee

Runoff generation: QMED per unit area

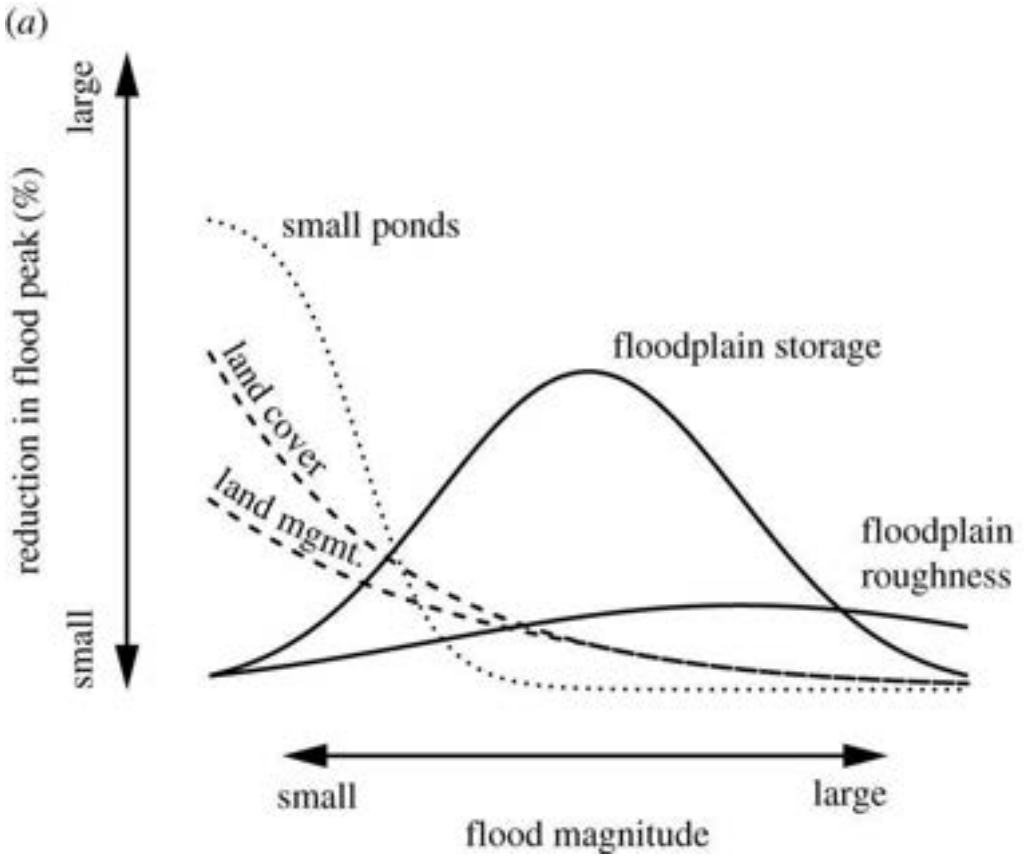


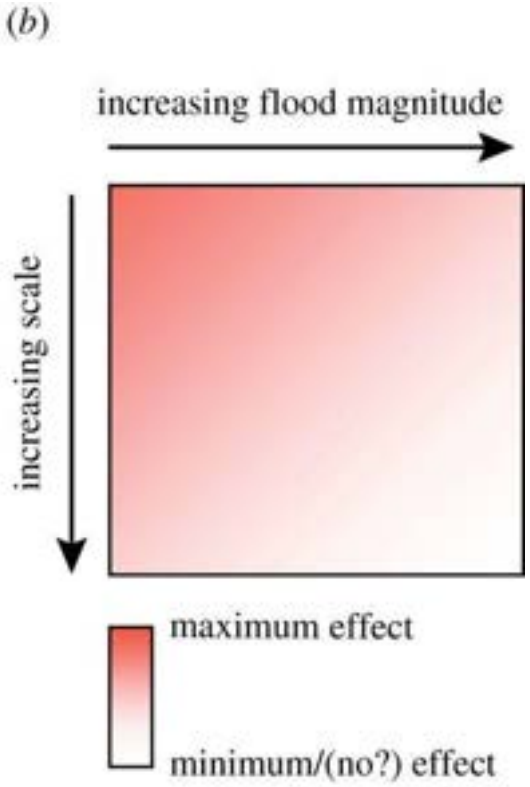
	Tributaries	Median flood QMED (m3/s)	Catchment area (km2)	QMED/CA (m3/s/km2)
NW	Shiplaw Burn	1.04	3.18	0.33
NW	Middle Burn	1.42	2.21	0.64
NW	Cowieslinn Burn	1.30	5.09	0.26
N	Craigburn	1.43	4.34	0.33
E	School	2.19	6.89	0.32
E	Middle Longcote	0.39	2.75	0.14

Snowmelt affecting largest peaks at catchment outlet

Date	Peak stage (m)	Snowmelt detected?
04/12/2020	1.132	Y
06/12/2015	1.089	N
22/11/2016	1.08	Y
27/12/2015	1.033	N
22/12/2014	1.011	N

Effectiveness of natural flood management?

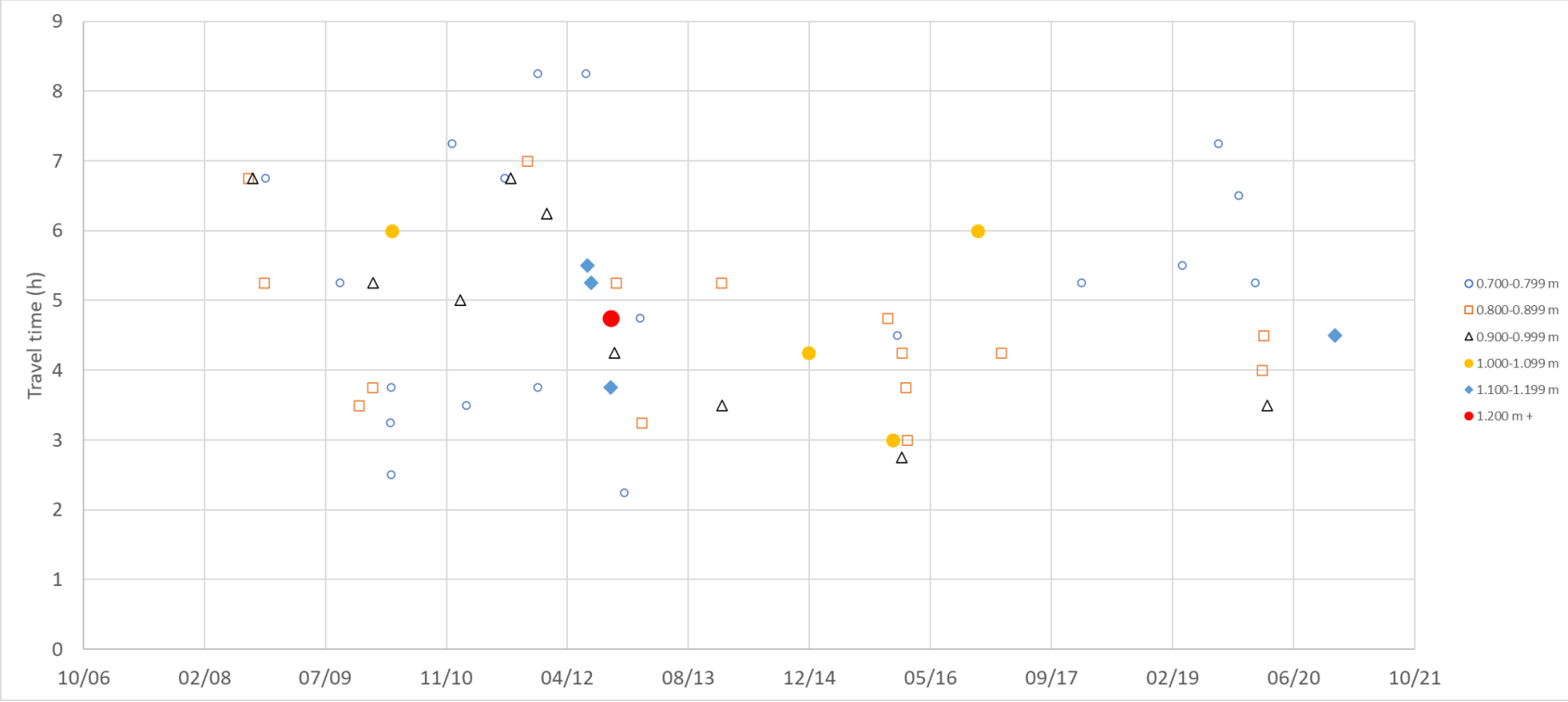




Dadson *et al.* (2017)

General paucity of field observations on which to make assessments

Flood peak travel time by magnitude



TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

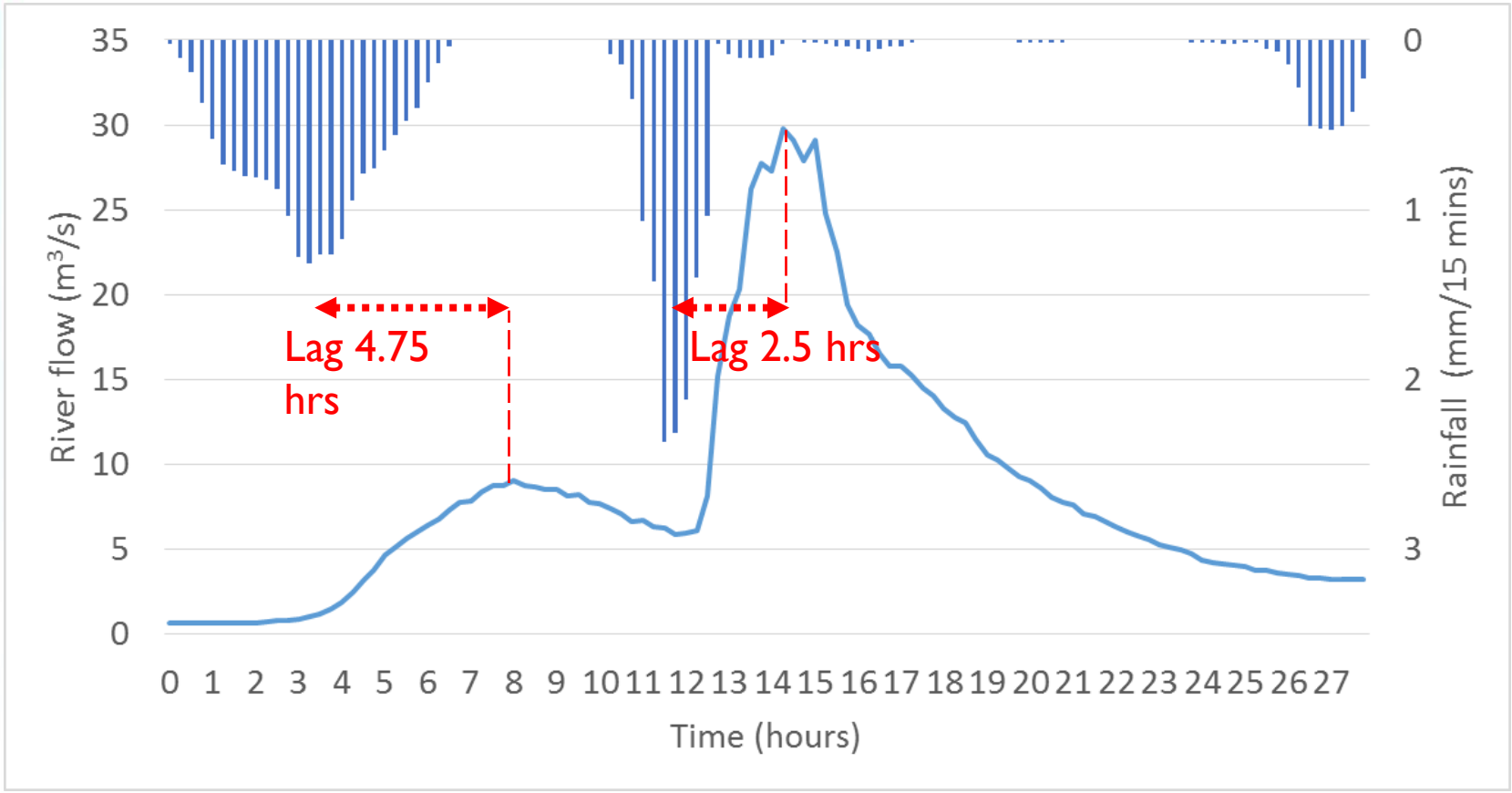
Interreg
North Sea Region
Building with Nature

University of Dundee

Focus on hydrological lag

- Easily understood measure of response
- Important for synchronisation at downstream confluence/receptor
- Unaffected by potentially challenging assumptions:
  - Flow rating
  - Baseflow separation
  - Rainfall accuracy

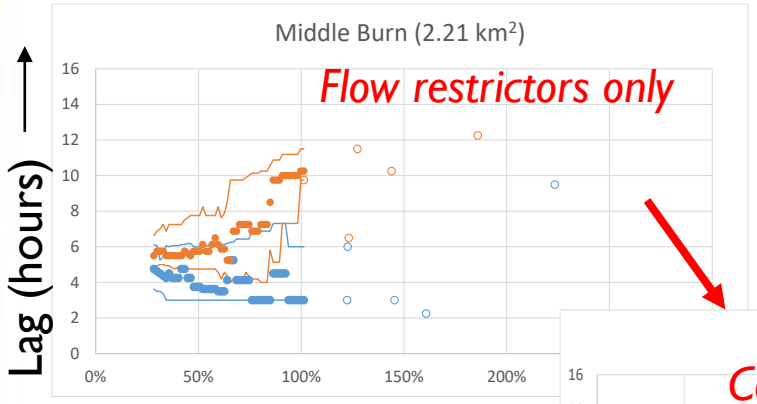
Hydrological lag as an indicator of attenuation

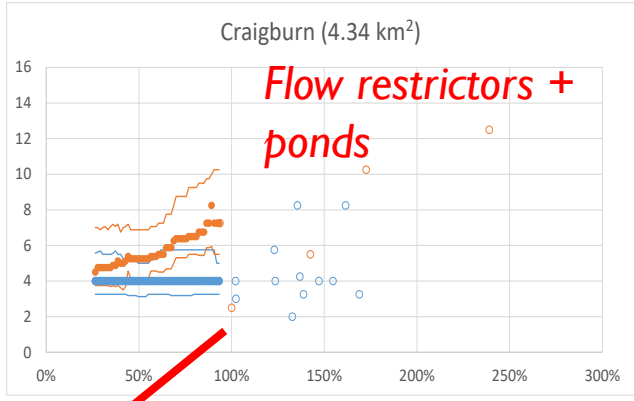


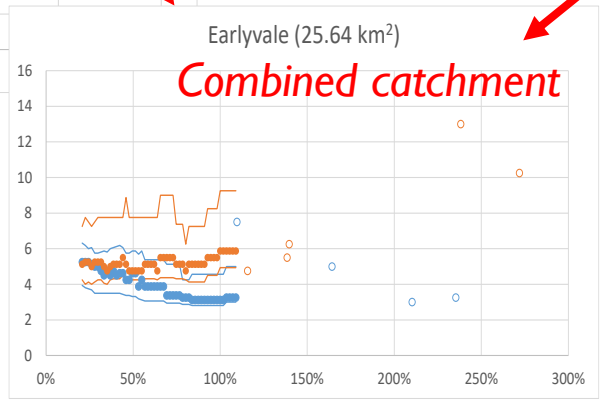
Selecting events for analysis

- Events ranked at each site
- Largest 100 events selected over 9 years of record
- Snowmelt-affected events not excluded
- Lag calculated from centroid of rainfall to flood peak
- 24 hr independence
- 1 hr minimum inter-event time in rainfall series
- 8 hr maximum lag

Median lag as a function of sampling threshold

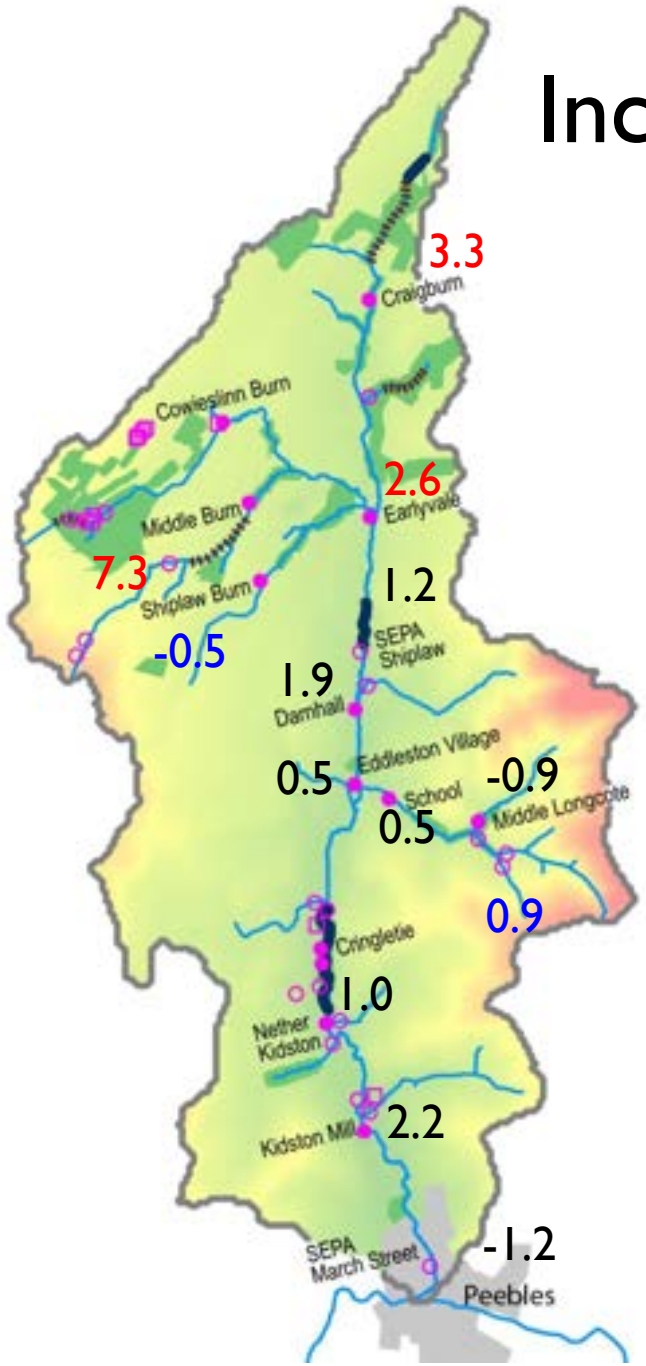






- Pre-NFM (2011-2013)
- Post NFM (2013-2019)

Increases in median lag (hr)



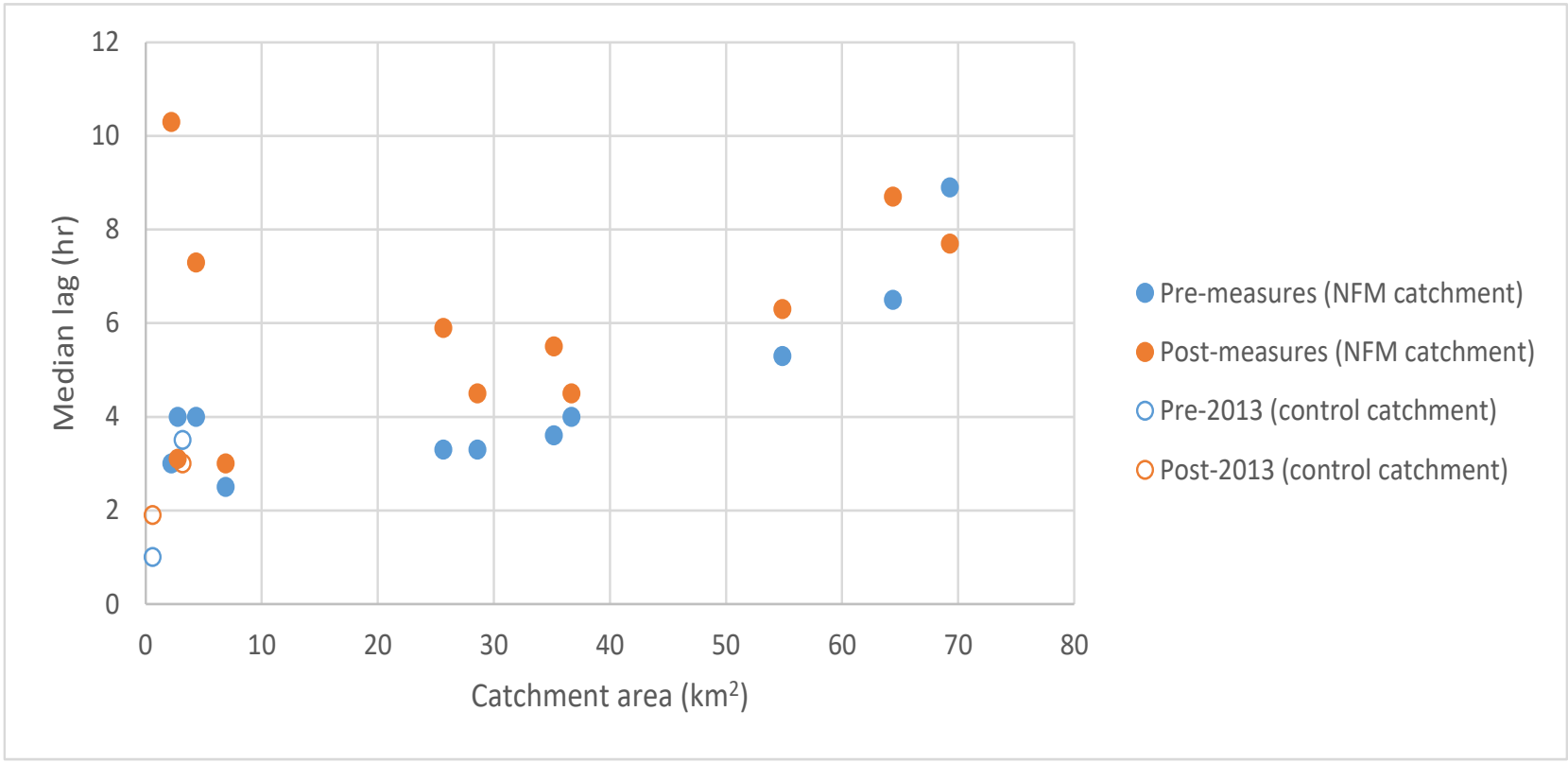
	Catchment area (km^2)	Median lag (hr) at highest sampling threshold (~QMED)	
		Pre-intervention	Post-intervention
NFM catchments			
Middle Burn	2.21	3.0	10.3
Craigburn	4.34	4.0	7.3
Earlyvale	25.64	3.3	5.9
SEPA Shiplaw	28.57	3.3	4.5
Darnhall	35.16	3.6	5.5
Village	36.69	4.0	4.5
Middle Longcote**	2.75	4.0	3.1
School**	6.89	2.5	3.0
Nether Kidston	54.84	5.3	6.3
Kidston Mill	64.38	6.5	8.7
SEPA March Street	69.3	8.9	7.7
Control catchments			
Shiplaw Burn	3.18	3.5	3.0
Upper Burnhead	0.59	1.0	1.9

3.3 Change significant at p<5%

1.2 Change not significant at p<5%

-0.5 Control catchment (not significant)

Lag as a function of catchment area



Recent papers…

ORIGINAL ARTICLE

CIWEM Flood Risk Management WILEY

Natural flood management, lag time and catchment scale: Results from an empirical nested catchment study

Andrew Black[1] | Leo Peskett[2] | Alan MacDonald[2,3] | Andy Young[1,4] | Chris Spray[5] | Tom Ball[5] | Huw Thomas[6] | Alan Werritty[3]

[1]Geography & Environmental Science, University of Dundee, Dundee, UK
[2]School of Geosciences, University of Edinburgh, Edinburgh, UK
[3]British Geological Survey, Lyell Centre, Edinburgh, UK
[4]Wallingford HydroSolutions, Wallingford, UK
[5]Department of Archaeology, Anthropology and Geography, University of Winchester, Winchester, UK
[6]Centre for Ecosystems, Society & Biosecurity, Forest Research, Talybont Research Office, Talybont on Usk, UK

Correspondence
Andrew Black, Geography & Environmental Science, University of Dundee, Dundee DD1 4HN, UK.
Email: a.r.black@dundee.ac.uk

Funding information
Scottish Government; European Regional Development Fund, Grant/Award Number: INTERREG North Sea Region Building With Nature programme

Abstract

Natural flood management (NFM) techniques attract much interest in flood risk management science, not least because their effectiveness remains subject to considerable uncertainty, particularly at larger catchment and event scales. This derives from a paucity of empirical studies which can offer either longitudinal or comparison data sets in which changes can be observed. The Eddleston catchment study, with 13 stream gauges operated continuously over 9 years, is based on both longitudinal and comparison data sets. Two years of baseline monitoring have been followed by 7 years of further monitoring after a range of NFM interventions across the 69 km² catchment. This study has examined changes in lag as an index of hydrological response which avoids dependence on potentially significant uncertainties in flow data. Headwater catchments up to 26 km² showed significant delays in lag of 2.6–7.3 hr in catchments provided with leaky wood structures, on-line ponds and riparian planting, while larger catchments downstream and those treated with riparian planting alone did not. Two control catchments failed to show any such changes. The findings provide important evidence of the catchment scale at which NFM can be effective and suggest that effects may increase with event magnitude.

KEYWORDS
catchment scale, Eddleston, empirical analysis, lag, natural flood management

1 | INTRODUCTION

Natural flood management (NFM) aims to take advantage of and work with natural processes to reduce flood risk, whilst delivering wider improvements in environmental quality and societal benefits in river catchments. A review by Lane (2017) classifies NFM interventions as those aimed at: (a) reducing the rate of rapid runoff generation on hillslopes, for example, through land management such as tree planting to enhance infiltration (Carrick et al., 2018); (b) storage of water during high river flows, for example, through creating temporary holding ponds (Nicholson, O'Donnell, Wilkinson, & Quinn, 2020); and (c) slowing flow by reducing the ease of connection between runoff sources and zones of potential flood inundation, for example, through constructing

ELSEVIER

Water Security
Volume 13, August 2021, 100091

How can we plan resilient systems of nature-based mitigation measures in larger catchments for flood risk reduction now and in the future?

Barry Hankin [a b], Trevor Page [a], Gareth McShane [a], Nick Chappell [a], Chris Spray [c], Andrew Black [c], Luke Comins [a]

Show more

+ Add to Mendeley Share Cite

https://doi.org/10.1016/j.wasec.2021.100091

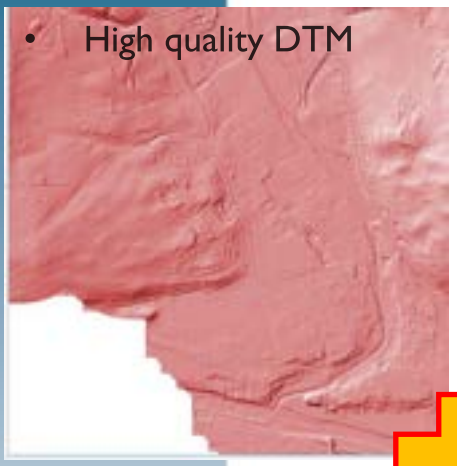
Get rights and content

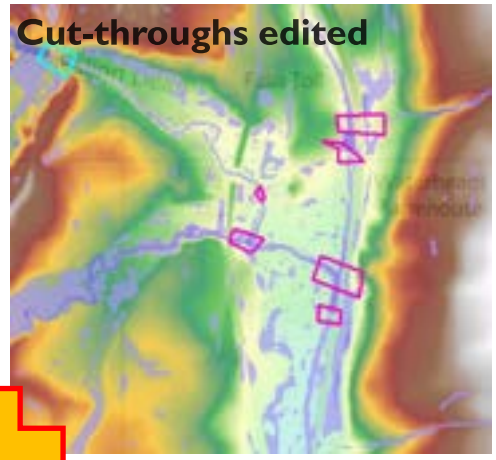
Abstract

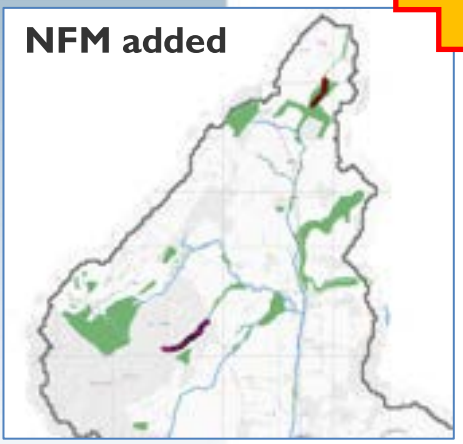
There is considerable empirical evidence that using nature-based solutions to restore and enhance hydrological processes such as infiltration, interception, floodplain re-connection and water storage, is effective at small scales for low to medium probability floods. However, the performance of systems of spatially distributed nature-based solutions at larger scales or under the more extreme flooding expected with climate change, has mainly been assessed using modelling. The mechanism by which carefully designed nature-based solutions can provide naturally adaptive pathways to divert higher flood flows into expandable areas of storage in the landscape, has been less formally investigated. This paper reports on new hydrometric data collected from one of eighteen small-scale, accurately monitored micro-catchments in Cumbria, UK, to study the effect in more detail. The micro-catchments have been set up by Lancaster Environment Centre as part of the Q-NFM project attempting to quantify changes in hydrological responses due to a range of natural flood management measures that have been installed by catchment partners. A direct-runoff 2d inundation model was setup and calibrated using accurate flow measurements upstream and downstream of new river restoration project in the Lowther catchment (2.5 km^2) for two large storm events (Storms Ciara and Dennis, February 2020). It was used to analyse how the storage on the floodplain can expand with flood magnitude, and can be enhanced with appropriately designed natural flood management. Model evidence was then assessed for the same mechanism in the larger UK catchments of Eddleston Water (70 km^2) and Culm (280 km^2) using the same whole-catchment direct-runoff

Whole catchment model using HEC-RAS2D

….uses the sub-grid topography for storage and conveyance calculations ….allows mesh refinement + hydraulic structures where detail needed



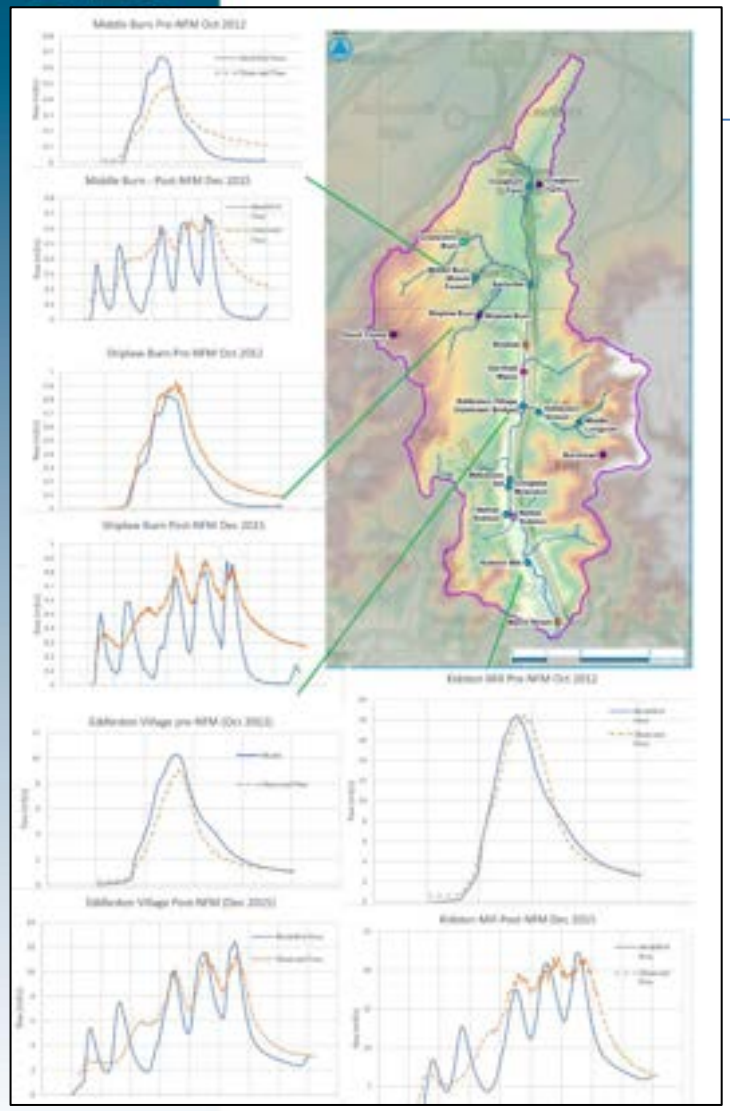




Preparation of Event Hydrology ReFH2

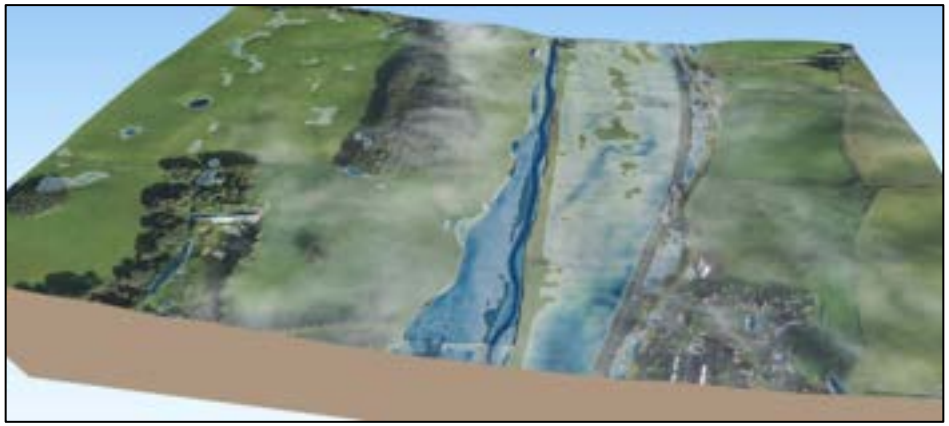
Calibration with Daymod (Cini calibration)

License Free software from US Army Corps of Engineers



Multi-scale Calibration (pre- and post-NFM)

- Use of Manning's n and change to geometry
- Across scale calibration for intensively monitored site
  - Small scale: Middle and Shiplaw Burn
  - Intermediate – Eddleston School
  - Large – Kidston Mill
- Further uncertainty analysis of Manning's versus hydraulic structure representation
- Trash line peak over-predicted, but footprint matched well



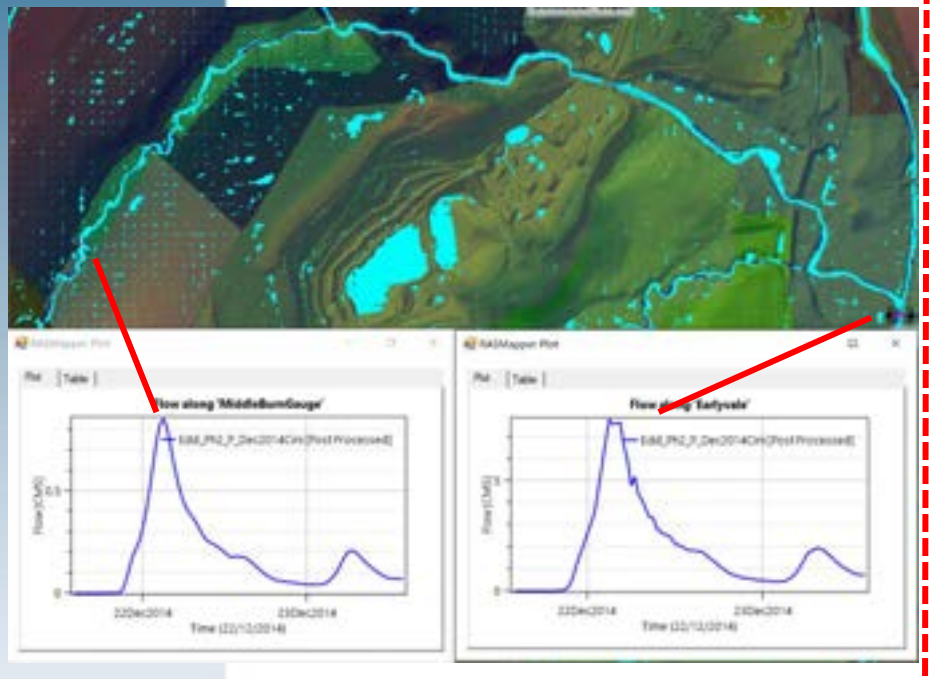
Comparisons with Flood study report / Peebles

- 200 years Borders report event

- 200 years Whole catchment model

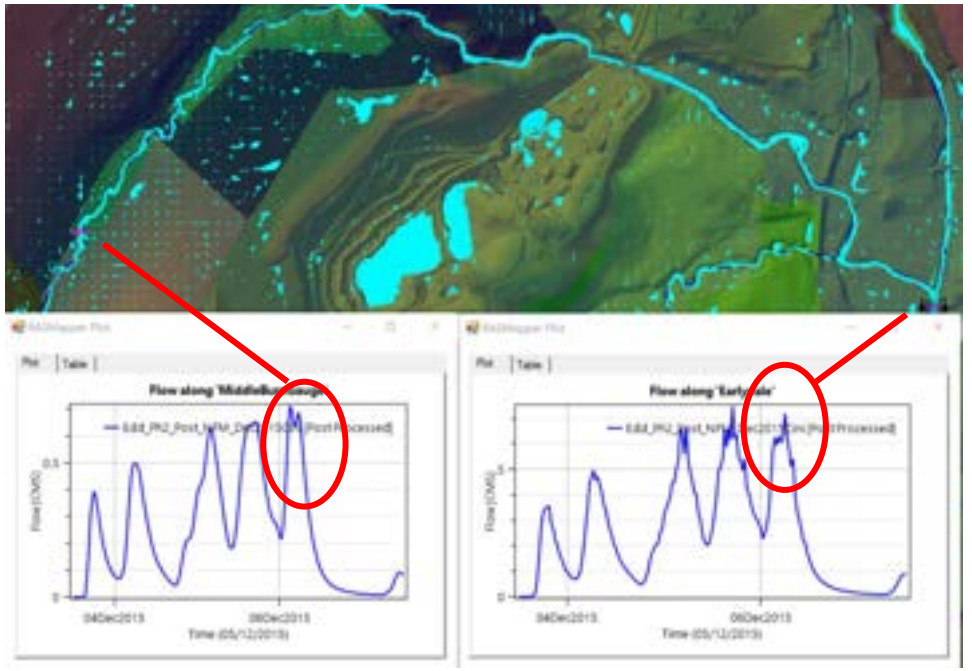
Modelled timing between Middle Burn and Earlyvale: pre- & post- NFM

- Pre-NFM



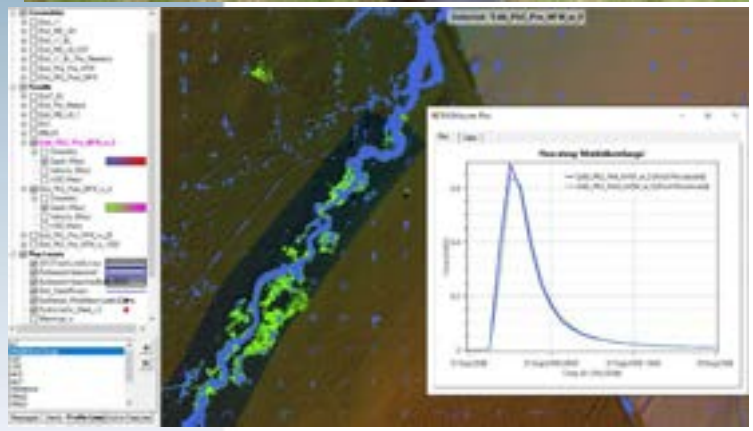
About 1 hour travel time between peaks in model between Middle Burn and Earlyvale

Post-NFM

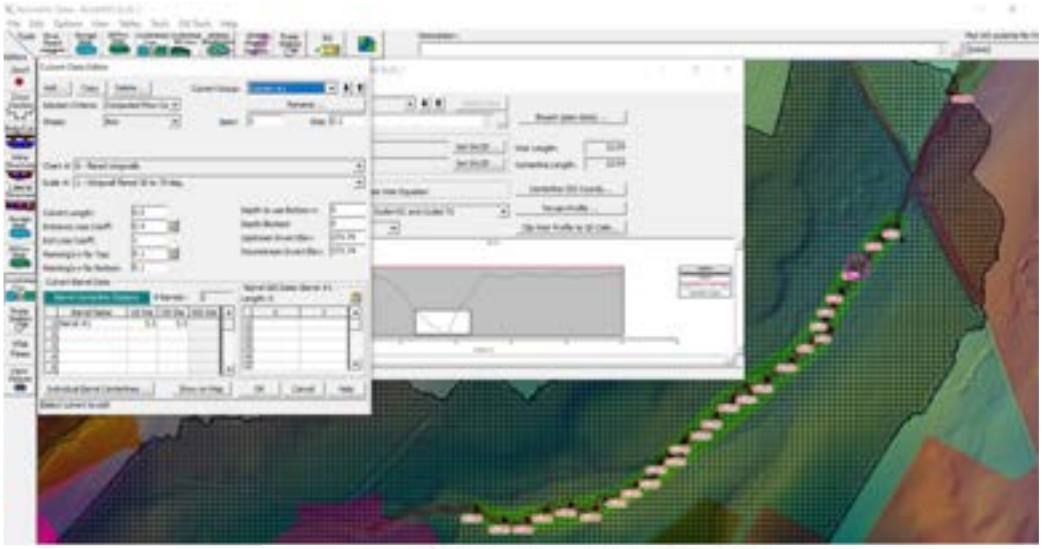


About 2 hours travel time between peaks for final peak. Similar to increase in data. Peak is noisy so lucky?

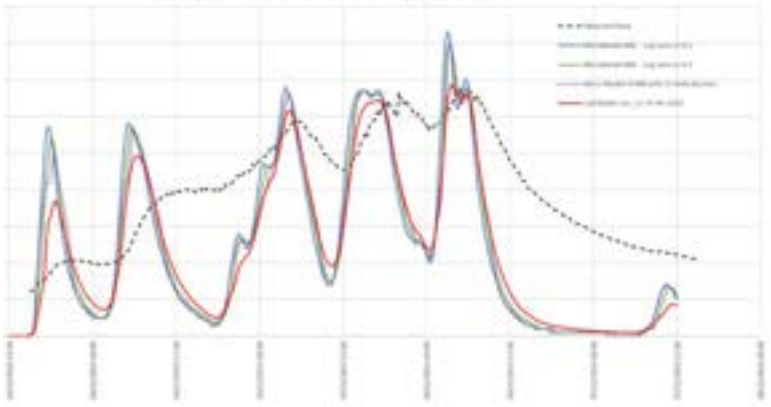
Representing NFM at broad scale with roughness and storage, but at fine-scale with more detailed features



- Changes represented as roughness as per Dixon in Addy (2019)

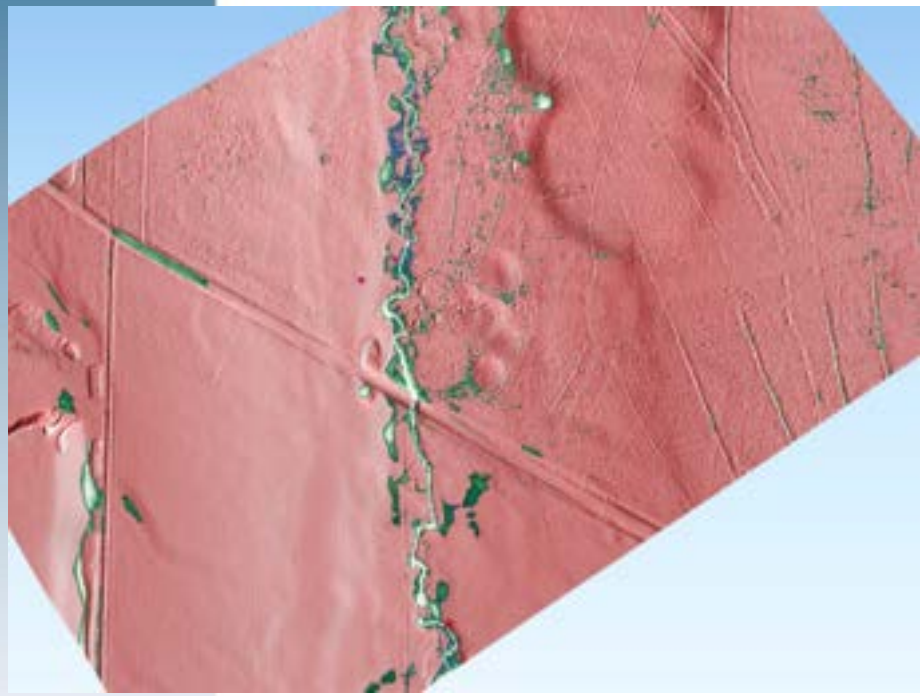


Changes represented as hydraulic units – requires time step reduction to control Courant



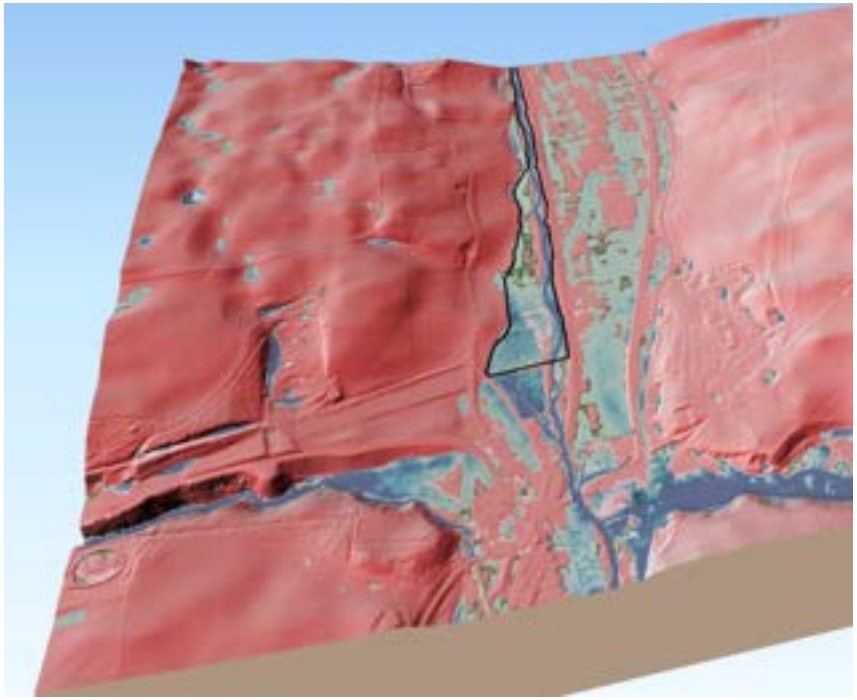
With and without NFM and Comparison with trash line survey

- NFM features



Middle Burn – design event with and without NFM

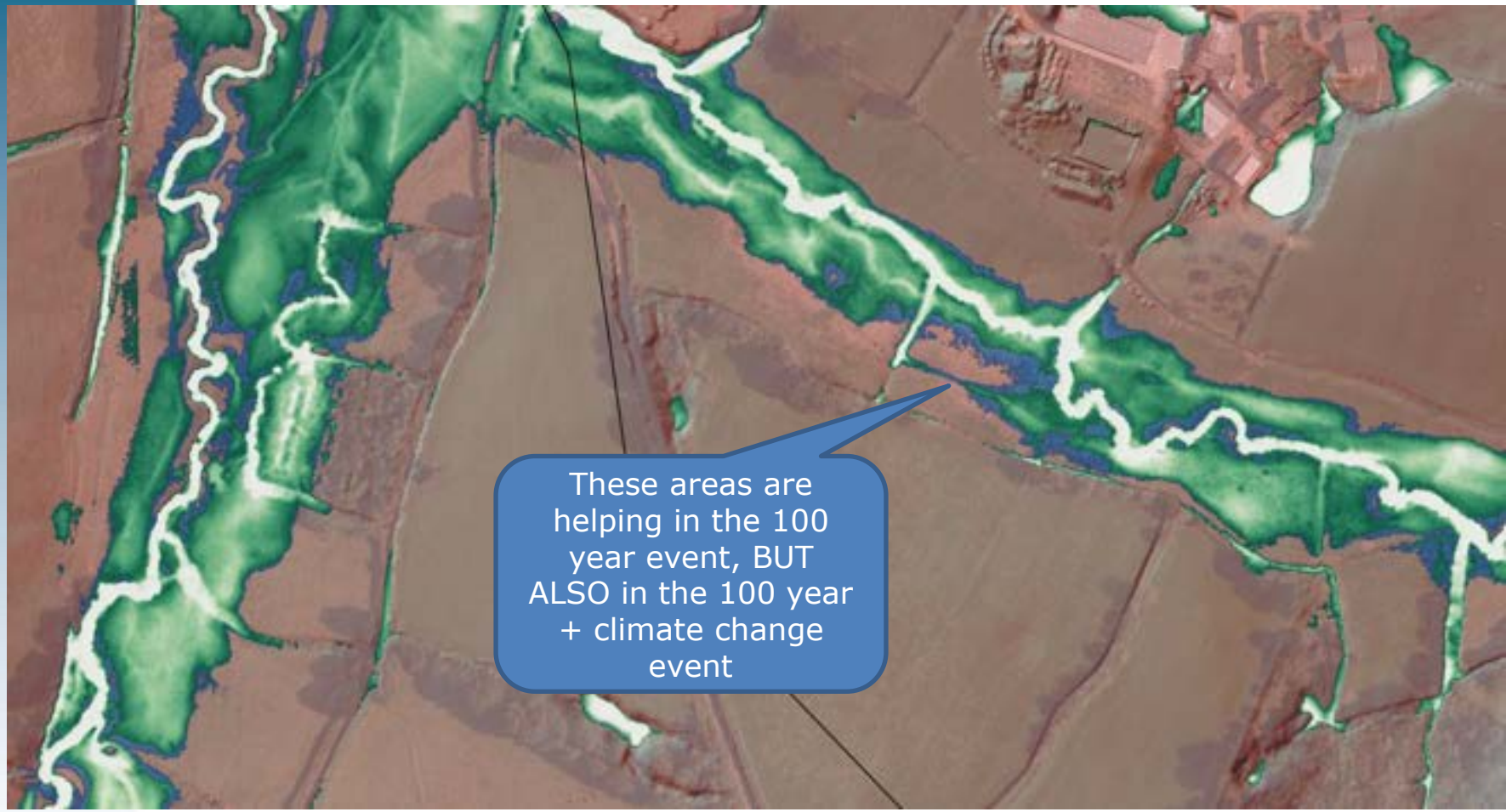
Evidence



- Trash line survey

TWEED FORUM

Expandable storage is occurring the Bolham sub-catchment (blue is climate change *with* riparian surface water tree planting against the green baseline climate change)– so over and above the present day flood *there is still more storage*



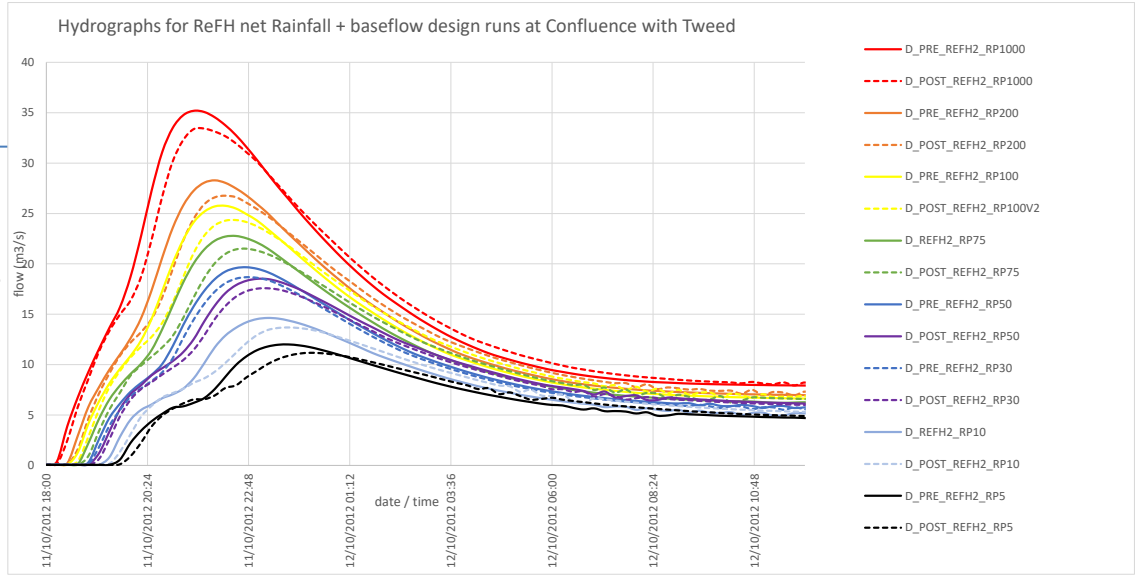
- Let's help the water on here temporarily even more easily….

Predictions & Benefits

Predicted flows at the confluence with the Tweed

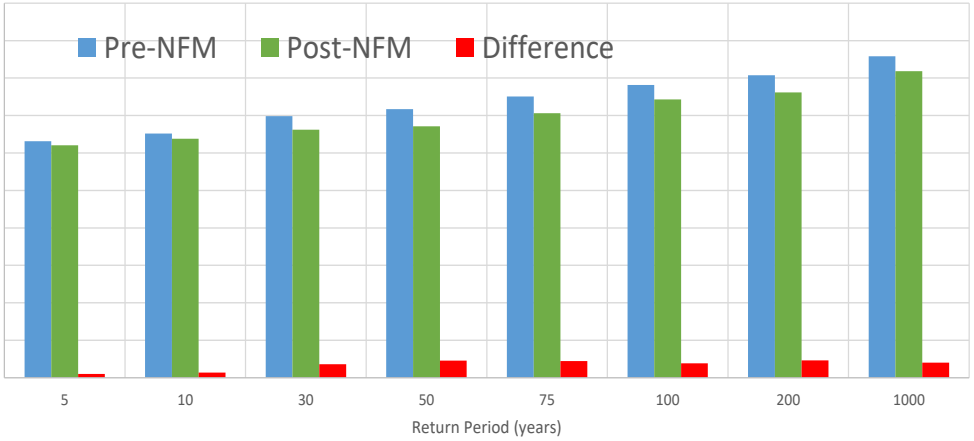
In the context of the Natural Capital Assessment (60 year), and assuming the benefits gradually establish over 15 years, NPV ~ £950k

So how does this compare with other ecosystem services?



Design Event	Peak Flow Baseline	Peak Flow (NFM)	% Peak reduction	Time Delay
RP1000	35.19	33.42	5.0%	00:15
RP200	28.29	26.76	5.4%	00:15
RP100	25.77	24.34	5.5%	00:15
RP75	22.77	21.51	5.5%	00:15
RP50	19.67	18.51	6.3%	00:15
RP30	18.68	17.58	5.9%	00:30
RP10	14.63	13.69	6.4%	00:30
RP5	12	11.17	6.9%	00:30

Estimated Damages. Average Annual Damages are *overestimated* using newest LiDAR in urban area; surface water flood risk is included.
Change to Annual Benefits / Average Damages Avoided across all NFM: £58.5k, or 2.5%



What is the impact of NFM measures on Aquatic Ecology?

Second aim of the Eddleston Study is:
- to assess the ***impact of NFM restoration*** on **habitats and species**

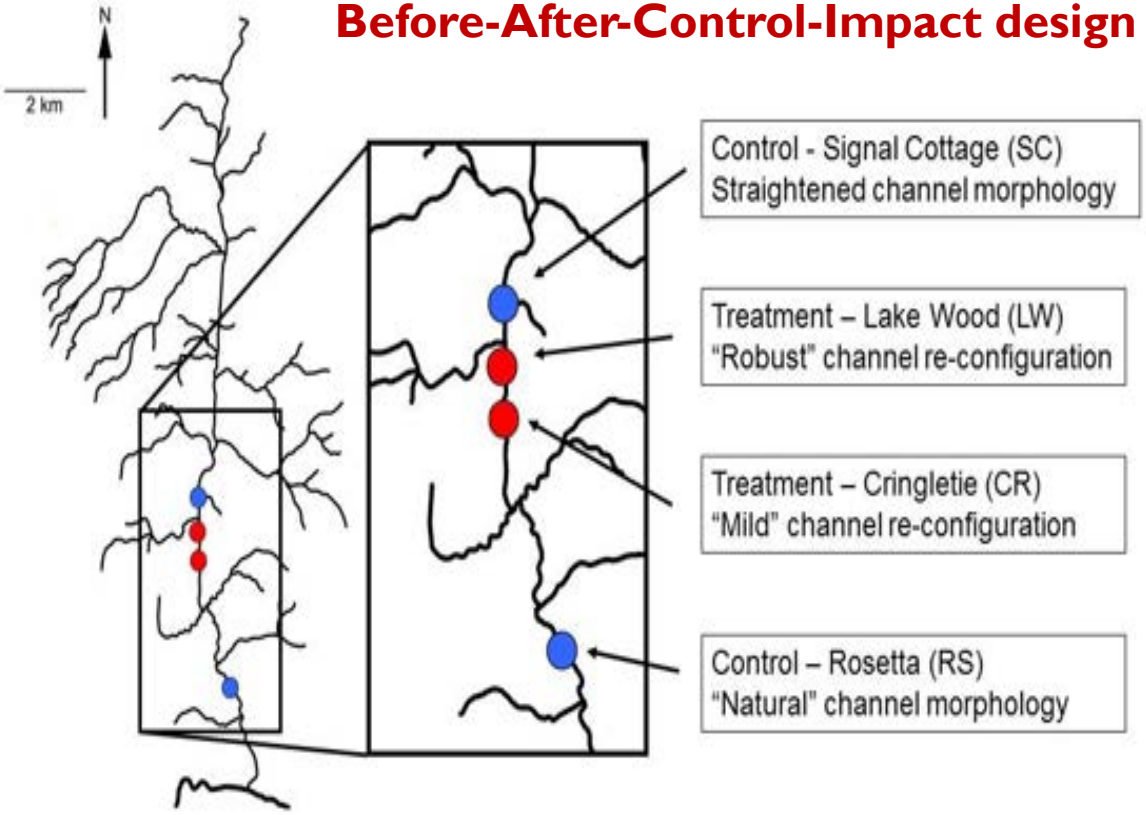
Focus on the remeandering of straightened channel

Also PhD study - Isabelle Costaz on hydrological impacts of new meanders

Linking NFM hydro-morphological interventions with detail of Ecological response

Channel Hydromorphology and Aquatic Ecology sampling

Before-After-Control-Impact design



Sediment and **Ecological** sampling undertaken at same locations

Surveys

2012 - pre works
2013 - pre works

meanders implemented at Cringletie and Lake Wood

2014 - analysed
2015 - analysed
2017 - analysed
2019 - analysed
2021 - in progress
2023 - planned

Demonstrate trajectory of recovery

- Channel re-configuration was completed on 25th July 2013 at Cringletie and on 11th September 2013 at Lake Wood.
- All sampling undertaken by SEPA
- Analyses by SEPA, Veritas Ecology & Apem

Habitat monitoring and channel sediment sampling

100m within each Reach is surveyed for Habitat Information

Pre- and post-restoration sampling undertaken at experiment and control sites

- **Habitat measures**
- **Channel sediment sampling**

Measure grain-size distribution, ranging from fine gravel to coarse cobble, as classified using the Wentworth Scale

Linking NFM hydro-morphological interventions with Ecological response

Veritas Ecology

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

University of Dundee

Interreg
North Sea Region
Building with Nature

Ecological monitoring

Aquatic macro-invertebrates, macrophytes & fish

- **Invertebrates** – modified kick sampling method proportion to the 5 habitat types (riffle, run, glide, pool, slack). Identify to species level = approx. 45,000 individuals of 90 species /year
- **Electro-fishing surveys**

TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

Trex Ecology

THE Tweed FOUNDATION

FORTH RIVERS TRUST

Veritas Ecology

University of Dundee

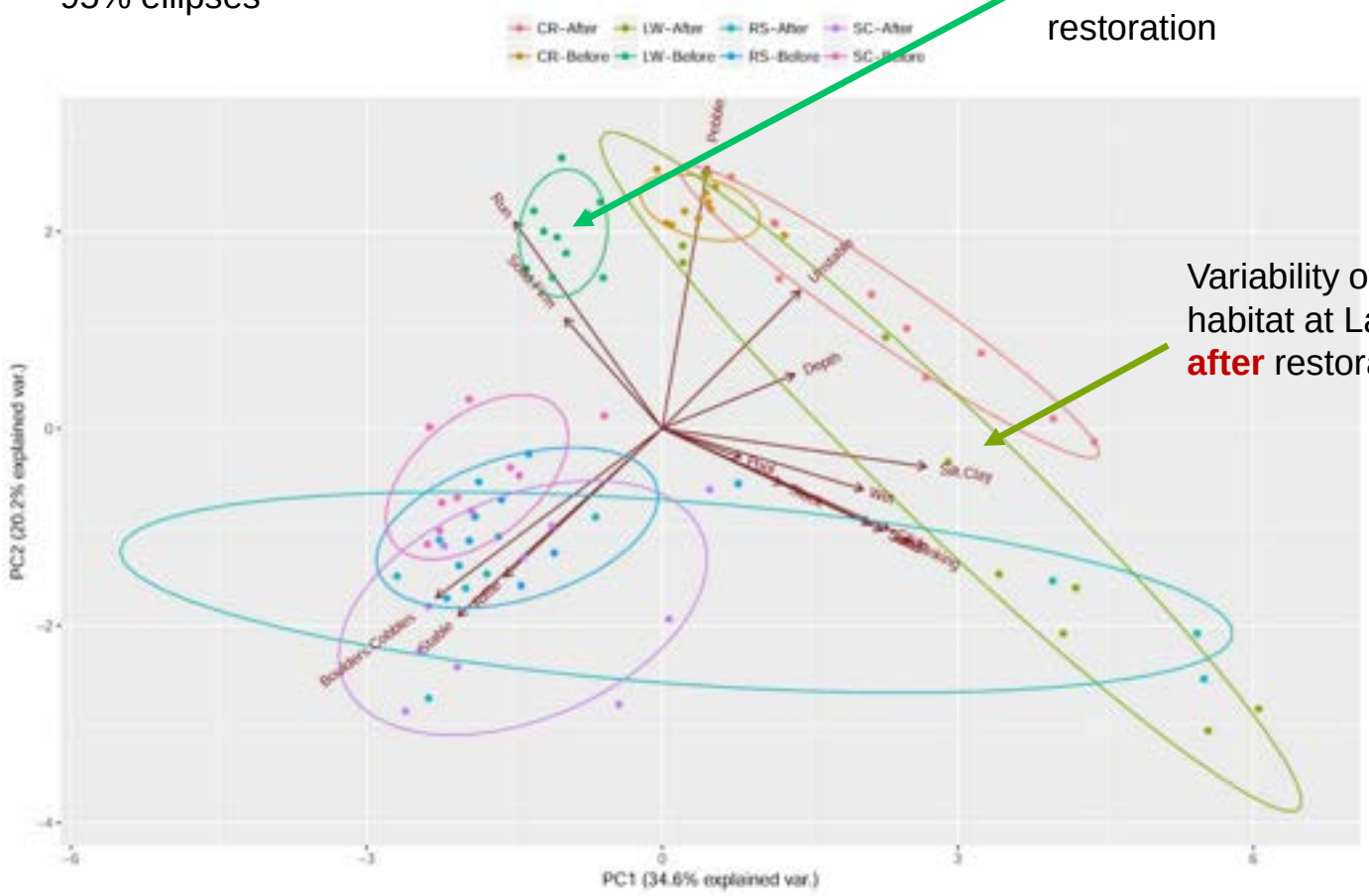
Has NFM intervention significantly changed the habitat?

Variability of the physical habitat before and after restoration

95% ellipses

Variability of available habitat at Lake Wood **before** restoration

Variability of available habitat at Lake Wood **after** restoration



TWEED FORUM

The Scottish Government
Riaghaltas na h-Alba

SEPA
Scottish Environment Protection Agency

University of Dundee

Interreg
North Sea Region
Building with Nature

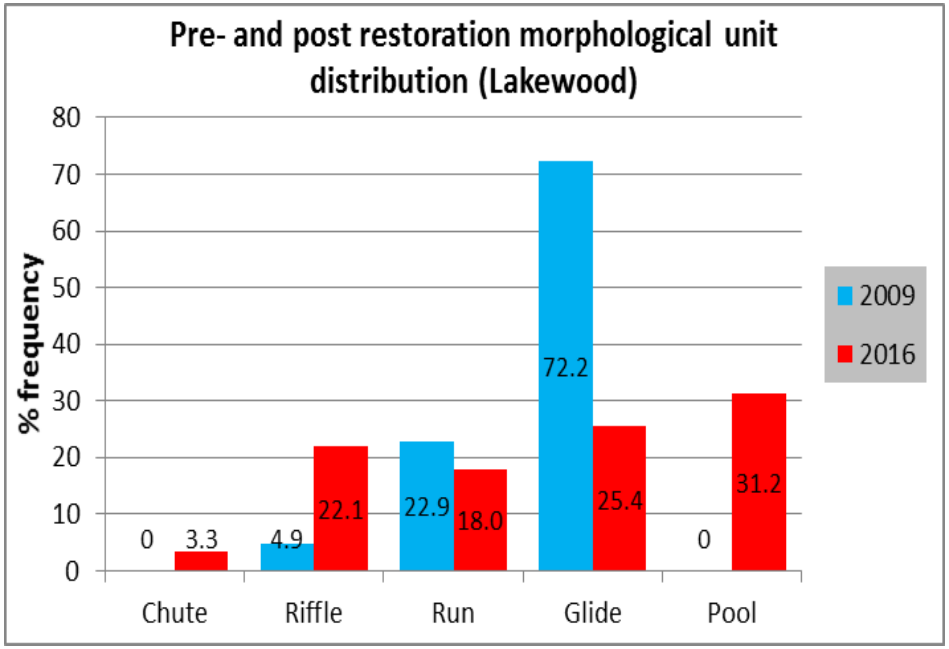
Veritas Ecology

NFM Re-meandering improves habitats and species

An increase in overall ***physical diversity of habitats*** within re-meandered sections, and an increase in habitat area.

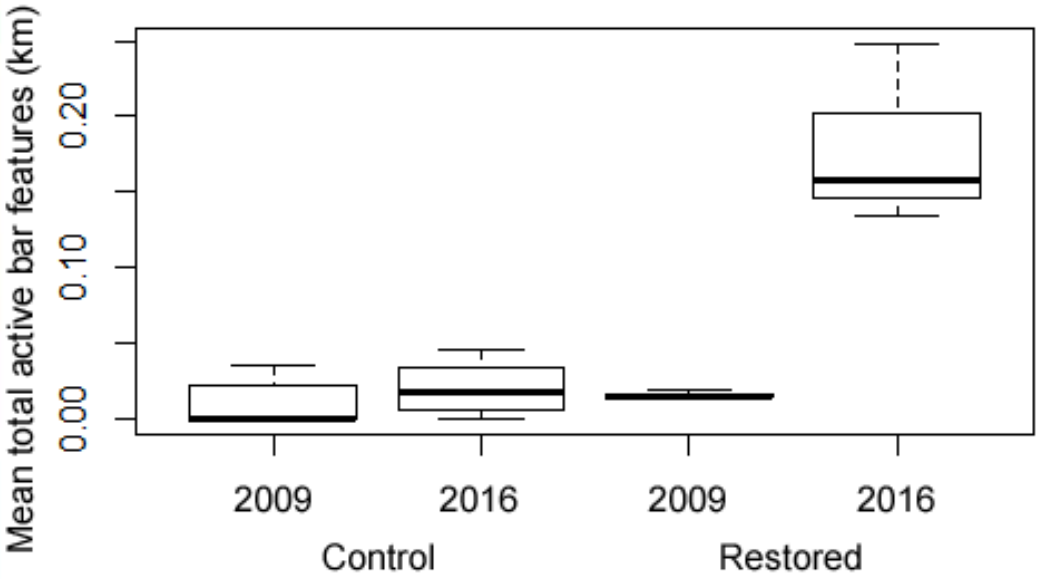
A potential increase in the number and extent of ***spawning habitats for salmon***, as indicated by changes in the amount and spatial distribution of favoured micro-habitats for salmonids

A rapid recolonization of re-meandered ***channels by aquatic macroinvertebrates***.



Pre- and post- restoration morphological unit distribution. Numbers represent percentage cumulative length of each morphological unit.

Key habitat: active bar features – increase in response to re-meandering for NFM



Boxplot details 5, 25, 50, 75 & 95 percentiles of the data

Possible increase in size of fish (salmonids) in the restored reaches

Significant increase in the active bar features in restored sections compared with control sections.

Such changes are important as it is the spatial distribution of alluvial bar features that drives patterns/ extents/ variability in morphological unit types.

Emerging results from Eddleston

- ***Different NFM measures can reduce flood risk*** through both *temporarily storing* surface waters and *delaying the peak floods*, as well as through increased surface roughness and groundwater connectivity

- Appreciable flood risk reduction through NFM is likely only to be achievable through *the* ***widespread application of many types of approach throughout whole catchment***

- ***NFM measures*** and habitat enhancement to improve ecological condition ***provide a wide range of additional benefits and ecosystem services***

- ***Potential for greater enhancement of other benefits now as well – walking & cycling (Sustrans)***




Can we put a value on NFM?

- ***NFM measures*** and habitat enhancement to improve ecological condition ***provide a wide range of additional benefits and ecosystem services***

Working with JBA and Mott MacDonald, we calculated:

- **Appraisal of NFM measures already implemented** in the Eddleston show a positive net present value (NPV) of **£950k from flood damages avoided**
- **NFM co-benefits delivered amount to £4.2million NPV** on-top of flood damages avoided by the same NFM measures - mainly from water quality improvements, carbon management, recreation, biodiversity and fisheries
- **An enhanced scenario** of NFM measures could deliver £2.85million NPV from flood damages avoided and a further £17.7million NPV from additional benefits.




Thank You

With thanks to the funders and supporters of the work on Eddleston, on Tweed and elsewhere covered in this presentation, including Scottish Government, SEPA and Tweed Forum, our many collaborators and, most importantly the land managers and community.

For further information, please contact:

a.z.black@dundee.ac.uk
C.J.Spray@Dundee.ac.uk
Barry.Hankin@jbaconsulting.com

For information on the **Eddleston Water Project** see:
http://www.tweedforum.org/projects/current-projects/eddleston