Restoration and storm-flow in peatland headwaters:

Results from the MS4W Peak District demonstration catchments

Tim Allott[1], Emma Shuttleworth[1], Martin Evans[1], Clive Agnew[1], Jon Gorham[1], Jane Mellor[1], Dave Milledge[2], Mike Pilkington[3], Rachael Maskill[3], Tom Spencer[3], Andy Jones[3], Jon Walker[3]

University of Manchester [1], University of Durham[2]

and Moors for the Future[3]

Landscape-scale degradation, Landscape-scale restoration

Peat erosion and rapid storm-flow runoff

Restoration by Re-vegetation

MOORS FOR THE FUTURE PARTNERSHIP

Restoration by Gully blocking

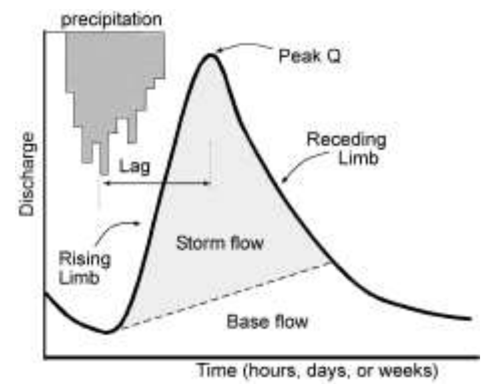
The Peak District Making Space for Water Demonstration Project

Will peat restoration reduce and/or slow the release of water from the hills and reduce downstream flood risk?

Our Initial Question

Can we detect reduced storm-flow from ***headwater catchments*** following restoration?

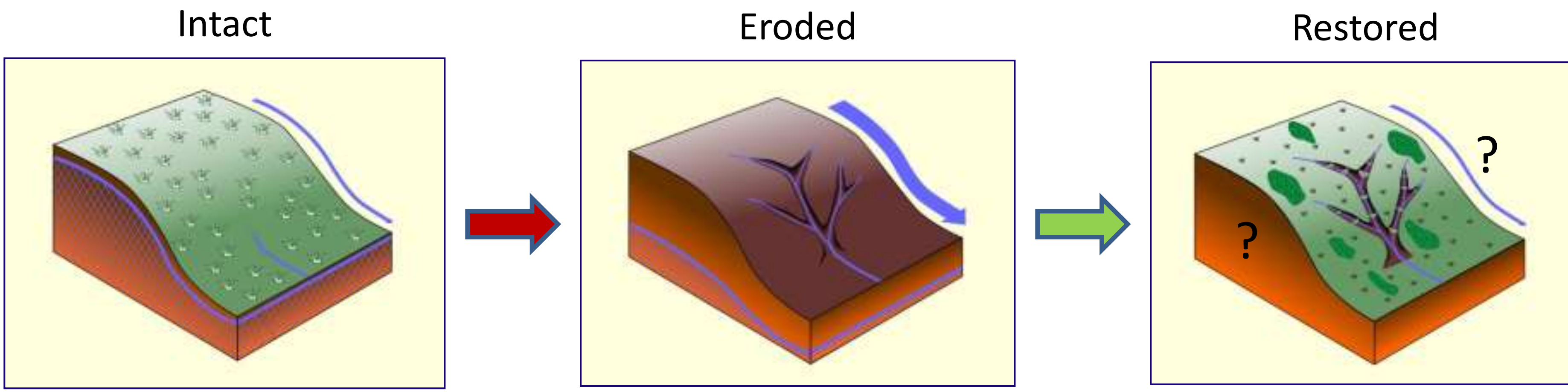
- Reductions in storm-flow peaks?
- Increases in lag times?
- Hydrograph attenuation?



Eroded peat

Early stage restoration

But ***how*** might restoration alter the hydrology??



Modelling and up-scaling require process understanding!

- Storage effects (water tables and soil water storage; surface storage)
- Flow pathways and overland flow effects

MS4W Peak District catchments:

How will the restoration alter hydrology and storm-flow behaviour?

Hypothesis 1

Re-vegetation will increase evapotranspiration rates, increasing depth to water tables and soil water storage

Hypothesis 2

Re-vegetation will increase infiltration rates and decrease evapotranspiration, reducing both depth to water table and soil water storage

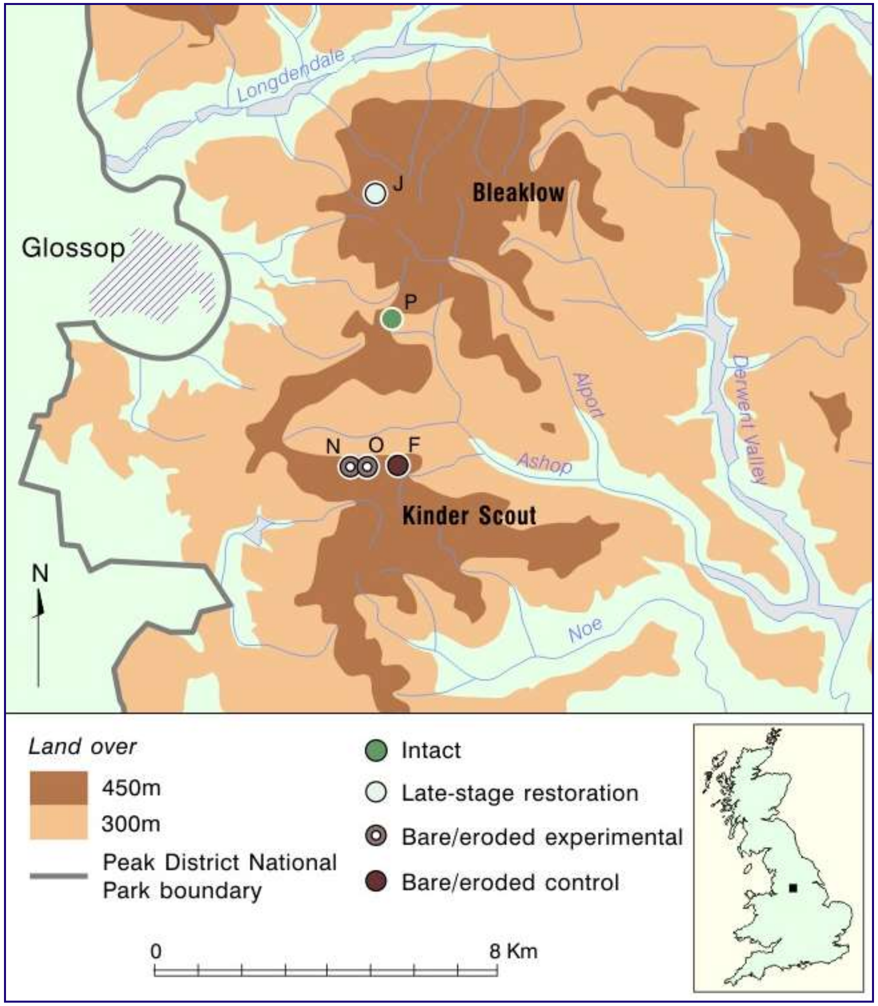
Hypothesis 3

Re-vegetation and gully blocking will increase within-storm catchment storage due to surface ponding of water within vegetation and behind gully blocks

Hypothesis 4

Re-vegetation and gully blocking will increase surface roughness effects, with peat surface re-vegetation reducing overland flow velocities and gully blocks and associated gully bottom re-vegetation reducing channel velocities

'*Making Space for Water*' Peak District demonstration project (2010-2015)



- Hectare-scale study catchments
- Monitoring rainfall-runoff, overland flow production and catchment water tables
- **Space-for-time** comparison of hydrological characteristics of intact, eroded and restored (re-vegetated) catchments
- **Before-after-control-intervention** (BACI) study of restored eroded catchments
  - Control
  - Intervention 1 = re-vegetation only
  - Intervention 2 = re-vegetation and gully blocking

The 'Space for Time' Study

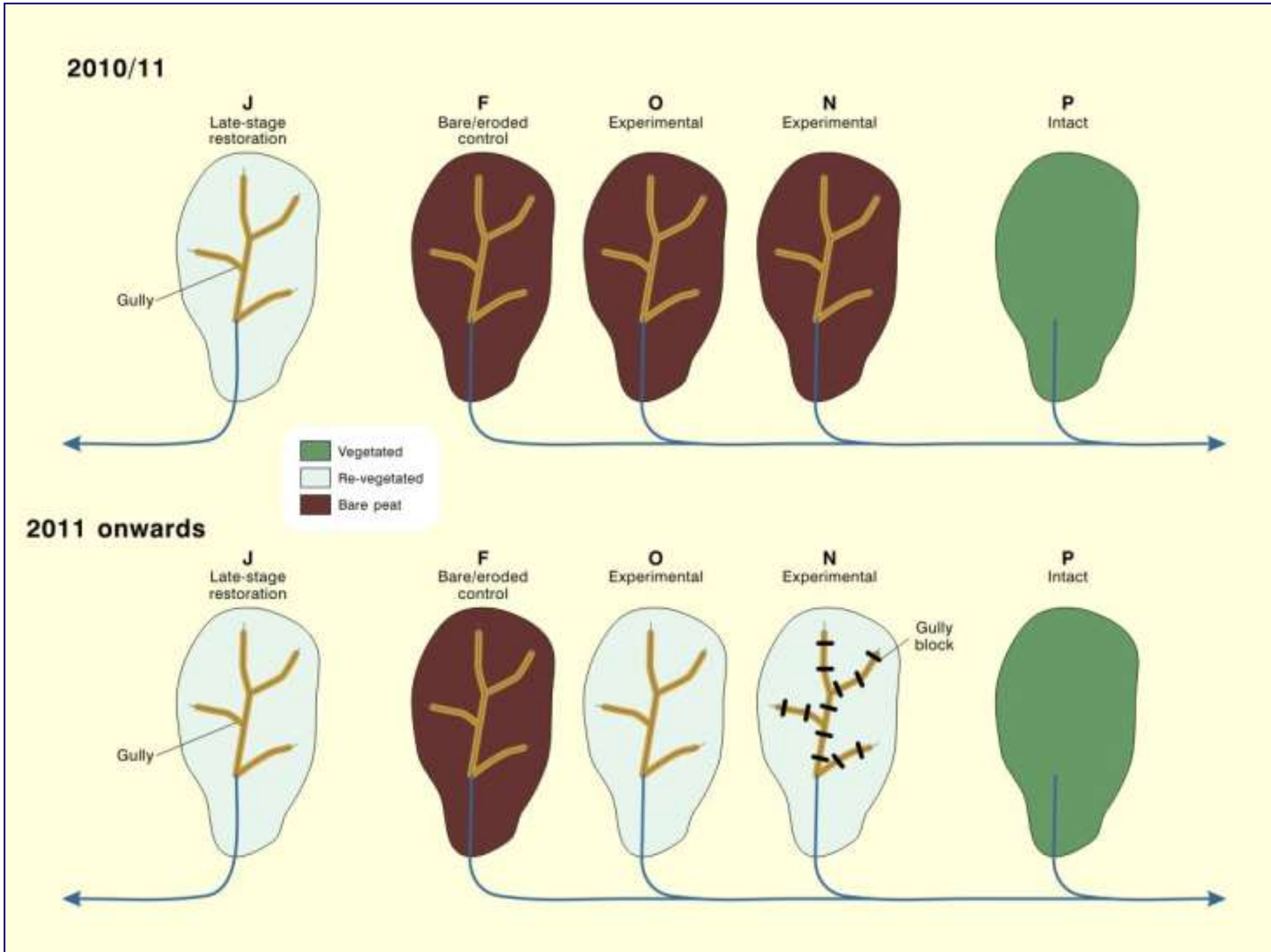
Past conditions → Degraded peats → Future conditions

Intact blanket peat catchment

Bare/eroded peat catchments

Restored catchment (was bare/eroded, but re-vegetated in 2003)

Before-After Study: Experimental Design



Micro-catchments circa 7000 m^2

Monitoring Data

Continuous monitoring

- *10 minute sampling*
  - Discharge
  - Rainfall
  - Met data
  - [Overland flow generation (plots)]
  - [Water tables (plots)]

Campaign monitoring

- *Weekly Sep-Dec sampling (2010 & 2014)*
  - Catchment water tables (n=45 per site)
  - Crest stage samplers for overland flow (n=27 per site)
  - Bulk overland flow (plots) (2010)

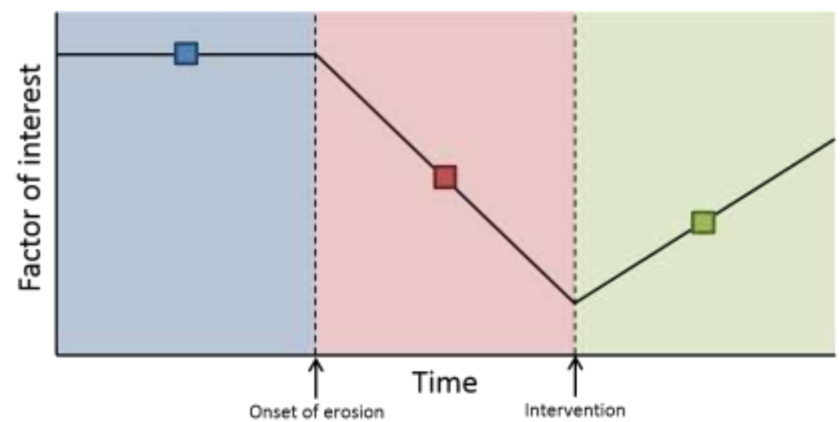
Data Analysis

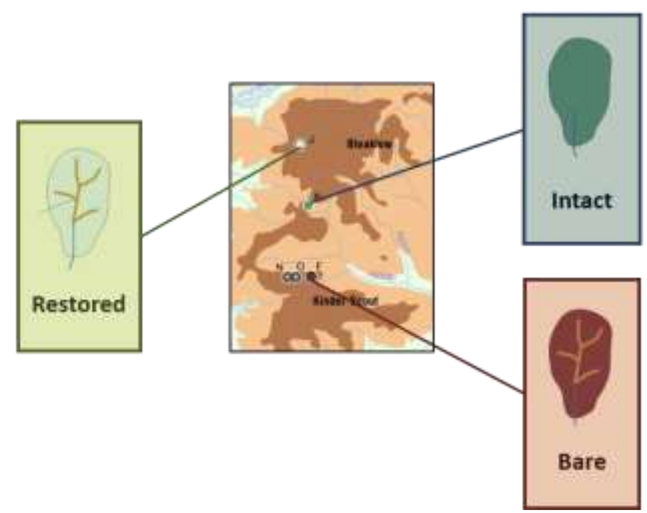
Space-for-time substitution

Infers temporal trends from **different aged** sites

Used to understand and model temporal processes that are otherwise unobservable

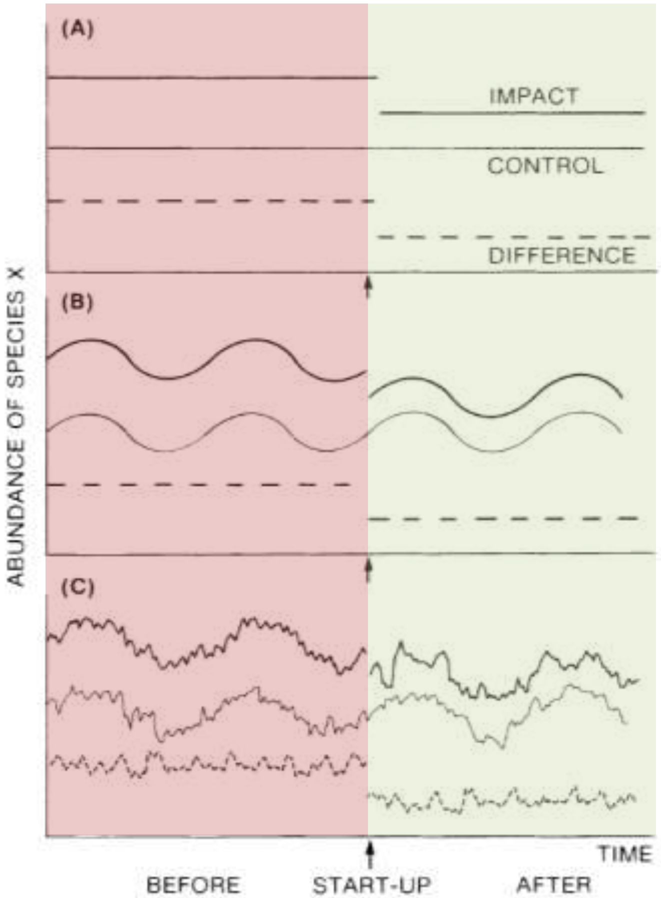
(i.e. no ‘before’ data)





Data Analysis

Before-after-control-impact (BACI)

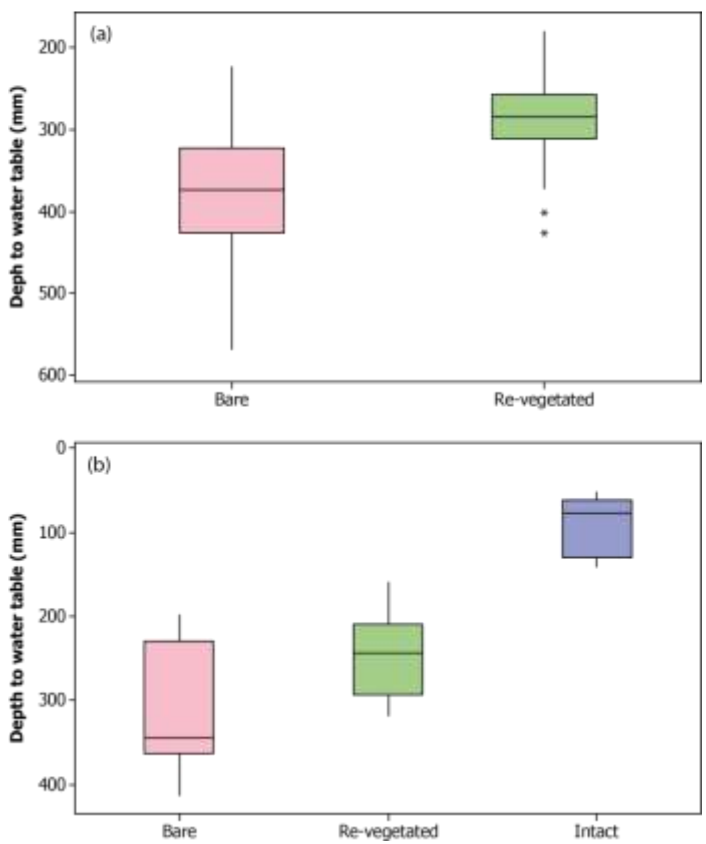


(Stewart-Oaten et al., 1986)

Uses data gathered **before and after** a treatment is applied

Compares the relative **difference** between a **control** site and an **impact** site to detect change following treatment

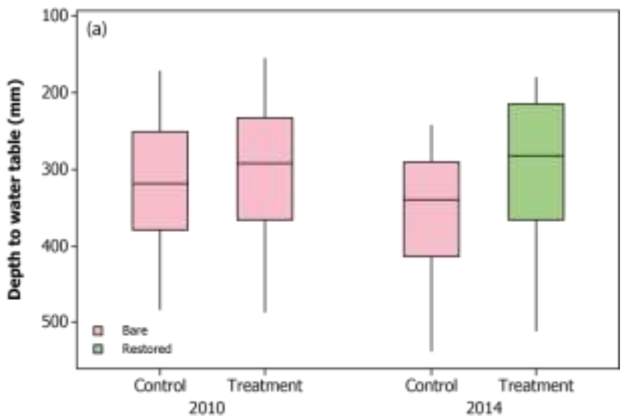
Water table results: Space-for-Time Studies

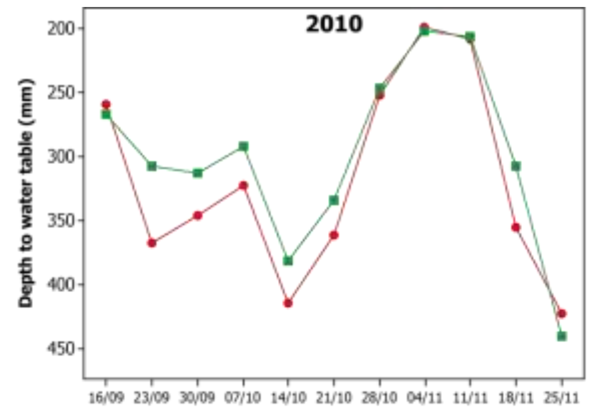


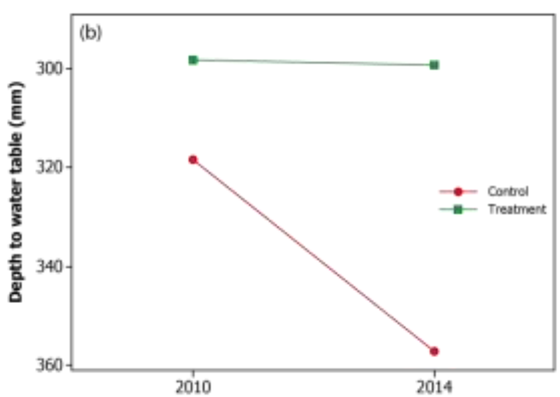
- Bare peat sites vs sites re-vegetated 7-8 years previously and intact sites
- Shallowest water tables found at intact sites
  - within 150 mm of the peat surface
- Deepest water tables found at bare sites
  - depths can exceed 550 mm
- Water tables were consistently higher at revegetated sites than bare sites
  - difference in median = 90 and 102 mm

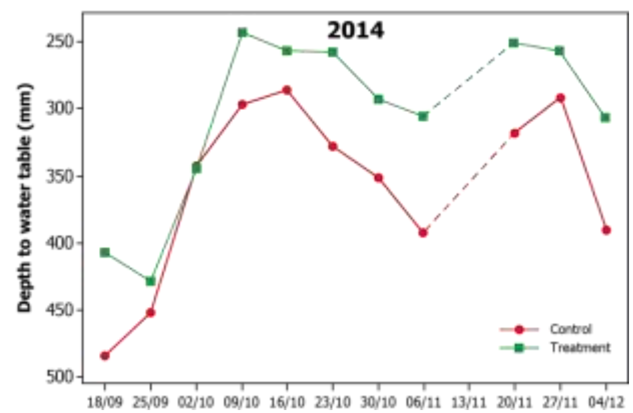
Significant differences between all site types

Water table results: BACI study



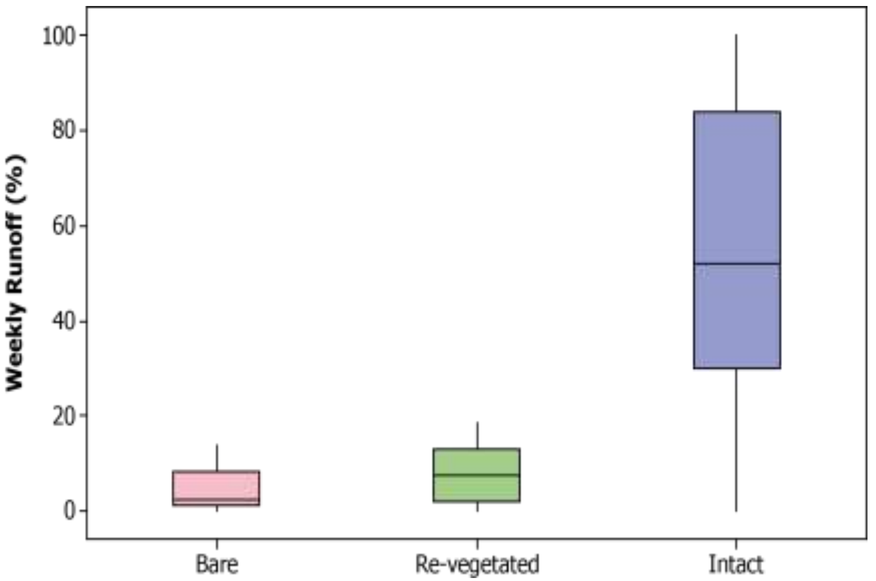






Relative decrease in water table depth of 35 mm 3 years after re-vegetation

Overland flow results: Space-for-Time Study

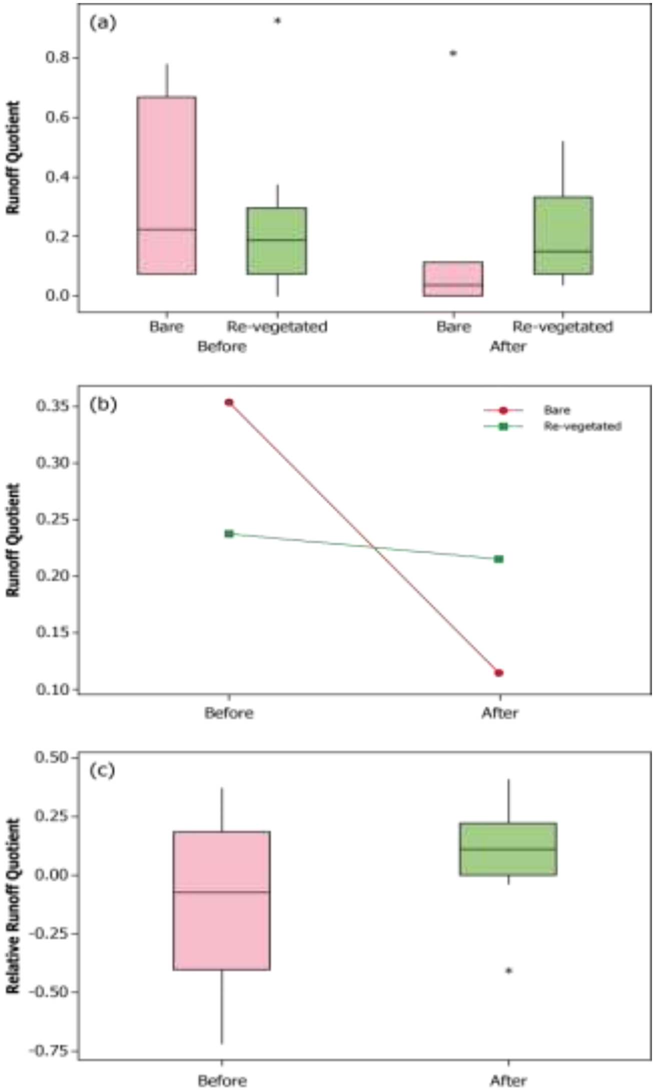


% of rainfall generating overland flow on interfluves

- Bare 2 – 7 %
- Re-veg 4 – 12 %
- Intact 36 – 74 %

Significant differences between all three site types

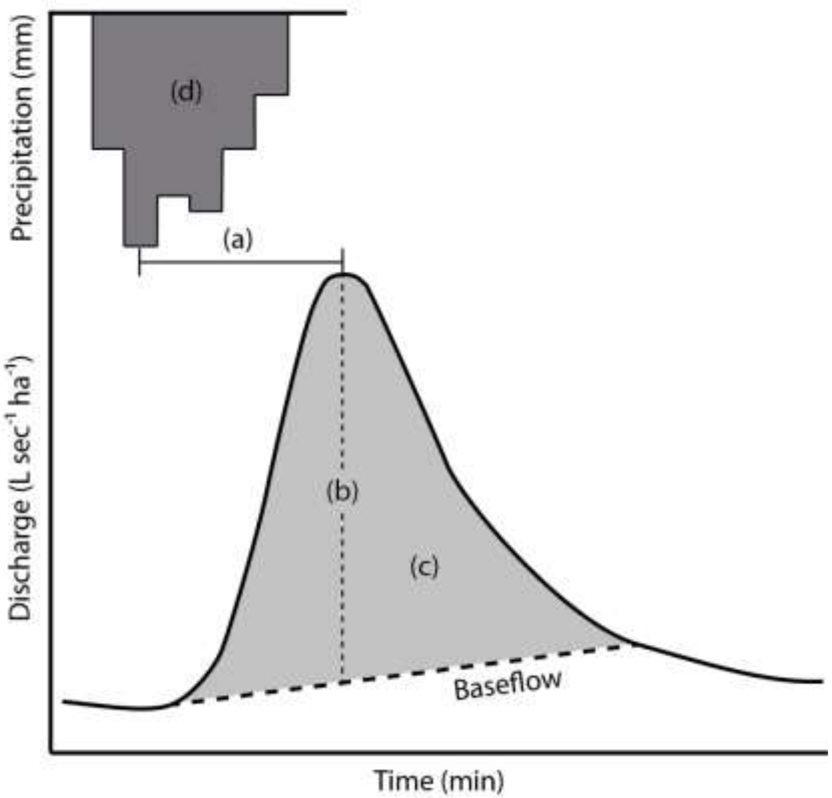
Overland flow results: BACI study



- **Raw data**:
  - Overland flow at both sites highly variable
  - No significant difference between sites
- **Relative data:**
  - 18% increase in relative overland flow production
  - Statistically significant

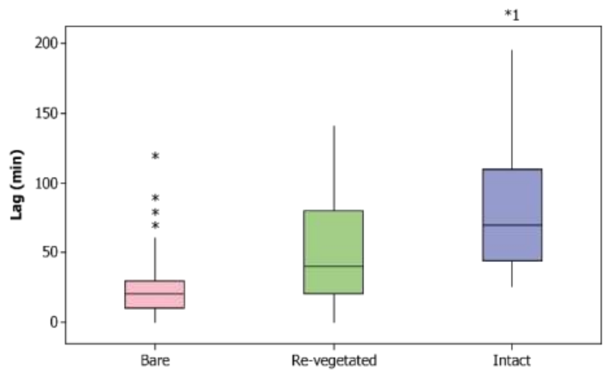
Significant increase in overland flow generation

Key storm-hydrograph parameters



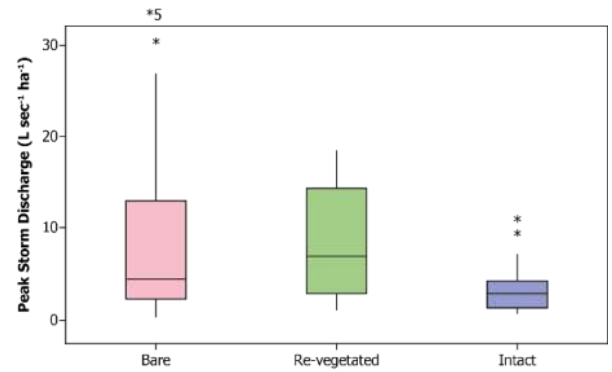
1. Lag time
2. Peak storm flow
3. Hydrograph shape index
4. % runoff

Hydrograph behaviour results: space-for-time study



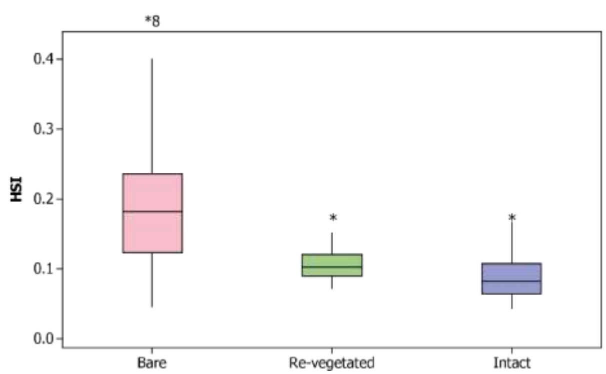
Significant differences between all three sites

Bare < Re-veg < Intact



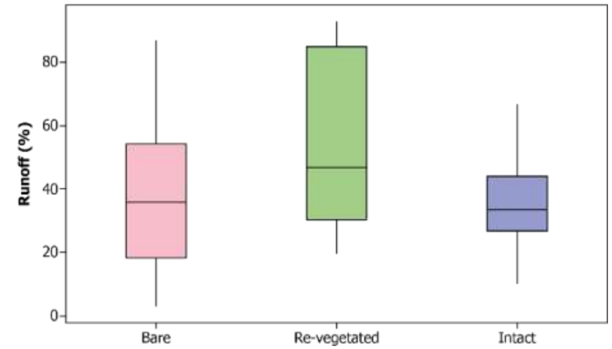
Intact different to bare and re-vegetated

Bare = Re-veg > Intact



Bare different to re-vegetated and intact

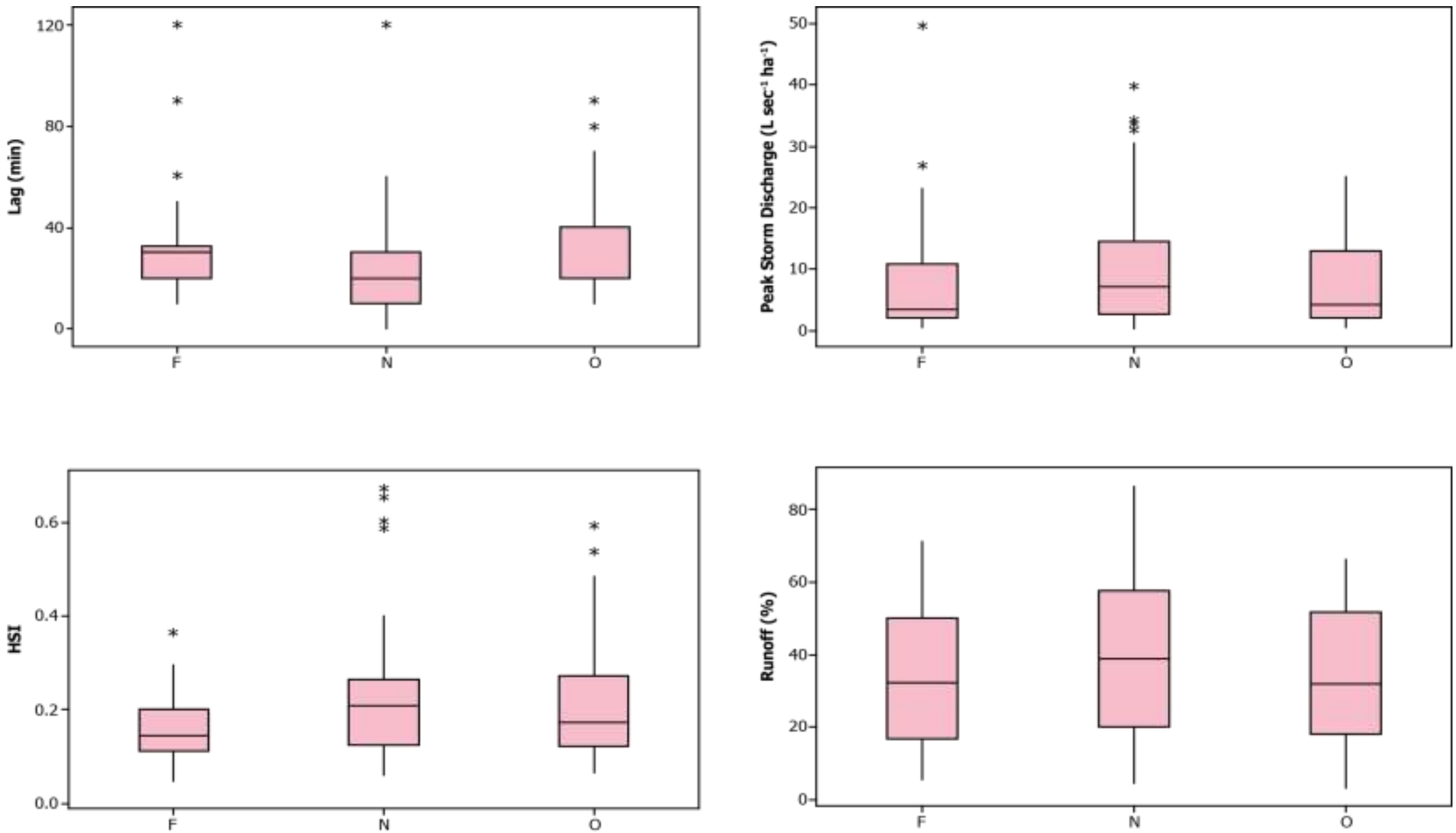
Bare > Re-veg = Intact



Re-vegetated different to bare and intact

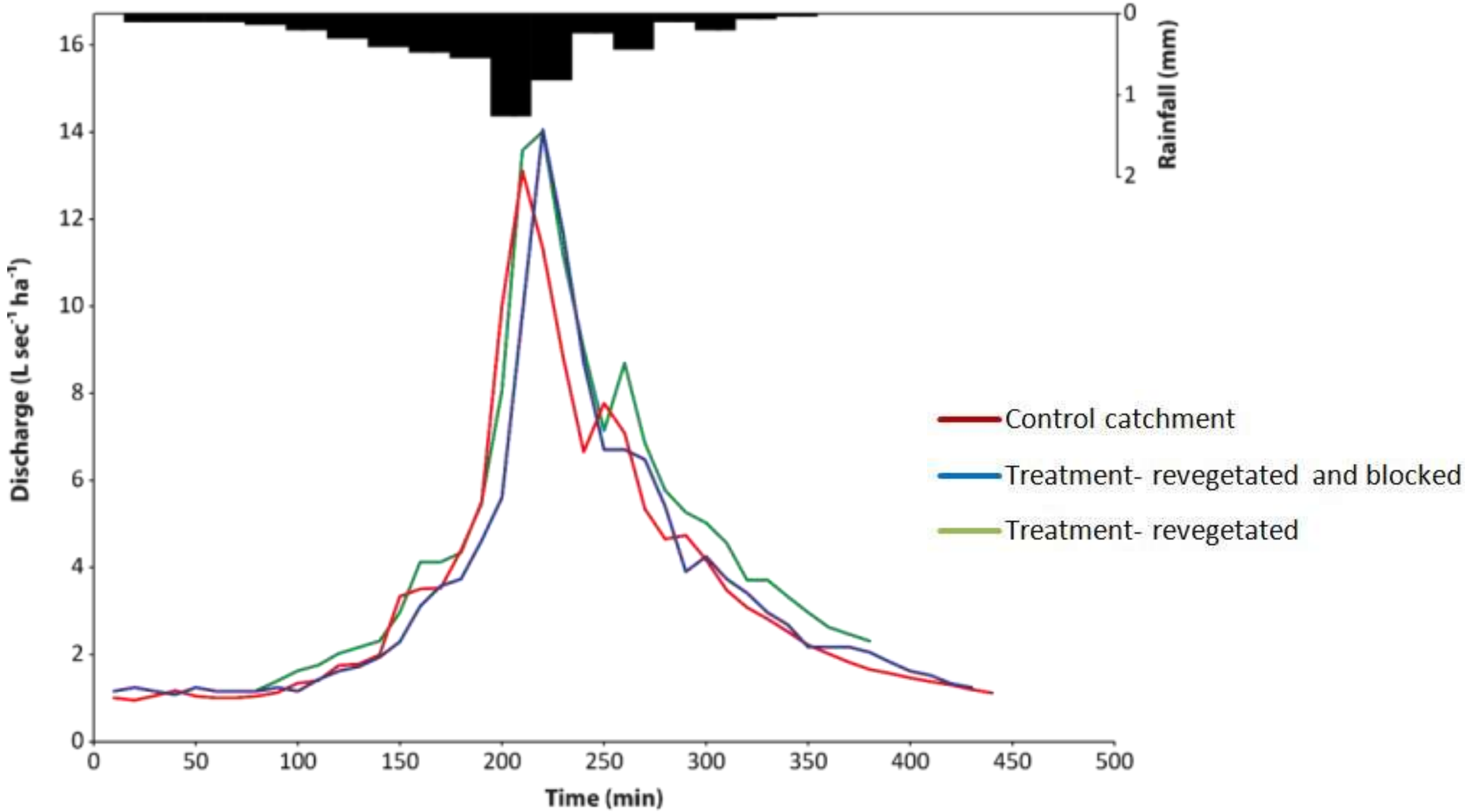
Bare < Re-veg > Intact

Hydrograph behaviour **before restoration**



No differences between sites before restoration

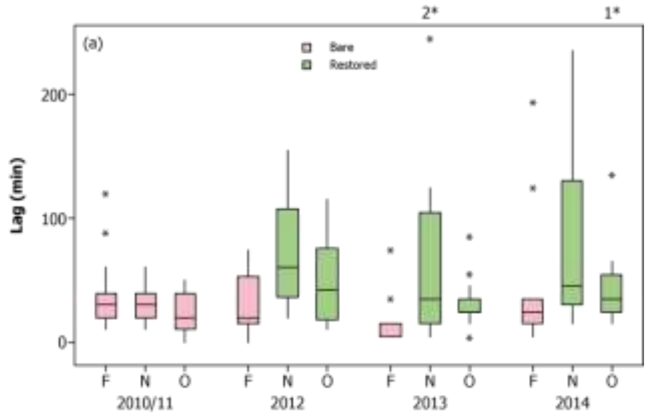
Hydrograph behaviour **before restoration**

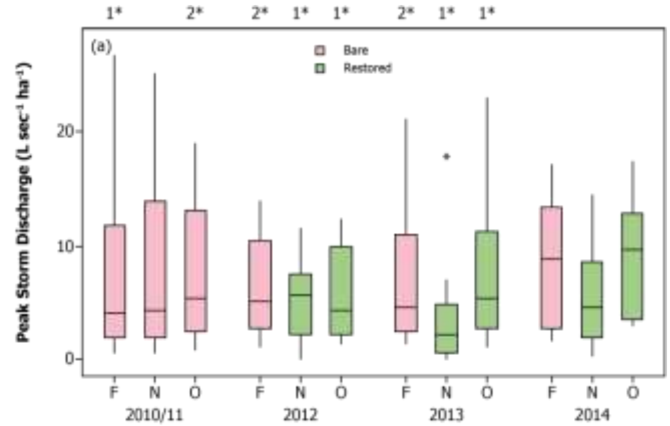


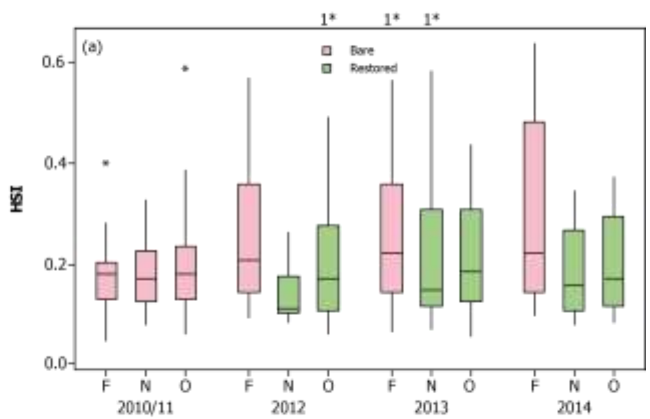
Example of storm hydrograph response before restoration

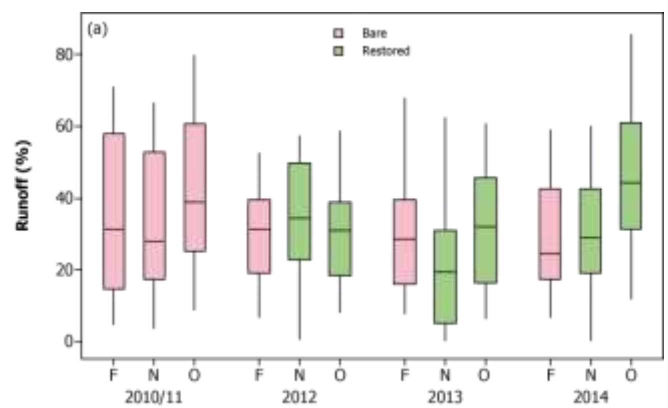
4th November 2010, total storm rainfall = 10.4 mm

Yearly hydrograph behaviour results: BACI study



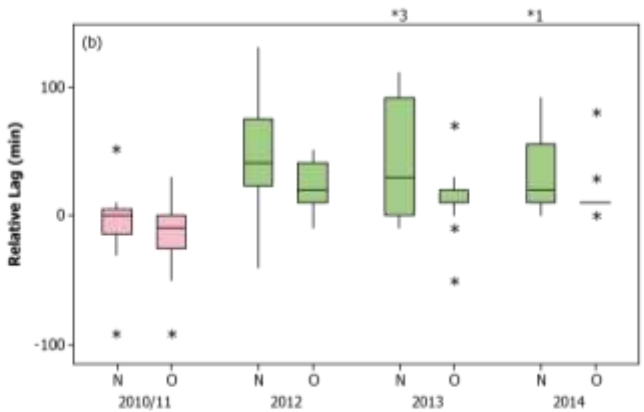


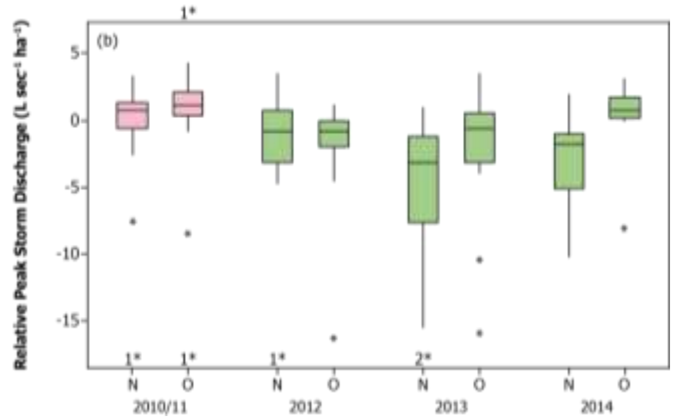


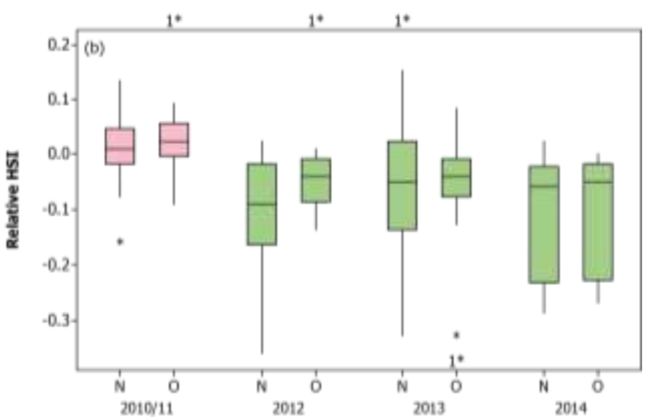


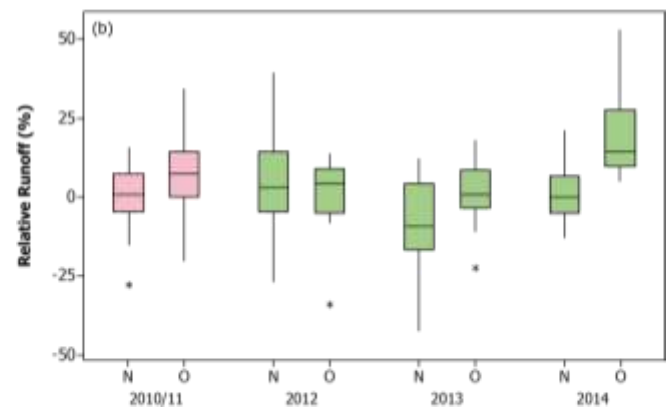
Obvious increase in lag times, other metrics less clear

Relative yearly hydrograph behaviour results: BACI study



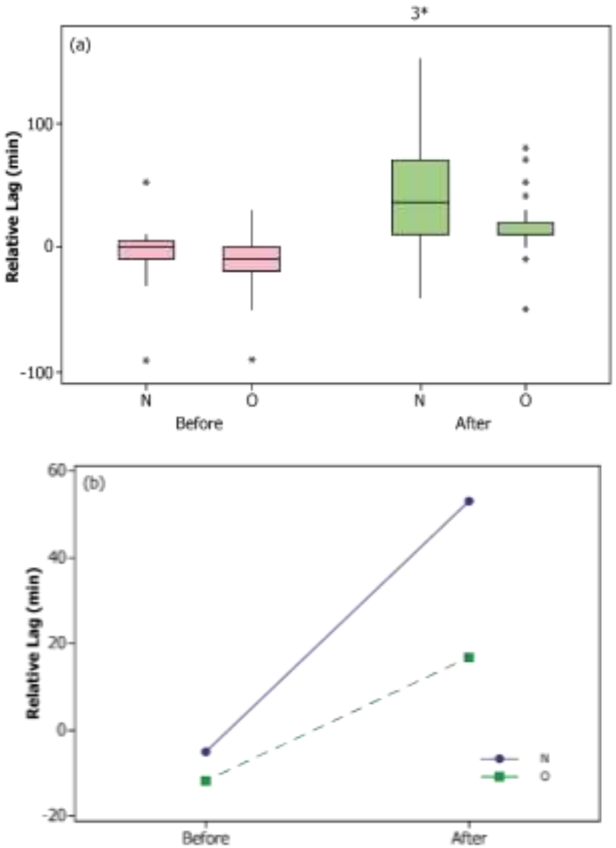






Clear immediate changes in Lag, Peak Discharge and Hydrograph Shape

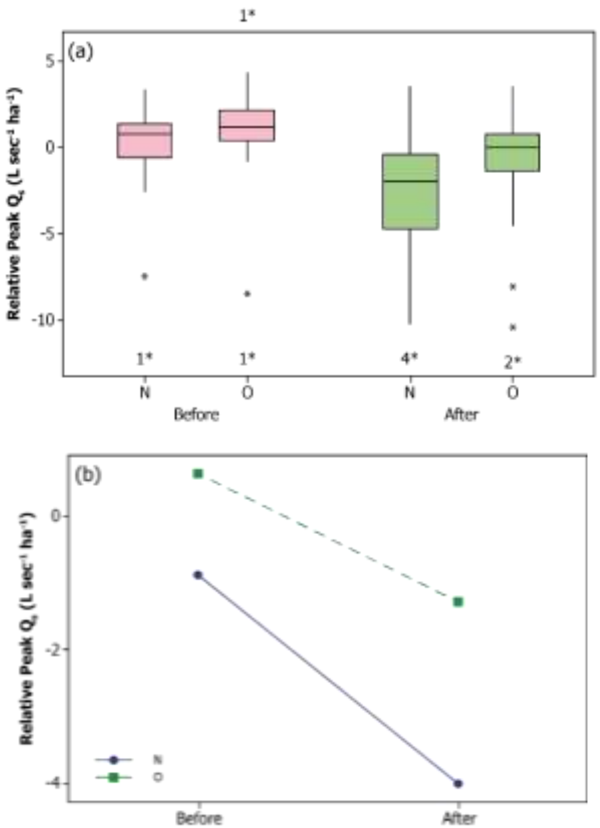
Lag times: BACI study



Catchment		Lag time (min)
Control		15
Re-vegetated		25
	% Control	**67%**
Re-vegetated and blocked		40
	% Control	**267%**

Significant **increase** in Lag-time

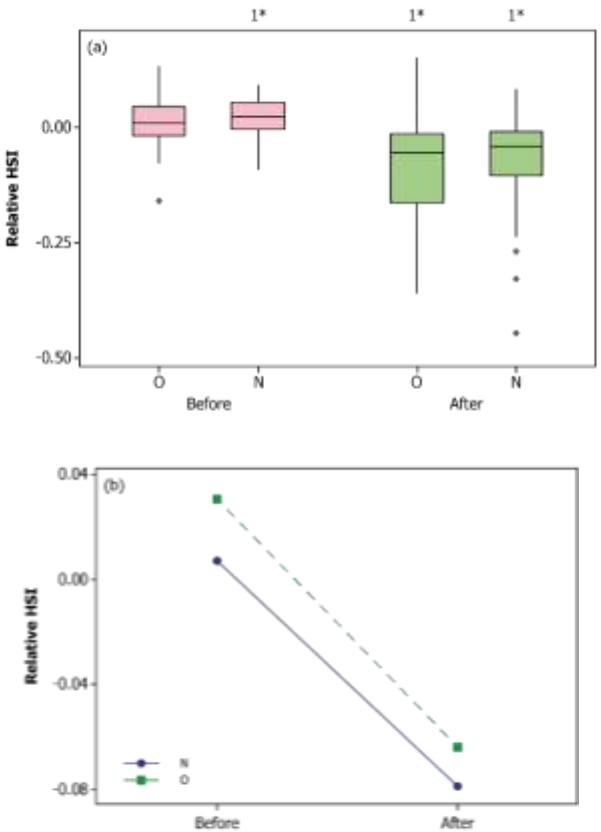
Peak storm discharge: BACI study



Catchment		Peak storm Q (L sec^{-1} ha^{-1})
Control		5.9
Re-vegetated		5.4
	% Control	**-8%**
Re-vegetated and blocked		3.7
	% Control	**-37%**

Significant **decrease** in Peak storm Q

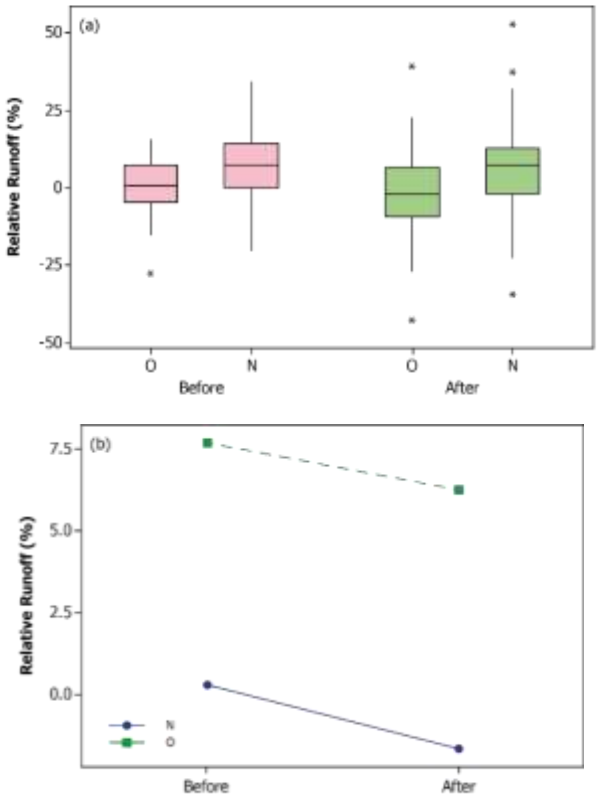
Hydrograph shape: BACI study



Catchment		HSI
Control		0.22
Re-vegetated		0.18
	% Control	**-19%**
Re-vegetated and blocked		0.14
	% Control	**-38%**

Significant **decrease** in HSI

Runoff: BACI study

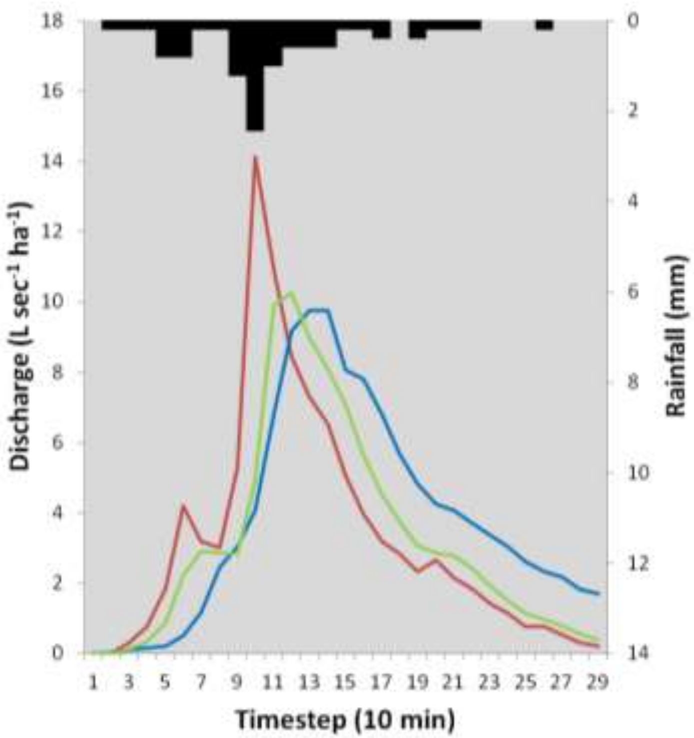


Catchment		% Runoff
Control		29.5
Re-vegetated		34.3
	% Control	**16%**
Re-vegetated and blocked		25.6
	% Control	**-13%**

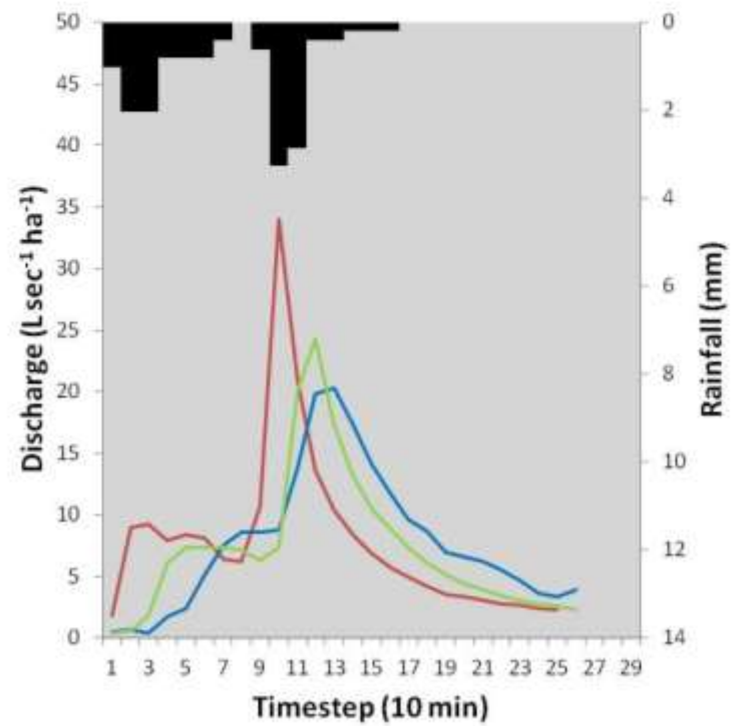
No change in percentage runoff

Hydrograph behaviour **after restoration**

19/7/2012
Storm rainfall = 11.2 mm



16/12/2013
Storm rainfall = 15.1 mm



Control catchment

Treatment- revegetated and blocked

Treatment- revegetated

High magnitude storms: BACI study

Do these changes still hold for the big events?

Catchment		Median lag time (min)		Median peak storm discharge ($L\ sec^{-1}\ ha^{-1}$)	
		Full dataset	Largest 10 storms	Full dataset	Largest 10 storms
Control		15	15	5.9	11.8
Treatment – re-vegetated		25	25	5.4	10.4
	% Control	**67%**	**67%**	**-8%**	**-11%**
Treatment – re-vegetated and blocked		40	35	3.7	5.4
	% Control	**267%**	**133%**	**-37%**	**-54%**

Yes! Median **lag increased by up to 133%** and **peak flow reduced by up to 54%.**

Key Results

Water tables

- Highest water tables at intact sites
- Deepest water tables at bare sites
- Re-vegetation significantly raises water tables

Overland flow

- Overland flow is more regularly generated at intact sites
- Overland flow production increases by 18% on interfluve surfaces following re-vegetation.
- However, surface runoff remains less prevalent at re-vegetated sites than in intact areas.

Storm hydrographs

- Significant, immediate changes in lag time, peak discharge, and hydrograph shape.
- No consistent change in percentage runoff
- Some apparent additional benefits of gully blocking, but not statistically significant.
- Observed changes persist in large storms.

MS4W Peak District catchments:

How will the restoration alter hydrology and storm-flow behaviour?

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Re-vegetation will increase evapotranspiration rates, increasing depth to water tables and soil water storage

Hypothesis 2

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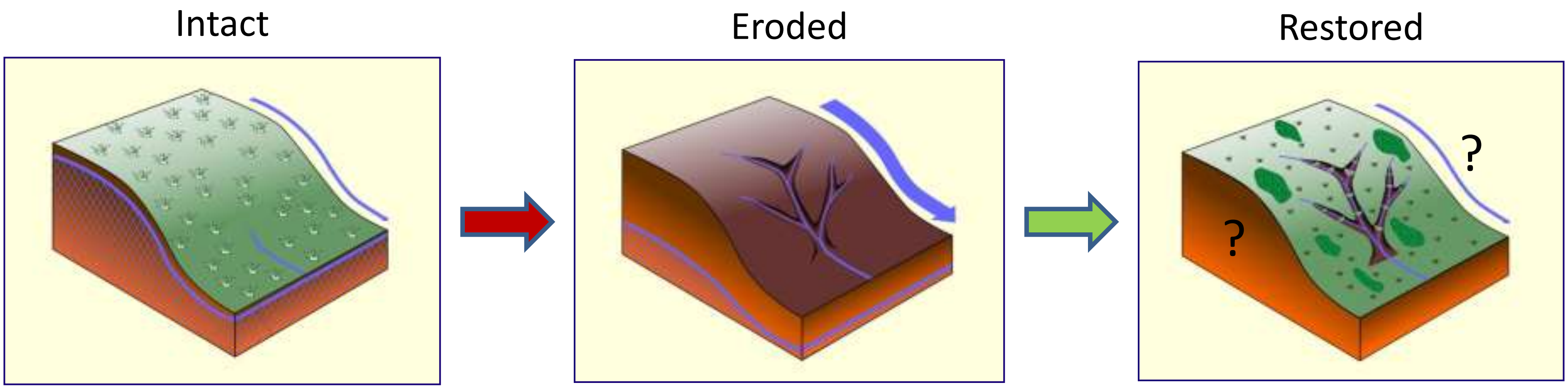
Re-vegetation and gully blocking will increase within-storm catchment storage due to surface ponding of water within vegetation and behind gully blocks

Hypothesis 4

Re-vegetation and gully blocking will increase surface roughness effects, with peat surface re-vegetation reducing overland flow velocities and gully blocks and associated gully bottom re-vegetation reducing channel velocities

What is responsible for the post-restoration hydrograph effects??



- There is no significant change in within-storm storage
- Data are consistent with reduced velocity of saturation excess overland flow

This process understanding allows robust modelling and upscaling!

Key Messages

- Peat restoration slows delivery of water from the headwaters
  - lag times increase (133% in large storms)
  - peak discharge declines (54% in large storms)
- Pronounced benefit from re-vegetation of bare peat, additional benefit from gully blocking
- Restoration can contribute to downstream flood risk reduction
  - Issue now is scale of the contribution

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Durham University

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Key Recommendations

- ***Sphagnum*** **re-introduction to maximise the storm-flow retardation**
- Further monitoring to evaluate full long-term and gully block effects
- Preservation of the eroded control micro-catchment
- Wider catchment scale modelling of flood risk benefits
- Incorporation of flood risk benefits into ecosystem service assessments

Department for Environment Food & Rural Affairs

Environment Agency

PEAK DISTRICT NATIONAL PARK AUTHORITY

National Trust

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