# Does changing connectivity due to beaver engineering result in changing hydrological function? Understanding impacts of the return of Eurasian beaver to Great Britain

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# Introduction to Presentation for EGU2020 Online

**Session:** GM3.6 (Dis)connectivity in hydro-geomorphic systems: emerging concepts and their applications

- Connectivity a useful concept for us to understand how environmental change including various land management or restoration approaches affect the interrelated structure and functioning of our landscapes.
- Beavers as ecosystem engineers can have significant impacts upon the structure and connectivity of riparian environments.
- Downstream disconnectivity, combined with lateral connectivity from dam building and wetland creation can have notable ecological, hydrological, geomorphic biogeochemical and socio-economic impacts.
- Beaver populations expanding and now reintroduced to much of their former European range.
- Researchers at the University of Exeter, alongside many project partners are undertaking a suite of transdisciplinary research to understand impacts of the return of beaver to the now intensively manged and populated landscapes of Britain (with broader relevance across the range of Eurasian beaver and North American beaver).
- Presentation focuses on hydrological research. Do changes in environmental structure and hydrological connectivity from dam building and wetland creation affect hydrological functioning i.e. rainfall-runoff and flow regimes?
- Previously published research has demonstrated flow attenuation due to beaver damming on a small/first order channel. Herein early results from new/ongoing monitoring across larger scales and with more extensive baseline datasets are also presented.
- Thoughts and feedback very welcome, particularly on hydrological data analysis.

# Introduction: Need for Nature Based Solutions

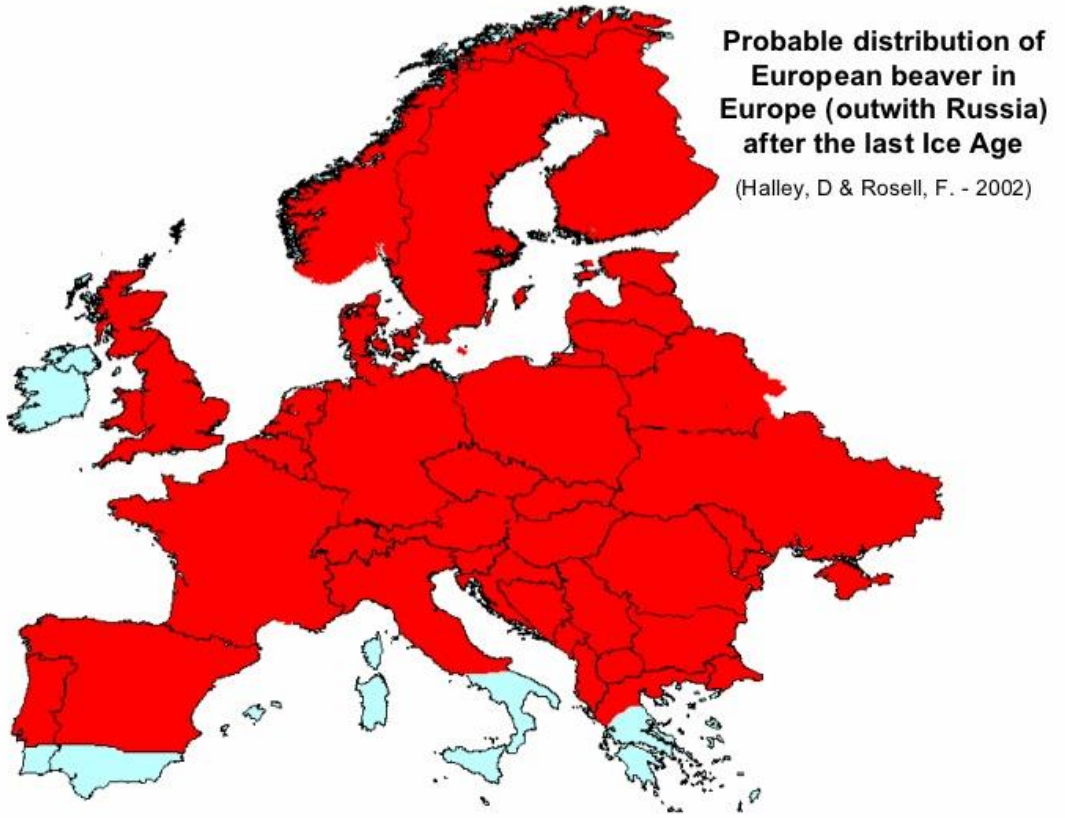
- Hydrological extremes combined with land (mis)management can cause both environmental and socio-economic damage:
  - Surface water flooding
  - Soil erosion
  - Diffuse pollution from agricultural land
  - Drought and associated water resource issues
  - Degraded ecology

- Solutions focussed on downstream palliative approaches i.e. building flood defences, dredging channels, extensive need for water treatment etc…

- Nature Based Solutions/Natural Flood Management/Working with Natural Processes/Landscape Restoration may offer alternative/complimentary solutions:
  - Enhancing resilience of downstream flood defences
  - Maintain elevated base flows in rivers during droughts
  - Filtering water and trapping sediment
  - Biodiversity/habitat enhancement
  - Natural spaces – health/wellbeing/tourism

- **Can Eurasian Beaver reintroduction play a valuable role?**
- **Can our research inform policy to maximise benefits whilst minimising conflict?**

# European Beaver (*Castor Fiber)*: Range and Context

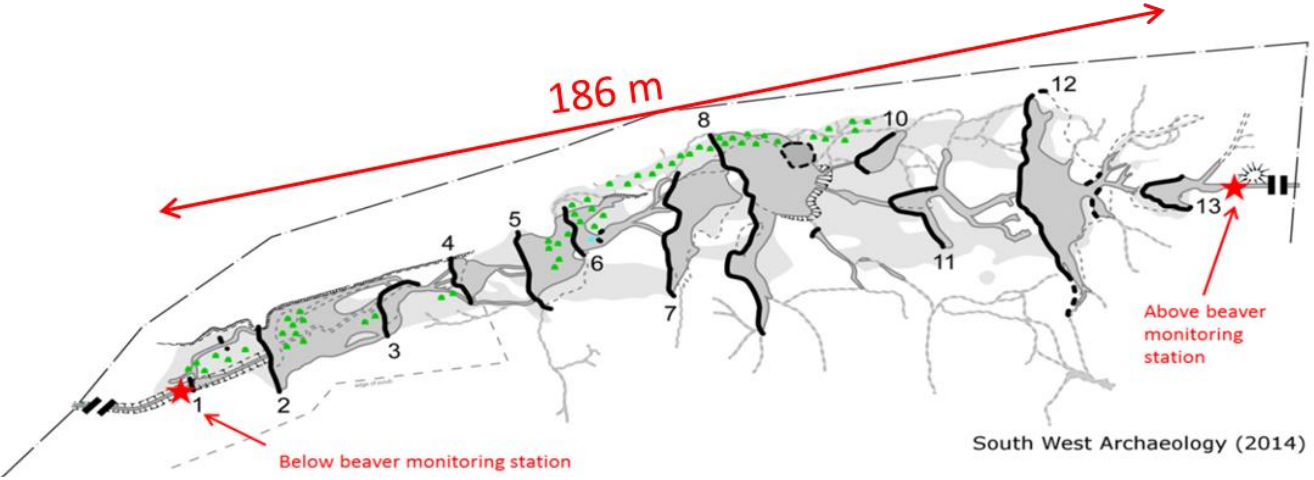



- Hunted to extinction in UK ca. 400 years ago (for fur, meat, castoreum).
- Similar reductions observed across Europe.
- Now reintroduced to much of former European range.
- In GB, official (Knapdale) and non-official (Tayside) releases in Scotland and current licensed trial England (River Otter, Devon).
- Additionally, an ever growing number of enclosed sites (many monitored by us for research purposes) and reports of un-licenced free-living populations.
- Hypothesised to previously had a large impact on structure and function of riverine ecosystems (Brown et al., 2018).
- Critical to understand the environmental and socio-economic impacts (both positive and negative) as beavers return to what is now a highly populated and modified landscape.

Brown et al., 2018. Natural vs anthropogenic streams in Europe: History, ecology and implications for restoration, river-rewilding and riverine ecosystem services. Earth-Science Reviews. DOI:10.1016/j.earscirev.2018.02.001

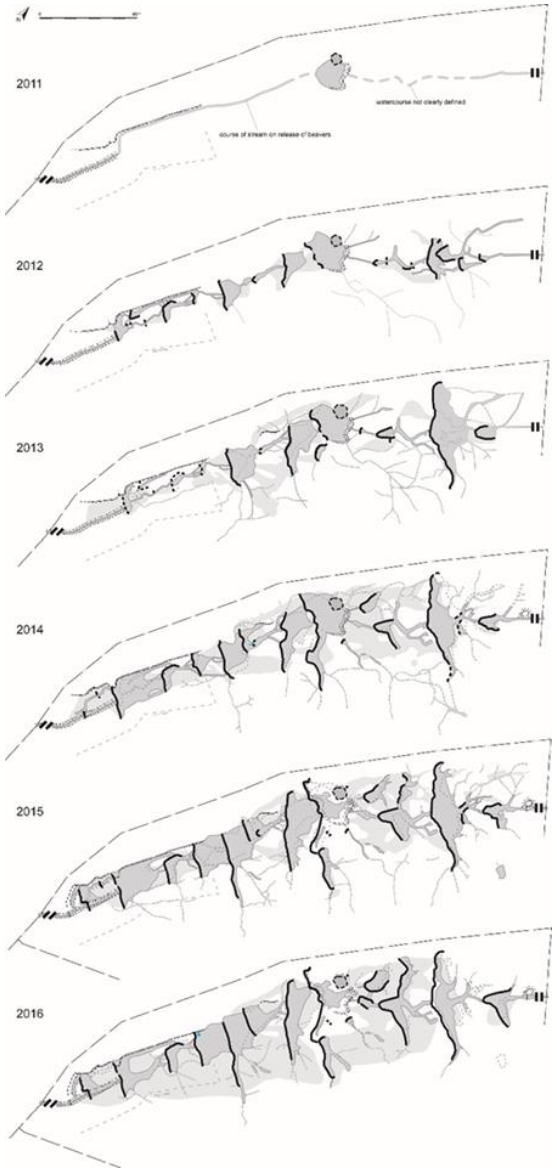
# Devon Beaver Project: Site Description

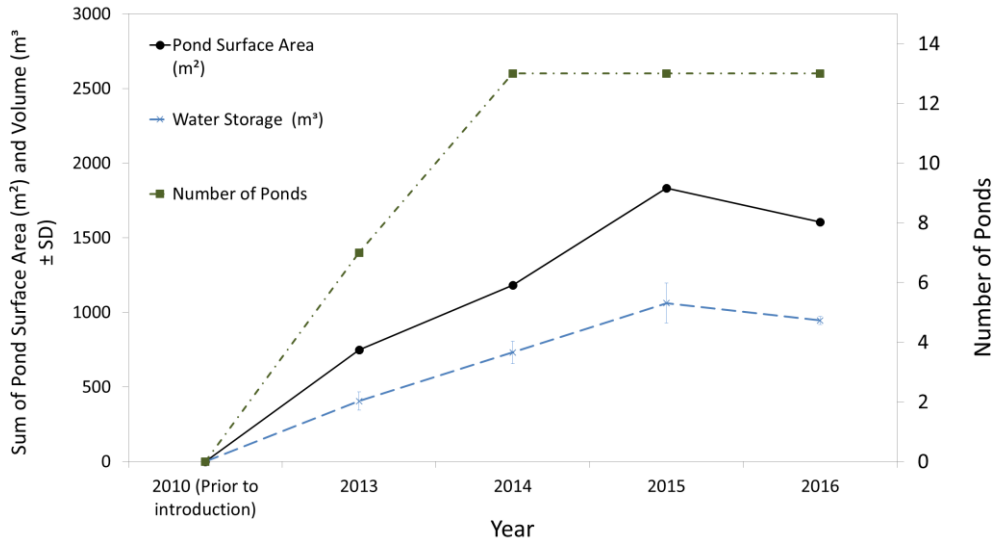

- Fenced 1.8 ha (0.2 km$^2$) site in North Devon
- 1$^{st}$ order tributary draining from 20 ha intensively managed grassland catchment.
- A pair of beavers introduced in 2011
- Changed site from small first order tributary running through woodland, to a diverse mosaicked wetland environment. Significant ecological change:
- Frogspawn increased from 10 clumps in 2011 to 580 in 2016.
- Species such as kingfisher and heron observed.
- Monitored change in site structure and associated hydrological function (quantity and quality).

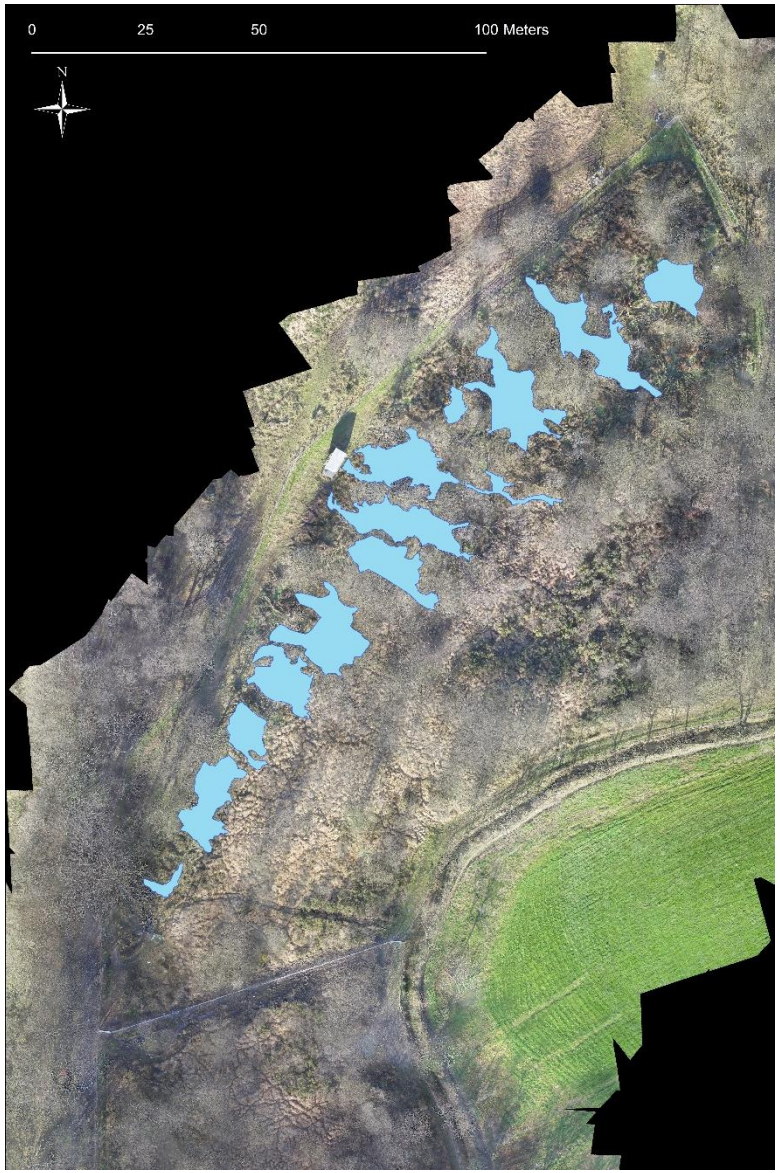



http://www.devonwildlifetrust.org/sites/default/files/files/Beaver%20Project%20update%20(LowRes)%20.pdf

# Results: Structural Change and Water Storage



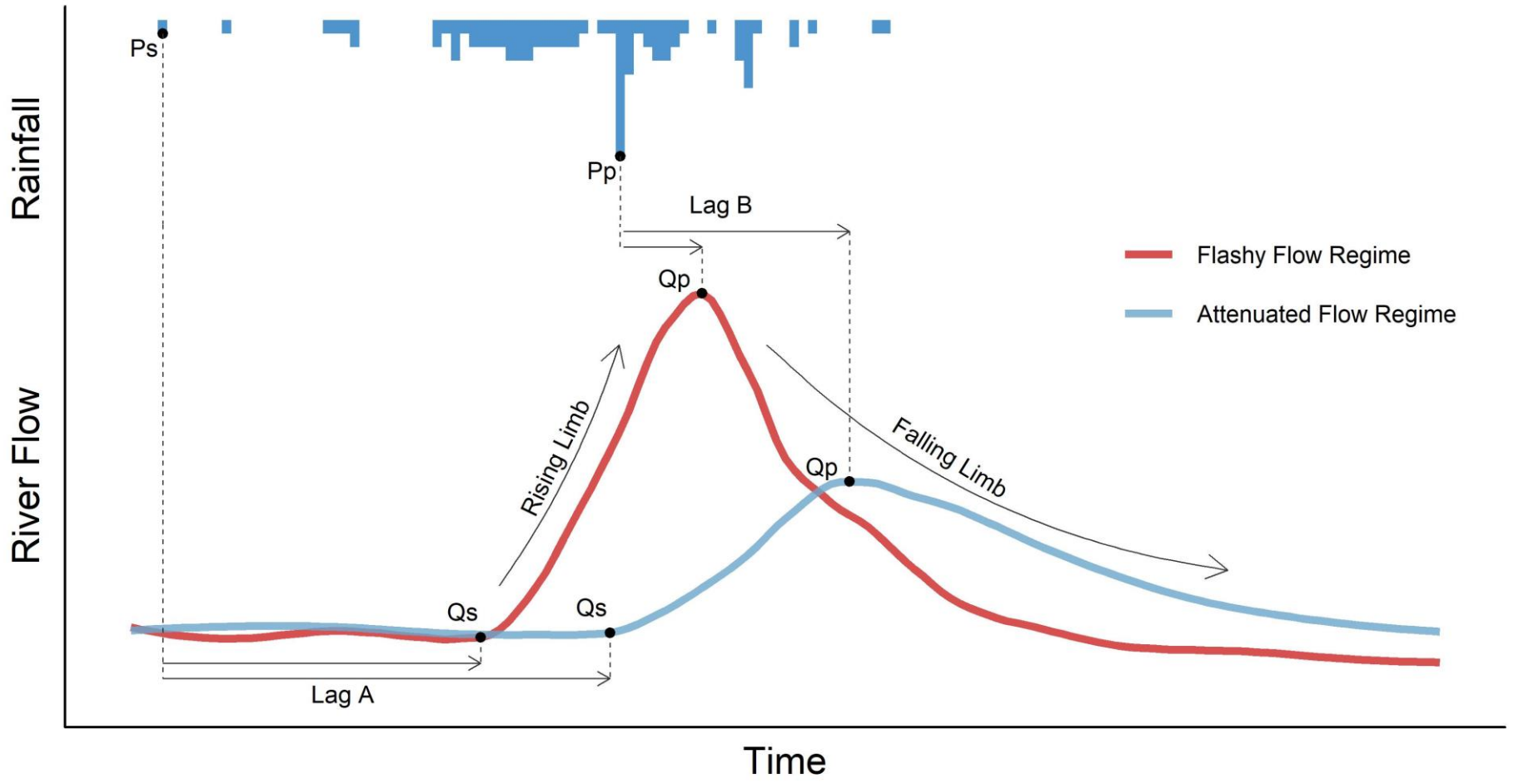




Puttock et al., 2015. Aerial photography collected with a multirotor drone reveals impact of Eurasian beaver reintroduction on ecosystem structure. Journal of Unmanned Vehicle Systems. DOI: 10.1139/juvs-2015-0005

Beaver engineered systems can reduce longitudinal (downstream) connectivity and increase lateral connectivity, pushing water sideways, reconnecting the river and land.

https://youtu.be/I1eGsZ9Fuk8

# Natural Flood Management - Concept

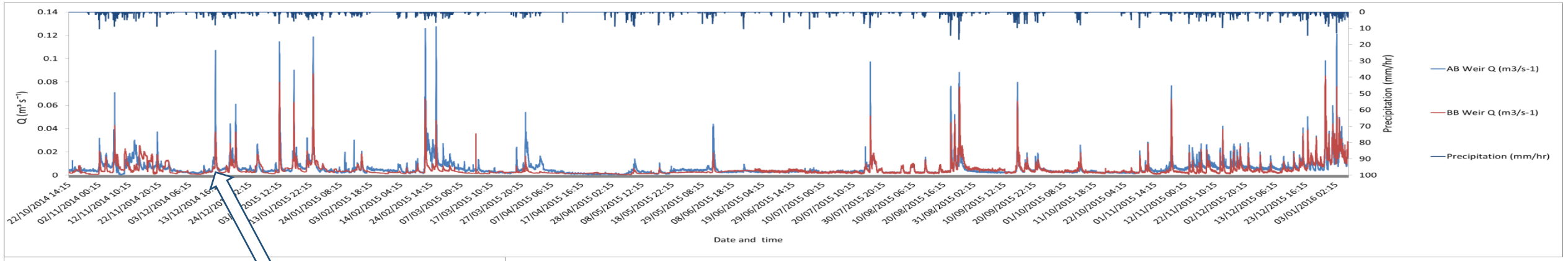


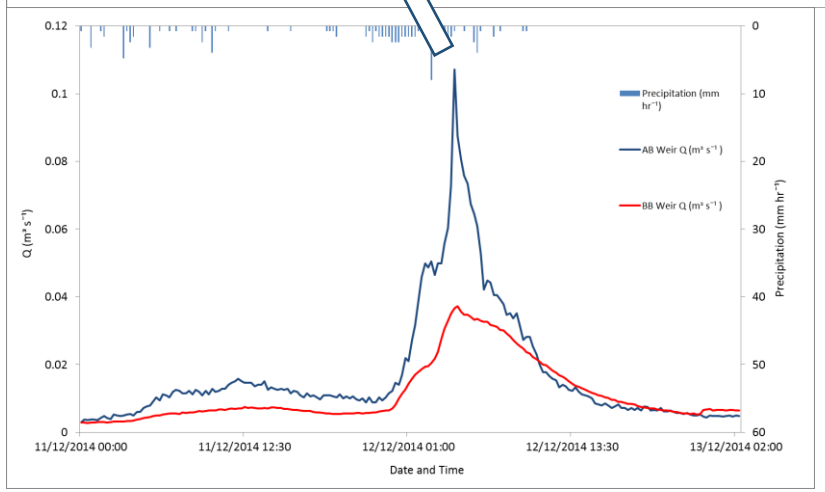

Seeking to slow the flow of water downstream during storm events. Can beaver dam sequences contribute to this?

# Results: Flow Attenuation

Continuous flow and rainfall data for 3+ years, quantifying the rate and amount of water entering and leaving the site.

Results (from 70+ rainfall-runoff events) indicate that beaver activity, particularly the building of ponds and dams, moderates the channel response to rainfall following storm events.



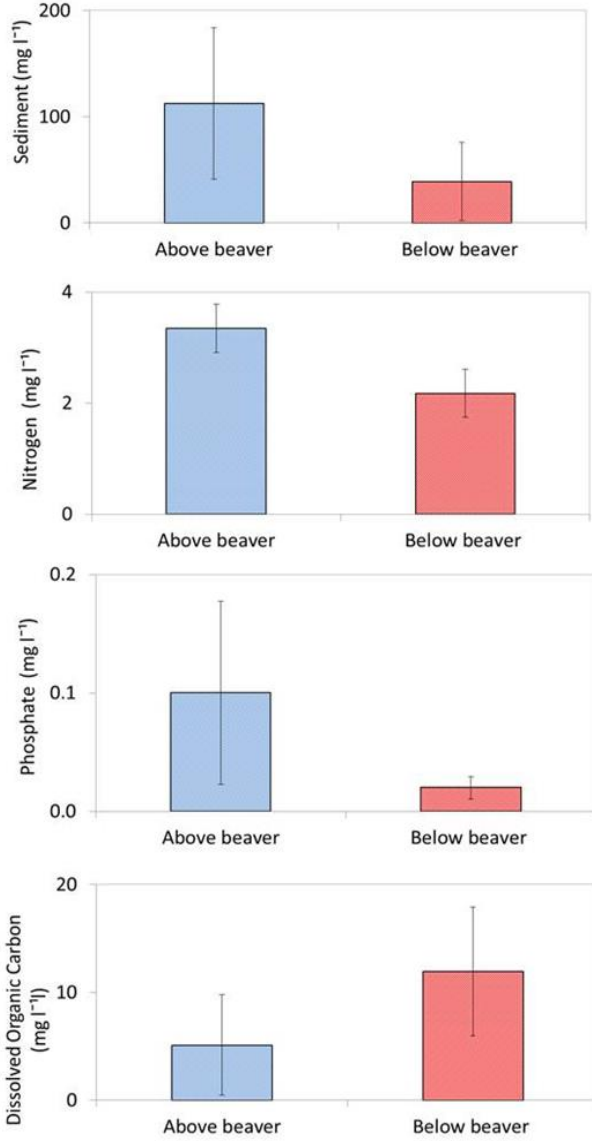




- Event Rain = 24 mm
- Above Beaver (blue)
  Peak Discharge = 0.11 ($m^3 s^{-1}$)
  Storm event discharge = 2923 ($m^3$)
- Below Beaver (red)
  Peak Discharge = 0.04 ($m^3 s^{-1}$)
  Storm event discharge = 1493 ($m^3$)

- Total storm event flow and peak flows reduced by ca 30 % below beaver site.
- Lag times (peak rainfall to peak flow) much shorter above beaver site than below (29 %).
- Water takes on average 1 hour to travel through site.
- Demonstrates flow attenuation due to beaver activity, including for largest events observed.


Puttock et al., 2017. Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands. Science of The Total Environment. DOI:10.1139/juvs-2015-0005

# Results: Water Quality



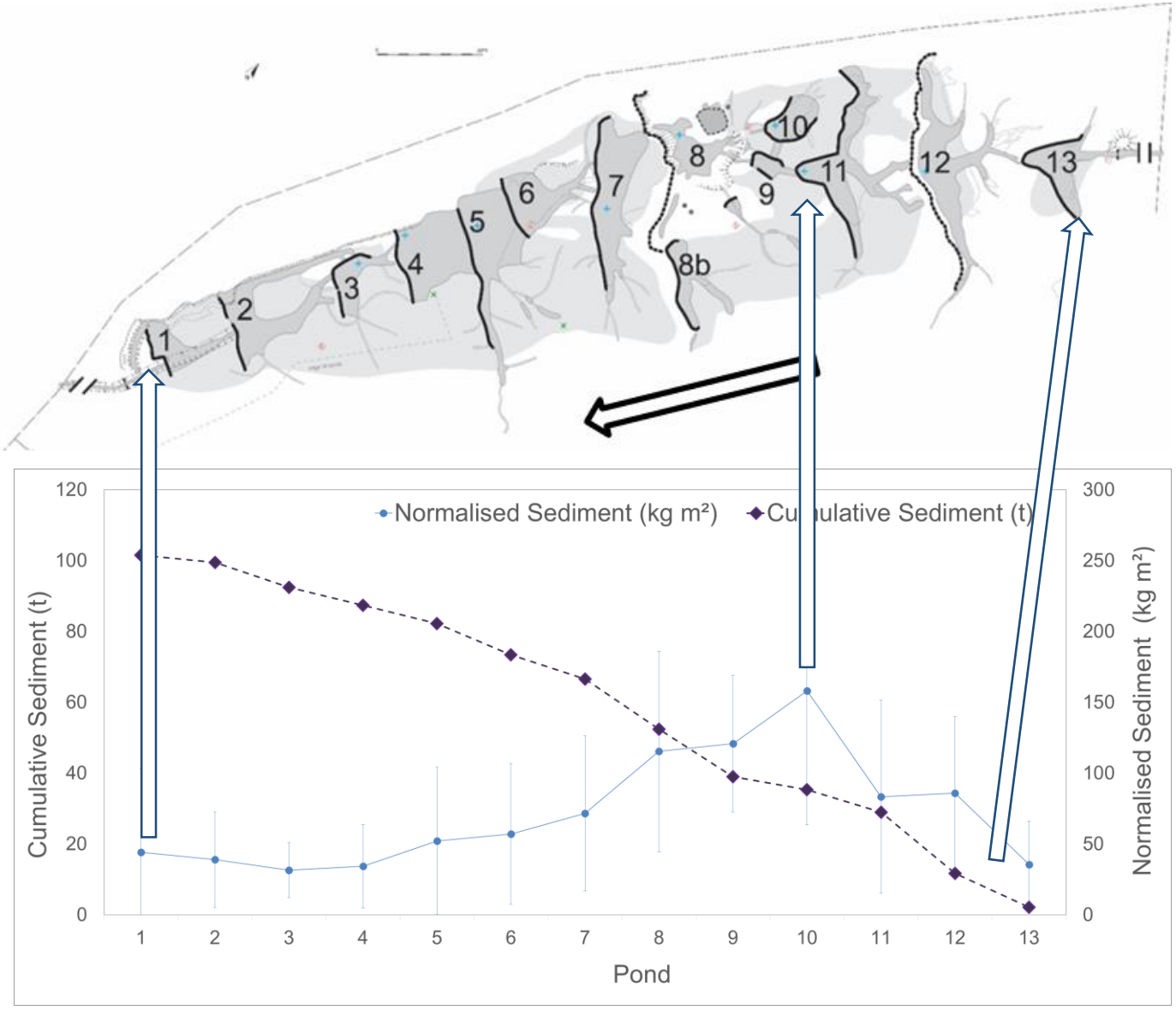

On average, compared to water entering from intensively managed grassland, each litre of water leaving the beaver-impacted site contained:

- 3x less sediment
- 0.7x less nitrogen
- 5x less phosphate
- 2x dissolved organic carbon

- Storm monitoring (17 events, 178 samples above, 119 below), suggests site may act as a filter for diffuse water pollutants from agriculture (suspended sediment, nitrogen and phosphate).
- However, more organic matter in the site, so potentially results in a greater loss of dissolved organic carbon than comparative agricultural land.
- Flow attenuation results in further reductions in total event loads.
- Indicates sediment and associated nutrients being trapped and stored within the beaver impacted site…

Puttock et al., 2017. Eurasian beaver activity increases water storage, attenuates flow and mitigates diffuse pollution from intensively-managed grasslands. Science of The Total Environment. DOI:10.1016/j.scitotenv.2016.10.122

# Results: Sediment and Nutrient Storage in a Beaver Engineered Wetland




- Dam pond sequence surveyed to quantify: sediment depth, volume and mass surveyed in addition to carbon and nitrogen content.

- 13 ponds held over 100 t of sediment (normalised average of ca 70 kg $m^2$ ponded extent).
- 15 t of carbon and 1 t of nitrogen.
- Size greatest control over storage, larger ponds hold more sediment per unit area.
- Position in sequence may play a role too.
- Estimation of source: >70 % from upstream catchment.
- Beaver ponds may have role to play in mitigating negative impacts of soil erosion and diffuse pollution from agriculture.
- At time of sampling, estimated ponds would have over 50 % remaining storage capacity, not accounting for continued modification by beavers of site over time to maintain/increase capacity.

- **Beaver sites can store sediment and nutrients in addition to water.**

Puttock et al., 2018. Sediment and Nutrient Storage in a Beaver Engineered Wetland, Earth Surface Processes and Landforms. doi: 10.1002/esp.4398

# Current State of National Policy

Recent increase in policymaker support for working with natural processes and beaver reintroduction (and ~ 90 % public support Auster et al., 2019) but recognised that more understanding is required to maximise benefits and minimise conflict.

HM Government

A Green Future: Our 25 Year Plan to Improve the Environment

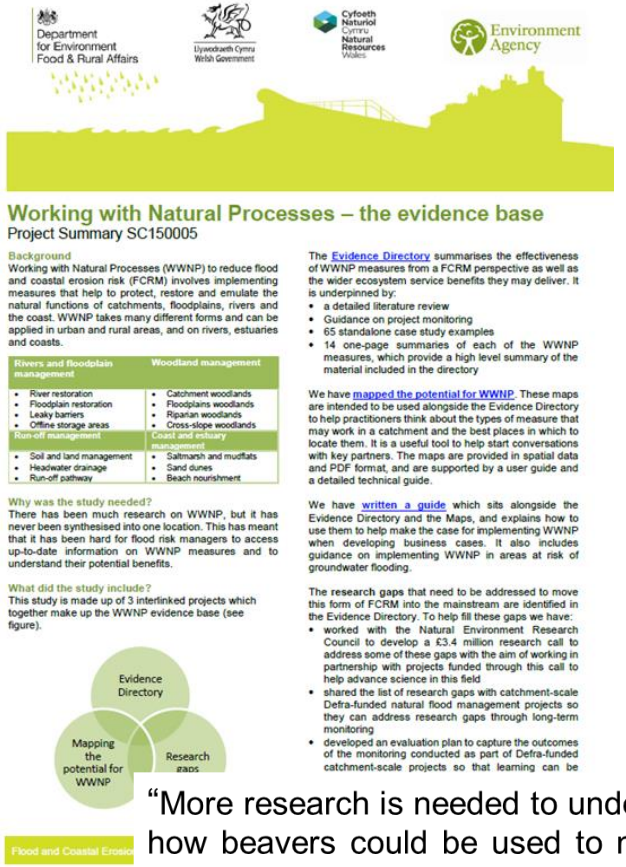
Hugh Graham and 2 others Retweeted

**Michael Gove** @michaelgove · 8 Dec 2017

Delighted to support the reintroduction of **beavers** to Britain


361 661 1.9K


We need the power of nature and human ingenuity working side by side. And when you think that the humble, native beaver has the power to transform vast landscapes by creating natural dams, it's clear that we need to think outside the box when it comes to helping the environment.



Department for Environment Food & Rural Affairs | Llywodraeth Cymru Welsh Government | Cyfoeth Naturiol Cymru Natural Resources Wales | Environment Agency

**Working with Natural Processes – the evidence base**

Project Summary SC150005

Background

Working with Natural Processes (WWNP) to reduce flood and coastal erosion risk (FCRM) involves implementing measures that help to protect, restore and emulate the natural functions of catchments, floodplains, rivers and the coast. WWNP takes many different forms and can be applied in urban and rural areas, and on rivers, estuaries and coasts.

| Rivers and floodplain management | Woodland management |
|---|---|
| • River restoration<br>• Floodplain restoration<br>• Leaky barriers<br>• Offline storage areas | • Catchment woodlands<br>• Floodplains woodlands<br>• Riparian woodlands<br>• Cross-slope woodlands |
| Run-off management | Coast and estuary management |
| • Soil and land management<br>• Headwater drainage<br>• Run-off pathway | • Saltmarsh and mudflats<br>• Sand dunes<br>• Beach nourishment |

Why was the study needed?

There has been much research on WWNP, but it has never been synthesised into one location. This has meant that it has been hard for flood risk managers to access up-to-date information on WWNP measures and to understand their potential benefits.

What did the study include?

This study is made up of 3 interlinked projects which together make up the WWNP evidence base (see figure).




The Evidence Directory summarises the effectiveness of WWNP measures from a FCRM perspective as well as the wider ecosystem service benefits they may deliver. It is underpinned by:

- a detailed literature review
- Guidance on project monitoring
- 65 standalone case study examples
- 14 one-page summaries of each of the WWNP measures, which provide a high level summary of the material included in the directory

We have mapped the potential for WWNP. These maps are intended to be used alongside the Evidence Directory to help practitioners think about the types of measure that may work in a catchment and the best places in which to locate them. It is a useful tool to help start conversations with key partners. The maps are provided in spatial data and PDF format, and are supported by a user guide and a detailed technical guide.

We have written a guide which sits alongside the Evidence Directory and the Maps, and explains how to use them to help make the case for implementing WWNP when developing business cases. It also includes guidance on implementing WWNP in areas at risk of groundwater flooding.

The research gaps that need to be addressed to move this form of FCRM into the mainstream are identified in the Evidence Directory. To help fill these gaps we have:

- worked with the Natural Environment Research Council to develop a £3.4 million research call to address some of these gaps with the aim of working in partnership with projects funded through this call to help advance science in this field
- shared the list of research gaps with catchment-scale Defra-funded natural flood management projects so they can address research gaps through long-term monitoring
- developed an evaluation plan to capture the outcomes of the monitoring conducted as part of Defra-funded catchment-scale projects so that learning can be

Flood and Coastal Erosion

"More research is needed to understand how beavers could be used to mitigate flood risk in the UK, however, local trials are producing interesting findings (see, for example, Puttock et al. 2017)."

Auster, R. E., Puttock, A., & Brazier, R. (2019). Unravelling perceptions of Eurasian beaver reintroduction in Great Britain. Area, area.12576. https://doi.org/10.1111/area.12576

# Ongoing Research: Need for Understanding Across Scales and Landuses

## Forest of Dean Beaver Project

- Release summer 2018 (+1 year baseline monitoring)
- 4.1 km$^2$ forested catchment.
- Upstream of town (Lydbrook) liable to flooding.
- Beavers now damming.
- Can beaver provide an NFM solution?
- Forestry commission also now working with us on a **Yorkshire Beaver Project,** again with NFM as main objective.

## Cornwall Beaver Project

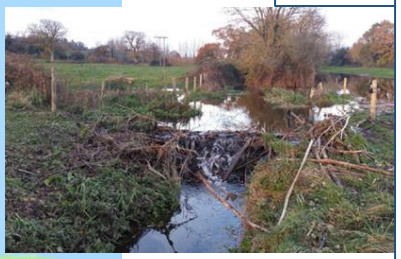
- 134 ha catchment, 2$^{nd}$ order
- Agricultural land use
- Beavers introduced Summer 2017
- Increased water storage and flow attenuation now being observed

## Other research projects and sites in development…




## Tayside Beaver Territory and Population Dynamics

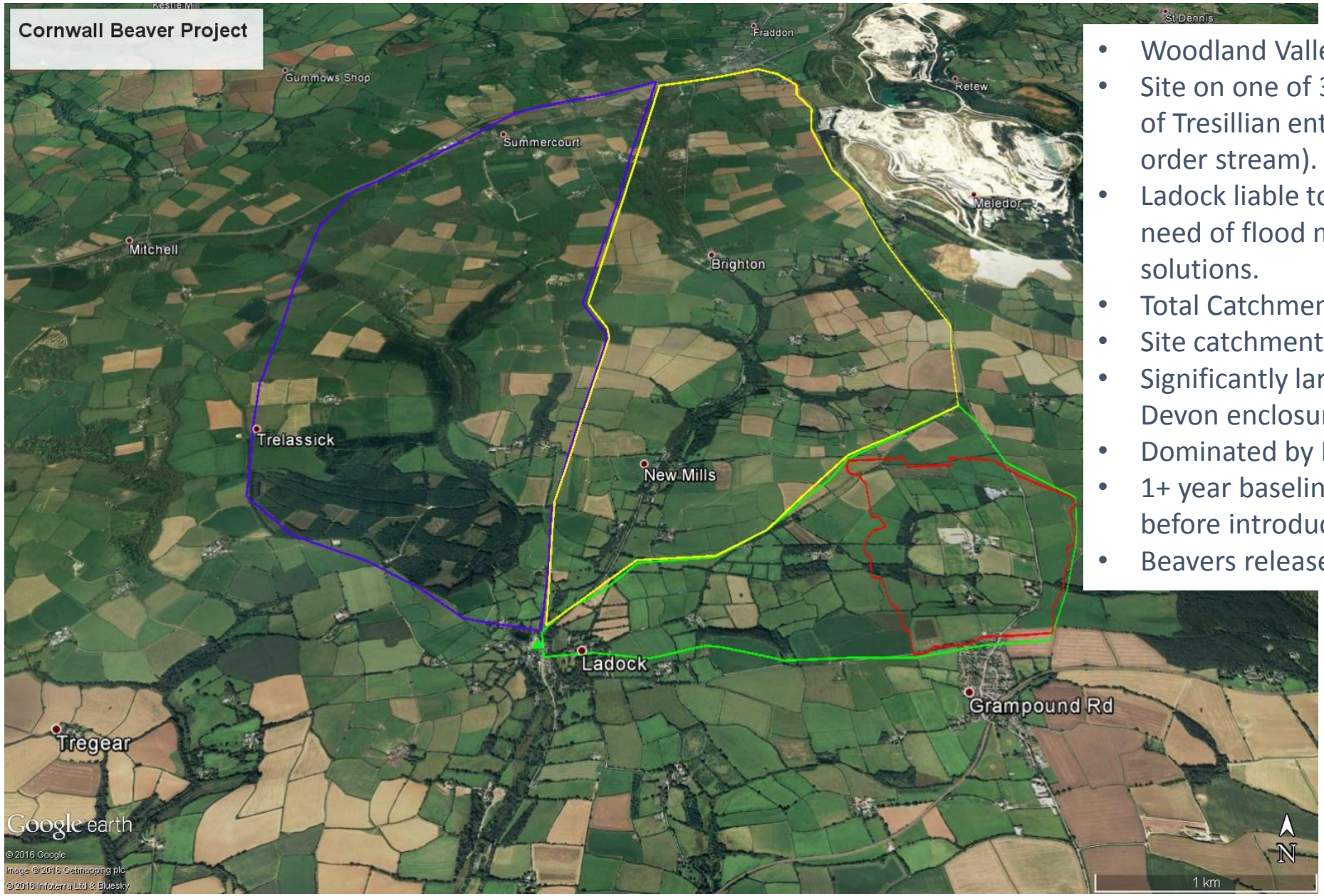
- Surveyed increase in territories and population estimates between 2012 (a) and 2018 (b).
- Gives understanding of wild beaver population catchment use and expansion patterns.
- Identification and understanding of potential management impacts.
- Calibration dataset for suite of models in development. Ca. 5000 km$^2$ catchment.
- https://www.nature.scot/snh-research-report-1013-survey-tayside-area-beaver-population-2017-2018



## River Otter Beaver Trial

- First licenced wild trial in England (reporting to Natural England in 2020).
- PhD projects (Hugh Graham) looking at environmental changes in catchment and socio and socio-economic impacts (Roger Auster)
- Partnership led by Devon Wildlife Trust has reported on broad range of environmental/social and economic impacts of beaver reintroduction.
- Inform UK policy and management strategies.
- 250 km$^2$ catchment scale, additional nested monitoring sites.
- http://www.exeter.ac.uk/creww/research/beavertrial/

# Cornwall Beaver Project

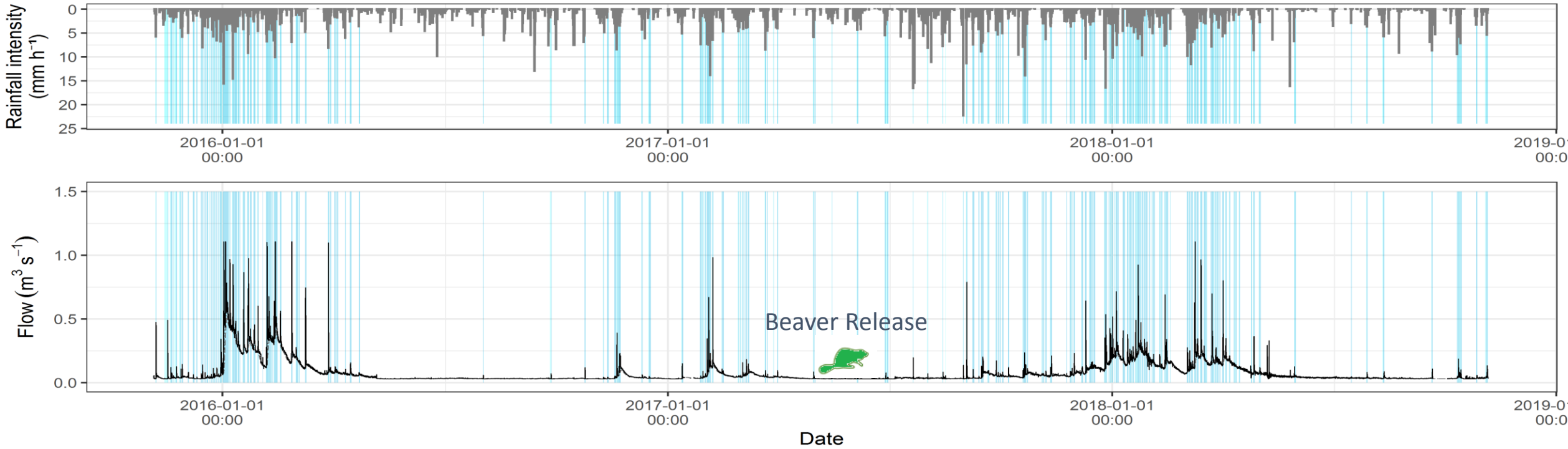



- Woodland Valley Farm
- Site on one of 3 main tributaries of Tresillian entering Ladock (2nd order stream).
- Ladock liable to flooding and in need of flood management solutions.
- Total Catchment + 2300 ha
- Site catchment 1.34 km$^2$.
- Significantly larger catchment than Devon enclosure (20ha)
- Dominated by Farmland.
- 1+ year baseline monitoring before introduction.
- Beavers released 16th June 2017

https://www.cornwallwildlifetrust.org.uk/beaverproject

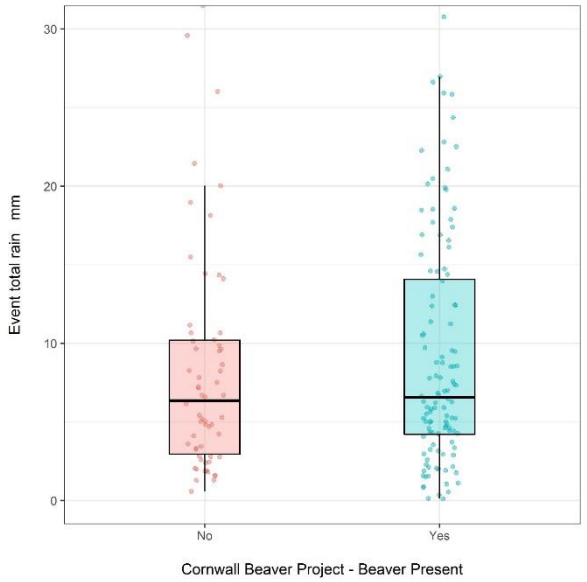


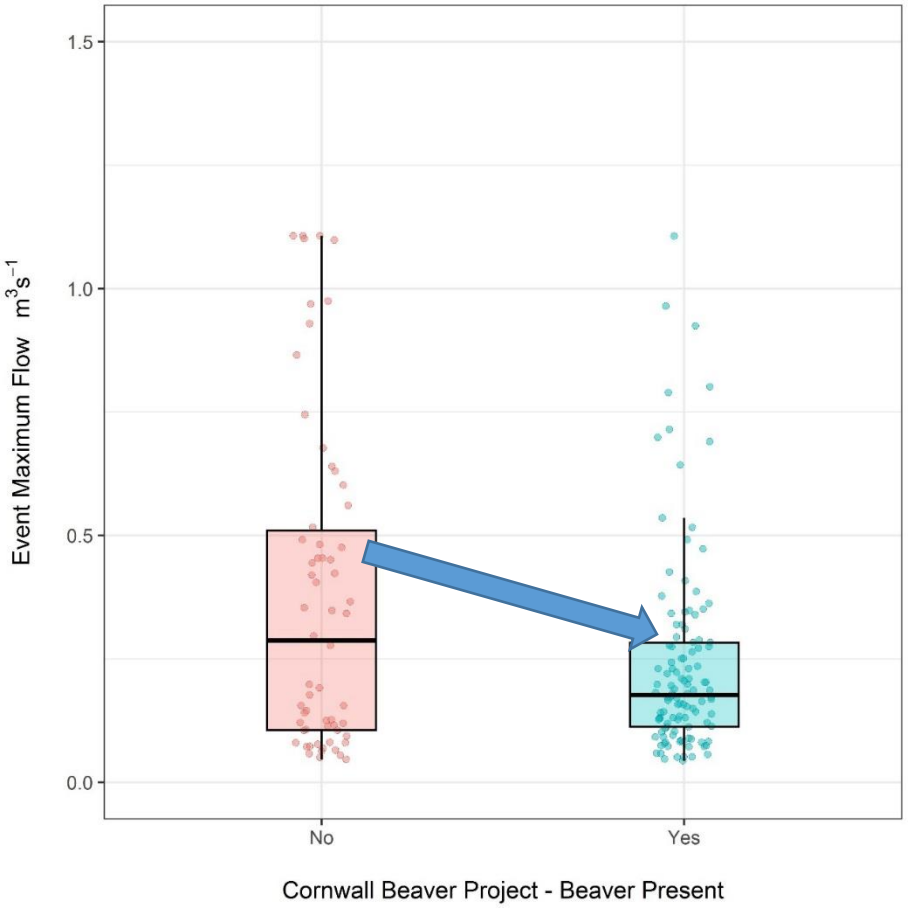

# Cornwall Beaver Project

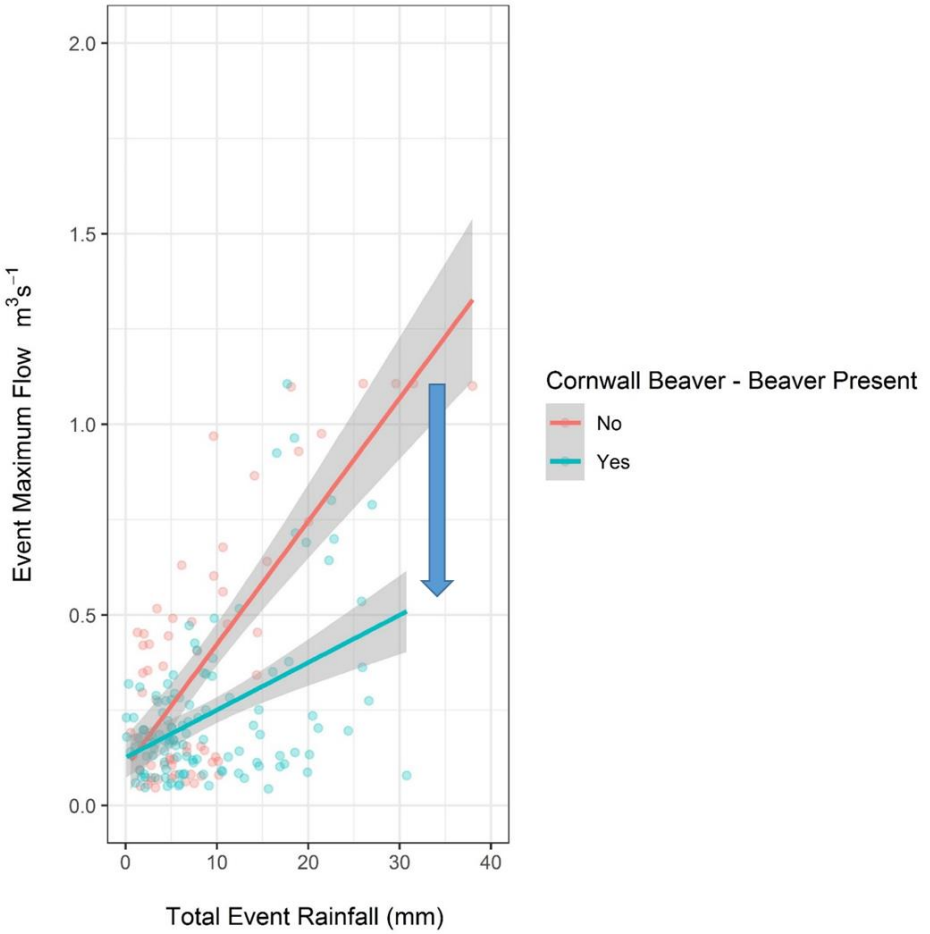



Event separation methodology: Ashe et al (*in prep*)

# Cornwall Beaver Project event summary data

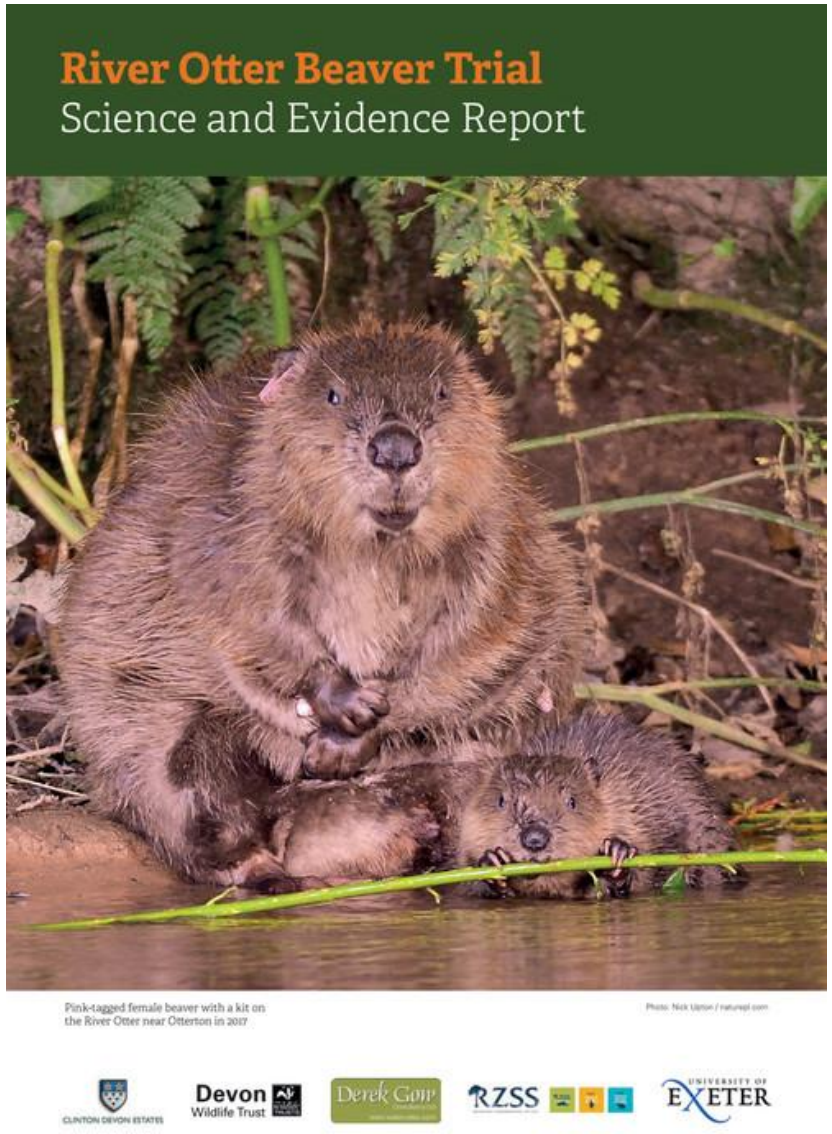



**100+ events pre and 100+ events post-beaver show a reduction in peak flow despite larger mean rainfall events**

# River Otter Beaver Project




- The ROBT provided a 5-year window to observe the colonisation phase of beavers into a lowland English river catchment.
- First official wild release in England.
- Report covers a wide range of interdisciplinary research by University of Exeter, University of Southampton, Devon Wildlife Trust and other project partners.
- Trial showed beavers were able to thrive in a modern English landscape increasing from 2 territories in 2015 to 13+ territories in 2019.
- A summary of quantifiable costs and benefits demonstrated that ecosystem service benefits of beaver at the catchment scale (biodiversity, water resources, ecotourism etc.) outweigh the financial costs incurred.
- However those who benefit from beaver may not always be the same as those who bear the costs.

- Trial extended by 6 months to allow government to make a decision on future of wild beavers.

http://www.exeter.ac.uk/creww/research/beavertrial/

# River Otter Beaver Project - East Budleigh

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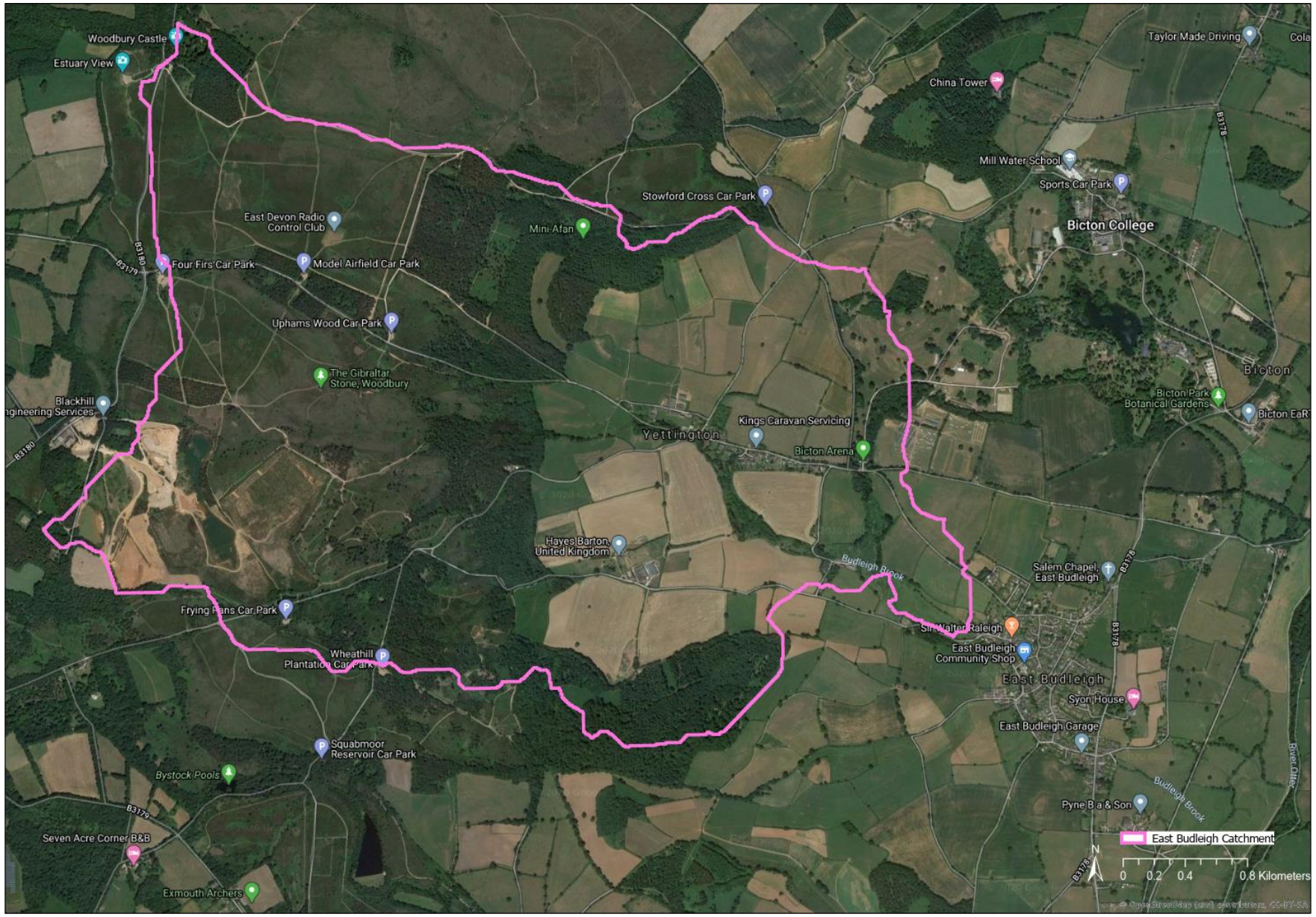
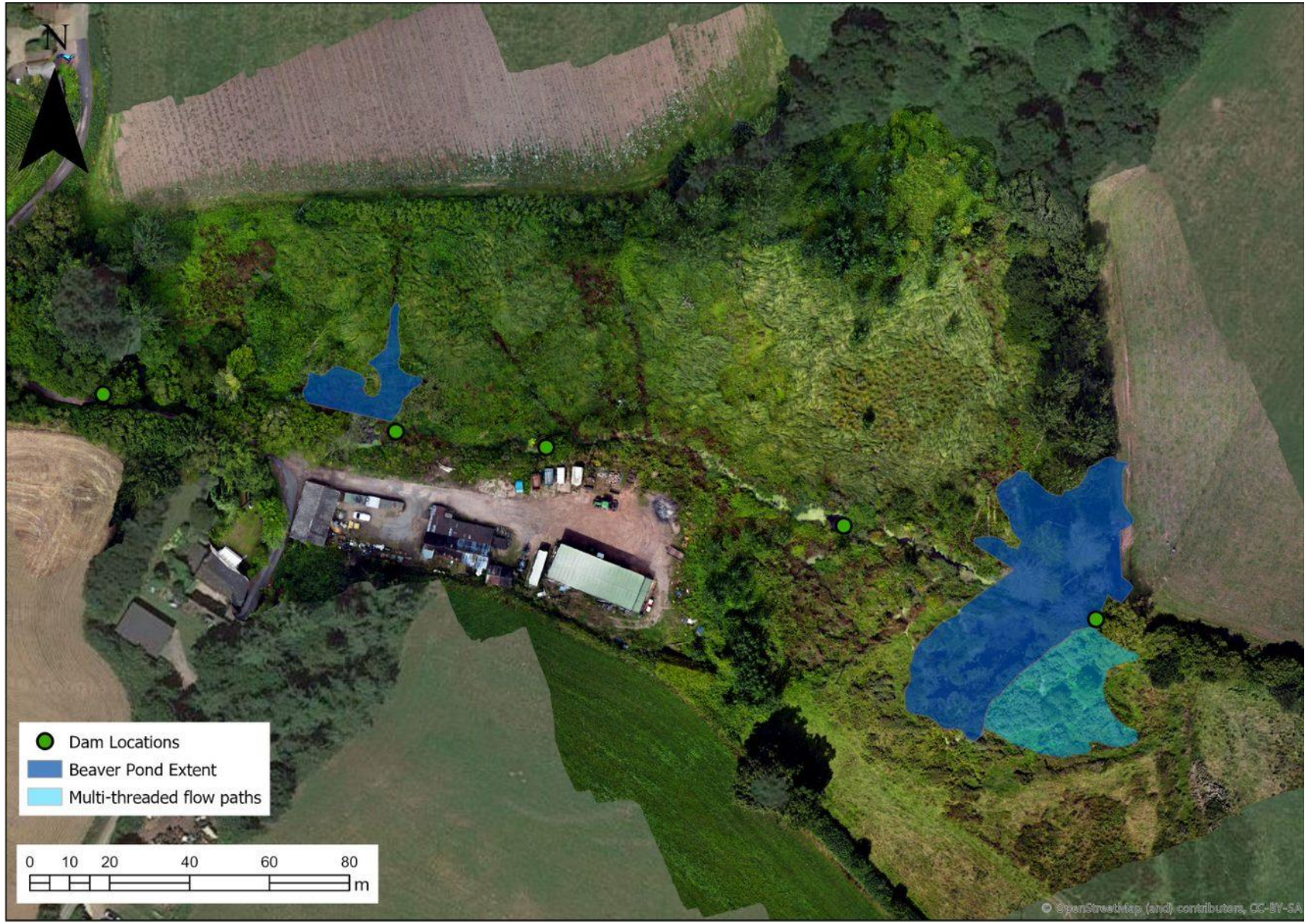


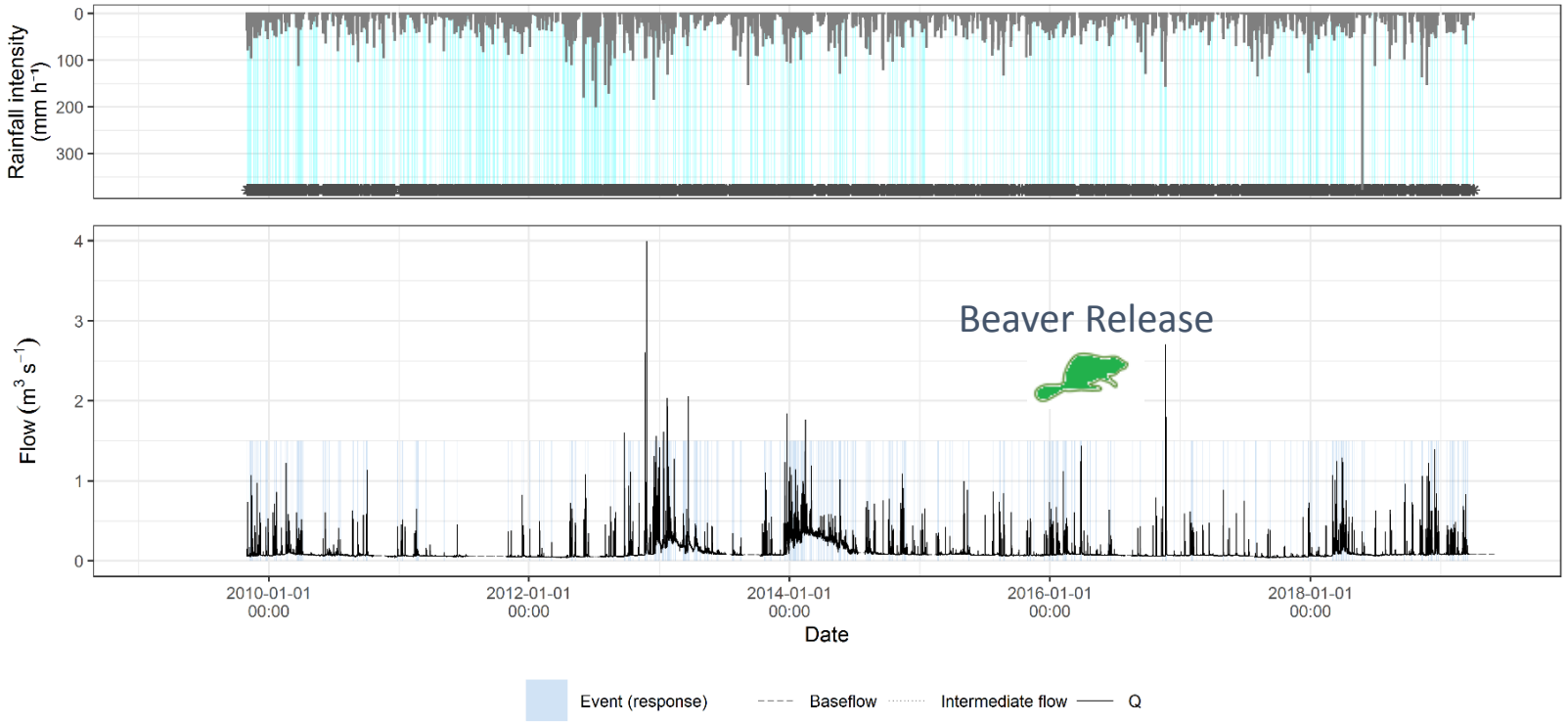

**6.3 km$^2$ catchment with mixed landuse and 3$^{rd}$ order stream upstream of a flood prone village**

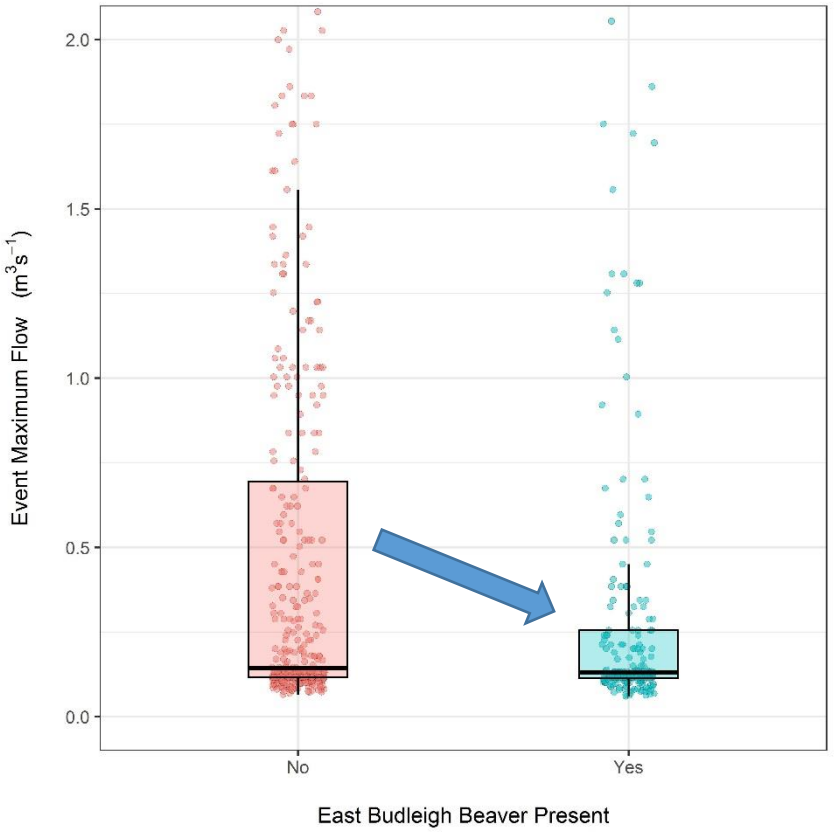
# River Otter Beaver Project - East Budleigh




## Ponds cover 1000 $m^2$ with an average depth of 1.7 m

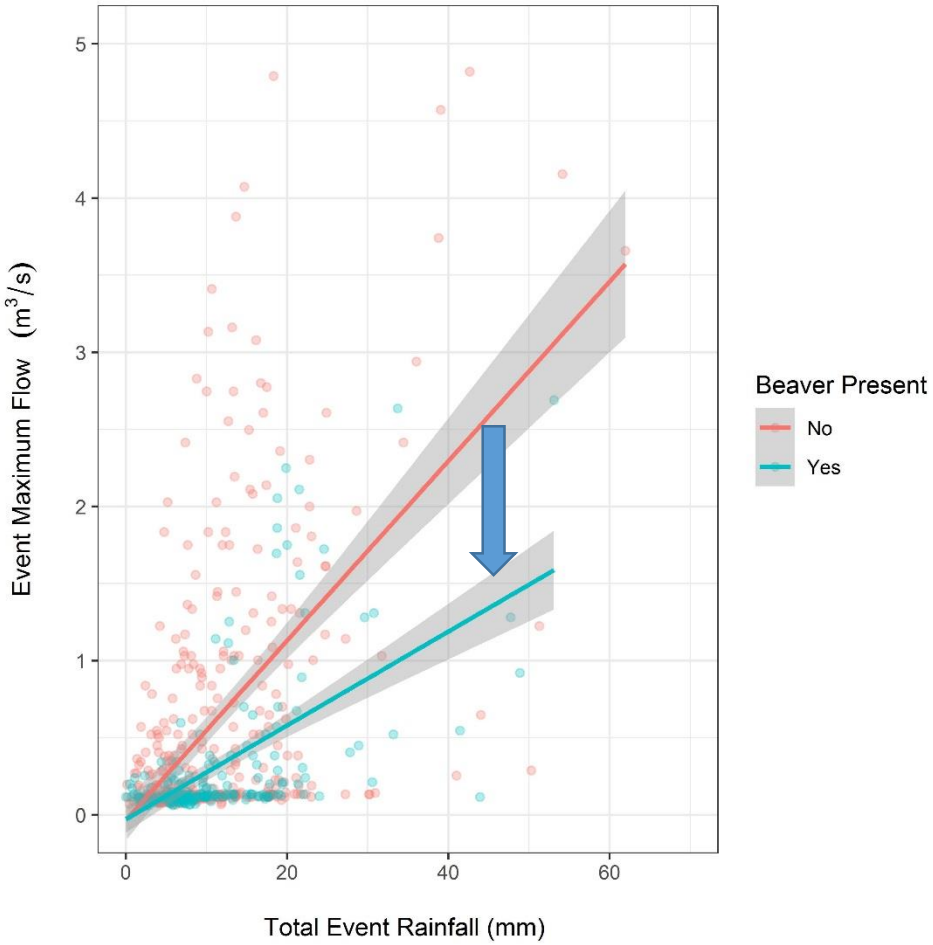
# River Otter Beaver Project - East Budleigh

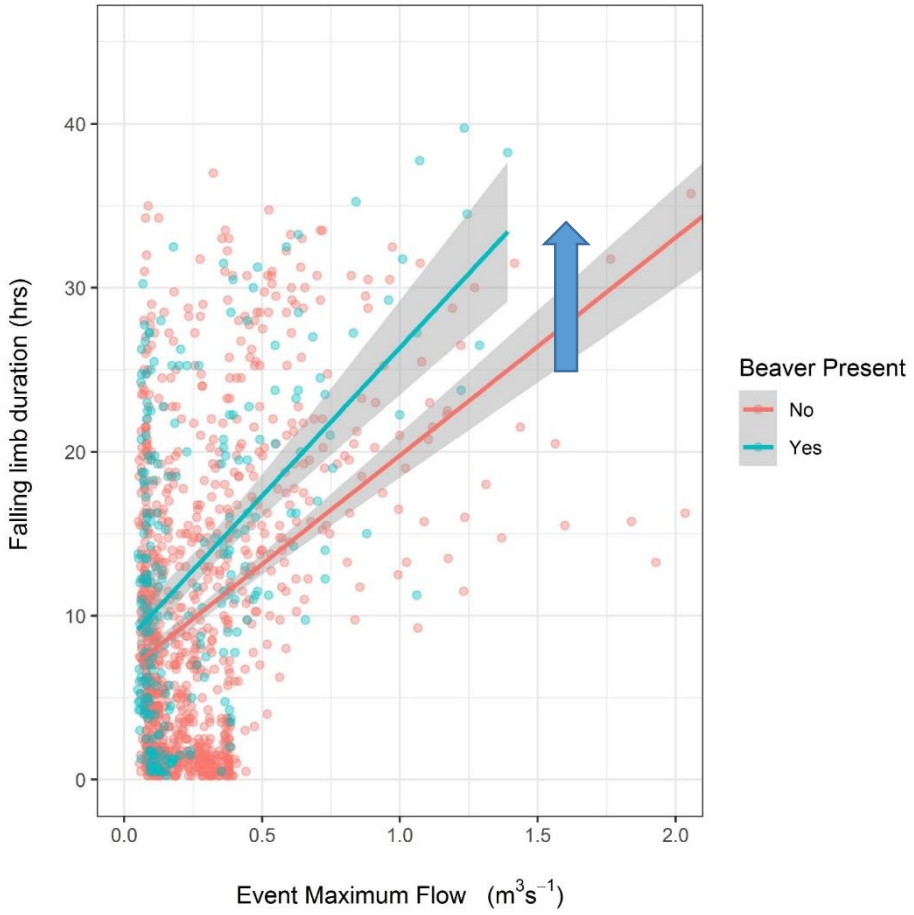



**~400+ events pre and ~200 events post-beaver show a reduction in peak flow despite larger mean rainfall events**

# East Budleigh data illustrating lower peak event flows and longer falling limbs duration



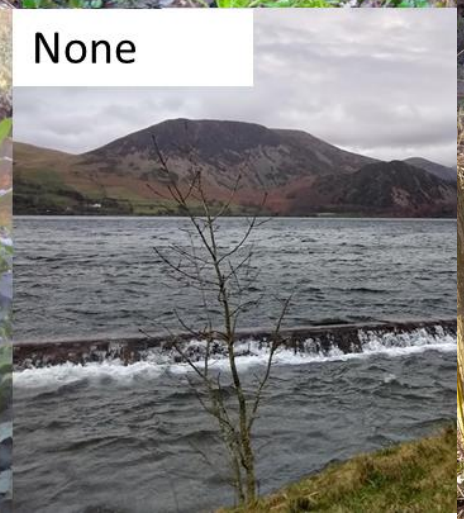




Across sites, requirement for further interpretation of hydrological data. However, results are indicating that structural change due to beaver engineering is altering hydrological functioning. Main impact is from dam building and to inform the return of beavers to Great Britain also beneficial to understand where beavers could dam…

# Beaver Dam Capacity Modelling

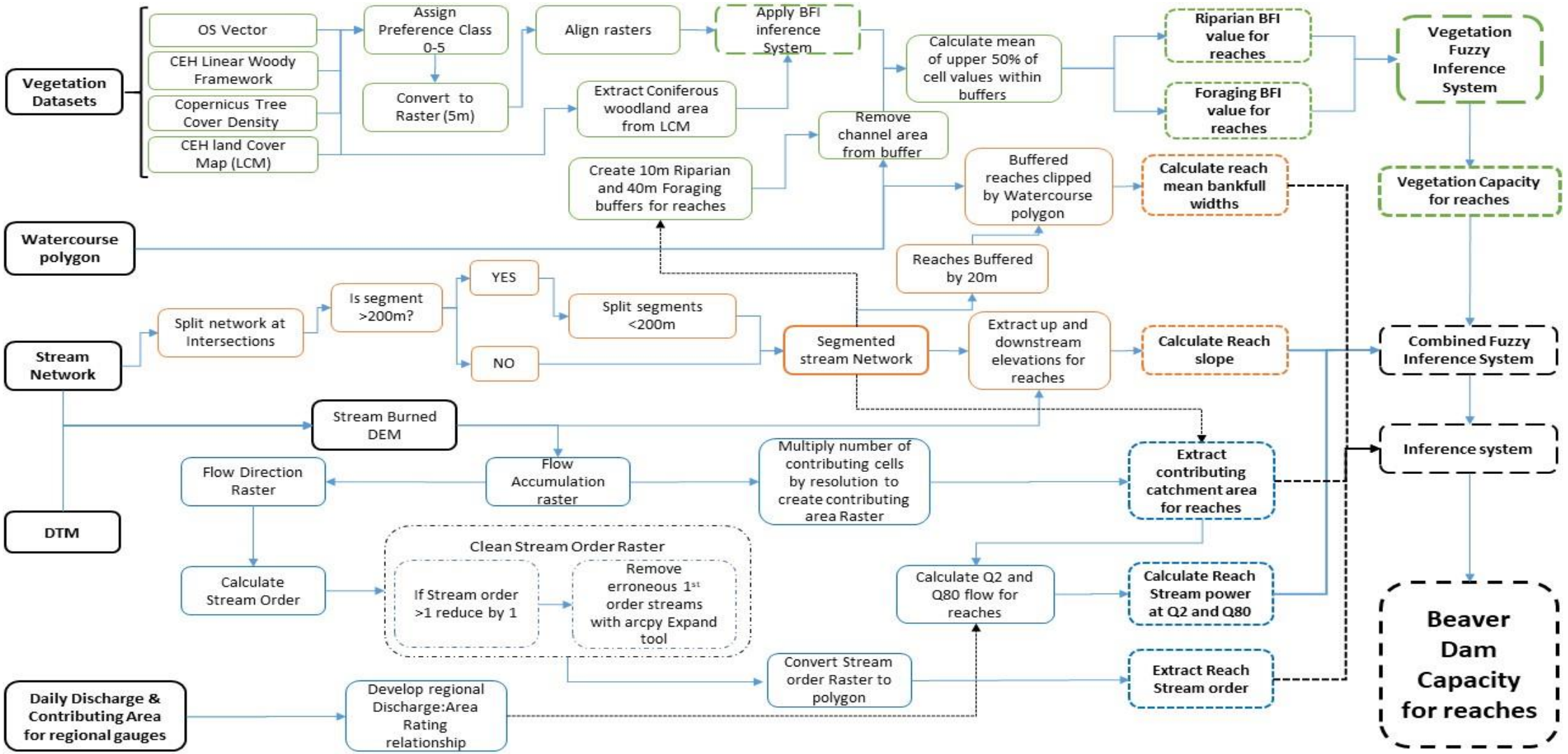
- Initially developed and tested in Utah, Macfarlane, et al. (2017) - BRAT (Beaver Restoration Assessment Tool).
- To understand the number of dams a river reach can support.
- Key for understanding where both environmental and socio-economic impacts of beaver may occur and design restoration strategies.
- Adapted and developed for a European landscape/GB datasets by Hugh Graham.
- Low cost, nationally-available data
- Beavers can dam in locations with suitable habitat and suitable stream conditions.
- Model inputs: **Vegetation (BVI)**, **Slope**, **stream power**, **stream width** and **contributing hydrological area**
- Combine with sequence of fuzzy-inference and inference systems.
- Field Validation against observed damming
- Being run nationally to support government decision making.
- Methods in development to predict dam numbers.



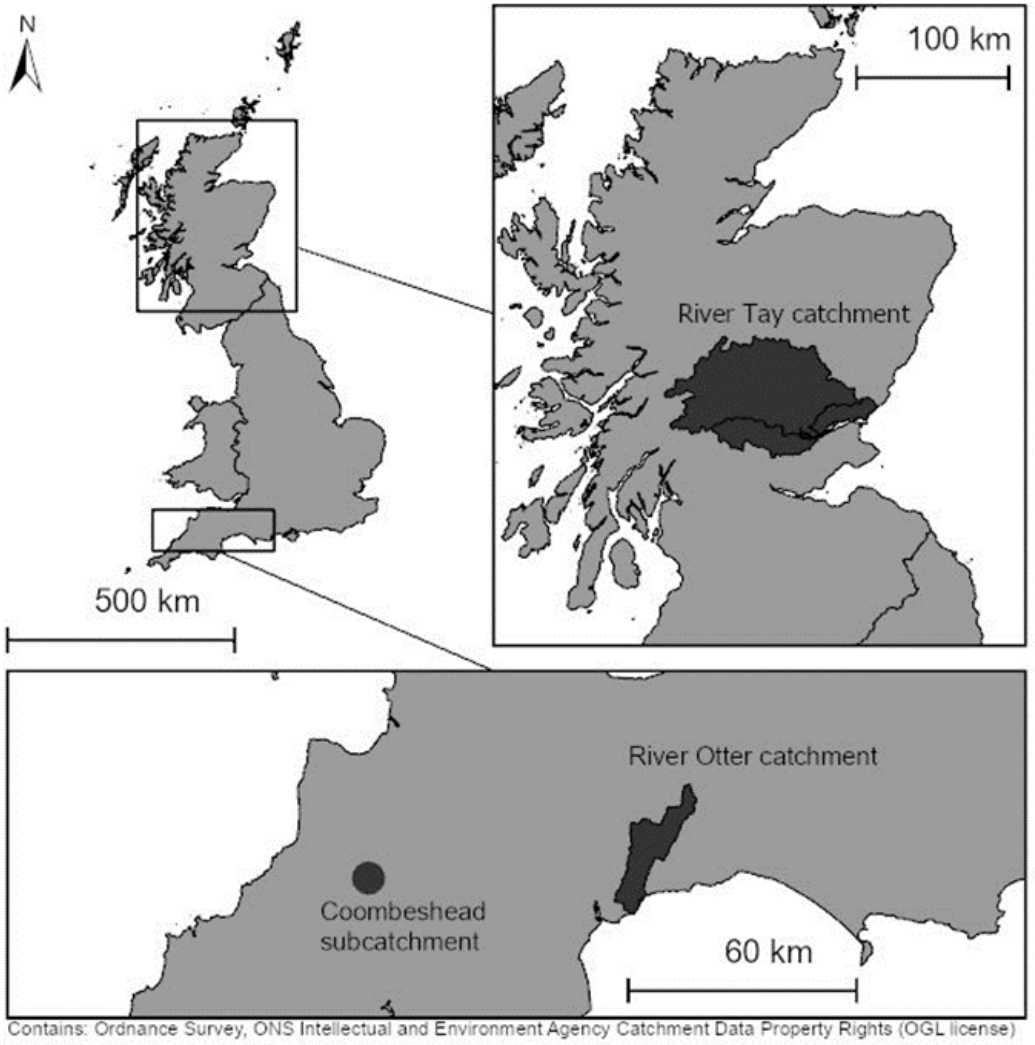

Macfarlane, W.W., Wheaton, J.M., Bouwes, N., Jensen, M.L., Gilbert, J.T., Hough-Snee, N., Shivik, J.A., 2017. Modeling the capacity of riverscapes to support beaver dams. Geomorphology. https://doi.org/10.1016/j.geomorph.2015.11.019

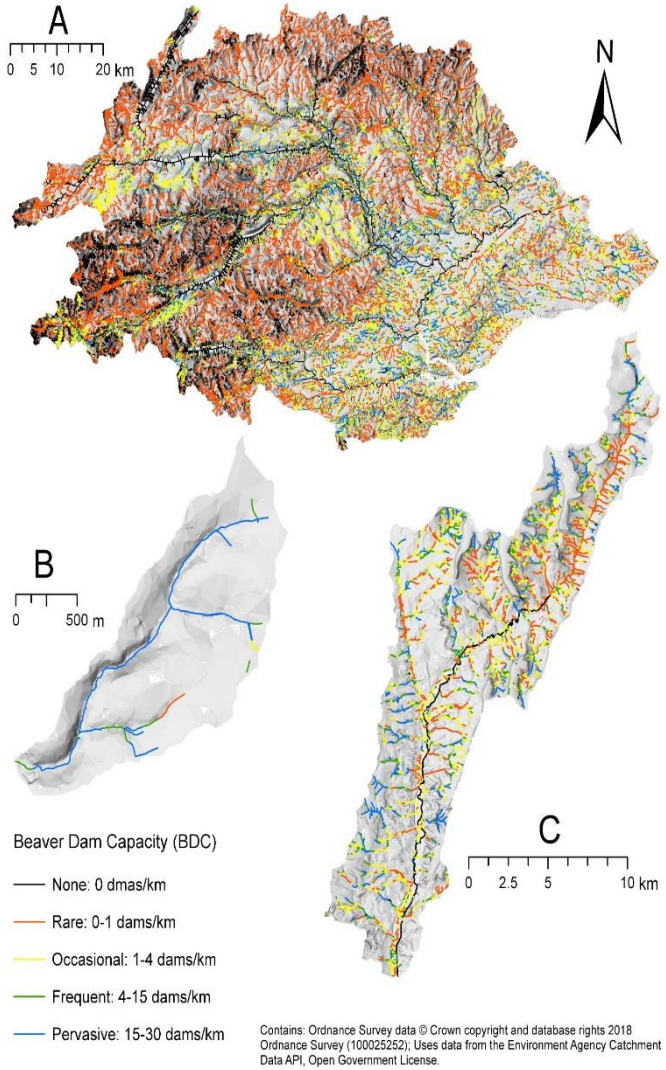
# Beaver Dam Capacity: Method

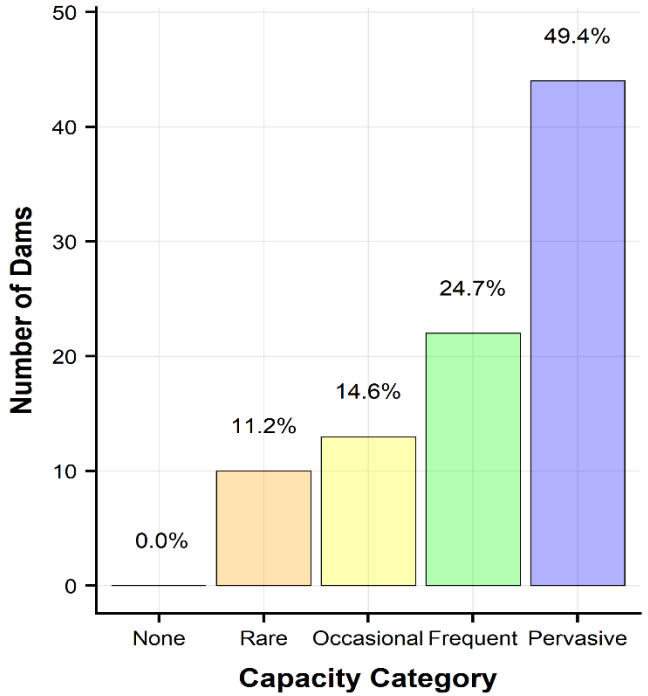



Graham, H. et al (2020 *in press*) Modelling Eurasian beaver foraging habitat and dam suitability, for predicting the location and number of dams throughout catchments in Great Britain., Journal of European Wildlife Research, DOI:10.1007/s10344-020-01379-w

Models calibrated across British study sites where survey data existed. No dams were observed in reaches where the BDC model predicted no capacity. An increasing number of dammed reaches are observed with higher capacity categories.




Graham, H. et al (2020 *in press*) Modelling Eurasian beaver foraging habitat and dam suitability, for predicting the location and number of dams throughout catchments in Great Britain., Journal of European Wildlife Research, DOI:10.1007/s10344-020-01379-w

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# Summary and Ongoing Work

- Results from multiple sites (and multiple scales) show beaver engineering can have a notable impact upon the structure and connectivity of riverine environments.
- Storing water and slowing flow in lowland, intensively managed landscapes.
- Suggests beavers may play a valuable role in catchment management strategies, improving the resilience of our landscapes.
- Continuing hydrological monitoring (both quantity and quality) across a range of sites, scales and land uses. Data analysis ongoing.
- Gaining an understanding of hydrological functioning and also where dams may occur in landscape. Interest in further modelling to upscale results to catchment scale and examine potential future population and damming scenarios.
- Continued engagement with policy makers to see how beavers can be part of land and catchment management schemes (“public money for public good”).



# Thanks to all colleagues, funders and associated partners


## Devon Beaver Project

Devon Beaver Project is led by Devon Wildlife Trust and the University of Exeter, and funded by Westland Countryside Stewards. Particular thanks go to John Morgan, the site owner, for hosting the reintroduction project and allowing site access for researchers. For site surveys the 3D Robotics Y6 was supplied by the University of Exeter's Environment and Sustainability Institute (ESI) environmental monitoring drone lab. Thanks also go to David Plumber for imagery (DavidPlummerImages.c.o.uk).

## River Otter Beaver Trial

The River Otter Beaver Trial is led by Devon Wildlife Trust, working in partnership with the University of Exeter, Clinton Devon Estates and the Derek Gow Consultancy. Data has been provided by the Environment Agency. Expert independent advice is also provided by Dr Roisin Campbell-Palmer, Professor John Gurnell and Gerhard Schwab. The trial is licenced by Natural England. Additional funding for Hugh Grahams PhD was provided by the Wellcome Trust and researchers also benefitted from a NERC public engagement grant.

## Cornwall Beaver Project

Cornwall Wildlife Trust and Chris Jones (Woodland Valley Farm) are leading the Cornwall Beaver Project on behalf of a wider partnership of individuals and organisations including; University of Exeter, University of Southampton, University of Plymouth, CoaST and Woodland Valley Farm. Thanks also go to Emilie Grand-Clement for imagery.

## Forest of Dean and Yorkshire Beaver Projects

The Forestry Commision are leading the Forest of Dean and Yorkshire Beaver Projects with thanks to Cath Bashforth in Yorkshire and Rebecca Wilson in the Forest of Dean.