
British Hydrological Society
Environment Agency
Drought hydrology:
50 years since 1976
Wednesday 17 June 2026, Institute of Civil Engineers

Mr Philip Duffy
CEO Environment Agency

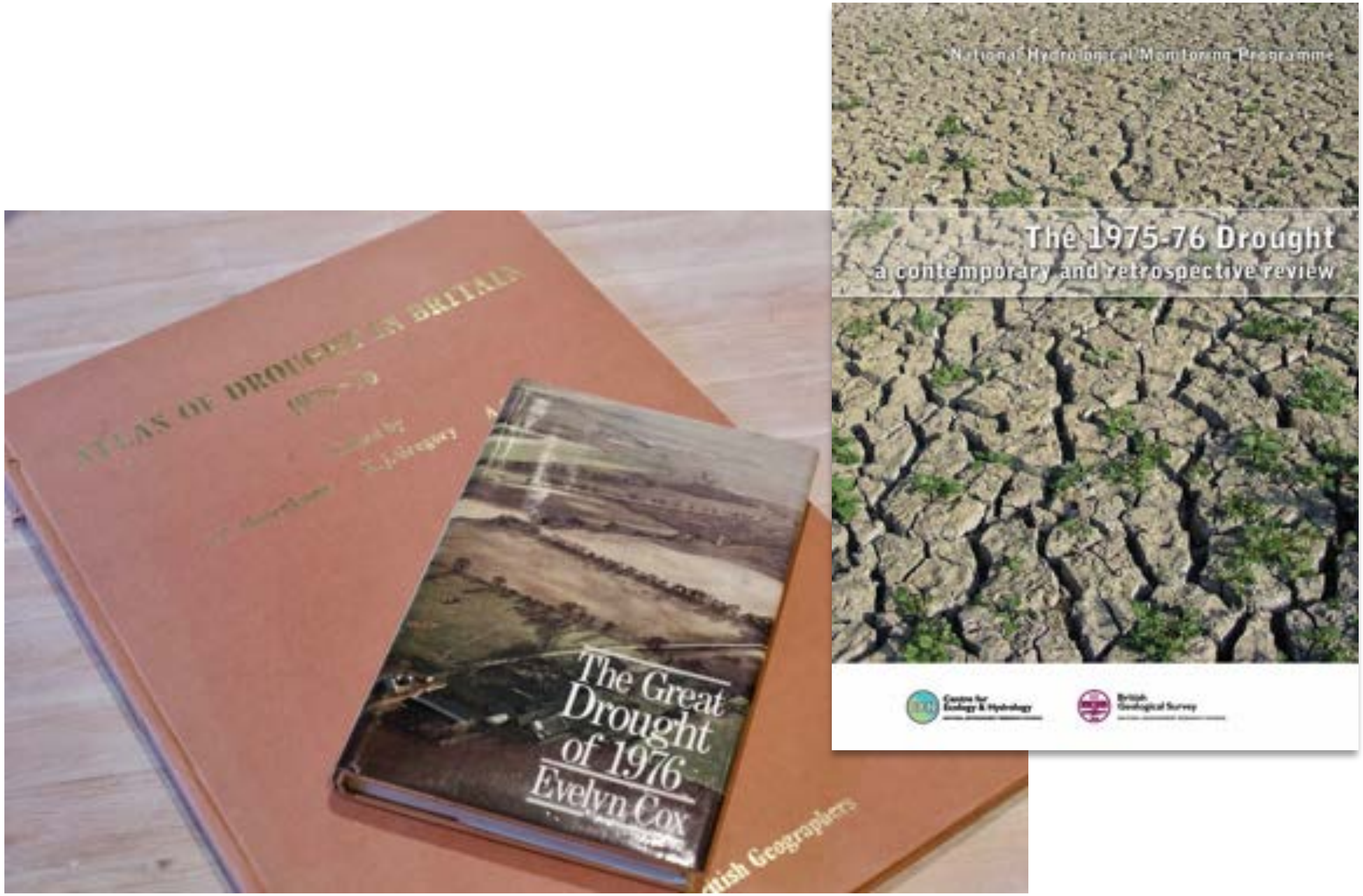
1976 – the great drought?

Glenn Watts

UKCEH

Our planet.
Decoded.

Contemporary sources

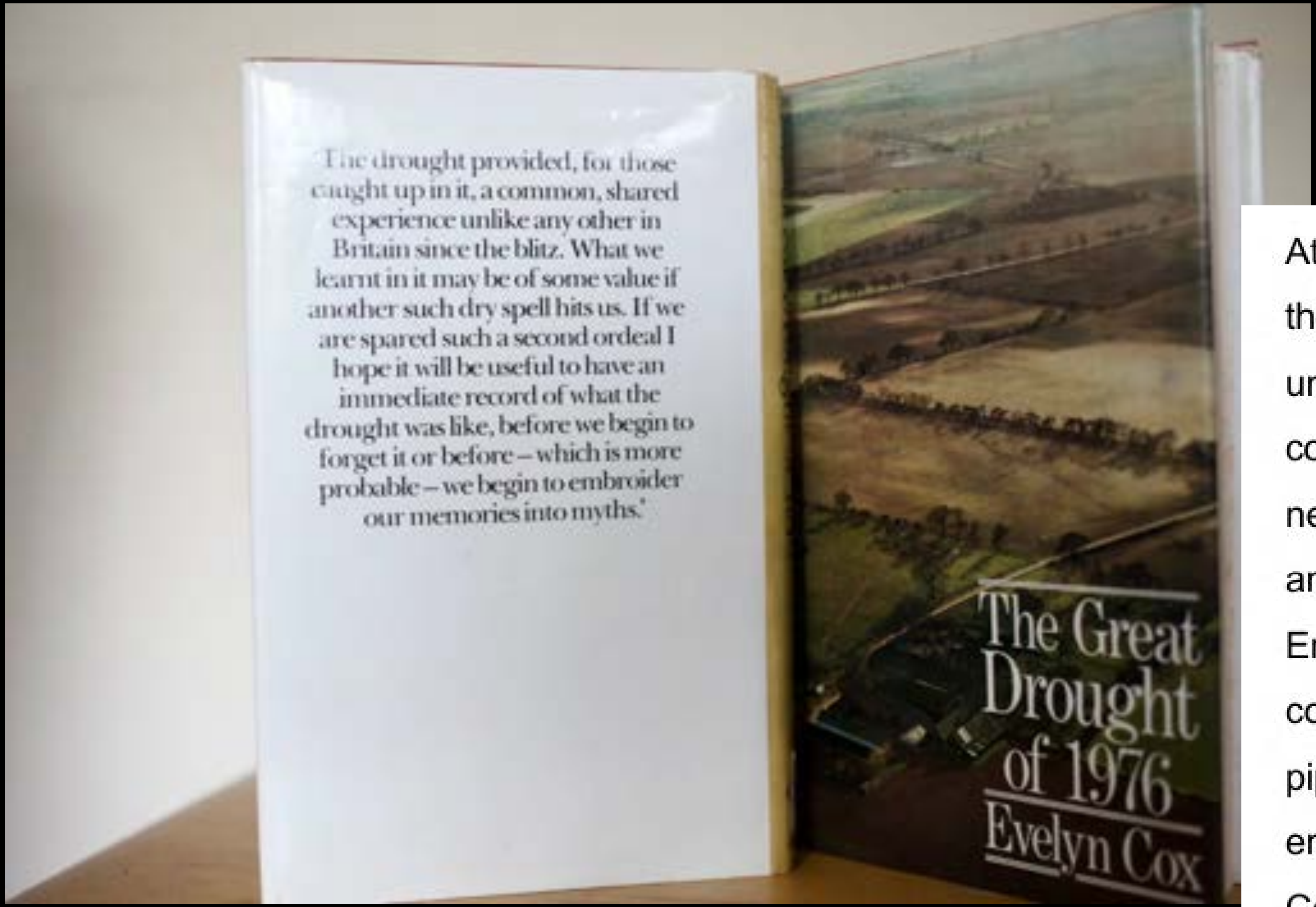


Cox 1978. The Great Drought of 1976

Doornkamp et al. 1980. Atlas of Drought in Britain 1975-76.

Rodda and Marsh 2011. The 1975-76 Drought: a contemporary and retrospective review.

How did it feel?



Attitudes towards water suffered an abrupt change during the summer of 1976. Weeks without rain and periods of unrelenting sunshine resulted in a yellow and brown countryside, empty streams, a rash of notices about the need to save water, restrictions and, in a few areas, shut-offs and standpipes. For the inhabitants of a major part of England and Wales the drought emphasised the considerable value of the wholesome and copious supply of piped water which has been the prerogative of almost the entire population of the United Kingdom for most of the 20th Century and which is normally taken for granted.

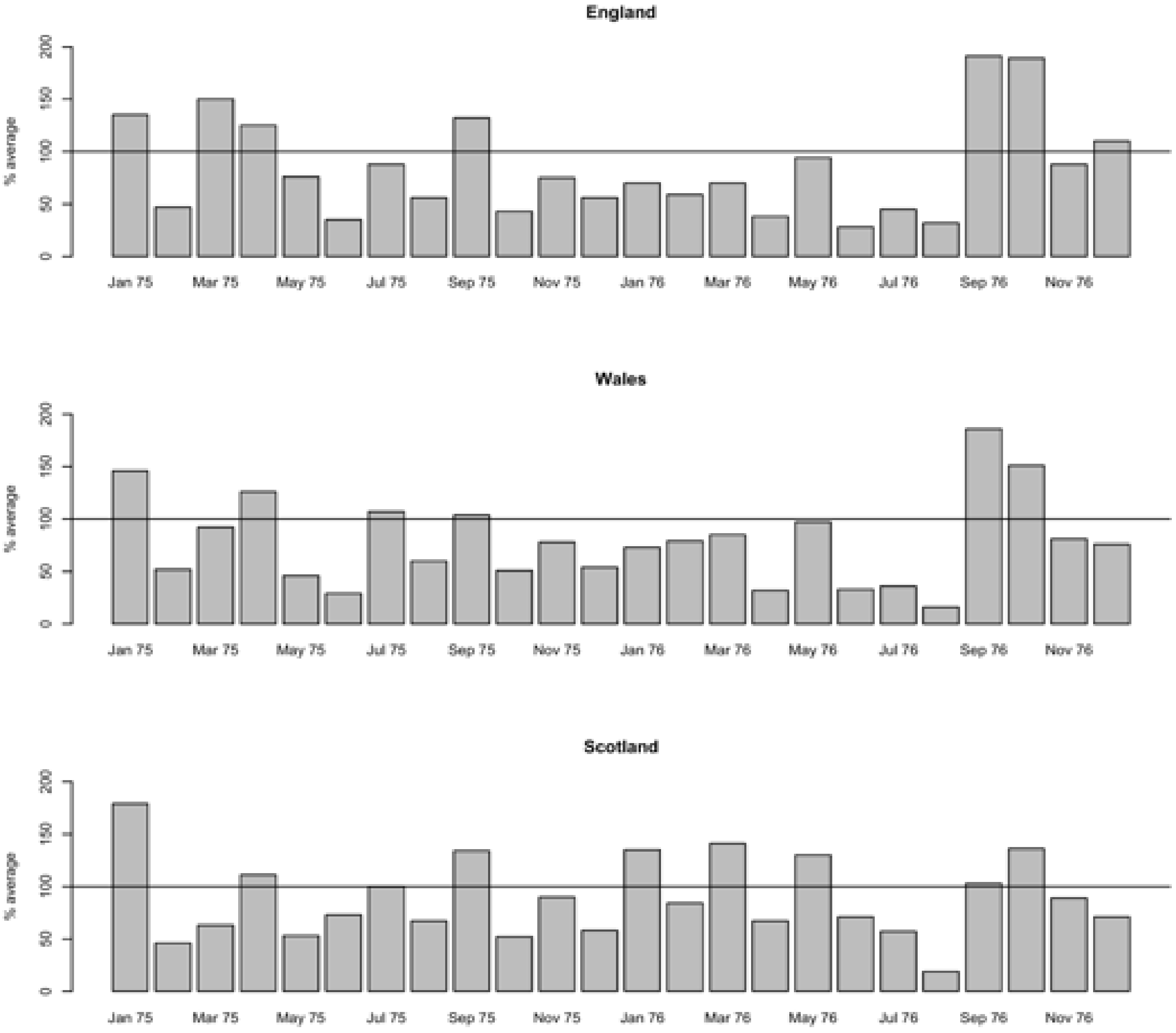
Evelyn Cox, 1978

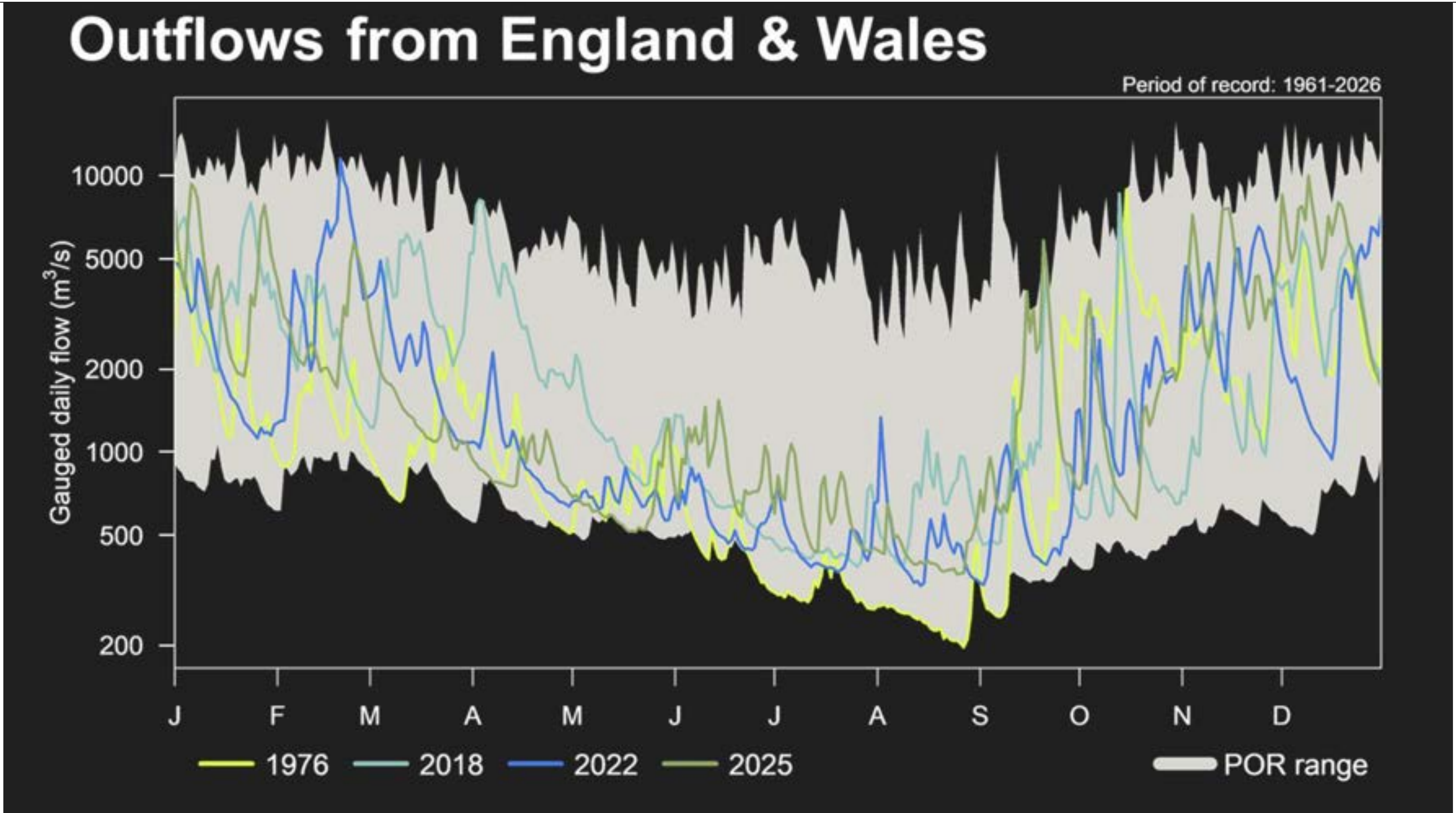
John Rodda, 1978

1975-76 rainfall

Source: Atlas of Drought

Reference period 1941-70




Outflows from England & Wales
Period of record: 1961-2026
Gauged daily flow (m3/s)
10000
5000
2000
1000
500
200
J
F
M
A
M
J
J
A
S
O
N
D
1976
2018
2022
2025
POR range

The great Drought?

- Low river flows across winter 75 into 76
- Ely Ouse – Essex transfer stopped June 76
- Ely Ouse dry in July
- July 76 Hosepipe bans across southern Britain
- Ladybird plague
- Night time rota cuts for 100,000 people in south Wales from July 76
- Extended to 1 million people in August

- Early August 76: 140 days supply left in Grafham
- End August 76: 20 to 50 days supply in Devon
- 24 August Minister for drought appointed
- Standpipes installed in Devon and South Yorkshire
- Standpipes used mid September 76 for 80,000 people in east Devon
- October 76 – backpumping to fill Grafham

Thank you.

For more information please contact:

gwatts@ceh.ac.uk
ceh.ac.uk
@uk_ceh

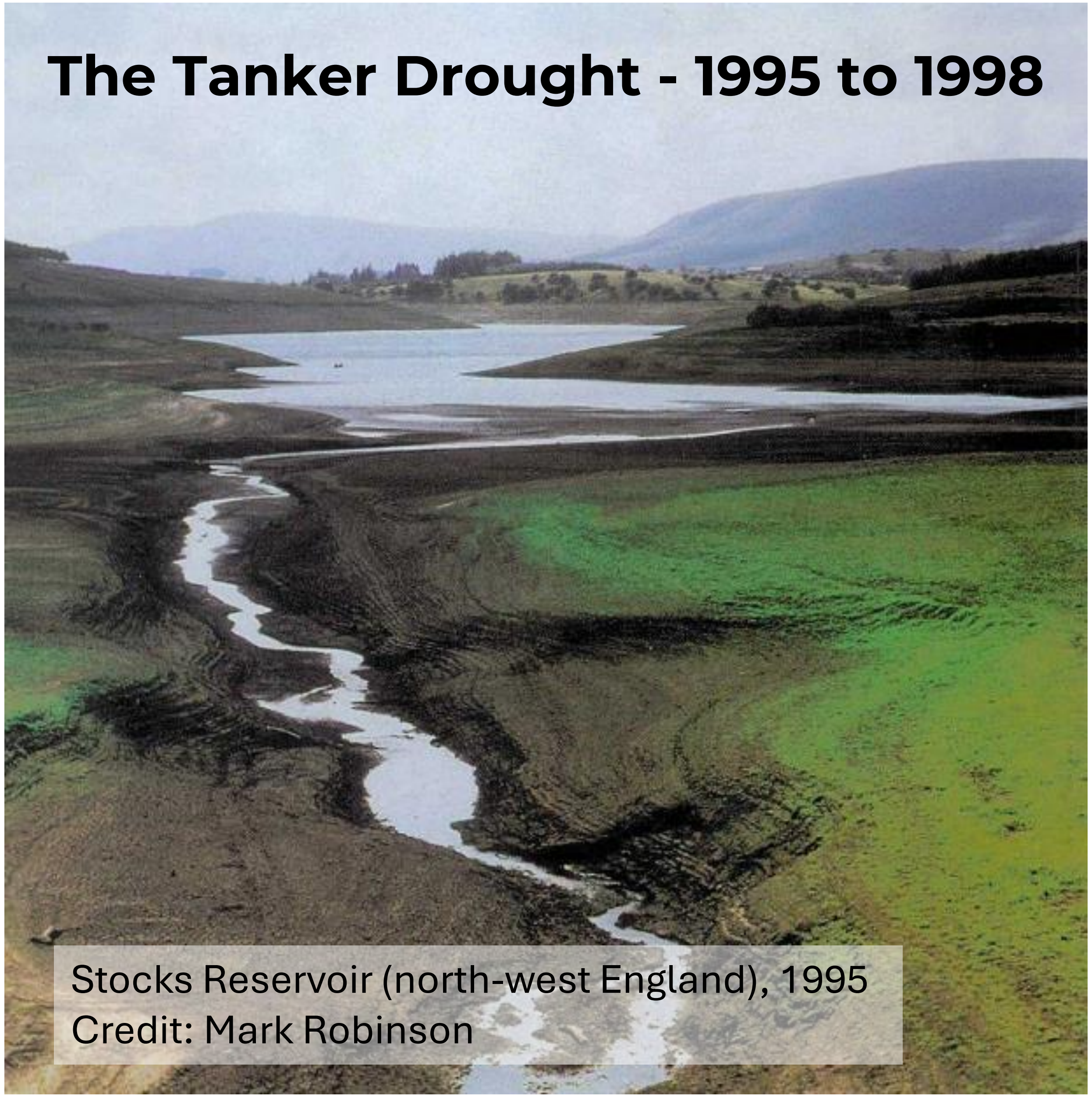
UKCEH

Our planet.
Decoded.

1976 to 2026 - What's Changed?

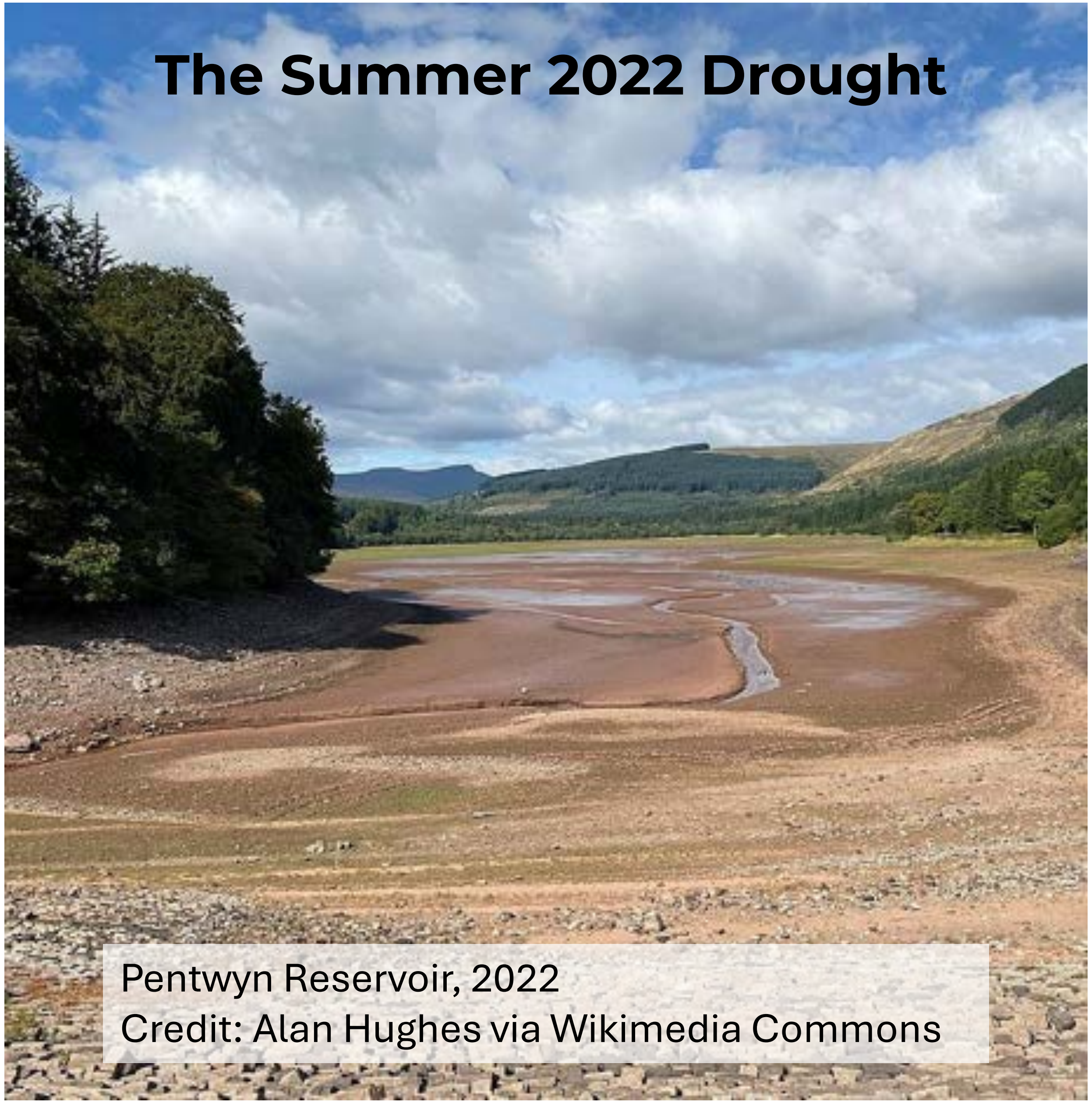
Dr Anna Murgatroyd
Newcastle University

The Tanker Drought - 1995 to 1998



Stocks Reservoir (north-west England), 1995
Credit: Mark Robinson

The Summer 2022 Drought



Pentwyn Reservoir, 2022
Credit: Alan Hughes via Wikimedia Commons

June brings more rainfall than all of spring to parts of UK

Recent heavy rain has followed the heatwave across much of the UK

Features

Is another heatwave on the way?

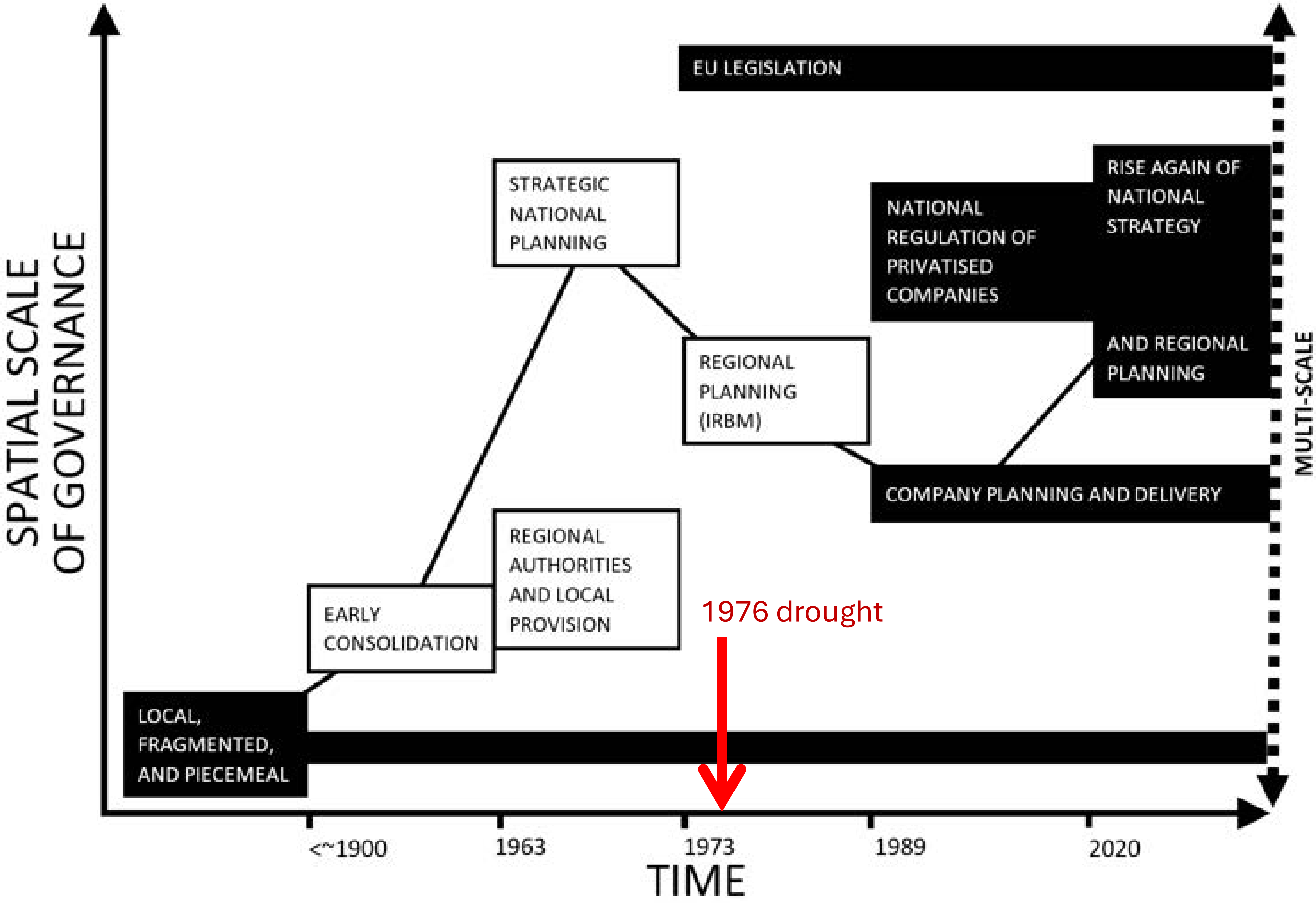
1 hour ago

June brings more rainfall than all of spring to parts of UK

1 day ago

https://www.bbc.co.uk/weather/

Credit: Leonard et al.



Water Industry Act 1991

1991 CHAPTER 56

An Act to consolidate enactments relating to the supply of water and the provision of sewerage services, with amendments to give effect to recommendations of the Law Commission.

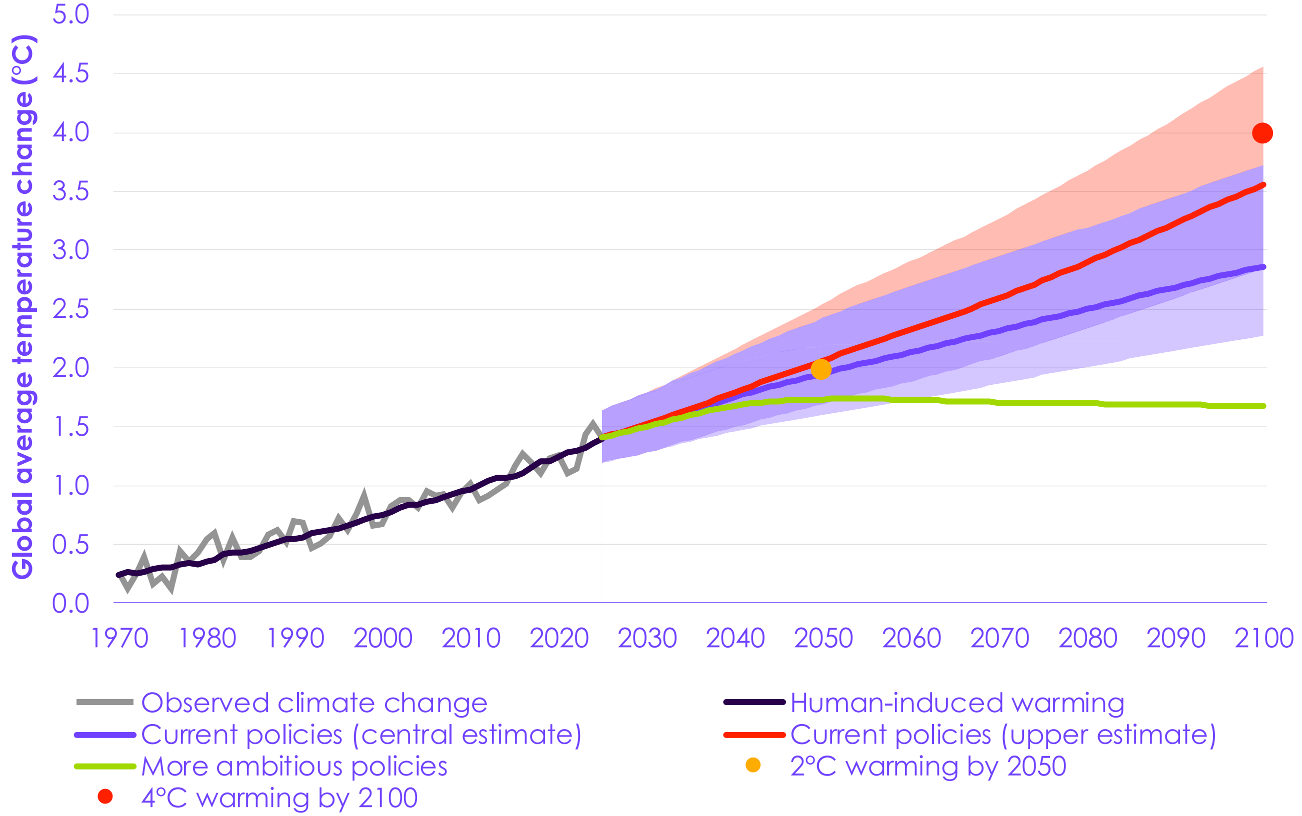
[25th July 1991]

https://www.legislation.gov.uk/ukpga/1991/56/


Final Water Resources Management Plan 2024
Main Report
Water for the North West
Main Document
Our Water Resources Management Plan 2024
Cambridge Water
Final Water Resources Management Plan 2024
Securing your water future
WATER RESOURCES MANAGEMENT PLAN 2024
Yorkshire Water
Water Resources Management Plan 2024
January 2025
South Staffs Water
Water Resources Management Plan 2024
Securing your water future
PR24
ESSEX & SUFFOLK WATER
WATER RESOURCES MANAGEMENT PLAN 2024
Thames Water
Water Resources Management Plan 2024
Section 1 – Introduction and Background
Affinity Water
Final Draft Water Resources Management Plan 2024
Technical Report
May 2025
WATER for LIFE
Southern Water

A Well-Adapted UK

The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)

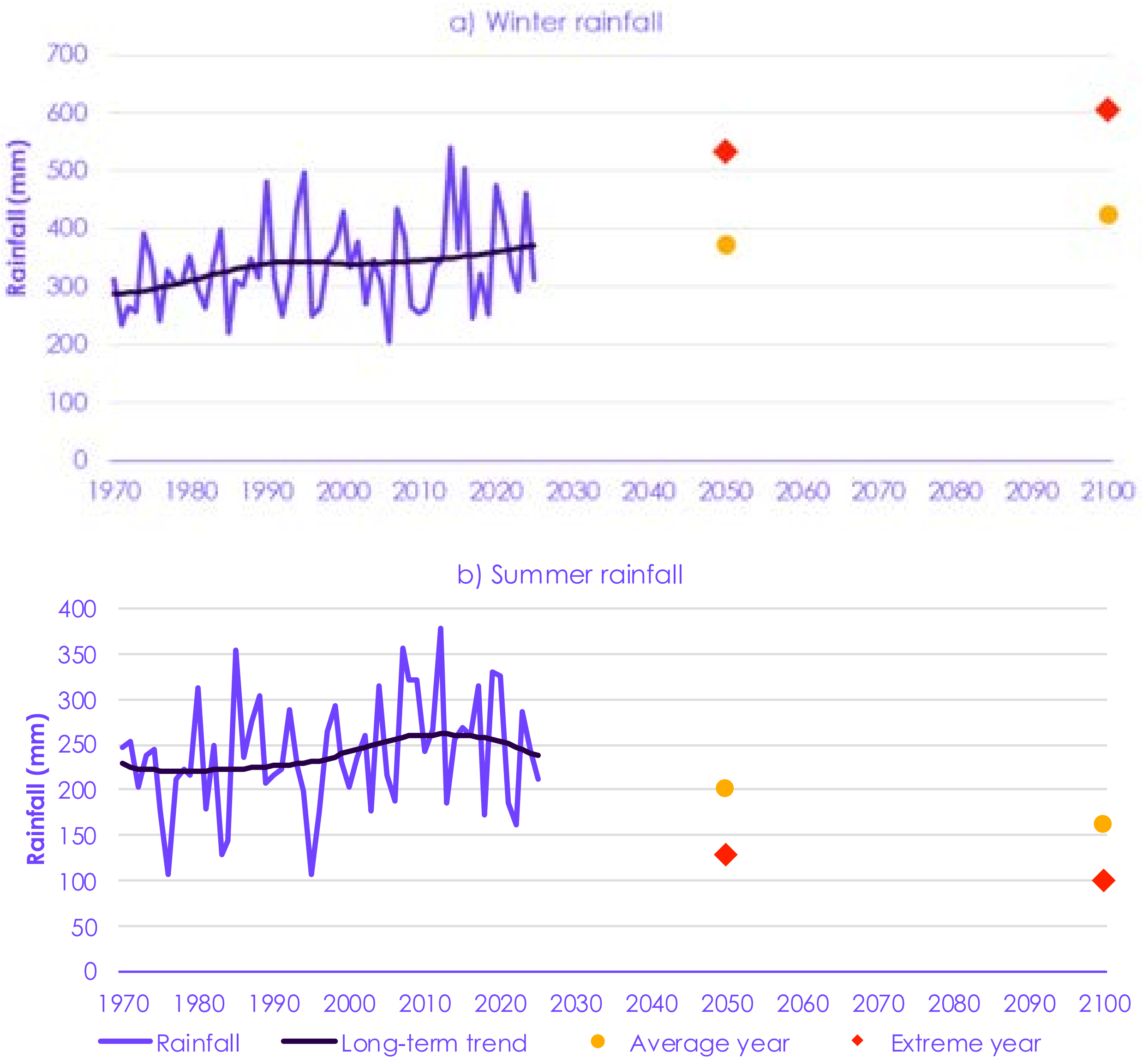


- Global temperatures have risen since 1970.
- Under current emissions scenarios, temperatures are projected to increase further to around **2ºC of warming by 2050**.
- It is possible that under current emissions warming could reach **4ºC by 2100**.

Credit: Climate Change Committee, Met Office

A Well-Adapted UK

The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)



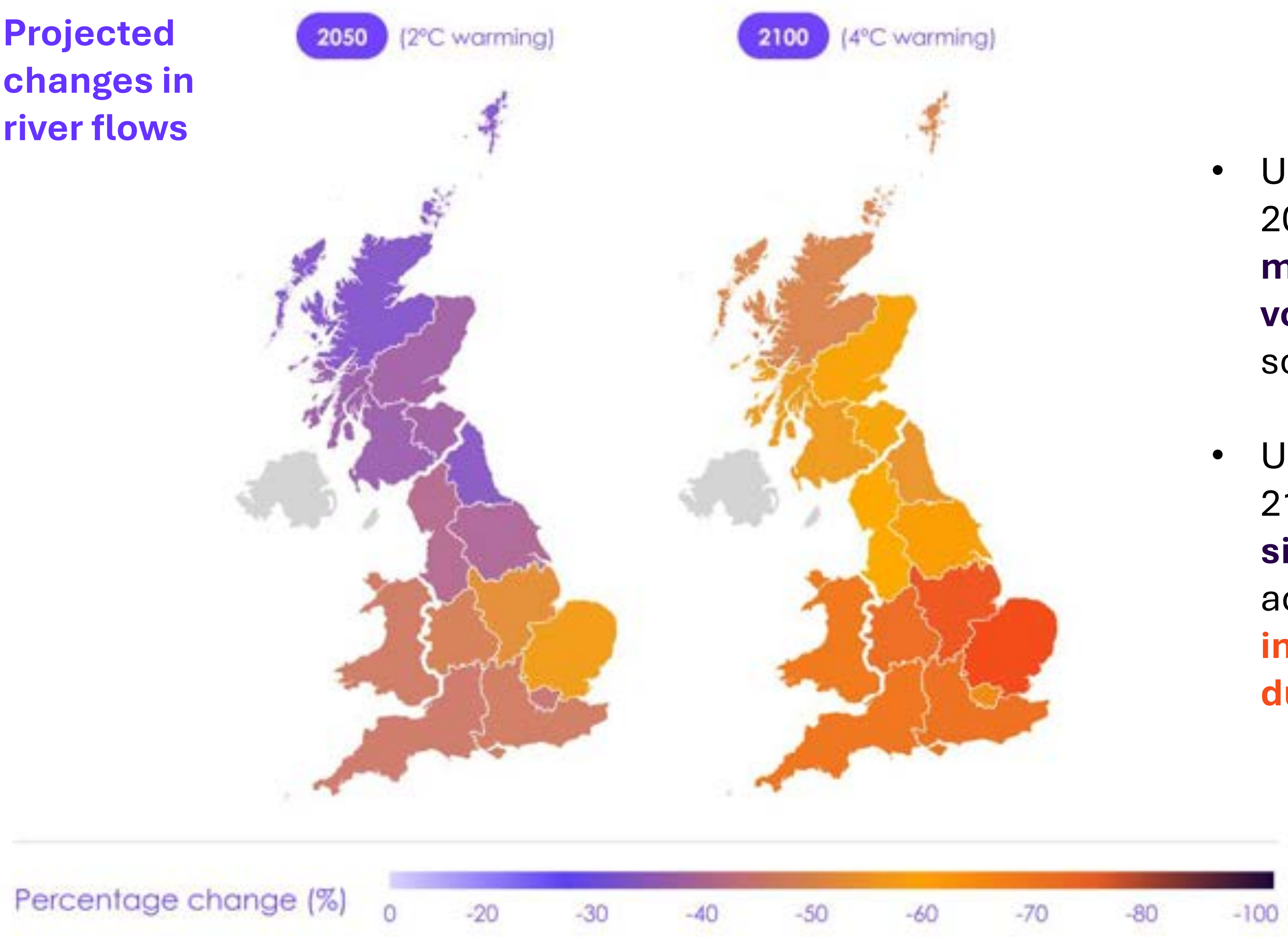
- UK winter rainfall shows a long-term increase since 1970.
- UK summer rainfall shows large year-to-year variability from 1970–2020.
- Projections for **2050** and **2100** show **drier average** and **extreme summers** under higher warming scenarios.

Credit: Climate Change Committee, Hollis et al, MET Office

A Well-Adapted UK

The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)

Projected changes in river flows



- Under 2°C global warming level by 2050, most regions experience **moderate reductions in low flow river volumes**, with the largest declines in southern and eastern England.

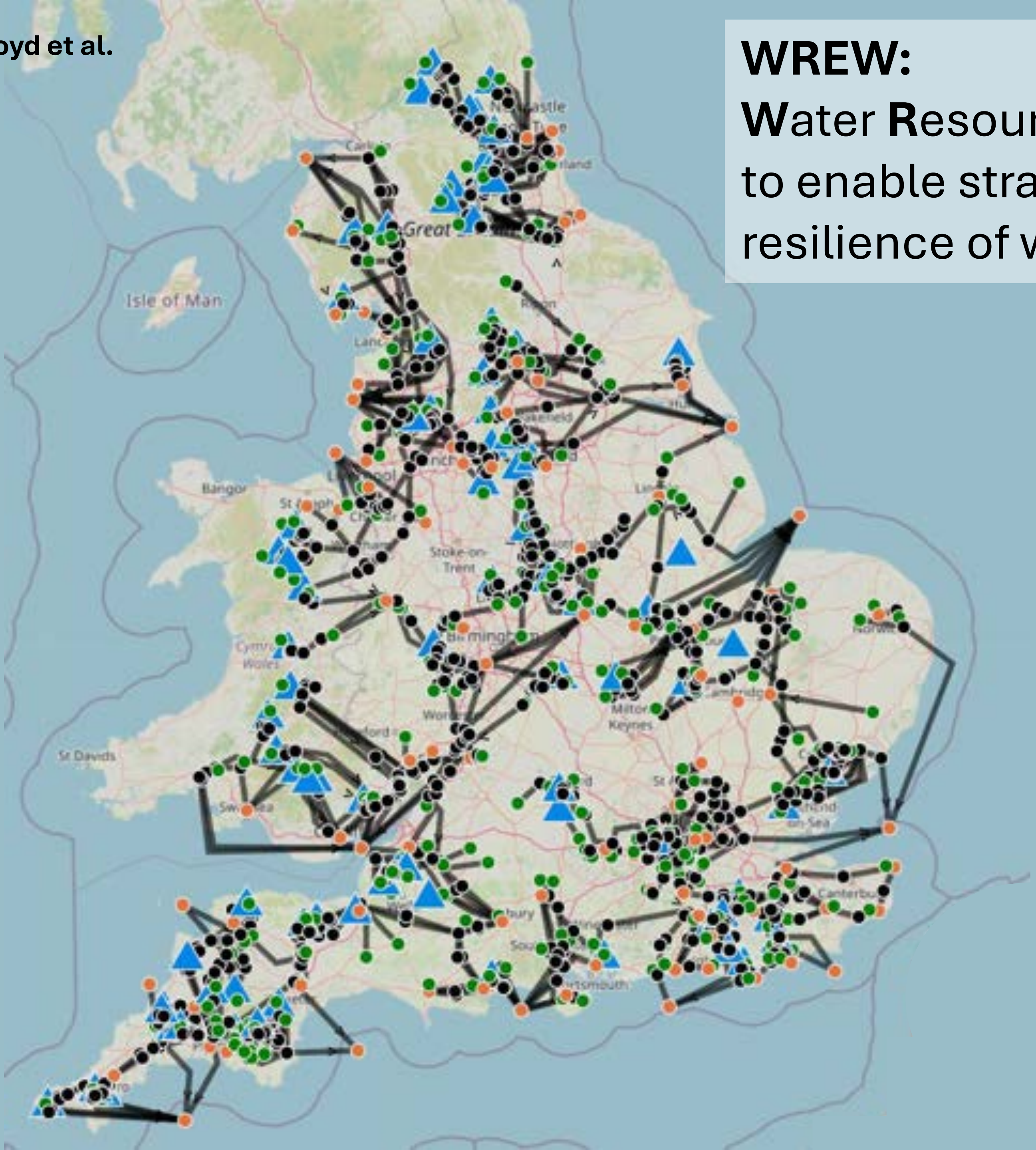
- Under 4°C global warming level by 2100, **reductions intensify significantly**, with major decreases across England and parts of Wales, **indicating much drier river conditions during droughts**.

Credit: Climate Change Committee

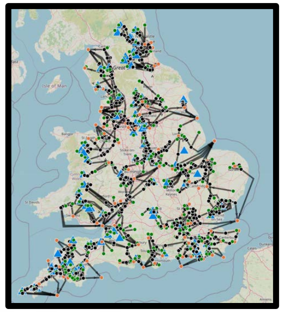
Credit: Murgatroyd et al.

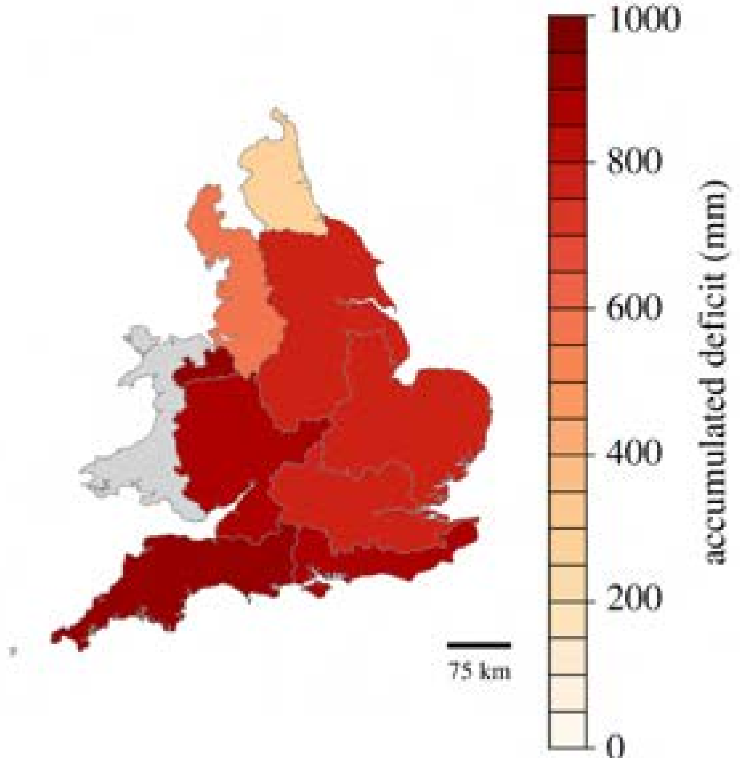
WREW:

Water **R**esources model for **E**ngland and **W**ales to enable strategic analysis of the drought resilience of water supply infrastructure

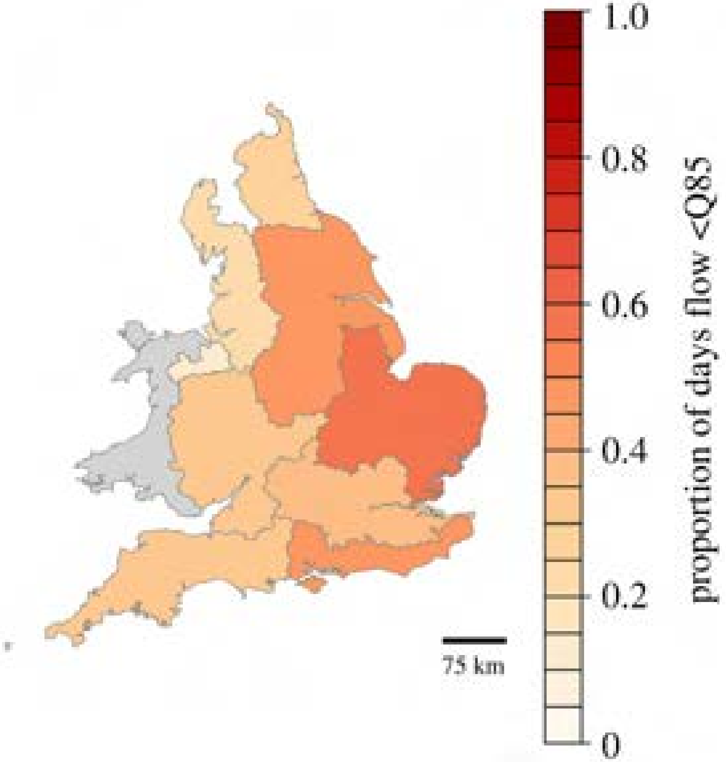


Strategic analysis of the drought resilience of water supply systems

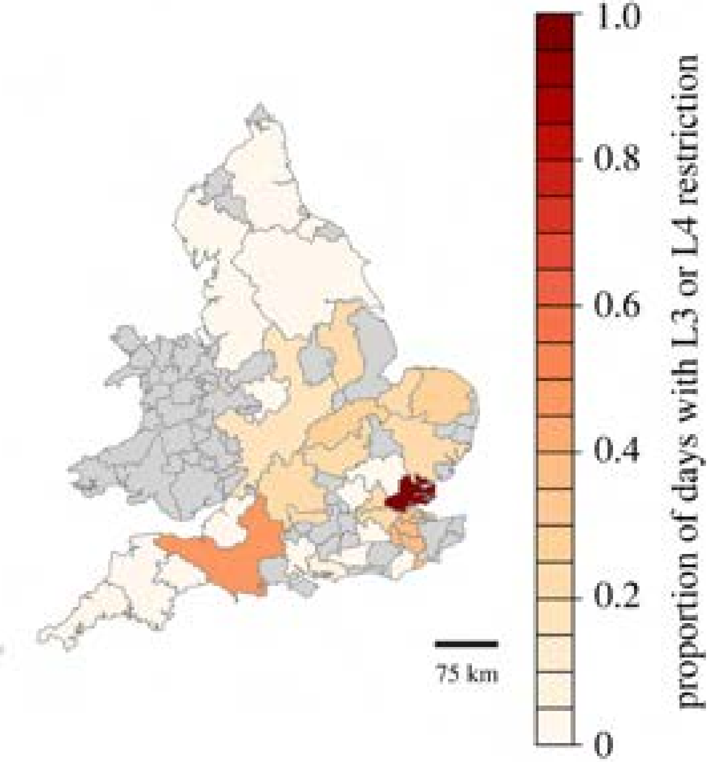




Synthetic national scale drought



Hydrological response



Water system response

Credit: Murgatroyd et al.

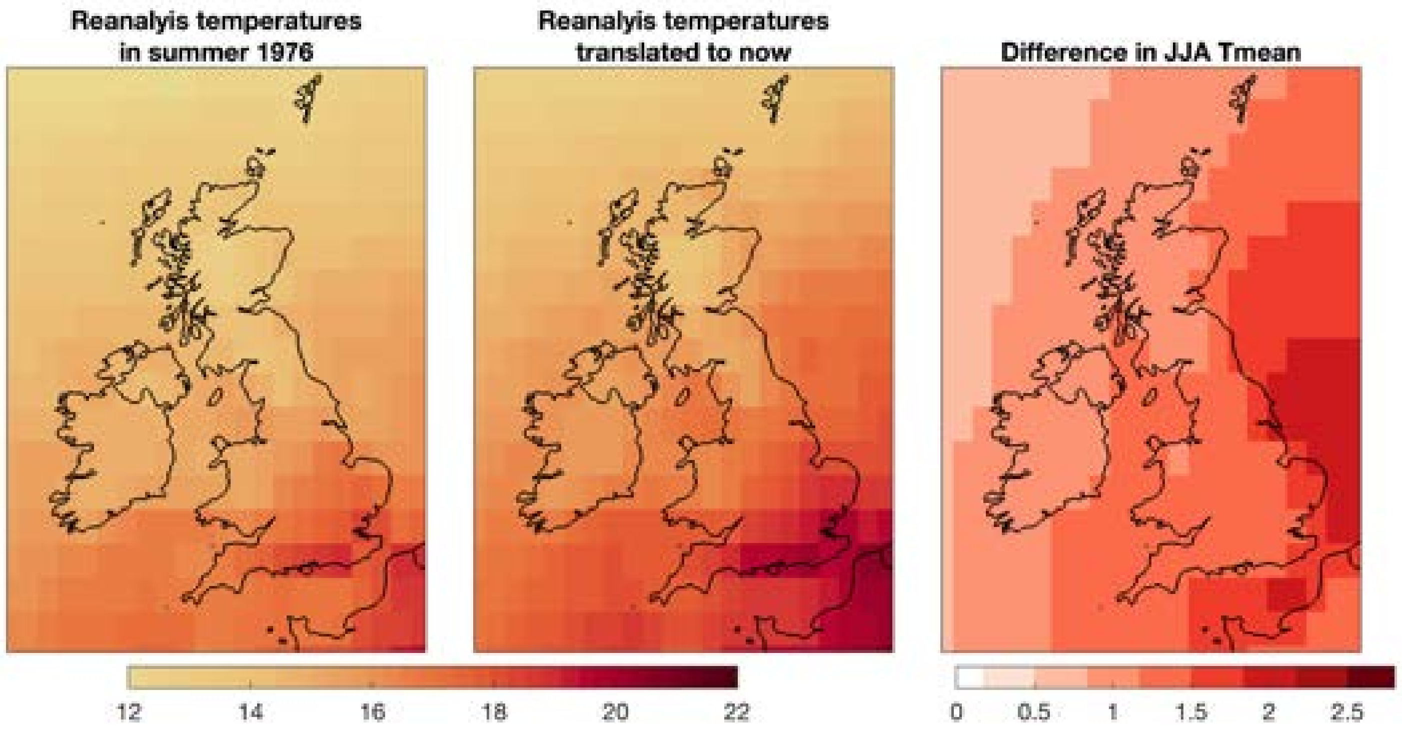

What would a 1976 style drought
look like with today?

Reanalysis-based storylines for 1976

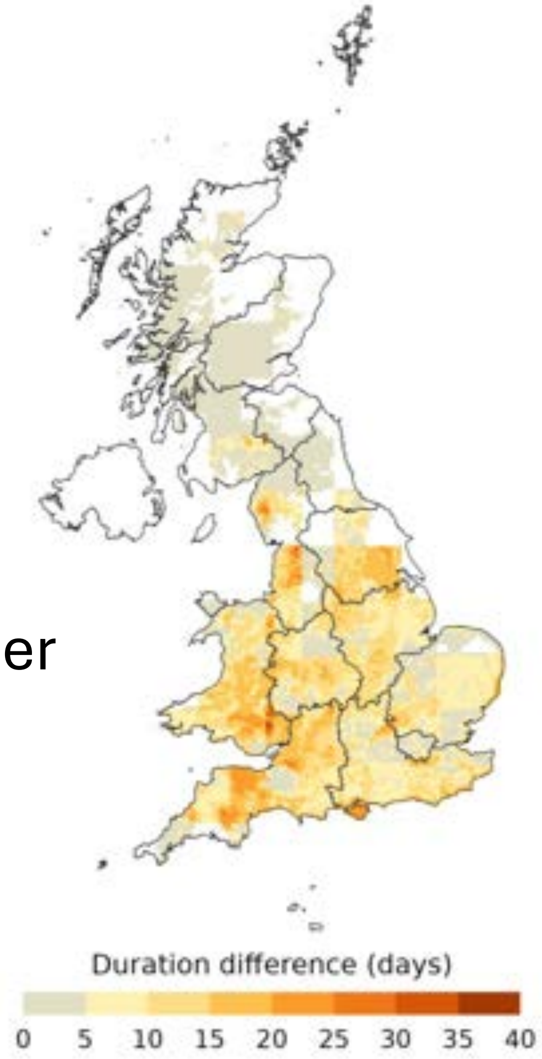
Visit this poster today!

Translating the weather of 1976 into a modern climate to consider how much hotter or drier or wetter it would be if the same weather patterns occurred again now

Approach: use the 20th Century Reanalysis to produce a pair of reconstructions for the weather of 1976, one using observed SSTs and one with modern SSTs.



Outcome: warmer summer with longer heatwaves



Credit: Ed Hawkins, James Carruthers, Hunter Quintal

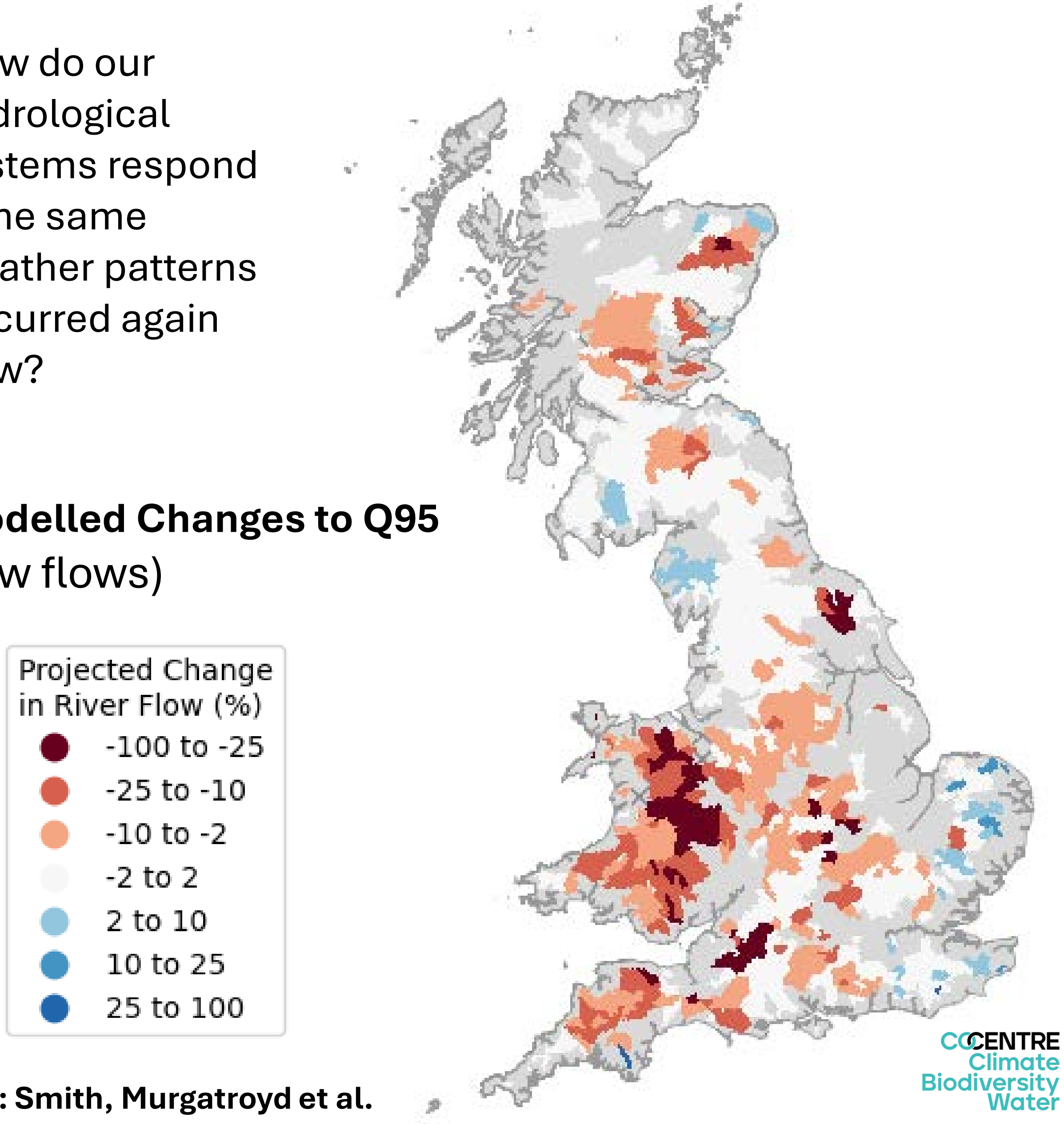
Centre Climate Biodiversity Water
Newcastle University
UKCEH
University of Reading

Reanalysis-based storylines for 1976

Visit this poster today!

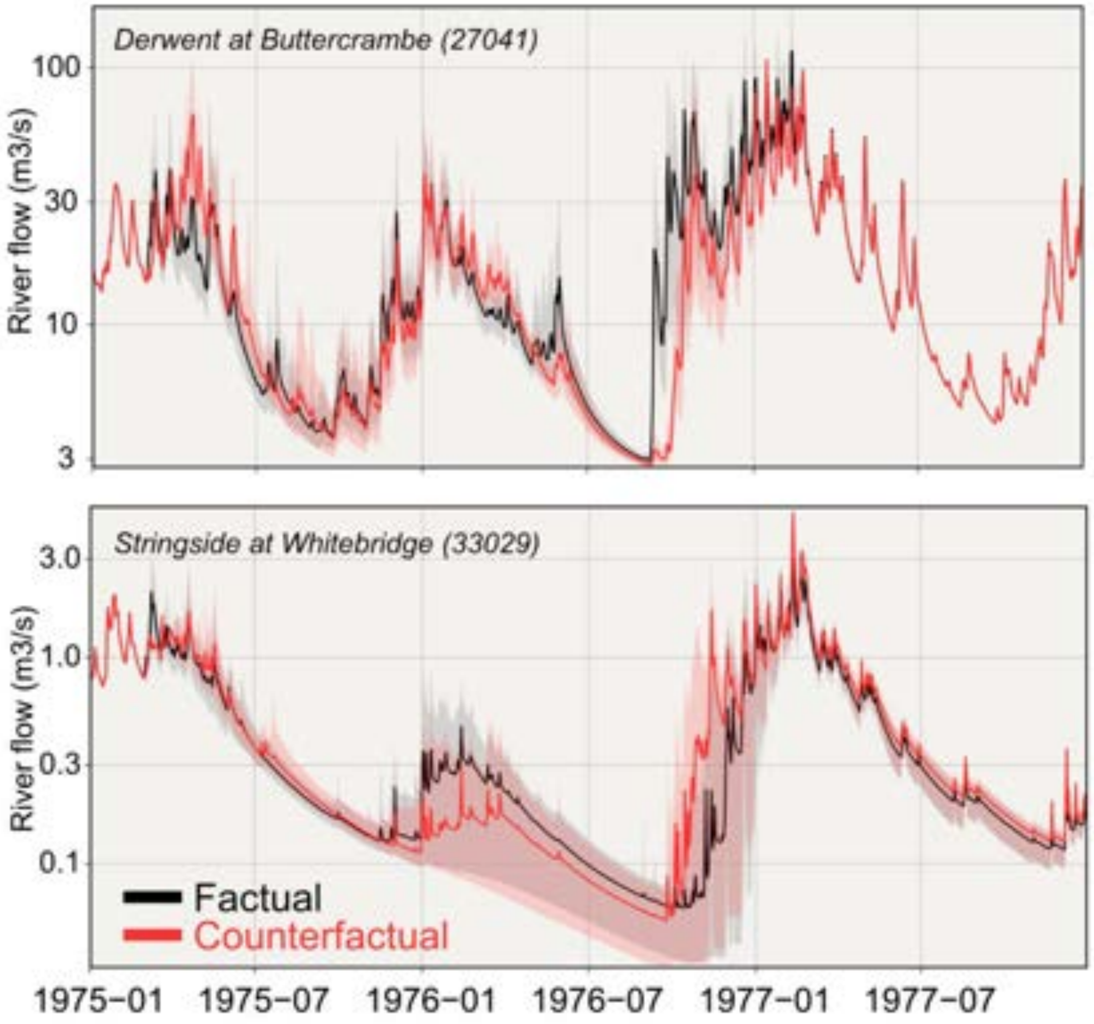
How do our hydrological systems respond if the same weather patterns occurred again now?

Modelled Changes to Q95 (low flows)



Credit: Smith, Murgatroyd et al.

Credit: Chan et al.

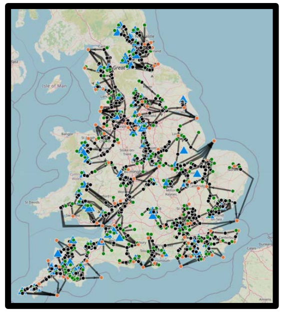


CCCENTRE Climate Biodiversity Water

Newcastle University

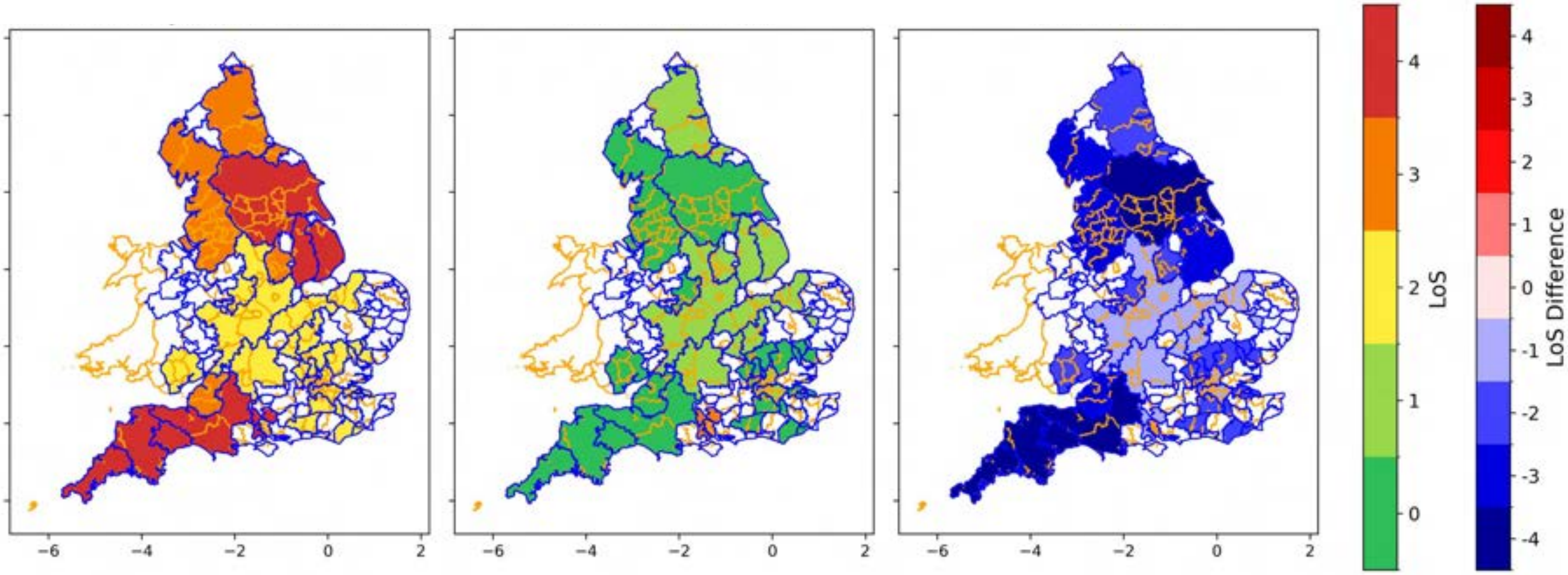
UKCEH

University of Reading



National Scale Level of Service for August 1976
– comparing historic to predicted modern conditions

Visit this poster today!



1976 system

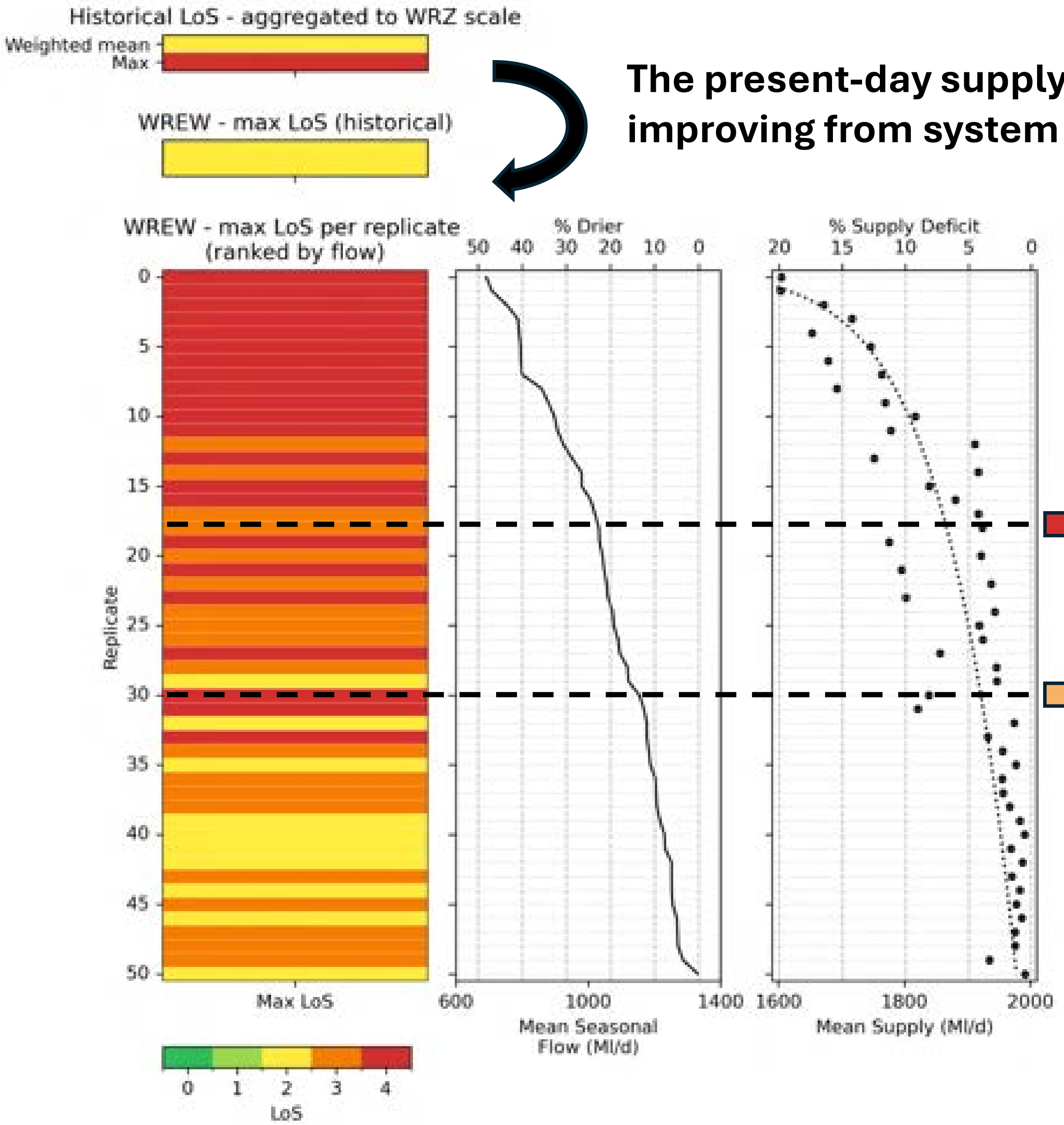
Current system 2021 demands

Difference

Credit: Water Resources Modelling team, Environment Agency

Credit: Water Resources Modelling team, Environment Agency

Visit this poster today!



The present-day supply system is more resilient to a repeat 1976 event – improving from system failure (LoS4) to Temporary Use Bans (LoS2)

Testing the present-day **London** supply system against alternative realisations of the 1976 drought reveal:

System failure (**LoS4**) occurs when River Thames flows are ~≥24% lower, equivalent to ~ ≥140 Ml/d less supply to London.

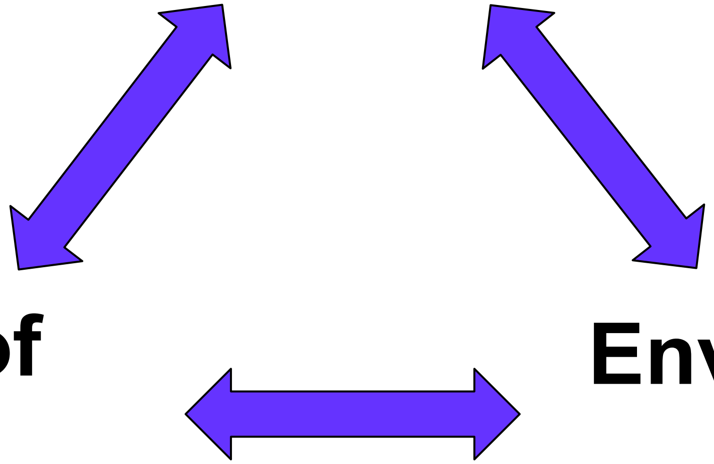
Non-essential Use Bans (**LoS3**) occur when River Thames flows are ~≥16% lower, equivalent to ~ ≥80 Ml/d less supply to London.

Credit: Jim Hall

A system under stress: The trilemma

Charges to water users

Affordability

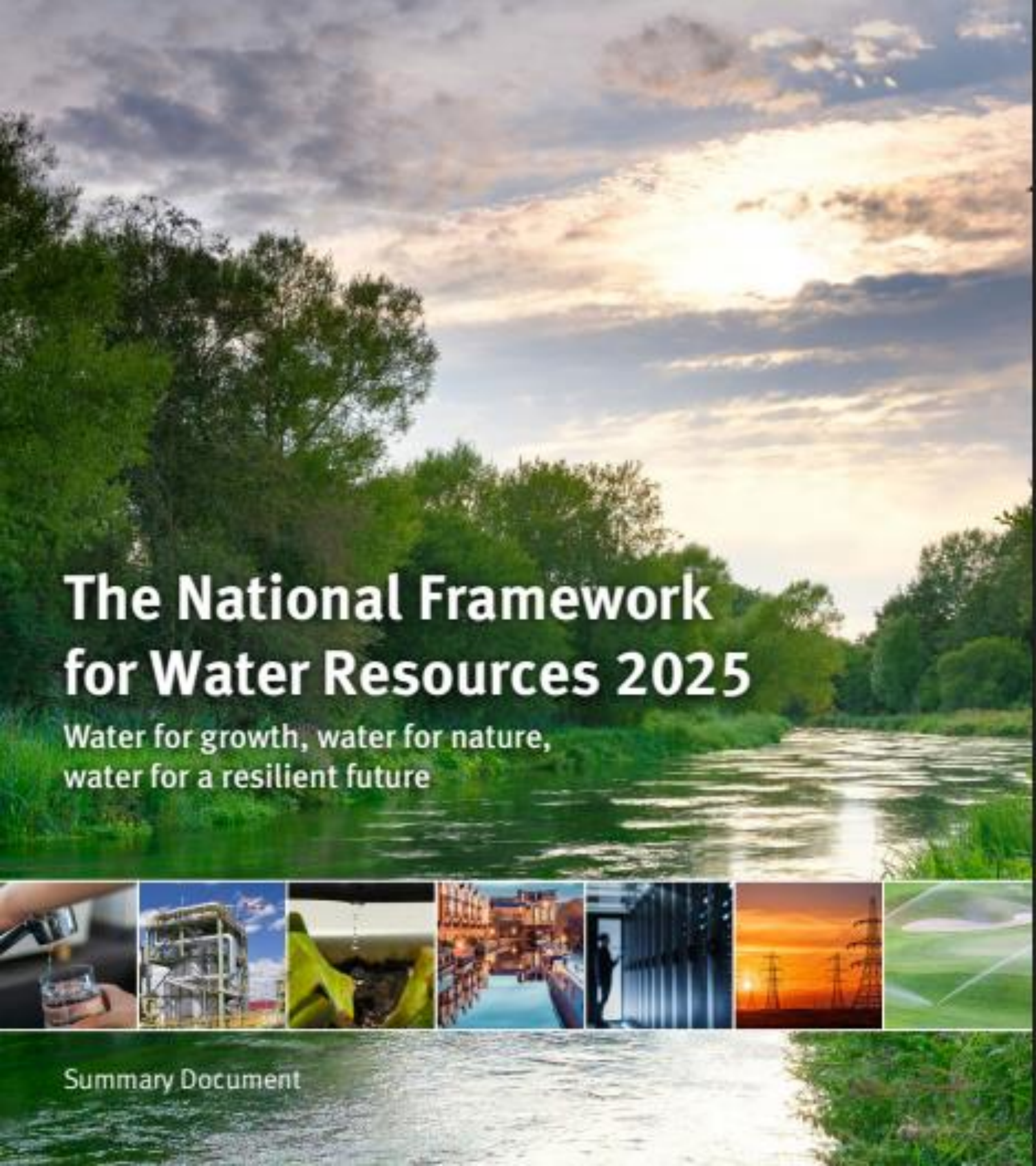


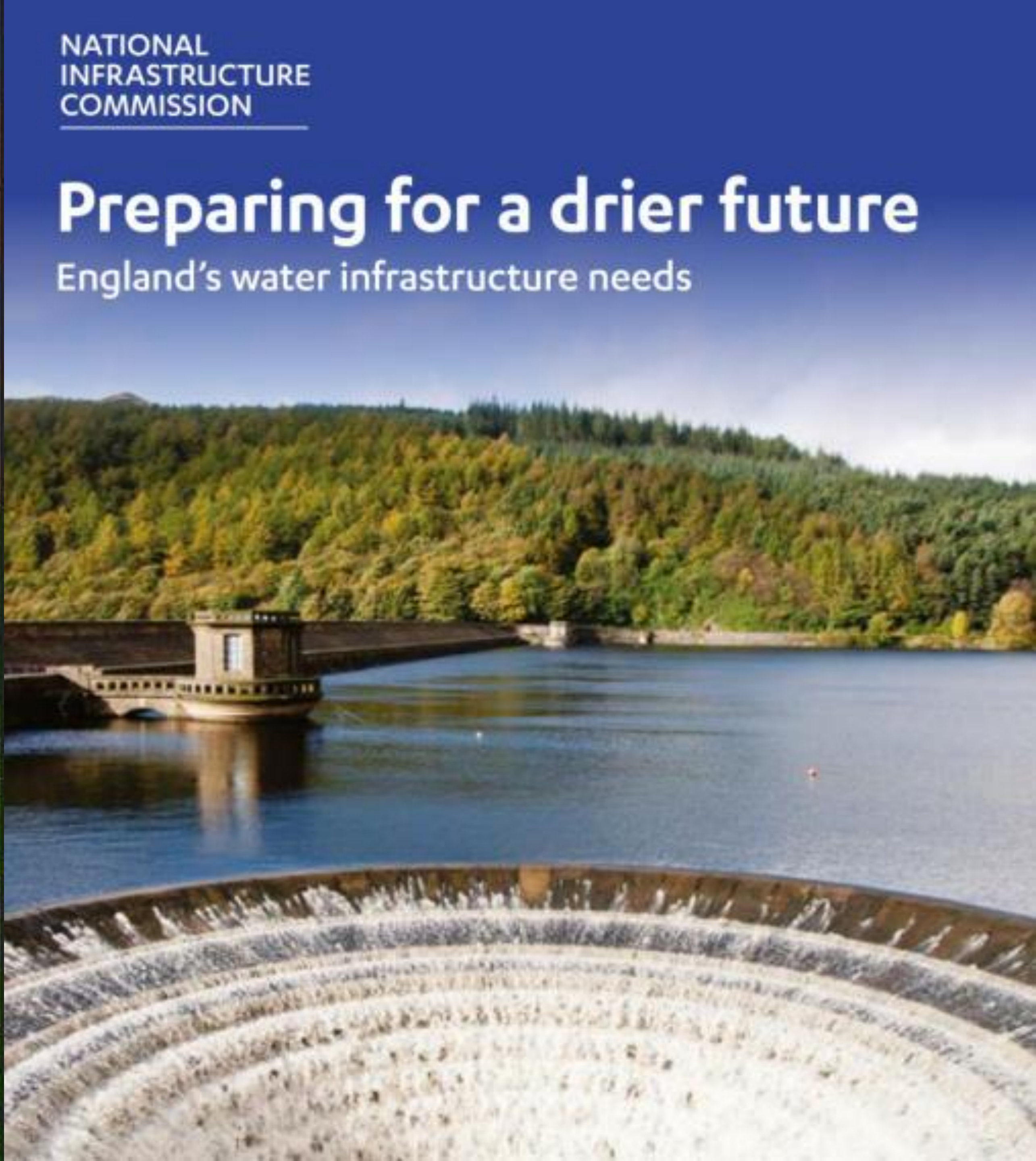
Security of Supply

Impacts of climate change and droughts
Growing demand
Leakage

Environmental impacts

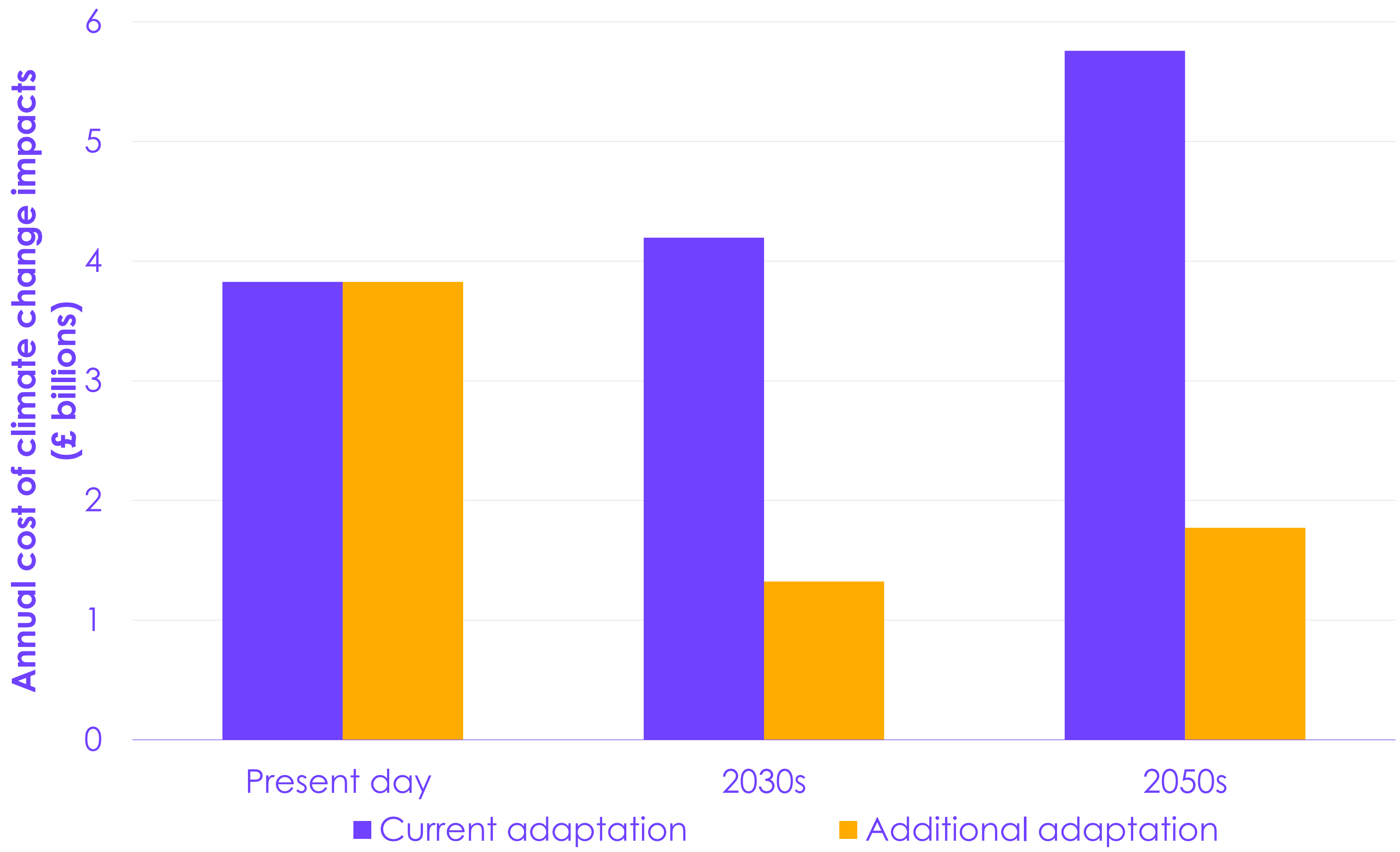
Deterioration of the freshwater environment
Carbon emissions


The National Framework
for Water Resources 2025
Water for growth, water for nature,
water for a resilient future
Summary Document


NATIONAL
INFRASTRUCTURE
COMMISSION
Preparing for a drier future
England's water infrastructure needs

A Well-Adapted UK

The Fourth Independent Assessment of UK Climate Risk (CCRA4-IA)



Cost-effective adaptation packages at a national-scale can significantly reduce the impacts of water scarcity on private water supply in industry, power, and agriculture sectors in the UK.

Credit: Climate Change Committee and WSP

Looking forward...

- Continued investment in water security under climate change

- Regulatory alliances aiming to progress strategic schemes to improve our resilience to drought

- Collaboration and cooperation across companies and regulators to identify the most efficient solutions

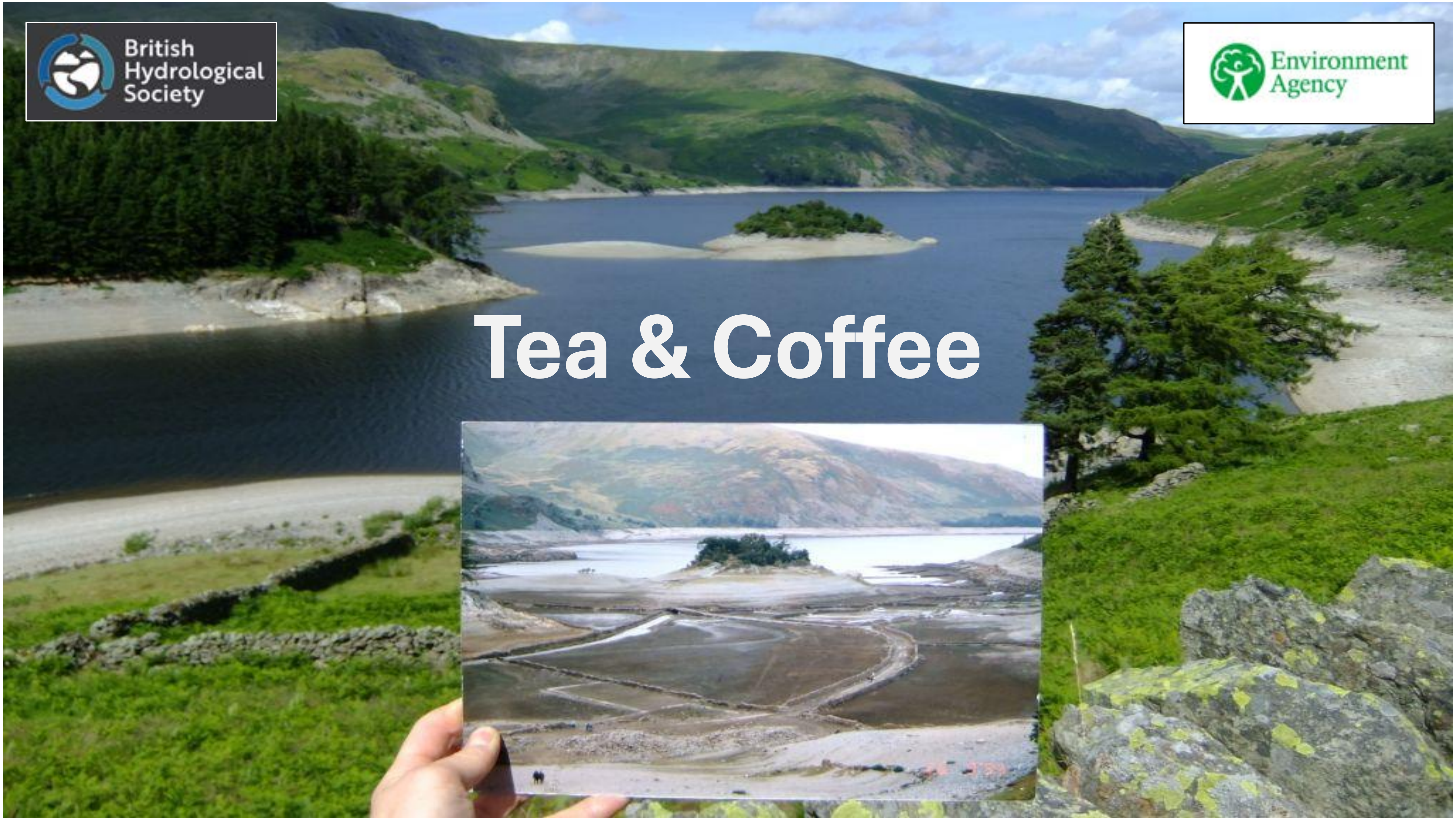
River Teme, 2022
Credit: Environment Agency Image Library/ Simon Derry

Dr Anna Murgatroyd
Newcastle University

British Hydrological Society

Environment Agency

Tea & Coffee



British Hydrological Society

Environment Agency

Session 2

The Water Supply Challenge

Helen Wakeham – Director of Water,
Environment Agency, England

Environment Agency

The summer that changed everything - 1976

Where the weeds and wild flowers took over

Nothing shows more dramatically how the great drought took over at Chew Valley Lake and Blagdon than these graphic photographs taken by Ralph Hudd for the *Bristol Evening Post*.

They were published on August 8 when Chew Valley Lake had dropped to 37% of capacity and Blagdon to 28%. In fact, the water levels went on dropping to 30% at Chew (on September 23) and 27% at Blagdon (on August 30) before the rains made the reservoirs "turn".

The tremendous growth of weeds and wild flowers this year was explained by the fact that the water receded so much earlier than usual so that they had time to take root and flourish right through to October.

The conspicuous flowers surrounding Mr. Wright are burr marigold, but other species which spread out from the lake margins included wild mint, creeping potentilla and camomile.

Above, left: Denny Island (trees top right) became a peninsular joined to the shore by acres of luxuriant growth. At high water Mr. Ernest Wright, the Recreations Officer, would be waist deep!

Above, right: The River Chew flowing under the bridge from Herriott's Pool was reduced to a trickle in the mud, flanked by thick plant life in the nature reserve area, and the lake receded into the distance.

Left: Mr. Wright among the cracks at Blagdon, with the fishing boats by then unable to reach even the temporary extension to the boat jetty.

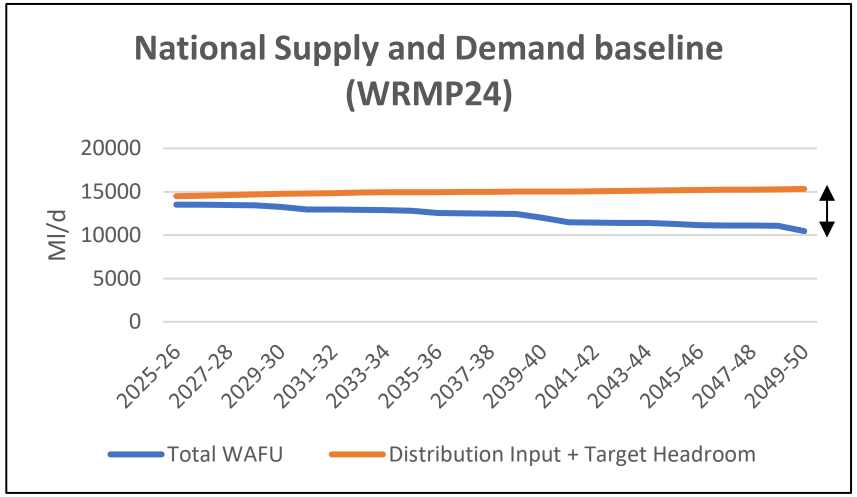
Right: The dam and dried-up approach to the spillway at Chew.

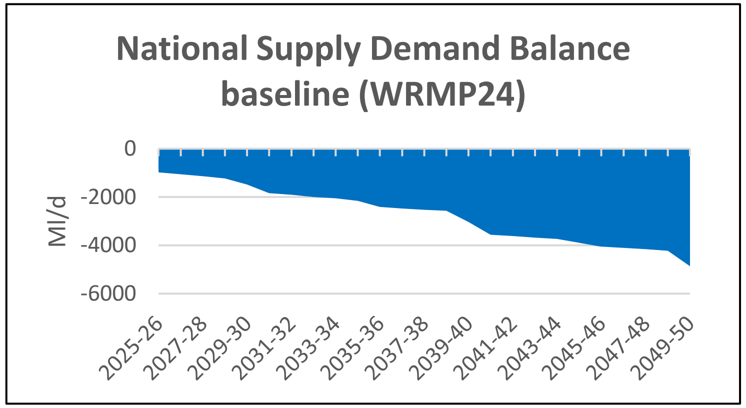
Used with permission by and credits to Bristol Water

The scale of the challenge

- National Framework for Water Resources: we face **a public water supply deficit of ~ 5 billion litres <u>per day</u> by 2055** driven by:

Climate Change	Population and Business Growth	Environmental Needs	Drought Resilience increases





- Regional variation but widespread water stress
- Non-public water supply sectors could face ~1 billion l/d deficit by 2055 – risks to food, energy and data.

*https://www.gov.uk/government/publications/national-framework-for-water-resources-2025-water-for-growth-nature-and-a-resilient-future

England – Perceptions vs growing reality of drought and water scarcity

Unsplash, 02/2017, Creative Commons

Environment Agency, 2025

Environment Agency, 2025

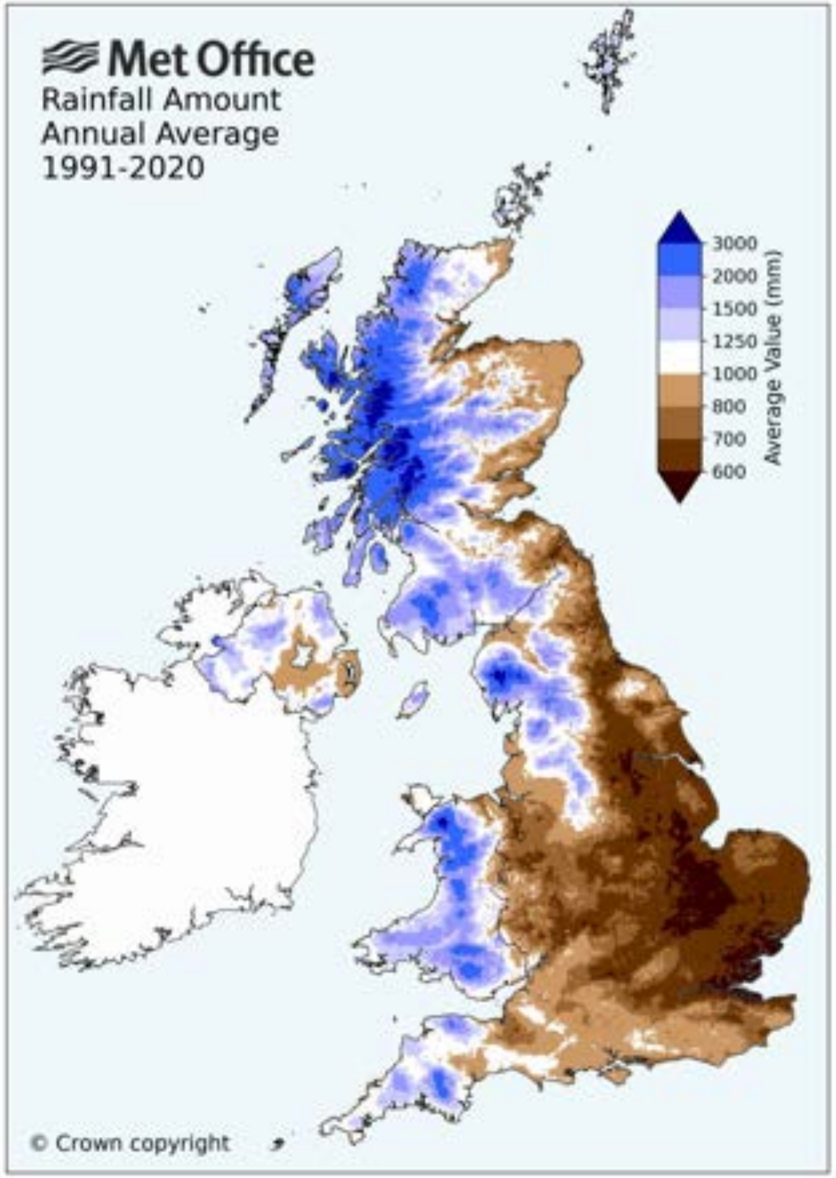
England is drier than most think

Average annual rainfall in England is 800-900mm but… driest in east and south-east.

London average is ~600mm, drier than -

- Most major cities in Texas
- The major cities in Australia
- Many European capitals

This is difficult to convey – especially during wet winters – which are getting wetter!



Map showing the 30-year (1991 — 2020) average annual rainfall amounts across the UK. MetOffice, Crown copyright.

Environment Agency

Last year was not an anomaly

2025 Drought

Driest spring in 132 years

Hosepipe restrictions for 8.5 million people

Nationally significant incident

Significant environmental impacts and response

Other sectors heavily impacted – agriculture and navigation

Images: Creative commons, 2026

Climate crisis and "Weather Whiplash"

- Volatile swings from flooding to drought!
- Wet winter of 25/26 immediately proceeded by dry spring in 2026.
- Record temperatures – 2025, hottest May temperature in 2026
- Driest April-May on record in 2026 across 8 hydrological areas across East and SE England
- A very wet start to June 2026!

Environment Agency

How is the EA responding to these challenges?

Environment Agency, 2024

Environment Agency, 2025

Image reproduced with permission from Helen Cooke, 2025

Environment Agency, 2010 (Richard Wood)

Environment Agency, 2024

Environment Agency, 2024

Continued **Water rights allocation role** crucial to ensure **sustainable catchments**

Driving **investment in new supplies,** including **less climate dependent** desalination and water recycling

Ensuring focus on **substantial, sustained reductions in water demand** – water used and water leaked

Robust planning frameworks - WRMP29 and Drought Plans – strengthening further with water reform

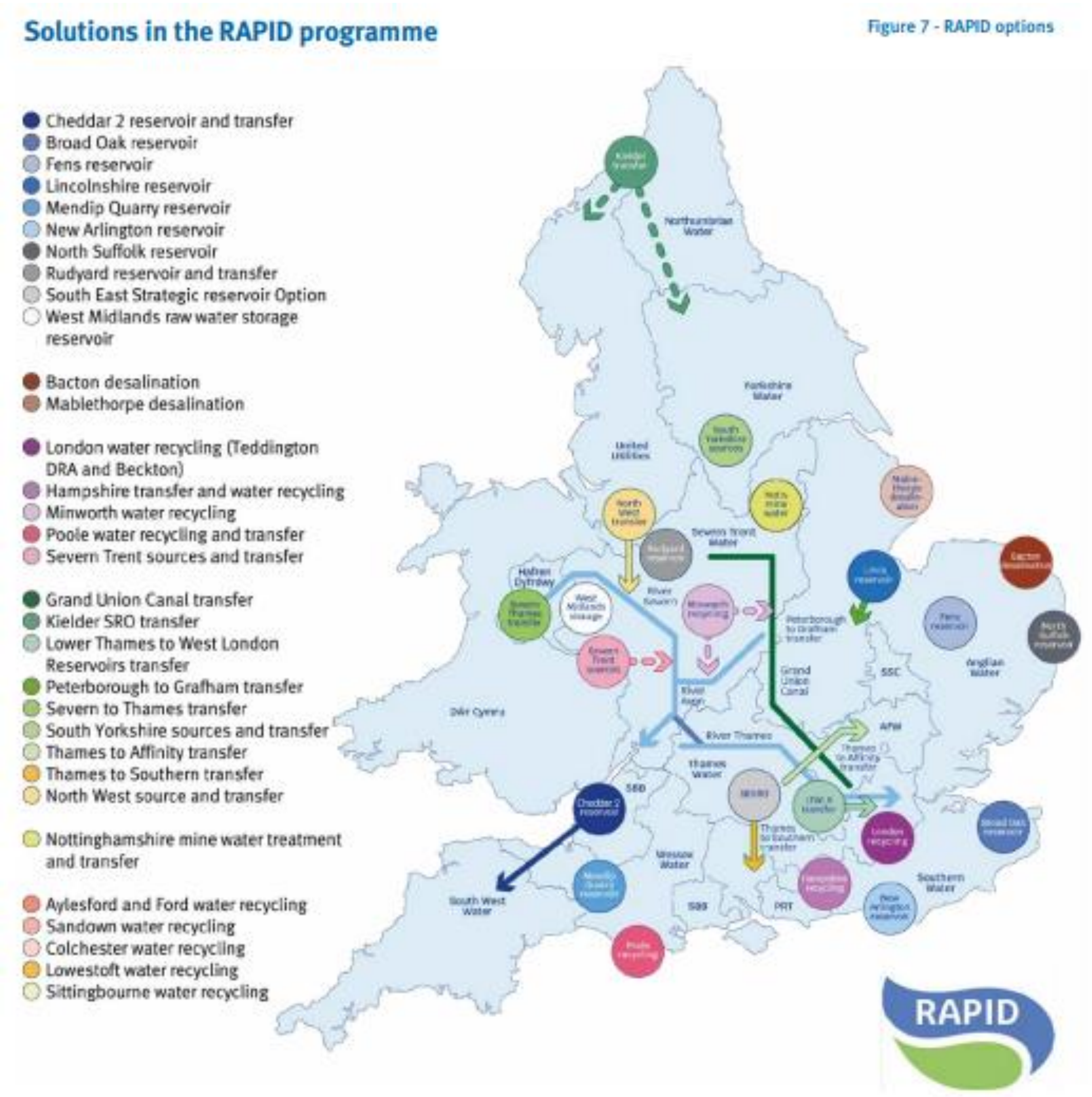
Supporting **holistic nature based solutions** for sustainable water management

Research coordination on drought – to improve monitoring, forecasting and resilience.

Engaging internationally for best practice on water resources/drought management

Environment Agency

Solutions – new water supplies



- **Strategic water resources** planned
- Forecast deficit requires **immediate delivery of new supplies**
- Moving towards **less climate dependent options** - water recycling and desalination
- **Supply options take time** – these aren't expected to be operational until the mid 2030s onwards

Summary of supply options in EA's water resources plan summary report: https://www.gov.uk/government/publications/a-review-of-englands-draft-regional-and-water-resources-management-plans/a-summary-of-englands-draft-regional-and-water-resources-management-plans

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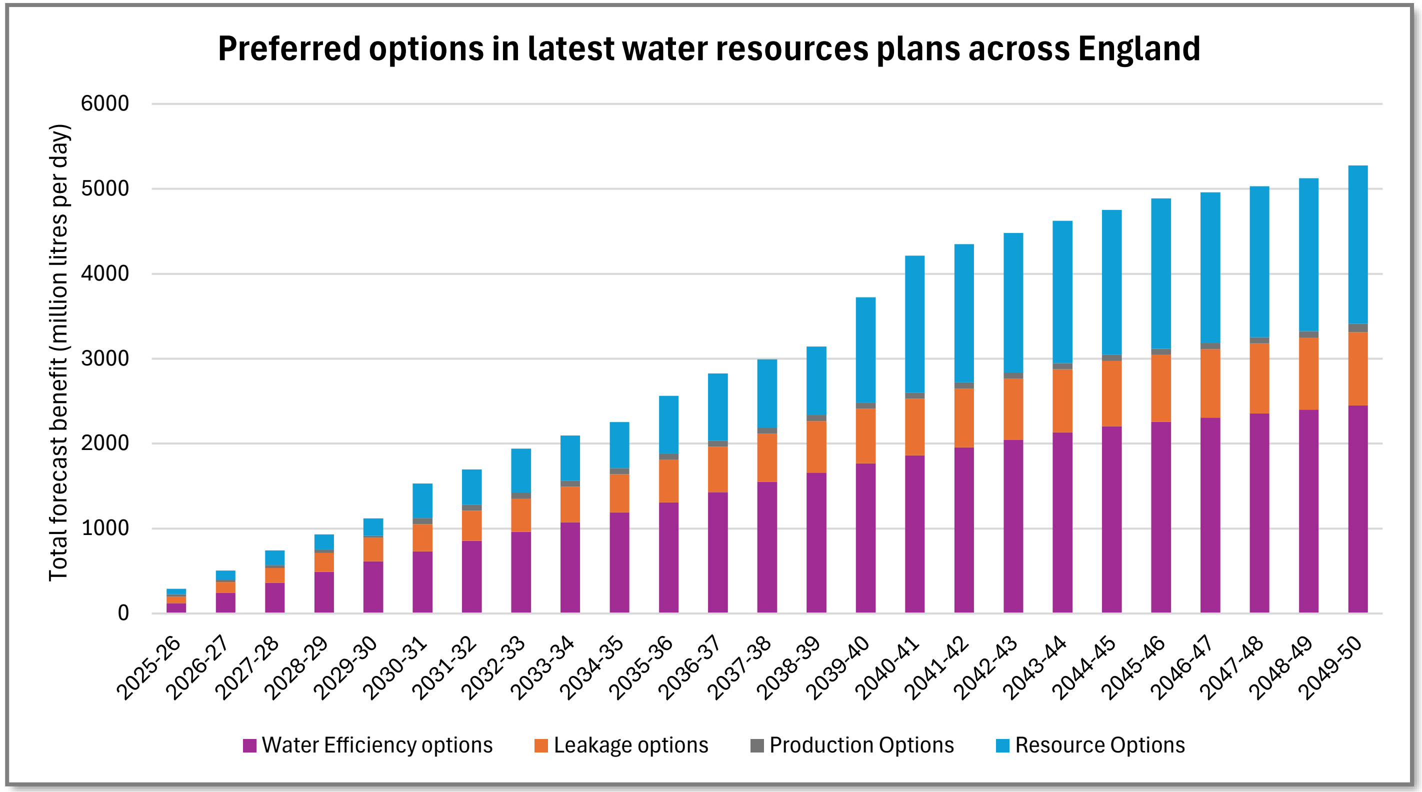
Solutions – water demand

- Improved spatial planning
- Water efficiency – smart metering and interventions
- Water demand policies
- Leakage reduction



Environment Agency, 2024

Water efficiency and leakage options ~70% of the solutions in short term, and > 60% throughout next 25 years.

Almost 20% assumed to be addressed by government water demand policies (Water label, building regulations and standards).

Environment Agency

The gaps and areas for focus

Earlier action before forecasted weather

Collaboration across sectors

Greater public awareness

Asset health focus

Better planning for severe drought

The opportunity

- Momentum from society's increased attention on water and its value
- New infrastructure – more supplies and connectivity
- Technology and Innovation – satellites and smart water meters
- Prioritising the natural buffers we have
- Forward-looking planning and coordination


Environment Agency, 2022


Environment Agency, 2021


Creative Commons, 2026


Environment Agency, 2025

A more resilient relationship with water

Environment Agency

Conclusion

Environment Agency, 2023

If future generations are to inherit a secure water future, then the time to build it is now.

Water resources planning with 50 years of climate change

Dr Geoff Darch

17th June 2026

Agenda

Historical context

Extreme drought

Recent experience, in a 1.5°C world

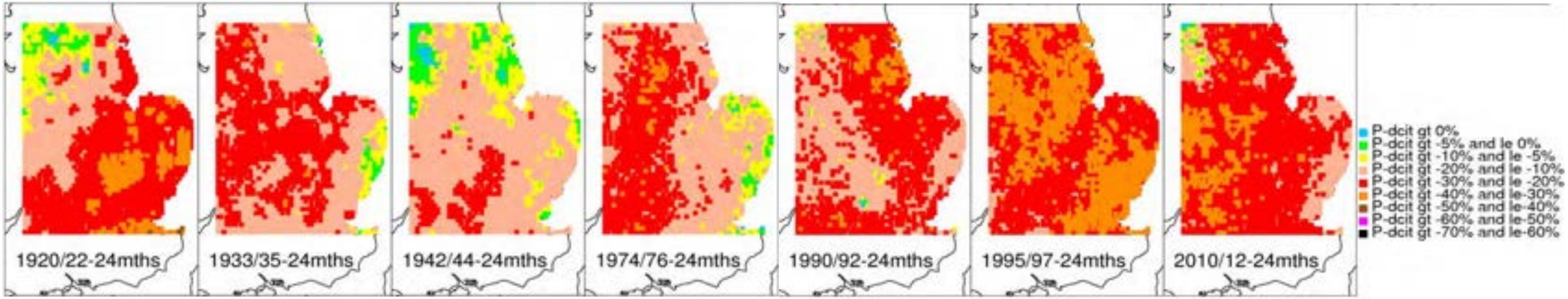
Future projections & storylines, in 2°C+ worlds

Adaptation: resilience to changing droughts

Summary

Historical context

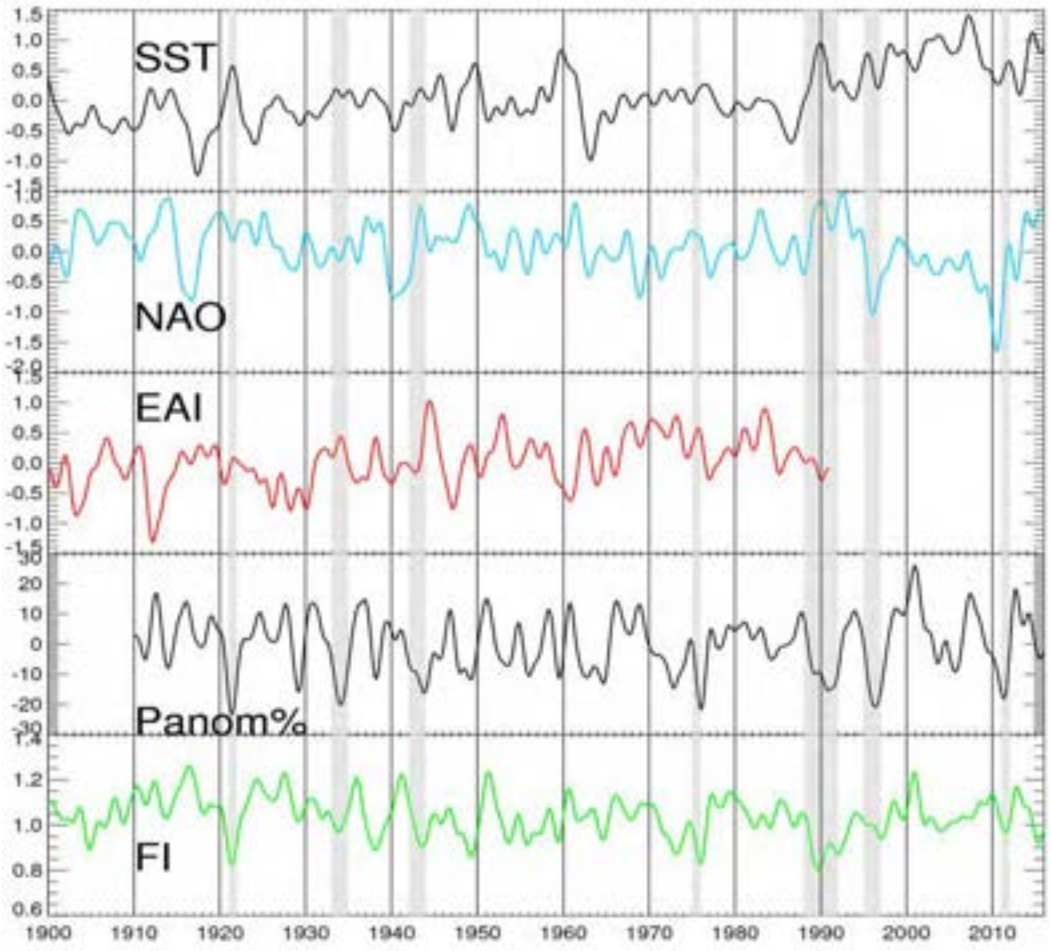
Drought in the east of England



Maps of 24-month precipitation deficit (as a percentage of expected long-term average) for each period preceding the drought end dates assumed

Source: Lister, D., Osborn, T., Jones, P., and Darch, G. 2018. *Observed droughts in the greater Anglian region since 1920*. CRU Research Publication 22. Climatic Research Unit, UEA, Norwich. https://www.uea.ac.uk/groups-and-centres/climatic-research-unit/cru-publications

Drivers of drought in the east of England



Monthly time-series of SST, NAO, EAI, areal precipitation in the AW region (as percentage anomalies) and a fluvial index, all smoothed with a 36-month filter during the period 1900-1990. Notable AW drought periods (in current focus) are shaded light grey.

Source: Lister, D., Osborn, T., Jones, P., and Darch, G. 2018. *Observed droughts in the greater Anglian region since 1920*. CRU Research Publication 22. Climatic Research Unit, UEA, Norwich. https://www.uea.ac.uk/groups-and-centres/climatic-research-unit/cru-publications

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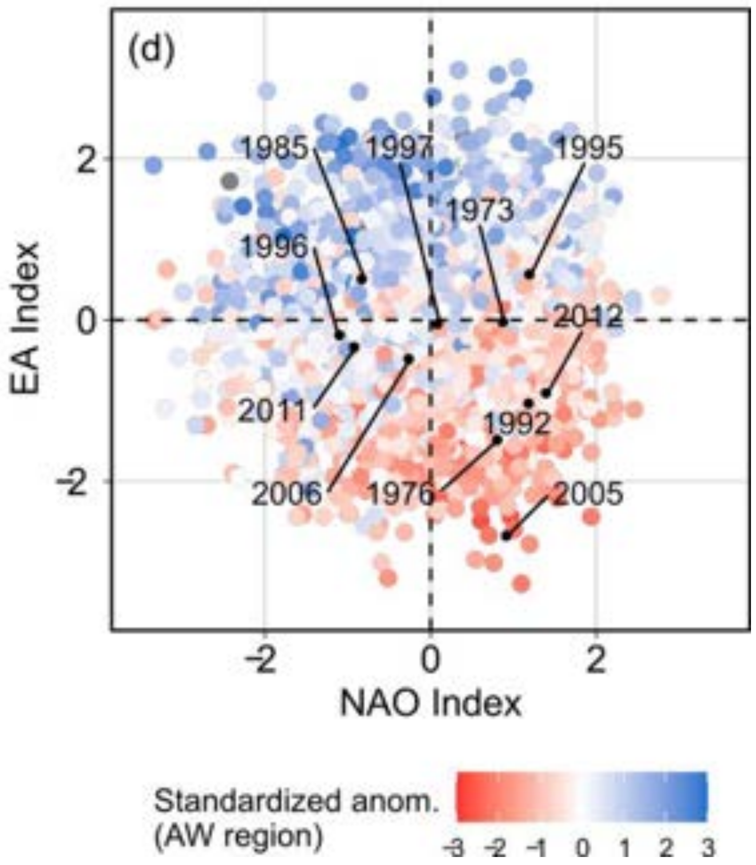
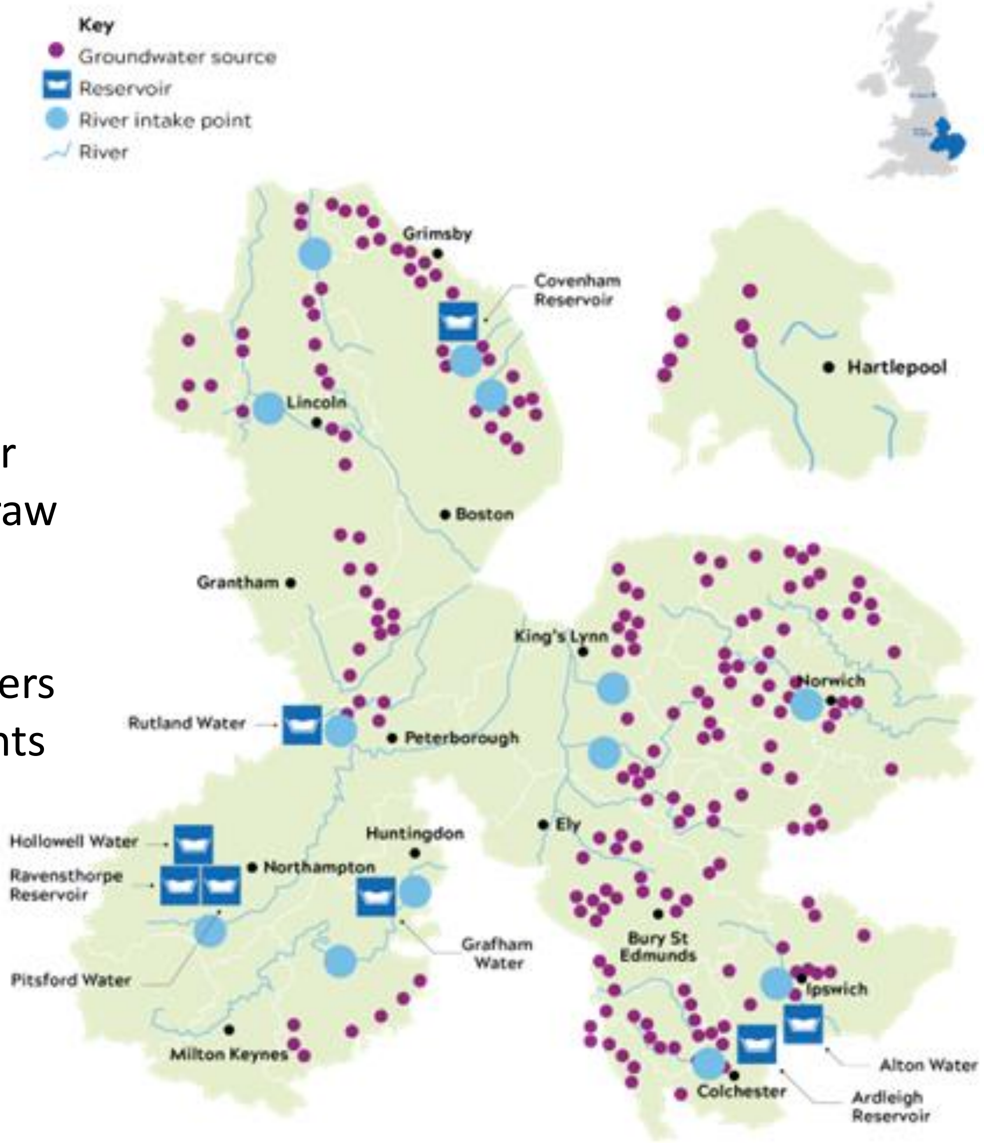


NAO index and EA index for each SEAS5 winter together with the rainfall anomalies over East Anglia associated with each winter (colours). Selected dry winters in the observations are shown by the black dots and the year labels.

Source: Chan, W. C. H., Arnell, N. W., Darch, G., Facer-Childs, K., Shepherd, T. G., and Tanguy, M. 2024. Added value of seasonal hindcasts to create UK hydrological drought storylines, *Nat. Hazards Earth Syst. Sci.*, https://doi.org/10.5194/nhess-24-1065-2024

System resilience to drought

Eight reservoirs hold just over **220 million cubic metres** of raw water; most are pumped storage reservoirs, with abstractions from reliable rivers in lower reaches of catchments



The east and north of the region is underlain by **large aquifers**, notably chalk but also limestone and sandstone, which naturally recharge in winter

Extreme drought

Evolution of planning approach to drought

Pre-2005

- *Worst drought on record*
- Extend historical record

2005-15

- *1 in 100-year +*
- Stochastic WGs
- Long historical rainfall-runoff modelling

2015-20

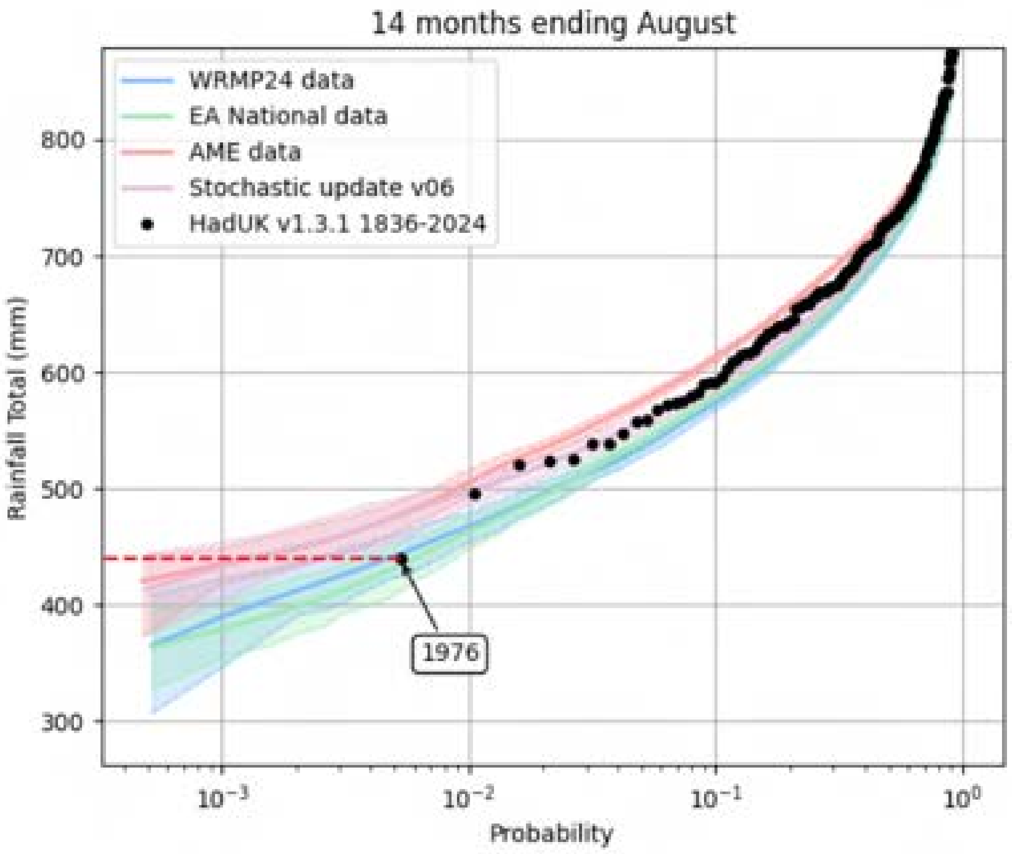
- *1 in 200 year*
- Improved WG
- Met. EVA
- Drought narratives

2020+

- *1 in 500 year*
- Advanced WG
- System RP
- Storylines

Estimating extreme drought using stochastics

love every drop anglianwater



	RP central estimate	RP lower estimate	RP upper estimate
WRMP24 data	215.0	133.0	434.0
EA National data	167.0	115.0	290.0
AME data	772.0	397.0	2101.0
Stochastic update v06	757.0	402.0	2001.0

Source: AtkinsRéalis (2026). *Environment Stochastic Rainfall Update for Water Resources Planning*, Prepared for Water Resources East.

How else might we estimate extreme drought?

love every drop anglianwater

Hydro-climatic reconstructions using:

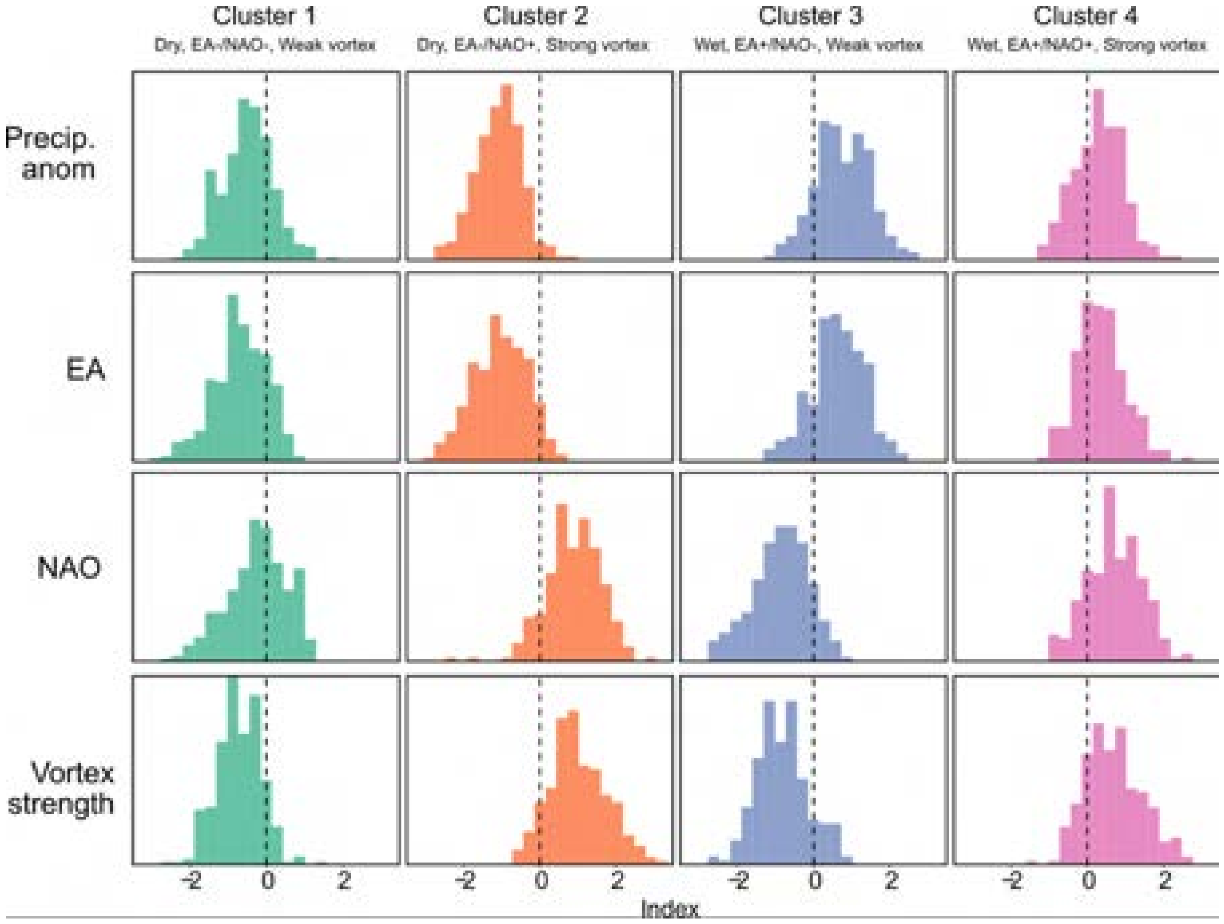
- Atmospheric pressure records
- Tree-ring data (Thurgood *et al*., in preparation)
- Documentary sources

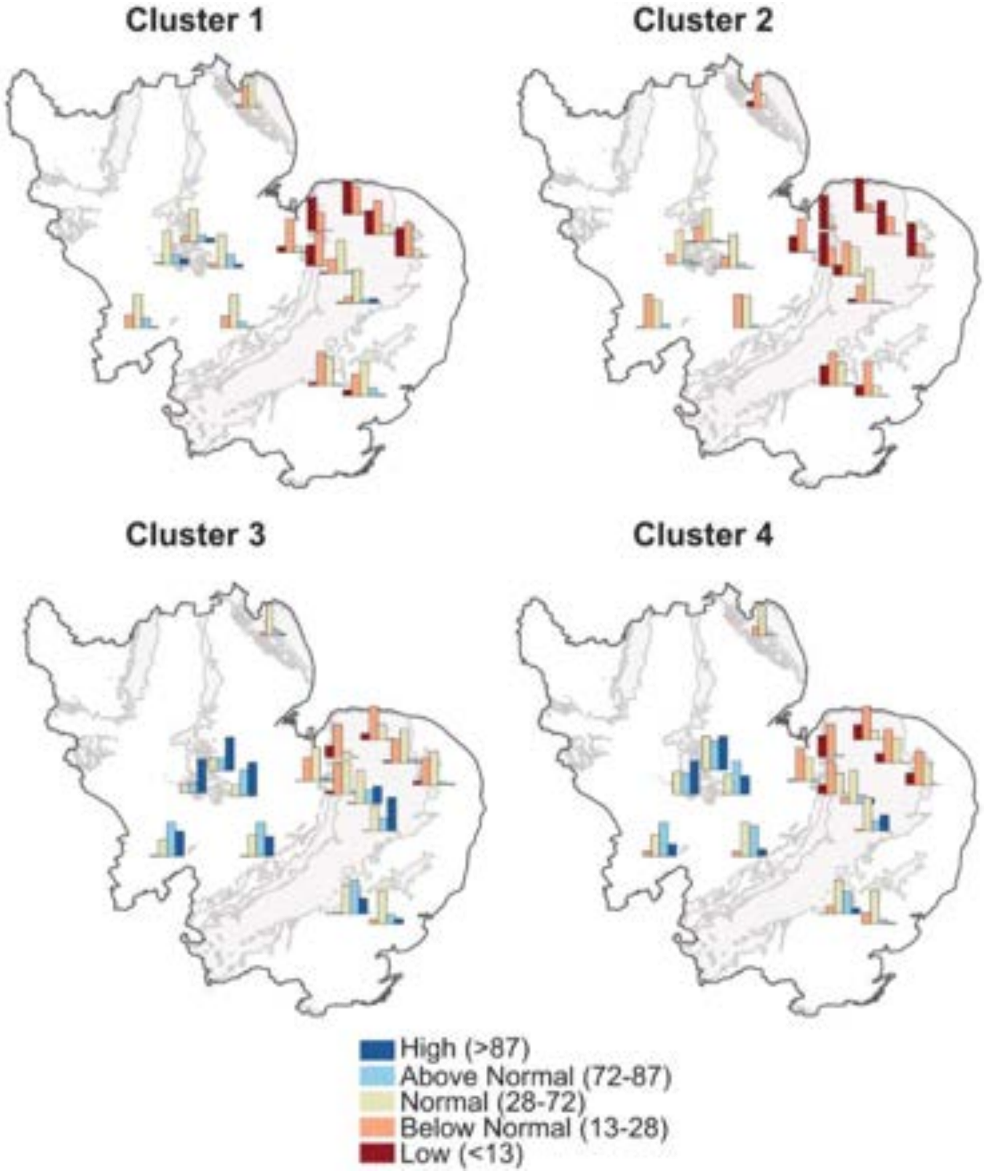
What emerging evidence suggests:

- There have been **more extreme droughts than recorded** in meteorological and hydrological observations
- Great Tudor Drought in NW Europe inc. England 1540-41
- Major drought in 943 (at the start of a drier climatic period)

Thurgood, J. *et al*. Assessment of whether tree-ring hydroclimate reconstructions are useful for characterising extreme drought in East Anglia (England), *in preparation*.

Storylines of extreme drought

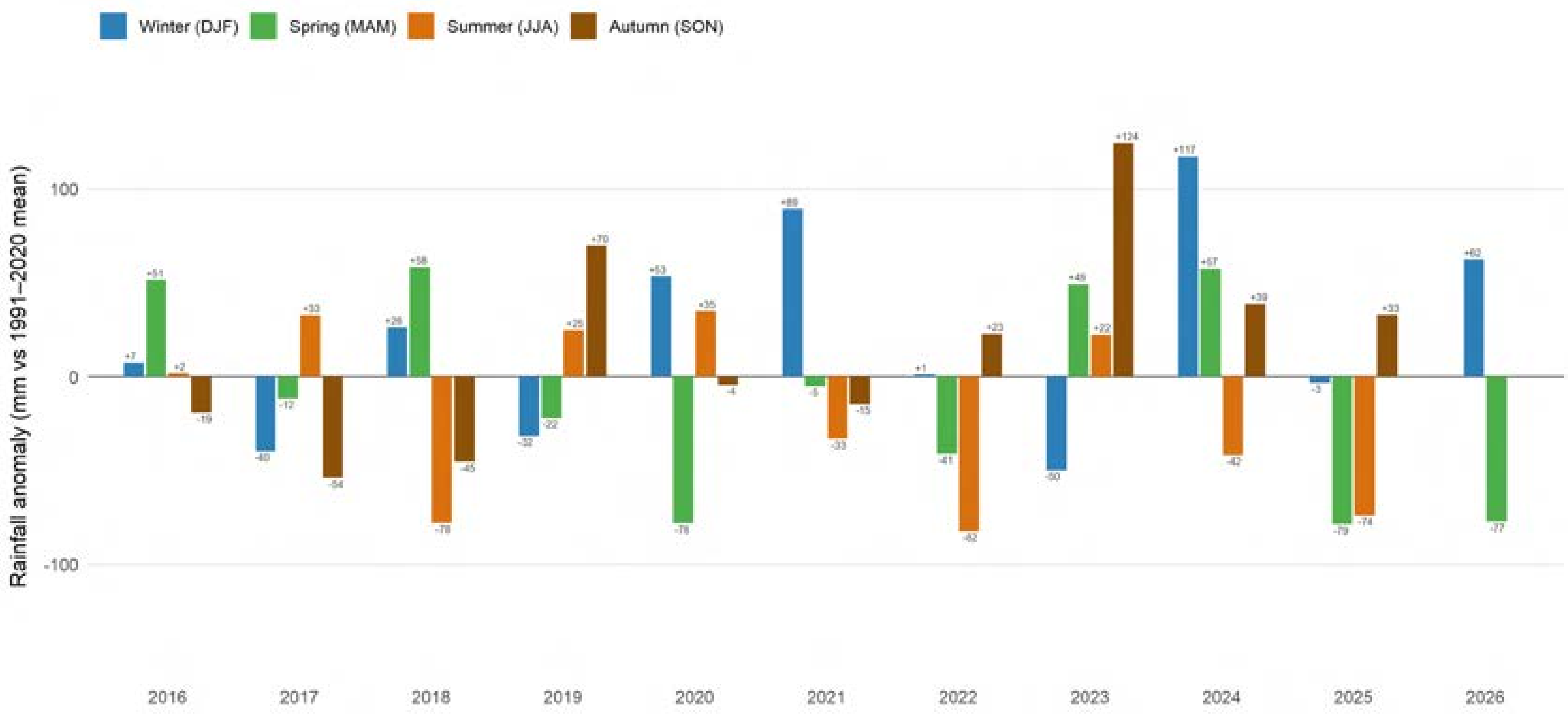




Source: Chan, W. C. H., Arnell, N. W., Darch, G., Facer-Childs, K., Shepherd, T. G., and Tanguy, M. 2024. Added value of seasonal hindcasts to create UK hydrological drought storylines, *Nat. Hazards Earth Syst. Sci.*, https://doi.org/10.5194/nhess-24-1065-2024

Recent experience, in a 1.5°C world

Whiplash weather? Rainfall over the past decade



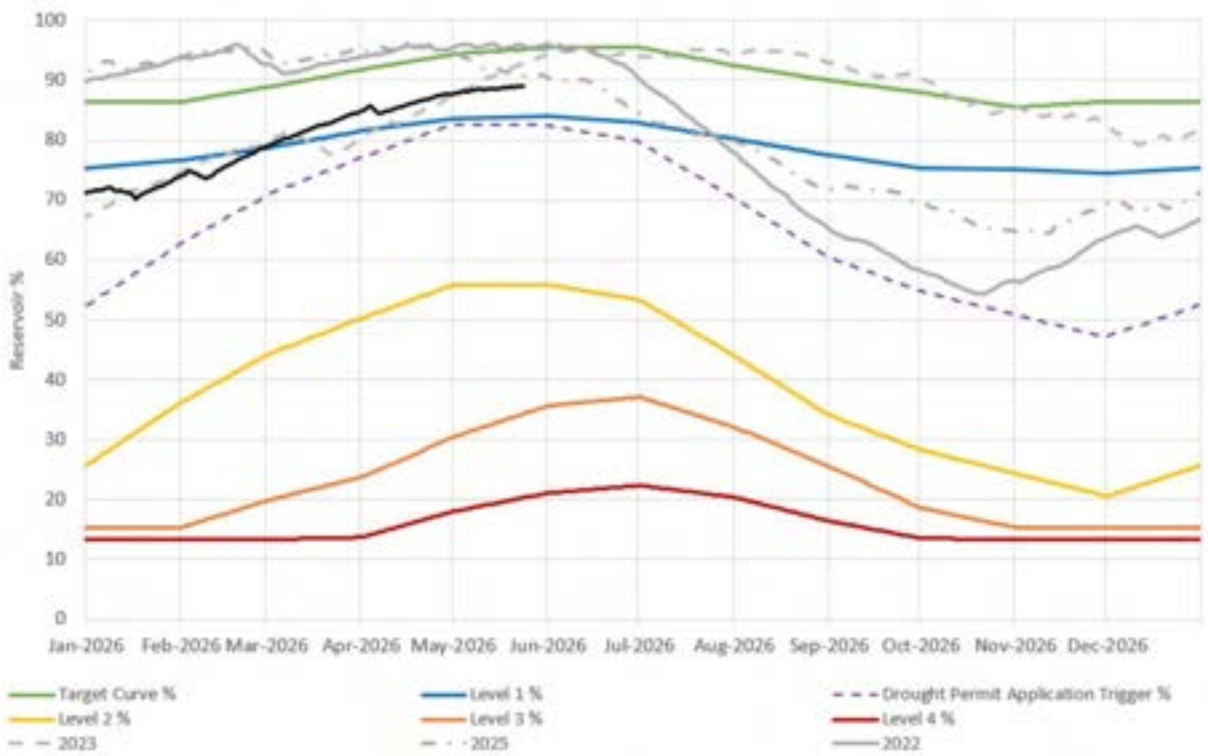
Recent experience

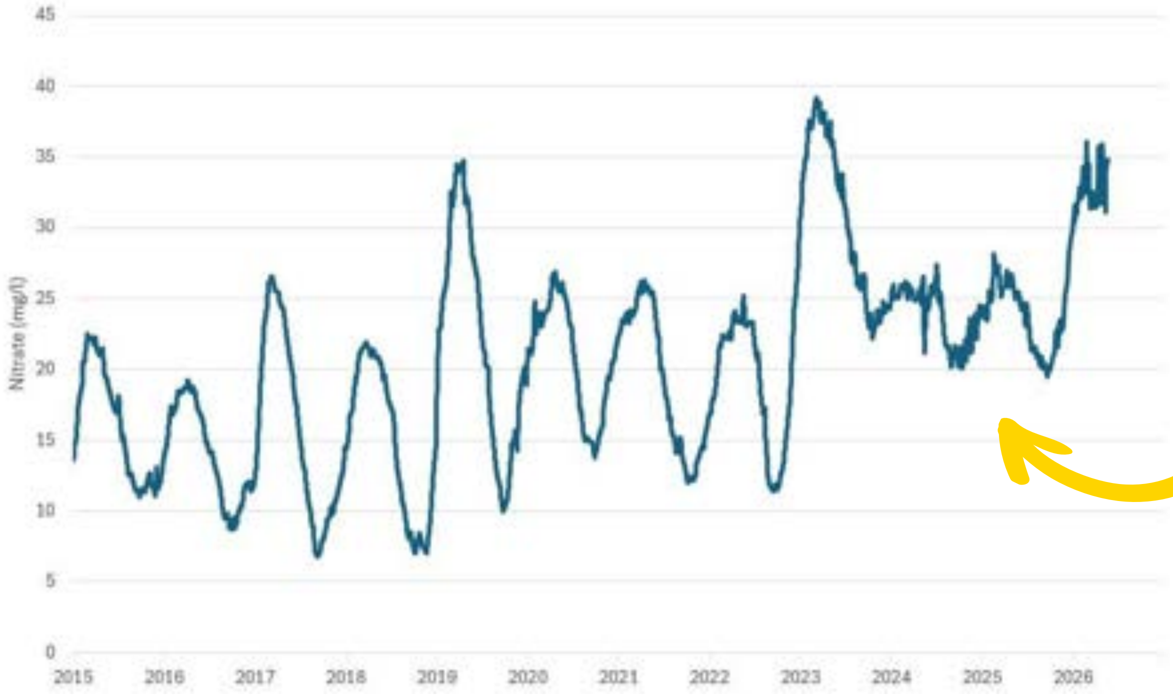
2022 was a potential harbinger of future summers:
- The highest ever temperature recorded in the UK: Coningsby, Lincolnshire at 40.3°C on 19 July 2022
- Record soil moisture deficits (exceeded in 2025)
- Wildfires destroyed homes in the east of England
- Impacts on agriculture and the natural environment

Recent **impacts on water resources** and water supply systems include:
- Record numbers of water main bursts
- Significant increases in peak demand for water, although moderated by the rollout of smart meters
- Local supply issues e.g. associated with firefighting
- Raw water quality impacts

Water quality impacts

Nitrate concentrations in Grafham Water (below) have affected the ability to refill the reservoir (right)

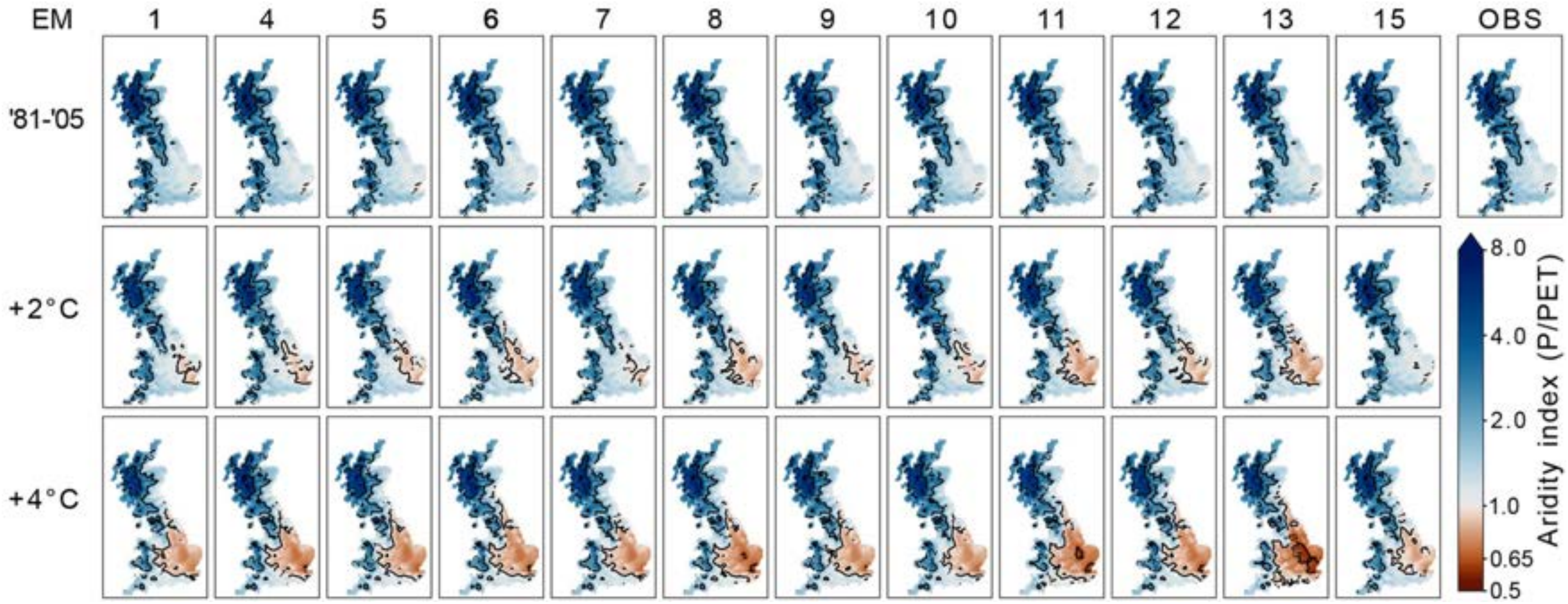




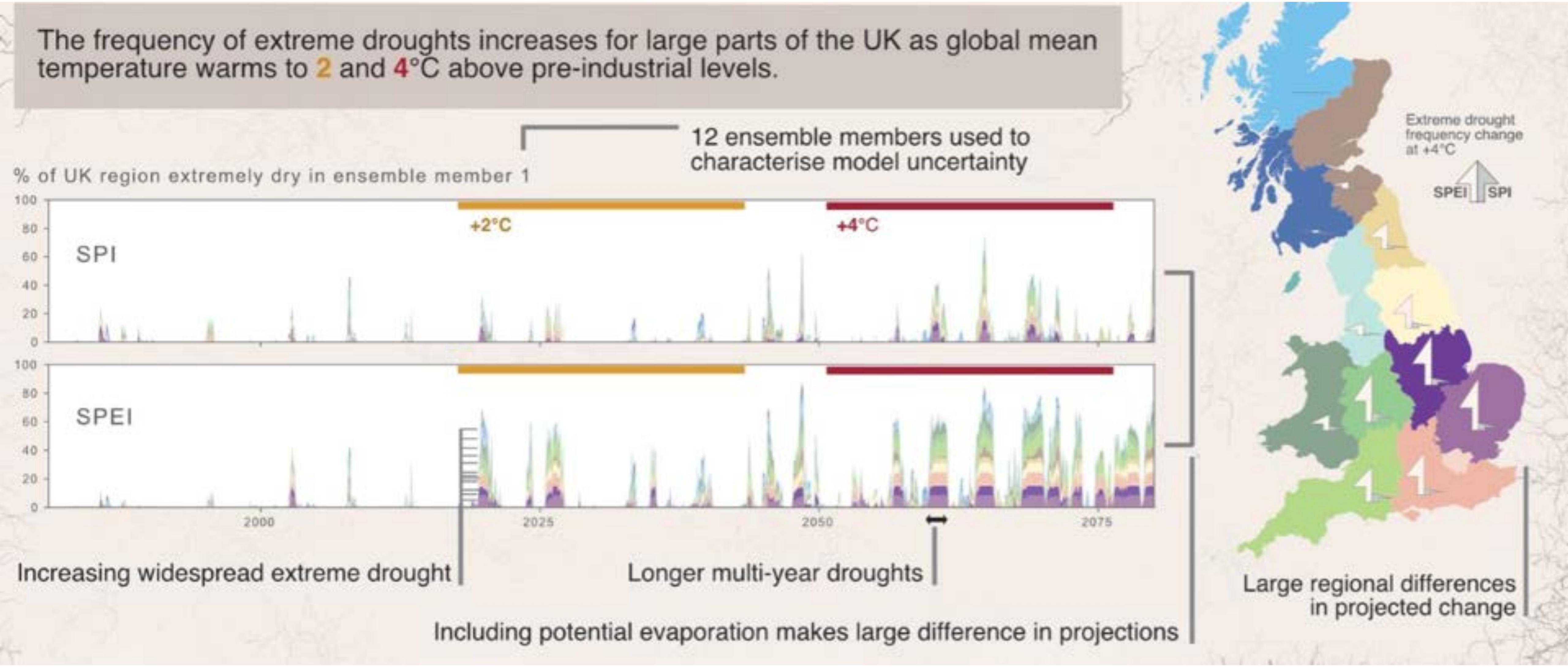
Higher nitrate levels and reduced ability to recover following the hot, dry summers of 2022 and 2025

Future projections & storylines, in 2°C+ worlds

Climate change projections

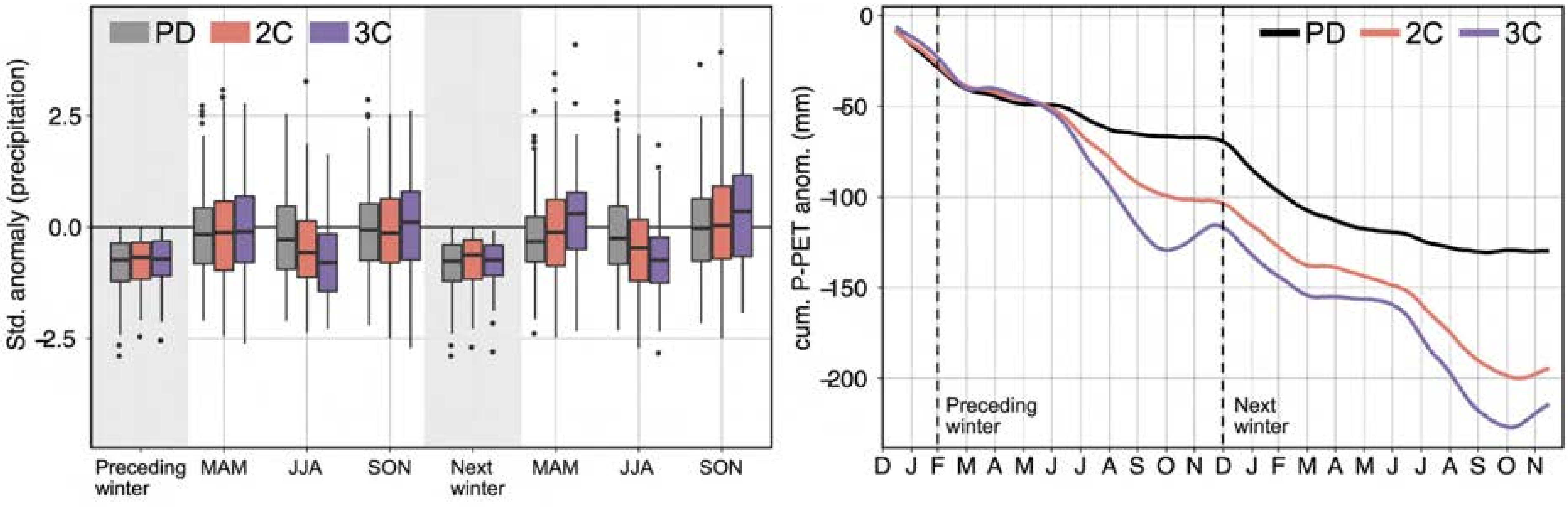


Source: Reyniers, N., Osborn, T. J., Addor, N., and Darch, G. 2023. Projected changes in droughts and extreme droughts in Great Britain strongly influenced by the choice of drought index, *Hydrol. Earth Syst. Sci.*, https://doi.org/10.5194/hess-27-1151-2023



Source: Reyniers, N., Addor, N., Darch, G., He, Y., Zha, Q., and Osborn, T. 2021. Understanding changes in meteorological drought in regional UK Climate Projections (UKCP18), EGU General Assembly 2021, online, 19–30 Apr 2021, EGU21-8713, https://doi.org/10.5194/egusphere-egu21-8713

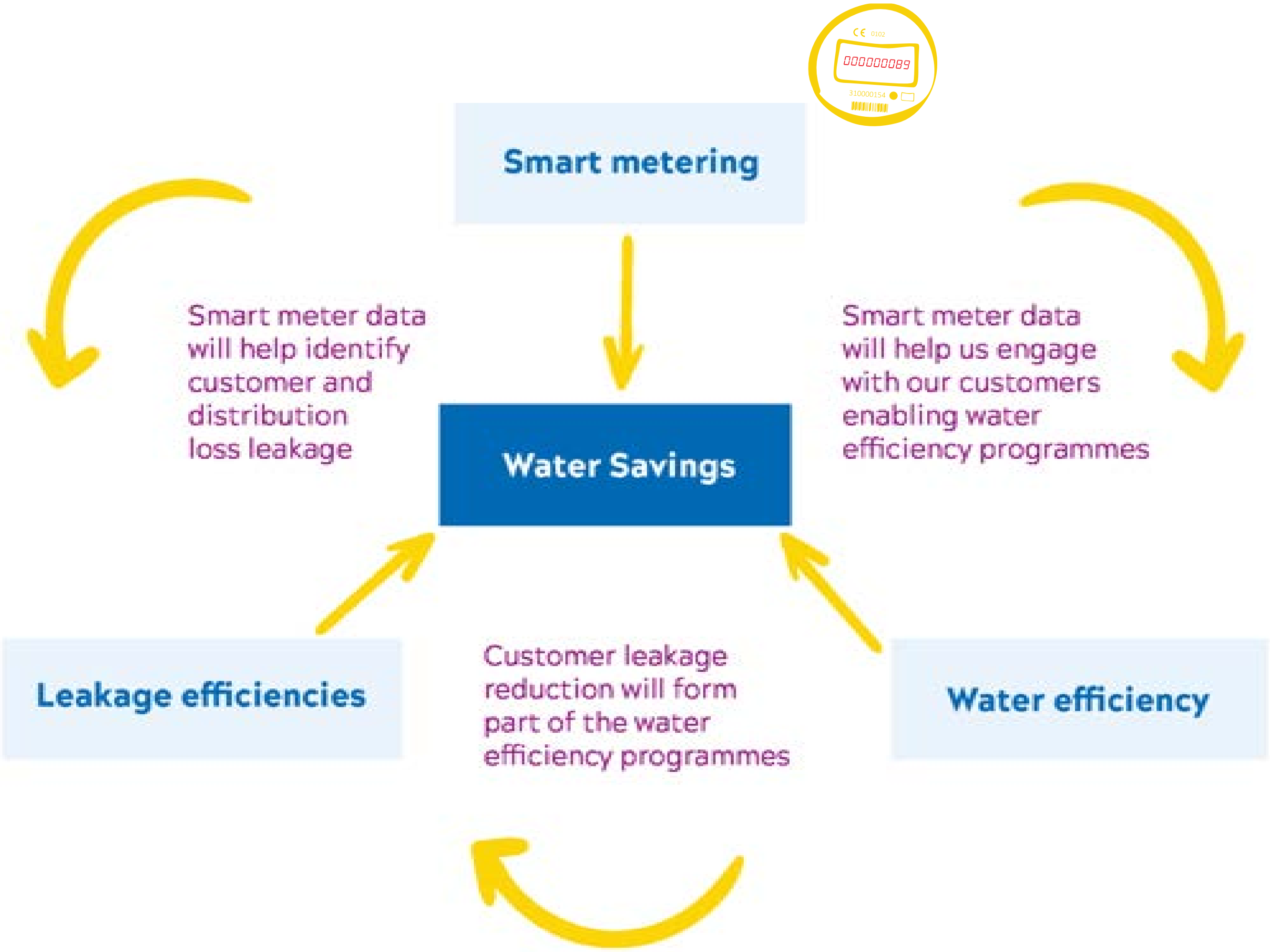
Storylines of climate change



Source: Chan, W. C. H., Arnell, N. W., Darch, G., Facer-Childs, K., Shepherd, T. G., Tanguy, M. and van der Wiel, K. 2023. Current and future risk of unprecedented hydrological droughts in Great Britain, *Journal of Hydrology*, 625, 130074, https://doi.org/10.1016/j.jhydrol.2023.130074

Adaptation:
resilience to changing droughts

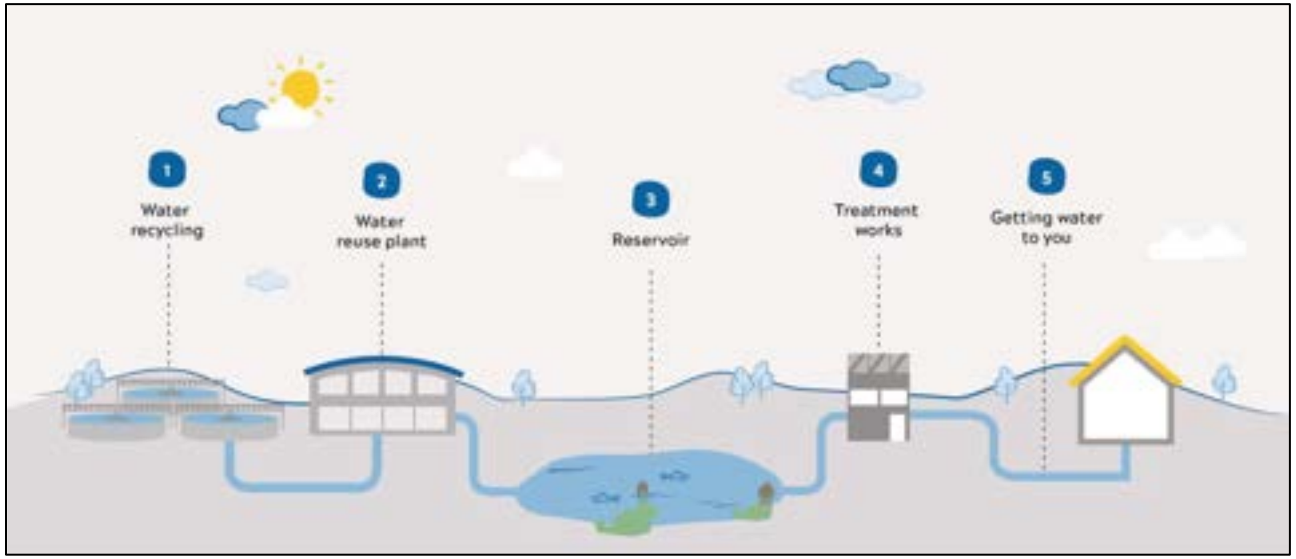
Demand management



New initiatives include:
- Compulsory metering
- Seasonal tariff trial
- Non-household tariff trial

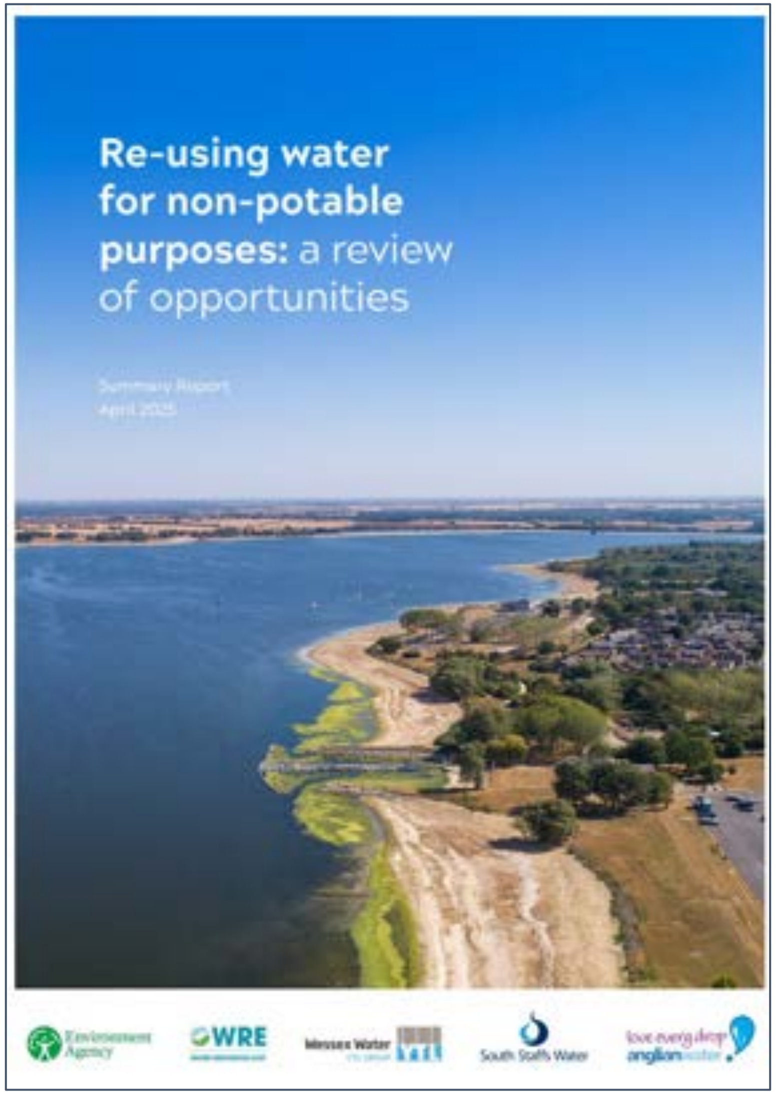
Future initiatives could include:
- Drought tariff
- Non-household water credit market

Water reuse and advanced water recycling



- Constructing advanced water recycling facility in Colchester
- Encouraging reuse for non-potable purposes, including reuse of final effluent for green hydrogen production

https://www.anglianwater.co.uk/corporate/strategies-and-plans/non-potable-water-reuse-a-review-of-opportunities/



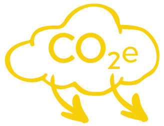
Additional storage

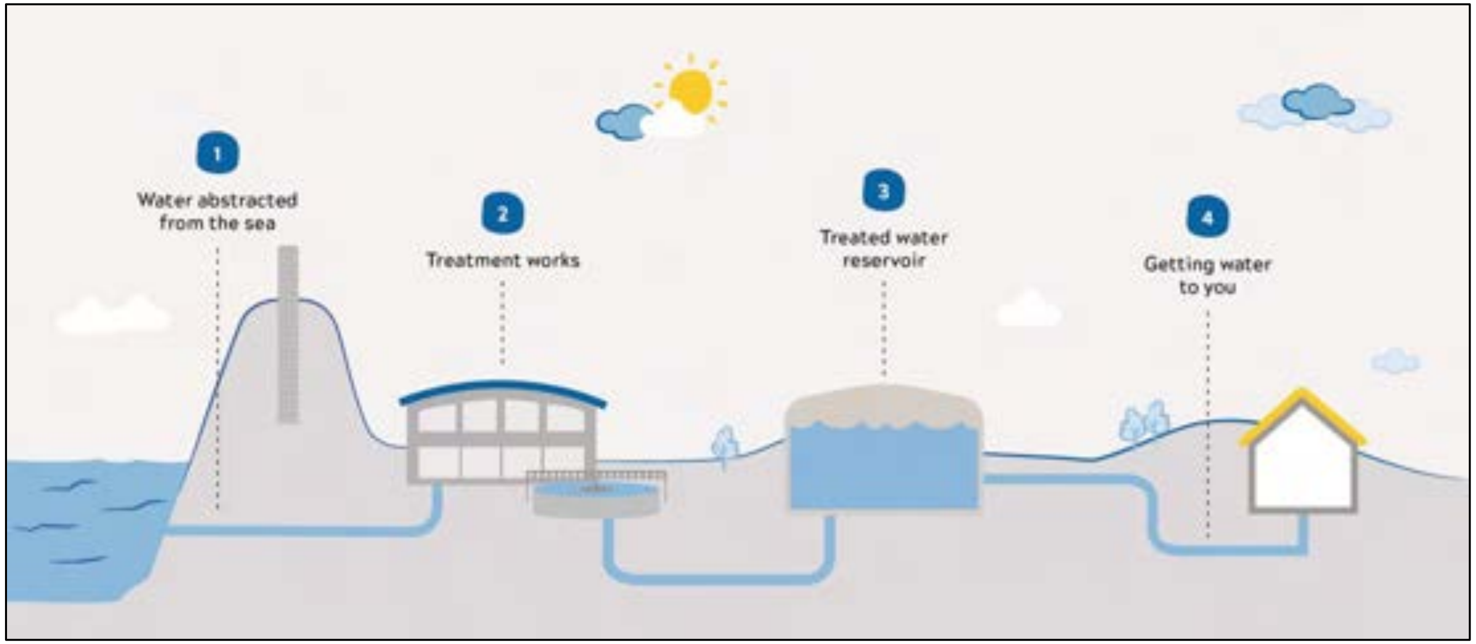
- Proposing to build two new reservoirs, with a total additional **100 million cubic metres** of usable storage
- **Fens Reservoir**, north of Chatteris, Cambridgeshire, with output shared between Anglian Water and Cambridge Water
- **Lincolnshire Reservoir**, south of Sleaford

Desalination

- Developing designs for **two desalination plants**, in Lincolnshire and Norfolk

- Likely to be used for **potable and non-potable** uses (e.g. green hydrogen production)





Summary

Summary

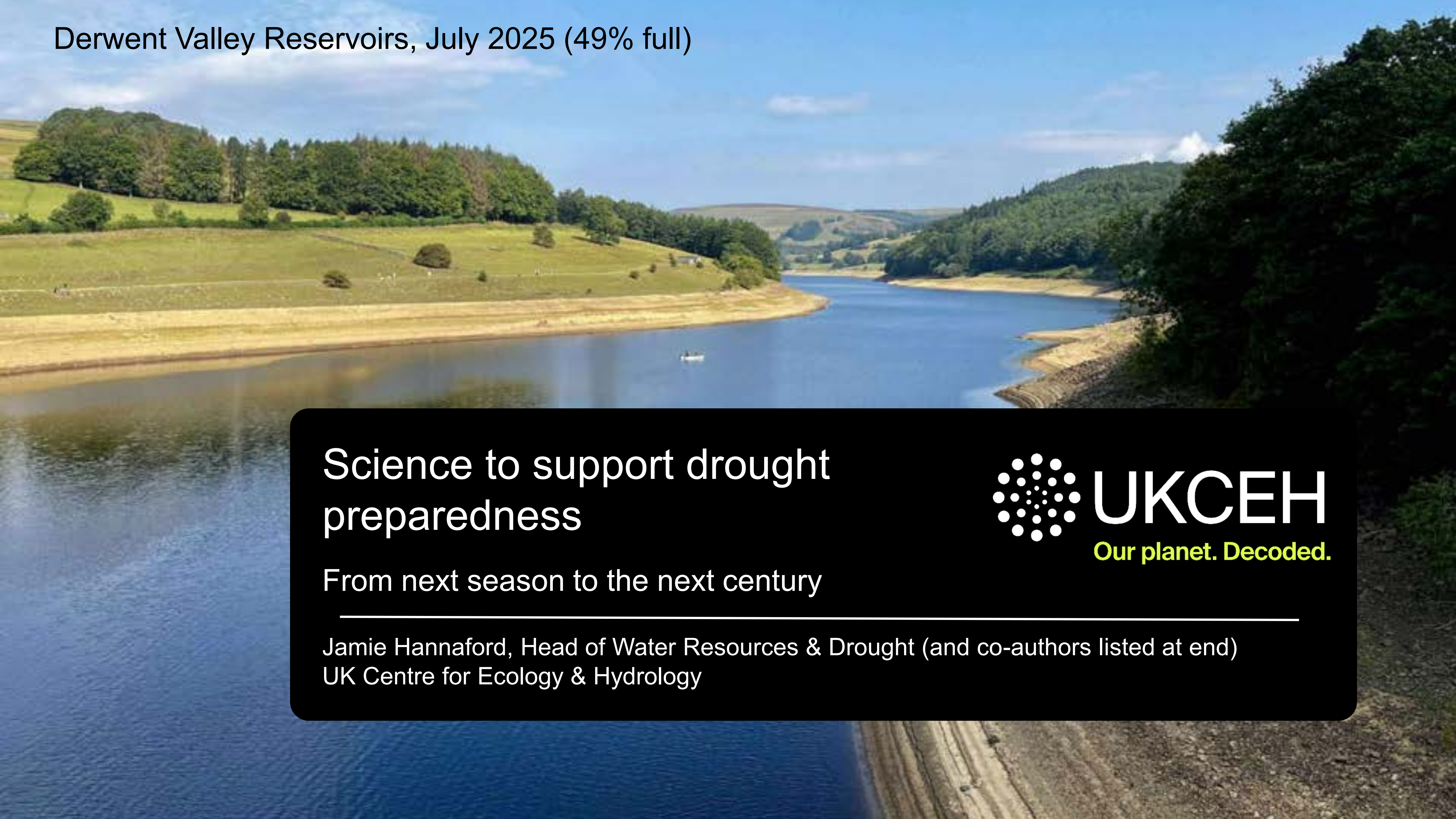
Drought is a recurrent feature of the English climate and **water supply systems have been designed to be resilient** to historical, c. 1 in 200-year droughts

The meteorological drivers of drought are becoming better understood, but **climate change will alter weather patters** and **exacerbate the risk of drought**

Resilience to extreme, c. 1 in 500-year drought depends on assessments that draw on a **wider variety of techniques** including proxies, reanalysis datasets, large ensembles and storylines

Demand management is already helping manage peak demand, and will become more sophisticated as smart meter rollout nears completion

Supply-side options will take advantage of generally wetter winters (reservoirs), existing sources (reuse and recycling) or proximity to the coast (desalination), **increasing drought resilience**



Derwent Valley Reservoirs, July 2025 (49% full)

Science to support drought preparedness

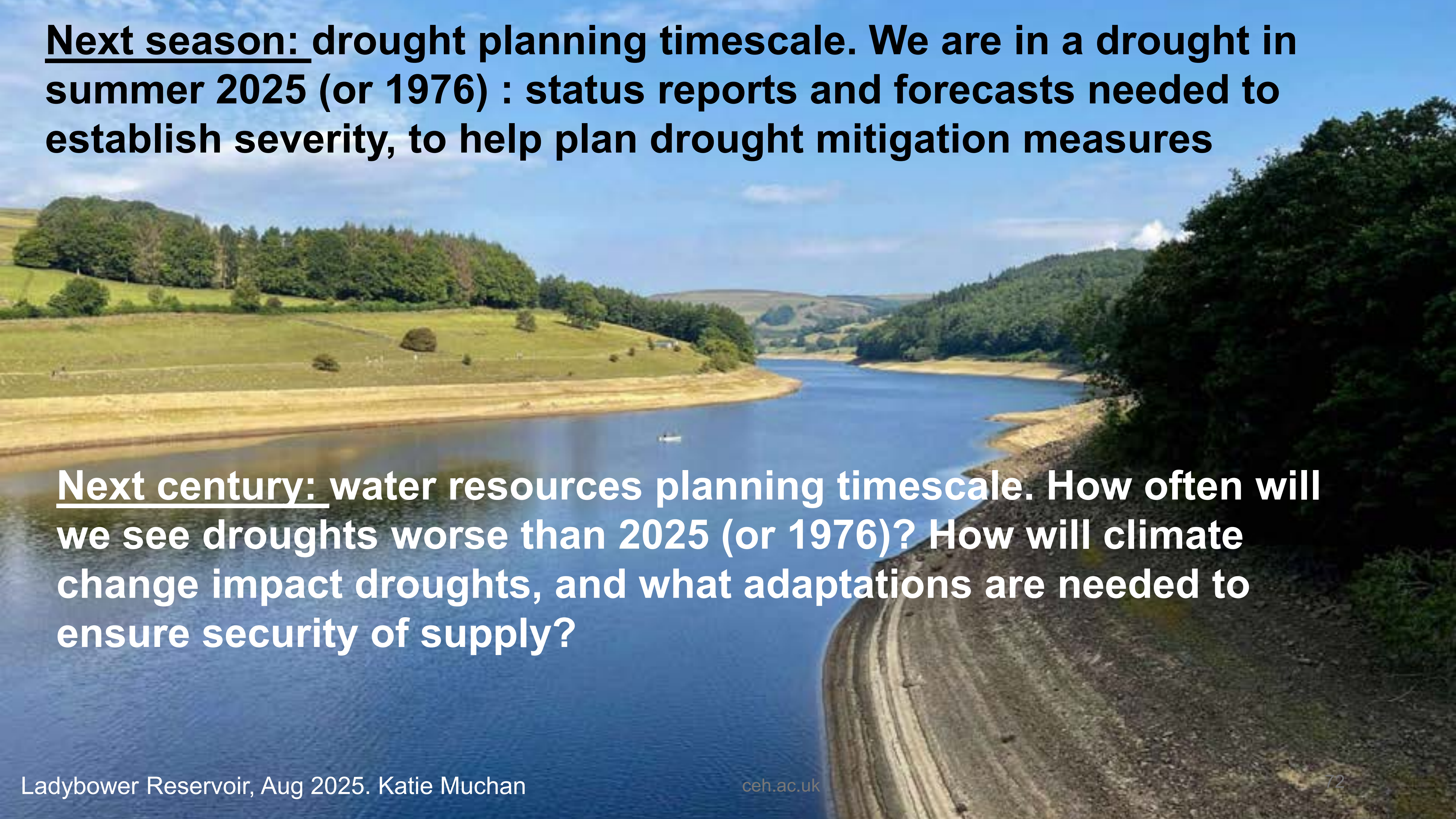
From next season to the next century

UKCEH
Our planet. Decoded.

Jamie Hannaford, Head of Water Resources & Drought (and co-authors listed at end)
UK Centre for Ecology & Hydrology

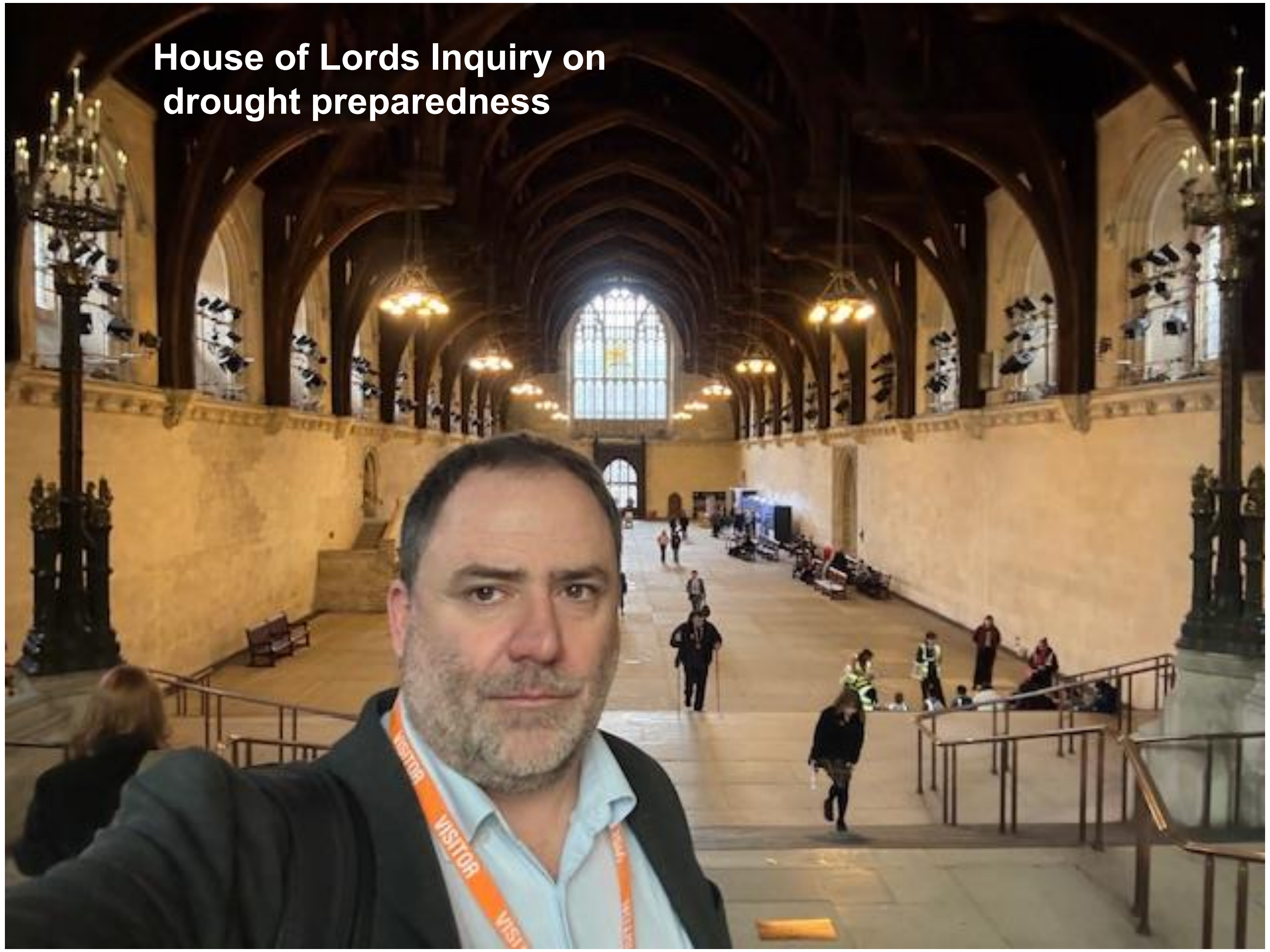
<u>Next season:</u> drought planning timescale. We are in a drought in summer 2025 (or 1976) : status reports and forecasts needed to establish severity, to help plan drought mitigation measures

<u>Next century:</u> water resources planning timescale. How often will we see droughts worse than 2025 (or 1976)? How will climate change impact droughts, and what adaptations are needed to ensure security of supply?



Ladybower Reservoir, Aug 2025. Katie Muchan

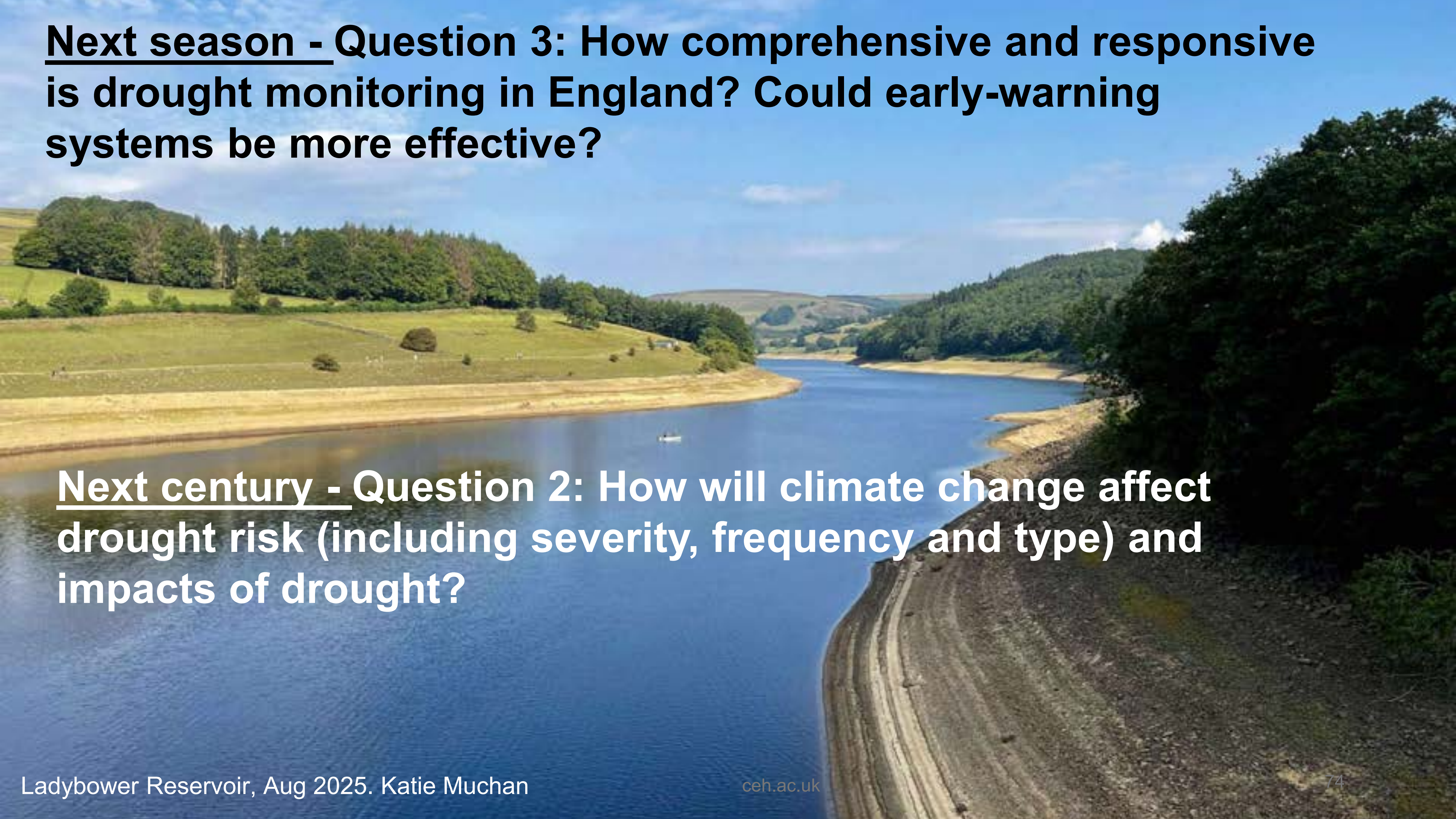
UKCEH



House of Lords Inquiry into drought preparedness: https://committees.parliament.uk/work/9406/drought-preparedness/

<u>Next season -</u> Question 3: How comprehensive and responsive is drought monitoring in England? Could early-warning systems be more effective?

<u>Next century -</u> Question 2: How will climate change affect drought risk (including severity, frequency and type) and impacts of drought?



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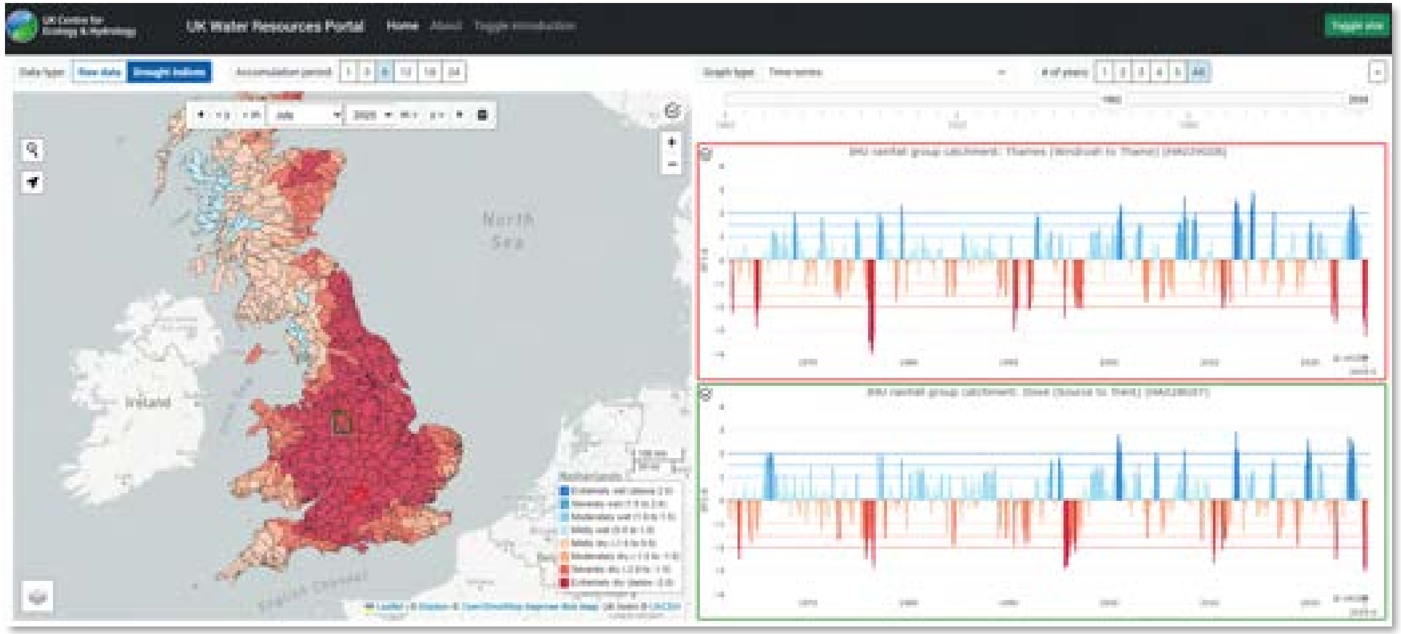
UKCEH

How effective is current monitoring and early warning?



Interactive, near-real-time monitoring since 2020:
UK Water Resources Portal: https://ukwrp.ceh.ac.uk/

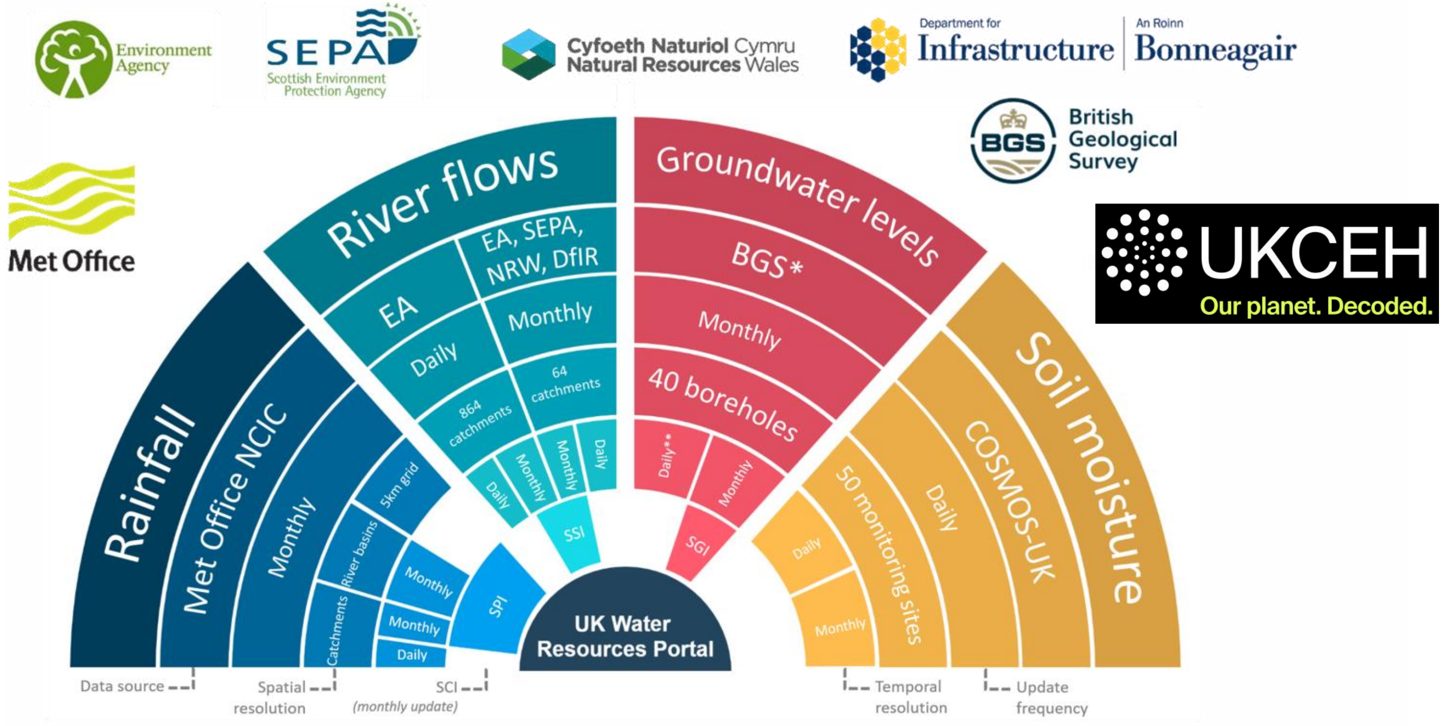
"We are actively promoting the use of the Portal via our drought teams and its referenced in our NRW drought plan… as a source for looking (at the) water situation"
Water Resources lead, Natural Resources Wales

"we use the portal…when water resources are tight. We manage increasing restrictions, and justifying that is backed up by stats from the Portal"
Principal Hydrologist, Canal and Rivers Trust

"I used the Portal during the 2018 drought. It was useful in showing how serious the situation was compared to the past. Data was used alongside other evidence on drought permit applications…."
Senior hydrologist, Yorkshire Water

The short version: current UK monitoring is world-leading, but we need to preserve it ("you can't manage what you don't measure")

How effective is current monitoring and early warning?



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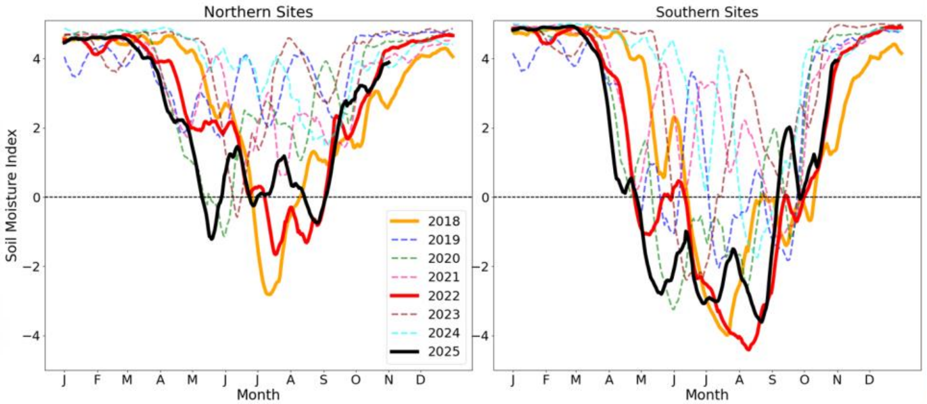
Gaps/Opportunities: what are we missing?

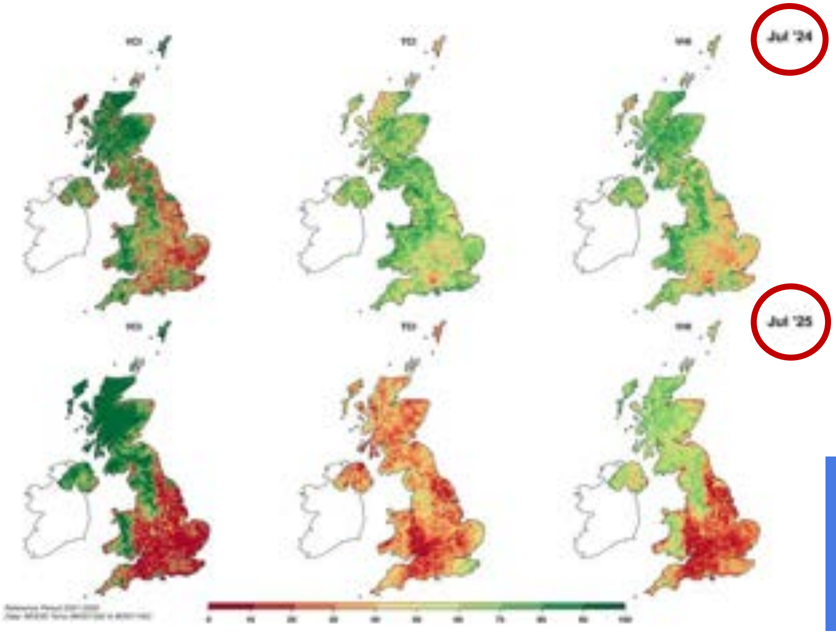


Magda Szczykulska
And the COSMOS-UK team

COSMOS-UK soil moisture in 2025. A revolution in soil moisture observing – but still only ~40 sites

Vicky Bell, Mark Rhodes Smith

Filling the gaps: with models
(Grid2Grid subsurface anomalies on Outlooks Portal, end Nov 2025)



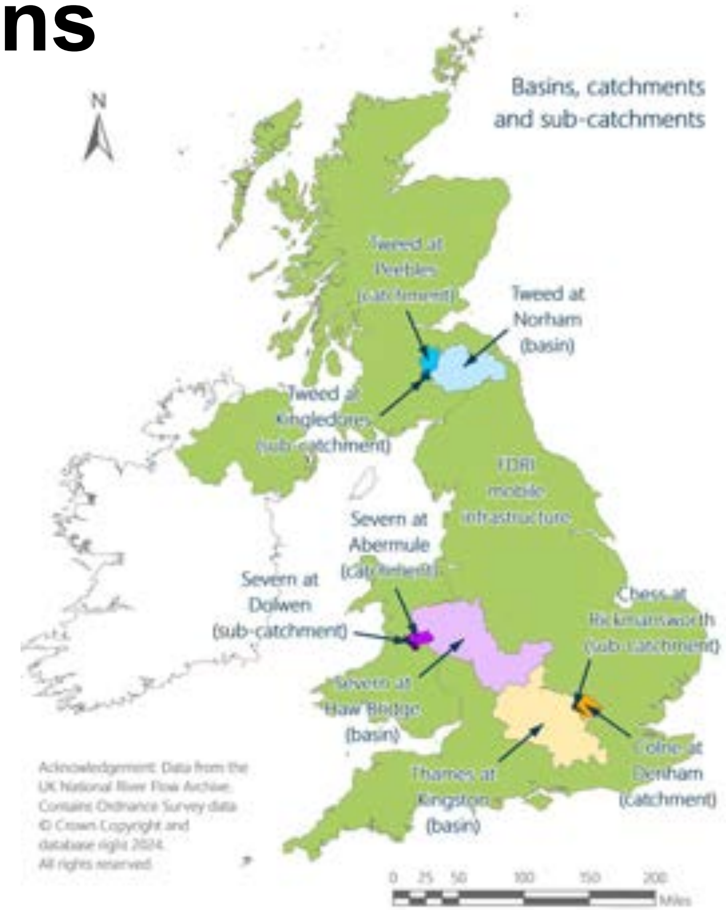
Filling the gaps: from space
(vegetation indices from MODIS)

Burak Bulut

Models and earth observation are powerful tools we need to make ready for prime time (complementing not replacing in-situ observations!)

For further information contact Jonathan Evans (jge@ceh.ac.uk)
or visit the FDRI website

Observations: future directions



DIGITAL

CAPACITY BUILDING

INNOVATION

FDRI will bring integrated observations of the terrestrial water cycle – a testbed for how to integrate observations during droughts

UKCEH

British Geological Survey

Met Office

Environment Agency

Cyfoeth Naturiol Cymru Natural Resources Wales

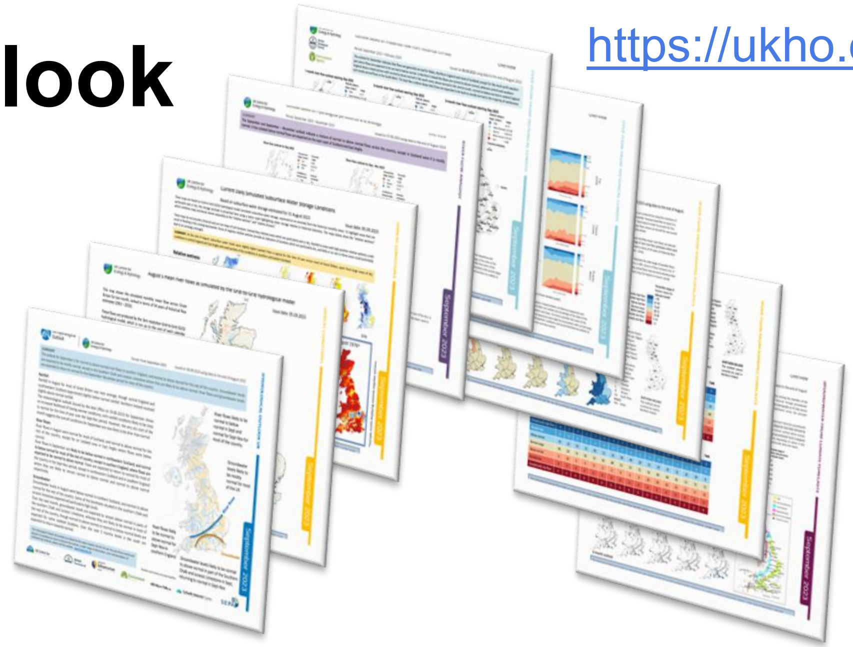
SEPA Scottish Environment Protection Agency

Department for Infrastructure An Roinn Bonneagair www.infrastructure-ni.gov.uk

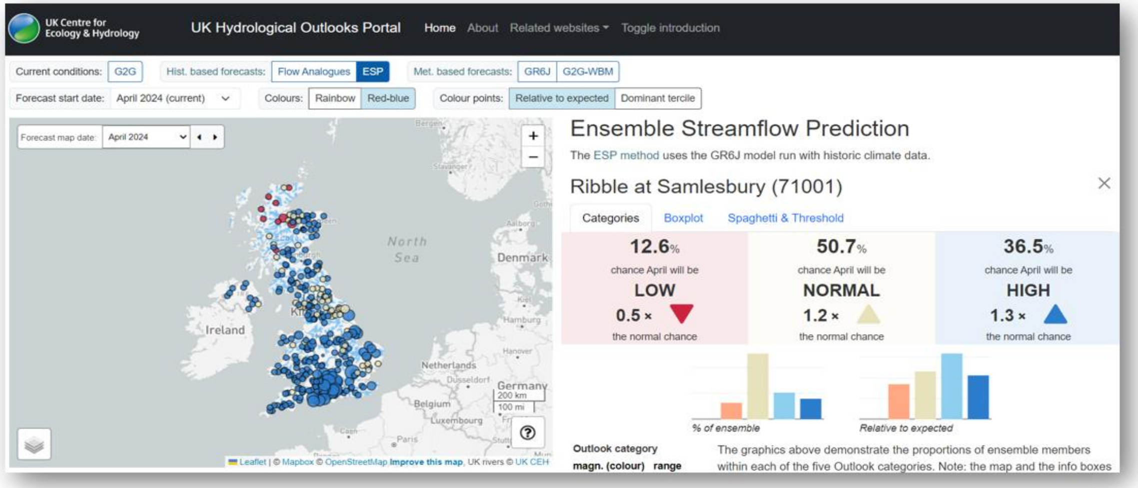
Forecasting: UK Hydrological Outlook

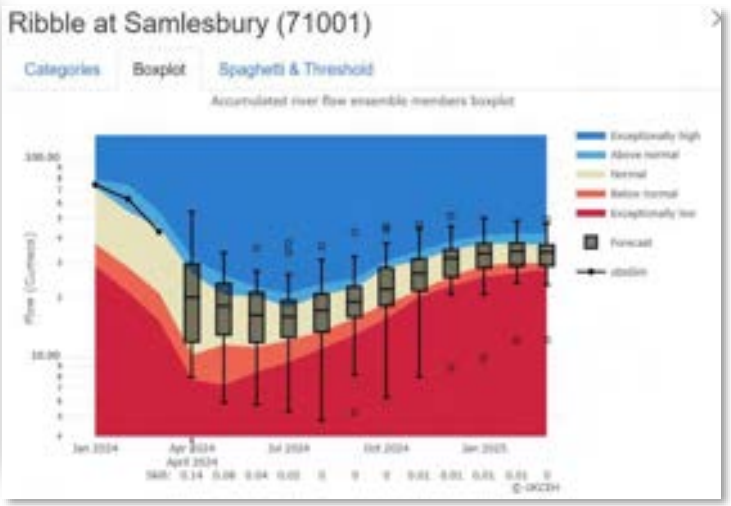
https://ukho.ceh.ac.uk/

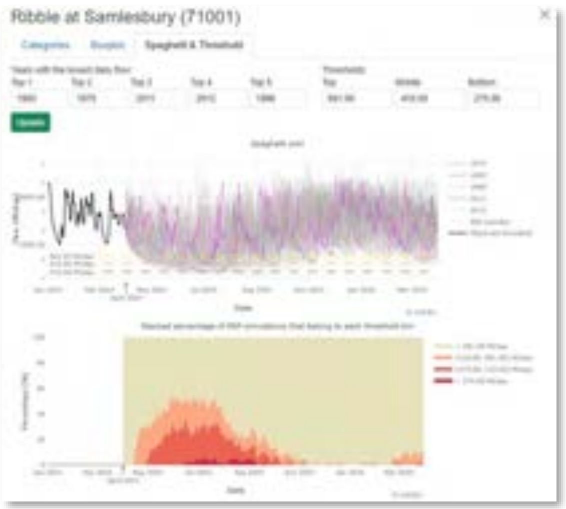
One of the world's first operational seasonal hydrological forecasting system – **initiated in 2013**



Interactive Outlook Portal



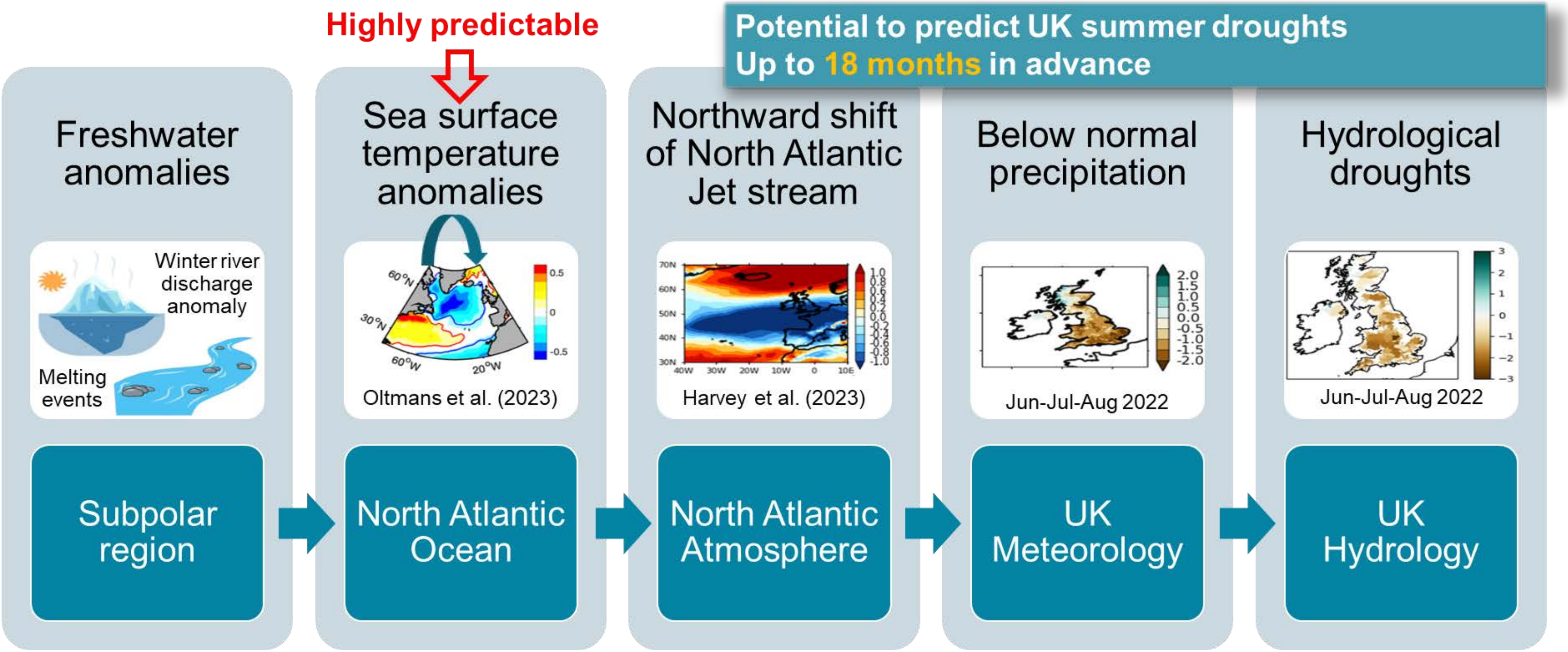




Gaps/Opportunities: improving our forecasts

Amulya Chevuturi et al. 2025
Nat. Comms Earth & Env't

Can we make reliable long-range forecasts of summer hydrology?



Promising avenues opening up for reliable forecasts across seasons and at long lead-times

Poster today….

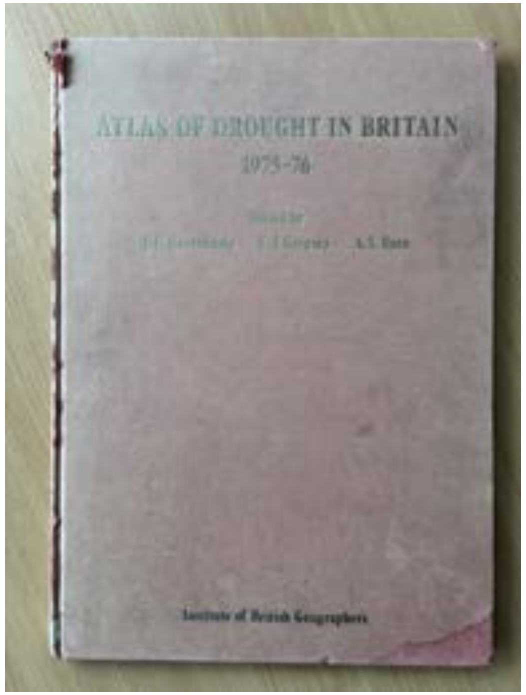
UKCEH Our planet. Decoded.

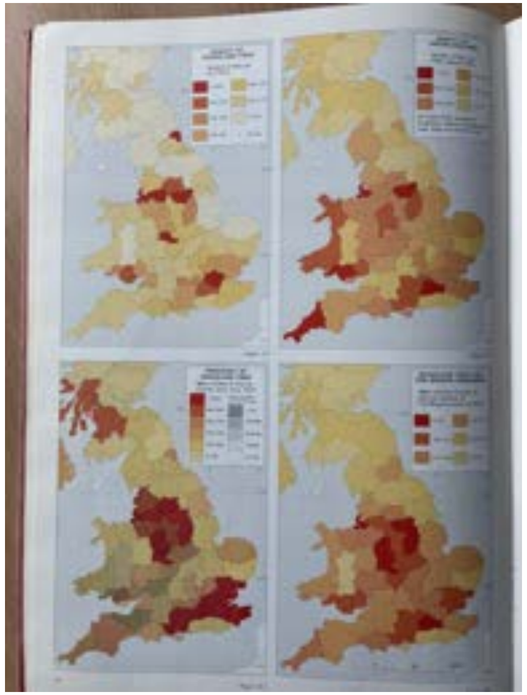
Could the 1976 UK Drought Have Been Predicted a Year in Advance?

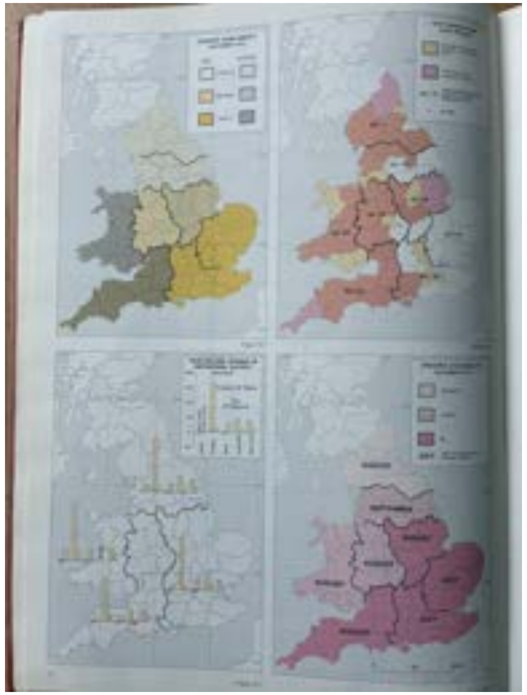
Amulya Chevuturi, Marilena Oltmanns, Wilson Chan, Eugene Magee, Maliko Tanguy, Cecilia Svensson, Ben Harvey, Jamie Hannaford

Gaps/Opportunities: impacts, the missing piece

House of Lords Summary: "Understanding the problem through better impact data and drought monitoring. Our understanding and response to drought is being undermined by a lack of data. We call on the Government to conduct a full environmental and economic assessment of drought to weigh the cost of inaction against the value of resilience. This should be supported by improved data collection and presentation, especially related to enhanced early warning systems"





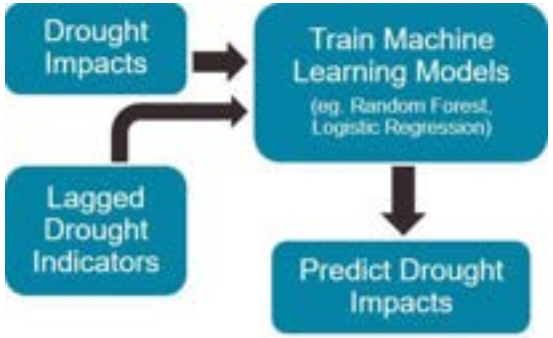


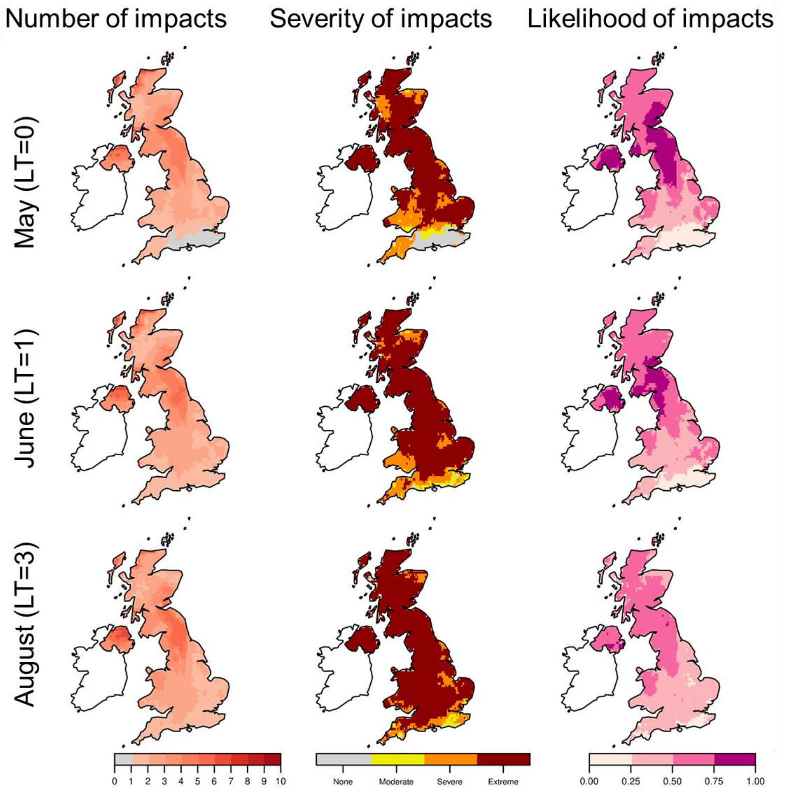
Atlas of the 1975 – 1976 drought. John Doornkamp et al. 1980

Gaps/Opportunities: impacts, the missing piece

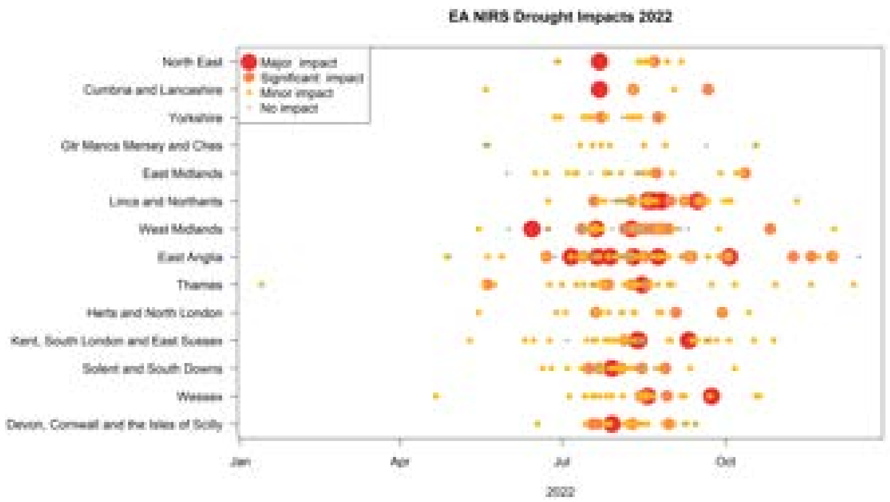
Iris Workshop May 2025

"The dual climate and biodiversity crises need new techniques to enable better resilience…Your emerging ability to forecast the impacts of drought will enable us to proactively anticipate, mitigate and reduce risk to nature recovery **(Jane Wilson, Natural England Drought Lead)**"





IRIS drought impact forecast (May – August 2025)
Burak Bulut et al. 2026

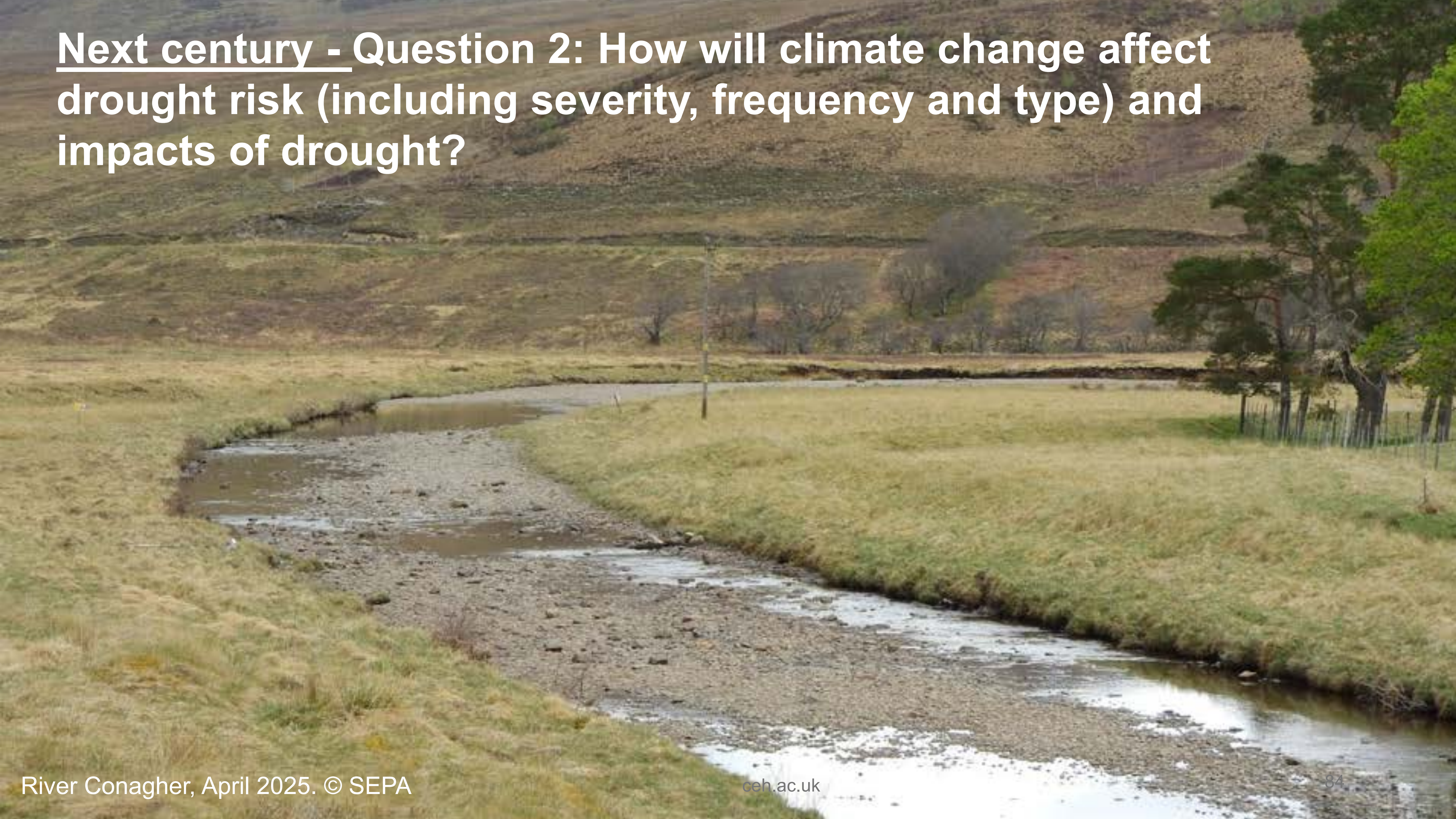


What next…?

- National Incident Reporting (NIRS)
- Natural England impacts monitoring
- UKCEH water quality monitoring
- Citizen science?
- Media reporting
- What else is out there?

The community is making inroads into impact-based warnings, but need coordination and investment to make this a reality

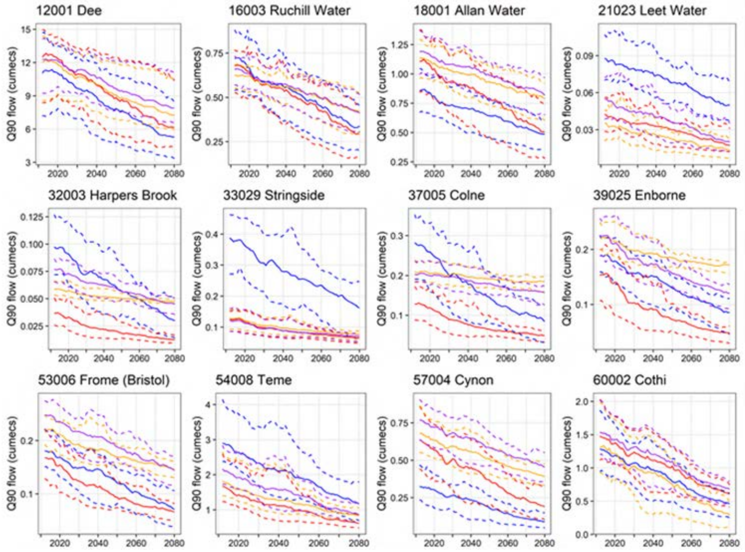
<u>Next century -</u> Question 2: How will climate change affect drought risk (including severity, frequency and type) and impacts of drought?



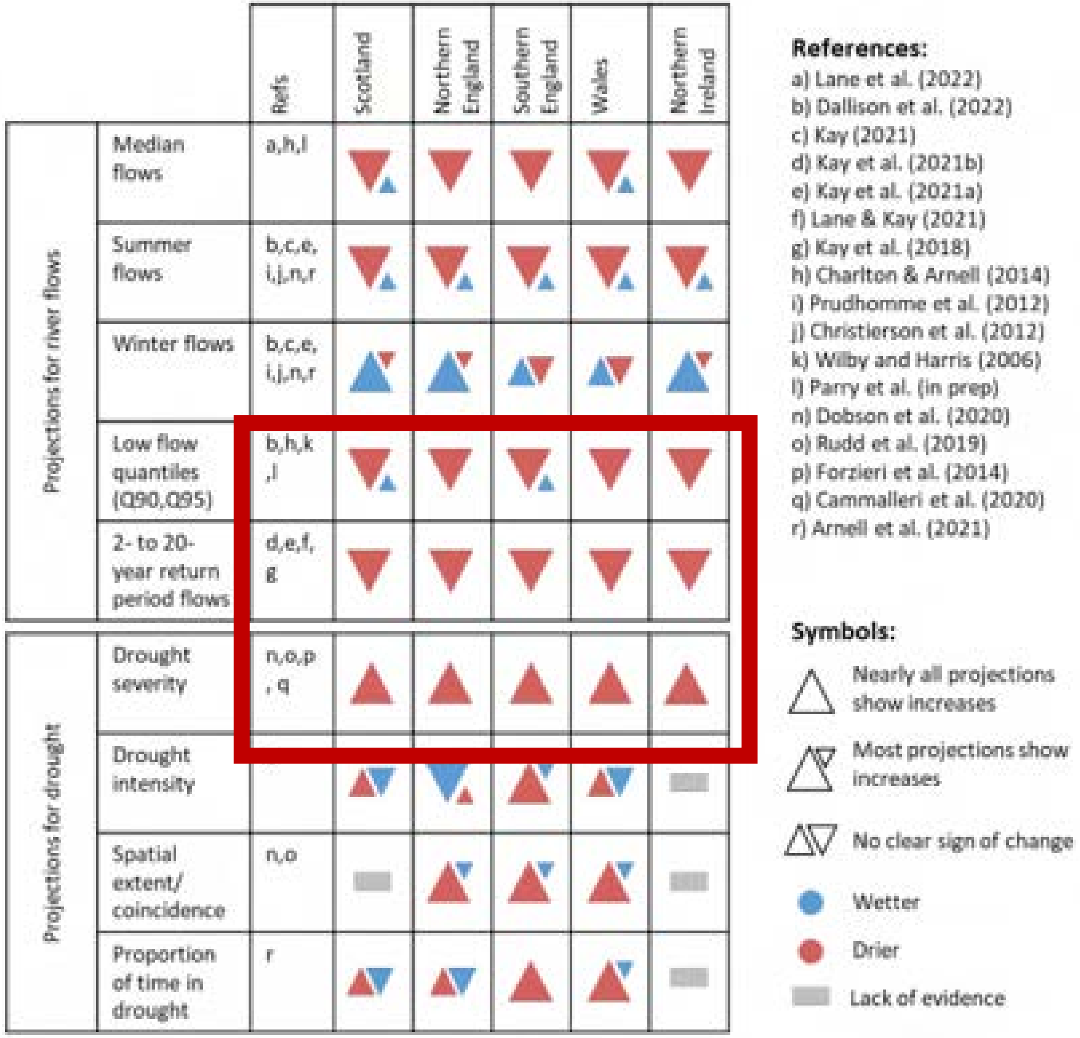
River Conagher, April 2025. © SEPA

UKCEH

What do we know?



Future summer low flows in the eFLaG projections based on UKCP18, 1980 – 2080 ([Parry et al. 2024](#))

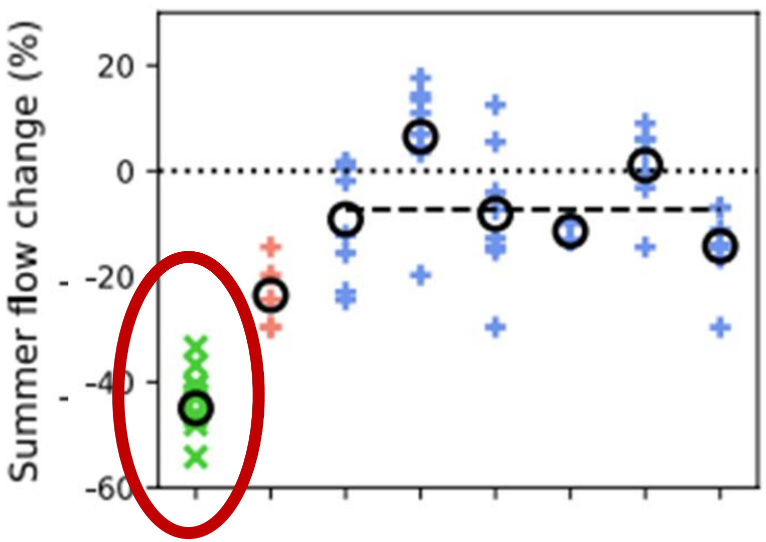


Rosie Lane, Alison Kay [(EA Review, 2023)](#)

All projections indicate worsening drought and diminishing low flows. But how low will they go?

What we don't know…

Clmate model uncertainties

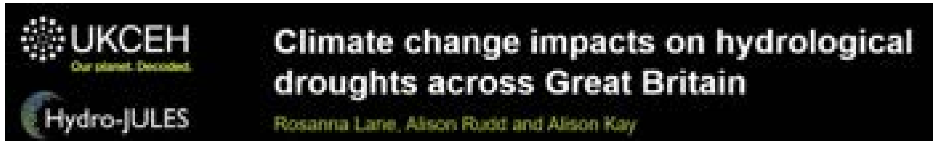


Comparing GB summer river flow changes from **UKCP18** (green) with other climate models from Euro-CORDEX (blue) Alison Kay et al. 2025

Hydrological model uncertainties

The Hydroprojections portal (in progess): Bringing together all UKCP18 community Hydrological model runs

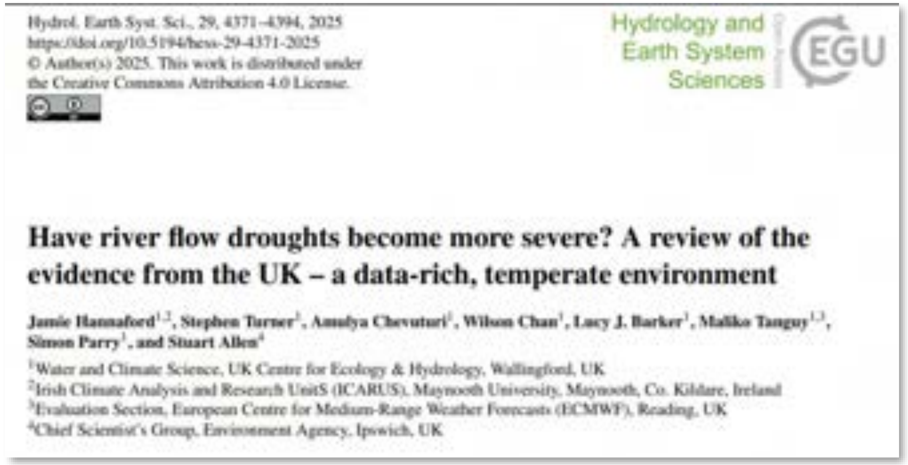
Poster today….



Community model intercomparison, 2026 (Rosie Lane, Helen Baron, Emma Robinson)

We need to bring all these different projections together to help decision makers explore the full range of uncertainties (and others not shown here!)

(And: have droughts *actually* become more severe…?)


Hydrol. Earth Syst. Sci., 29, 4371–4394, 2025
https://doi.org/10.5194/hess-29-4371-2025
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Hydrology and Earth System Sciences

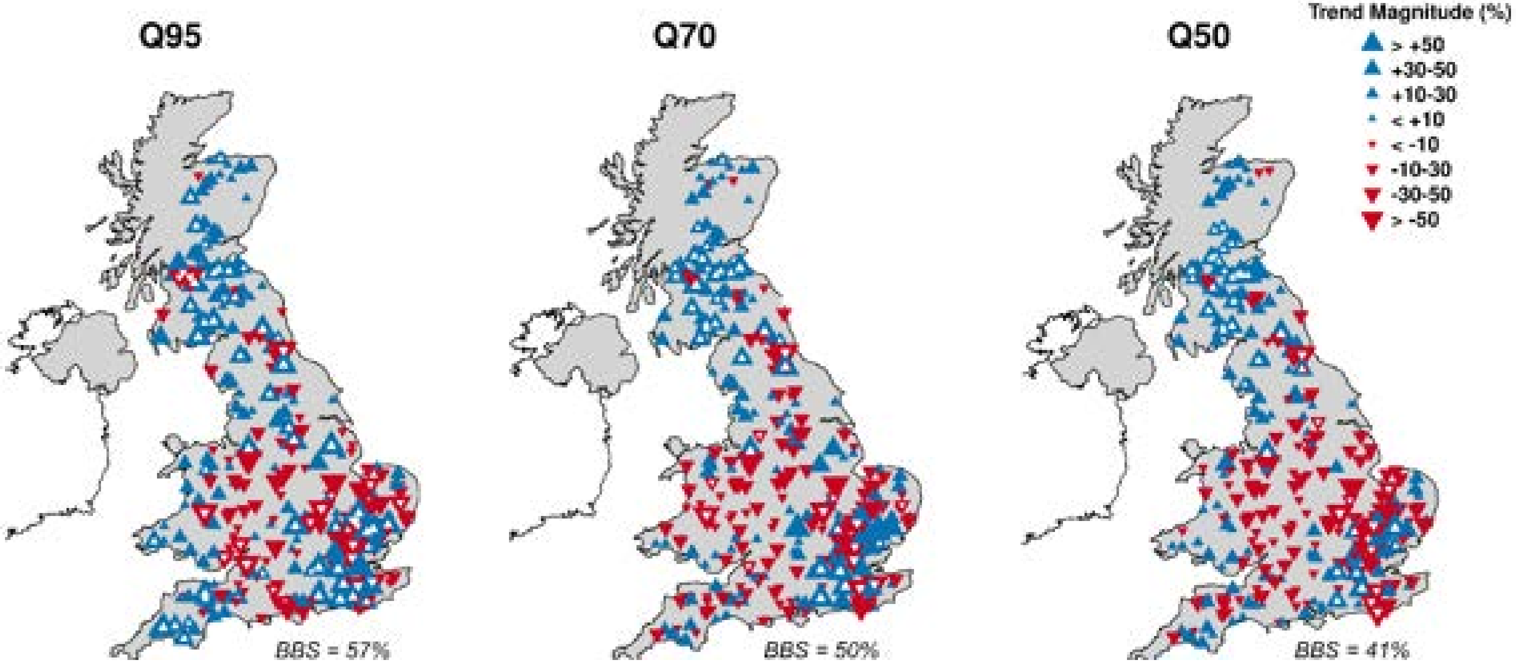
EGU

Have river flow droughts become more severe? A review of the evidence from the UK – a data-rich, temperate environment

Jamie Hannaford[1,2], Stephen Turner[1], Amulya Chevuturi[1], Wilson Chan[1], Lucy J. Barker[1], Maliko Tanguy[1,3], Simon Parry[1], and Stuart Allen[4]

[1]Water and Climate Science, UK Centre for Ecology & Hydrology, Wallingford, UK
[2]Irish Climate Analysis and Research UnitS (ICARUS), Maynooth University, Maynooth, Co. Kildare, Ireland
[3]Evaluation Section, European Centre for Medium-Range Weather Forecasts (ECMWF), Reading, UK
[4]Chief Scientist's Group, Environment Agency, Ipswich, UK

[Hannaford et al. 2025. HESS](#)

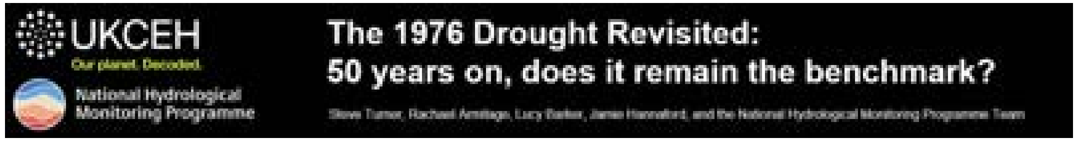


Trends in low flow indicators, 1965 – 2022

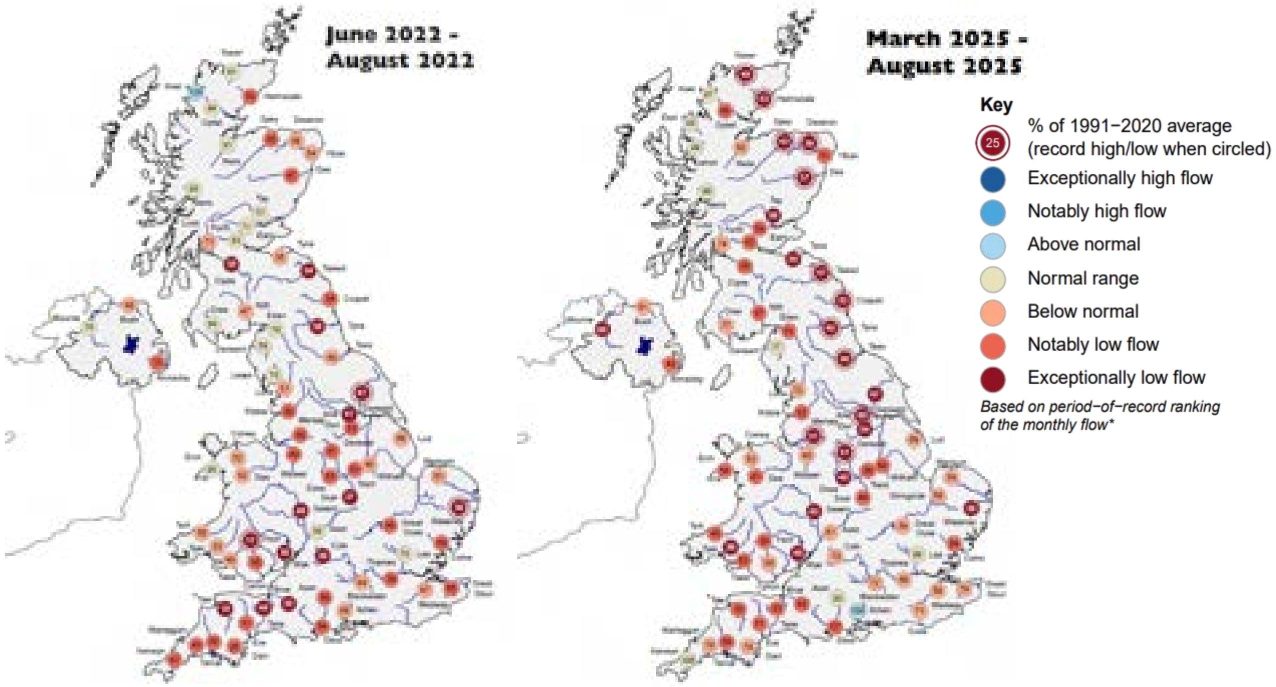
https://www.carbonbrief.org/guest-post-is-climate-change-making-uk-droughts-worse

A mixed picture. Little compelling evidence of worsening hydrological drought…

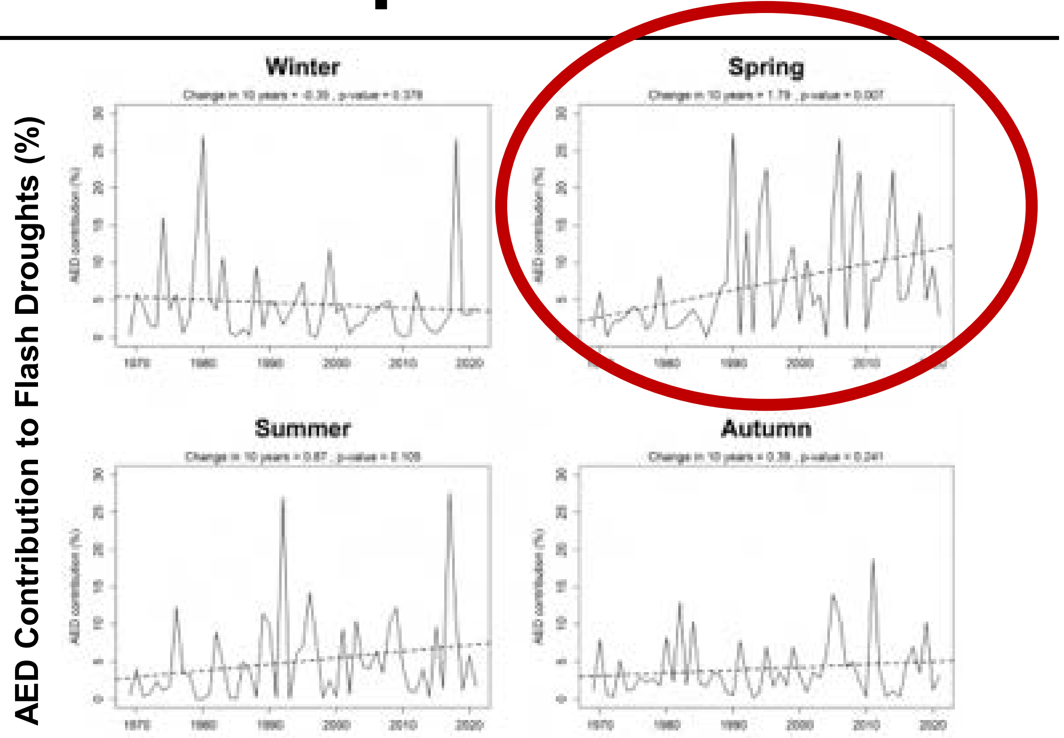
Poster today….



UKCEH But recent droughts are a ‘wake-up call’



Recent droughts ‘feel like something different’…
Spring/summer river flows in 2022 and 2025
(Lucy Barker et al. 2024; UKCEH, 2025)



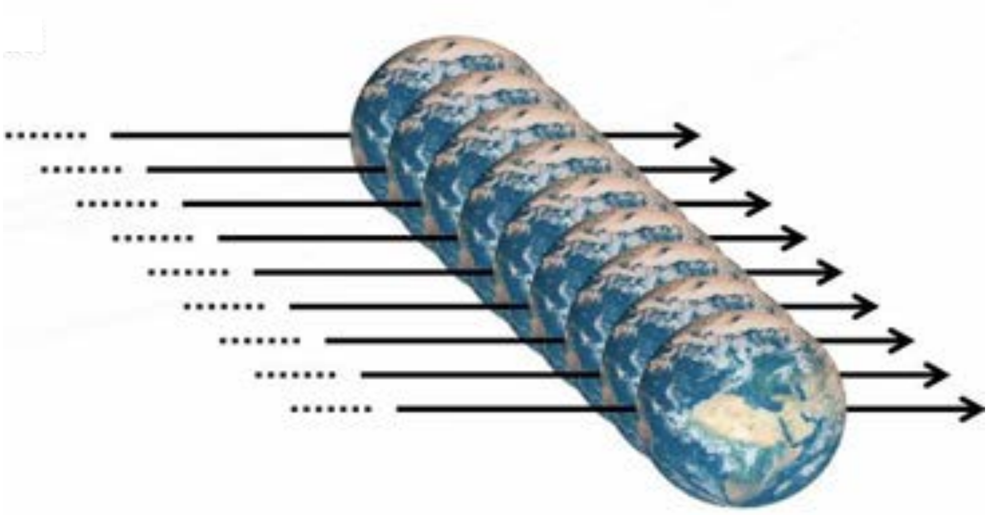
More of this: **Flash Droughts** and a growing role of Atmospheric Evaporative Demand (AED)
(Ivan Noguera et al. 2025)

...but rising temperatures ARE making droughts worse and this will continue in future!

Opportunities: we need to go large…

UKCEH

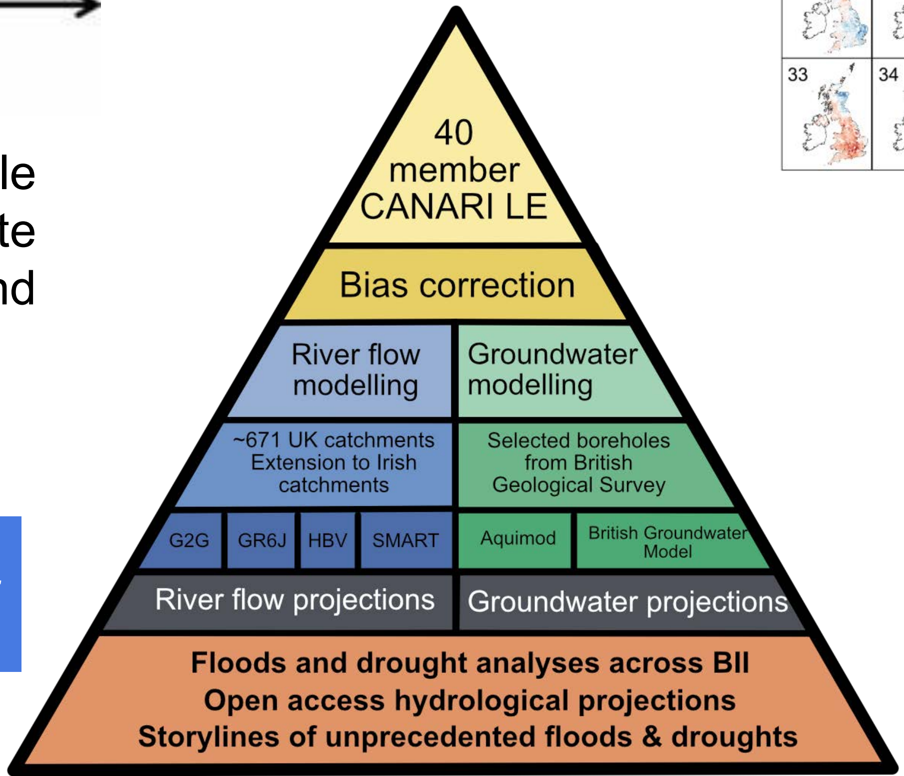
CANARI



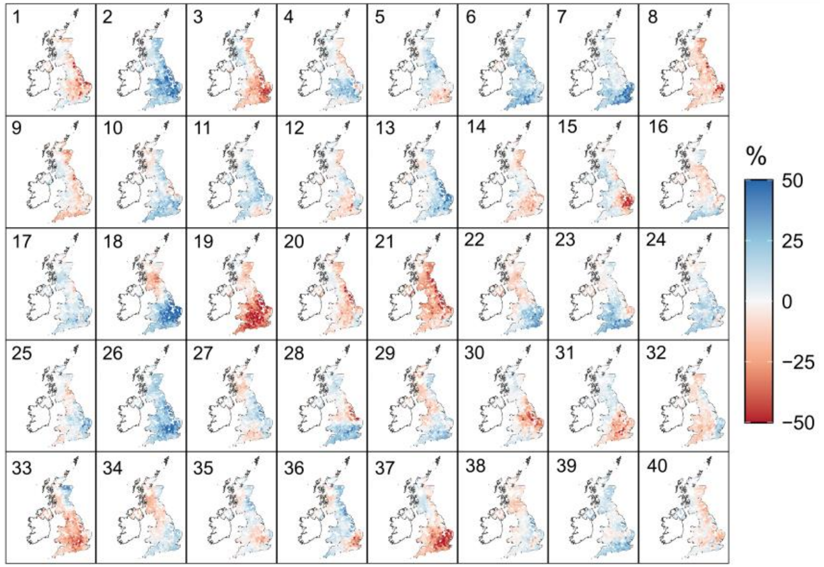
CANARI - UK's first Large Ensemble designed to explore the effect of climate variability on ***floods & droughts*** and ***dry-to-wet/wet-to-dry*** extremes)

canari.ac.uk

CANARI is a step-change in UK hydroclimate modelling: understanding a much wider range of variability



Wide range of possible hydrological trends in historical climate from the CANARI Ensemble (Wilson Chan)




Journal of Hydrology

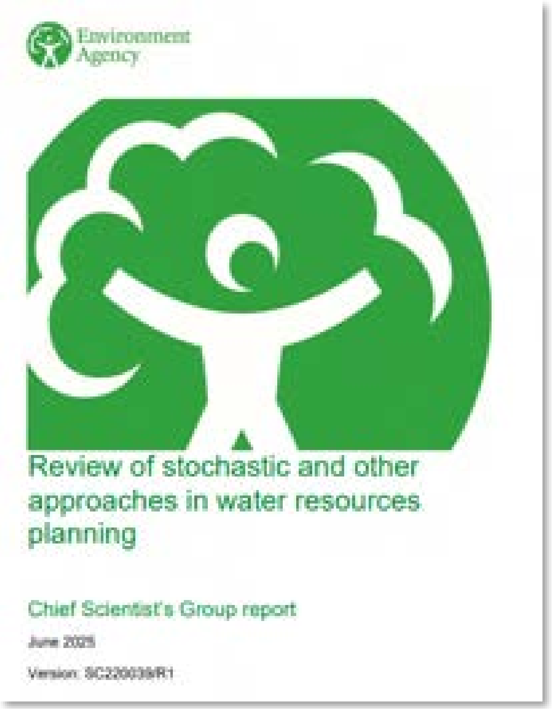
ELSEVIER

Climate variability conceals emerging hydrological trends across Great Britain

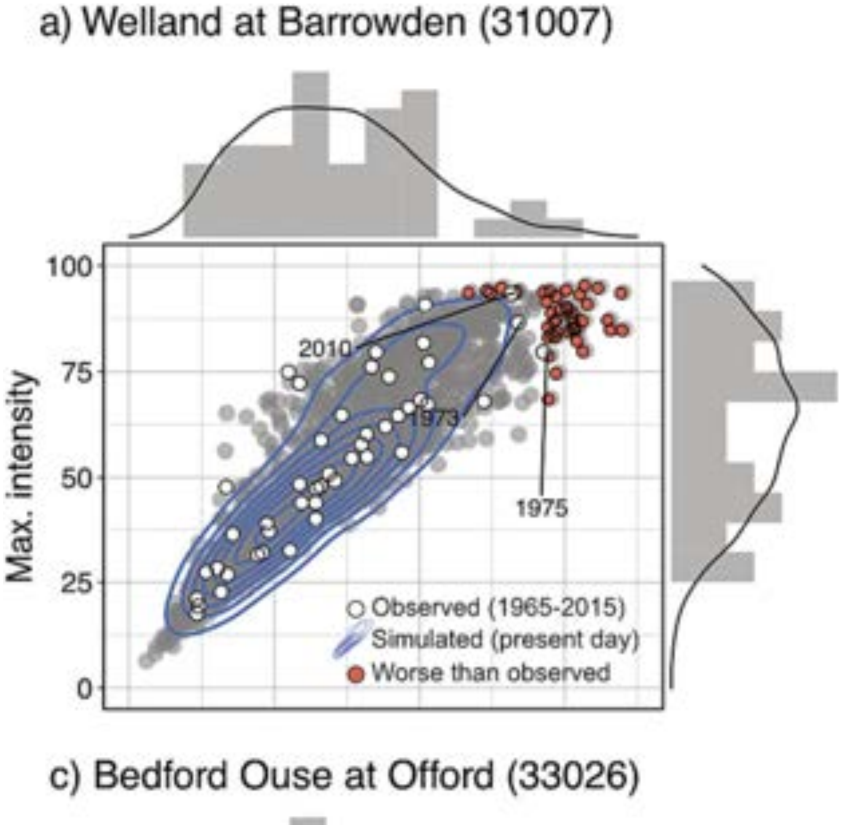
Wilson Chan et al. 2025

'Hydrological variability is large and under-sampled' and the past is just one realisation…

How can this help in water resources planning?



Review of stochastic approaches to planning – highlighted utility, but also shortcomings, and challenges of rigorously defining 1/500 year drought…



[Wilson Chan, Journal of Hydrology 2023:](#)
Using **Large Ensembles** to find plausible droughts worse than observed, now and in future

…but also highlighted potential for other approaches
Such as bottom-up methods based on Large Ensembles and physically-based ‘storylines’

Planning under deep uncertainty: Large Ensembles include a wider range of extremes for stress-testing. Storylines enable us to test our systems to the types of droughts that we are vulnerable to

Poster today….

UKCEH

Conclusion: Scientists and water planners need to come together to co-design next-generation approaches to improve drought preparedness on both timescales

Co-Centre for Climate + Biodiversity & Water
Ireland – UK investment of £30m 2024 - 2030
https://www.ukri.org/news/joint-funding-for-new-co-centres-on-climate-and-sustainable-food/

CO CENTRE Climate Biodiversity Water

love every drop anglianwater

Dŵr Cymru Welsh Water

[next season] How comprehensive and responsive is drought monitoring in England? Could early-warning systems be more effective?

Drought monitoring is very effective and the UK’s systems are world-leading (and we need to keep them that way)

But there are gaps and opportunities for imrprovement and we also **need to work together** to maximise the benefits from existing systems and design new ones that meets the needs of a wide range of users.

[next century] How will climate change affect drought risk (including severity, frequency and type) and impacts of drought?

We know climate change will worsen droughts, but there are significant uncertainties as to how big this problem will be.

Powerful new datasets and tools are becoming available that will help planning in this ‘deep uncertainty’ setting. We **need to work together** to demonstrate their potential and pave the way for ‘next generation’ planning approaches.

Thank you

UKCEH staff contributing
to House of Lords submission:

Lucy Barker, Wilson Chan, Amulya Chevuturi, Jonathan Evans, Katie Facer-Childs, Matt Fry, Alison Kay, Rosanna Lane, Gareth Old, Steve Turner, Phil Vincent, Glenn Watts

Also: Burak Bulut, Rachal Armitage, Eugene Magee, Magdalena Szczykulska, Gemma Nash

Funding:

- National Capability (NC UK)
- CANARI
- HydroJULES
- Climate+ Co-Centre
- IRIS

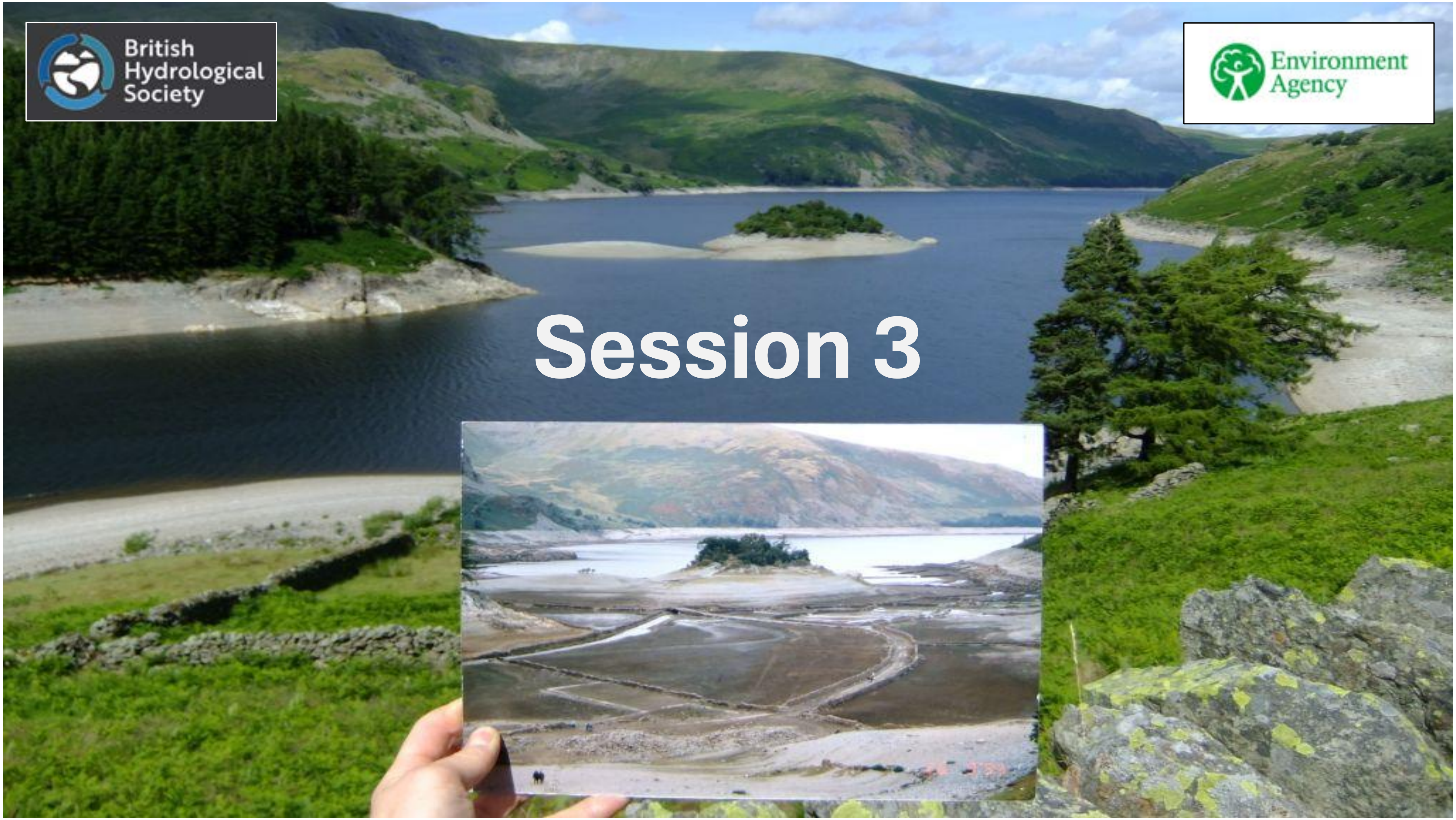
UKCEH
Our planet. Decoded.

Questions

Prof Dame Angela McLean
Government Chief Scientific Advisor

Dr Robert Bradburne
Environment Agency Chief Scientist


British Hydrological Society
Environment Agency
Lunch


British Hydrological Society
Environment Agency
Session 3

Getting into hot water: drought & heatwave impacts on river temperature

David M. Hannah[1], J.C. White[1], I.A. Malcolm[2], F.L. Jackson[2], K. Khamis[1], S.J. Dugdale[3], S. Krause[1], G. Garner[1], V. Ouellet[1], M. Finney[1], D. Eardly[1], Env. Agency, ETH-Zurich & collaborators

[1]Birmingham Institute for Sustainability & Climate Action and Geography, Earth & Env. Sciences, University of Birmingham, UK

[2]Scottish Government's Marine Directorate; [3]University of Nottingham

d.m.hannah@bham.ac.uk   www.bham.ac.uk/bisca

UNIVERSITY OF BIRMINGHAM | Birmingham Institute for Sustainability and Climate Action

UNESCO uniTwin unesco Chair

https://www.linkedin.com/in/david-m-hannah-63069914/

Digital artwork by Copilot

Summary

River water temperature exerts a fundamental control on freshwater ecosystem structure, function and services with cascading impacts on people, yet the processes governing extreme thermal conditions remain only partially resolved across spatial and temporal scales. Recent droughts have highlighted the tendency for low flow conditions to coincide with elevated river heating - producing significant thermal stress on ecosystems and for socio-economic activities. Process-based studies in temperate environments demonstrate that these river temperature extremes emerge from interacting controls: including non advective energy fluxes, reach scale habitat and hydraulic characteristics (such as residence time and riparian shading) and advective influences associated with fluctuating water source contributions (e.g. surface-groundwater interaction)s. Critically, the relative importance of these controls varies with catchment context, river network position and antecedent hydroclimatic conditions. There is also growing recognition that sustained periods of anomalously warm river temperatures, termed ‘riverine heatwaves’, represent an emergent and escalating climate risk. These events integrate atmospheric forcing, hydrological drought and internal river processes, but remain poorly captured by existing monitoring strategies and models.

This talk synthesises insights from drought-focused river temperature studies with the emerging riverine heatwave concept to develop an integrated perspective on extreme thermal conditions. We show how drought-driven mechanisms can propagate and persist across river networks, amplifying ecological impacts and risks to human systems. This demonstrates the urgent need for a process-informed framework to strengthen prediction, attribution and management of thermal extremes. The contribution emphasises the importance of interdisciplinary, multi-scale approaches to understand and mitigate intensifying thermal pressures on river ecosystems under climate and hydrological change.

For further details, please contact David at: **d.m.hannah@bham.ac.uk**

When the river runs dry:

Drought impacts on UK freshwater ecosystems. . .

Rachel Stubbington[1], Judy England[2]
and Romain Sarremejane[1]
[1]Nottingham Trent University
[2]Environment Agency

Photo: Environment Agency

Prof. Rachel Stubbington
rachel.stubbington@ntu.ac.uk

…in particular rivers and streams

…especially chalk streams

…including their 'winterbournes'

Fed by chalk aquifers in south and east England

Globally rare: ~85% in England

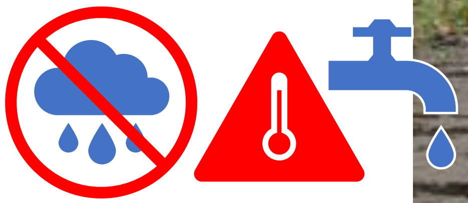
'Gin-clear' waters, salmon fisheries, riverflies

Photo: mine

…in particular rivers and streams

What is ecological drought?

- Drought is natural
- Climatic and human drivers[1]
- This talk: climatic drought in context of pressures e.g. abstraction

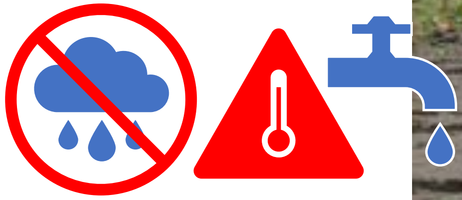


"…we need to **rethink the concept of drought** to **include the human role**"
(Van Loon et al. 2016)

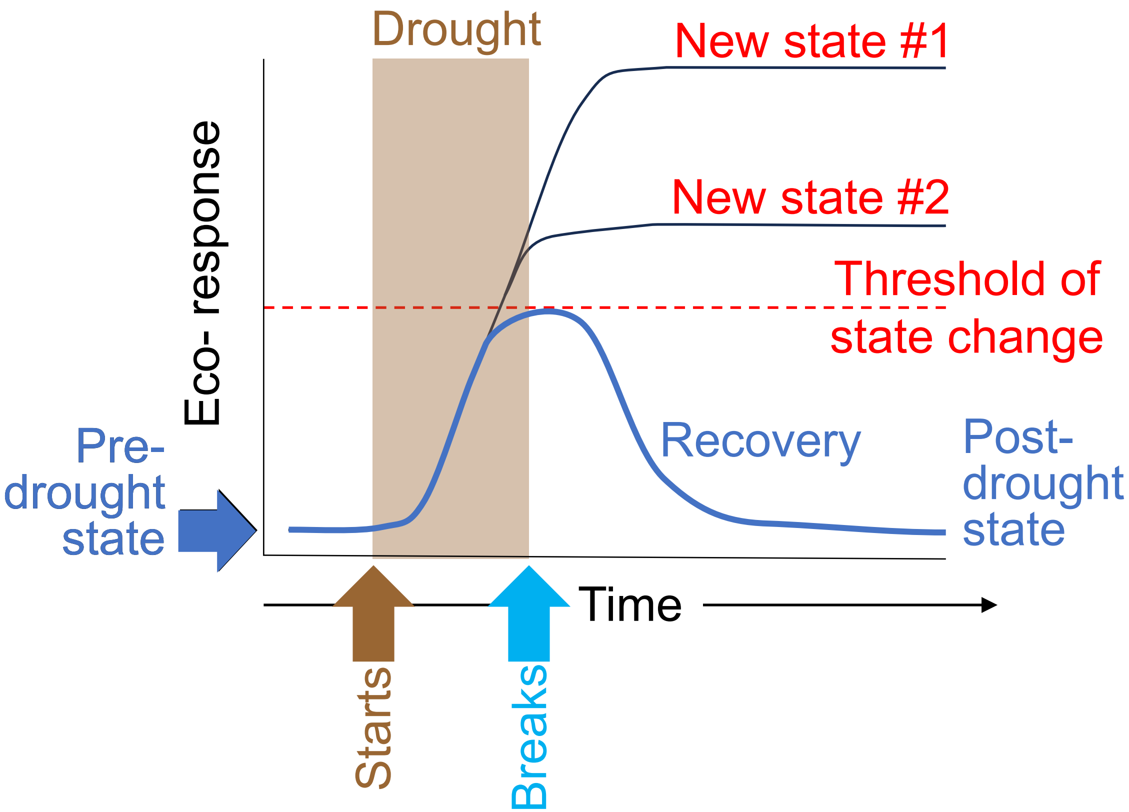
[1]Van Loon et al. 2016. *Nat. Geosci.* **9:** 89–91.

What is ecological drought?

- Drought is natural
- Climatic and human drivers[1]



- This talk: climatic drought in context of pressures e.g. abstraction
- Ecological definitions emphasize <u>persistent</u> impacts on organism- to- ecosystem-scale structure/function
- But in rivers, recovery is typically rapid
- Eco- drought is better defined based on <u>severe</u> impacts[2]



[1]Van Loon et al. 2016. *Nat. Geosci.* **9:** 89–91.
[2]Smith 2011. *J. Ecol.* **9:** 656–663.

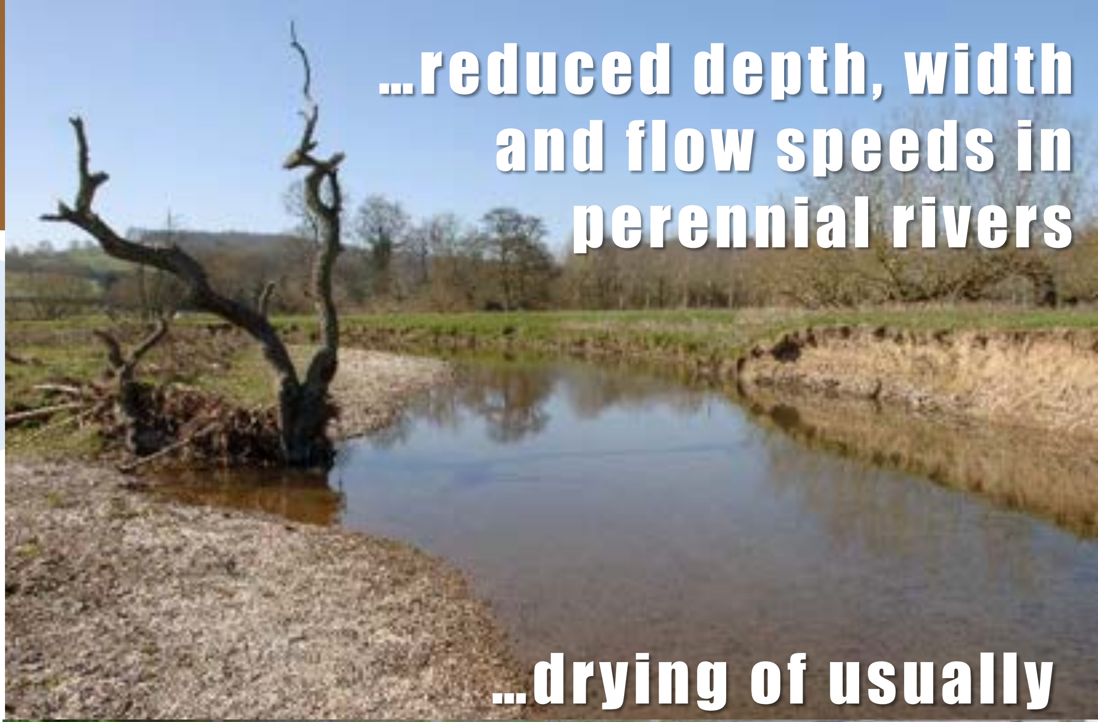
How does hydrological drought unfold in rivers and streams?

To a river, drought is typically prolonged and notably low flows and drying…

A typical sequence[1] as depths and/or flow speeds decline:

- Marginal vegetation isolated
- Fast-flowing, gravelly riffles lost
- Connected water/pools/ surface water/subsurface water lost

Habitat diversity, extent & connectivity decline, especially in natural systems



[1]Boulton 2009. *Freshwater Biol.* **48:** 1173–1185.

Droughts have short-term(?) negative effects on freshwater biodiversity

- **Richness[1]** and **abundance** of sensitive species **decrease** as flow declines
- Low flows may disrupt life cycles of fish including salmon – and cause **fish kills**
- If rivers stop flowing or dry, **aquatic animals die**

Photo: Tim Flood

As flow declines, water crowfoot is outcompeted. As a result, insects including riverflies decline whereas midge larval thrive

Photos: Nigel Howard-Jones

[1]Species richness i.e. the number of species

Droughts have short-term(?) negative effects on freshwater biodiversity

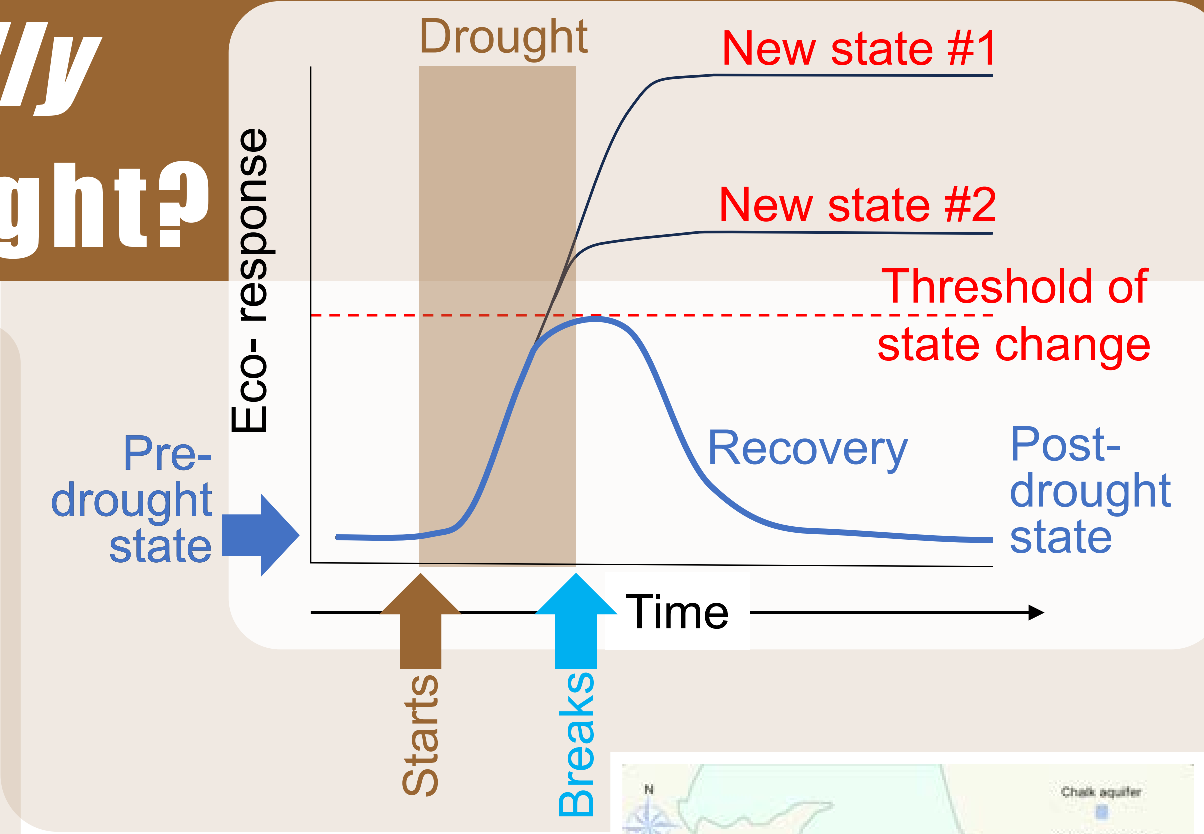
- **Richness**[1] and **abundance** of sensitive species **decrease** as flow declines
- Low flows may disrupt life cycles of fish including salmon – and cause **fish kills**
- If rivers stop flowing or dry, **aquatic animals die**
- Community-level **recovery** appears to occur in weeks to 1–3 years
- **Loss** of some species may be long-term or **permanent**

[1]Species richness i.e. the number of species

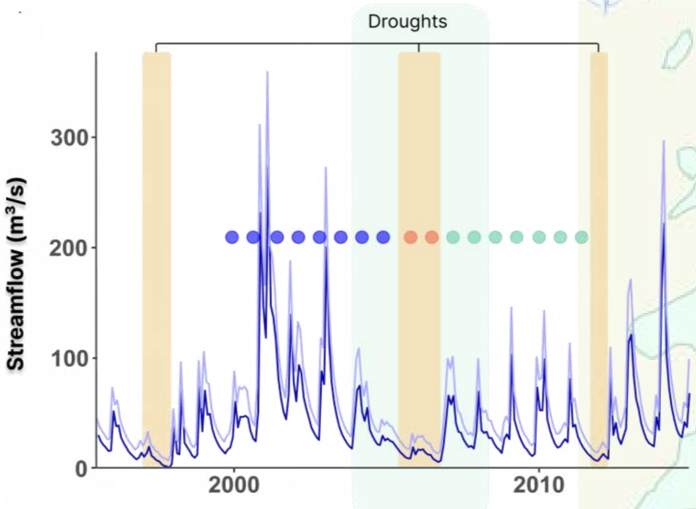
Do river communities *really* recover quickly from drought?

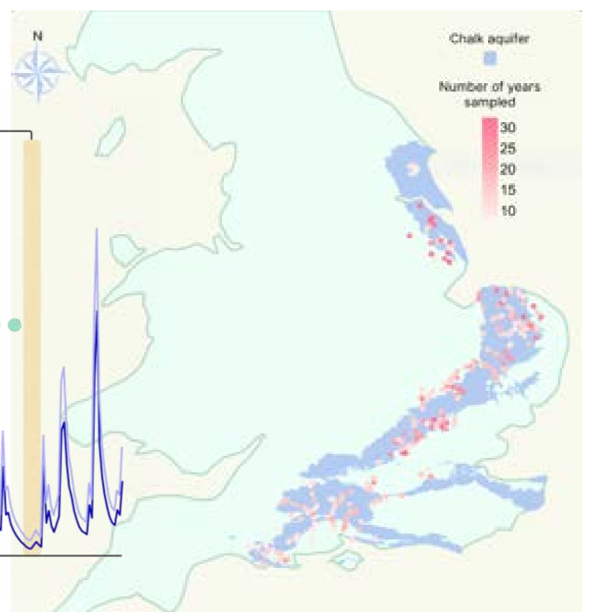
Research suggesting rapid post-drought recovery:

- lacks pre-drought data
- is based on data from 1 or few years
- considers 1 or few sites



We[1] used Environment Agency aquatic invertebrate community + flow data to study large-scale (chalk-wide), long-term (30 years) patterns…



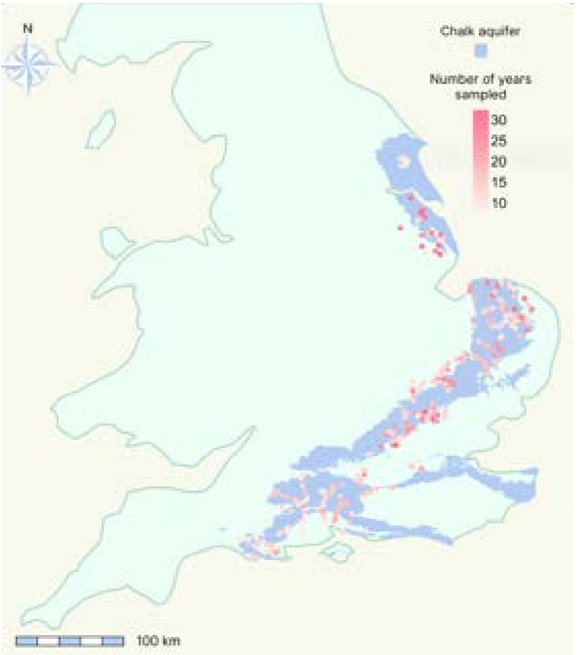


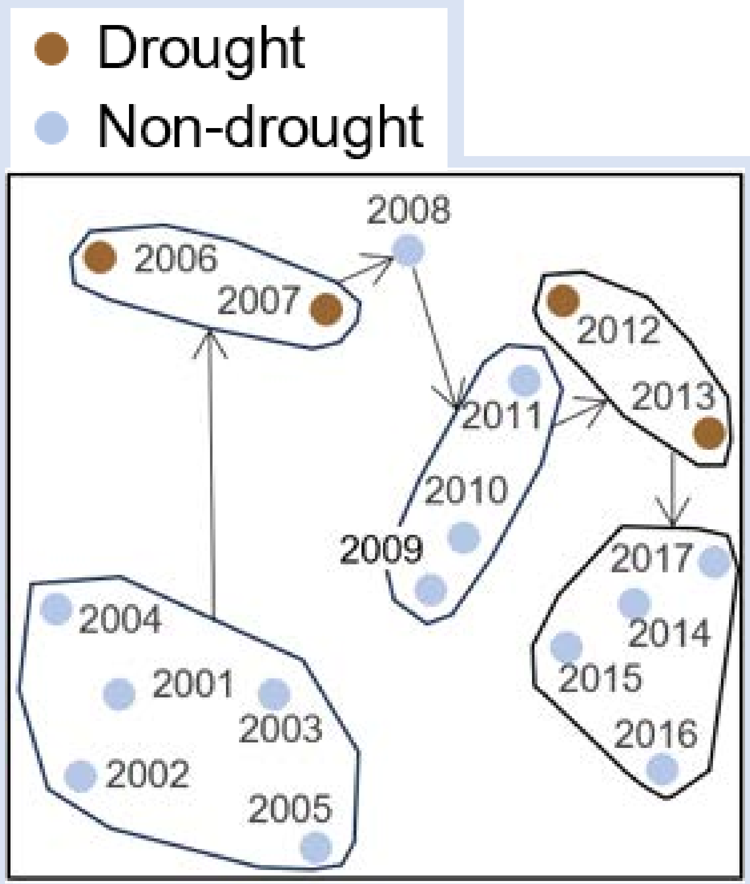
[1]Ro Sarremejane (NTU), Judy England, Stu Allen (EA), Glenn Watts (CEH) : Sarremejane et al., accepted *Freshwater Biol.*

…Past drought has caused long-term shifts in aquatic invertebrate communities

Based on 359 chalk-stream sites across 30 years:

- Communities at **47% of sites experienced persistent drought-associated shifts** in composition





Each circle represents the species composition of a sampled community

Sarremejane et al., accepted, *Freshwater Biol.*

…Past drought has caused long-term shifts in aquatic invertebrate communities

Based on 359 chalk-stream sites across 30 years:

- Communities at **47% of sites experienced persistent drought-associated shifts** in composition
- Pollution-sensitive species characterized post-drought, 'shifted' communities 🧐
- Did drought enable these species to colonize after long-term water quality improvement?

A pollution-tolerant hoglouse

A pollution-sensitive juvenile mayfly

Photos: Cyril Bennett via SmartRivers library

Sarremejane et al., accepted, *Freshwater Biol.*

Beyond biodiversity: changes to ecosystem function and services

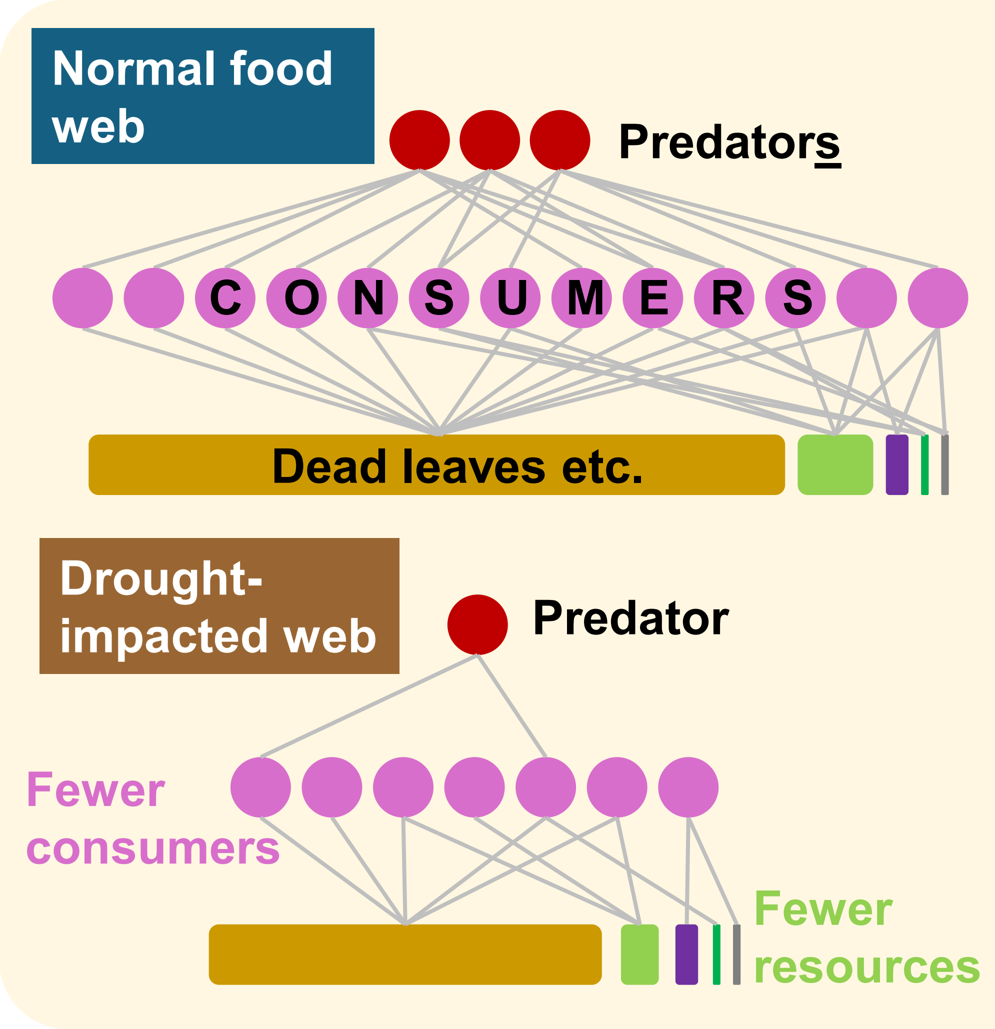
Ecosystem functioning:

- Species loss and taxonomic shifts may not affect ecosystem function due to **functional redundancy**
- But ecological (e.g. food web) simplification may precede **collapse**:
- Shifts to species-poor, function-poor states

Consequences for **ecosystem services** e.g.

- Fisheries
- Recreation
- Water quality regulation

Below: a comparison of 'normal' and drought-impacted food webs



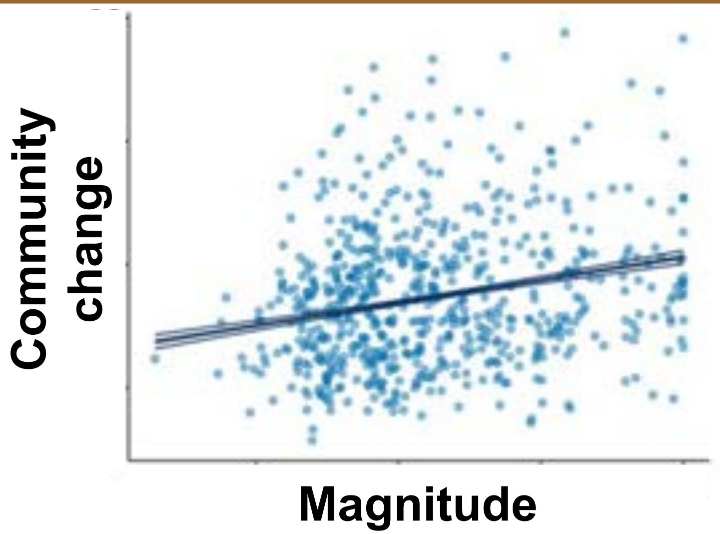
Ledger et al. 2013 *Nat. Clim. Change* **3**: 223–227.

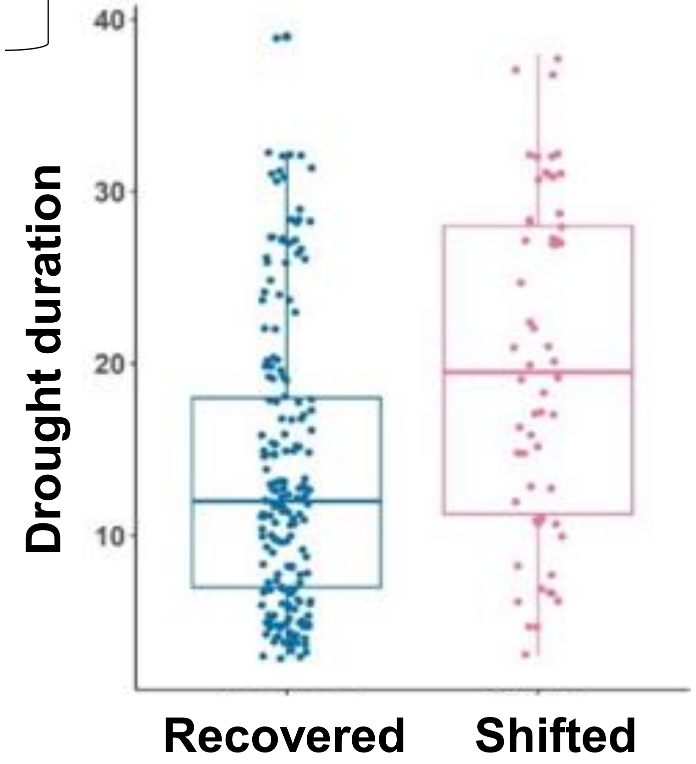
Ecological impacts differ depending on drought characteristics

Droughts with greater impacts:

- **Duration**: are longer[1]
- **Magnitude**: are more intense[1]

Severity





[1]Sarremejane et al., accepted, *Freshwater Biol*.; [2]Sarremejane et al. (2021) *Glob Change Biol* **27**: 4024–4039

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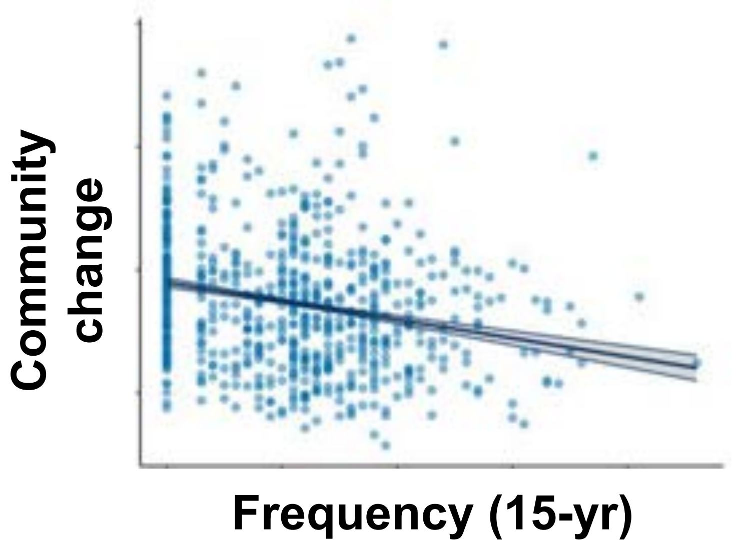
- **Frequency**: are *less* frequent[1] (?)

Severity



[1]Sarremejane et al., accepted, *Freshwater Biol*.; [2]Sarremejane et al. (2021) *Glob Change Biol* **27**: 4024–4039

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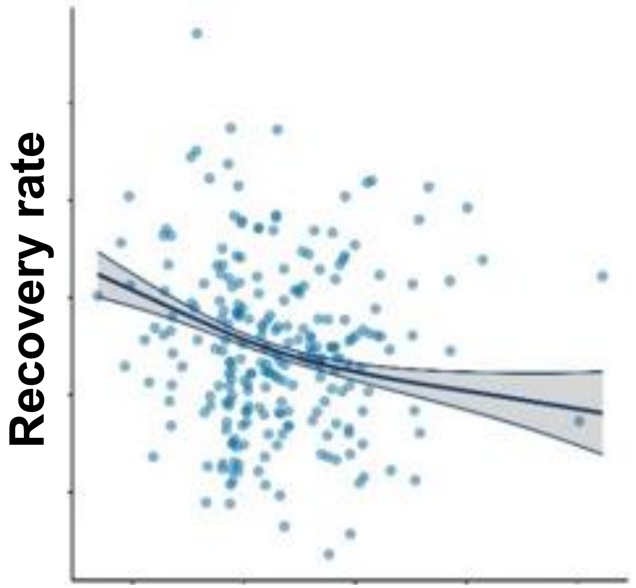
- **Rate of termination**: are ended by large floods[1]
- **Timing**: start earlier and include summer



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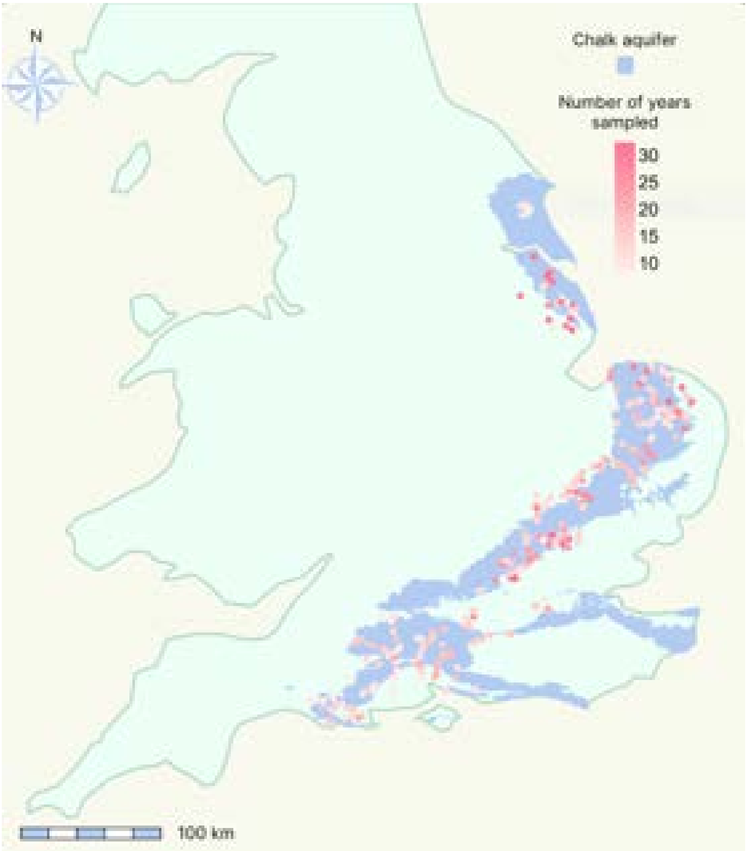
- **Frequency**: are *less* frequent[1] (?)
- **Rate of onset**: start more quickly
- **Rate of termination**: are ended by large floods[1]
- **Timing**: start earlier and include summer
- **Spatial extent**: are more widespread[2]



[1]Sarremejane et al., accepted, *Freshwater Biol*.; [2]Sarremejane et al. (2021) *Glob Change Biol* **27**: 4024–4039

How will biodiversity respond to future drought?

Hotter drought: ↑ **water temperature** and ↓ **oxygen** may kill sensitive species…

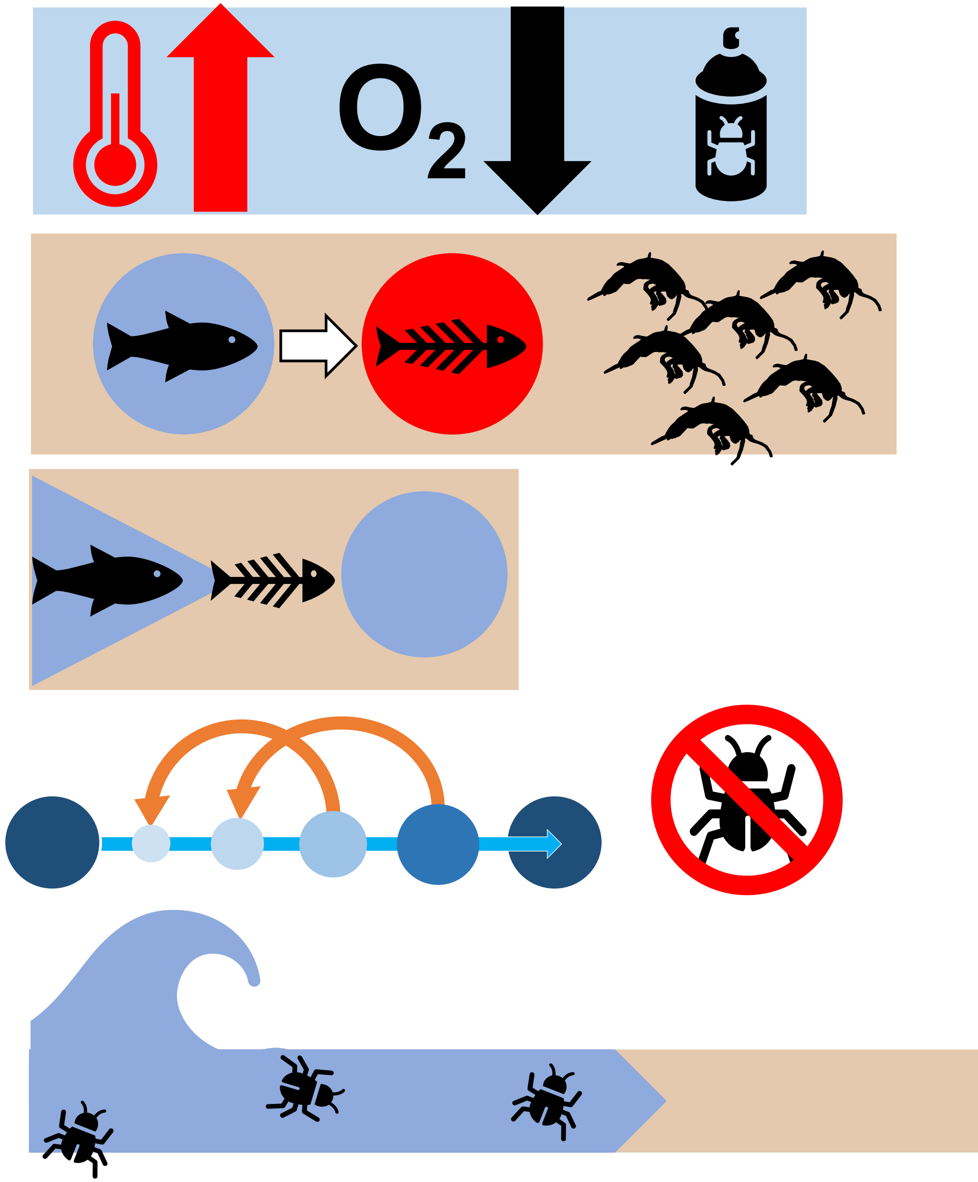
…fish first, releasing prey from control

Faster onset may limit refuge use, then increased **severity** reduces survival therein

An increase in drought **frequency** could interrupt recovery

An increase in droughts **broken by floods** could displace colonists from refuges

Short, sharp, hot, fast-onset ‘flash’ drought?



Drought impacts differ in ground- and surface-water-fed rivers

Almost all UK eco- studies: chalk streams

Droughts unfold differently depending on **water source**:

- **Groundwater-fed** rivers are vulnerable to dry winters that limit aquifer recharge
- **Surface-fed** systems are flashier: vulnerable to short, sharp, summer droughts and drought–flood transitions[1]

Impacts could be greater in surface-fed systems, especially small ones that dry

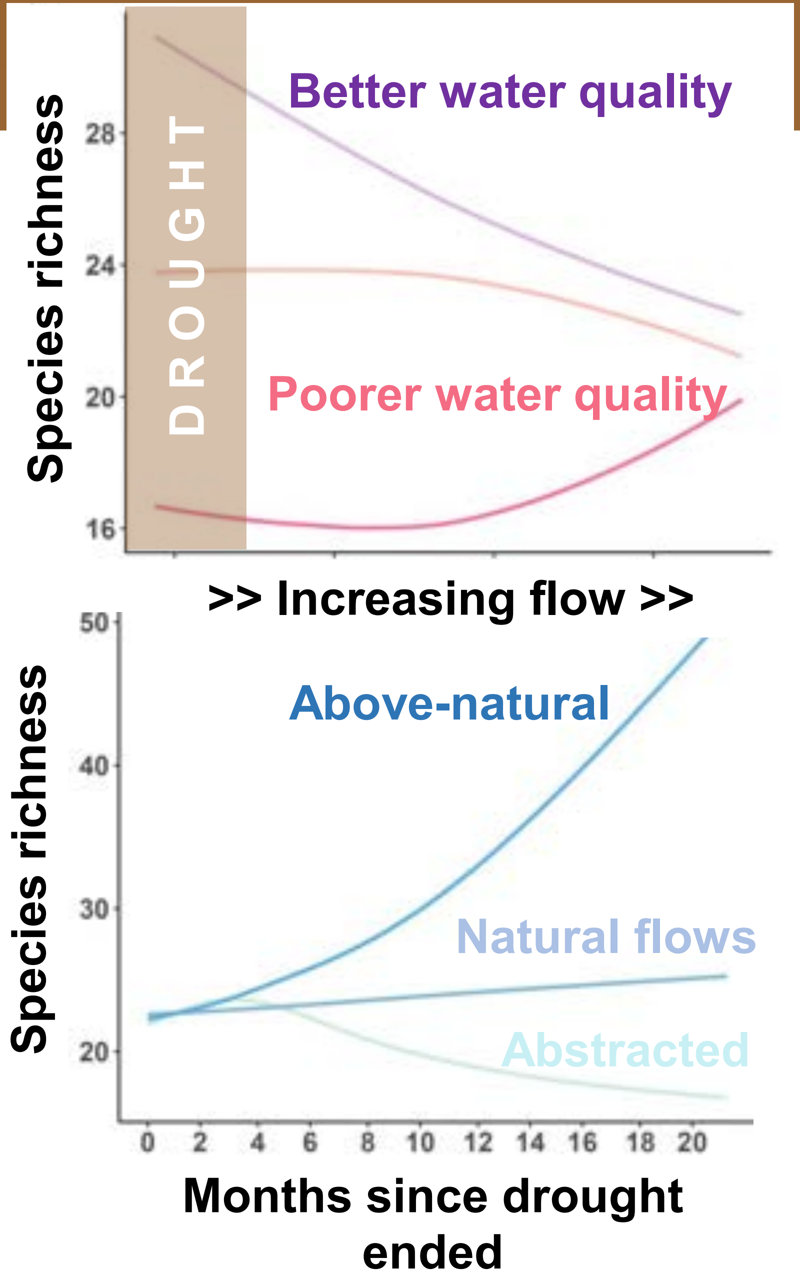
[1]Armitage… Hannaford et al. 2026. *EGUsphere* 3154

https://commons.wikimedia.org/wiki/File:Confluence,_Allt_Creagach_-_geograph.org.uk_-_6591.jpg

Human pressures alter the ecological impacts of drought

Based on 2500 invertebrate samples from 179 chalk-stream sites:

- **Poor water quality** (higher nutrients and less oxygen): greater drought-associated declines in biodiversity
- **Abstracted sites**: greater drought-associated declines; slower recovery…
- … and the opposite at **sites with above-natural flows**



[1]Sarremejane et al. (2024) *J. Appl. Ecol.* **61**: 2616–2627

Human modification of habitat naturalness alters 'drought' impacts

Habitat naturalness influences diversity and availability of drought refuges – how?

Based on invertebrate communities sampled post-drying in 3 less- to more-natural chalk streams:

- Community recovery was slower at
    - sites isolated by **artificial barriers** (which may also prevent fish movement)
    - **fine-sediment**-impacted sites

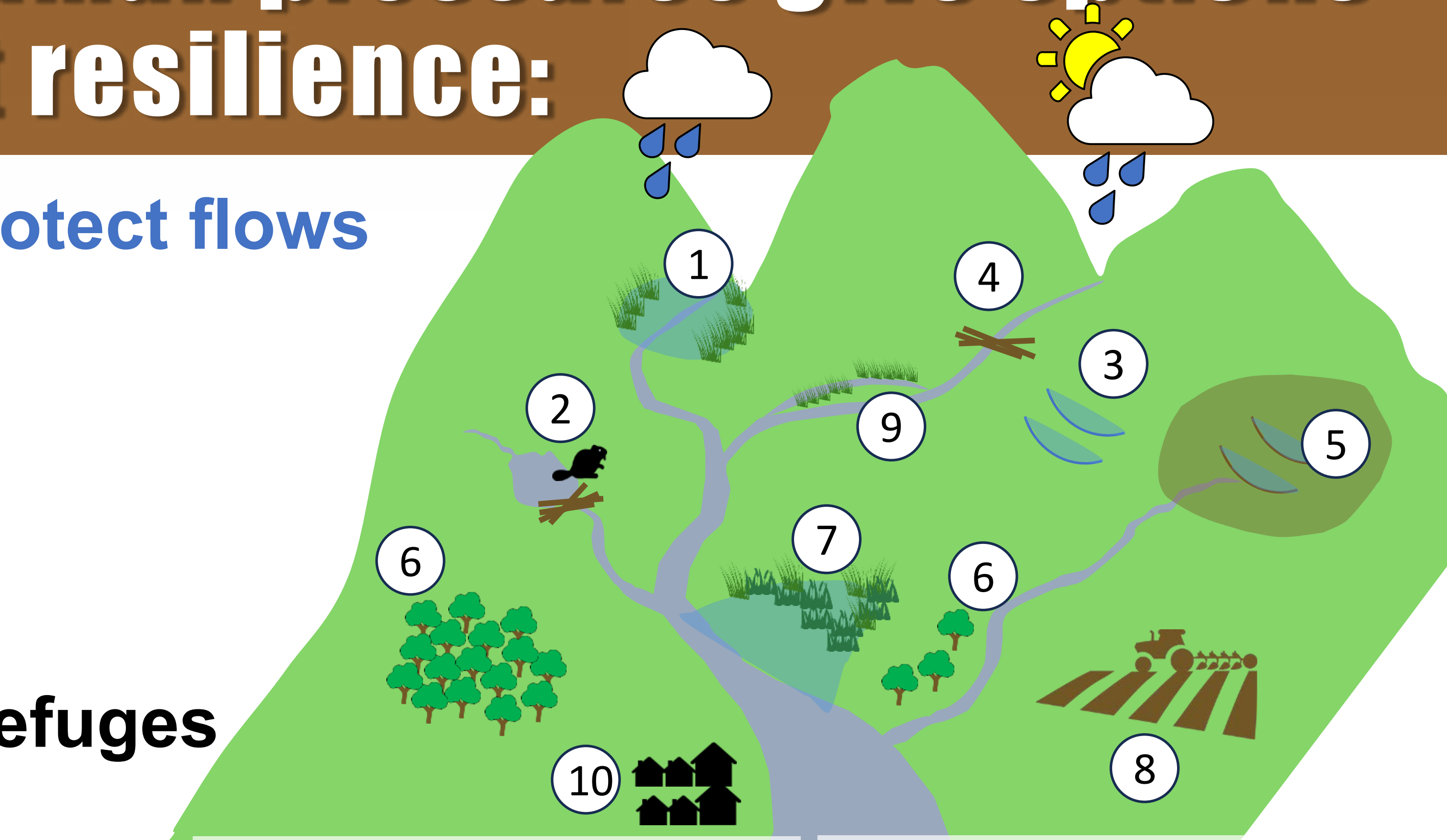
[1]Gething et al. in prep.

Interactions with human pressures give options to increase drought resilience:

- Manage water resources: **protect flows**
- **Restore** rivers to:
  - improve **water quality**
  - physical **habitat quality:**

    maintain and enhance **refuges**

    increase **connectivity**
- Catchment-wide nature-based solutions



1. Headwater management
2. Beaver dams
3. Run-off management
4. Leaky barriers
5. Peatland management
6. Woodland/tree planting
7. Floodplain restoration
8. Land / soil management
9. River restoration
10. SUDS

+ monitoring of ecological impacts and recovery

Image: Judy England

Acknowledgements

- Thanks to my coauthors, especially Judy England and Romain Sarremejane
- Our work is funded by the Environment Agency and NTU

Supporting literature:

Received: 23 February 2024 | Accepted: 8 July 2024
DOI: 10.1111/1365-2664.14771
Journal of Applied Ecology

RESEARCH ARTICLE

Human impacts mediate freshwater invertebrate community responses to and recovery from drought

Romain Sarremejane[1] | Judy England[2] | Mike Dunbar[2] | Rosalind Brown[2] | Marc Naura[3] | Rachel Stubbington[1]

WIREs WATER
Focus Article | Open Access

The effects of drought on biodiversity in UK river ecosystems: Drying rivers in a wet country

Rachel Stubbington, Judy England, Romain Sarremejane, Glenn Watts, Paul J. Wood

First published: 09 July 2024 | https://doi.org/10.1002/wat2.1745 | VIEW METRICS

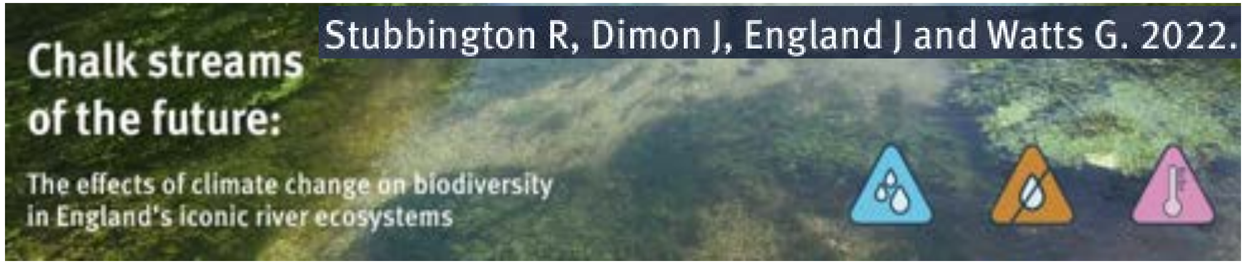
G: The ecological effects of drought on England's rivers

Prof. Rachel Stubbington, Nottingham Trent University

Overview

Summary

This review considers the ecological effects of drought—which may manifest instream as conditions from low flows to long dry phases—in England's rivers and streams. The review:



Contact

Rachel Stubbington / Nottingham Trent University (NTU) / rachel.stubbington@ntu.ac.uk

Temporary Use Bans – A Reality Check

Andy Ball – HR Wallingford

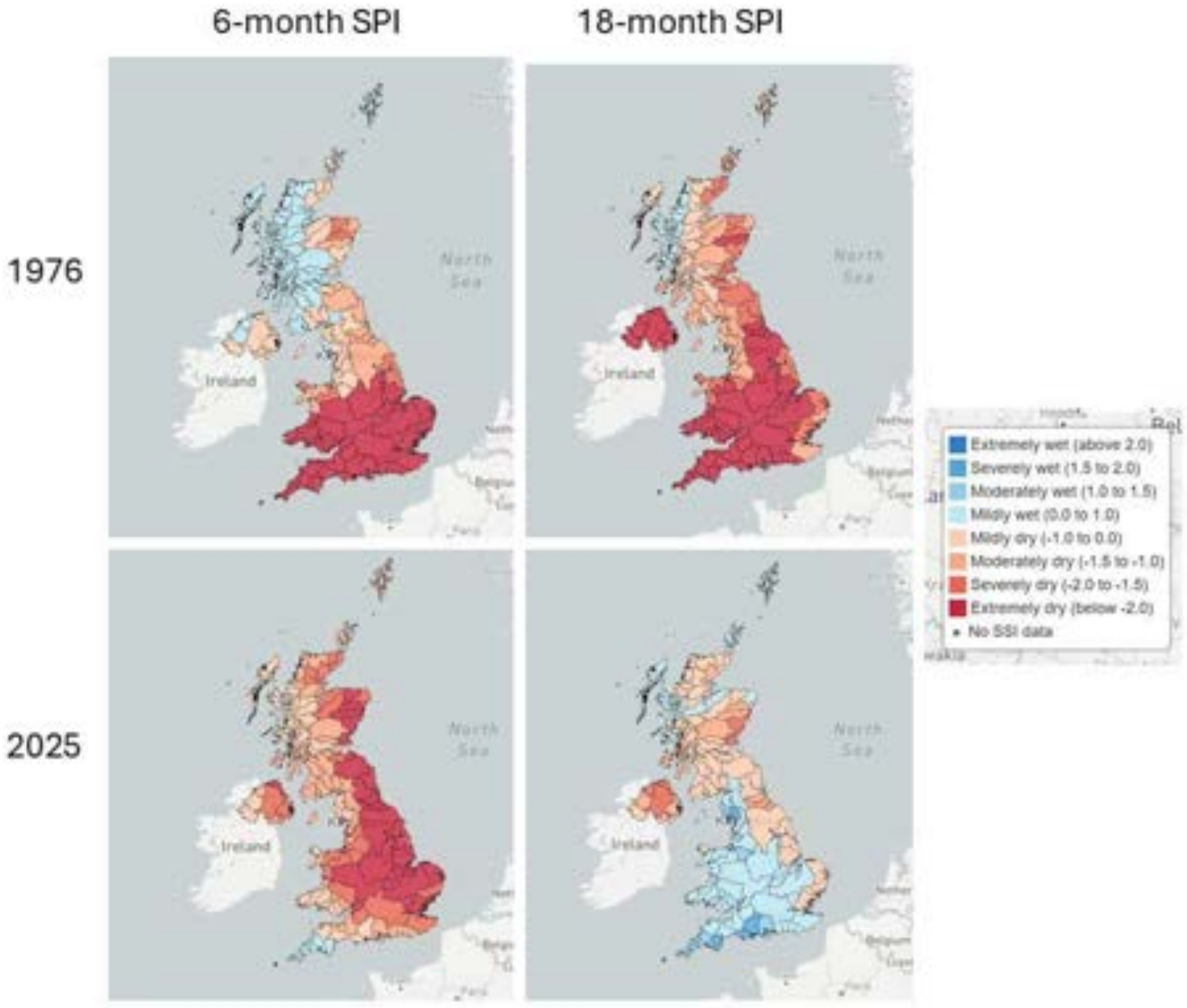
Tom Nelson – Artesia

UKWIR's project lead was Oluseyi Onifade and UKWIR's project manager was Paul Henderson

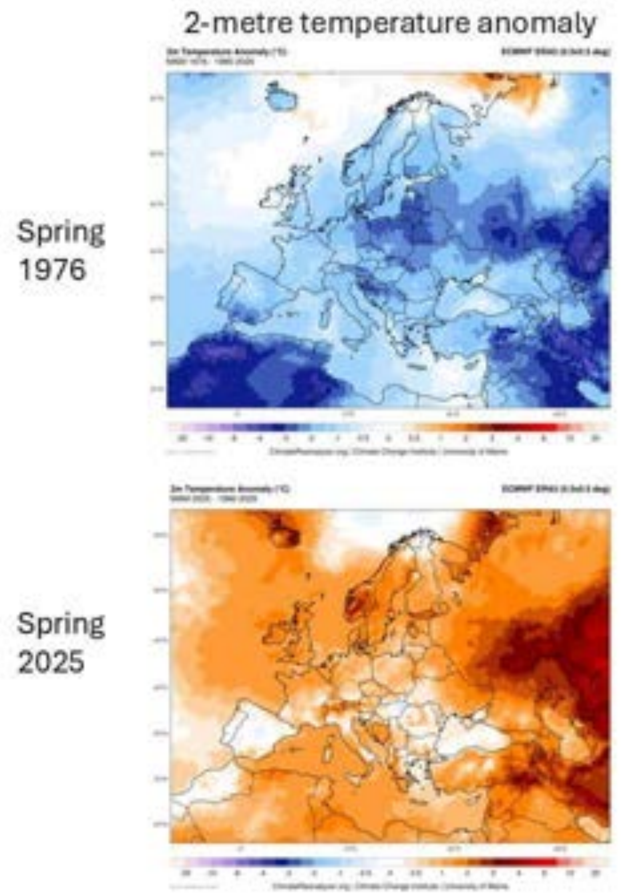
1976 and 2025

1976 was preceded by dry weather, 2025 was not.

Baker, L, University of Reading https://blogs.reading.ac.uk/weather-and-climate-at-reading/2025/how-does-the-uk-summer-so-far-compare-to-the-extreme-hot-dry-summer-of-1976/



1976 and 2025

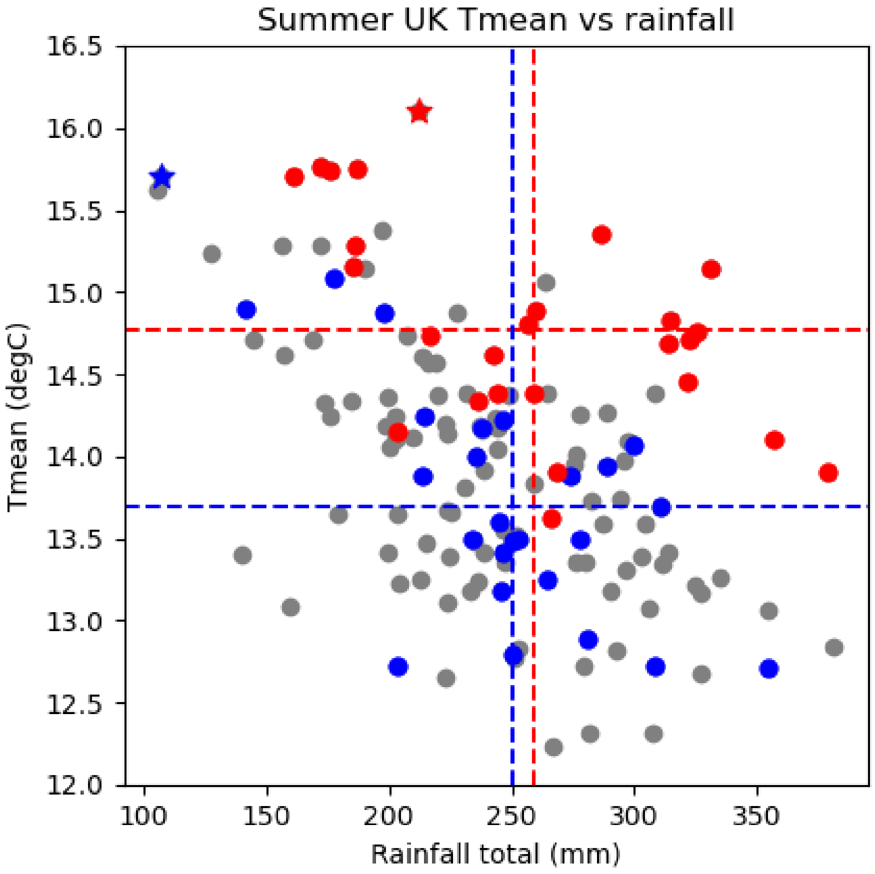


Spring of 1976 was not hot, 2025 was much warmer across the whole of Europe

Summer of 1976 was hot, 16 days of >30^{O}c

Baker, L, University of Reading
https://blogs.reading.ac.uk/weather-and-climate-at-reading/2025/how-does-the-uk-summer-so-far-compare-to-the-extreme-hot-dry-summer-of-1976/

Baker (2026), Weather (submitted)



TUBs are a key tool to managing water resources during a drought. They are included in levels of service.

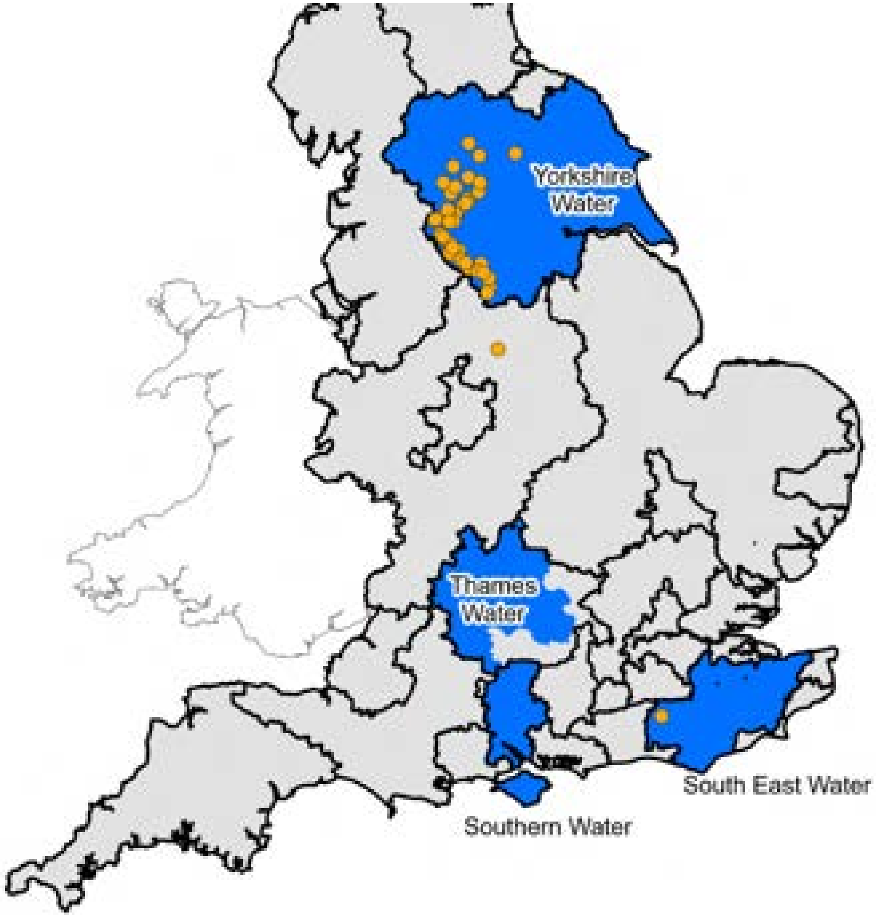
All water companies in England did some communication campaigns.

Four companies applied for TUBs.

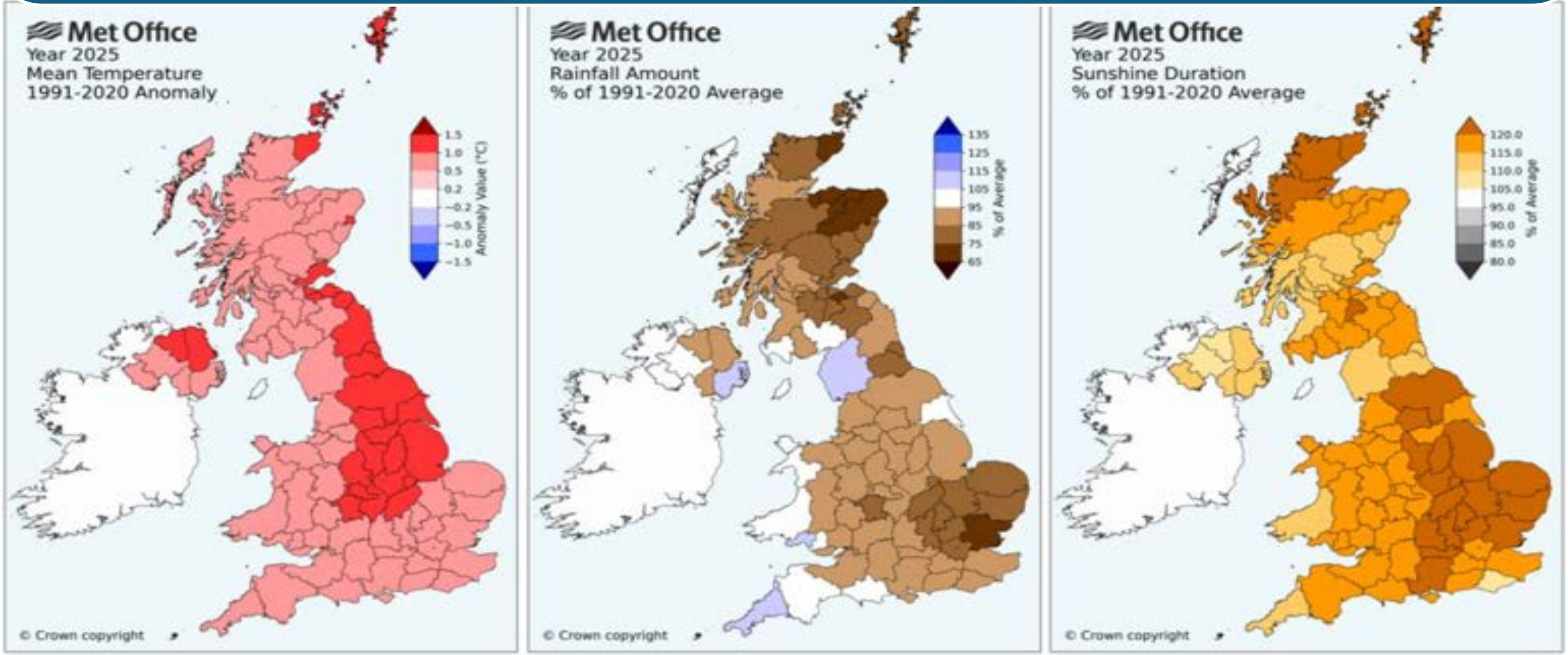
TUBs were not for every WRZ.

Drought permits and orders were issued to allow changes in abstraction.

Some companies got close to NEUBs.

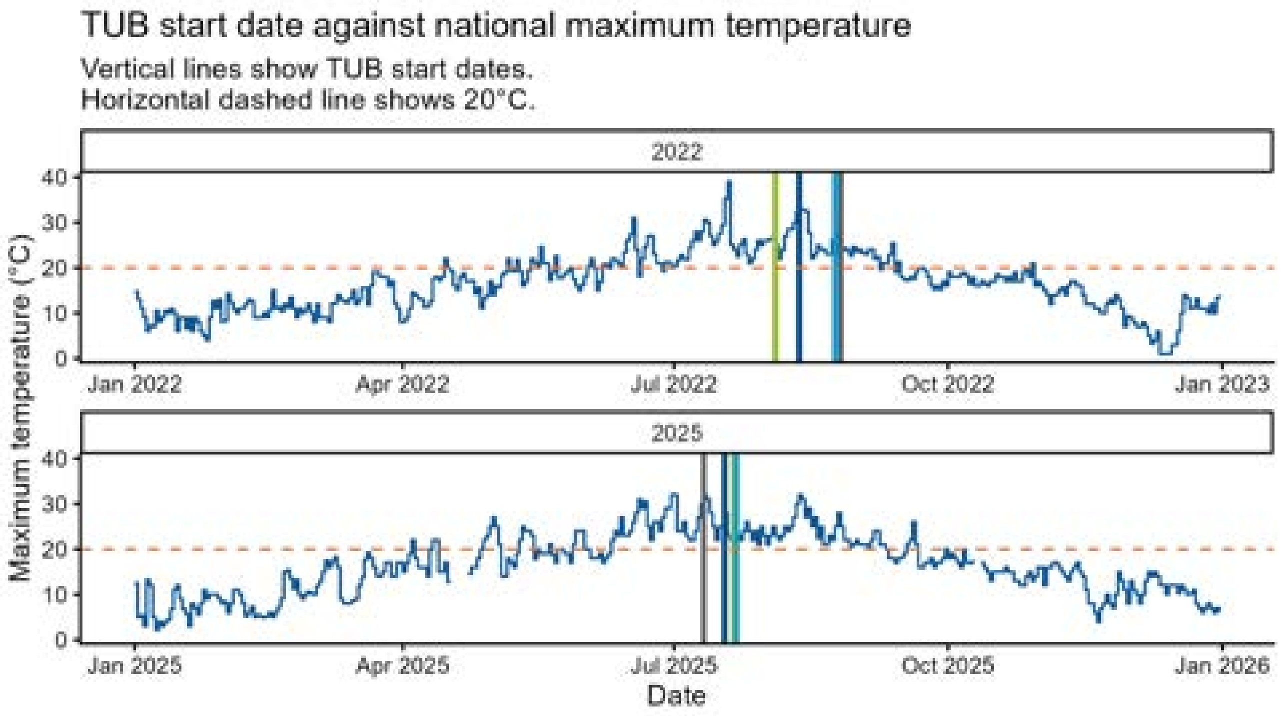


UKWIR commissioned an urgent piece of work, whilst the restrictions were still in place, to understand what impacts communication campaigns and TUBs had on demand: Review of the impacts of early implementation of Communications Campaigns and Temporary Use Bans in 2025 (Summary report).



Timing of TUBs

- In 2022, all four TUBs started in August.
- In 2025, all TUBs started in July, capturing more of the summer drought.
- However, there was a hot period before any TUBs in 2025, and three major temperature and demand peaks.
- High consumption during these earlier periods will have increased stress on resources, even if they pre-dated drought triggers.



- Data was collected from four companies with a TUB in 2025, and two without.
- Companies provided data at DI, DMA, and individual household level.
- This combination of regions and scales allowed a more granular analysis, representing both different areas and property types.
- Statistical techniques were applied to all datasets to quantify the impacts of TUBs, as well as other drivers of demand.

DI

- Mix HH, NHH, leakage
- Daily consistent datasets
- Long time series
- Homogenous across companies

DMA

- Contains mostly HH, but some NHH and leakage too
- High temporal resolution
- Shorter time series
- Less consistent across companies

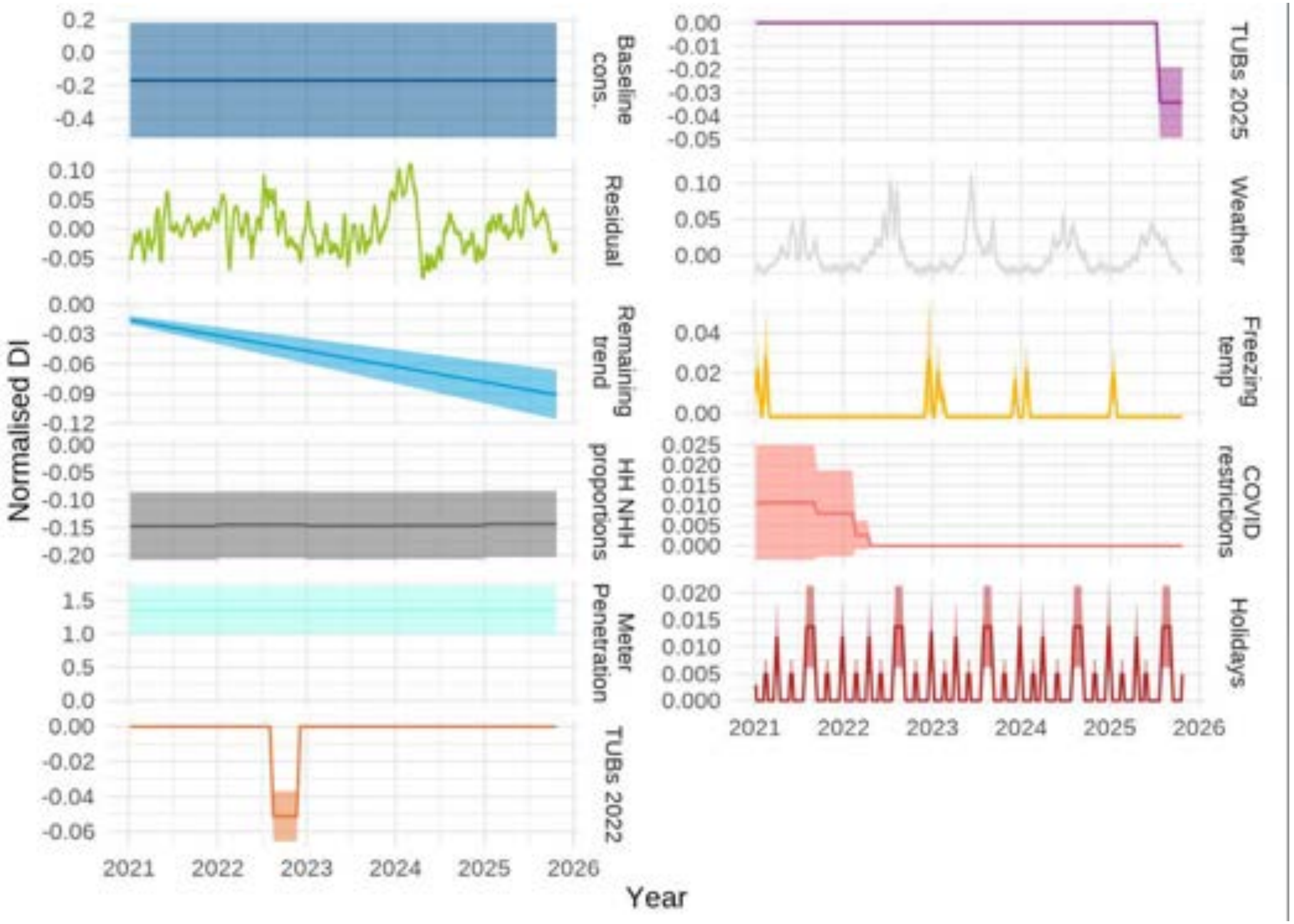
HH

- Direct HH readings
- Might include some CSL
- Heterogeneous quality of data across companies
- Various time series length, but generally shorter than DI and DMA

Application of temporal decomposition – DI

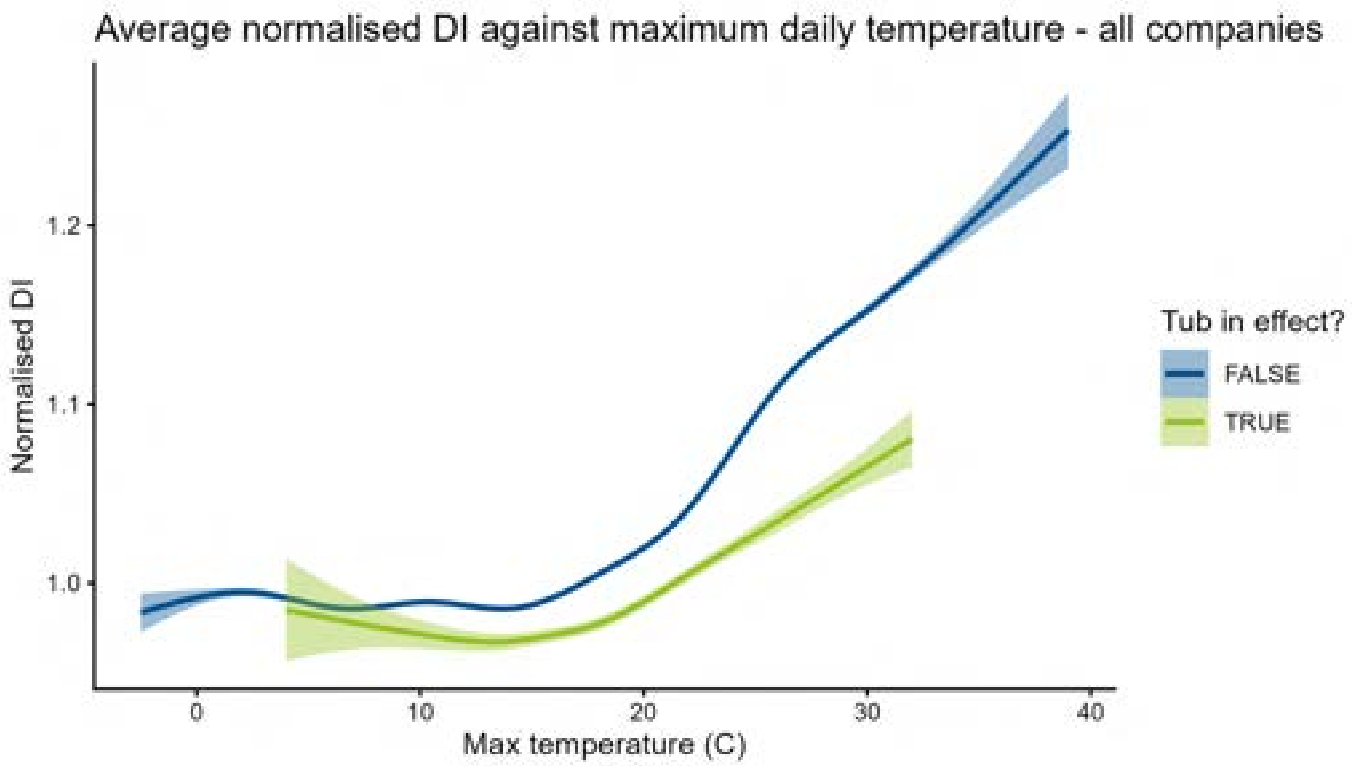
An example plot for one WRZ is provided here. As it is applied to normalised DI, the components can be interpreted directly:

- We observe a realistic impact of weather and freezing spells.
- COVID-19 results in increased DI, as do holiday periods.
- There are some trends due to HH/NHH proportion, meter penetration, and other uncaptured structural trends.



Relationship between temperature and DI

- DI is relatively stable for temperatures below a certain threshold.
- Above this threshold, DI increases in line with temperature.
- TUBs seem to mitigate some of this increase, having a seemingly larger effect as temperature increases.
- This threshold temperature is important in both deciding how to apply TUBs, and how to include them in plans.



DMA data

Considered effects

- Weather
- Seasonal effect
- Weekends and holidays
- % meter penetration
- Customer cohort
- COVID-19
- Consumer price index
- MNF as a proxy for leakage
- Offset by number of properties
- TUBs
- Interaction terms

Model development

- DMA sample selection
  - Temporal data coverage
  - Initial model performance
  - Diversity in DMA sizes
- DMA analysis
  - Covariate and proxies
  - AIC-based model selection
  - Linear models and GAMs

Estimation

- Estimation of historical TUBs
  - Predict total flow (TUB) with TUBs
  - Predict total flow (NT) with no TUBs

$$\%\text{ change in flow} = \frac{\text{flow(TUB)} - \text{flow(NT)}}{\text{flow(NT)}} \times 100\%$$

- TUB impacts as function of
  - Weather – max temperature
  - ACORN modal class
  - Average garden size

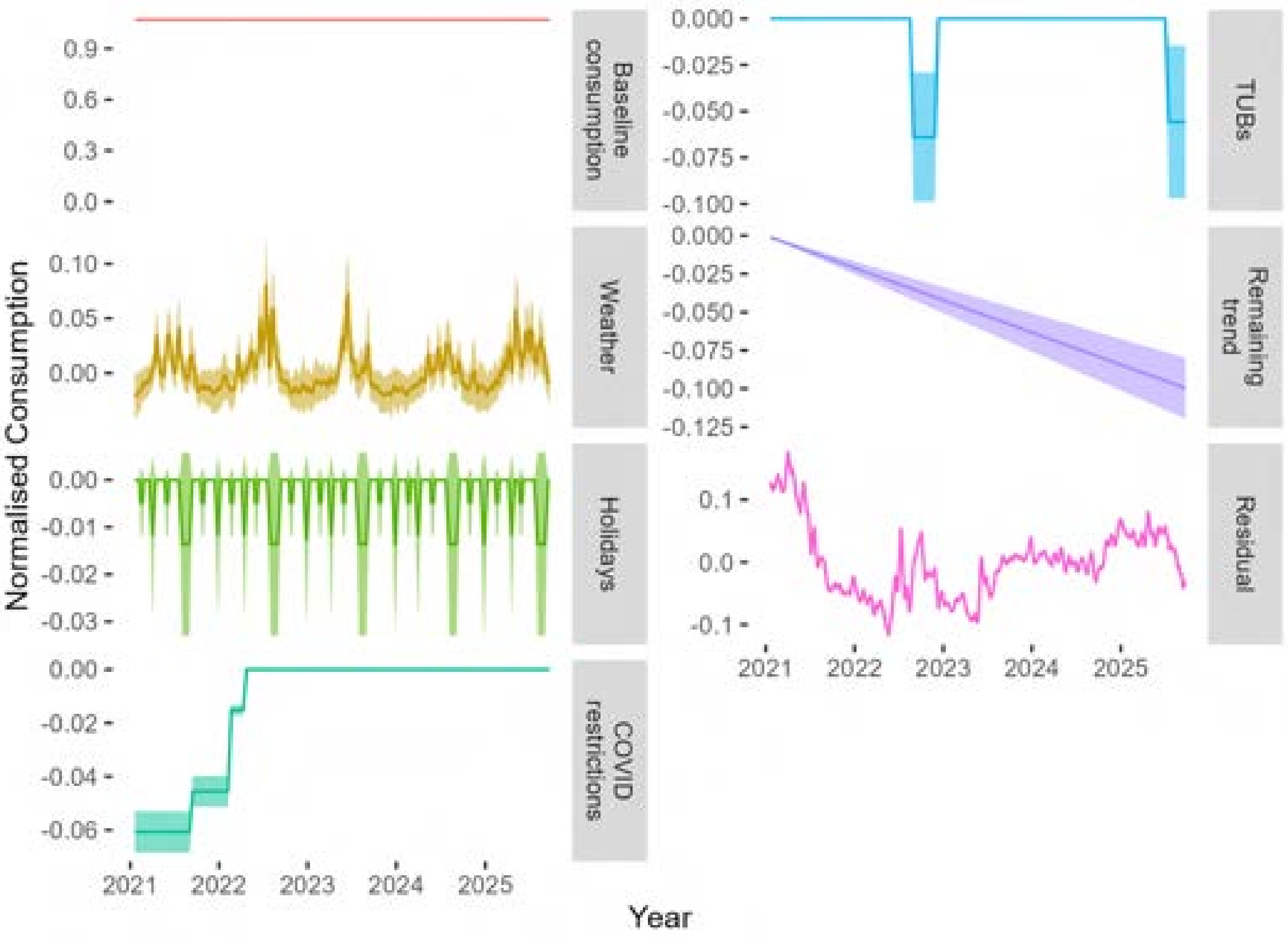
Application of temporal decomposition – HH

There are some key differences between the DI and HH analysis:

- HH analysis is a more 'direct' measurement (no NHH, limited leakage), at property level.
- Data sets are much bigger (there are thousands of properties).

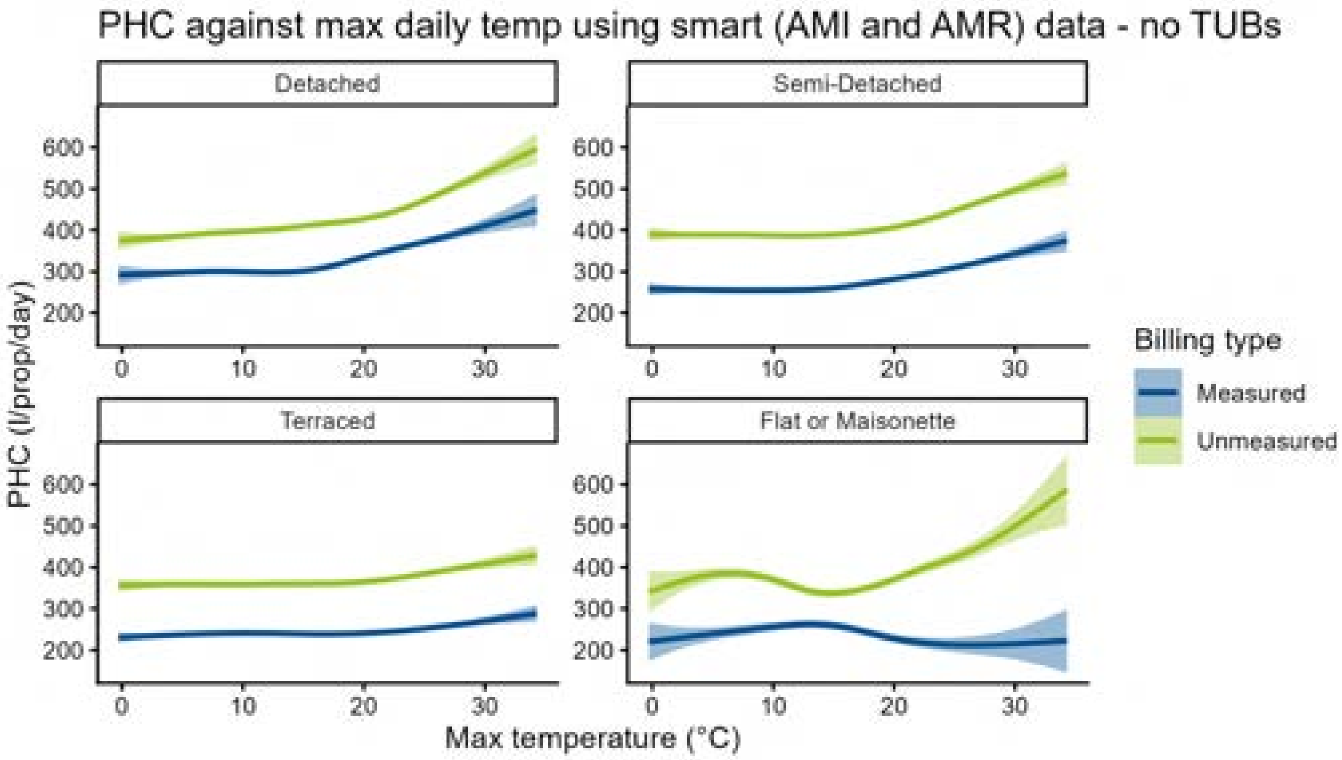
BUT

- The data quality is more heterogeneous.
- Data is not representative of company level (i.e. all unmeasured IHM in one company).



Relationship between temperature and household consumption

- Household consumption is relatively stable for temperatures below a certain threshold, for all property types and measured and unmeasured properties.
- A similar pattern is seen in detached, semi-detached, and terraced properties – although the effect seems stronger in detached properties. This is likely to relate to garden size.
- Flats and maisonettes show a slightly different profile. Measured properties so no change with temperature, while unmeasured properties see an increase as temperature increases.



Results – some warnings

- The results are complex and need to be interpreted and used carefully.
- If you plan to use them, we suggest you review the information provided in the report.
- The results are very specific, it is difficult to infer what would have happened in 1976, but we draw some broad conclusions.
- Distribution Input data should be used to answer the question “how much water was saved by the TUBs implemented in 2025 in each Water Resource Zone?”, while District Meter Area and Household analysis give additional context around where this water was saved and behaviour by different customer groups.

At a DI level…

- We have derived the estimation of the impact of TUBs on DI for all WRZs affected by TUBs in 2025.
- Based on this we could estimate the impact on companies (considering only the WRZs where TUBs were in place in 2025)

Company	Effect of 2022 TUB	Uncertainty	Effect of 2025 TUB	Uncertainty
Company B	-0.3%	±1.6%	-4.5%	±1.4%
Company C	+0.3%	±1.5%	-2.4%	±1.50%
Company D	-1.9%	±1.5%	-3.0%	±1.70%
Company F	-2.2%	±1.5%	-1.7%	±1.5%

At a DMA level…

- The DMAs used are not representative of each company, they are samples
- Savings vary with temperature
- So the more hot days there are, the larger the savings

Conditional TUB impact x **Likelihood of conditions** = **Estimated TUB impact**

Max temp (°C)	Mean % change
< 17.5	-1.01%
17.5 ~ 22.5	-2.09%
22.5 ~ 27.5	-3.15%
27.5 ~ 32.5	-4.20%

x

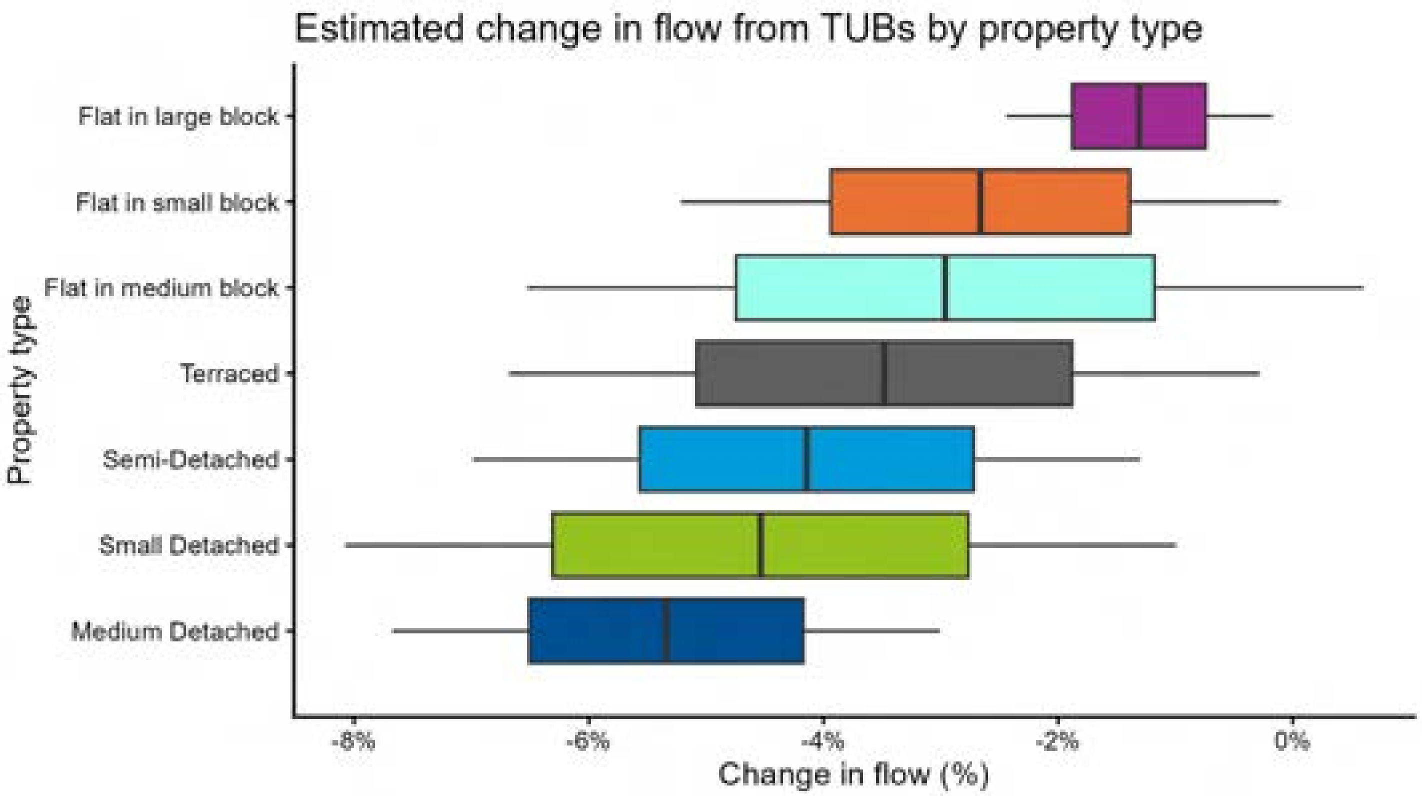
Max temp (°C)	TUB 2022	TUB 2023	TUB 2025
< 17.5	61%	8%	39%
17.5 ~ 22.5	31%	88%	52%
22.5 ~ 27.5	6%	4%	9%
27.5 ~ 32.5	2%	0%	1%

=

TUB 2022	TUB 2023	TUB 2025
-1.23%	-2.82%	-2.01%

At a HH level…

- Savings from unmeasured households are greater than measured households.
- Savings again vary by temperature
- The savings vary by property type



Results

The extensive data sets and analysis show that the impact of TUBs follows a more complicated behavioural response than previously considered:

- The savings from TUBs vary depending on temperature, location and property type, interestingly rainfall is not a big factor.
- Savings on unmetered properties were greater than measured properties in the studied samples.
- The largest impacts are in larger detached houses, during very hot days, which in 2025 were mainly in early summer.
- The smallest impacts are on smaller properties, when the temperature is milder.
- Savings from TUBs are impacted by the number of hot days above a threshold (>20 degrees, although the threshold varies by region).
- This project demonstrates that estimating the savings from TUBs is more complicated than previously understood.
- A simple number or percentage is therefore insufficient to estimate the savings from TUBs

Conclusions

- TUBs are a useful tool for managing demand in a drought.
- Their impact will vary depending on a range of measurable factors which have been presented and analysed in this project, including property type, demographics and weather.
- The impact of TUBs should no longer be defined as a single percentage value.
- Communication campaigns are a necessary pre-cursor to TUB implementation. However, it is challenging to measure their direct impact in reducing water use.

So what?

- We will have more droughts
- Companies are investing in additional water supply resilience, but TUBs will still be needed
- Companies can use this data to prioritise investment, campaigns and research
- We need to be wary about over-stating the benefits of TUBs – they are a key tool in drought
- More research could be undertaken:
  - Is there TUBs fatigue?
  - Who ignores TUBs?
  - What will TUBs impacts be in a hotter UK?

So looking back to 1976....

Restrictions were more severe in some parts of the UK than TUBs.

Things have changed a lot since 1976:

- Many more flats, apartments and maisonettes – TUBs have less of an impact on consumption in these property types
- Much more metering – TUBs have less of an impact on measured properties
- Generally hotter – TUBs have more of an impact in hotter weather, and rain has much less impact
- Increase in affluence – possible increase in non-essential use (garden watering etc)
- Leakage has gone down – leakage not affected by TUBs
- Less industrial demand – not affected by TUBs

1976 and All This

Changing social attitudes & expectations of drought in England

Kevin Collins
Engineering and Innovation, STEM

Drought hydrology: 50 years since 1976
17 June 2026 ICE London

The Open University

1976: ‘The past is a foreign country. They do things differently there’ (Hartley, 1953)

Trade Unions: 12 million members

Ford Fiesta launched

Inflation: 16%

Selby coalfield opens

Concorde 1st commercial flight

Formula One James Hunt

Queen *Bohemian Rhapsody*

ABBA *Mamma Mia* and *Dancing Queen*

Apple Computer

1976 Drought – Public Compliance

Previous national emergencies: freezes, floods, droughts

Post-war generation

"Social Contract"

National event

Media / Fines

High Levels of Compliance

Stand-pipes

Significant impacts

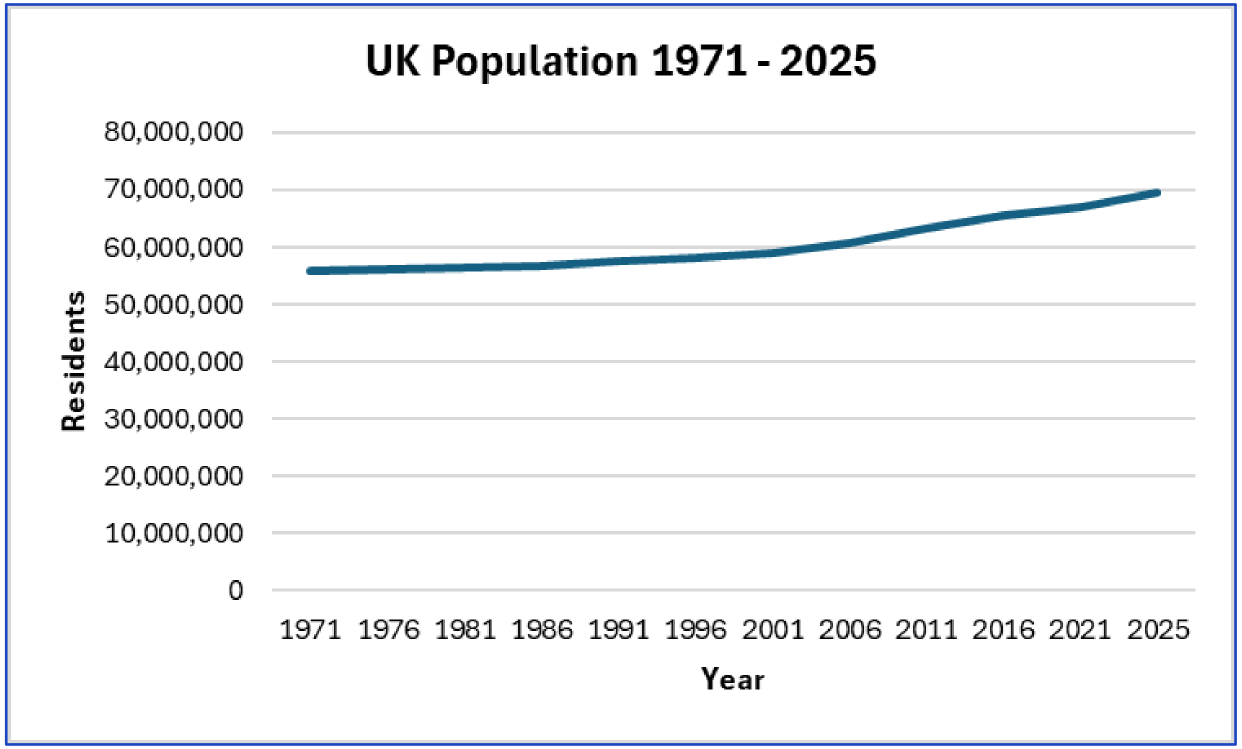
Restrictions

Substantial inconvenience

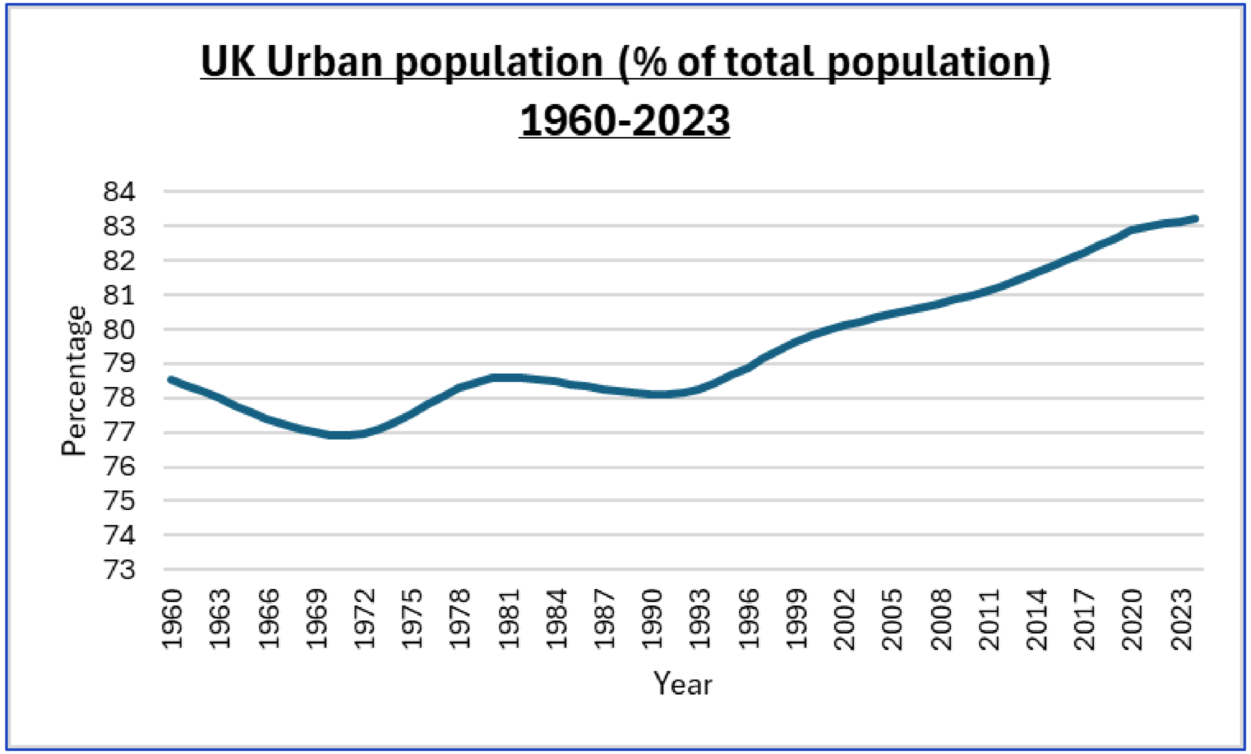
Friction in holiday areas / neighbouring authorities

Since 1976...population increase and urbanisation

Increasing population, increasingly urban

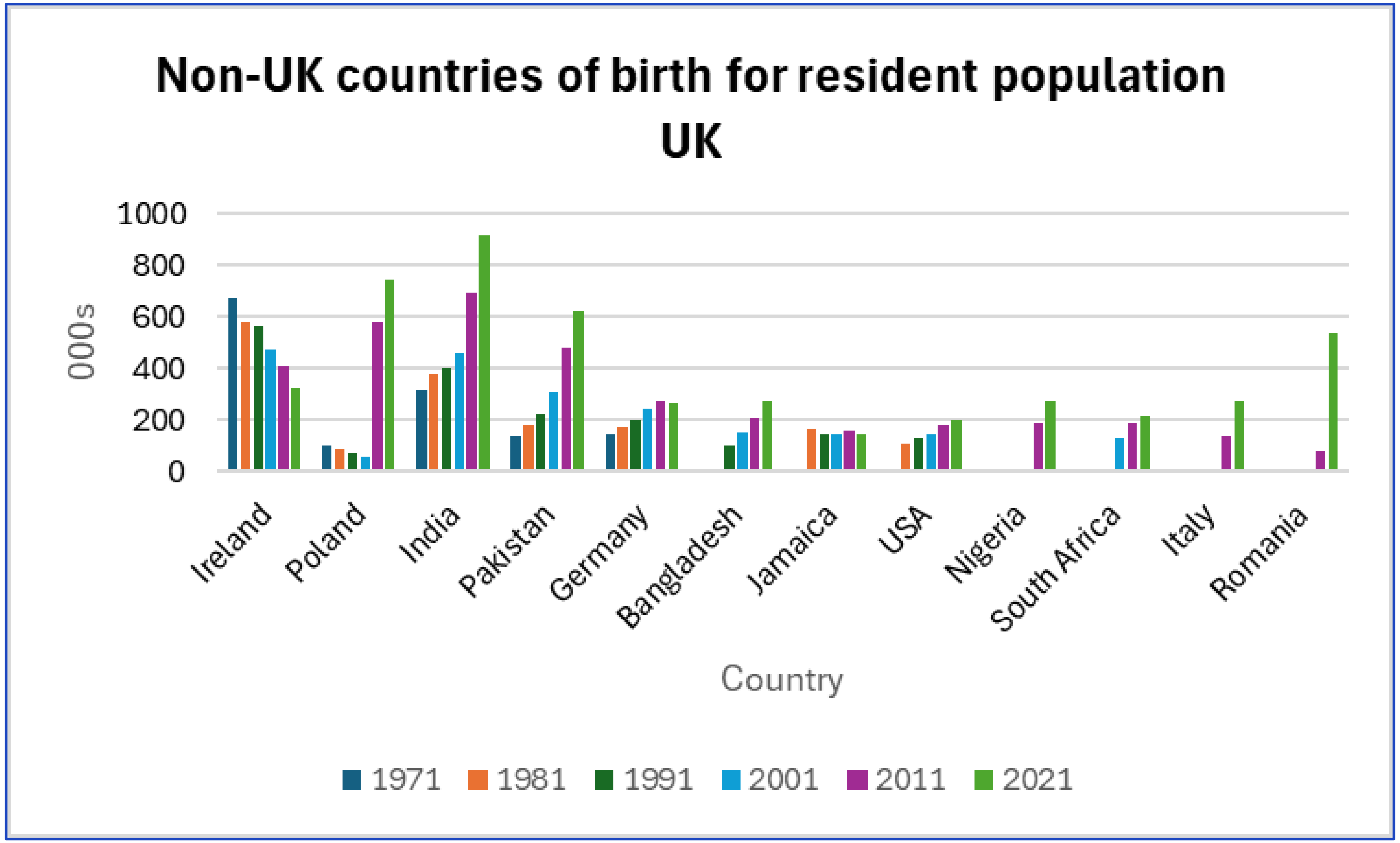


(Office of National Statistics Census Data 1971-2021)

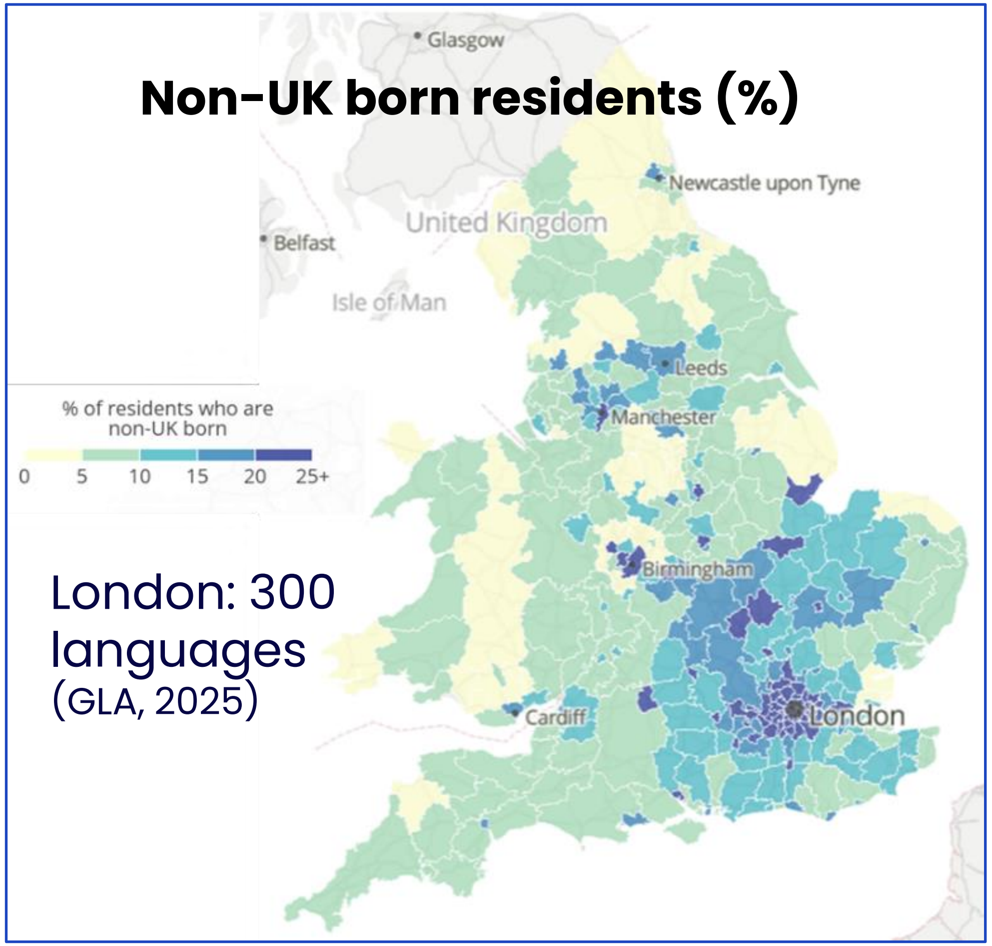


(World Bank data, 2026)

Since 1976... non-UK born population



(Office of National Statistics Census Data 1971-2021)



London: 300 languages
(GLA, 2025)

(Office of National Statistics, 2022)

Urbanisation affecting behaviours?

"Extinction of nature experience" (Pyle, 1978)

75% of direct nature interactions by 32% of the population (Cox et al., 2017)

Less care, belonging, sense of place, stewardship (Bashan et al., 2021; Oh et al., 2020)

Time in nature: age, education, income, gender, location (Oh et al., 2021; Gov UK, 2025b)

Childhood nature experiences shape lifelong attitudes (Stanley, 2022)

Gen Z environment behaviours: income, information access, and convenience (Andruszkiewicz et al., 2023)

UK / Non-UK Born Behaviours and Information Sources

No differences in water conservation behaviours UK / Non-UK born (Gatz-Kerro et al., 2026)

Sources of Information (%)

	Internet	Social Media	Media	Educators	NGOs; religious; word of mouth; not looking	Total
Non UK born	41.7	18.9	18	5.1	16.2	100
UK born	58	27.6	8	0.6	5.7	100

Trust in information about environmental issues (%)

	Govt.	NGOs	Professionals in Envt. Sector	Peers and Friends	Religious institutions	Other	Total
Non UK born	62.6	10	13.4	2.7	4.6	6.7	100
UK born	38.4	29.2	22.2	5.9	1.1	3.2	100

Behaviours: 2004-6 drought

Comparison Anglian region and Southern Water region (Dessai and Sims, 2010)

PRIMARY CAUSE
Lack of rain

TRUST
Most: Environment Agency via media
Less: Government / water companies
Least: Friends and tabloid newspapers

UNDERSTANDING
Situation serious so change practices

RESPONSIBILITY
Not individuals / small impact.

BEHAVIOURS
If changed, continued after the drought.

FUTURE SCENARIOS
Accept restrictions rather than pay more

AFTER
No significant difference between the regions **outside** drought periods.

Demand: South West Water 2022-23 Drought

Consumption	WRMP19 22/23	Actual 22/23	Diff. Ml/d	Diff %
Measured Non-Household	140	156	15	11
Unmeasured Non-Household	2.8	3	0.2	8
Measured Household	213	232	19	9
Unmeasured Household	82	120	37	46

Data from (South West Water, 2024). All figures rounded

"…unmeasured customers are not switching to measured bills due to their water use behaviour."

(South West Water 2024:14)

Metering - equity and fairness

Per capita use 135-150 l/day since 2005
60% households now metered

🔢 Metering reduces water use 22%

🏠 Equity issues for low income households

👪 Resistance from larger households

⚖️ Ongoing tensions: fairness of usage

(Ornaghi and Tonin, 2021)

Reasons for not changing behaviours?

🏛️ **Governance**
Supply-driven design and legislation prioritise drinking water quality and quantity.

🏠 **Standard of Living**
Water as essential to quality of life

👤 **Experience**
Consumers shielded from the consequences of drought (Bryan et al., 2019)

👁️ **Perception**
Past experiences, family influence, and media

⚖️ **Public Acceptance**
Fairness ↔ equity ↔ trust ↔ legitimacy

Public anger:
illegal discharges into waterways,
leakage rates,
financial engineering and debt-piling,
failing regulation

(Jaffer, 2025)

Trust and legitimacy over time

2005

Water companies had failed in their 'attempts to gain, maintain and repair' (p340) their legitimacy

(Ogden & Clark, 2005)

2012 Drought

Lack of legitimacy and trust of water companies limited effectiveness of public responses to drought

(Russel-Verma, 2013)

2018 Heatwave

Willingness to act depends on belief water company is 'also doing its part' to reduce water

(Larbey & Weitkamp, 2020)

After 2022 drought

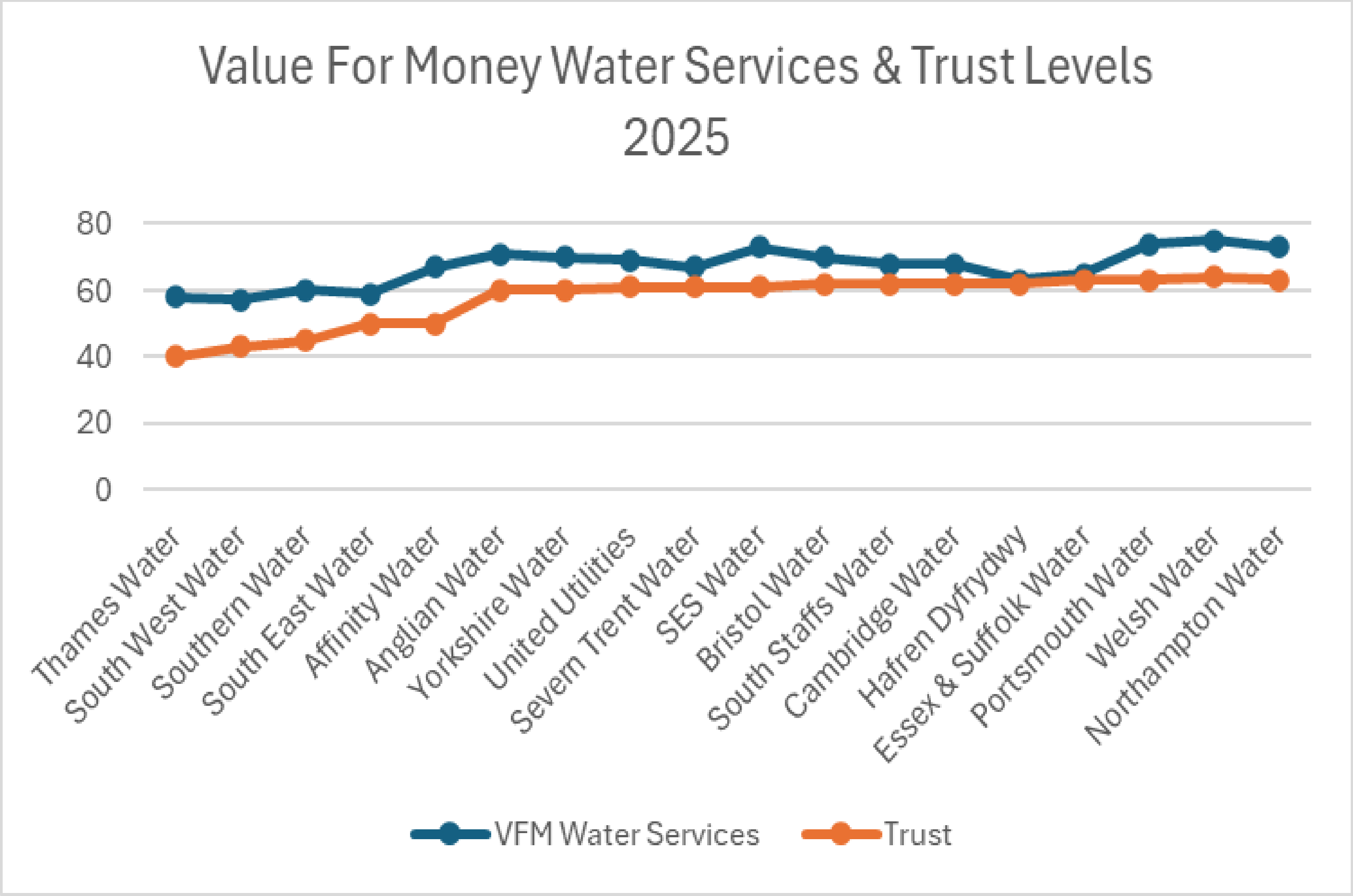
47% : shareholders first

27% : water provider acting for the environment

25% : water provider acts for customers

(OFWAT, 2023)

Value for Money and Trust Levels 2025



Lowest trust level in last 10 years

(After CCW, 2025)

Media framing of drought

Daily Star

Spy on Neighbours Over Hosepipe Ban

Grass up a Granny

4 August 2022

The Times

Clean It Up Campaign

18 February 2023

Daily Star

Let's Enjoy it Folks

Costa Bravo

16 June 2025

Daily Star

Yet Another Heatwave

School Jollydays!

14 July 2025

Daily Mirror

NATIONAL WATER CRISIS

DRY ALERT

Emergency Plans to Tackle Drought After 50 year low

13 August 2025

The SUN

As firms waste 107m litres a day…

It's 35 C and water chiefs moan about kids' pools being filled up

PADDLING FOOLS!

27 May 2026

Improving Drought Communications

1	**Language**	Explain and expand on definitions Use the word drought where appropriate
2	**Routes**	Two-way system: multiple routes of communication
3	**Availability**	Materials openly and publicly available
4	**Trust**	Communications from trusted, verified sources
5	**Design**	Accessibility, language and statistics according to audience Narratives, being emotive, and empowering action
6	**Delivery**	Variety, but simple / short methods are preferred
7	**Timing**	Continual reporting between, in and recovery Flood-drought continuum and climate change risks and resilience

After Facer-Childs et al., (2025)

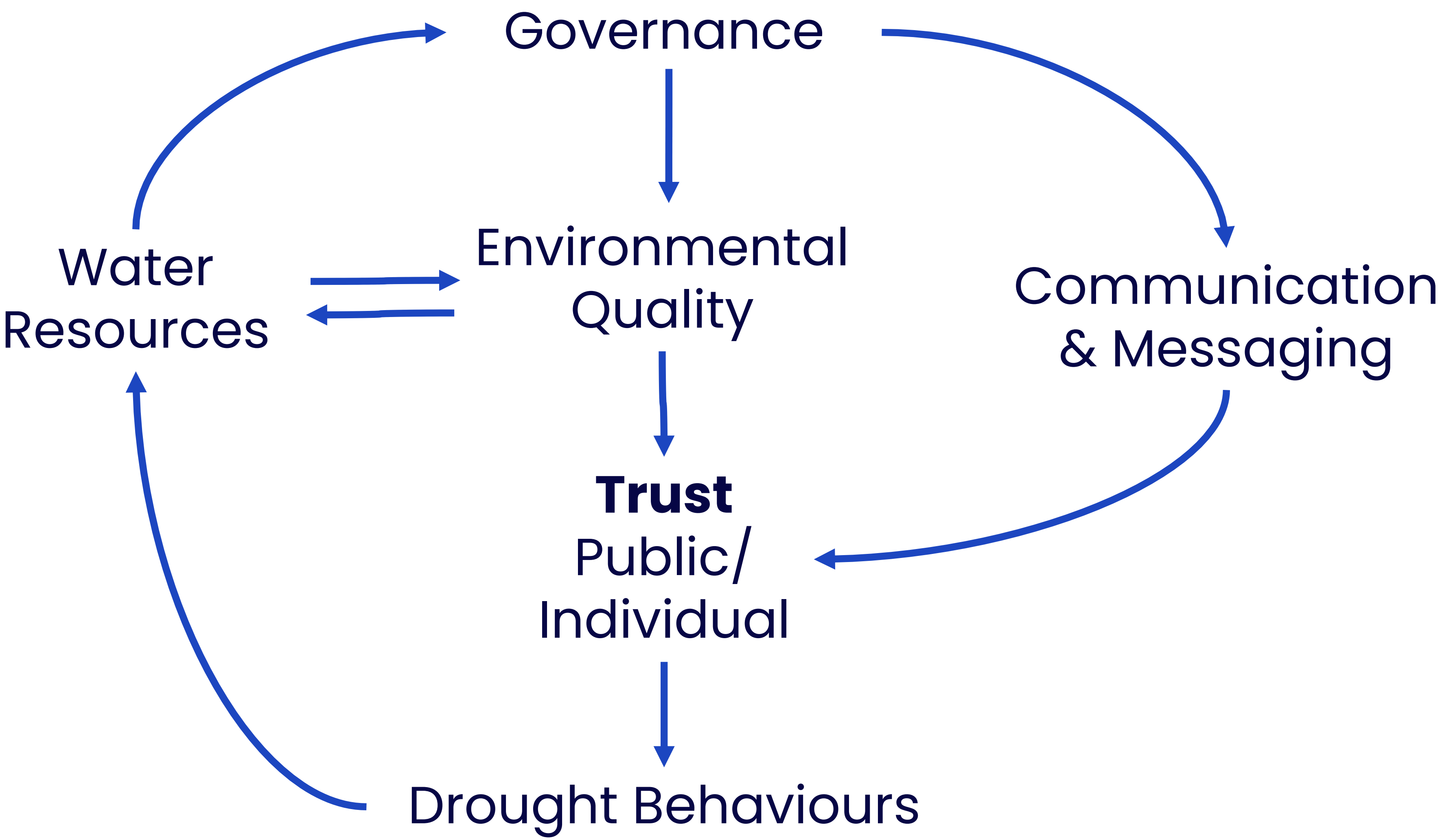
Drought Messaging

Needs to have a

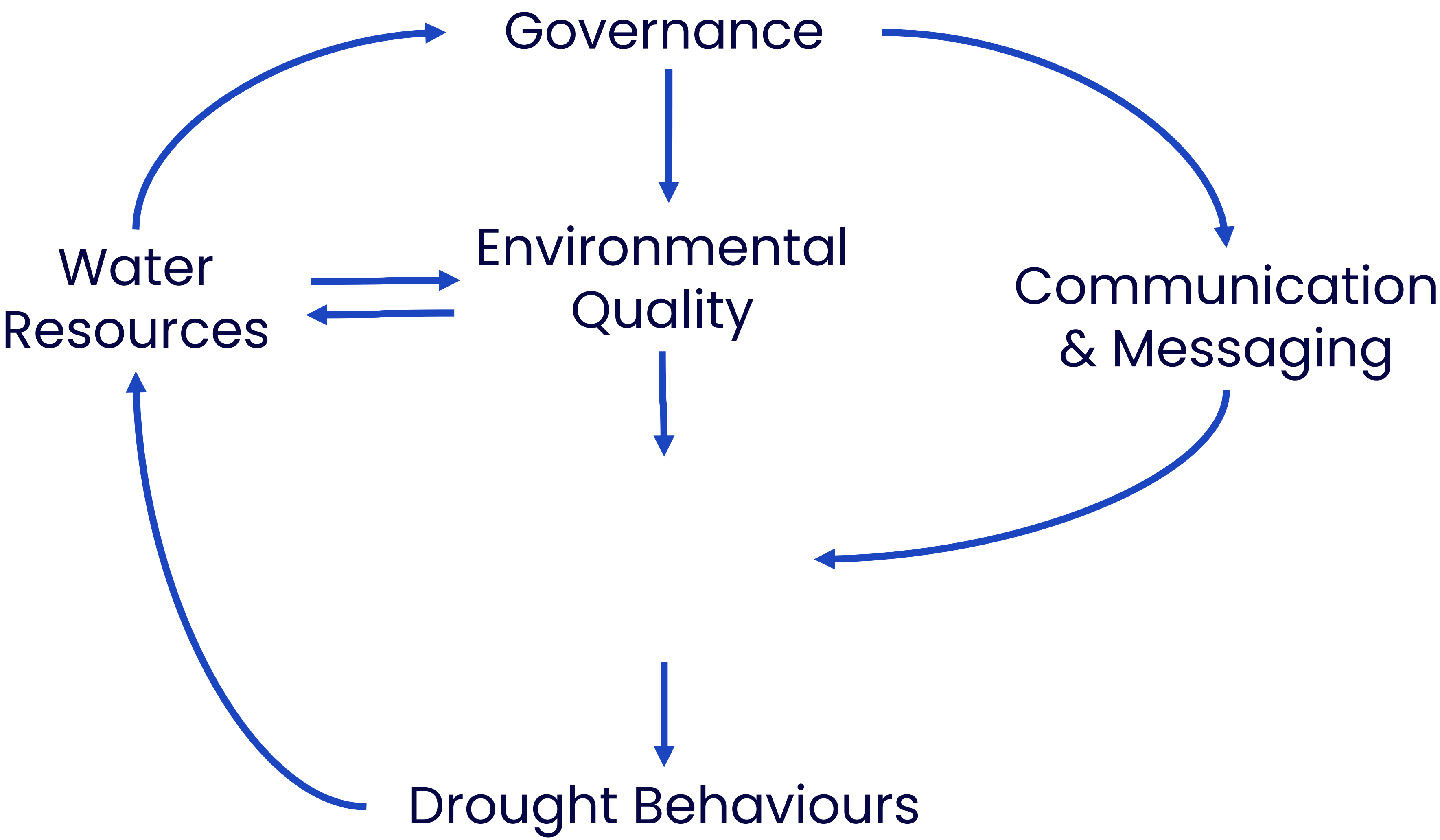
- sense of urgency
- belief in the need for action
- serious, urgent tone of voice
- ‘why’ factor
- water-saving tips / activities

(CCW, 2023)

Trust: filter for behaviours



Trust: filter for behaviours



New Vision: White Paper 2026

Efficiency focus
Opportunity to reset

But:
Droughts?
Timetable?
Practice?

Increasing bills.
26% 2025-26 (Water UK, 2025)
5.4% 2026-27 (Water UK, 2026)

More ‘water poverty’?

Beware Jevons' Paradox...

Increased water bills

Network investment, leakage reduction, treatment upgrades, new reservoirs, desalination

More water available!

Use more water!

Drought

Restrictions

Why are there restrictions when paying higher bills?

Reduced Trust

What if focus on trust, identity and responsibility?

A system to… improve drought resilience and adaptation by developing collective trust, identity and responsibility for water use in order to deliver more sustainable water futures.

Reimagine the role of the public:

stakeholder ✗
audience ✗
consumer ✗
customer ✗

→ **Water managers:** co-governors of water systems and droughts

Communications which focus on individual's role, skills and capabilities to act in their own contexts

Rewards? (CCW, 2025b)

Concluding remarks

1976: compliance high

1976+ demand 135–150 l / day per capita

Drought: demand spikes major challenge, esp. unmetered

Attitudes: vary, individual actions insignificant

Communication: improving, but trust is fundamental

Trust: Can my children swim safely here? Are leakages minimised?

Water managers: as co-governors of water systems and droughts

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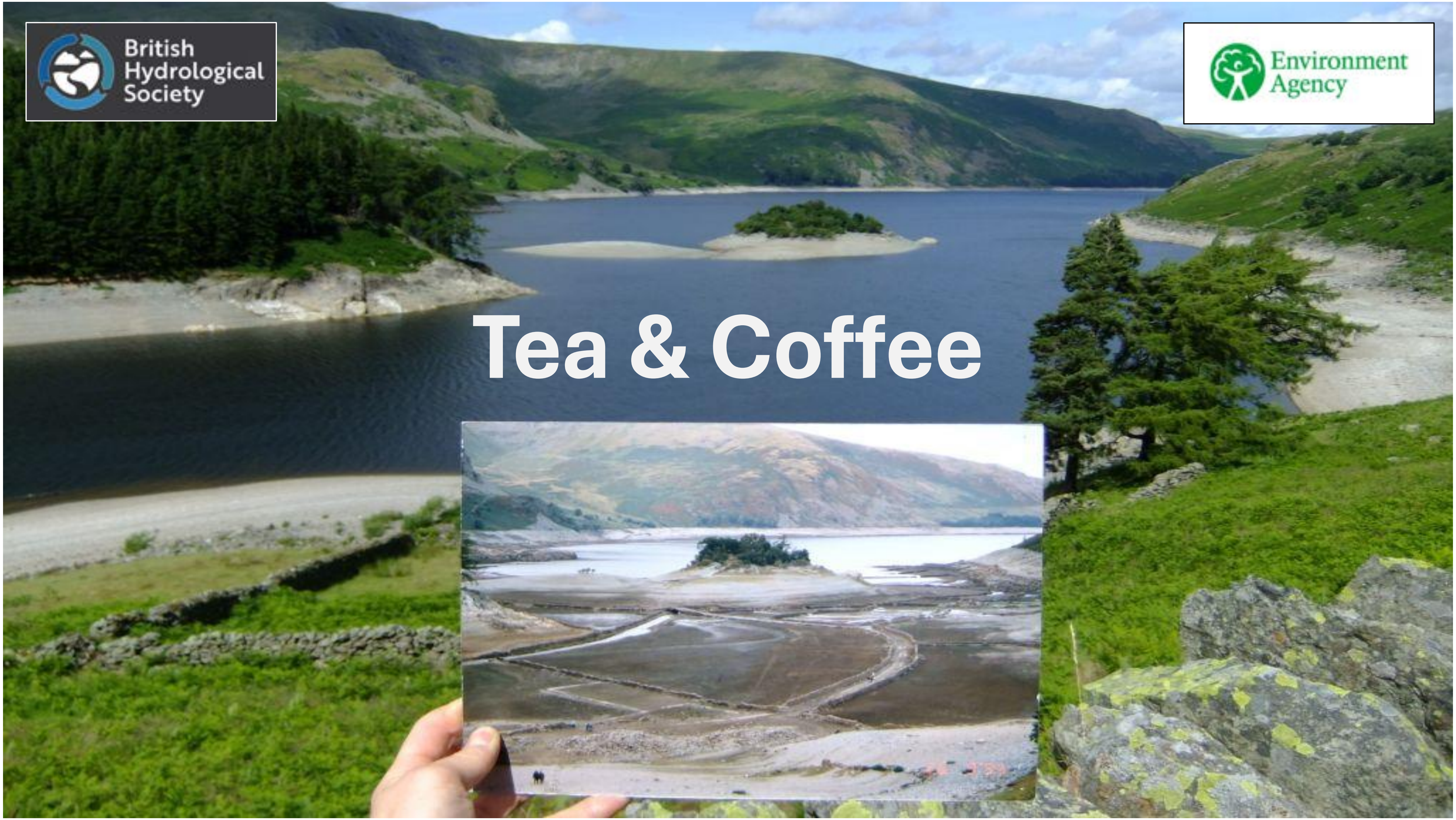
Thank you

The Open University

Questions

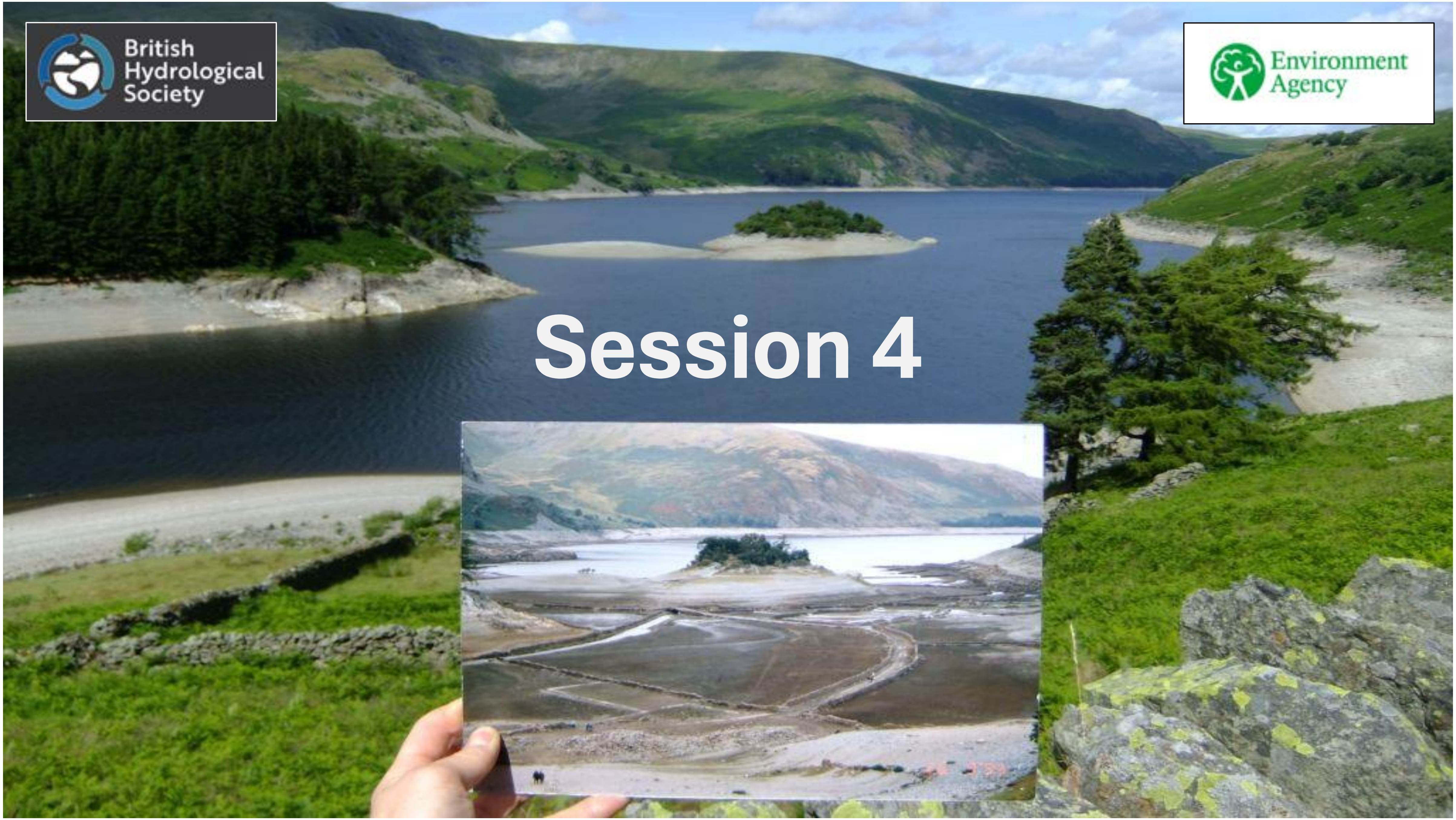
Tea & Coffee



British Hydrological Society

Environment Agency

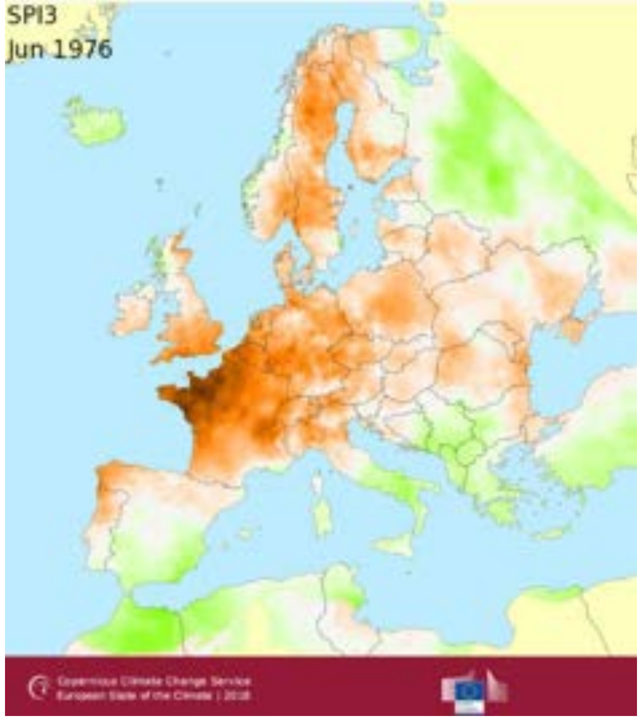
Session 4



Jean Spencer

Independent Chair

National Framework for Water Resources

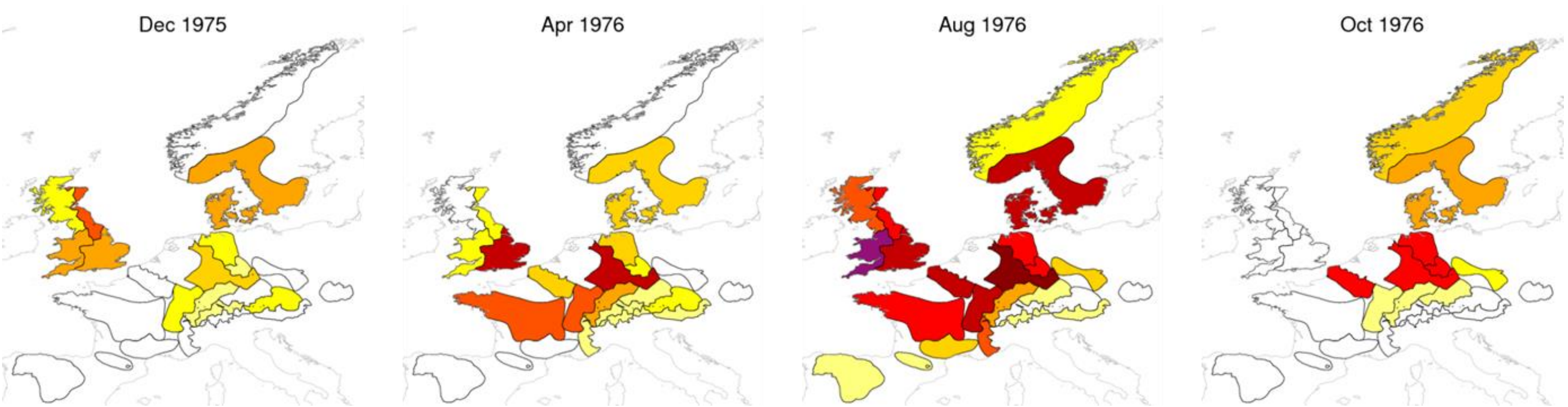


The 1976 drought in Europe

Panel Discussion

Jamie Hannaford (UKCEH), Stuart Allen (EA), Yves Tramblay (IRD France), Karin van der Viel (KNMI, Netherlands), Kerstin Stahl (U. Freiburg, Germany)

With thanks to Giovanni Bernadi (UKCEH) for editing



Development of regional river flow anomalies through winter 1975 – autumn 1976

Microsoft Teams

"Panel Discussion" on international perspectives of 1976 event

2026-06-08 11:22 UTC

Recorded by
Jamie Hannaford

Organized by
Jamie Hannaford

Discussion

Opportunity for questions and reflections

Where were you in 1976?

What do you think has changed the most?

How should we tackle future challenges?

British Hydrological Society

Environment Agency


British Hydrological Society
Environment Agency
Drought hydrology:
50 years since 1976
Wednesday 17 June 2026, Institute of Civil Engineers