2024 Ineson Lecture

Tuesday 19th November at the Geological Society, Burlington House, London.

Groundwater famine and feast. Quantifying future groundwater extremes

The International Association of Hydrogeologist British National Chapter, together with the Hydrogeological Group are pleased to announce the 2024 Ineson Lecture on the theme of groundwater extremes – floods and droughts. The Ineson Lecture this year is sponsored by Project Groundwater Northumbria, led by Gateshead Council, and funded by Defra as part of the £200 million Flood and Coastal Innovation Programmes (FCIP) managed by the Environment Agency.

Programme

09:30 am Registration & coffee in the Lower Library

10:30 am Welcome, Harriet Carlyle (Chair of IAH GB Chapter)

10:35 am Introduce sponsor, Geoff Parkin (Project Groundwater Northumbria specialist lead for the Forecasting and Warning Workstream)

10:45 am Keynote Speaker Introduction

10:50 am **Keynote speaker: David Macdonald (British Geological Survey)** Groundwater flooding – from mechanisms to mitigation

11:50 am Will Rust (Cranfield University) Groundwater teleconnections: decoding hidden patterns in hydrological extremes

12:15 pm Ilias Karapanos (Affinity Water) Managing water resources in a changing climate – Droughts & Floods

12:40 pm John Day Bursary

12:45 pm Lunch & Hydro Group AGM 1 hr

13:45 pm Wilco Klutman (Arcadis) Forecasting groundwater levels in the Netherlands – testing the theory during the 2018 drought

14:10 pm Mark Fermor (GeoSmart Information Limited) Towards a more complete flood risk model for Britain: The role of groundwater

14:35 pm Gemma Coxon (University of Bristol) Quantifying floods and droughts in rapidly changing human-water systems

15:00 pm Hydrogeological Group Medal Awards

15:15 pm Tea

15:45 pm Ineson Lecture Introduction

15:50 pm **Ineson Lecture: John Bloomfield (British Geological Survey)** Understanding hydrogeological extremes in a non-stationary world

16:50 pm Panel discussion

17:20 pm Drinks reception in the library

Speaker Abstracts

Geoff Parkin (Geoff Parkin Hydro Ltd) *Introduction to event sponsor – Project Groundwater Northumbria*. For the past two hundred years or so, water in mined coal seams in the NE of England have been pumped to keep them dry. In the present post-closure phase, water level recovery is actively managed to avoid polluting discharges to the surface and the risk of groundwater flooding, but as levels rise they may activate pathways and interactions with urban infrastructure that did not exist prior to mining. Project Groundwater Northumbria (PGN) was initiated by Gateshead Council to transform our understanding and response to groundwater flooding in this context. PGN is funded by the Flood and Coastal Resilience Innovation Programme (FCRIP) over a 6-year period as one of 25 projects (3 related to groundwater) aiming to discover and implement innovative solutions that enhance flood resilience. PGN brings together new monitoring, geological and hydrogeological modelling, groundwater flood risk mapping and forecasting, and knowledge sharing and community engagement, providing locally implemented outcomes that are relevant to other areas with similar industrial heritage.

Dr David Macdonald (British Geological Survey) *Groundwater flooding – from mechanisms to mitigation.* The recognition of groundwater-related flooding has grown over recent decades both within the UK and globally. The body of research on the topic is also growing. This has examined the mechanisms and controls of groundwater flooding, along with the associated risk and the nature of impacts. Although knowledge gaps still exist, the improved understanding that has resulted has informed the management of the risk, and approaches to early warning and mitigation are being tested. The public in groundwater flood-affected areas are becoming increasingly aware of the mechanism and the need to adopt appropriate measures to reduce their flood risk. In this keynote talk, developments in groundwater flood research will be reviewed, 'from mechanisms to mitigation', with a particular focus on the work undertaken by the speaker and his colleagues at the British Geological Survey. The talk will also draw on observations from living in a groundwater-flood prone urban area and the challenges of local residents in developing effective flood action plans.

Will Rust (Cranfield University) *Groundwater teleconnections: decoding hidden patterns in hydrological extremes.* Groundwater extremes are projected to have increasingly severe societal and environmental impacts in a warming world. Forecasts of hydrological drought are an essential tool for minimizing these impacts, however existing early warning systems are often limited to sub-seasonal lead times due non-stationarities in weather-hydrology systems. This limitation poses a significant challenge to managing groundwater drought at a strategic level, where longer lead times are required to build resilience. Groundwater teleconnections – long-distance relationships between atmospheric systems such as the North Atlantic Oscillation (NAO) and groundwater – may offer a novel solution. Here we will explore how latent multi-year behaviours in the NAO, principally a seven- to eight-year cycle, can have a dominant influence on groundwater records and the occurrence of groundwater drought. These cycles can explain up to 40% of borehole level behaviour and show a significant covariance with the number of boreholes in drought conditions in the UK. Furthermore, using machine learning methods, these NAO behaviours can be skilful predictors of regional drought at lead times of 4 years, with model skill (r2) of up to 0.8. Modelled errors vary from 14% (percentage of boreholes in drought) in flashy hydrological regions or short droughts (< 3 months), to 2% for longer duration droughts (> 8 months). Given the importance of teleconnection systems in driving hydrological extremes across the planet, these results identify a new opportunity for long-lead hydrological drought forecasting with potential global applications.

Ilias Karapanos (Affinity Water) *Managing water resources in a changing climate – Droughts & Floods.* In the public water supply context, a "drought" is typically associated with a period of below average rainfall that has an impact on water availability and source output. There are different types of droughts, with certain weather patterns affecting the surface water or groundwater systems in variable ways as each drought evolves. On the other side of the spectrum, in the last couple of years, flooding has taken place in a greater frequency than anticipated. In a changing climate, the sway between these two extremes is likely to remain and water resources management will be key going forward to ensure resilience is maintained at all times. This presentation will look into the historic responses to both droughts and floods from a water company perspective and suggest ways to enhance resilience in the future.

Wilco Klutman (Arcadis) *Forecasting groundwater levels in the Netherlands – testing the theory during the 2018 drought.* The reliability of any forecasting of the effects of groundwater on surface water starts with the understanding of the groundwater system. Wilco will discuss the behaviour of groundwater in stream valleys, and the mechanisms which restore the groundwater and stream water levels in these area under standard recharge scenarios as well as extreme recharge scenarios. Using analytical methods, nowcasting as well as forecasting of groundwater levels was undertaken. The work was tested during a drought scenario providing an opportunity to compare the predicted to the reality and understand whether the identified required measurements would have actually allowed an early warning of the consequences of the drought?

Mark Fermor (GeoSmart Information Limited) *Towards a more complete flood risk model for Britain: The role of groundwater.* Understanding the groundwater component of flooding today and with our changing climate is key to risk assessment on both a national and property scale. Traditional flood models simulate surface runoff but do not represent the groundwater system dynamically, limiting the predictive capability. Findings are presented showing the relative impact of climate change on the makeup of UK flood risk from different sources, including groundwater. Groundwater causes disproportionately more damage in certain situations and a new paradigm (FloodSmart Analytics) for flood risk assessment has been developed that enables quantification of the influence of groundwater on flooding events and consequences. The new national 5m resolution model brings emergence and routing of groundwater into the context of the other main flood sources and damage estimates to provide a more complete flood risk estimate for property on a nationally consistent basis. Consideration of the different catchment lag characteristics for groundwater and rivers reveals the importance of recognising flooding events as the coincidence of two events, and the need to quantify joint probability when forecasting future flooding events. The example of 2014 flooding in the Thames valley is used to demonstrate the potential for future catastrophic flooding that is not identified using current forecasting methods, and the need to move to a more holistic catchment approach to flood risk assessment and management.

Gemma Coxon (University of Bristol) *Quantifying floods and droughts in rapidly changing human-water systems.* Floods and droughts are increasing in their frequency, severity and duration, with the recent UK drought in the summer of 2022 and flooding from Storm Henk in 2024 underlining the severe impacts from hydrological extremes. Quantifying future floods and droughts is a key challenge for environmental scientists, particularly when accounting for changes in climate, land use, water demand and management. This presentation will draw on recent advances in national-scale hydrological modelling to show how an integrated approach considering surface-water, groundwater and human-water interactions is critical for modelling future floods and droughts. It will look ahead to the need for collaborative science to unlock advances in flood and drought prediction and reflect on opportunities to achieve this via major new programmes, including the UK Flood and Drought Research Infrastructure.

John Bloomfield (British Geological Survey) *Understanding hydrogeological extremes in a non-stationary world.* We're living in a non-stationary world where the intensity and frequency of climate extremes as well as other drivers of environmental change have varied and are predicted to vary in a non-trivial manner both spatially and temporally. Here, we consider the progress already made over the last 30 years or so in understanding hydrogeological extremes, particularly groundwater drought.

After introducing a conceptual framework for analysis of hydrogeological extremes, including understanding how hydrogeological stationarity can be a function of both spatial and temporal scales, we will explore the value of using standardised time series in the analysis of hydrological extremes. We will then look at a series of case studies, focussing on groundwater droughts, illustrating how hydrogeological extremes can be characterised and quantified over a range of spatio-temporal scales, and we will end by discussing some of the challenges that we face in improving our understanding of future groundwater droughts and floods and their impacts.

In this overview of our changing understanding of hydrogeological extremes, we hope to highlight three related themes: i.) the importance of well-constrained conceptual or perceptual models of catchments, and the benefits of consistent definitions of hydrological extremes; ii.) the challenge of obtaining suitable monitoring and observational data, for what are typically rare events; and, iii.) the challenge of sustaining and growing investment in information, expertise and knowledge generation related to hydrogeological extremes.

Speaker Biographies

Dr Geoff Parkin is an independent hydrological consultant and Director of Geoff Parkin Hydro Ltd and Visiting Fellow at Newcastle University. He has more than 30 years of experience in modelling and field studies of integrated groundwater/surface water systems, having developed and tested numerical methods and model software related to most parts of the water cycle. His global experience includes Integrated Water Resources Management (IWRM), modelling and capacity building in the Palestinian Territories, Ethiopia and the other Nile Basin riparian countries, forest and climate studies in South America, and various studies in Europe. He now works on research, advisory and teaching roles with water industry partners in the UK, and is currently specialist lead for the Forecasting and Warning Workstream of the FCIP Project Groundwater Northumbria study, based in Gateshead in NE England.

Dr David Macdonald is a Principal Hydrogeologist with the British Geological Survey, who has worked for the organisation since 1989. He is also the Head of Station at the Survey's Wallingford Office. David joined BGS with a BSc in Geophysics from the University of Edinburgh, and an MSc in Water Resource Systems Engineering from Newcastle-upon-Tyne University. In recent years he completed a PhD at University of Reading studying groundwater processes in floodplain environments. David has worked on a wide range of water resource projects across the globe, with particular interest in the sustainability of water supplies from low storage, hard rock aquifers in Africa and Asia, under a changing climate. David has an expertise in groundwater flooding in both clearwater and permeable superficial deposit settings in the UK. His research has addressed the understanding of groundwater flood mechanisms in these settings, the quantification of risk, and approaches to manage this risk. In recent years he has focussed on the efficacy of nature-based solutions as a means to reduce groundwater flooding.

Dr Will Rust is a Research Fellow in Environmental Data Science at Cranfield University. His research investigates how the dynamics of environmental systems – such as hydrological and ecological systems – vary over time and across spatial scales. His focus is on the response of hydrological and ecological systems to human and environmental influences (such as weather and climate) and how the configuration of these systems effects their resilience to change. He is currently working across two NERC projects focusing on hydro-ecological restoration, resilience and the role of blue-green infrastructure in improving ecosystem services. He has previously led groundwater and river flood modelling projects at a local and regional scale, including the UK and overseas.

Dr Ilias Karapanos is a water resources specialist with over 18 years' experience in the field of hydrogeology and water resources management. Working as a hydrogeologist for Affinity Water since 2011, his research has primarily focused on low flow studies and the impact of public water supply abstraction on river flows and groundwater levels in the Chalk aquifer. Ilias has managed several National Environment Programme projects and has led numerous pumping tests and groundwater pollution investigations. On his current role as the Head of Water Resources Management Planning team at Affinity Water, he is responsible for the delivery of the Water Resources Management Plan (WRMP), which is the long-term strategic plan for water resources looking into the supply-demand balance up to 2075. He also provides advice and technical support to a number of teams within the business, including drought resilience and flood management of water resources. Ilias is a Chartered Geologist with the Geological Society and a Council member since Spring 2024.

Wilco Klutman is a Dutch Physical Geographer (Msc. Utrecht University) with over 15 years' experience with Arcadis in The Netherlands. His focus is on connections between the hydrological, hydrogeological and man-made environment, effectively analyzing these inputs and developing comprehensive water system conceptualizations. With extensive experience in geohydrology and the utilization of regional, as well as smaller scale, groundwater models, Wilco translates these conceptualizations into the modelling environment. Wilco has worked on groundwater flooding and drought projects for a broad range of interested parties including provinces, water utilities, Rijkswaterstaat, water boards, and municipalities to contractors, road builders, and developers.

Mark Fermor is a hydrogeologist with over 35 years of experience primarily in the UK advising on water resources, flooding, contamination and environmental risk management. Mark founded ESI in 1996, a specialist soil and groundwater consultancy advising the water industry, regulatory bodies, waste management and property and infrastructure companies on catchment resources and risk management. In 2013 he founded GeoSmart Information Limited, a specialist environmental risk data and analytics enterprise that published the first groundwater flood risk map for Britain in 2014 and over the last ten years has developed FloodSmart Analytics, a combined flood risk from all sources model used across all parts of the property cycle from regulatory planning, property development and transactions, insurance, lending and asset management. Current work is focused on flood and climate risk assessment and management, particularly working with asset management and in the insurance and finance sectors.

Gemma Coxon is an Associate Professor in Hydrology and UKRI Future Leaders Fellow based at the University of Bristol. Her research focusses on understanding and predicting hydro-climatic extremes (floods and droughts) in changing environments. She built and co-developed the hydrological model DECIPHeR which is now used for hydrological predictions across the UK and led the development of the CAMELS-GB dataset consisting of hydrometeorological timeseries and landscape attributes for 671 catchments across the UK. Her team works closely with communities, water companies, and regulatory bodies across the UK, and are currently involved in projects on (1) delivering a £38M large-scale investment in flood and drought research infrastructure in the UK and (2) informing the development of new water infrastructure as part of the Ofwat RAPID programme.

Dr John Bloomfield is a Principal Hydrogeologist at the British Geological Survey (BGS) where he has worked for the last 33 years. He joined the BGS after a Masters in Structural Geology and a Doctorate in experimental rock deformation, both from Imperial College. He initially worked on BGS' core characterisation programme for NIREX before managing BGS' Aquifer Properties Laboratory and leading work on characterisation of the physical properties of aquifers. In the early 2000s he became the Groundwater Resources Topic and Team leader for BGS where he has overseen a wide range of projects investigating geological controls on hydrogeology, and, for the last decade or more, groundwater responses to hydrological extremes and climate change. He has published over 80 papers in the peer-reviewed literature on topics as diverse as: the behaviour of DNAPLs in the subsurface; the effect of climate change on the fate of pesticides; groundwater stygobites; models of the growth fractures; the hydrogeology of the Chalk; and, fractal scaling of groundwater levels. His recent work has focussed primarily on groundwater drought.

Posters

Innovate use of groundwater to boost resilience during high demand water supply events

Paul Wilson,[1] Rebecca Ni Chonchubhair[1], Conor Courrtney[2]
[1]British Geological Survey, [2]Northern Ireland Water Ltd

How the innovative use of groundwater is being considered to solve water supply deficit and high demand supply events in Northern Ireland. Can it solve everything and what are the challenges and considerations that need to be made? This poster will present on the challenges currently being faced and how groundwater has been freshly considered as an option to address water supply deficits, particularly during high demand events. It will discuss some of the difficulties faced and the practical challenges of reintroducing groundwater abstraction back into public water supply production in the 21st Century.

Linking hydrological indices to impact: Insights from 200 years of flood and drought reporting in a Chalk catchment

Matthew Ascott[1], Kathryn Graves[2], Ben Marchant[1], John Bloomfield[1]
[1]British Geological Survey, [2]Chesham Town Council

Standardized hydro-meteorological indices (e.g. standardized precipitation index (SPI), standardized precipitation-evapotranspiration index (SPEI), standardized groundwater index (SGI)) are commonly used in analyses of hydrological extremes, but relationship between these indices and observed flood and drought impacts are poorly constrained. This is in part due to a scarcity of long-term datasets of flood and drought impacts. Here we report the development and analysis of a local scale database of flood and drought impacts derived from newspaper records for 1800 – 2022 in a groundwater dominated lowland catchment in Southeast England (UK). Logistic regression was used to evaluate relationships between standardized indices (SPI-1 to SPI-48, SPEI-1 to SPEI-48, SGI) and reported flood and drought impacts. The strongest predictor variables and accumulation periods varied between floods and droughts. Potential drought and flood threshold values for standardized indices are assessed. The protocol developed here can be applied to other catchments to better characterise flood and drought impacts and how these relate to the driving hydrology.

Exploring the relationship between groundwater drought and evapotranspiration with the JULES land surface model

Sarah Collins (BGS)

Hydrological droughts can last months to years and impact large areas, leading to a multitude of ecological and socio-economic harm. The role of evapotranspiration (ET) in drought is very variable and there is contradicting evidence on the impact of anthropogenic warming on groundwater drought in the UK. We integrate a distributed groundwater model into the JULES land surface model (JULES-DGW) and simulated a Chalk catchment in southern England over the period 1901–2015. The model showed a good match to river flows (Kling-Gupta efficiencies 0.73–0.83) and groundwater levels (r2 = 0.92). Splitting the model into three roughly equal periods (1901–1938, 1939–1976, 1977–2015), we found a general trend of drying with small drops in average moisture in the unsaturated zone and average groundwater levels, caused by increases in annual ET (58%, 59%, 61%) and decreases in recharge (40%, 38%, 36%) as a fraction of precipitation. The model suggests drier conditions in the unsaturated zone in late summer/early autumn in the most recent period have led to a delay in the recharge season. No increase in capillary rise was simulated throughout the modelling period and ET was found to have a positive anomaly in most cases of severe drought.

Conceptual model development to inform flood and drought observational infrastructure design in the Chess

Matthew Ascott[1], Joel Blackburn[1], James Sorensen[1], John Bloomfield[1], Jon Evans[2], Gareth Old[2]
[1]British Geological Survey, [2]UK Centre for Ecology and Hydrology

Floods & Droughts Research Infrastructure is a £38 million project commissioned by UKRI-NERC to improve our understanding of how, when and where floods and droughts occur in the UK. This will inform action to improve our resilience to the increasing impacts of climate change. The River Chess catchment in SE England is one of three

catchments selected for fixed infrastructure. The Chess is a groundwater fed river situated on the Chalk with a base flow index of 0.95, highlighting the importance of the Chalk aquifer on surface flows. Work to date has used existing information to develop a conceptual model of the functioning of the catchment and identify any remaining uncertainties. The poster highlights elements of the catchment water balance, proposed monitoring infrastructure types and locations, uncertainties and the next steps.

The Role of Groundwater in Adapting to Climate Change and Increasing Resilience to Drought

Brady Johnson[1], Jean-Christophe Comte[1], Rachel Helliwell[2], Alan MacDonald[3], Chris Soulsby[1]

[1]University of Aberdeen, School of Geosciences, AB24 3UF, Scotland, UK. [2]James Hutton Institute, Centre of Expertise for Waters, Aberdeen AB15 8QH, Scotland UK. [3]British Geological Survey, Edinburgh EH14 4AP, Scotland UK

In recent years, Scotland has experienced some of the most severe droughts on record with 2022 seeing the Scottish Environmental Protection Agency (SEPA) categorise all eastern Scotland river catchments in moderate to significant water scarcity status. At these levels, SEPA has authority to strategically suspend abstraction permits in these areas. Drought in Eastern Scotland is predicted to be more frequent and severe under most climate change scenarios. Although groundwater supplies many citizens in rural areas and supports major agricultural and economic sectors (e.g. whisky distilling), groundwater infrastructure is often limited and located in shallow, low storage aquifers most at risk during drought conditions.

The study draws on observations and data obtained between the Deveron and Tweed River catchments on the east coast of Scotland with a focus on the Ythan and Dee catchments in Aberdeenshire, while incorporating characteristic response and monitoring data throughout aquifers in eastern Scotland. Groundwater level data is obtained from existing monitoring networks and will be supplemented with new instrumentation in areas of interest from this project. Long term water level trends have been identified and modelled incorporating hydrogeologic properties related to storage and/or lithology and structure. Relationships between the annual magnitude and timing of groundwater level change in both drought and typical climate conditions are being developed for identified hydrologic regimes in the region (e.g. high storage, low recharge; low storage, high recharge) with a focus on aquifers that may be more resilient to future water scarcity issues and extreme drought events.

Project Groundwater Lincolnshire: Scopwick groundwater flooding

Victoria Crellin (AtkinsRéalis)

Project looking at groundwater flooding at Scopwick Lincolnshire, being carried out for Lincolnshire County Council (LCC) under Project Groundwater – Greater Lincolnshire (PGW) as part of the Flood and Coastal Resilience Innovation Programme (FCRIP), funded by the Department for Environment, Food & Rural Affairs (Defra). The trial community of Scopwick has increasingly suffered from sewer related flooding over the last decade, despite numerous relining activities. This project is focused on improving the understanding of groundwater flooding, with a view to trialling solutions to manage groundwater flooding issues.

Groundwater and drought in the horn of Africa

Alan M MacDonald, Donald J MacAllister, Seifu Kebede, Tilahu Azagegn, Eddie Banks and Rachel Bell

Groundwater is often relied on to provide secure drinking water, particularly in rural Africa, where other options are limited. The increased incidence of drought and its likely escalation due to climate change raise questions as to how resilient groundwater is to drought, and how the performance of different technologies used to access groundwater compares during drought. Here we report the results of three research studies undertaken in Ethiopia to directly address these questions. We first examine hydrographs from 19 wells, springs and boreholes during the 2015/16 El-Niño drought and the years following. Secondly, we report the results of a survey of groundwater recharge for 50 sampled boreholes from 4 woredas (districts) and, lastly, we examine the response of >5,000 different water points from across Ethiopia from January to April 2016 as the drought evolved. The results from the three studies all give a consistent story: groundwater supplies, particularly those accessing groundwater deeper than 15 metres, are resilient to the short-term effects of drought and become increasingly important as other water sources (e.g., springs) fail. Hand-pump-operated boreholes were often the most reliable sources during drought periods, although motorized boreholes, if accompanied by active monitoring and maintenance, also proved so. Springs and hand-dug

wells were generally, but not universally, severely impacted by drought, with those at higher elevations most affected. Recharge studies using environmental tracers suggested that the mean residence time of groundwater (<100 metres deep) is in the order of several decades across the Ethiopian Highlands. This indicates modern recharge is occurring but is not reliant on very recent rainfall; thus, groundwater is both resilient to drought and renewable when managed appropriately. Additional pressures put on groundwater supplies by the drought were shown to be mitigated by an active and sustained campaign of monitoring and maintenance as drought evolved.

Dewatering a Groundwater Ocean

Juan Rivera (Envireau Water)

Channel Iron Deposits (CID) in the Pilbara region in Western Australia are a great source of iron ore for mines, but can also store large volumes of groundwater. The large groundwater quantities observed during the mineral exploration, made it necessary to include a thorough hydrogeological feasibility assessment for a new proposed mine. In an area with high evapotranspiration and only seasonal rainfall, one would expect recharge into the CID aquifer to be low; however, it was identified that discharges from upstream mines were recharging the CID aquifer at a fast pace, which would increase the pumping costs for the new mine in order to extract the mineral. Groundwater surplus in the area can bring mining projects down. Catchment management usually reflects the present and past water issues, but future users are not included and will have to deal with what is already in place, making current catchment management plans an unfair system.

Future-Proofing the Scotch Whisky Sector: Strategies for Climate Resilience

Shona Symon (Envireau Water)

Securing a reliable water supply is paramount for the distilling industry. Increasingly volatile weather patterns and stringent regulations are already limiting production capacity and constraining expansion opportunities. In addition, Climate Change predictions show that the River Spey, vital to whisky production in Speyside, is projected to experience severe low flows twice as often compared to current levels. Groundwater resources, particularly shallow systems used widely across the distilling sector, face a similar crisis, with declining recharge and heightened depletion risks.

Access to consistent groundwater sources is critical in maintaining distilling operations across the six distilleries located in Dufftown. Working across all these distilleries has allowed a thorough review of the key risks to be identified, including an assessment of how vulnerable these water sources are to climate change. This has then been used to inform decision making to ensure that effective water management
contributes positively to increased climate resilience.

Learnings from Test Pumping Exercises Conducted in a Confined Limestone Aquifer in Drought Conditions.

Jenny Harrison (Envireau Water)

An extended Constant Rate Test (CRT) pumping exercise was undertaken on a water supply borehole towards the end of the drought period in 2022. The water level in the borehole did not reach equilibrium during the test. A series of hydrographs are presented, showing the CRT pumping exercise and analysis of the background groundwater recession based on other monitoring points and long-term historical records. The data supports a more pragmatic approach towards abstraction licensing and the use of longer duration operational tests to consider aquifer response to pumping over increasingly frequent seasonal groundwater extremes.

Project Groundwater Greater Lincolnshire: Exploratory groundwater modelling for sustainable abstraction and flood alleviation in Grimsby, Barton and Barrow

Claire Cook (WSP)

In Lincolnshire, DEFRA's 'Project Groundwater' funding is being used by a local council led consortium of the Environment Agency, National Flood Forum and academics with inputs from Anglian Water to better understand the causes of groundwater flooding associated with both the Chalk and Limestone aquifers and develop innovative management solutions. In Grimsby, following saline intrusion problems, significant reductions in industrial and public water supply abstraction have resulted in groundwater rebound with flooding of basements focused around blow well pathways through the Till which blankets the coast-marginal marsh. The leaky sewer system acts to

intercept and reduce flooding risks but the higher rates of diluted effluent create problems for treatment. Analysis of historical groundwater level and abstraction relationships combined with modelling has demonstrated that increased abstraction combined with locally lowered drainage offers the best way forward, as well as reducing sewer surcharging and providing a valuable resource of clean groundwater for public supply and potentially for open-loop heating of the hospital. Enhanced monitoring of groundwater levels is essential to assess effectiveness into the future of climate change as sea levels rise and inland recharge rates fall to guard against the risks of saline intrusion.

From drips to drenches: an investigation into the East Yorkshire Chalk's Gypsey Race

Kieran Topen and Caroline Ball (SWECO)

As part of Yorkshire Water's WINEP investigations into abstraction impacts on WFD surface water bodies, monitoring has been undertaken during a period of significant drought followed by a very wet period. This study examines these groundwater extremes as experienced by the East Yorkshire Chalk's Gypsey Race, as well as the preceding period when climate change impacts have also been identified. The project aims to develop the understanding of how both groundwater and surface water interact with public water supply abstraction and emphasizes the importance of catchment conceptualization in water resource management. The findings contribute to a better understanding of the challenges posed by fluctuating groundwater conditions as the aquifers respond to climate change, which will support future strategies for sustainable management in the region.

Transnational, Harmonised Data Gathering, Monitoring and Evaluation of Groundwater Dynamics in the Context of Climate Change

Peter van der Keur (GEUS), Stefan Broda (BGR), Mariana Gomez (BGR), Georgina Arnó (ICGC), John Bloomfield (BGS), Bentje Brauns (BGS) , David Pulido (IGME)

This poster presents the European Groundwater Monitoring Database (EUGM), a transnational platform for harmonized groundwater data collection and monitoring across Europe. EUGM will support a database of groundwater levels, and will the data can be used, e.g. for trend detection and evaluation of drought histories with the Standardized Groundwater level Index (SGI). At the later stages of the project this GSEU (Geological Surveys for Europe https://www.geologicalservice.eu), near-real-time data will also be used for short- and long-term forecasting.

Groundwater systems response to major, continental-scale droughts: a multidecadal case-study for Europe

Bentje Brauns[1], John Bloomfield[2], David Hannah[3], Ben Marchant[1], and Anne van Loon[4]

[1]British Geological Survey, Keyworth, UK. [2]British Geological Survey, Wallingford, UK. [3]School of Geography, Earth & Environmental Sciences, University of Birmingham, Birmingham, UK. [4]Institute for Environmental Studies, Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

Groundwater systems are susceptible to drought, but the link between meteorological droughts and groundwater responses is complex due to varying climate drivers, catchment characteristics, and human interventions. Previous studies have often been geographically or temporally limited. Here, using a European-wide dataset, we present a multidecadal analysis of major meteorological drought episodes on groundwater systems at the continental scale. Groundwater levels were standardized, and analysed using the Standardised Groundwater level Index (SGI). Cluster analysis revealed spatially coherent 'type' hydrographs across different areas of Europe, and highlighted the importance of the 'memory' of groundwater systems.

Guidance on Assessing Risk to Controlled Waters from UK Land Contamination Under Conditions of Future Climate Change

Emma Khadun (SoBRA)

Presented on behalf of the SoBRA controlled waters and climate change subgroup who are updating and reissuing the guidance published in August 2022 ('Guidance on Assessing Risk to Controlled Waters from UK Land Contamination Under Conditions of Future Climate Change') to consider future extreme weather. This poster will detail best practice on how to incorporate climate change into a conceptual site model from a hydrogeological and contamination perspective.

Climate Change Mitigation and Adaption for Vulnerable Communities in South Sudan

Groundwater Relief

The South Sudan Enhancing Community Resilience and Local Governance Project Phase II (ECRP-II) aims to improve access to services, strengthen flood resilience, and enhance institutional capacity for local service delivery and integrated disaster risk management. The project is Managed by the Ministry of Finance & Planning with the Local Government Board on behalf of the Government of South Sudan and implemented by the International Organization for Migration (IOM).

The IOM have contracted out a Groundwater Relief (GWR) led consortium of 7 organisations (Groundwater Relief, Arup, Acacia Water, The University of West England, Groundwater Science, University of Reading and the University of Cardiff) to undertake a range of activities to Support Disaster Relief Response.

Five target counties have been identified for assistance; Rubkona (Unity), Twic East (Jonglei), Pibor (Pibor AA), Fashoda (Upper Nile) and Duk County (Jonglei).

Project Groundwater Northumbria

Gateshead Council

Ineson 2024 – Burlington House, London

Geoff Parkin

19th November 2024

About Project Groundwater Northumbria

In November 2020, the Department for Environment, Food & Rural Affairs (DEFRA) launched an exciting opportunity for local innovation by inviting lead local flood authorities (LLFAs) to apply for funding through the Flood & Coastal Resilience Innovation Programme (FCRIP). This initiative aims to unite local authorities, businesses, and communities in a collaborative effort to discover and implement innovative solutions that enhance flood resilience in their areas.

Gateshead Council's LLFA team seized this opportunity, successfully preparing and submitting a bid that led to the creation of Project Groundwater Northumbria (PGN) in 2021.

Proudly, PGN stands as one of the twenty-five groundbreaking projects sponsored by FCRIP, paving the way for a more resilient future.

This project will conclude in 2027.

Department for Environment Food & Rural Affairs

Environment Agency

Flood and coastal resilience innovation programme

Part of the £200m
Flood and coastal innovation programmes

Project Groundwater Northumbria

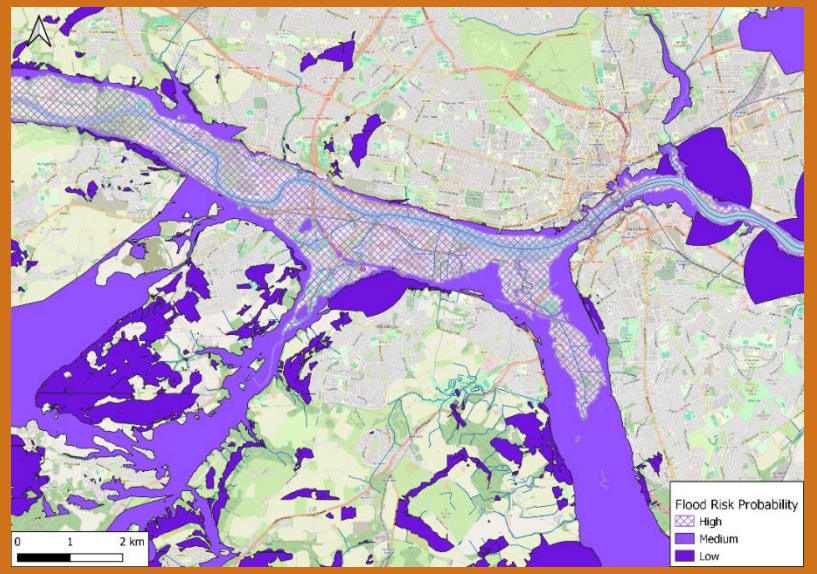
Gateshead Council

PGN's vision is to transform our understanding and response to groundwater flooding.

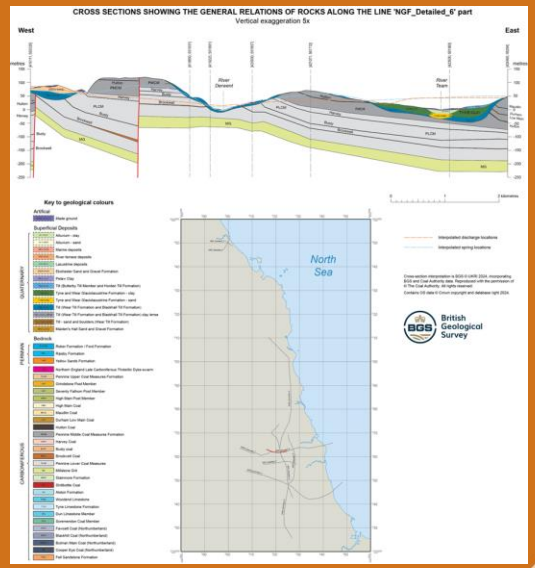
The Action Plan

1. **Monitoring and Evidence Collection:** Utilise cutting-edge monitoring technology to accurately track groundwater levels.
2. **Forecasting and Warning System Development:** Establish a system to keep communities informed and enhance flood preparedness.
3. **Groundwater Flood Risk Mapping:** Create comprehensive maps to provide an evidence-based framework for groundwater risk management.
4. **Groundwater Report Development:** Analyse the impact of industrial heritage, historical groundwater management, and urbanisation on groundwater behaviour in the Northeast region.
5. **Knowledge Sharing and Community Engagement:** Foster collaboration and learning across various communities, including outreach initiatives in STE(A)M (science, technology, engineering, and mathematics).

Project Groundwater Northumbria



Extract of initial susceptibility groundwater map over parts of Newcastle and Gateshead created by Project Groundwate Northumbria



Extract of hydrogeological cross section from the Gateshead study area – section crossing the rivers Derwent and Team valleys

The lack of comprehensive groundwater flood risk mapping represents one of the challenges faced in managing groundwater flood risk in the northeast region.

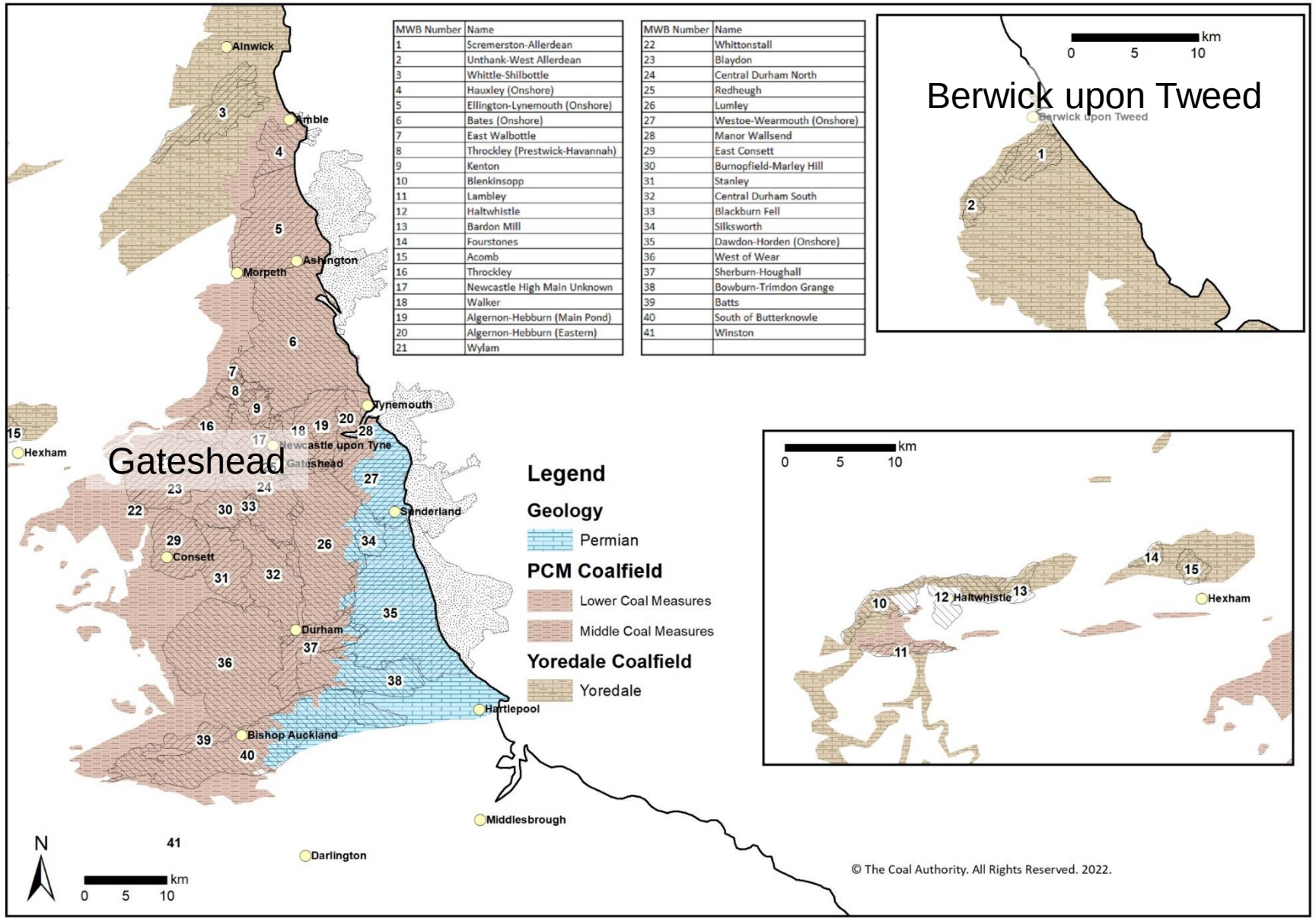
Project Groundwater Northumbria is collaborating with researchers and specialised organisations to enhance our groundwater flood risk management strategies, particularly as we adapt to a changing climate. We are committed to making a meaningful impact in this critical area.

"It is difficult to predict groundwater flooding. Groundwater levels are not monitored in every part of England." -www.gov.uk/guidance/groundwater-flooding

Mine Water Blocks

Mine Water Blocks (MWBs) are groups of colliery mine workings which have continuous variation of mine water levels within the block

PGN has 2 focus areas each with a group of MWBs:
- Berwick upon Tweed
- Gateshead



MWB Number	Name
1	Scremerston-Allerdean
2	Unthank-West Allerdean
3	Whittle-Shilbottle
4	Hauxley (Onshore)
5	Ellington-Lynemouth (Onshore)
6	Bates (Onshore)
7	East Walbottle
8	Throckley (Prestwick-Havannah)
9	Kenton
10	Blenkinsopp
11	Lambley
12	Haltwhistle
13	Bardon Mill
14	Fourstones
15	Acomb
16	Throckley
17	Newcastle High Main Unknown
18	Walker
19	Algernon-Hebburn (Main Pond)
20	Algernon-Hebburn (Eastern)
21	Wylam

MWB Number	Name
22	Whittonstall
23	Blaydon
24	Central Durham North
25	Redheugh
26	Lumley
27	Westoe-Wearmouth (Onshore)
28	Manor Wallsend
29	East Consett
30	Burnopfield-Marley Hill
31	Stanley
32	Central Durham South
33	Blackburn Fell
34	Silksworth
35	Dawdon-Horden (Onshore)
36	West of Wear
37	Sherburn-Houghall
38	Bowburn-Trimdon Grange
39	Batts
40	South of Butterknowle
41	Winston

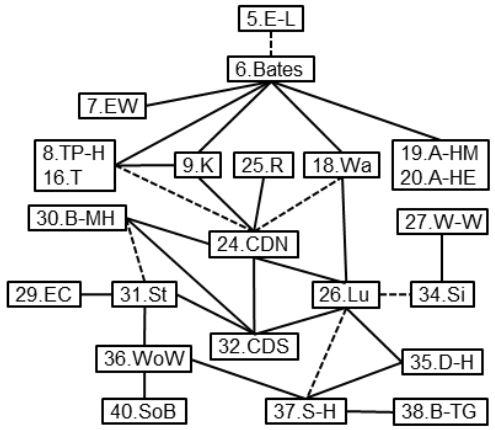
Source: Hydrogeological Conceptual Model: North East Mine Water Blocks – Introduction Report

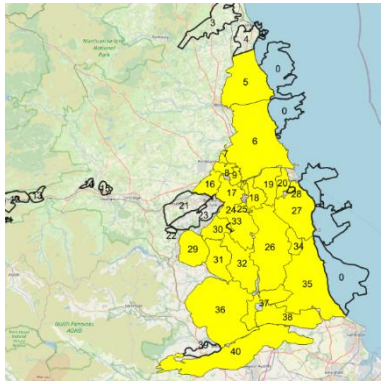
Project Groundwater Northumbria

MWB inter-connections

Although some MWBs are isolated, many have known connections with adjacent blocks through abandoned mine shafts, roadways etc, which may be active or inactive at different water level thresholds.

The figures below illustrate the potentially contiguous set of MWBs across the NE coalfield





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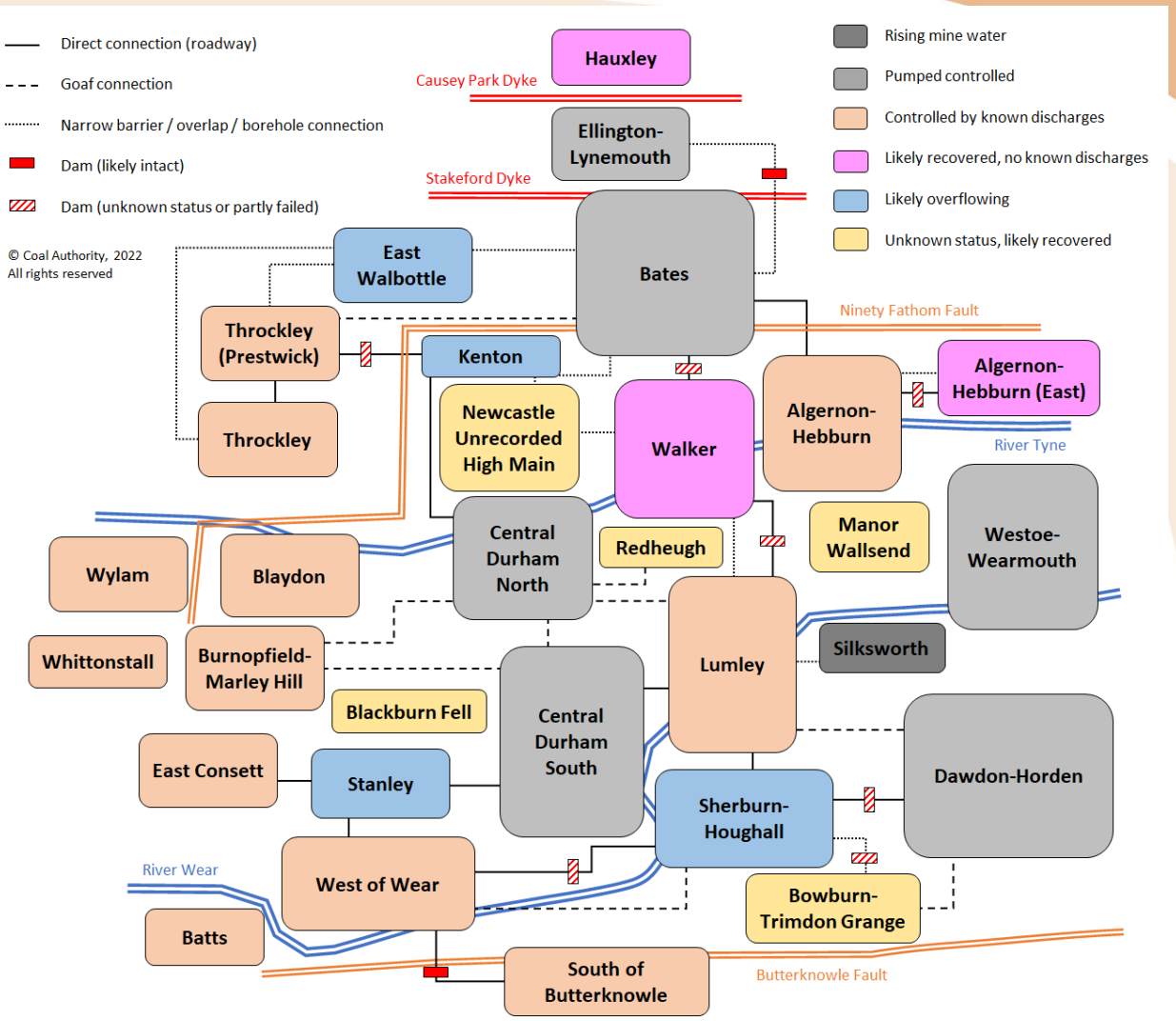


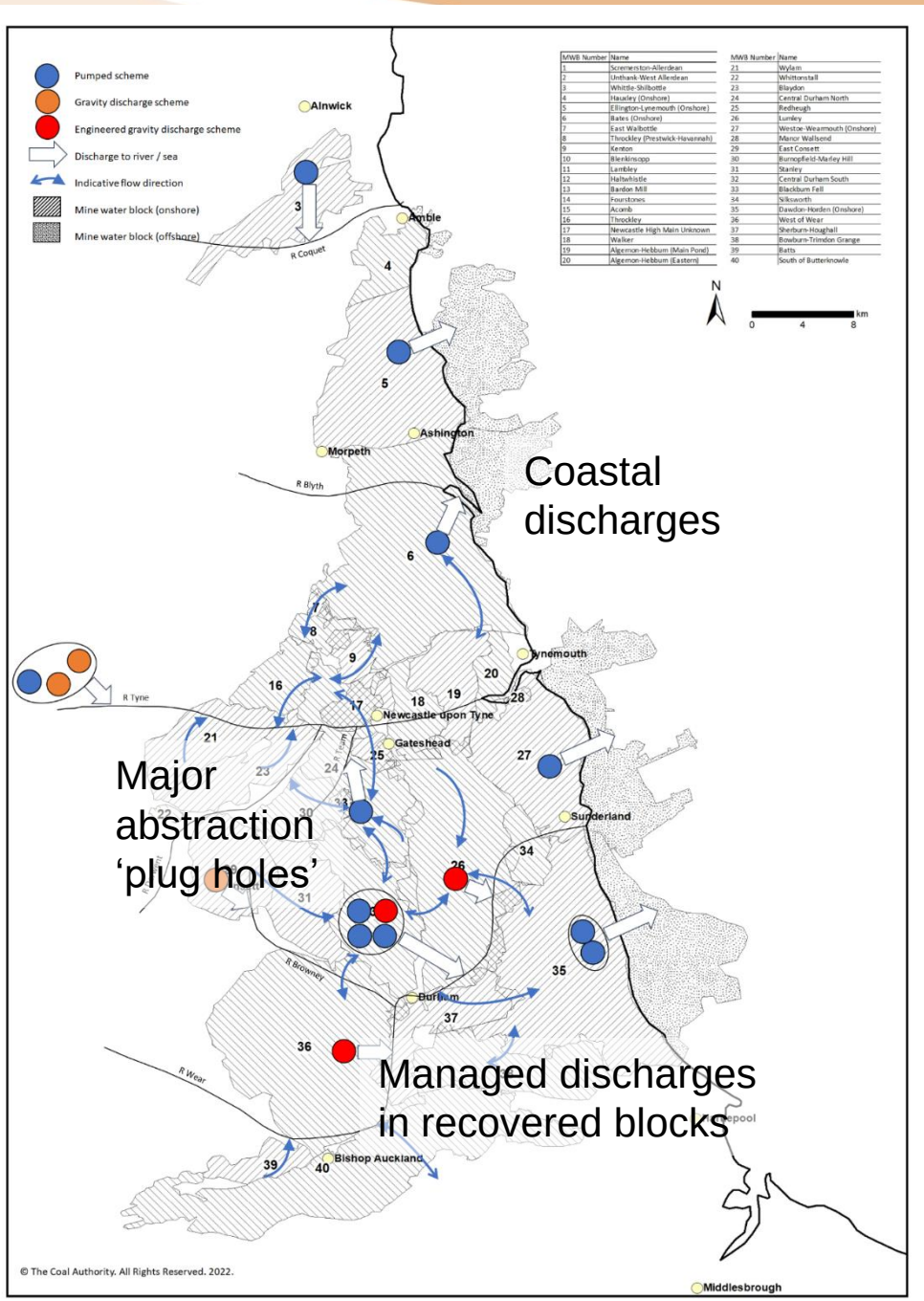
Source: Hydrogeological Conceptual Model: North East Mine Water Blocks – Introduction Report

Mine water level management

During mining, coal seam workings were pumped to keep them dry. As collieries were closed, pumping has continued by the Coal Authority (CA) in collaboration with the EA, to prevent polluting discharges to surface waters.

Abstractions have been gradually reduced as ‘managed recovery’, with controlled discharges to the surface.

Source: Hydrogeological Conceptual Model: North East Mine Water Blocks – Introduction Report



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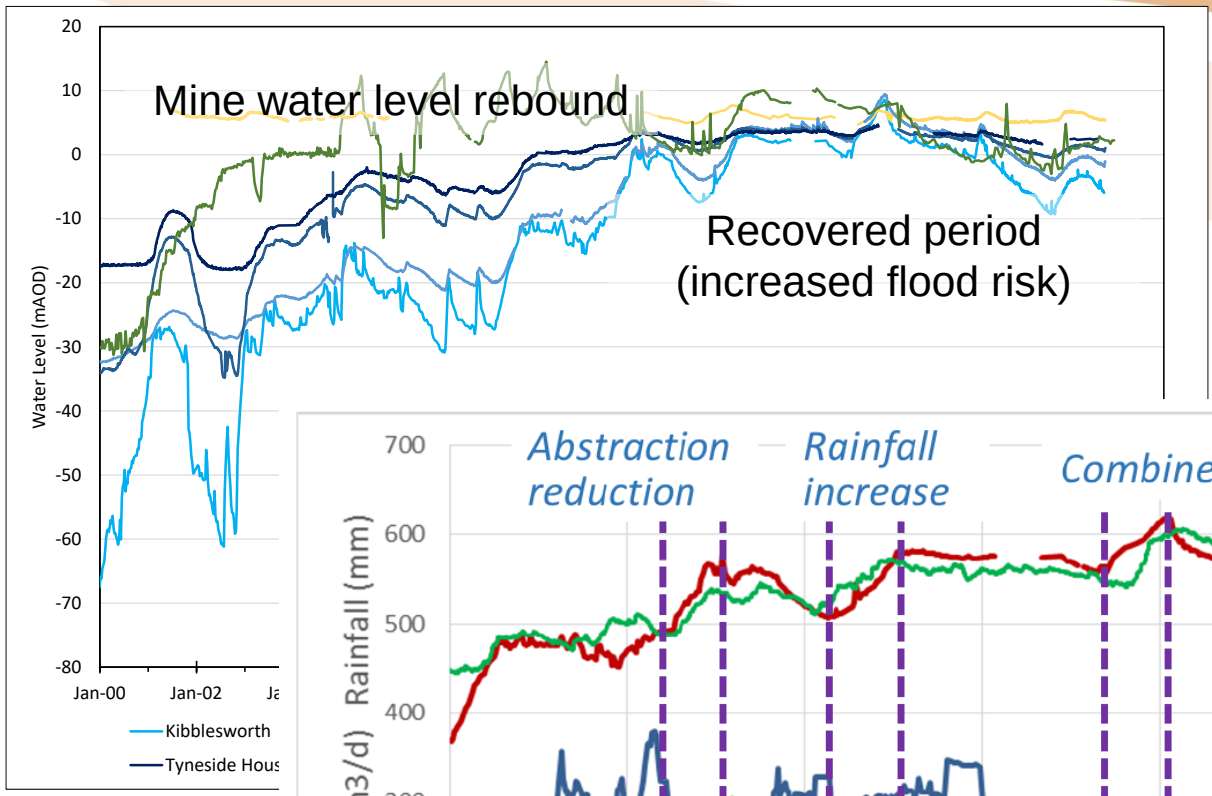
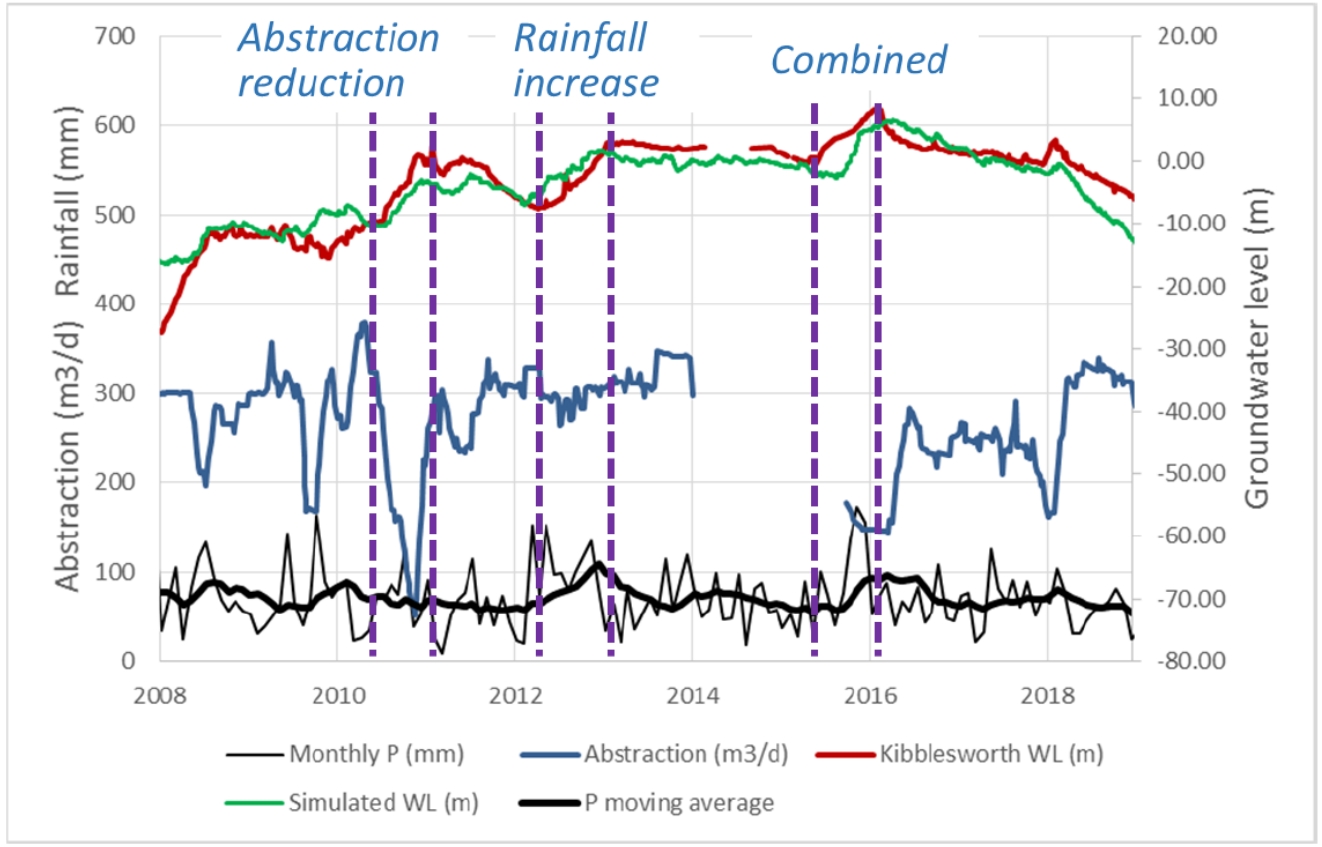
Mine water level responses

Following a period of water level rebound as abstractions were reduced, relatively high water levels create increased risk of polluting discharges or flooding, due to combinations of variations in pumping rate and/or recharge.





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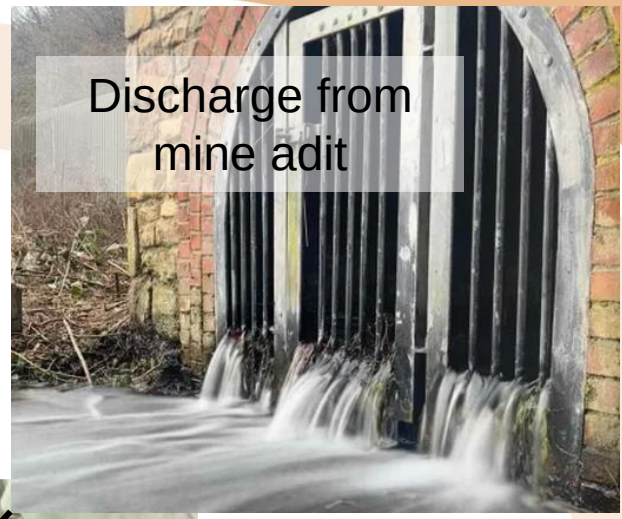
PGN focus study area

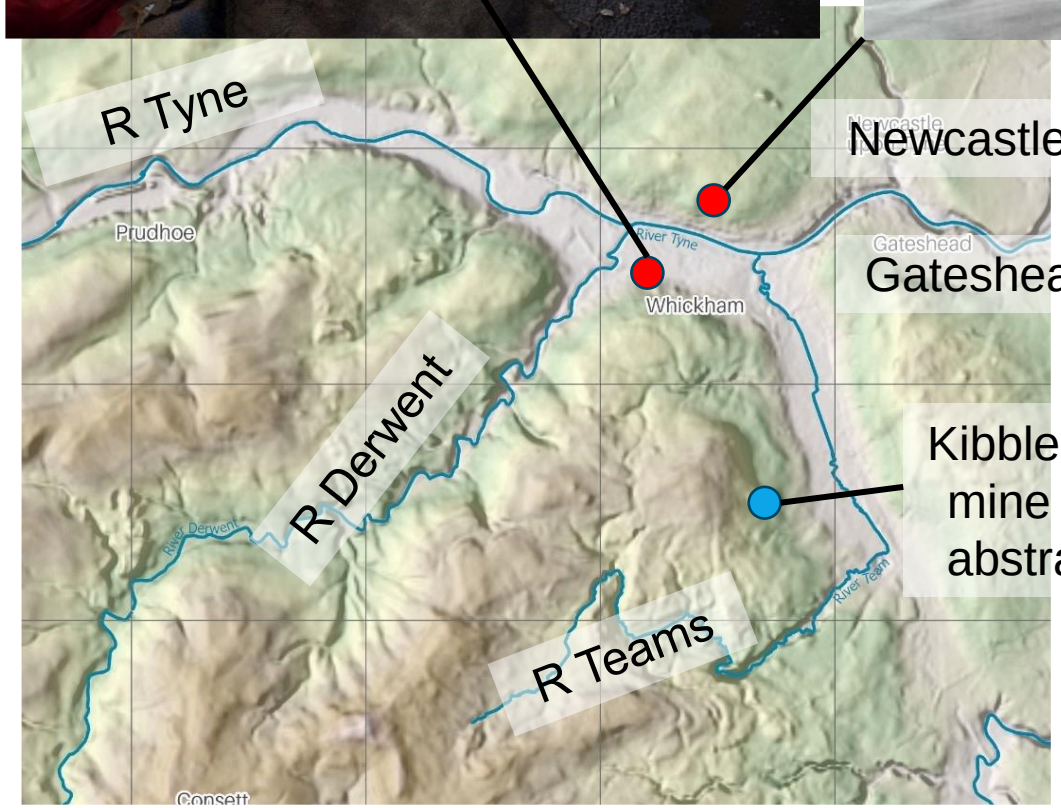
An ‘unexplained’ flood (persistent, and not obviously related to excessive rainfall) occurred at a site along the Tyne valley, in an industrial area and also affecting access roads to the commercially significant Metro Centre retail area.

Subsequent investigations showed the likely cause to be the pump at Kibblesworth which had not been operative due to technical reasons.

This highlighted the deficiency at that time in hydrogeological expertise in Gateshead Council, the LLFA.

Project Groundwater Northumbria





Viewpoint of next slide

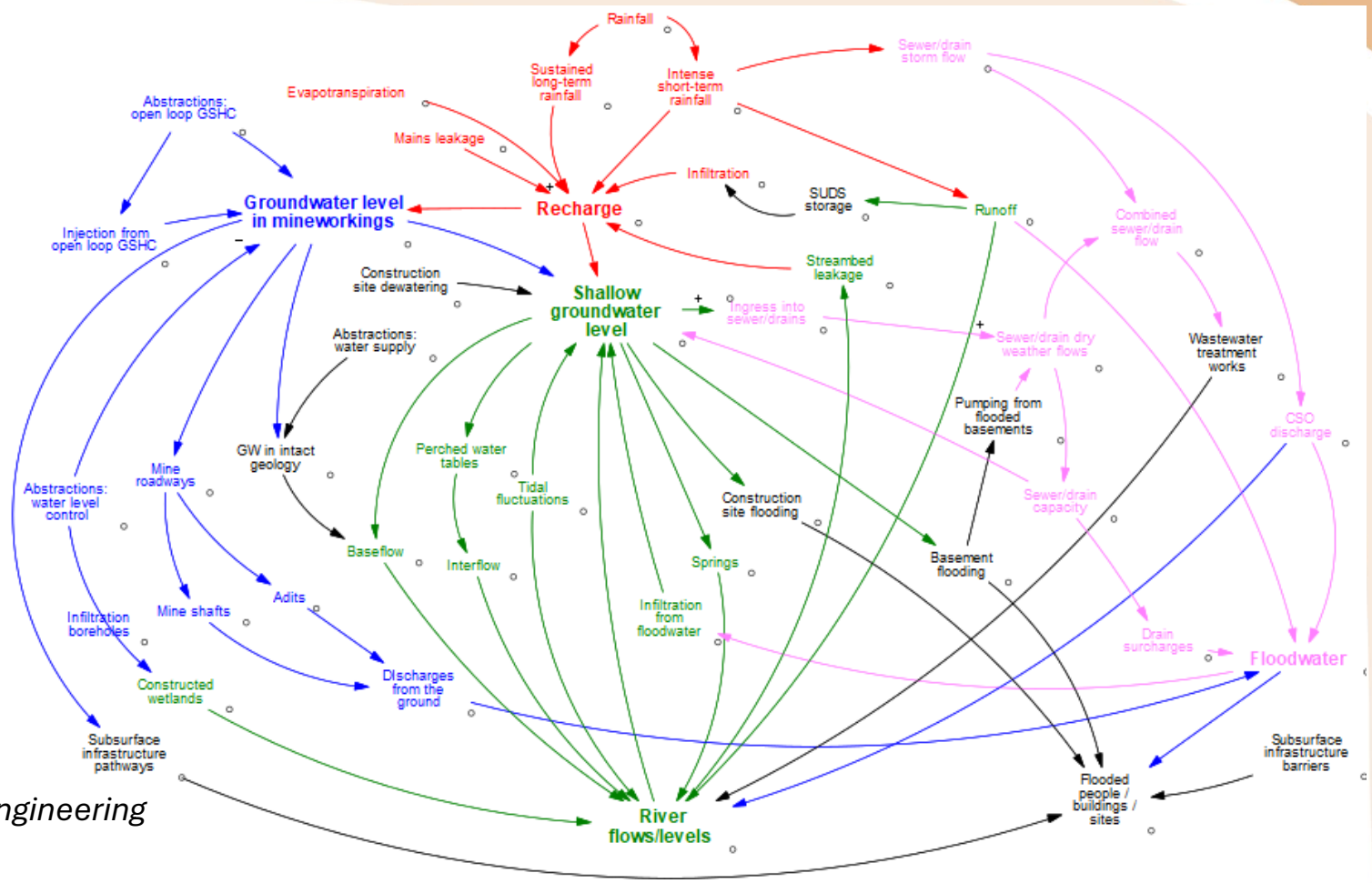

Flooded site
Mine adit
Recharge zone
Flood risk zone
Urban development
Kibblesworth abstraction
Image Landsat / Copernicus
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Image © 2023 CNES / Airbus
Google Earth

Flow pathways (systems approach)

A systems approach was used to make a generic assessment of possible natural and human-modified flow pathways.

This is being used to help build quantitative models of pathways from recharge through mine workings to surface expression.

It also highlights the interconnected nature of the physical system, despite the disconnects in organisational responsibilities[1].



blue: mineworkings, red: recharge, green: diffuse flow in superficial deposits, pink: surface/storm drains, black: not yet defined

[1]Parkin G
Briefing: Groundwater flooding – a hidden hazard
Proceedings of the Institution of Civil Engineers – Civil Engineering
https://doi.org/10.1680/jcien.24.00905

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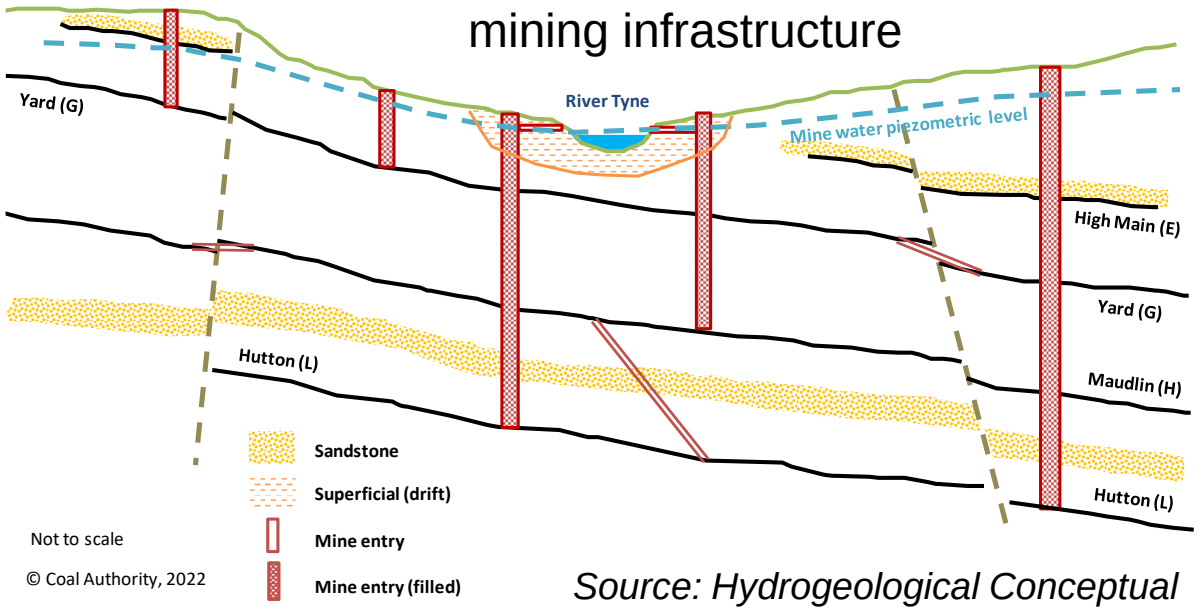
Flow pathways (hydrogeological)

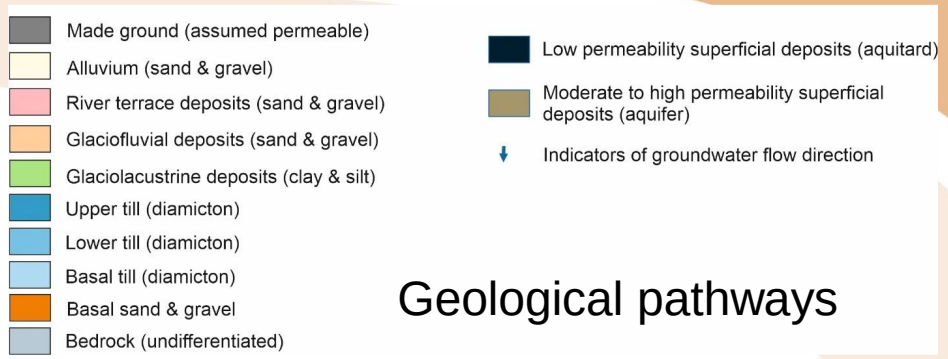
Detailed place-specific conceptual hydrogeological models help to support flood risk mapping and forecasting, and design of new monitoring boreholes

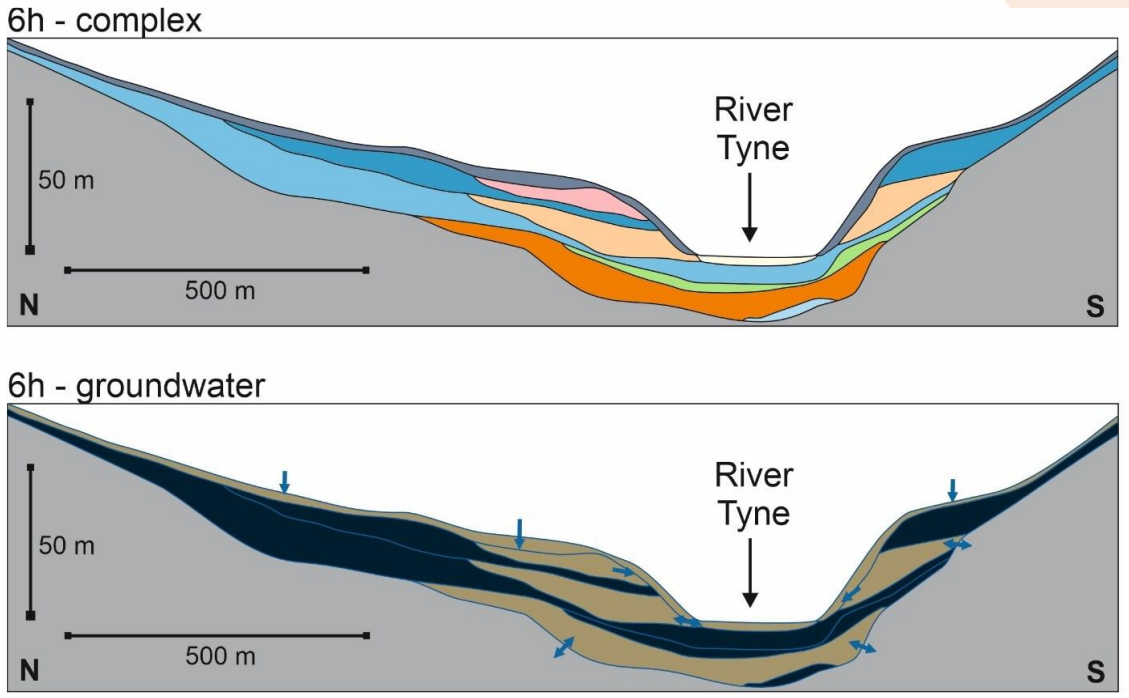
Pathways through mining infrastructure



Source: Hydrogeological Conceptual Model: North East Mine Water Blocks – Introduction Report

Geological pathways





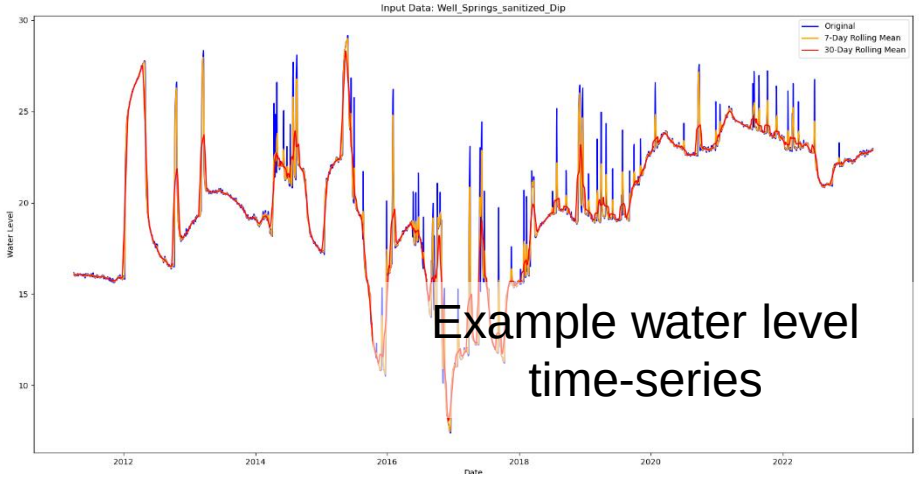
Source: Superficial hydrogeological domains for the Gateshead area - Project Groundwater Northumbria. British Geological Survey Report CR/24/066

Project Groundwater Northumbria

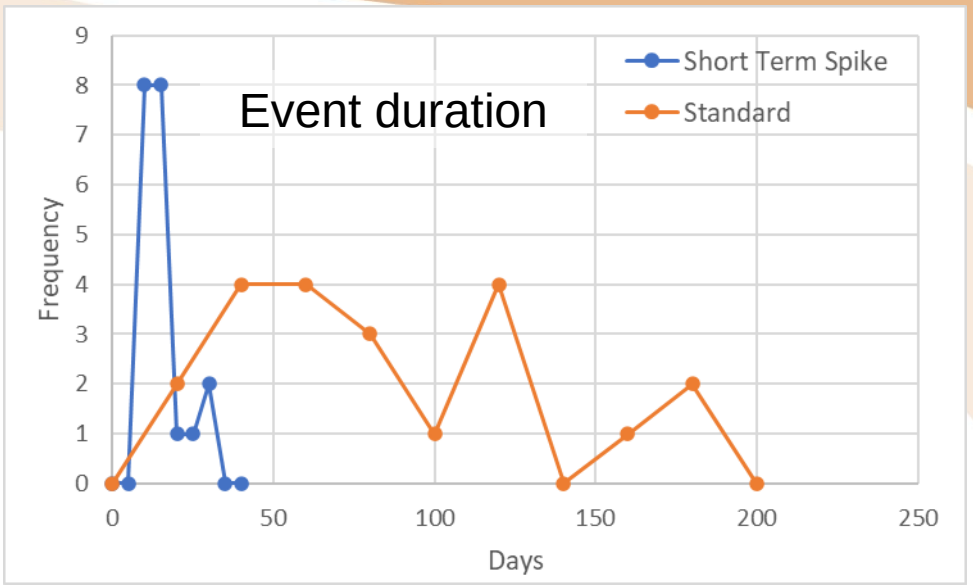
Response catalogue

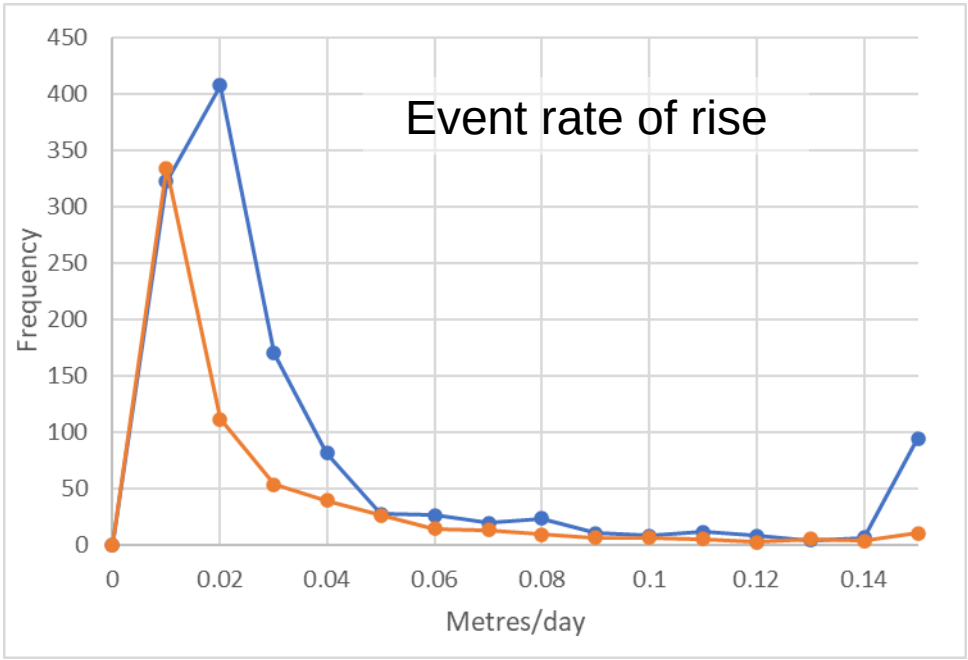
There is a lack of historical water level time-series data at critical locations, with our new boreholes only providing recent monitoring data.

Data from 21 representative sites across the region have been analysed to provide statistics to support a forecasting system. In many sites, 2 modes of response were evident – rapid short term spikes, and standard seasonal responses.



Example water level time-series





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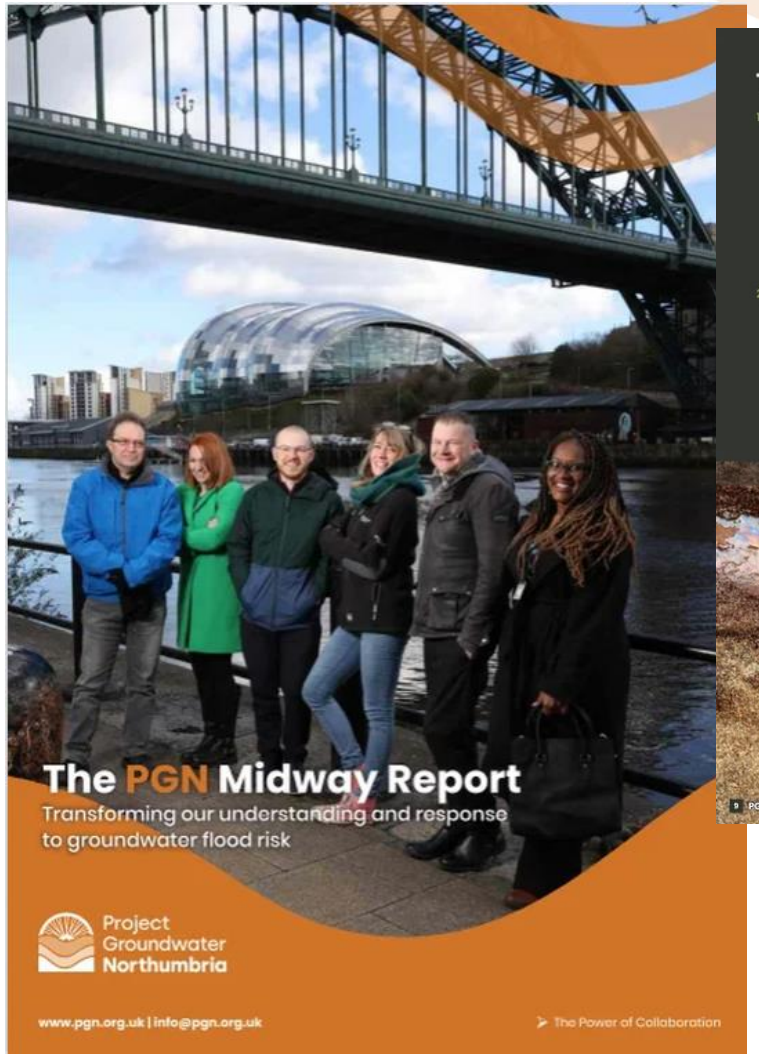

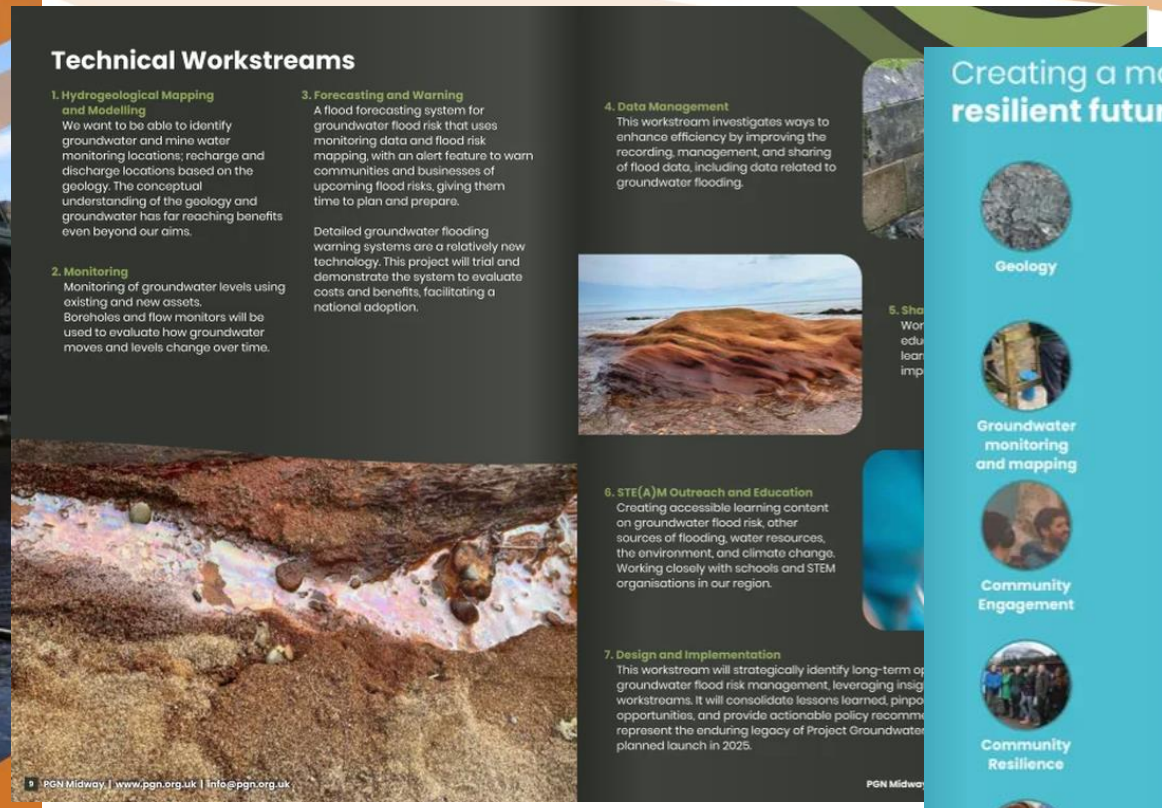

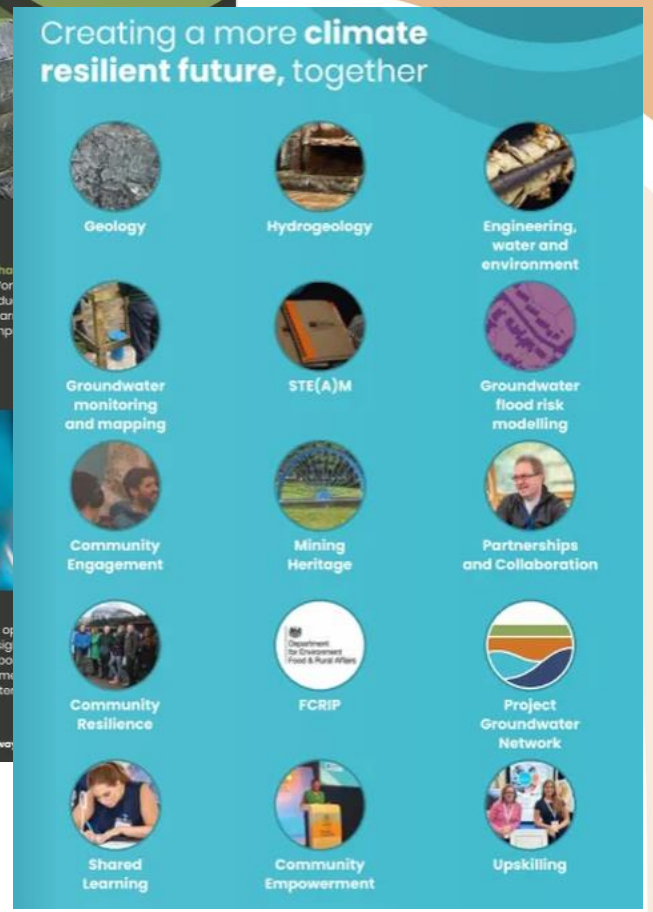

The Coal Authority · Environment Agency · Flamingo Heights · Geoff Parkin Hydro · Newcastle City Council · Groundwater Science · BGS British Geological Survey · Northumbrian Water living water · ARUP

Project Groundwater Northumbria

...and hot off the press, see our midway report at https://online.flippingbook.com/view/1005249619/

The PGN Midway Report

Let’s Stay Connected

OUR WEBSITE

THE PGN PODCAST

LINKEDIN

Project Groundwater Northumbria

Thank you for listening

Project Groundwater Northumbria

Groundwater flooding: from mechanisms to mitigation

DAVID MACDONALD

Ineson 2024, 19 November

British Geological Survey

Journal of
Flood Risk Management

Groundwater flooding within an urbanised flood plain

D. Macdonald[1], A. Dixon[2], A. Newell[1] and A. Hallaways[3]

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2 Groundwater Monitoring and Drilling Ltd, Chalgrove, UK
3 NCPMS, Environment Agency, Frimley, UK

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Email: dmjm@bgs.ac.uk

DOI: 10.1111/j.1753-318X.2011.01127.x

Key words
Flood mitigation; flood plain; groundwater; groundwater flooding; Oxford; River Thames; urban flooding.

Abstract

In Europe in recent years, there has been recognition of the need to better understand the risk from groundwater flooding. This recognition has been due both to the occurrence of major flooding events clearly attributable to groundwater and the inclusion of groundwater flooding in European and national legislation. The case study of the city of Oxford on the River Thames flood plain in UK is used to examine the mechanisms for groundwater flooding in urbanised flood plain settings. Reference is made to an extensive data set gathered during a major flood event in 2007. Groundwater flooding of a significant number of properties is shown to occur in areas isolated from fluvial flooding because of high ground created historically to protect property and the transport network from flood inundation. The options for mitigating this form of flooding are discussed; measures to increase the rate of conveyance of flood waters through Oxford, designed to reduce fluvial flood risk, have also been recognised as a means for reducing groundwater flood risk within the city.

Introduction

Groundwater flooding is the emergence of groundwater at the ground surface away from perennial river channels and can also include the rising of groundwater into man-made ground, including basements and other subsurface infrastructure (Macdonald *et al.*, 2008). The impact of groundwater flooding can be severe under conditions where the 'normal' ranges of groundwater level and groundwater flow are exceeded. In Europe, the risk from groundwater flooding has received more attention since its inclusion in the EU Floods Directive (2007/60/EC). The Directive, which came into force in November 2007, includes provisions for assessing the risk from groundwater flooding (Cobby *et al.*, 2009), producing groundwater 'flood hazard maps' and introducing measures to address any significant risk. The inclusion of groundwater within the Directive follows serious groundwater flooding events in the past decade. The impact of groundwater flooding has been most severe in areas of Chalk outcrop and in the flood plains of major rivers. Groundwater flooding in Chalk catchments occurs where antecedent conditions of high groundwater levels and high unsaturated zone moisture content combine with intense rainfall. Resulting groundwater level rises of up to tens of metres can cause significantly increased stream base flow and spring flow, and the reactivation of dormant springs in dry valleys remote from perennial stream channels. Flooding is often prolonged because of high groundwater levels maintained by extended periods of drainage from the unsaturated zone (Pinault *et al.*, 2005). Examples include the flooding in 2000 and 2003 in southern England (Finch *et al.*, 2004) and the Somme Valley (Negrel and Petelet-Giraud, 2005).

The focus of this paper is groundwater flooding in the flood plains of major rivers. Where the deposits associated with flood plains are permeable, these are generally saturated to levels close to the ground surface and hydraulically well connected to the associated rivers. Here, groundwater can contribute significantly to river flow during summer months and extended dry periods; in wetter periods, rivers can be effluent, recharging the flood plain sediments. During periods of increased flow, and before the banks are overtopped, the naturally high ground of river levees can contain river water while low-lying ground beyond can be flooded because of rising groundwater. In the case of the River Danube flood plain in 2008, damage occurred to buildings because of water pressure on basements, resulting from abnormally high groundwater levels associated with high river levels (Kreibich and Thieken, 2008). The onset and recession of groundwater flood events in this type of setting is typically much shorter than that in Chalk catchments.

Flood plains in the past have been attractive locations for urban development for reasons such as their coincidence

Structure of the talk

- Impacts of groundwater flooding
- Settings for groundwater flooding
- Management and mitigation of groundwater flooding

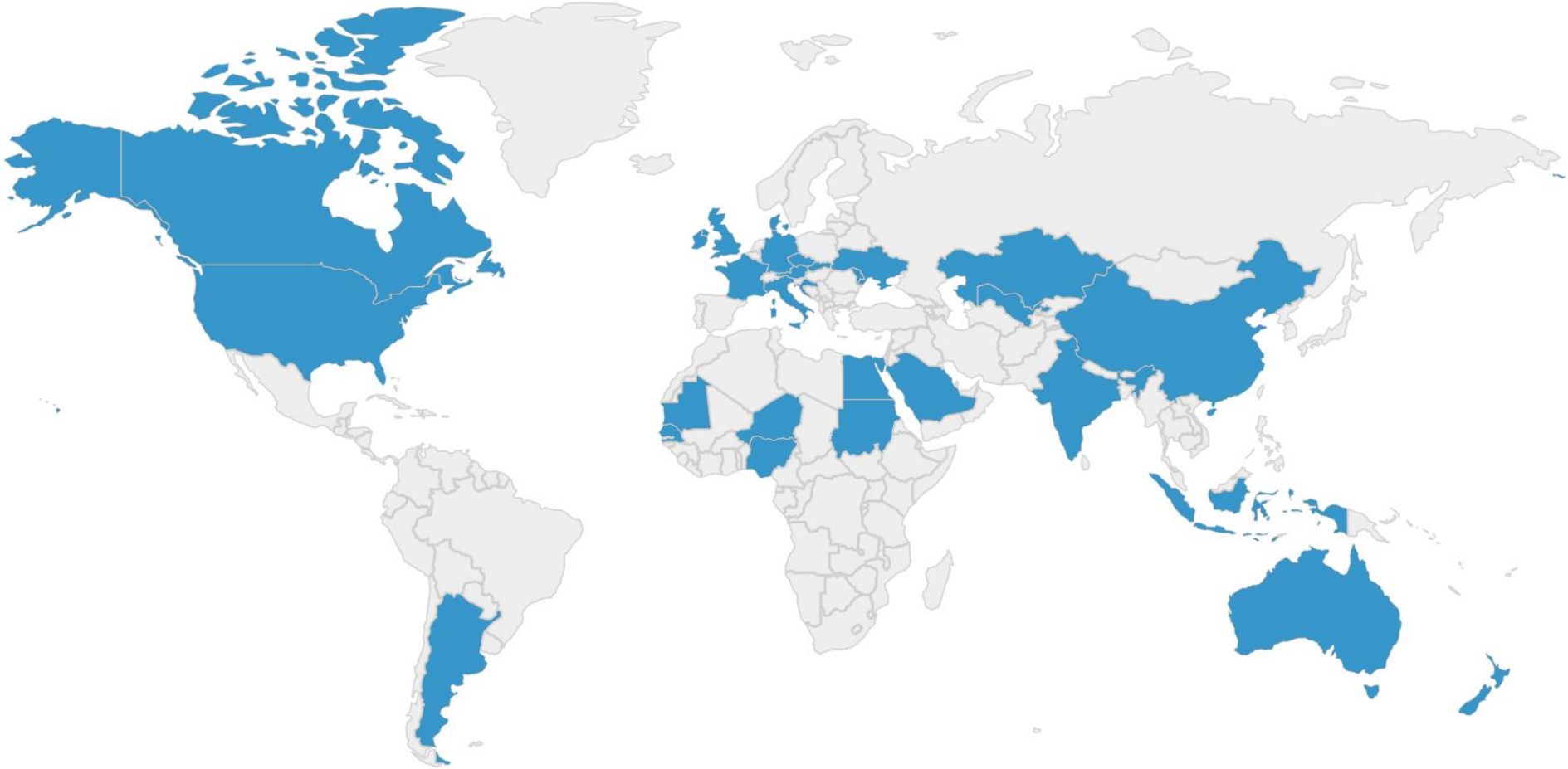
Definition of groundwater flooding

Emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the ‘normal’ ranges of groundwater level and groundwater flow are exceeded

Definition of groundwater flooding

Emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the ‘normal’ ranges of groundwater level and groundwater flow are exceeded
or where anthropogenic influence has caused a rise in base groundwater levels that has resulted in frequent flooding in these settings even when groundwater is within its new normal range

Case studies on groundwater flooding in past 5 years



Research topics – past 5 years

- Groundwater flooding in coastal areas
- Groundwater flooding in karstic regions
- Mitigation of groundwater flooding
- Climate change implications for groundwater flooding
- Mapping of groundwater flooding
- Describing impacts of groundwater flooding
- Urban groundwater flooding - rebound/importing of water
- Compound drivers of flooding (relative importance of gw)
- Land use change and groundwater flooding
- Minewater rebound
- Groundwater infiltration to sewers
- Linking models for better event simulation
- Rising of groundwater levels in agricultural areas
- Economic analysis of damage from groundwater flooding

Tampa Bay Times, 2021

Impacts

Impacts of groundwater flooding

- Water at surface in low-lying areas
- Anomalous springs causing water to flow downslope
  - flooding property, transport routes, public amenities etc
- Inundation of basements and subsurface infrastructure leading to damage of:
  - property, transport network, building structures, electrical/telecomms systems etc
- Infiltration of groundwater to sewers
  - inoperative toilets, overwhelming STW, need to pump waste from network

ground&water web site

Impacts of groundwater flooding

- Changes in hydraulic pressures and uplift
  - damage to buildings, tunnels, roads and flood defences
- Reduced capacity of retention ponds – consecutive storms
- Impacts on terrestrial ecosystems
  - reduced O_2 in root systems
- Damage to agriculture due to waterlogging

Impacts of groundwater flooding

- Impact of polluted groundwaters
  - damage to underground structures
  - contamination of water supplies & aquatic ecosystems
- Mobilisation of legacy pollutants at shallow depths
- Inundation of landfills
- Long term rising of gwls causing reduced performance of on-site sanitation

- Economic cost of GWF
  - Annual cost - England: £156M (CCC), £530M (ESI, 2016)
  - Calgary 2013 flood – C$84.2M (Abboud, 2018)

Settings

Groundwater flooding settings

- Clearwater flooding
- River-driven groundwater flooding
  - permeable superficial deposits (PSD)
- Urban groundwater rebound

Improving the understanding of the risk from groundwater flooding in the UK

D.M.J. Macdonald, J.P. Bloomfield, A.G. Hughes, A.M. MacDonald, B. Adams & A.A. McKenzie
British Geological Survey, Maclean Building, Wallingford, Oxfordshire OX10 8BB, UK

ABSTRACT: Groundwater flooding has been shown to be a significant component of the risk from flooding in the UK. Its inclusion within the EU Floods Directive highlights the need to understand more about the processes that control groundwater flooding and to define the associated risk. In this paper the main groundwater flooding scenarios are described and the challenges in estimating return periods and mapping risk set out. In addition, ongoing and recently completed work by the British Geological Survey which aims to improve the understanding of risk from groundwater flooding in the UK is presented.

1 INTRODUCTION

Groundwater flooding can cause significant social and economic disruption and is a threat in many areas of north-west Europe. For example, in the first assessment of its kind in England and Wales, Jacobs (2004) estimated that 380,000 properties are located on the most vulnerable formations, the exposed Chalk of southern England. The scale of the problem has been recognised by the Department for the Environment, Food and Rural Affairs (Defra) which, through the Environment Agency of England and Wales (EA), is looking at the establishment of a national database of flooding from all sources, including groundwater, and the extension of its flood risk maps and warning service to cover groundwater.

The characteristic feature of groundwater flooding events is the relatively long duration compared with fluvial flooding. Groundwater flooding is defined here as the emergence of groundwater at the ground surface away from perennial river channels or the rising of groundwater into man-made ground, under conditions where the 'normal' ranges of groundwater level and groundwater flow are exceeded. The impact of groundwater flooding can occur before water levels reach the ground surface where there is inundation of building basements and buried services or other assets below ground level. Groundwater levels that rise above ground have the potential to reach low-lying areas protected from fluvial flooding. Exceptionally large flows from perennial springs or large flows from intermittent or dormant springs, which also come under the above definition of groundwater flooding, can cause both localised flooding in the vicinity of the springs and down gradient where surface water drainage channels may not be adequate.

2 GROUNDWATER FLOODING SCENARIOS

There are three scenarios described here for groundwater flooding. Firstly, long-lasting, often regionally extensive, groundwater flooding can be caused by the water table in an unconfined aquifer rising above the land surface as a response to extreme rainfall (Fig. 1). This is often referred to as *clearwater flooding*. It is this form of flooding that has caused significant damage to properties on the Chalk outcrop of southern England in recent years. Flooding occurs when antecedent conditions of high groundwater levels and high unsaturated zone moisture content combine with intense rainfall. In the Chalk this can cause groundwater levels to fluctuate over several tens of metres. For example, in the winter of 2000/1 groundwater flooding was associated with unusually high levels of rainfall: for an eight month period starting in September 2000, rainfall in south east England was 183% of the long-term average, equivalent to a greater than 100 year return period. Groundwater levels were already high as there had been several years' above average recharge. Significant flows occurred in dry valleys in localities remote from floodplains. River flow reflected the high rainfall as well as the contribution from groundwater discharge. Flows at most river gauging stations greatly exceeded the long-term averages for ex-

Groundwater flooding settings

- Clearwater flooding
- River-driven groundwater flooding
  - permeable superficial deposits (PSD)
- Urban groundwater rebound
- Raised groundwater levels due to land use change
- Mine water rebound
- Sea level rise-driven groundwater flooding

Improving the understanding of the risk from groundwater flooding in the UK

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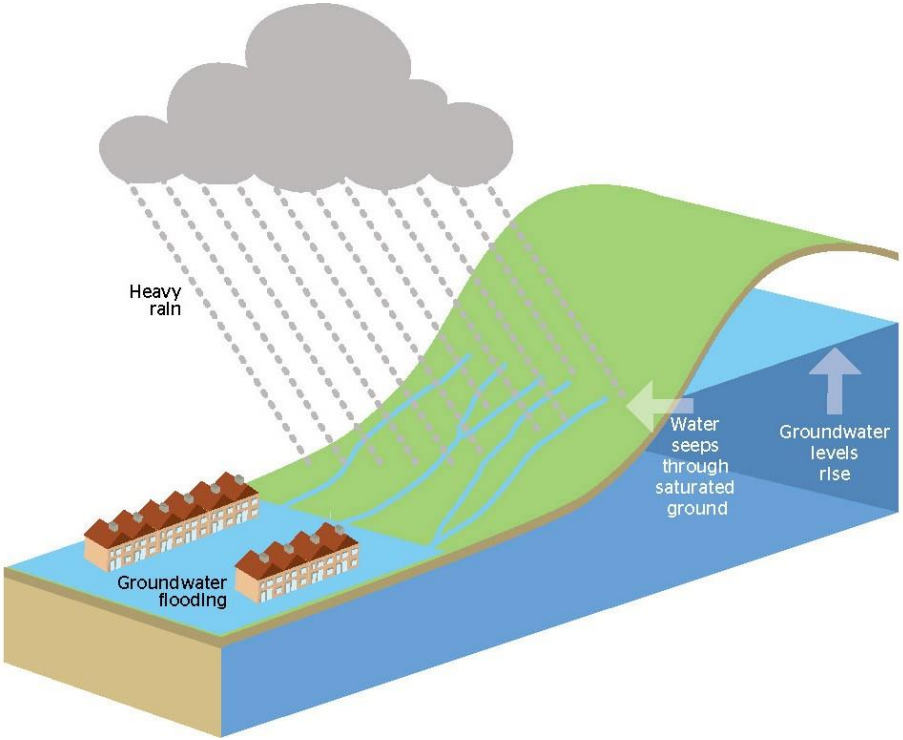
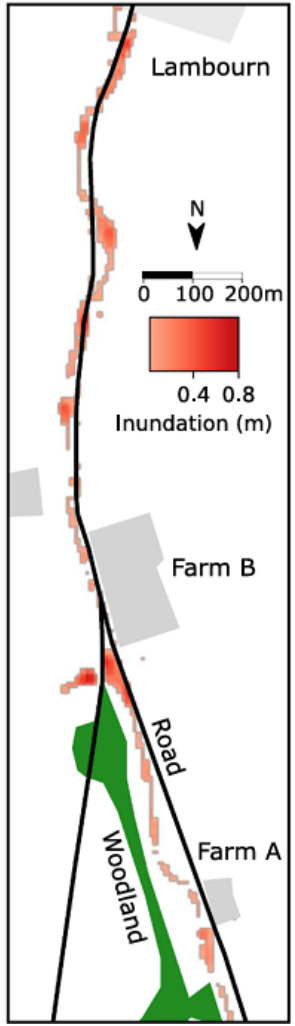
Clearwater flooding



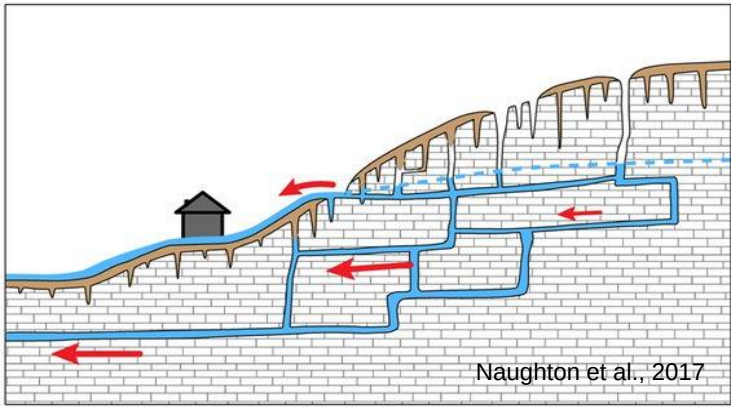
Recent research on clearwater flooding

- Impacts, mapping and mitigation (Becker et al., 2022)
- Flooding case studies (e.g. West Africa: Hado et al., 2021, Brisibe et al., 2021)
- Linking models to improve flood simulation (Collins et al., 2020; Peña et al., 2021)
- Incorporating improved geological representation (Kearsey et al., 2023)
- Natural Flood Management and groundwater (Badjana et al., 2023; Barnsley 2022; Collins et al., 2023)
- Karst and groundwater flooding

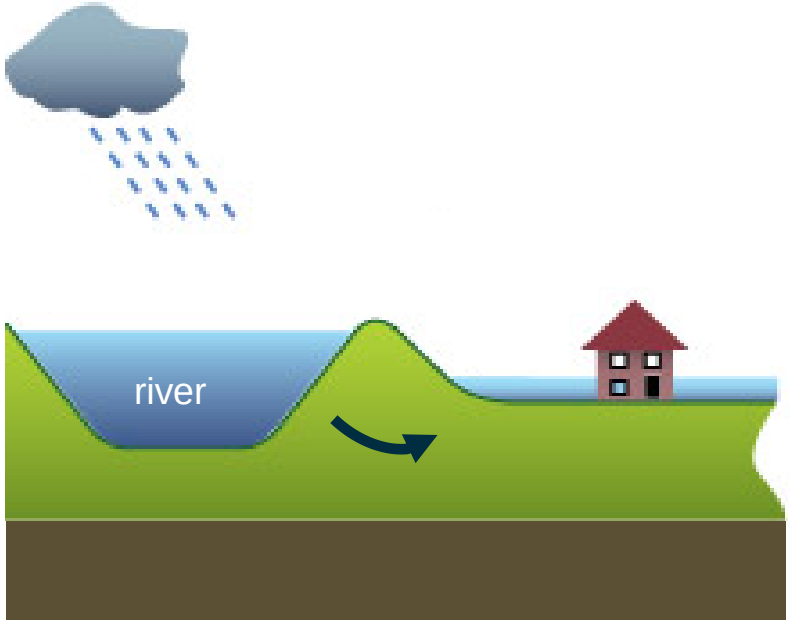


Clearwater flooding – karst studies

- Ireland
  - automated approach with remote sensing to map flooded areas (McCormack et al., 2022)
  - modelling GWF in lowland karst using pipe network models (Gill et al., 2021)
  - forecasting flooding using machine learning – flood vol., rainfall, tide levels + gwls (Basu et al., 2022)
  - impact of CC on flooding and ecohydrology – median/extremes significantly greater, flooding season later (Morrissey et al., 2023)
- Also
  - USA (Peña et al., 2022); Slovenia (Ravbar et al., 2021); Indonesia (Cahyadi et al., 2019); France (Erguy et al., 2022)

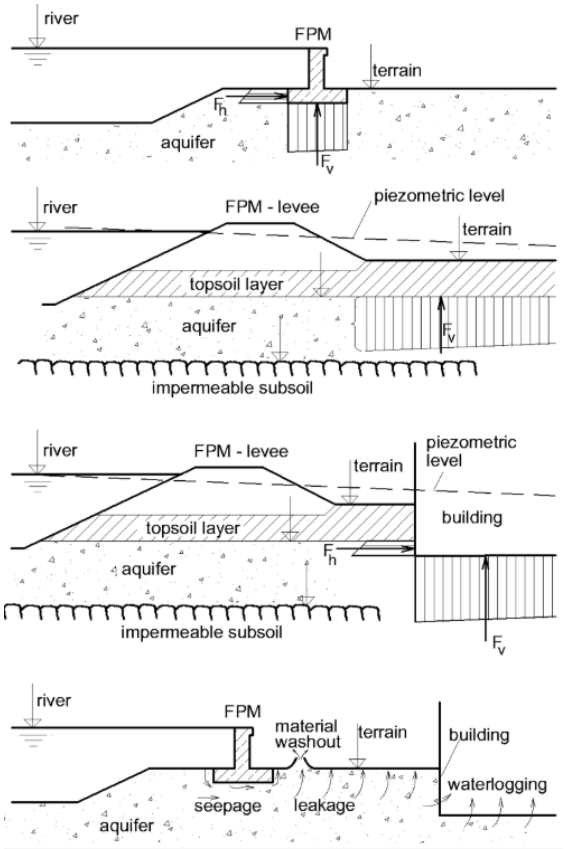


River-driven groundwater flooding - permeable superficial deposits



Recent research on river-driven PSD flooding

- issues with defences to protect from R-D GWF and associated issues (Říha et al., 2023)
- exploring options for reducing flood risk: pumping boreholes, drains, barriers to groundwater flow (Kumar & Yazdan, 2022)
- recognising R-D GWF in designing flood reduction measures and estimating flood costs - Calgary (Bryant et al., 2022)
- investigating controls on GWF in New Orleans: drainage-induced land subsidence; PSD hydrogeology (Yang & Tsai, 2020)



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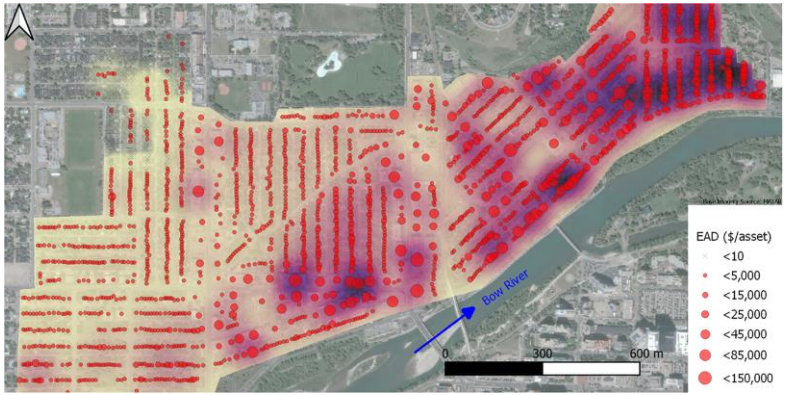

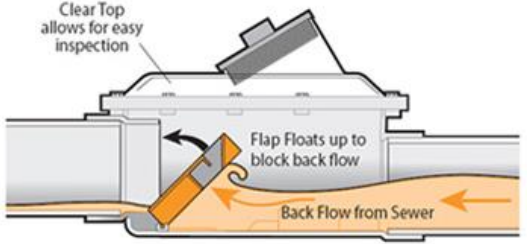

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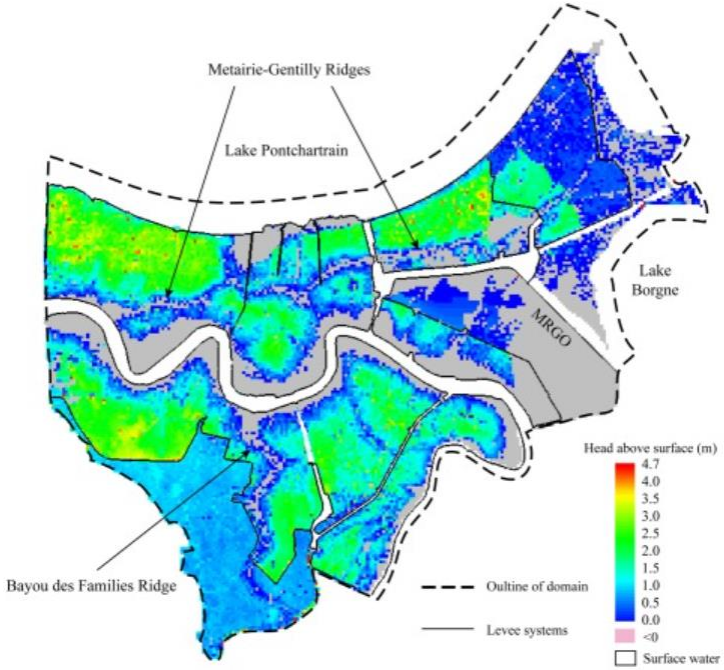
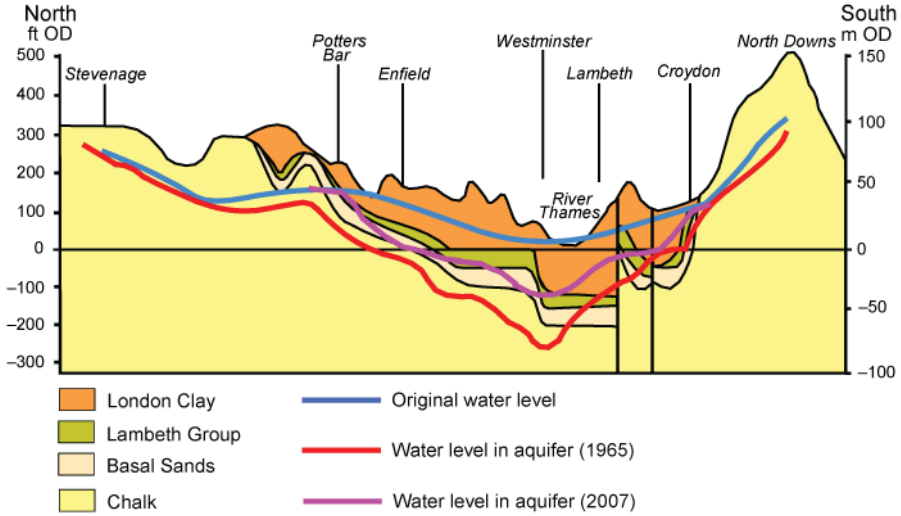


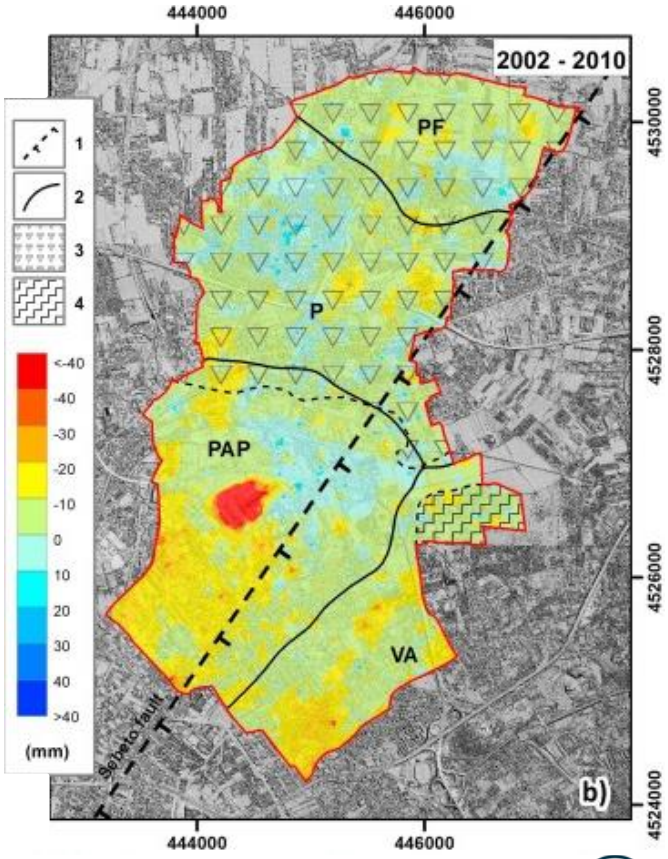
Urban groundwater rebound

- Urban abstraction increases with growing population and industrial use
- Groundwater levels decline as abstraction greater than recharge
- Construction occurs based on low groundwater level conditions
- Groundwater quality deteriorates due to urban pollution
- Groundwater abstraction reduces due to quality and declining industry
- Groundwater levels recover causing inundation of (subsurface) infrastructure



Recent research on urban rebound

- Naples
  - Rises of >16m occurred since 1990s - flooding of basements, agricultural soils, archaeological sites,
  - research on ground uplift (Coda et al., 2021), machine learning to identify areas most at-risk to GWF (Allocca et al., 2021)
- Milan (Sartirana et al., 2022)
  - data-driven approach in Milan to identify at-risk areas to support urban planning – focus on u/g car parks
- New York City (Rosenzweig et al., 2024)
  - GWF due to urban rebound already been experienced in many neighbourhoods
  - USGS study to monitor, investigate and model groundwater flooding in the city



cumulative surface uplift (mm)

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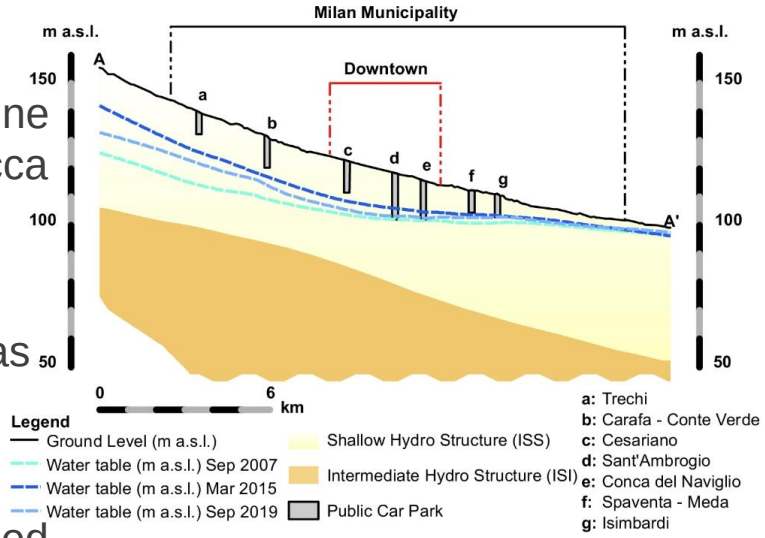

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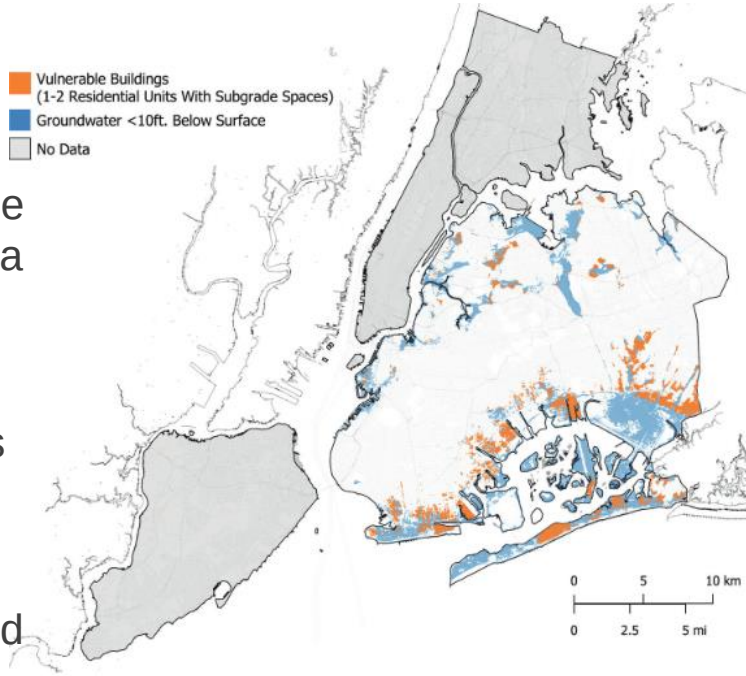
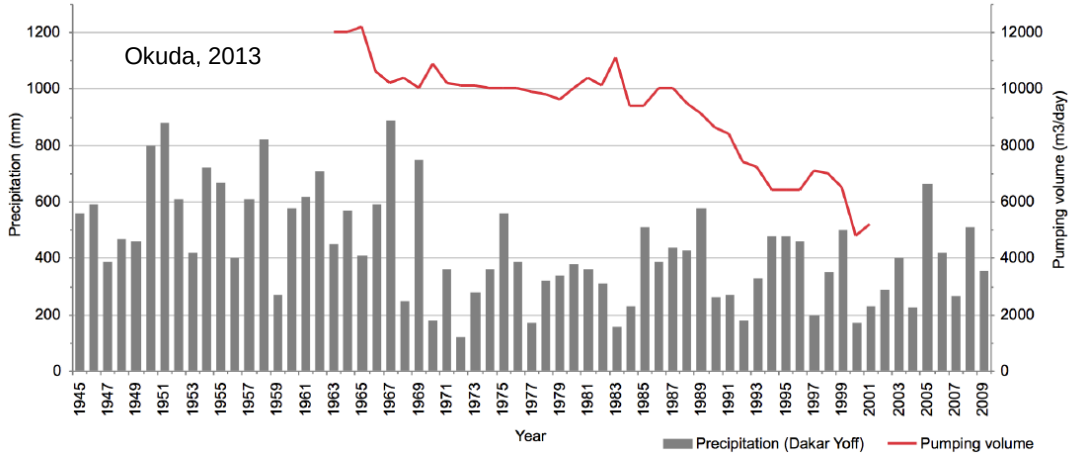


Urban rebound - West Africa

- Dakar
  - groundwater rebound in low-lying peri-urban areas that also accumulate surface runoff
  - highly populated marginal land with limited storm water drainage



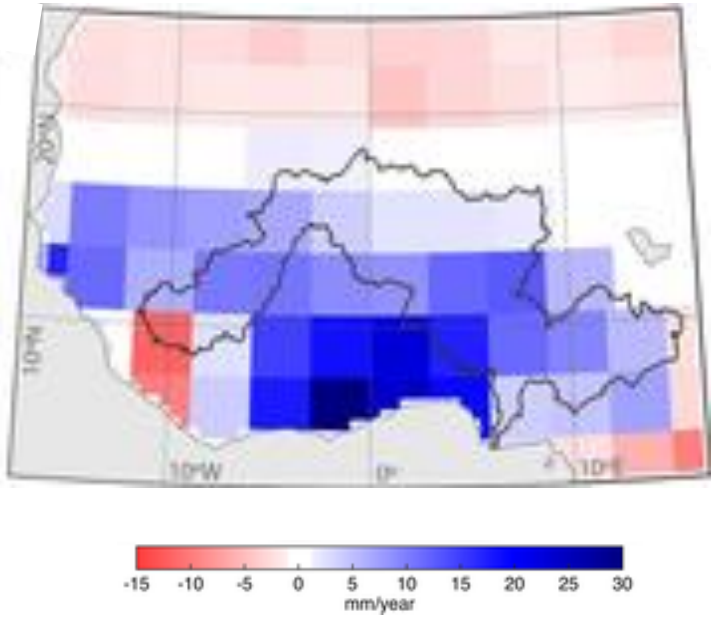
Land use change and rising groundwater

- Wisconsin - Kastelic & Loheide (2023)
  - case studies of lake level rise (e.g. ~5m in 70 yrs)
  - displaced residents, flooding of critical infrastructure, damage of agricultural lands
  - shift from historical oak savannah and tallgrass prairie to agricultural lands reducing ET + increase in precipitation amounts increasing recharge
  - solutions?: returning agricultural areas to native vegetation or introducing high-water use crops

- Deng & Bailey (2020): Colorado - increase use of groundwater for irrigation to reduce GWF
- Houspanossian et al., 2023: S.American plains - GWF due to expansion of agric.
  - positive effects: buffering crop production during droughts - appears to compensate for negative effects of reduced sowing area

West Africa – land use change

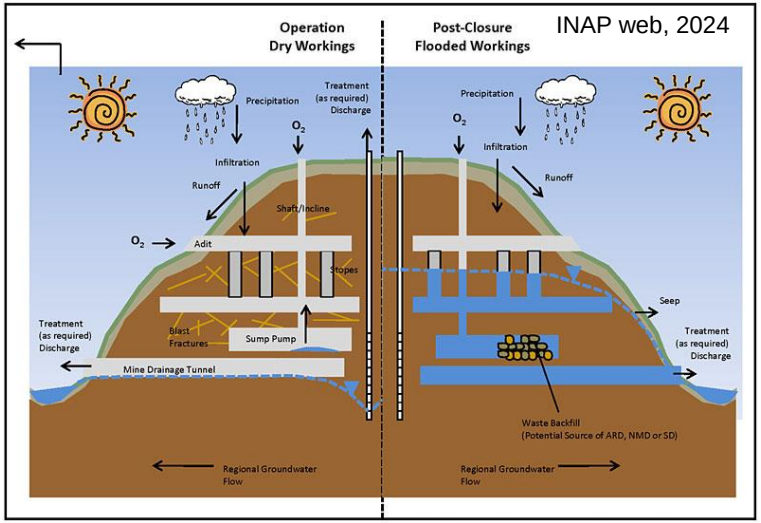
- Scanlon et al. (2022)
  - assessed spatiotemporal variability in water storage and related controls (climate, human intervention) in major African aquifers
  - GRACE: rising TWS trends were found in aquifers in western Africa (23–49 km^3 over 18 yrs), attributed to increased recharge from land use change and cropland expansion
  - ‘increasing groundwater levels in western Africa will need to be managed because of locally rising groundwater flooding’
- e.g. Niamey (Hado et al., 2021); secondary cities in Senegal



GRACE: trends in TWS, 2003-13 (Werth et al., 2017)

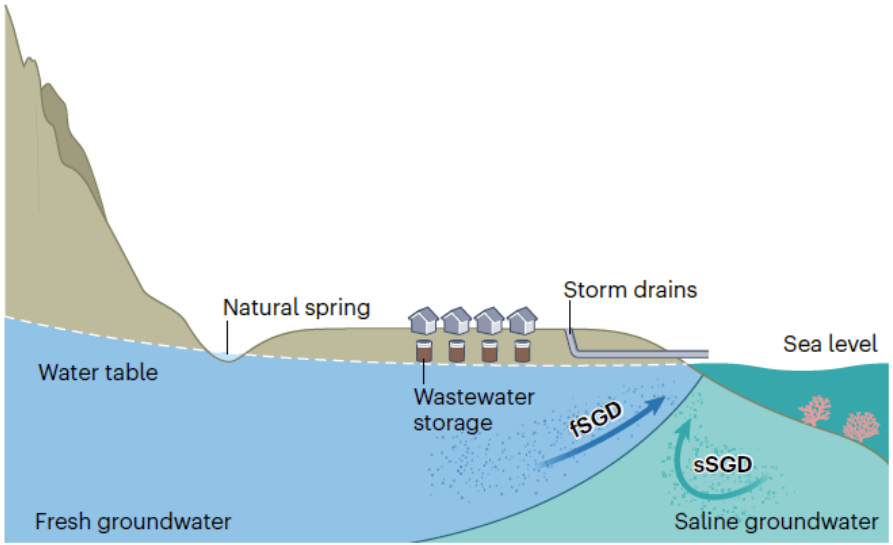
Minewater rebound

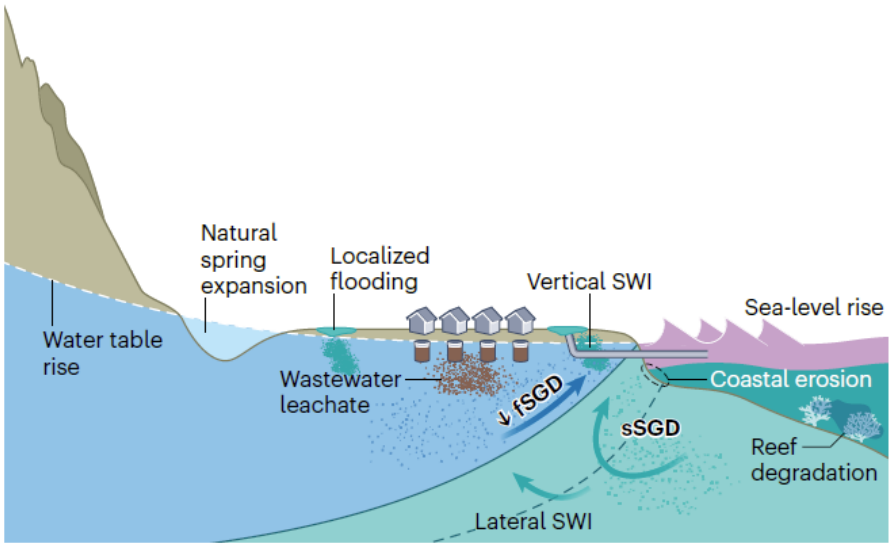
- After colliery closure, cessation of dewatering results in progressive rise of groundwater and flooding of old workings and surrounding rock
- Impacts of acid mine waters
  - surface water pollution
  - flooding of agricultural, industrial, residential areas
  - inundation of landfills
  - overloading and clogging of drains and sewers
  - pollution of overlying aquifers
  - ground deformation due to renewed mining subsidence and reactivation of faults
- Much of the research is related to cessation of coal mining in China and Germany



INAP web, 2024

Groundwater-related flooding in coastal areas

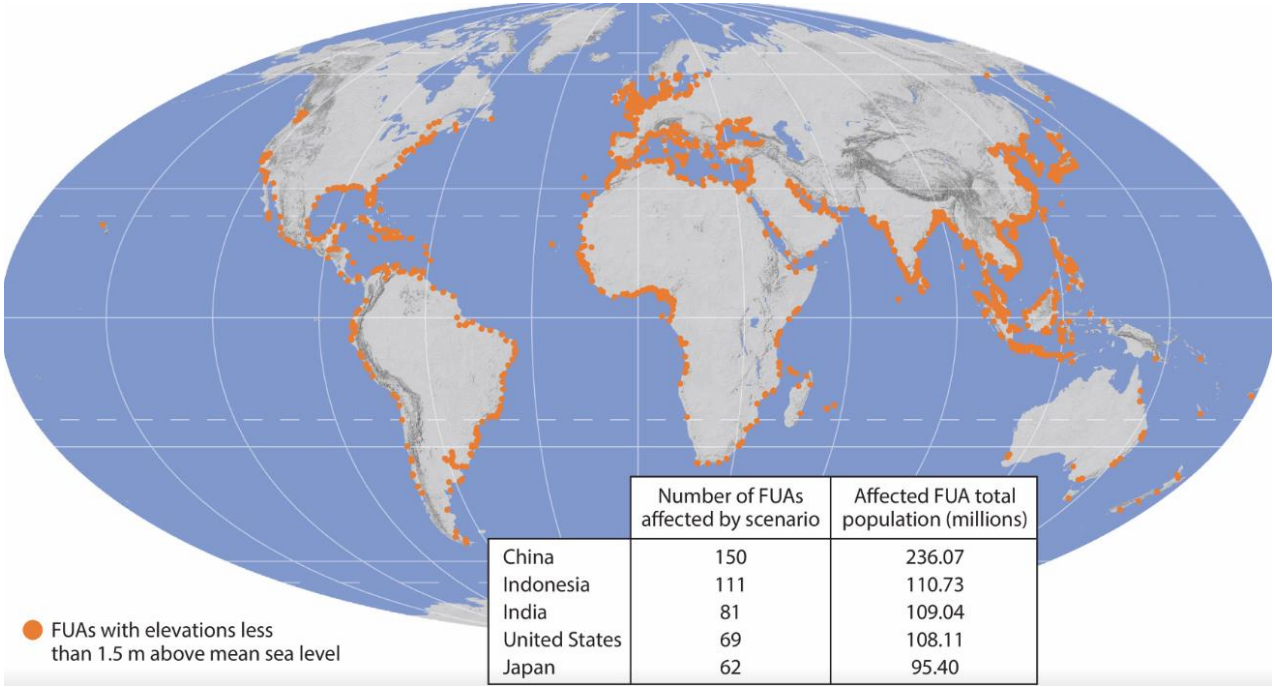




Reviews: Richardson et al., 2024; Zeydalinejad et al., 2024; Habel et al, 2024; Green et al., 2024; Rozell, 2021

Groundwater-related flooding in coastal areas

- Sea Level Rise (SLR) of 20cm occurred globally over last 140 yrs
- past century, rate of rise of 1–2mm/a in most regions, has doubled since 2006 to 3–4 mm/a
- SLR median projections 0.3 to 1 m for 2100



	Number of FUAs affected by scenario	Affected FUA total population (millions)
China	150	236.07
Indonesia	111	110.73
India	81	109.04
United States	69	108.11
Japan	62	95.40

Habel et al, 2024 – globally, 1546 functional urban areas

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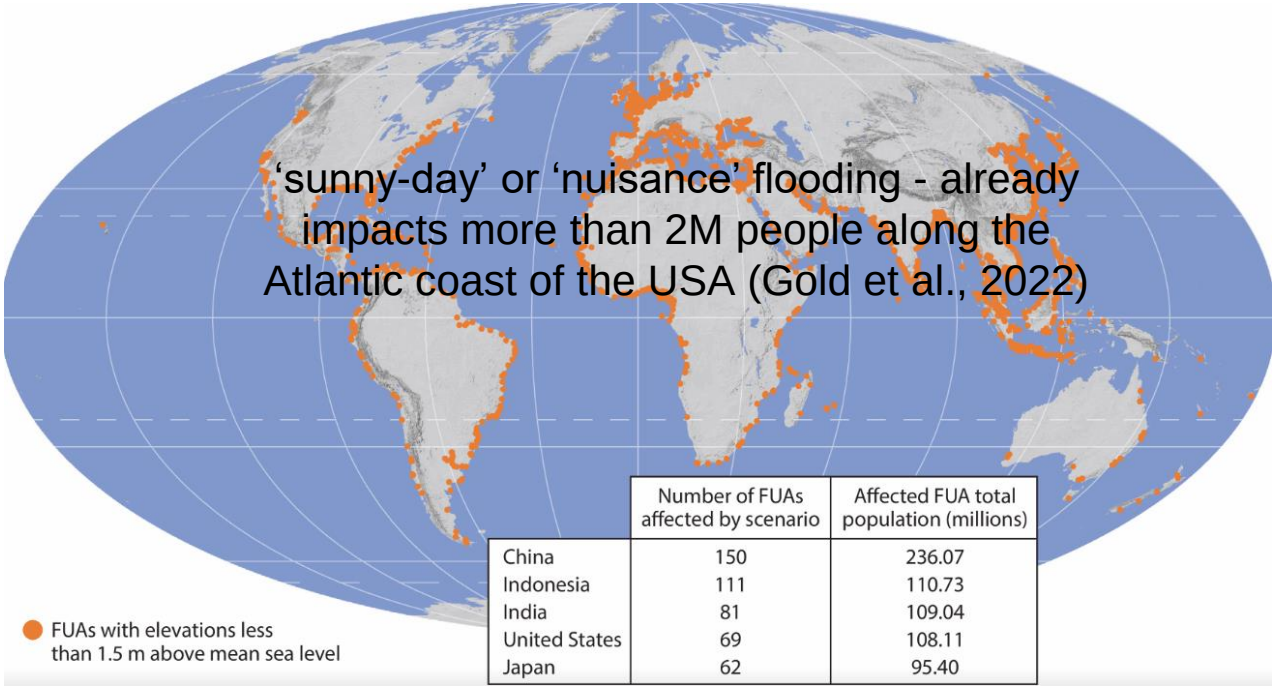

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Modelling threat of coastal groundwater hazards from SLR – Befus et al., 2020

- simulated a range of SLR using single-layer MODFLOW models with constant heads at coast (no-flow elsewhere)
- no change in recharge or abstraction
- low-lying areas infilled with drain cells
- 1m rise – areas prone to flooding expand from 650-970m by a further ~50-130m inland
- coastal topography key controlling factor

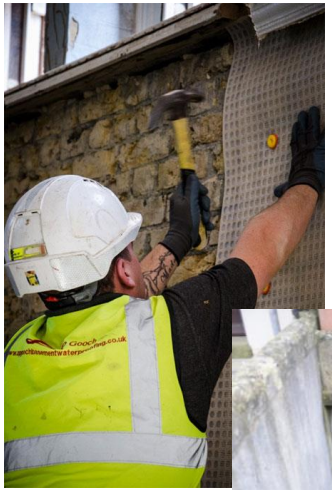
Groundwater flooding in coastal regions

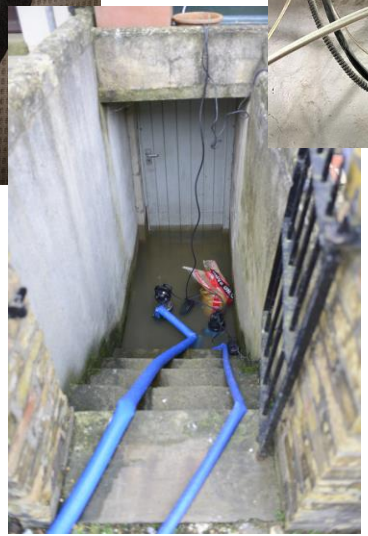
- urban coastal zones often host large amounts of buried chemical contamination (Jiao & Post, 2019)
- on site sanitation: Honolulu, Hawai‘i - ~90% cesspits compromised during present-day king-tide events - contamination of coastal groundwater potentially pervasive (Habel et al., 2020)
- periodic wetting/drying causing: increase in salt concentration around water/wastewater/storm networks – accelerated corrosion; degradation of building foundations – impacts hard to detect (Habel et al., 2024)
- culturally sensitive areas: e.g. in 25 Caribbean island nations >20% of cemeteries within 100 m of the coast (Mueller & Meindl, 2017)
- increase liquefaction susceptibility in earthquake-prone regions (Grant et al., 2021)
- compound flooding particularly severe in atolls (Tajima et al., 2023) and sand barriers (Housego et al., 2021)

Management and Mitigation

Mitigation of impacts – household and local level

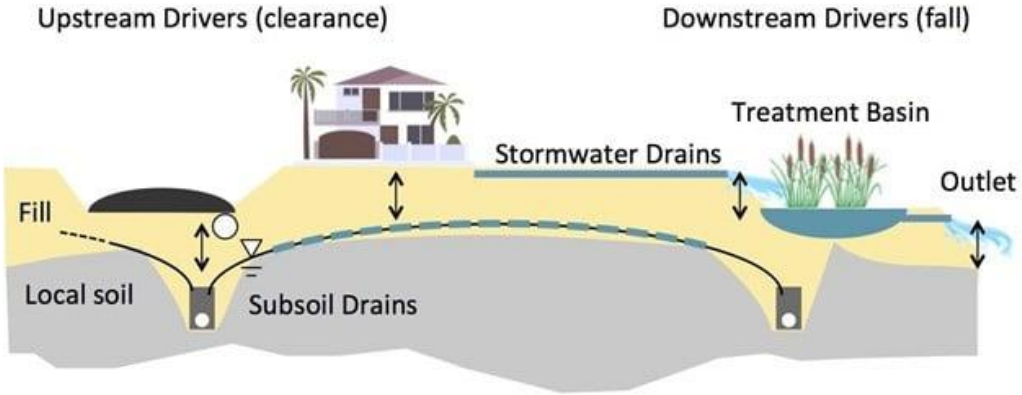
- resilience measures – tiles, electrics, tanking
- pumping for households or a number of buildings
- sand bags, where flows occur downslope
- local drainage systems





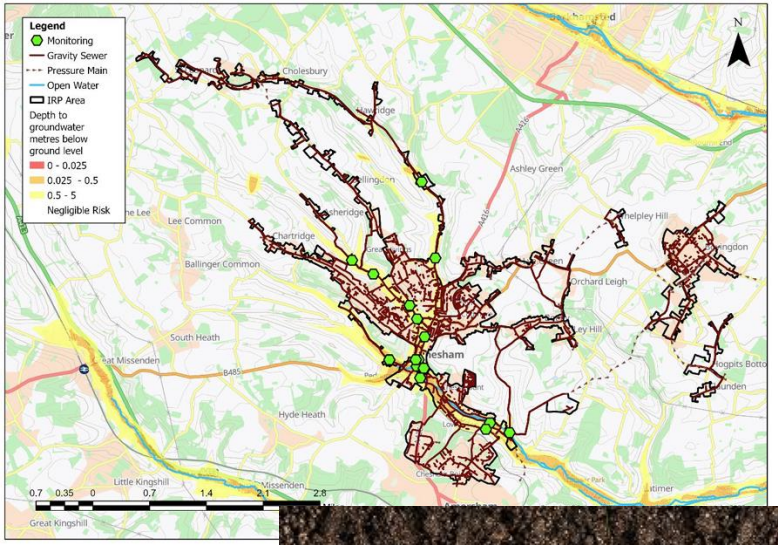
Mitigation of impacts – municipal level

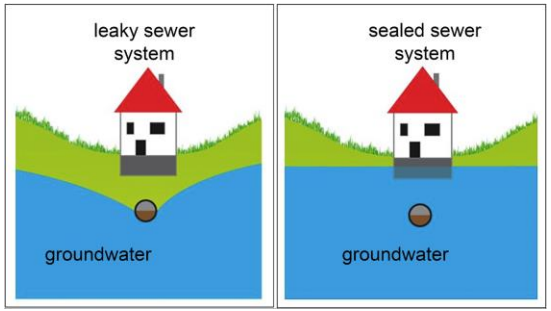
- Drainage & land raising (Thompson et al, 2021)
- Installation of backflow valves and sump pumps (Bryant et al., 2022)
- Management of river levels (e.g. Oxford Flood Alleviation Scheme)
- Barriers to subsurface flow from rivers (Říha et al., 2023)
- Fluvial flood defences in combination with pumping (Kumar & Yazdan, 2022)
- Extension of drainage network in coastal regions (Morgan, 2024)

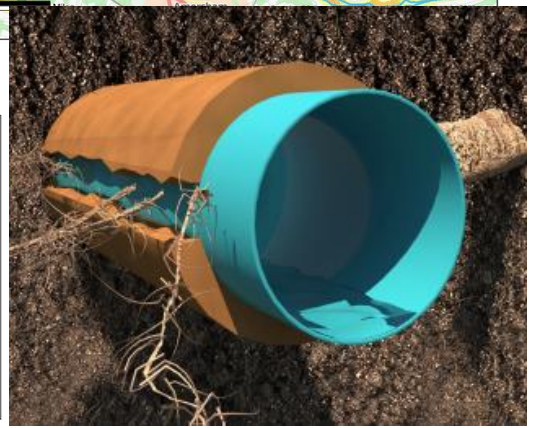


Mitigation of impacts – waste & water quality

- pump sewage at vulnerable locations
- improved sewerage systems:
  - from OSS to piped
  - sewerage only
  - lining of sewers
    - monitoring to optimise where to repair (Thames Water, 2021)
    - Hoboken, NJ - as sewers repaired, water table rises (Su et al., 2022);
- remediation of legacy landfills
- regular assessment of building state - consider materials used



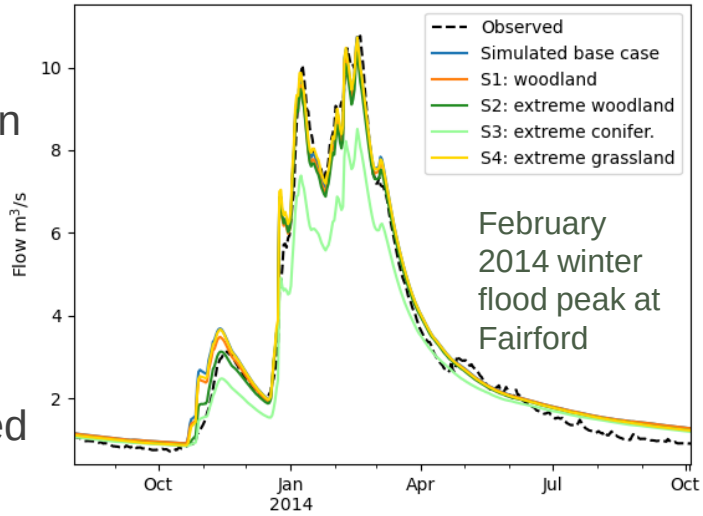




Mitigation of impacts – natural flood management

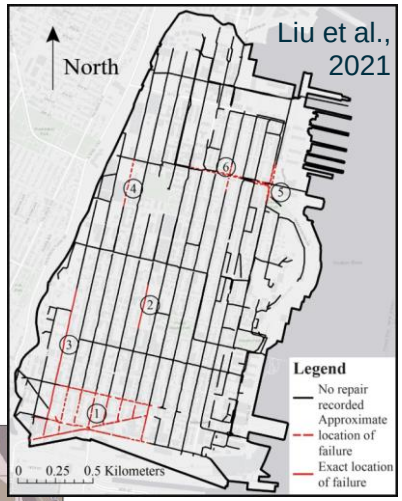
Reduce recharge to or increase discharge from aquifer through increasing ET

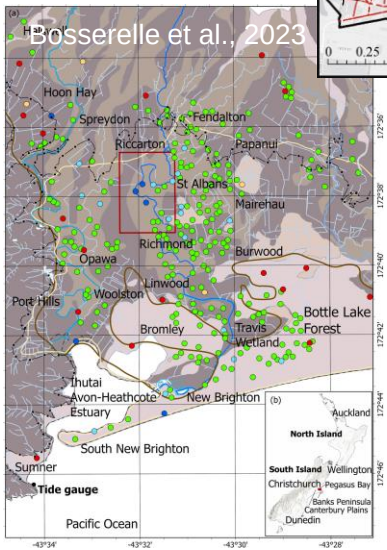
- Barnsley, 2022: NFM in gw-dominated catchments
  - River Test - increasing tree cover, revegetating river channels, installing woody debris dams
  - flood peak reduction averaging 5% but no reduction in flood duration
- Collins et al., 2022
  - Upper Thames - woodland planting & conversion of arable to grassland
  - 1-6% reductions in winter peak flows with broadleaved
  - large-scale spruce planting potential to significantly reduce winter peak flows BUT impact on summer mean flows (e.g. 12% reduction in July mean flow)



Mapping & data-driven approaches

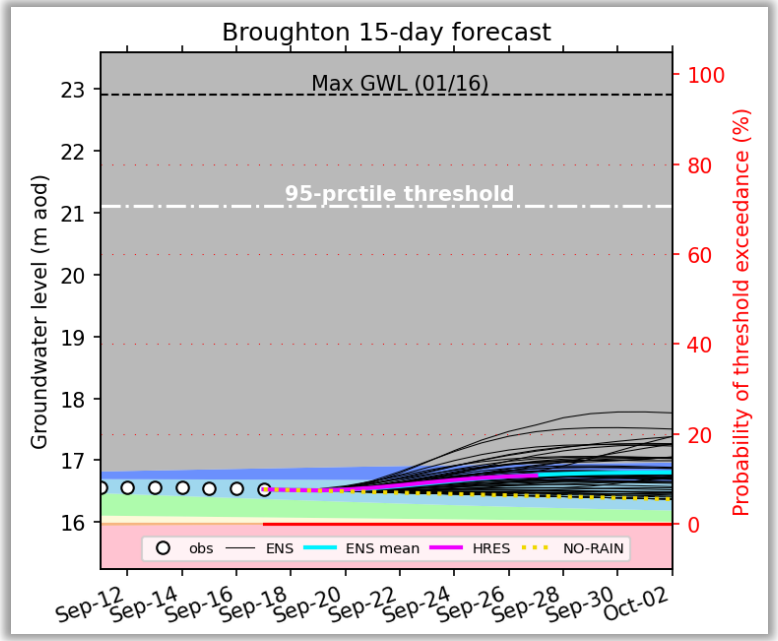
- Merchán-Rivera et al., 2022
  - Bayesian-based Framework to create risk maps based on MODFLOW modelling using observations from a small flood-prone area of Germany
- Liu et al., 2021
  - ML applied to GWF of sewer networks in Hoboken, USA to optimise repair. Water table, soil type, pipe size/shape/material + infiltration rate measurements.
- Bosserelle et al., 2023
  - dense network of boreholes in Christchurch, NZ. Data-driven analysis - spatial interpolation, autocorrelation, clustering, cross-correlation and trend analysis. Primary feature - proximity to tidal rivers and their correlation with tidal signals



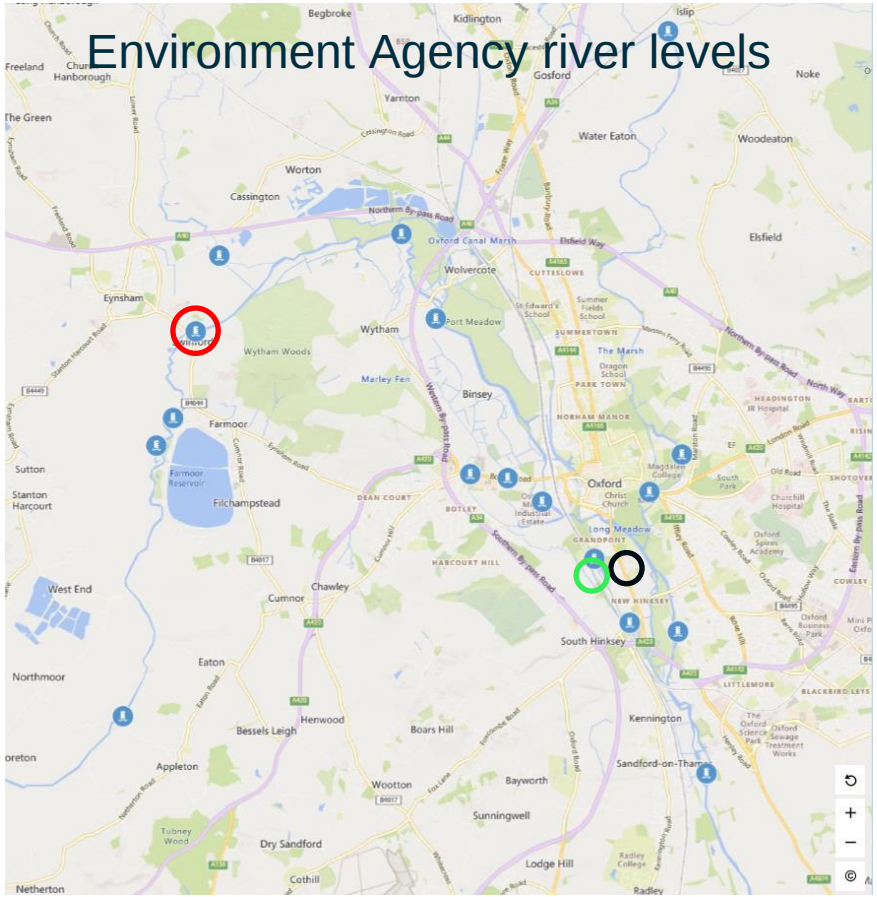


Groundwater flood early warning systems

- UK (EA/FFC)
  - EA GWL monitoring network linked to Flood Alerts and Report
  - Groundwater Flood Forecasting Service (15, 30, 46 days) based on lumped-parameter borehole models
- Elsewhere
  - Netherlands, Germany most advanced and comprehensive systems
  - Australia, France, USA more locally-focussed systems



Environment Agency river levels



Key

Base map

- Default view
- Satellite view

Flood warnings

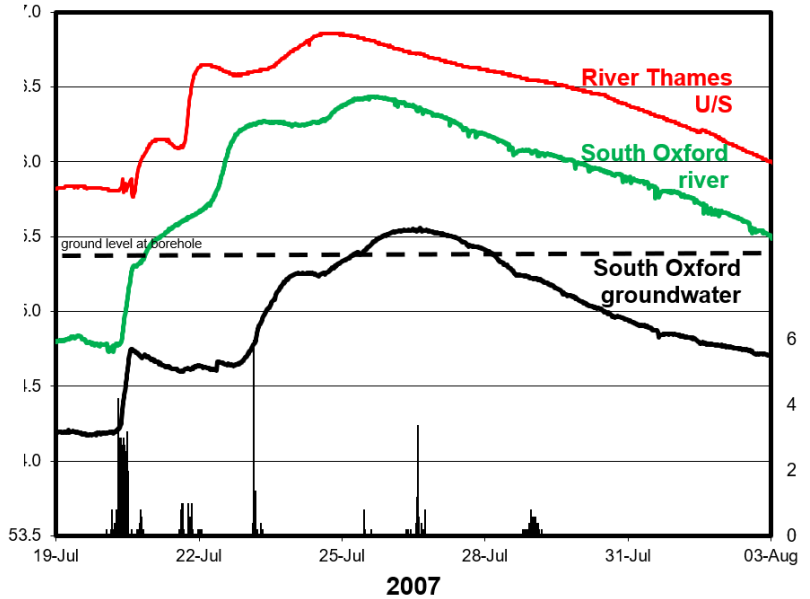
- Severe flood warning
- Flood warning
- Flood alert

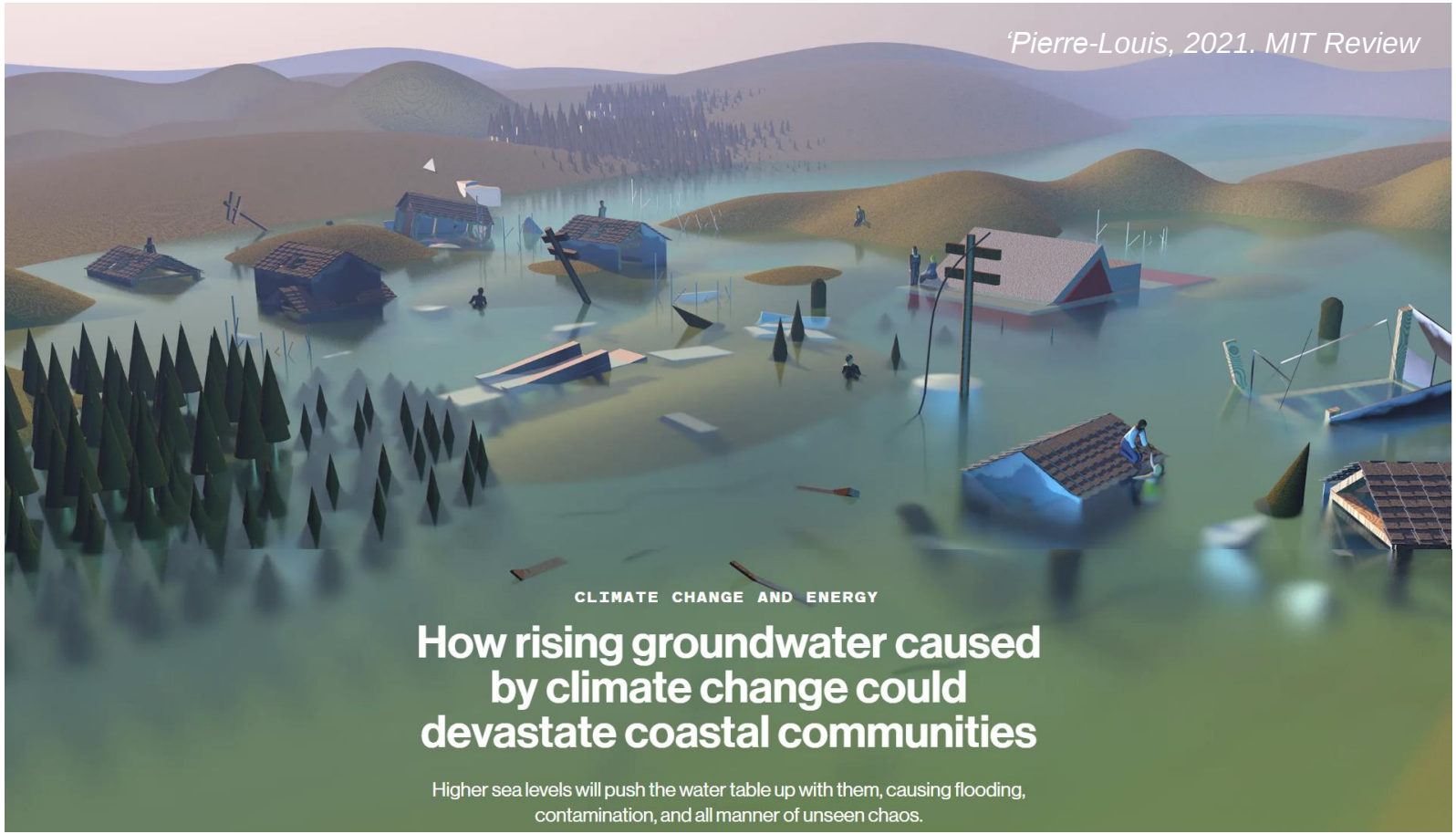
Levels

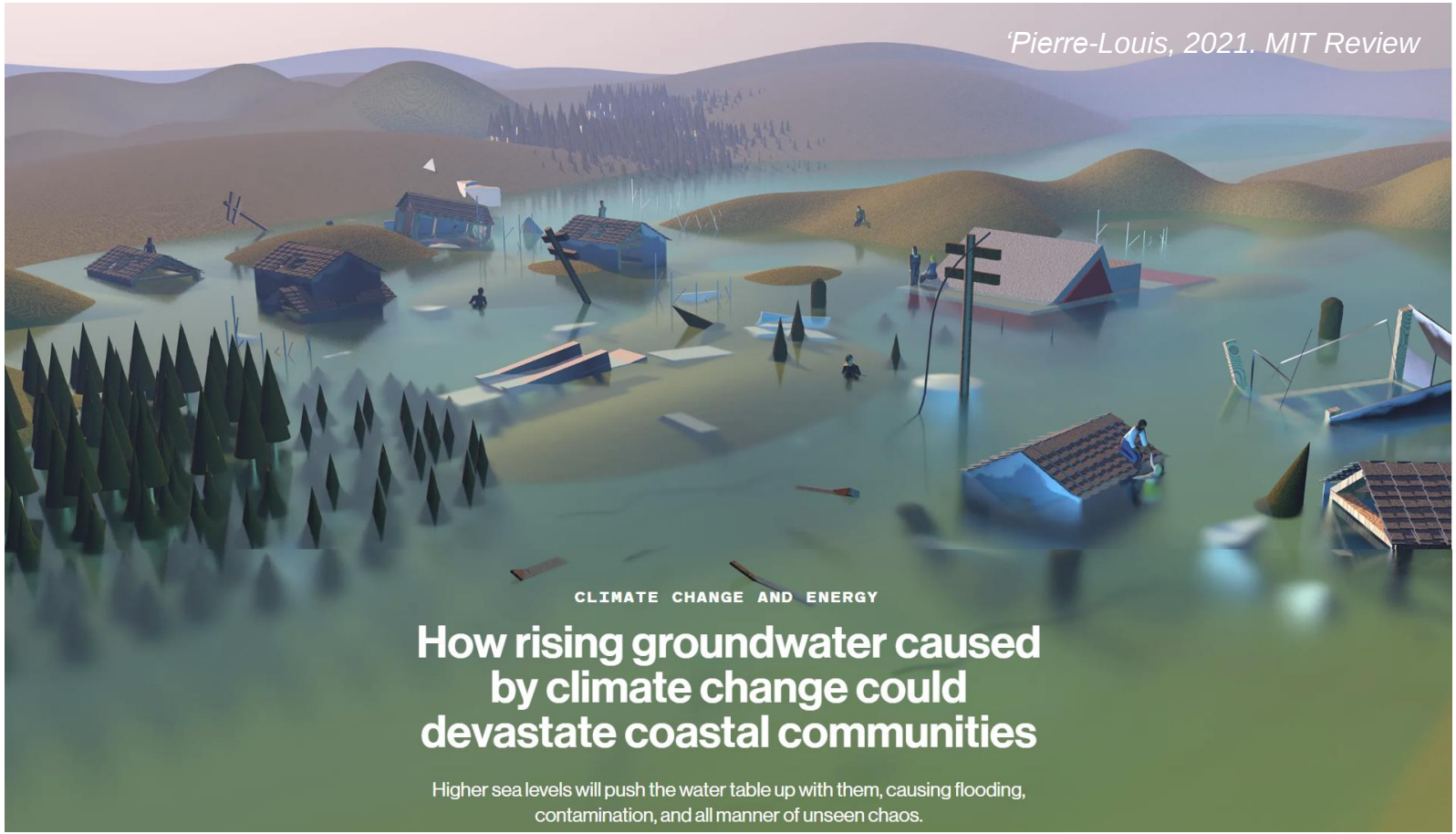
- River
- Sea
- Groundwater
- Rainfall

Early warning of groundwater flooding in South Oxford

Project Groundwater
Are you flood resilient?




‘Pierre-Louis, 2021. MIT Review
CLIMATE CHANGE AND ENERGY
How rising groundwater caused by climate change could devastate coastal communities
Higher sea levels will push the water table up with them, causing flooding, contamination, and all manner of unseen chaos.



'managed retreat may be the only practical option' (Rozell, 2021)

Thank you

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Groundwater Teleconnections:
decoding hidden patterns in hydrological extremes

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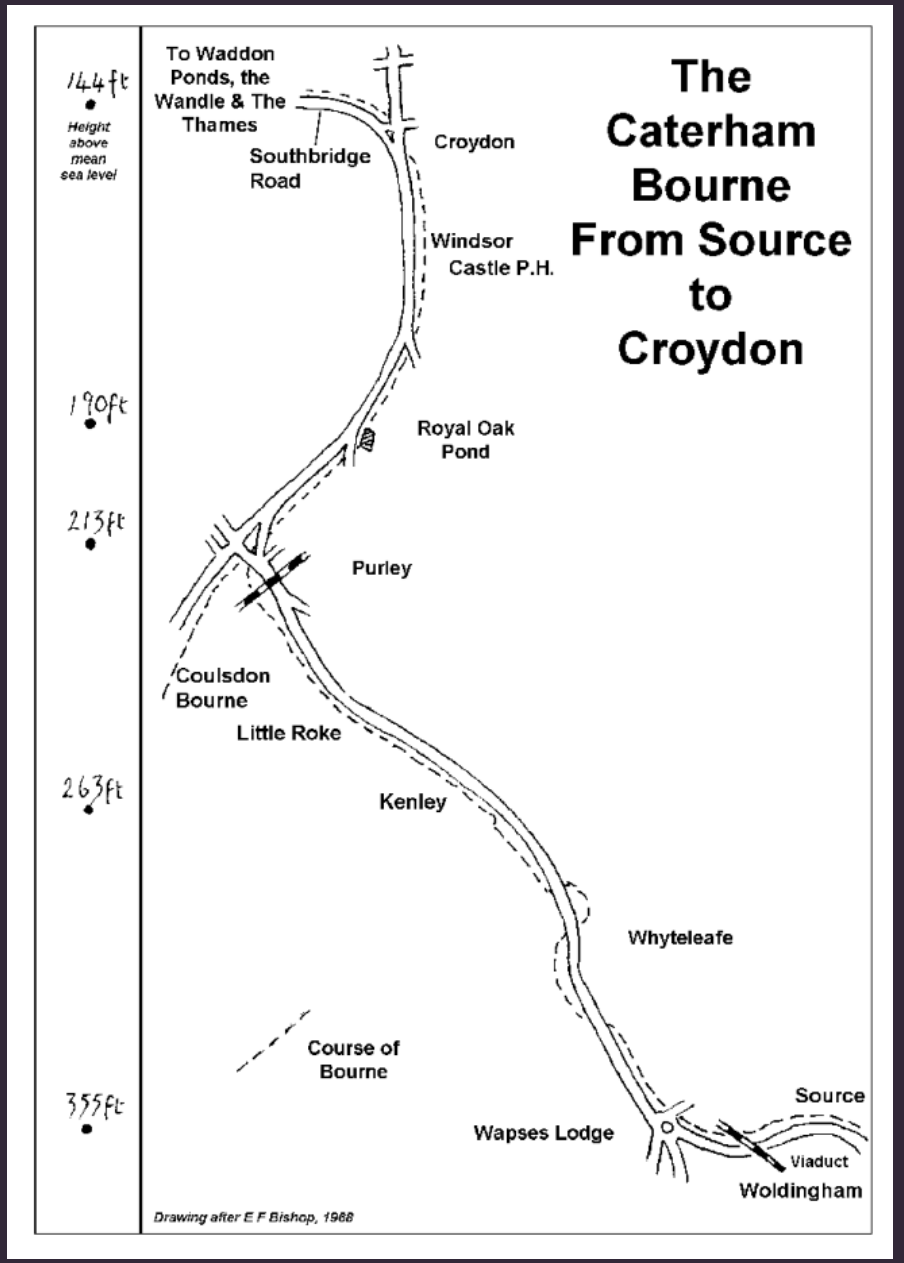
The Bourne

- An intermitted chalk stream
- Rises in the North Downs and flows through Caterham and Purley
- Joins the Wandle in Croydon

The Caterham Bourne - Coulsdon Heritage Facebook group



Bourne Society, 2002. A Celebration of the Bourne. The Bourne Society. https://bournesoc.org.uk/bslivewp/wp-content/uploads/A-Celebration-of-the-Bourne-Web-fileCS.pdf

The Bourne

- History of extreme flooding
- Parts of Caterham, Purley and Croydon underwater for many months

2000-01 flooding. https://www.tandridgeindependent.com/2023/12/08/tandridge-past-the-rise-of-the-river-bourne/

2013-14 flooding. https://www.getsurrey.co.uk/news/local-news/caterham-bourne-flood-alert-thames-6507327

2013-14 flooding. Croydon Flood Investigation. URS.

"Ordinarily the Bourne is a tiny stream,…but every 7th year it swells to an extraordinary manner, rushing along its narrow bed like a torrent…invading the dwellings of the inhabitants of the low-lying quarter of Croydon known as Old Town. This singular phenomenon has been observed for centuries, and yet its cause is still an unfathomed mystery which nature guards most jealously."

Croydon to the North Downs; a Handy Guide to Rambles in the District by Thomas Frost, 1881

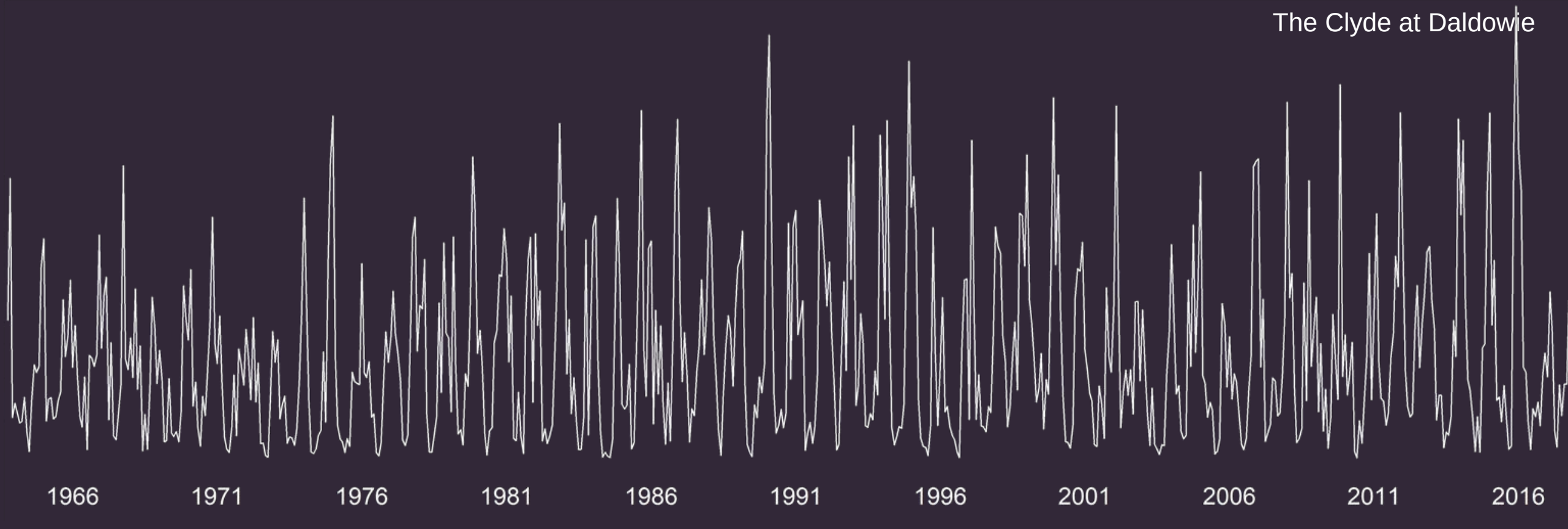
Mr W W Swatland testing the waters at his pub, the Rose and Crown, 1904

https://midweekwayfarers.blogspot.com/2021/01/the-wandle-croydon-and-caterham-bourne.html

“In the same yere [1473 New Style] womere watere ranne hugely with suche abundaunce of water that nevyr manne sawe it renne so muche afore this tyme. Womere is callede the woo watere: for Englyschmen, when thei dyd fyrst inhabyd this lond, also sone as thei see this watere renne, thei knewe wele it was a tokene of derthe or of pestylence or of grete batayle; wherefore thei called it womere (for we as in Englysch tonge woo and mere is callede watere, which signyfieth woo watere;) and this womere is vii myle from Sent Albons at a place callede Markayat; … … and another at Croydone in Suthsex that when it betokeneth batayle it rennys foule and trouble watere; and whenne betokene the derthe or pestylence, it rennyth clere as any watere, but this yere it ranne ryght trouble and foule watere.”

- John Warkworth’s Chronicle, 1473

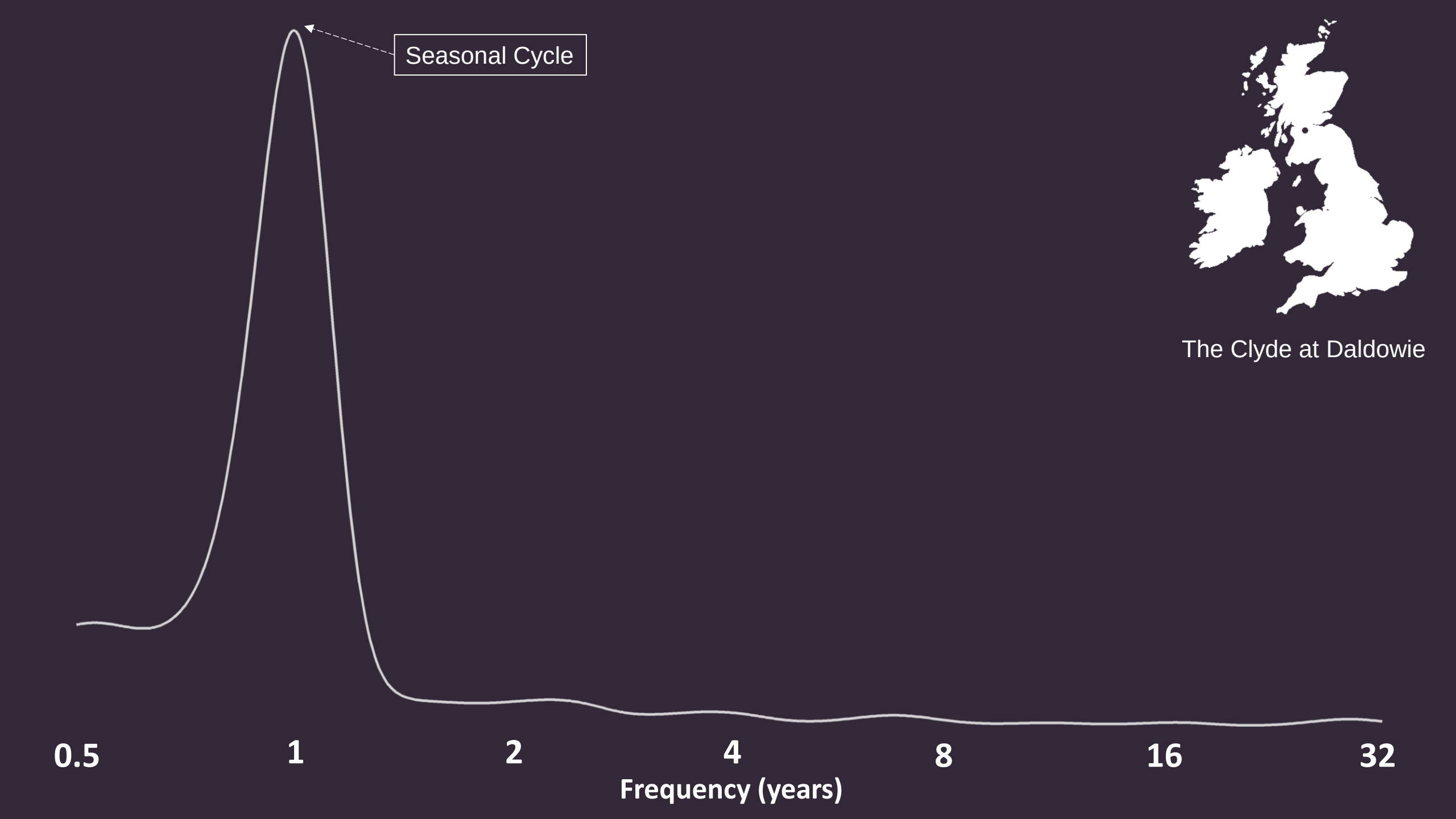
The Clyde at Daldowie



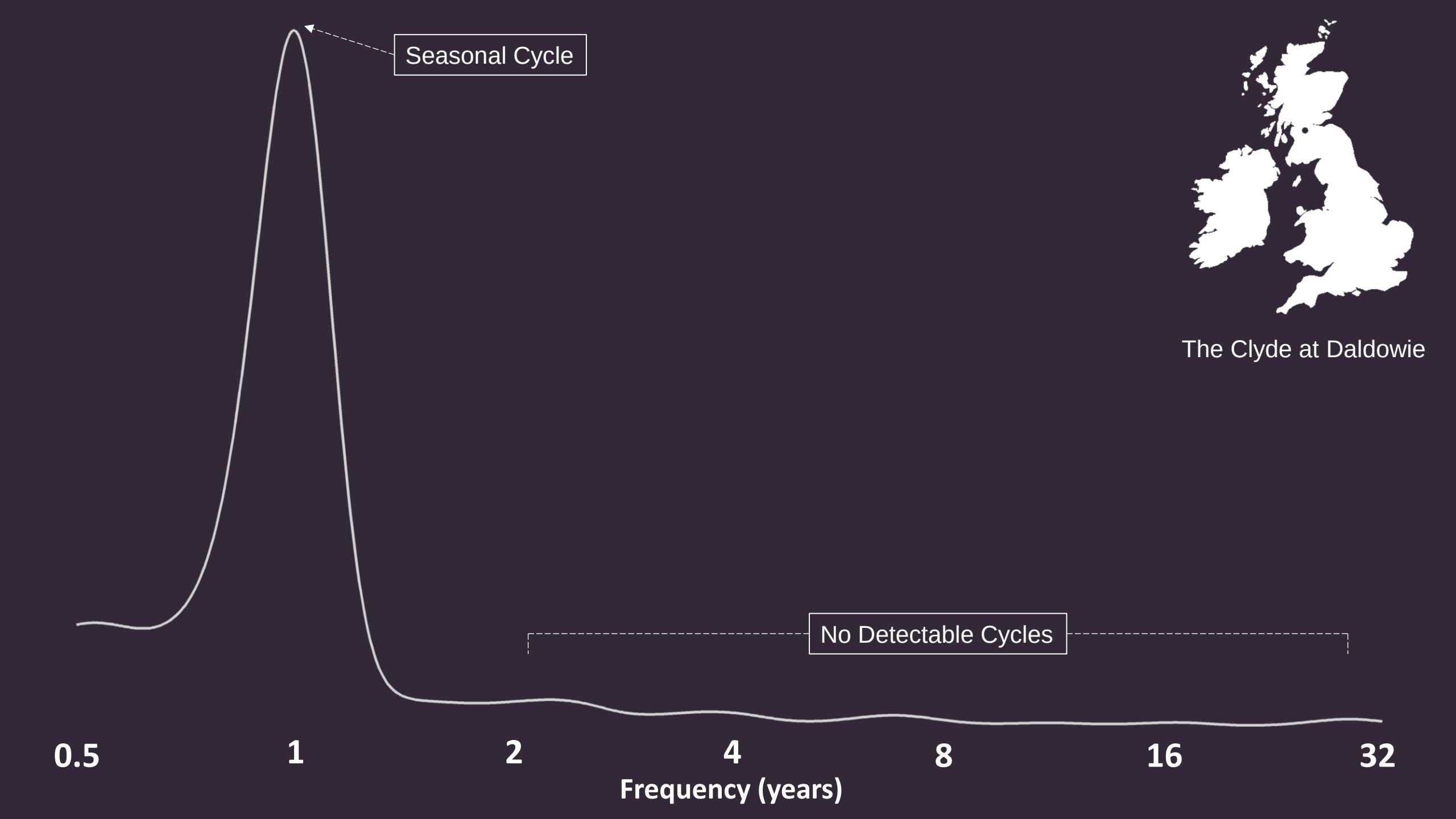
The Clyde at Daldowie

0.5 1 2 4 8 16 32

Frequency (years)



The Clyde at Daldowie



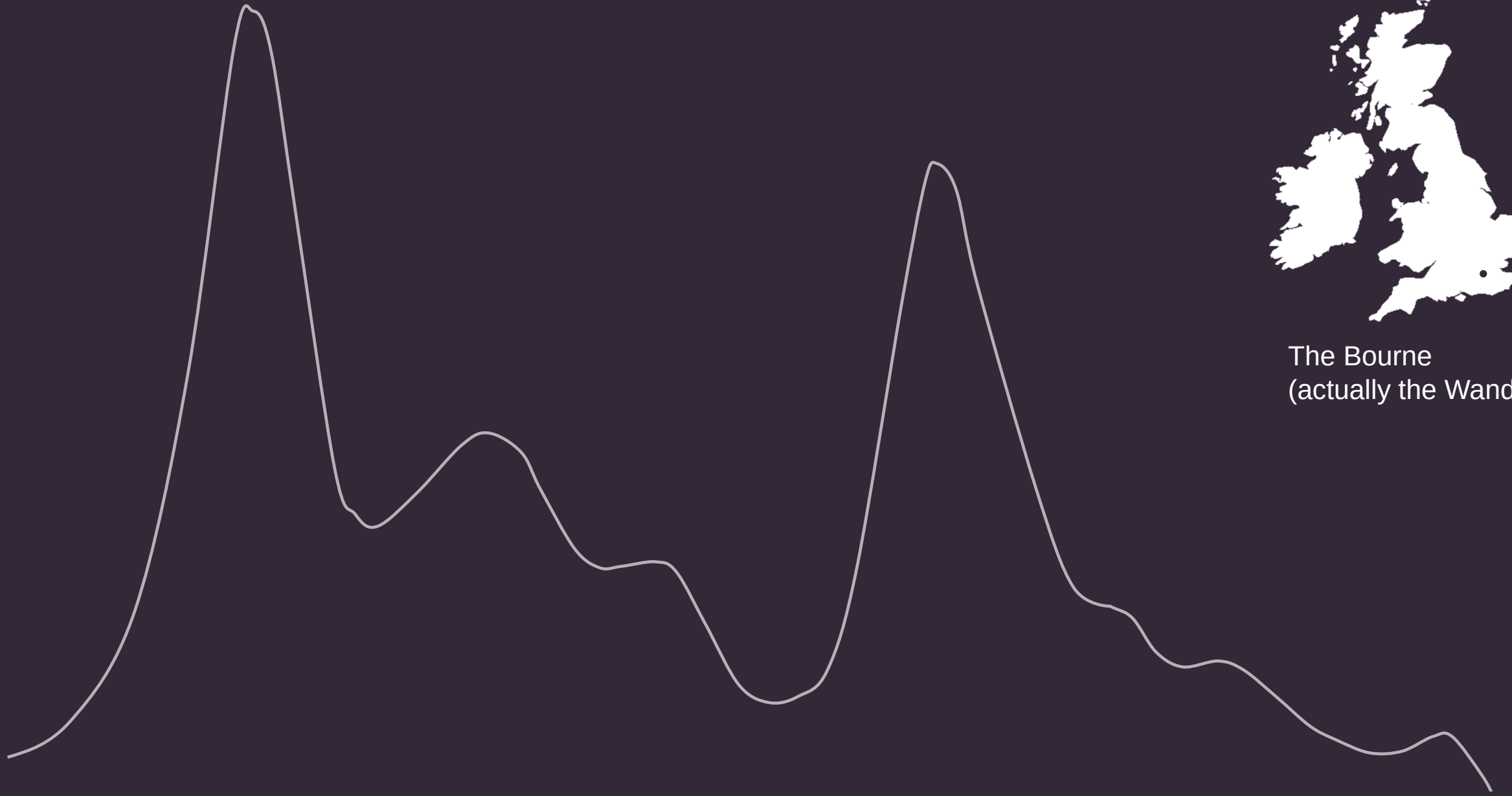
The Clyde at Daldowie

The Bourne

0.5 1 2 4 8 16 32

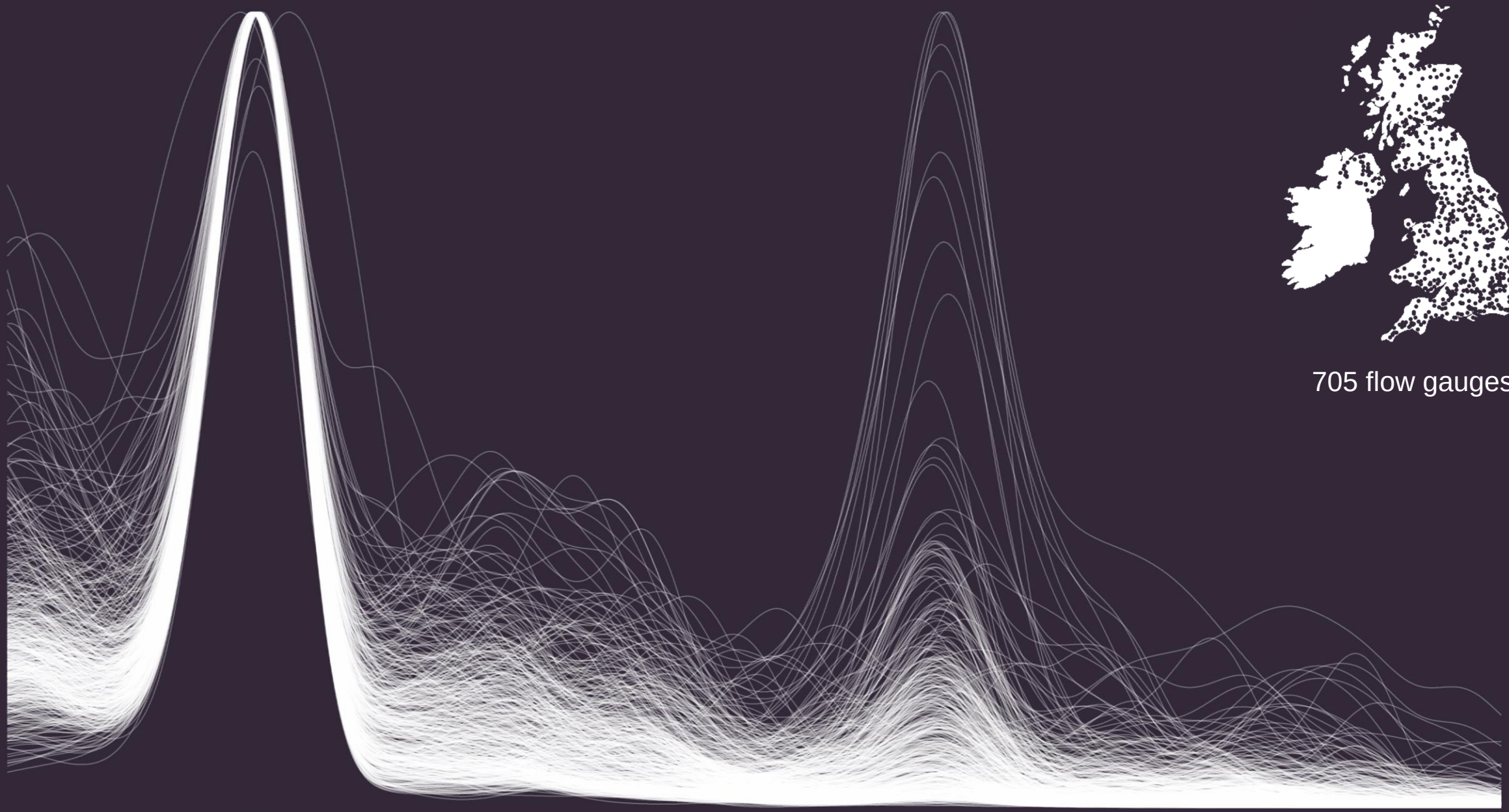
Frequency (years)

Rust et al, 2021



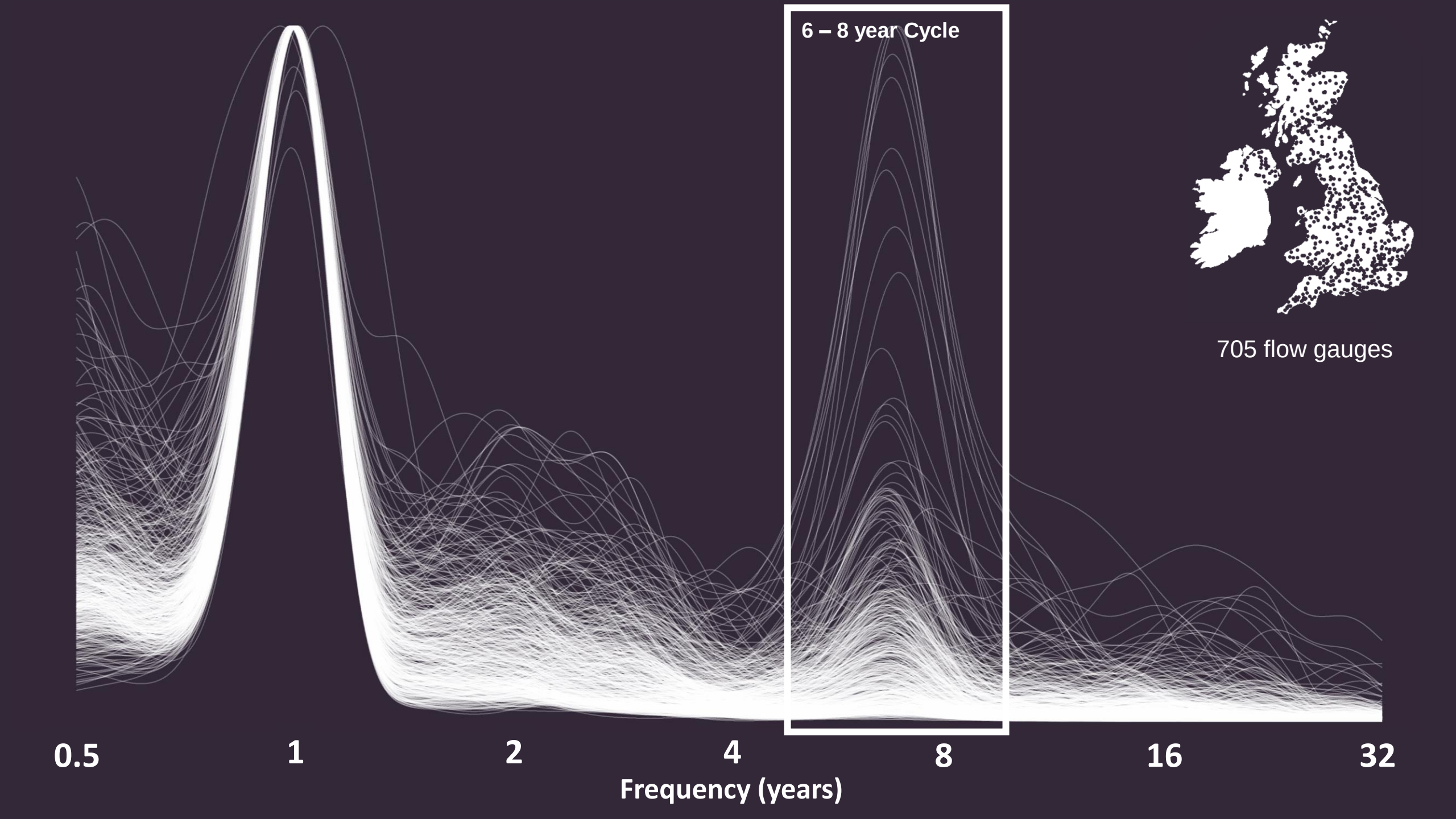
The Bourne
(actually the Wandle)

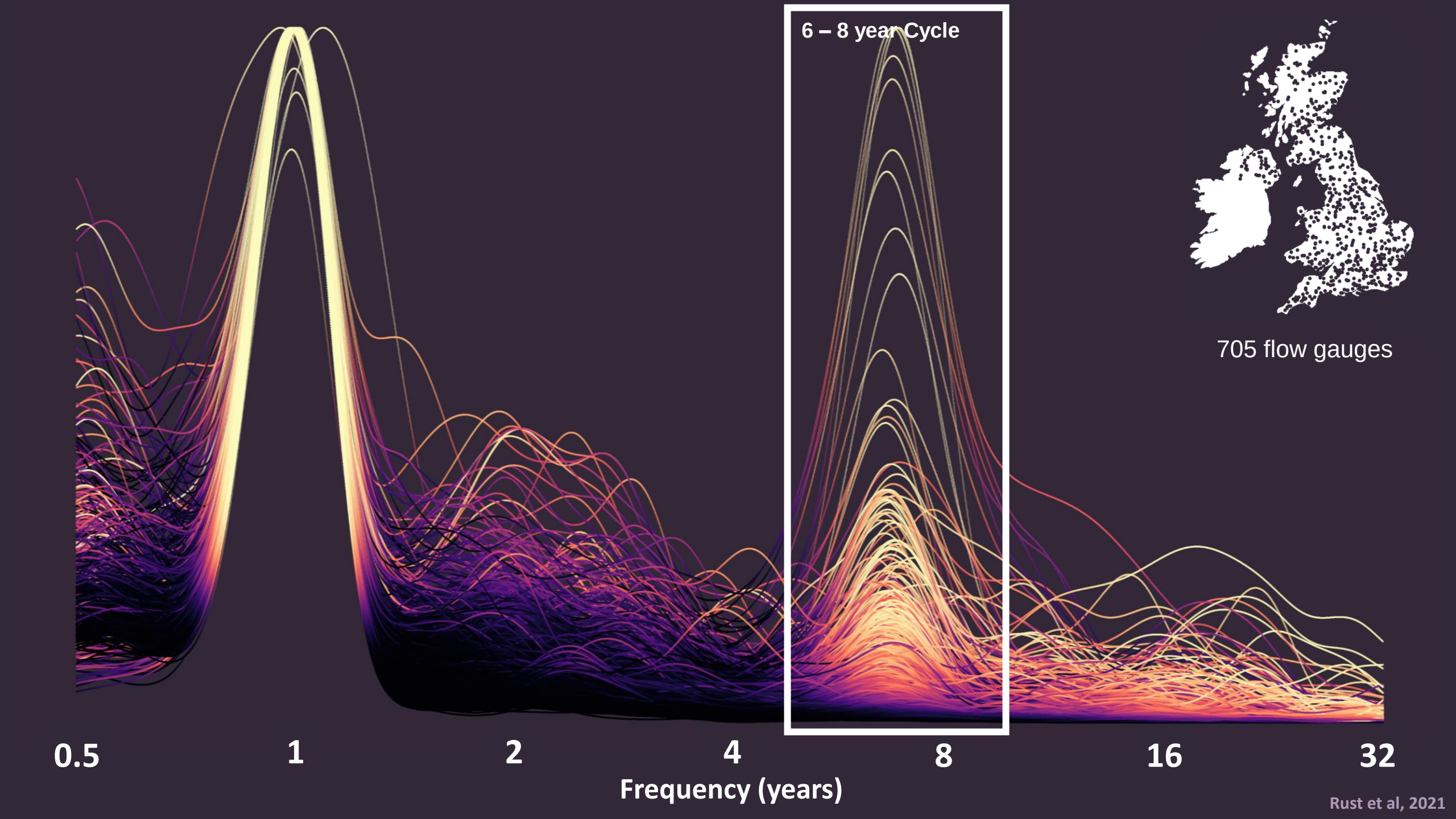
Rust et al, 2021. https://doi.org/10.5194/hess-25-2223-2021



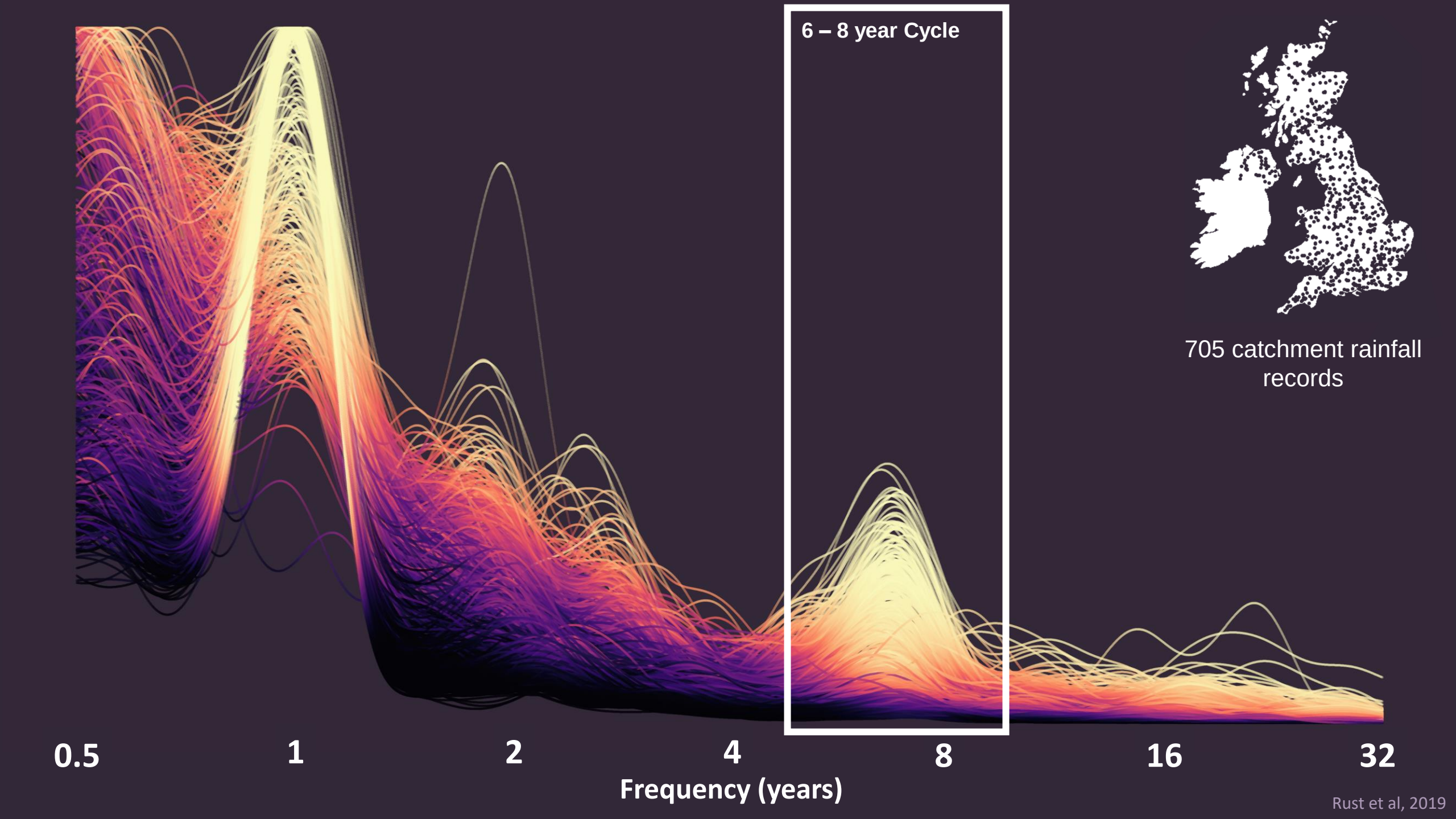
705 flow gauges

Rust et al, 2021. https://doi.org/10.5194/hess-25-2223-2021

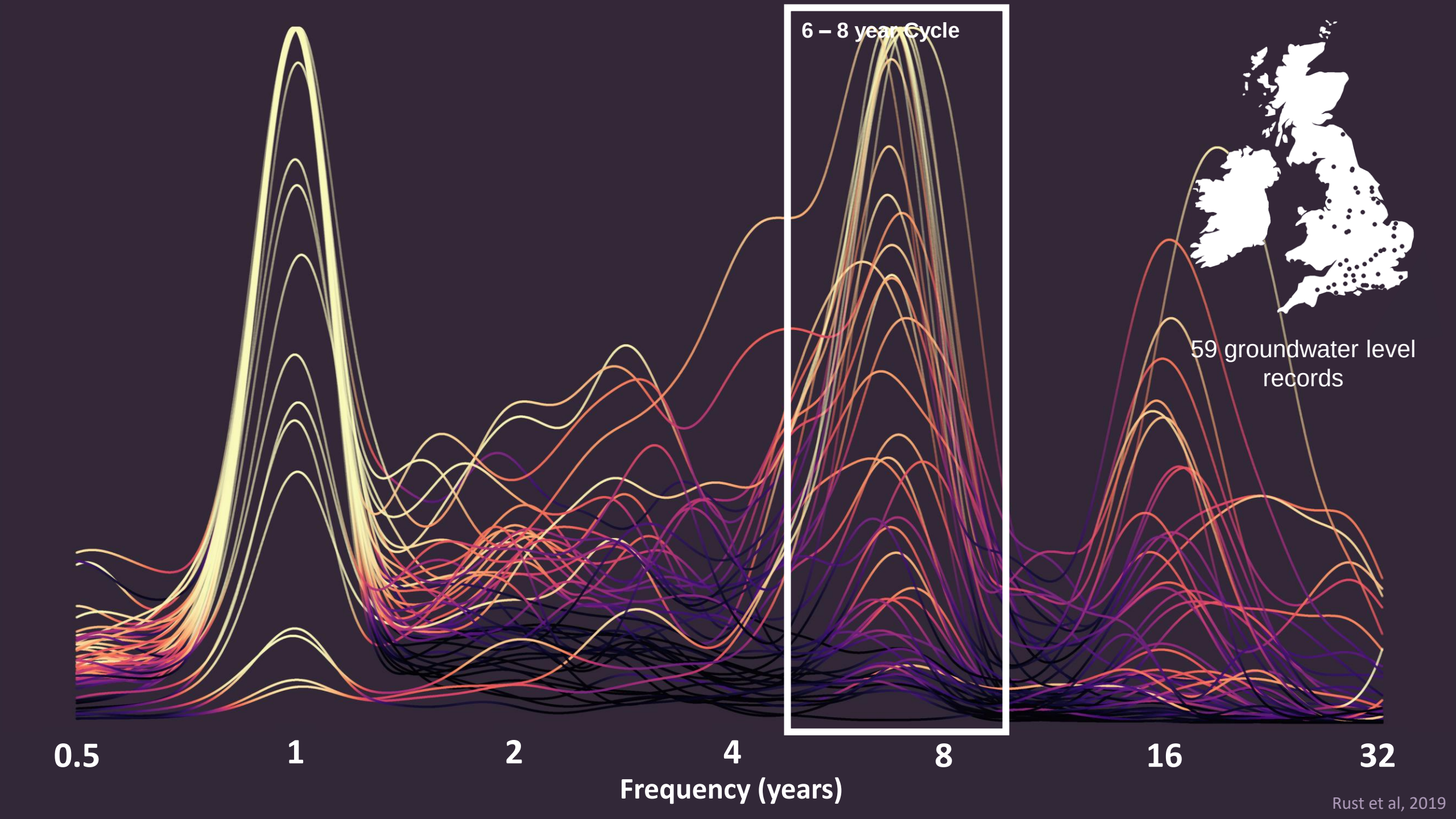

6 – 8 year Cycle
705 flow gauges
0.5
1
2
4
8
16
32
Frequency (years)



Rust et al, 2021



Rust et al, 2019



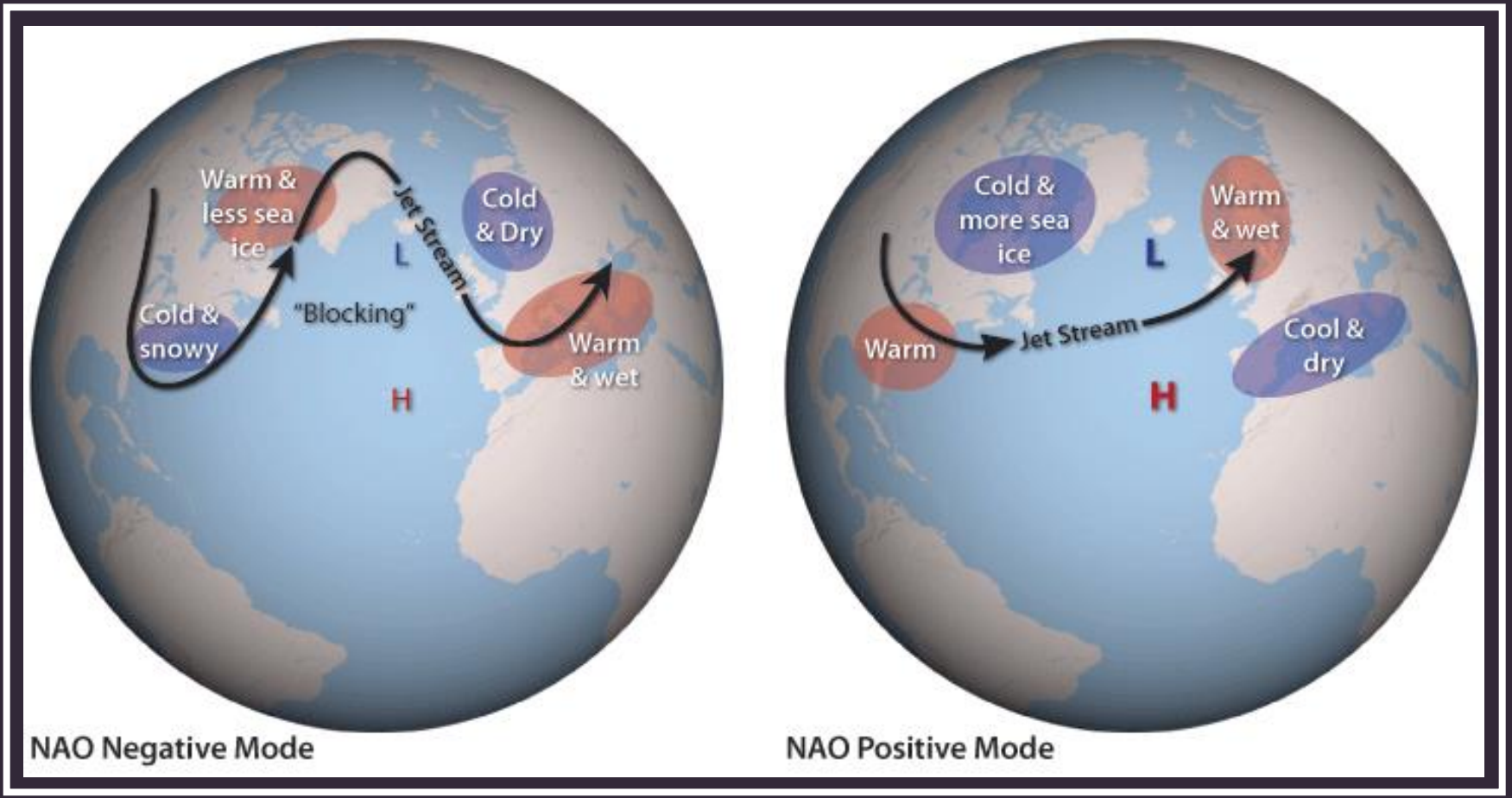
Rust et al, 2019

Questions…

1. What drives these cycles in **rainfall records**?
2. Why are they **strongest** in groundwater records?

What drives these cycles in rainfall records?

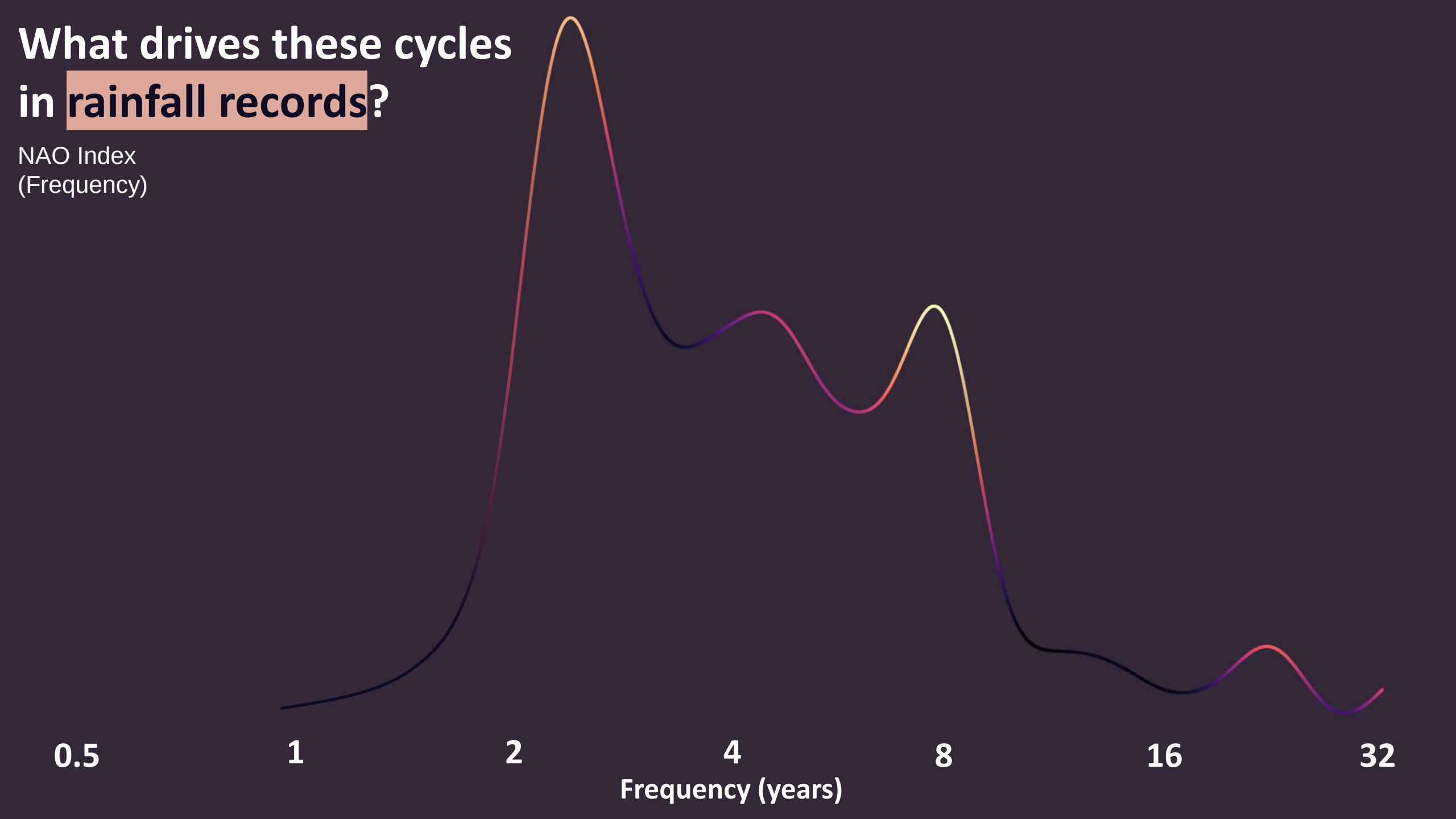
North Atlantic Oscillation



National Oceanic and Atmospheric Administration. (July 22, 2016). ''NAO Modes''

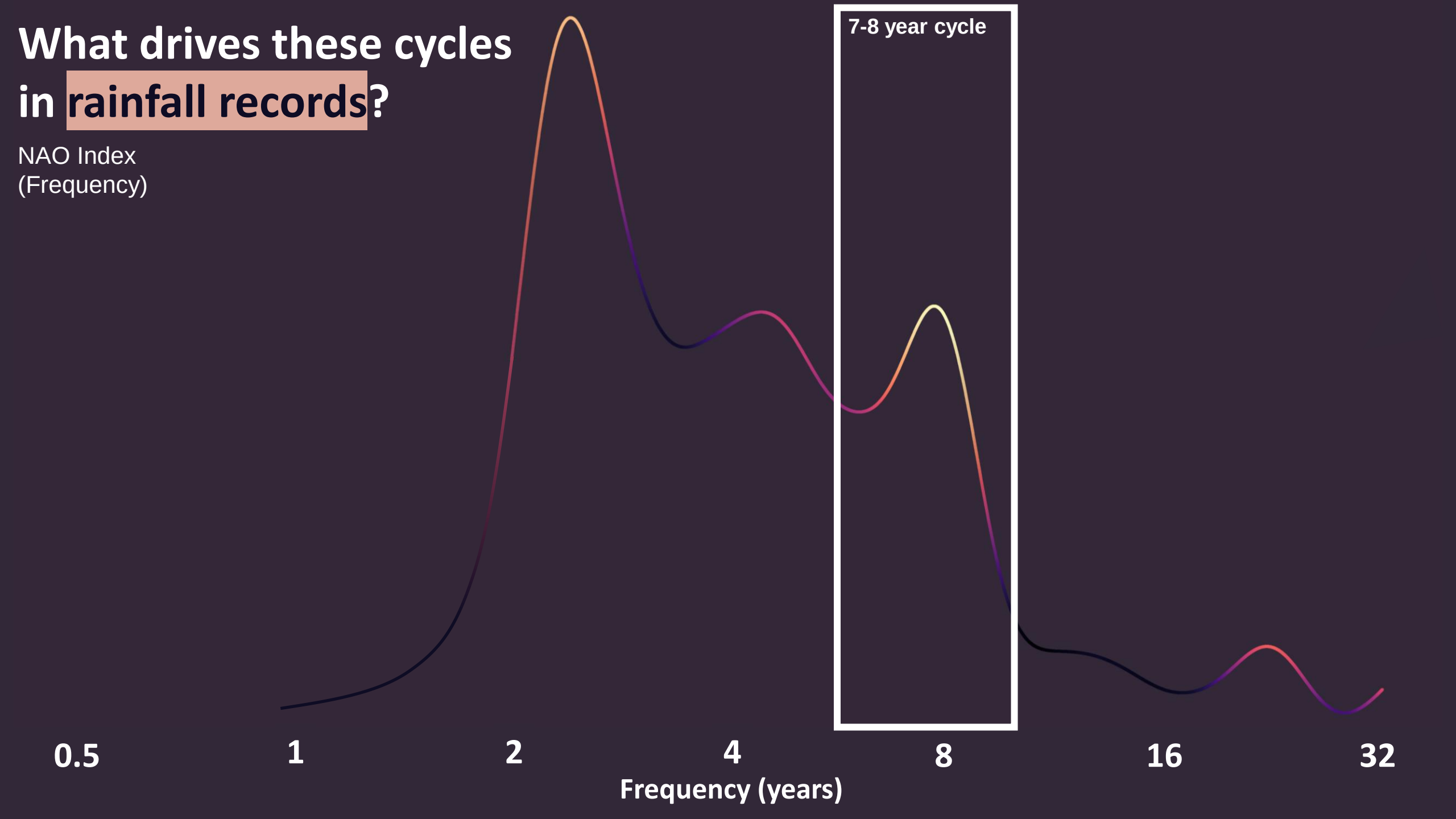
What drives these cycles in rainfall records?

NAO Index
(Frequency)

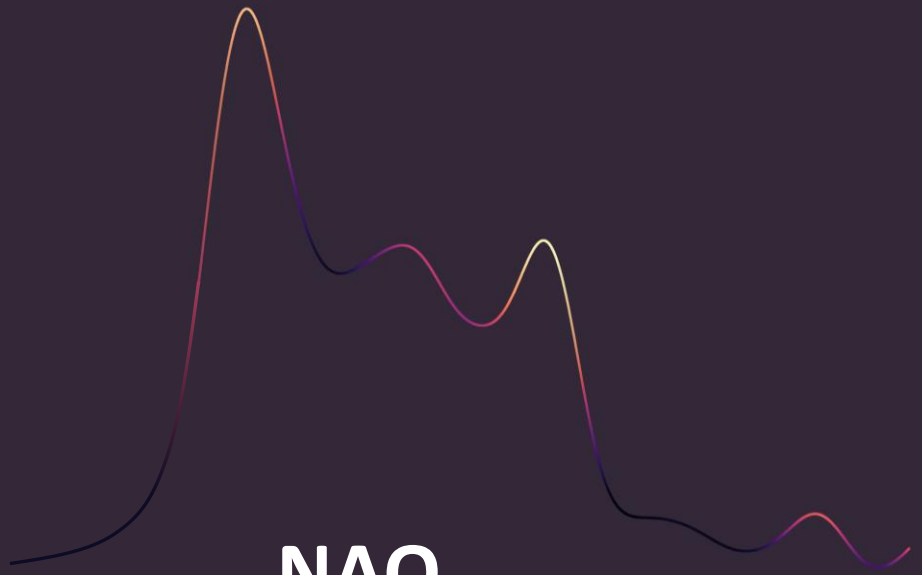


What drives these cycles in rainfall records?

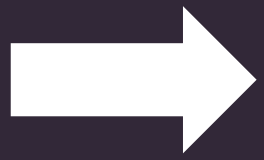
NAO Index
(Frequency)

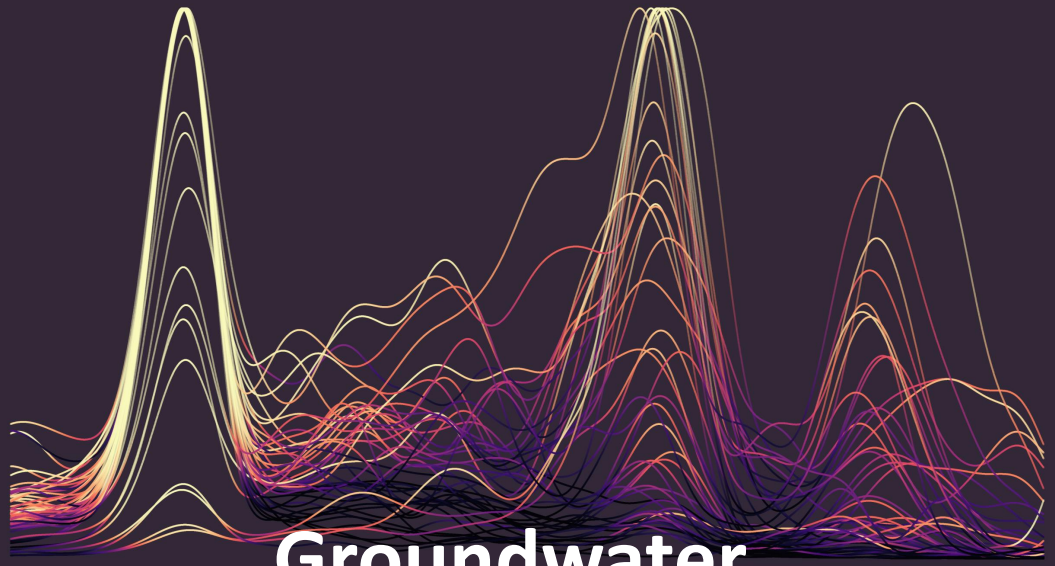


Why are they strongest in groundwater records?



NAO

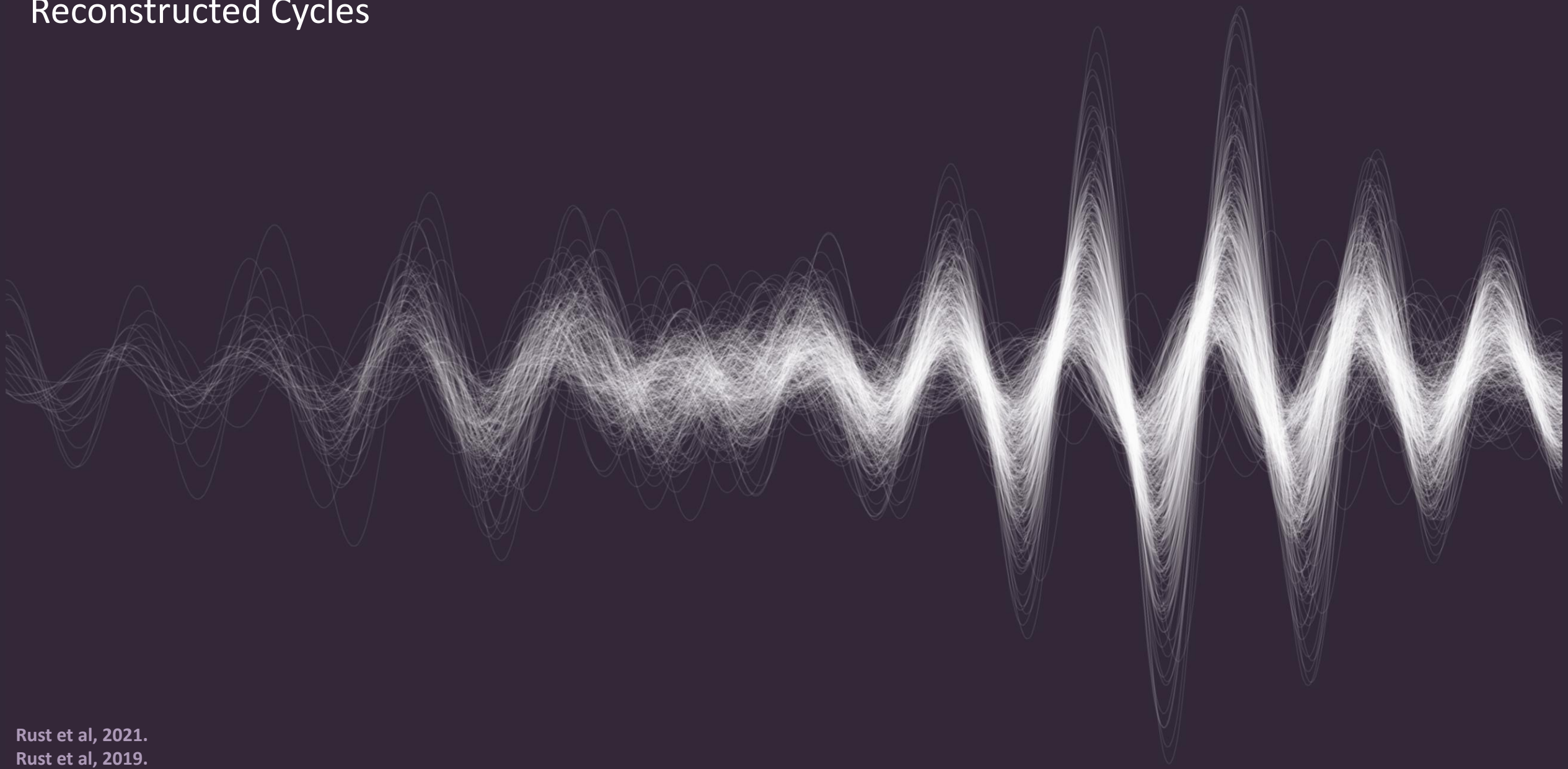




Groundwater

Groundwater Teleconnection

Reconstructed Cycles



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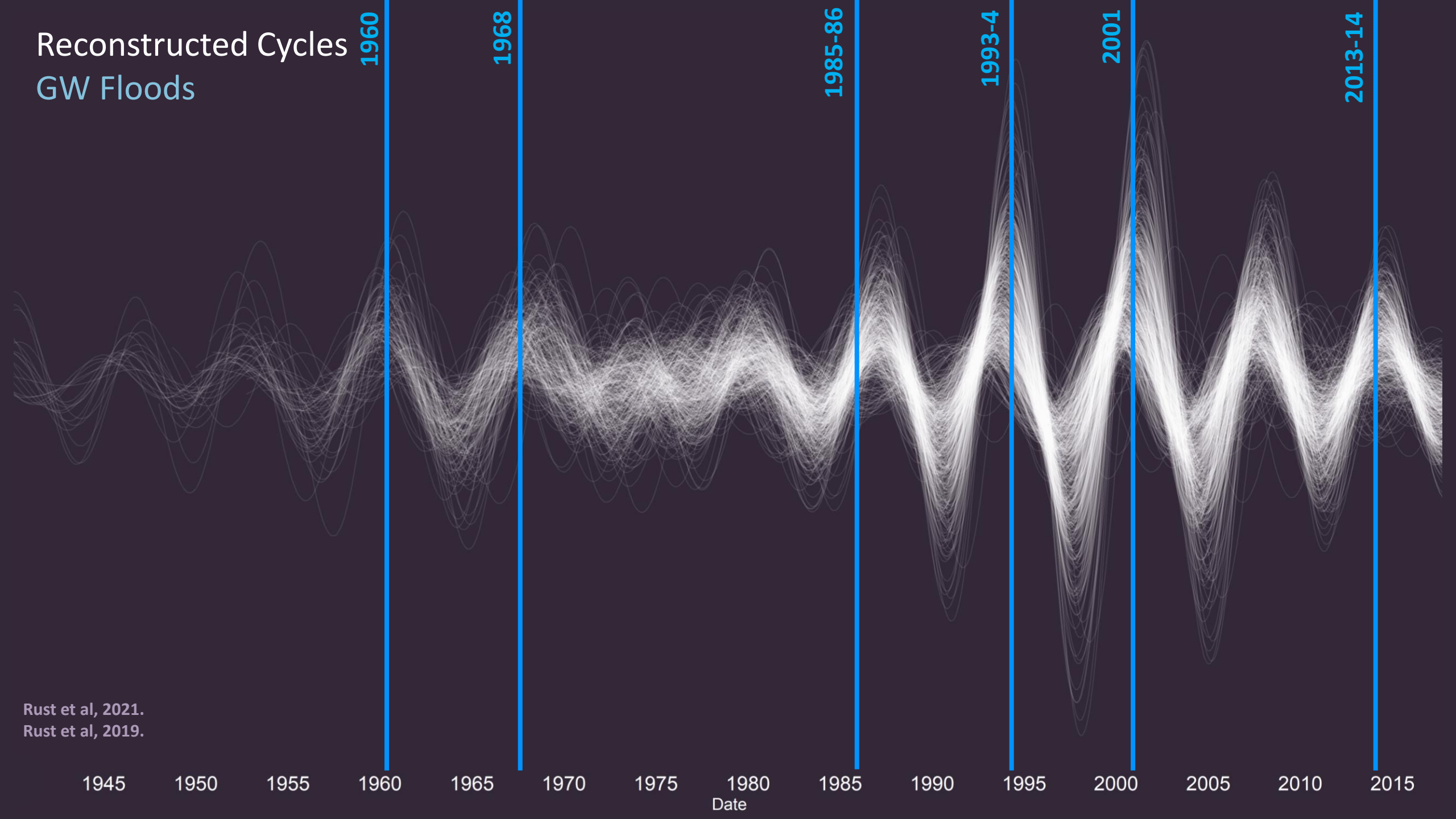
Rust et al, 2019.


Reconstructed Cycles
GW Floods
1960
1968
1985-86
1993-4
2001
2013-14
Rust et al, 2021.
Rust et al, 2019.
1945
1950
1955
1960
1965
1970
1975
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2005
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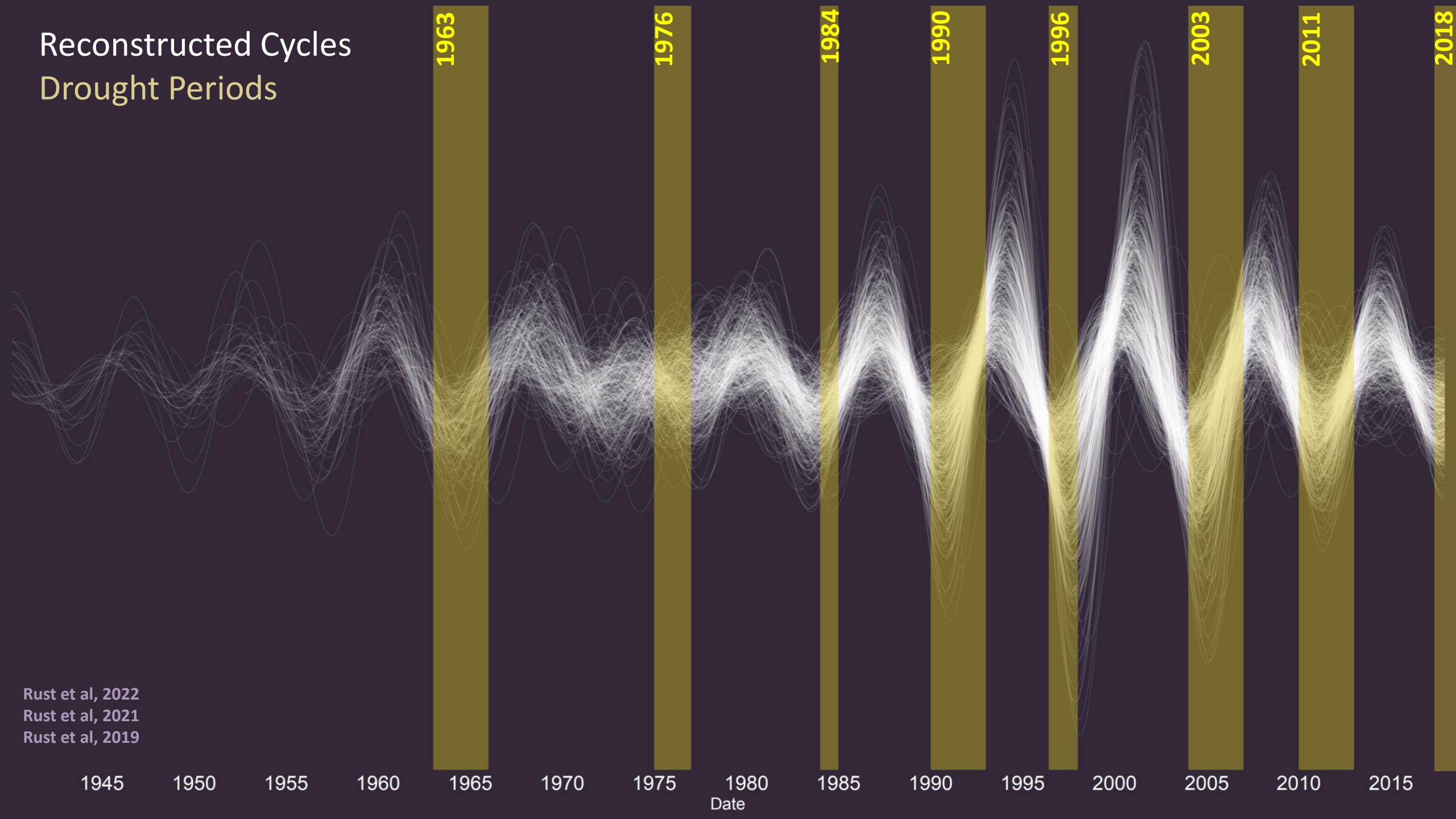
Date


Reconstructed Cycles
Drought Periods
1963
1976
1984
1990
1996
2003
2011
2018
Rust et al, 2022
Rust et al, 2021
Rust et al, 2019
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
1995
2000
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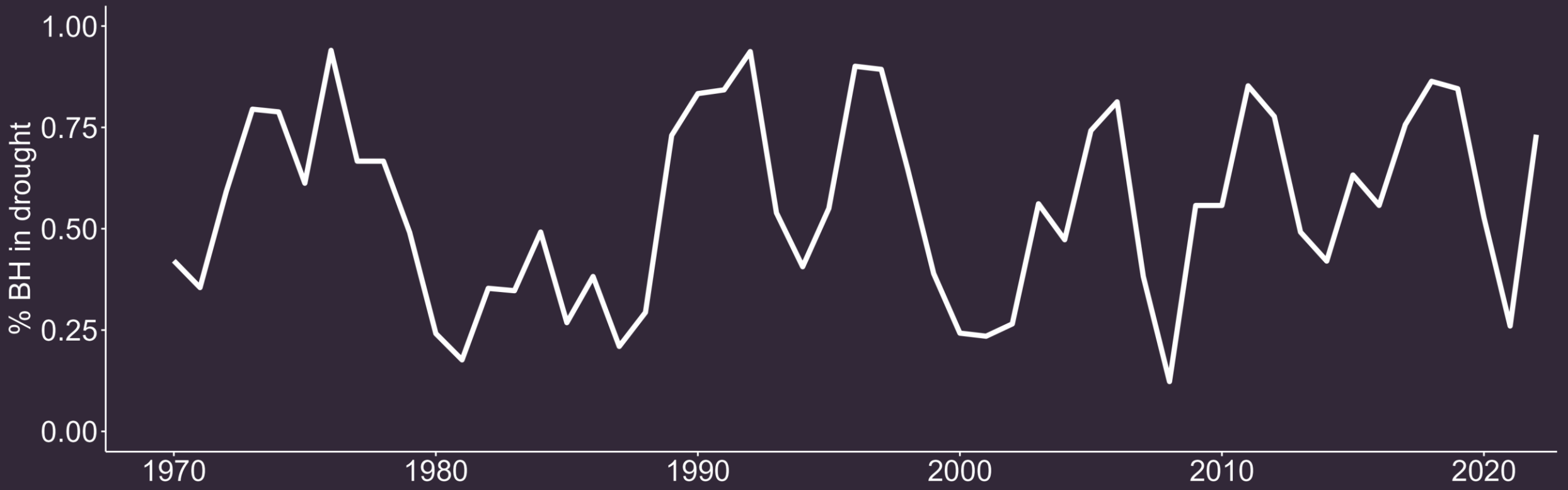
2015
Date

Multi-year NAO Cycles can be used to forecast GW Drought

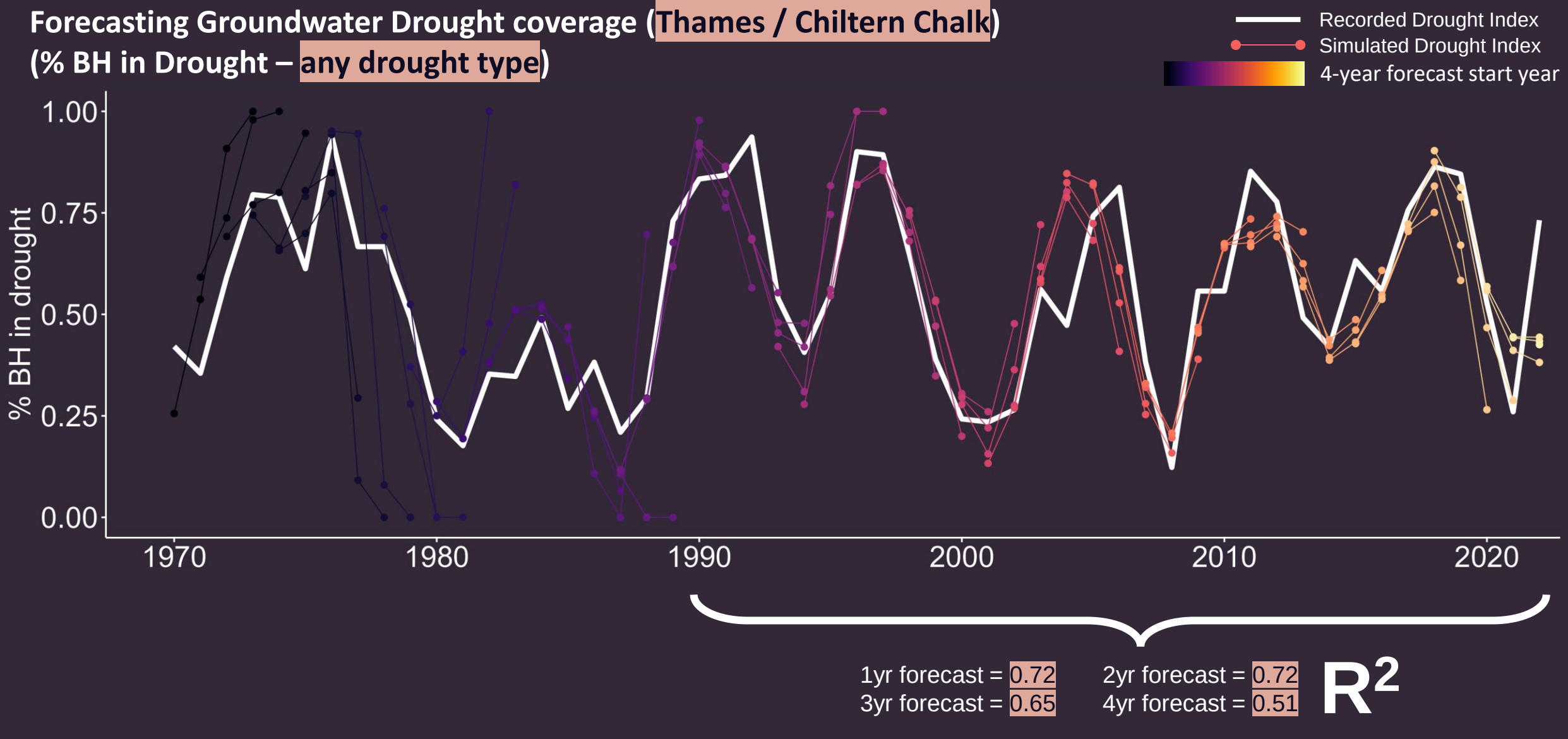
Groundwater Drought coverage (Thames / Chiltern Chalk)
(% BH in Drought – Any drought)



Rust et al, 2024.

Multi-year NAO Cycles can be used to forecast GW Drought

Forecasting Groundwater Drought coverage (Thames / Chiltern Chalk)
(% BH in Drought – any drought type)

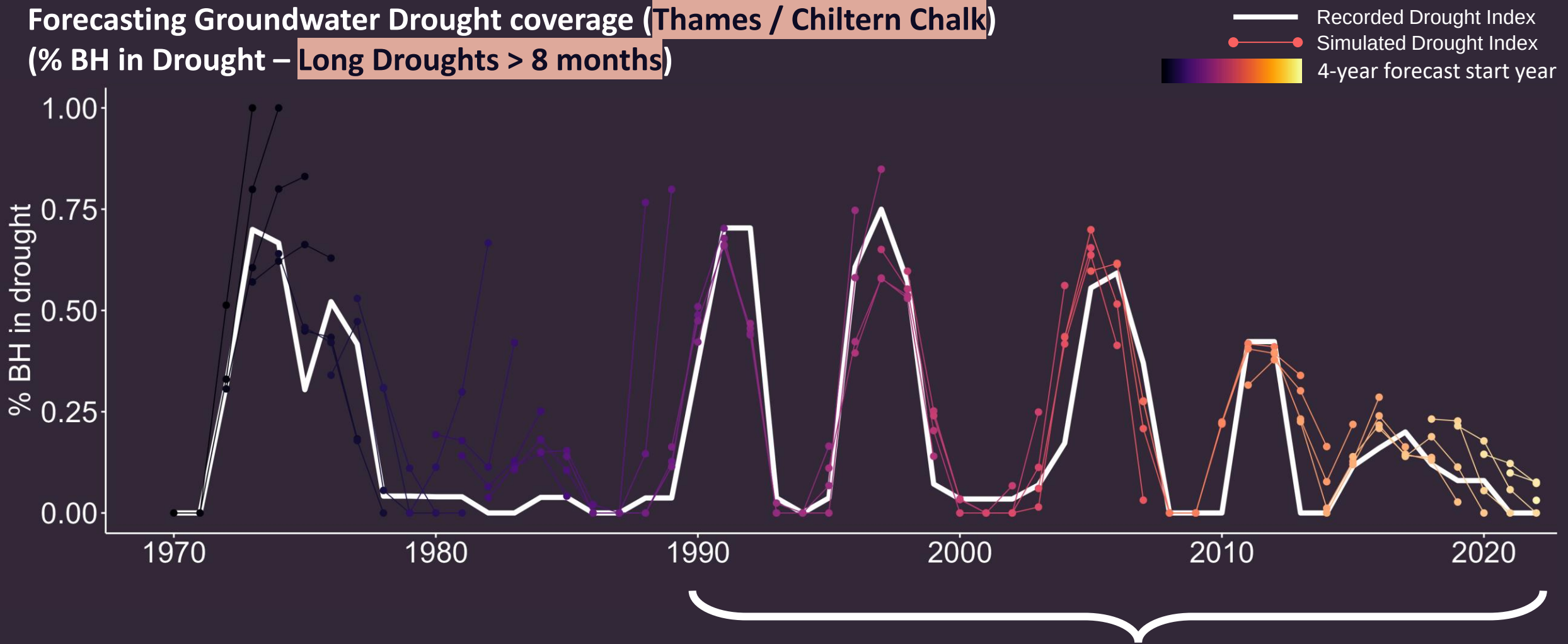


1yr forecast = 0.72
2yr forecast = 0.72
3yr forecast = 0.65
4yr forecast = 0.51
R^2

Rust et al, 2024.

Multi-year NAO Cycles can be used to forecast GW Drought

Forecasting Groundwater Drought coverage (Thames / Chiltern Chalk)
(% BH in Drought – Long Droughts > 8 months)



1yr forecast = 0.82
2yr forecast = 0.80
3yr forecast = 0.80
4yr forecast = 0.71
R^2

Rust et al, 2024.

Summary…

- Multi-year cycles in the NAO influence groundwater extremes in the UK
- Their influence is non-stationary over time
- Sufficient dependency for predictive capability (using machine learning)

Further Reading…

Rust, W., Holman, I., Corstanje, R., Bloomfield, J., & Cuthbert, M. (2018). A conceptual model for climatic teleconnection signal control on groundwater variability in Europe. *Earth-Science Reviews*, *177*, 164-174.

Rust, W., Holman, I., Bloomfield, J., Cuthbert, M., & Corstanje, R. (2019). Understanding the potential of climate teleconnections to project future groundwater drought. *Hydrology and Earth System Sciences*, *23*(8), 3233-3245.

Rust, W., Cuthbert, M., Bloomfield, J., Corstanje, R., Howden, N., & Holman, I. (2021). Exploring the role of hydrological pathways in modulating multi-annual climate teleconnection periodicities from UK rainfall to streamflow. *Hydrology and Earth System Sciences*, *25*(4), 2223-2237.

Rust, W., Bloomfield, J. P., Cuthbert, M. O., Corstanje, R., & Holman, I. P. (2021). Non-stationary control of the NAO on European rainfall and its implications for water resource management. *Hydrological Processes*, *35*(3).

Rust, W., Bloomfield, J. P., Cuthbert, M., Corstanje, R., & Holman, I. (2022). The importance of non-stationary multiannual periodicities in the North Atlantic Oscillation index for forecasting water resource drought. *Hydrology and Earth System Sciences*, *26*(9), 2449-2467.

Rust, W., Bloomfield, J. P., & Holman, I. (2024). Long-range hydrological drought forecasting using multi-year cycles in the North Atlantic Oscillation. *Journal of Hydrology*, *641*, 131831.

Affinity Water

Managing water resources in a changing climate – Droughts & Floods

Dr Ilias Karapanos
Head of WRMP

Who we are

- Largest Water Only Supplier in the UK
- We distribute potable water to c3.9 million customers in the South East
- 3 geographical regions (Central, East and Southeast)
- Daily supply of 950 Megalitres (Million litres) per day on average
- Supply is predominantly groundwater based
- Area of serious water stress
- WRMP – strategic plan
- DMP – operational plan

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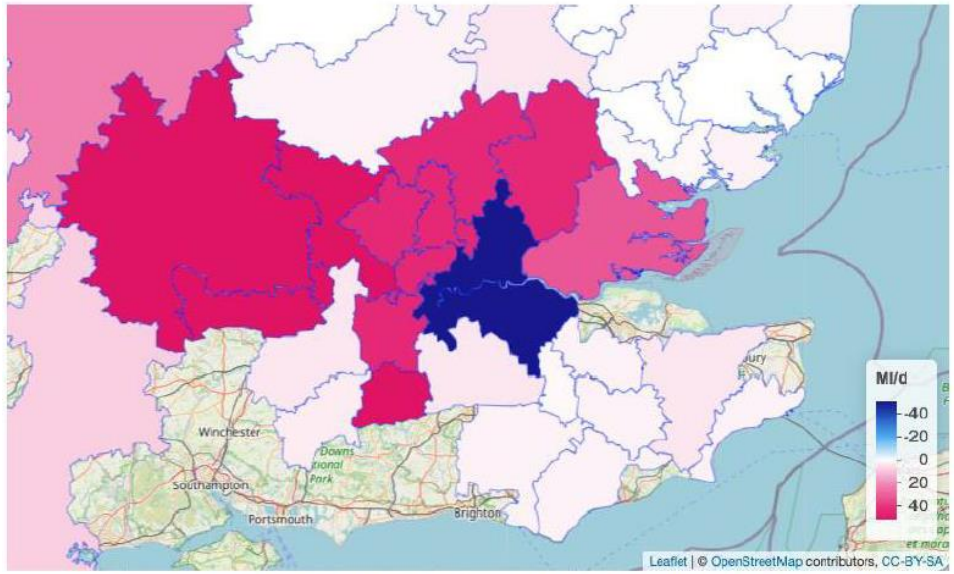
Challenges for Water Resources Management

- Increasing Population
- Climate Change
- Mains Leakage
- Per Capita Consumption (PCC)



Increase in total demand (Ml/d) from January to October 2020 due to Covid-19 policies

Current UK average PCC
(litres per person per day)

140 Ofwat, 3-year average based on AR23

Current Affinity Water area PCC
(litres per person per day)

154 based on AR24

PCC target to 110 l/h/d by 2050
Leakage reduction to 50% by 2050

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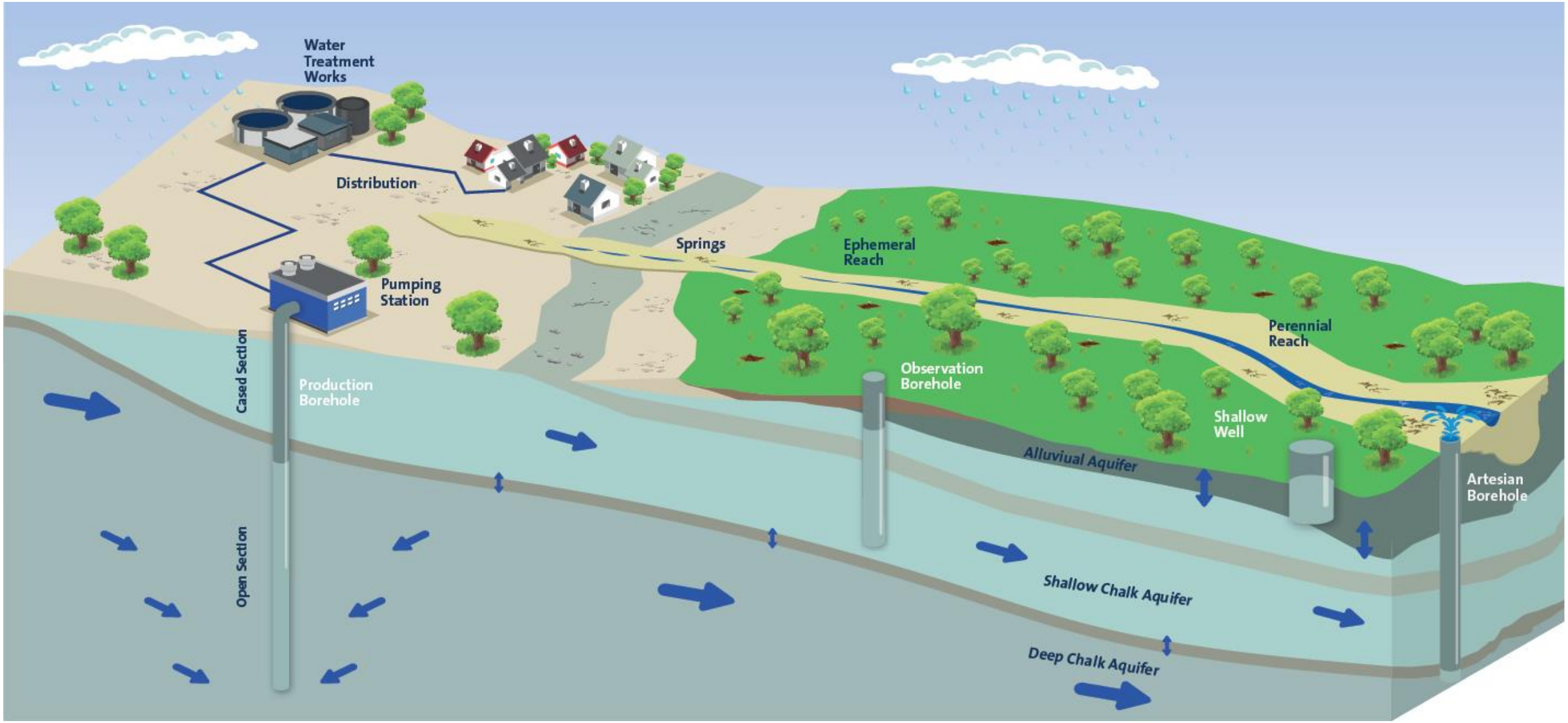
A conceptual schematic of the Chilterns Chalk



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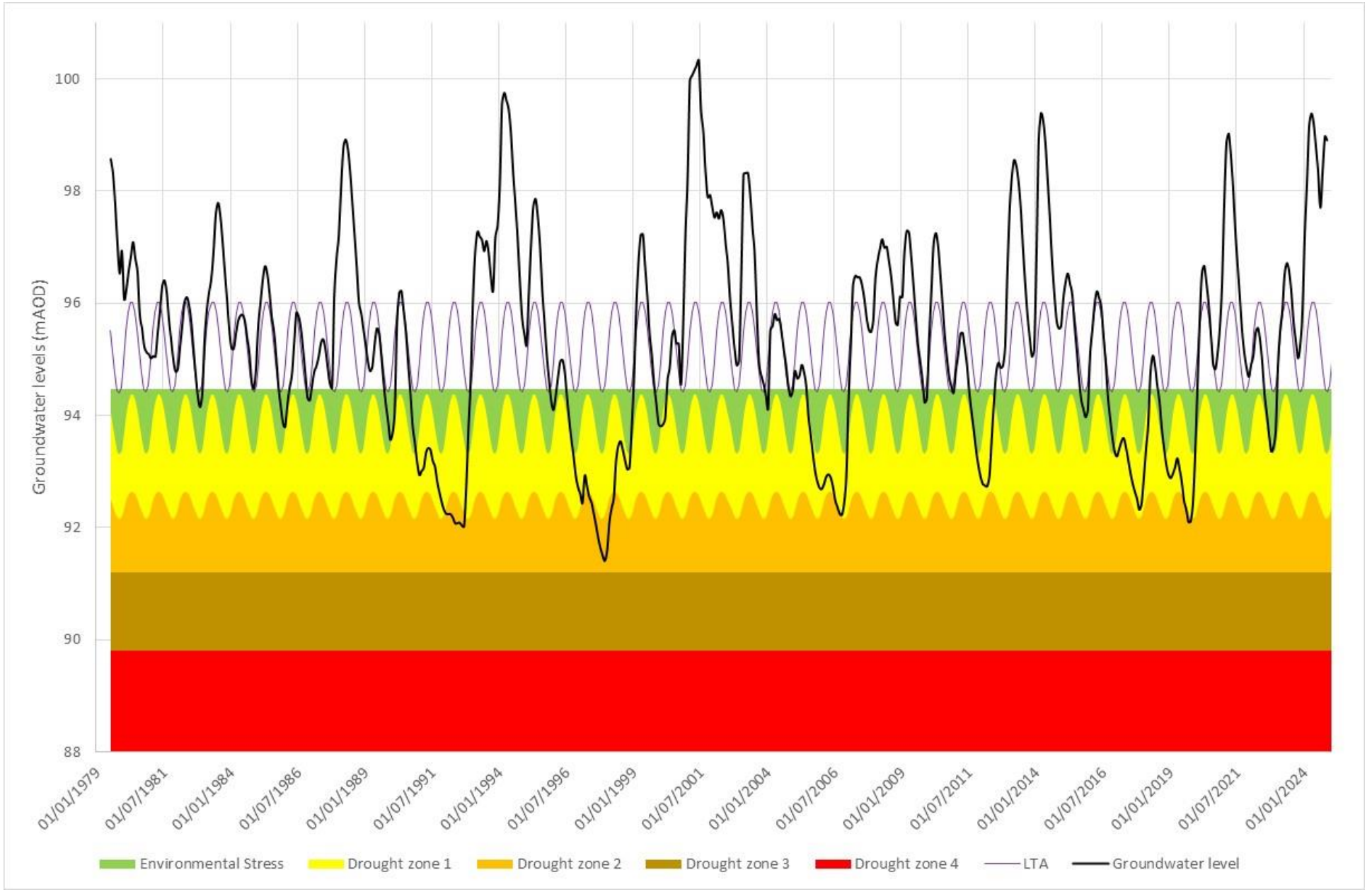
Drought definition & our Drought Triggers



- GW drought defined based on Chalk groundwater levels at several key OBHs
- Since the 80s, 5-6 GW drought events & 5-6 flood events
- Decreasing GWLs can impact on Deployable Output in DAPWL constrained sources

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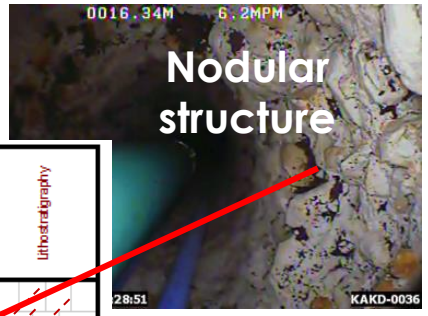
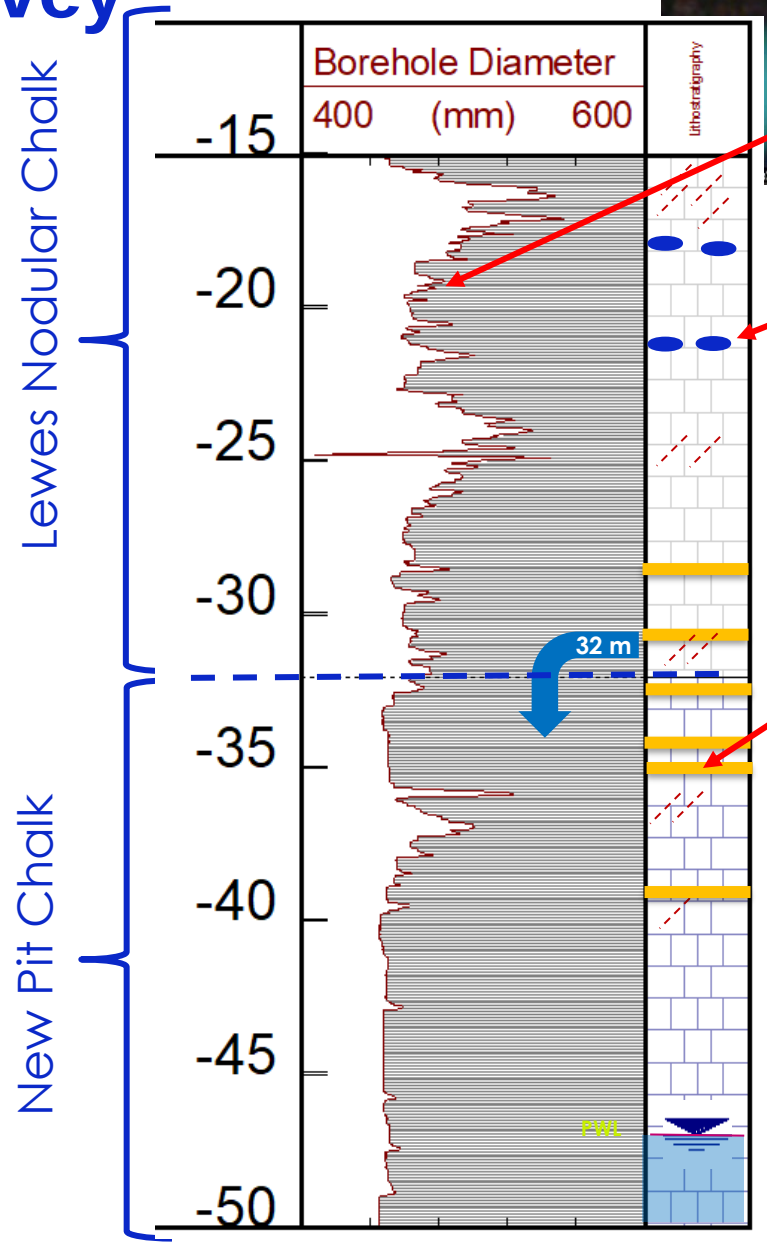
Downhole camera survey





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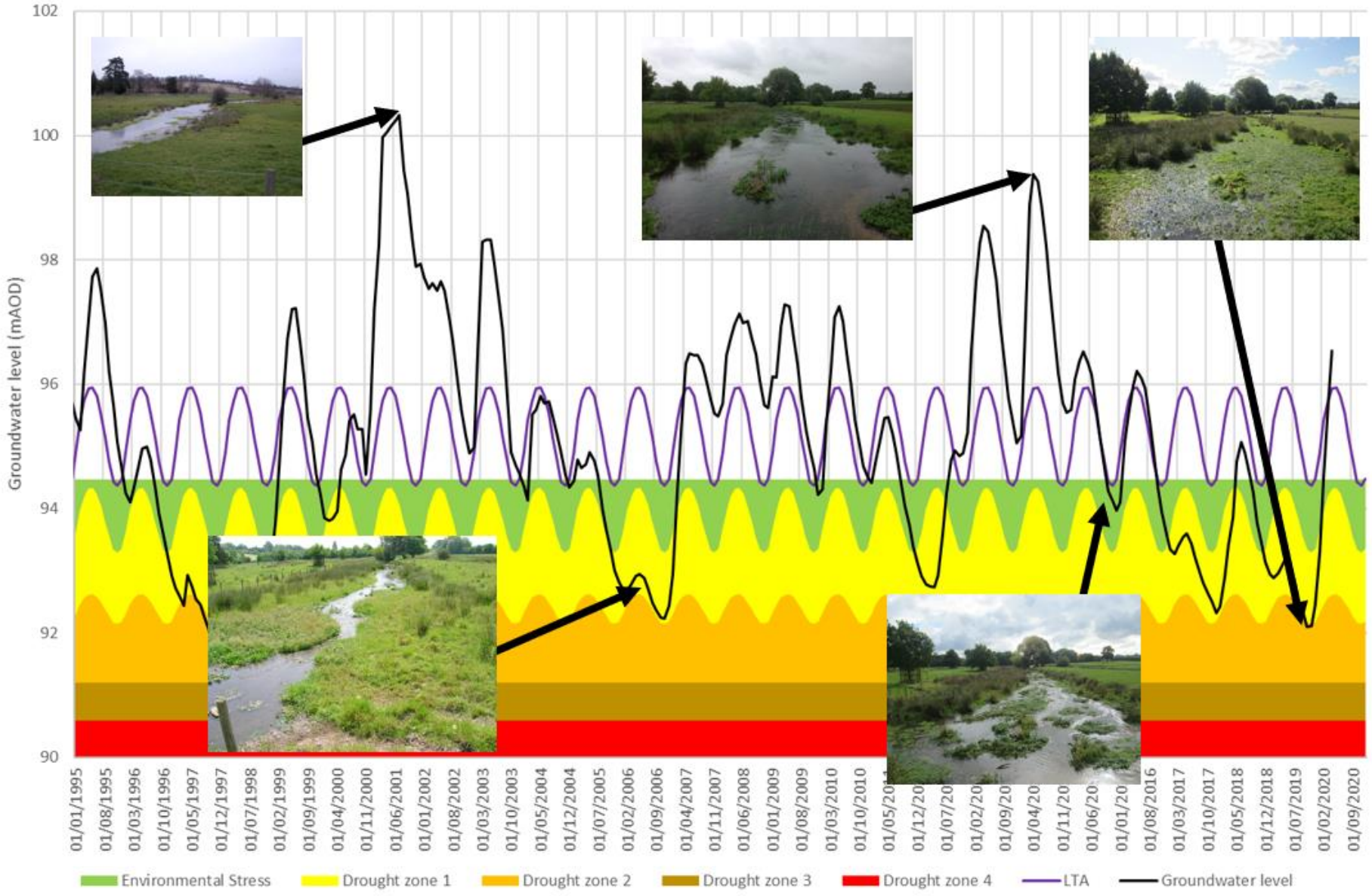
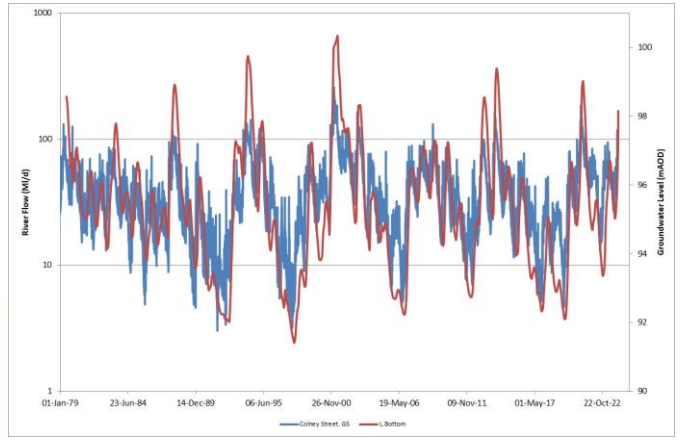
Drought Triggers and River Baseflow





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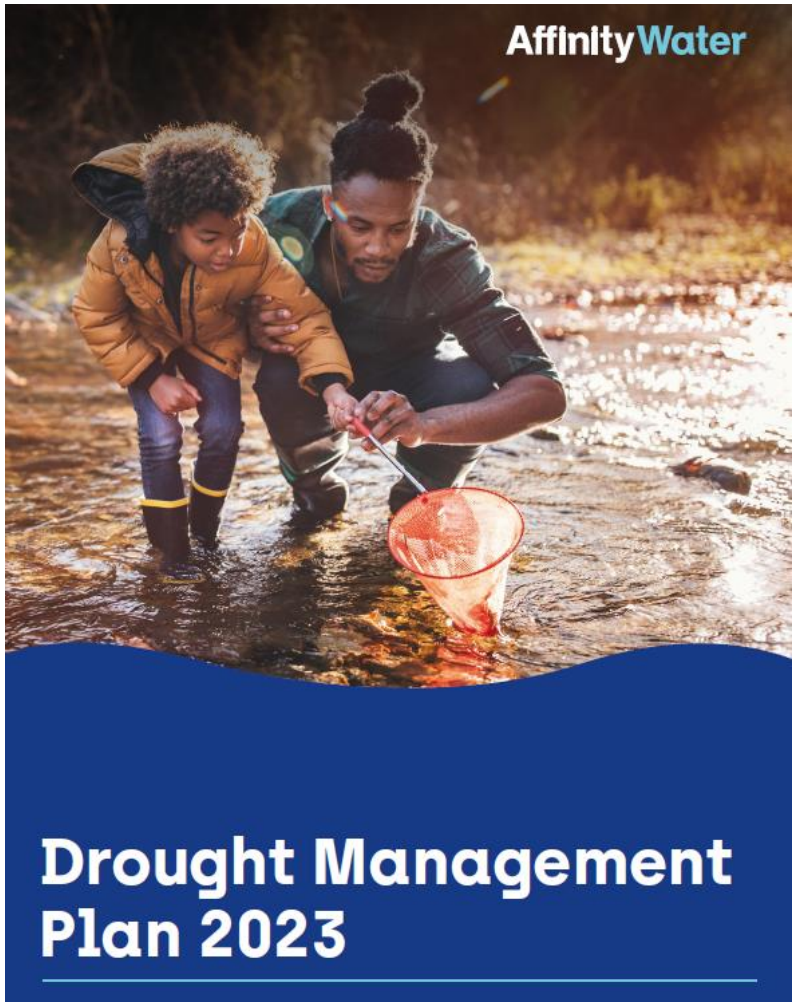
Our Drought Management Plan

- A statutory operational plan, links to WRMP LoS
- Informed by operational and industry experience, regulator guidance and our customers and stakeholder priorities
- Designed to manage a drought of up to 1 in 200 year severity
- A more extreme drought would trigger the Emergency Plan, and would likely involve regional management
- No drought is the same, plan is designed to be adaptable

Drought Management Action	Frequency pre 2024	Frequency post 2024
Temporary Use Ban restrictions	1 in 10 years	1 in 10 years
Demand-side ordinary drought orders restricting non-essential use (also known as non-essential use bans)	1 in 40 years	1 in 40 years
Category 1 supply-side drought permits/drought orders	1 in 40 years – 1 in 100 years	1 in >200 years
Category 2 supply-side drought permits/drought orders	> 1 in 100 years	1 in >200 years
Emergency drought orders	Deemed unacceptable but could be used for short periods of time in localised areas as a result of a civil emergency	Deemed unacceptable but could be used for short periods of time in localised areas as a result of a civil emergency



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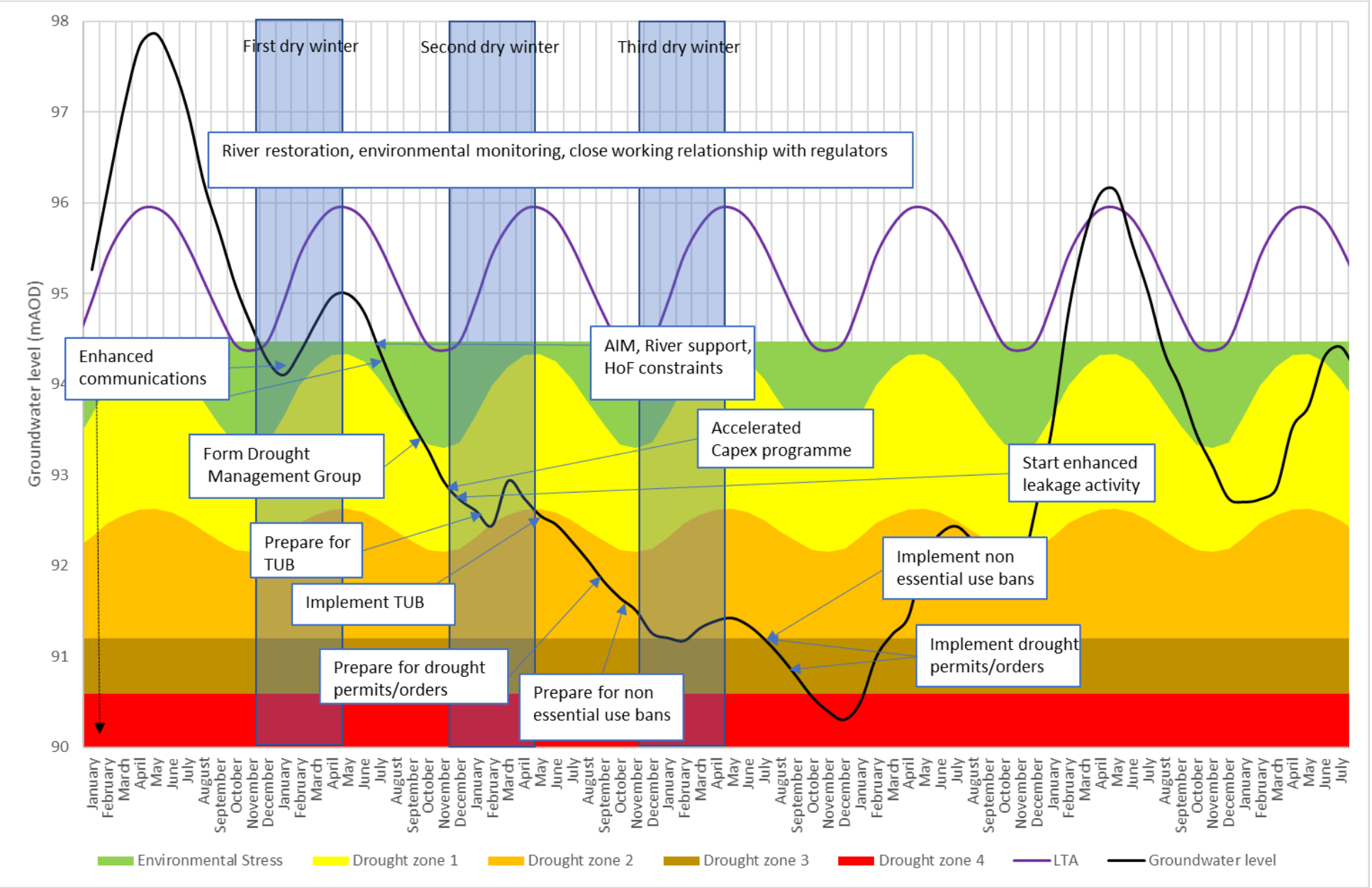
Drought Plan Worked Example



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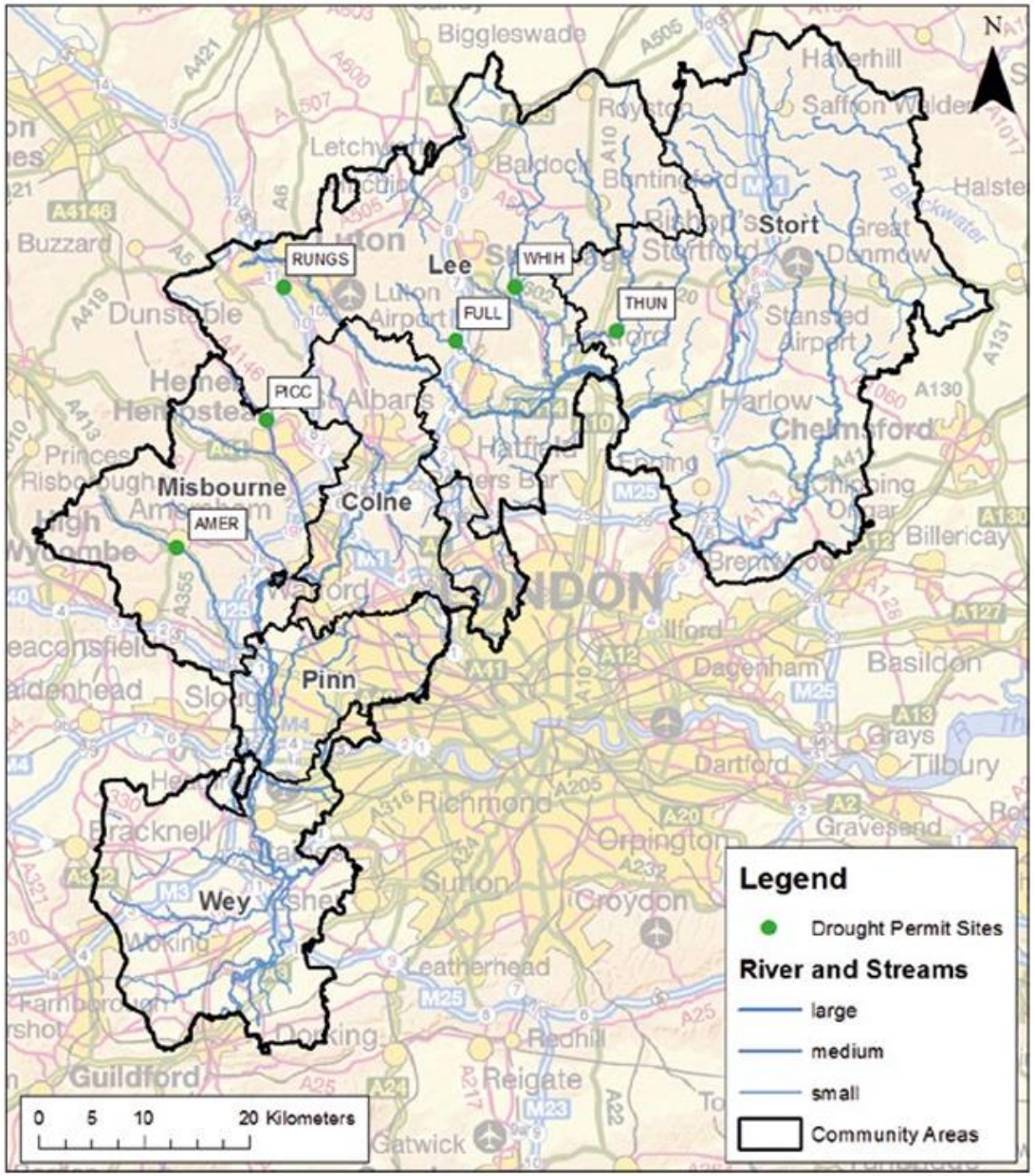
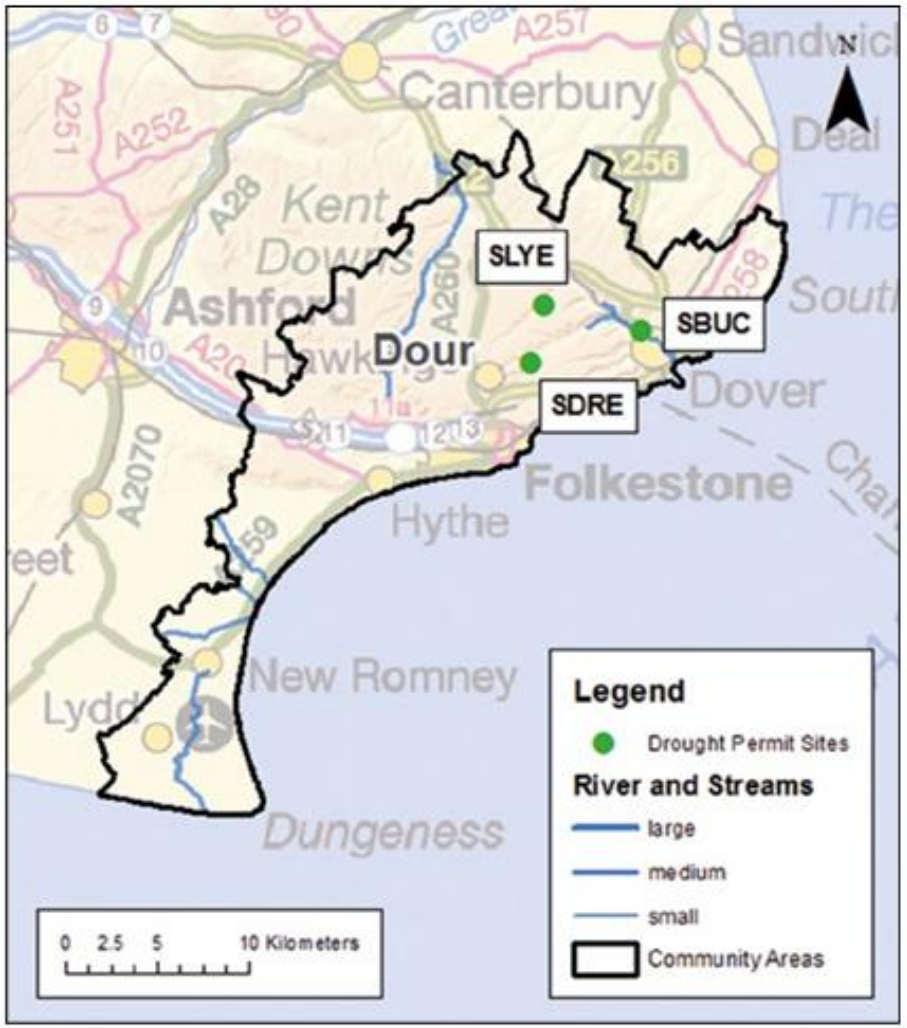
Drought Permits





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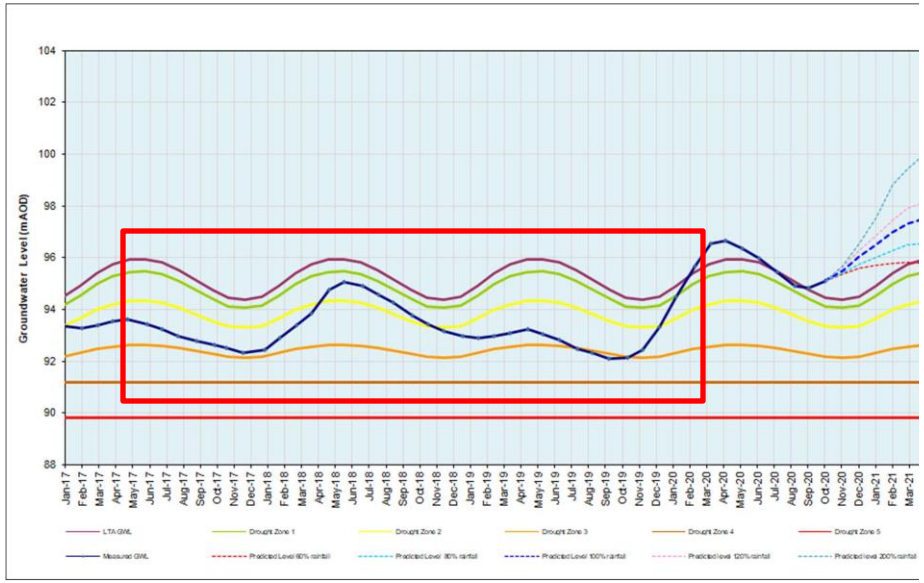
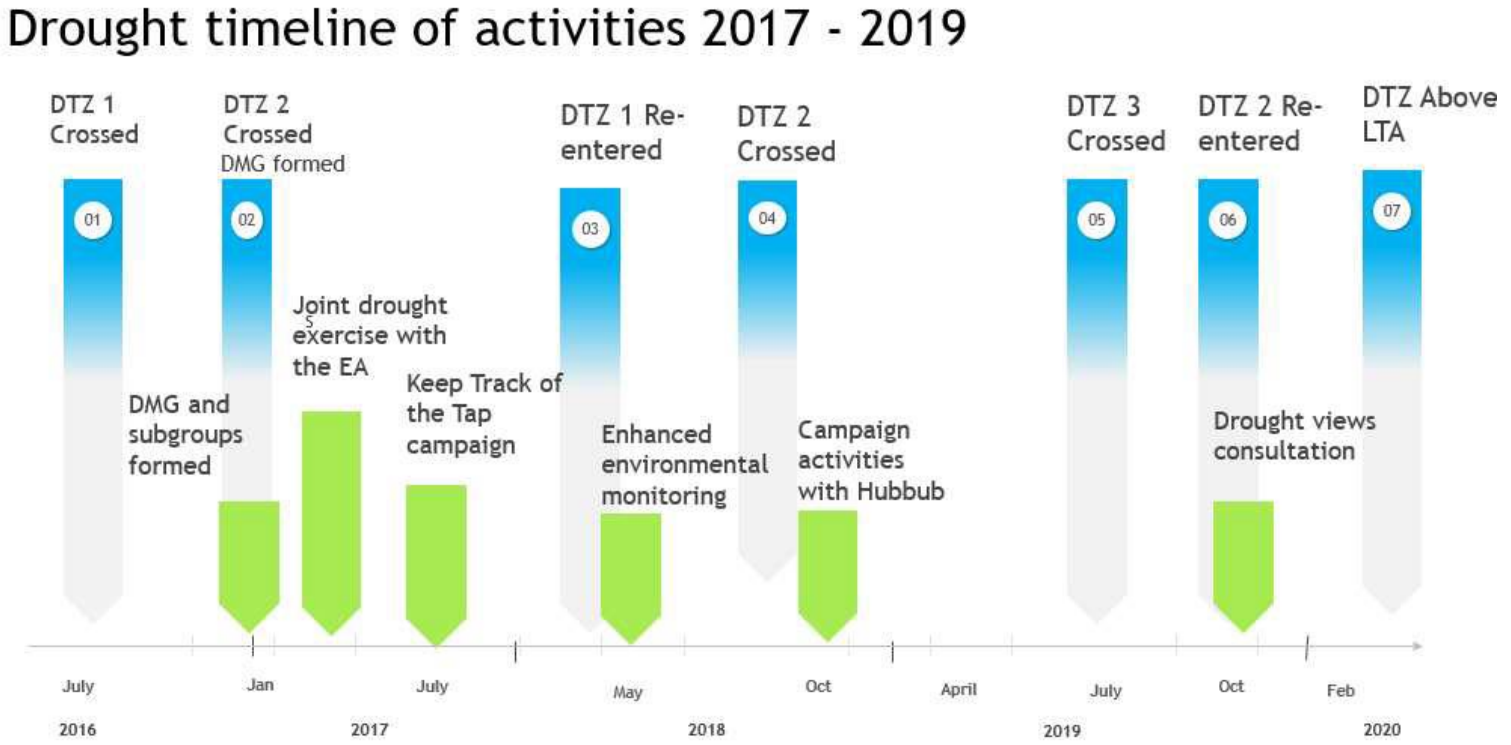
2017-2019: The Groundwater Drought





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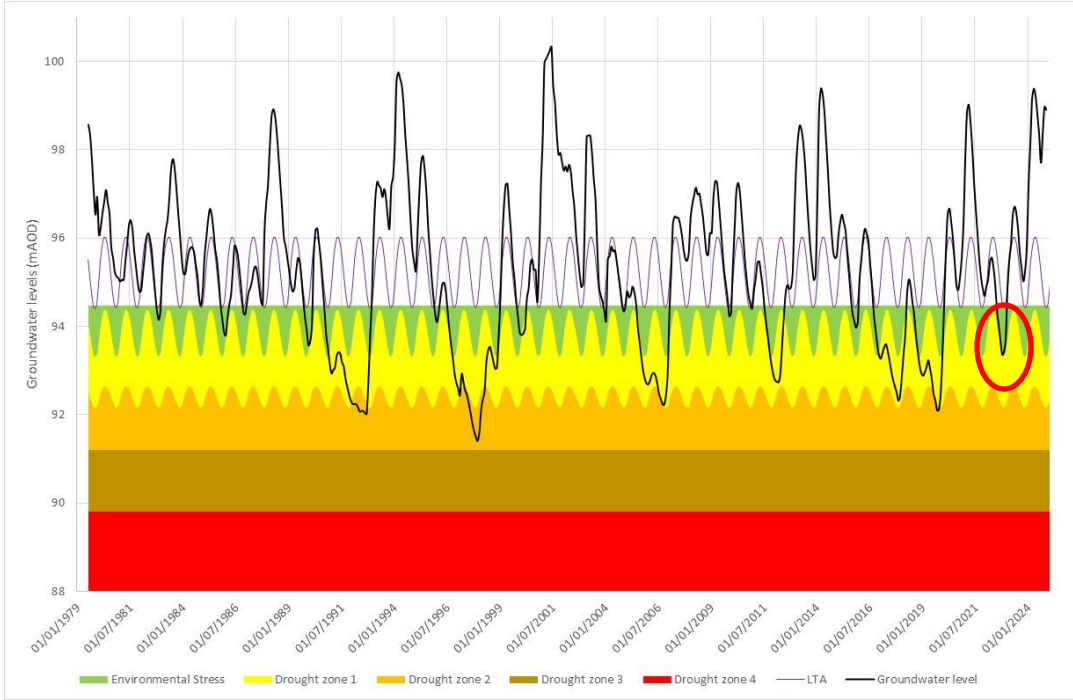
2022 – The Surface Water Drought

Apr 22	May 22	Jun 22	Jul 22	Aug 22	Sep 22	Oct 22	Nov 22	Dec 22	Jan 23	Feb 23	Mar 23	Apr 23
BAU	BAU	BAU	BAU	BAU	1	1	BAU	BAU	BAU	BAU	BAU	BAU
BAU	1	1	1	1	1	1	1	1	1	1	1	1
BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU
BAU	BAU	BAU	1	1	1	1	BAU	BAU	BAU	BAU	BAU	BAU
BAU	BAU	BAU	BAU	1	1	1	1	1	1	1	BAU	BAU
BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU	BAU
BAU	BAU	BAU	BAU	1	1	1	1	BAU	BAU	BAU	BAU	BAU
BAU	BAU	BAU	BAU	1	1	BAU	BAU	BAU	BAU	BAU	BAU	BAU
BAU	1	1	1	2	2	1	BAU	BAU	BAU	BAU	BAU	BAU
BAU	1	1	1	2	2	1	BAU	BAU	BAU	BAU	BAU	BAU
BAU	1	1	1	1	2	2	1	BAU	BAU	BAU	BAU	BAU
BAU	BAU	BAU	1	1	2	2	2	1	1	2	2	1
BAU	BAU	1	1	1	1	1	1	BAU	BAU	BAU	BAU	BAU
BAU	1	1	2	2	2	2	2	2	2	1	1	BAU
BAU	BAU	BAU	1	1	2	1	BAU	BAU	BAU	BAU	BAU	BAU
BAU	BAU	1	1	1	1	1	BAU	BAU	BAU	BAU	BAU	BAU
BAU	BAU	1	1	2	2	2	2	1	BAU	BAU	BAU	BAU



- Definition of Resilience
- In a 2022 type drought, which sources of supply would be more resilient?
- What is the role of groundwater going forward?
- What about the Sustainability Reductions? Should there be cessations?

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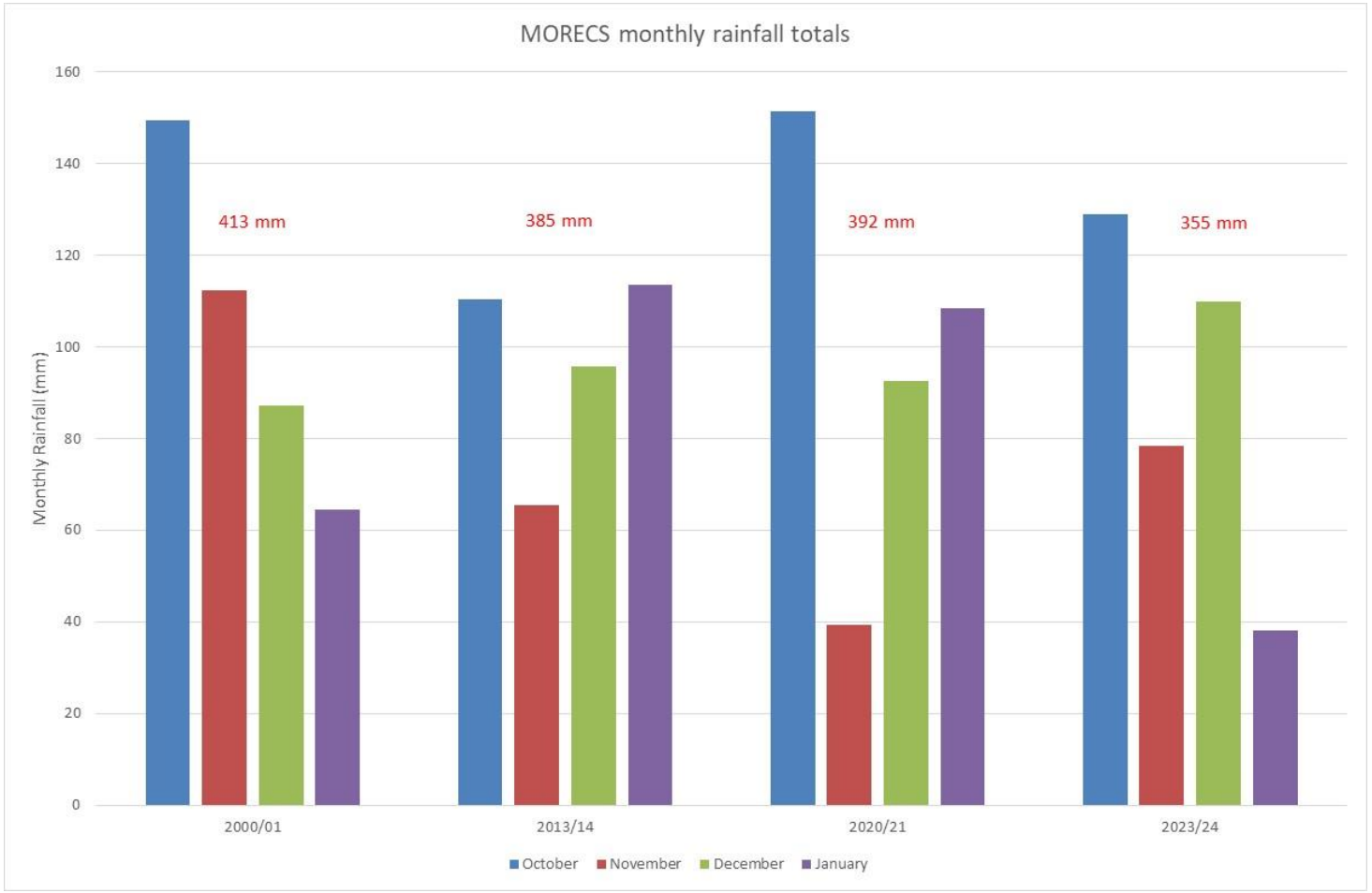
The other side of the spectrum – Floods

- We operate almost 250 boreholes across over 100 pumping stations
- The majority of these are in river valleys, where groundwater levels are close to the surface
- This means that some locations and sites are prone to being inundated by rising groundwater levels, following prolonged above average rainfall, usually during the winter period
- Such events occurred in 2001, 2014, 2021 and 2024, following very wet winters



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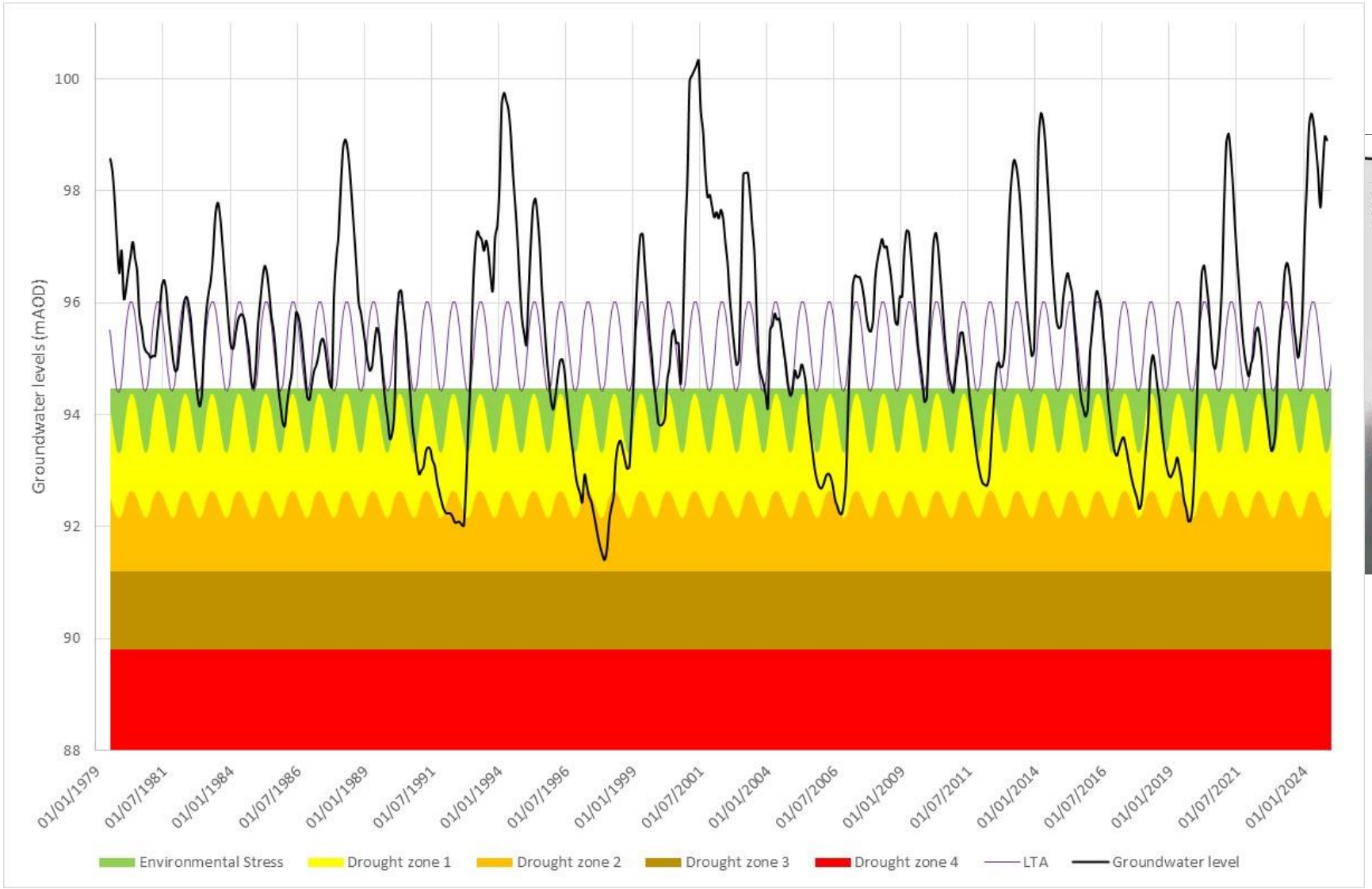
Where are we now? Out of the woods?



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Flooding impacts

- Inundation of the site, making access difficult and creating trip hazards
- Boreholes going artesian when pumps stop (if headworks are not sealed) potentially flooding below ground chambers and re-introducing the flooded water into the borehole upon pump start up (WQ issues)
- Floodwater damaging low lying equipment
- Potential water quality implications for the raw water which may impact treatment capability (e.g. pollutant mobilisation, turbidity increases or changes that adversely impact coagulation)

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Flooding impacts

Impacts during flood conditions

- Rainfall patterns (amount and intensity) determine groundwater flooding occurrence and duration
- GW abstraction does not have a widespread effect as cone of depression shrinks during high GWLs
- The WQ in PWS sources can be at risk due to sewer overflows, so appropriate measures need to be taken to mitigate this risk
- Issues with high nitrate concentrations that typically occur after groundwater levels peak, due to travel time in the aquifer and "piston effect".

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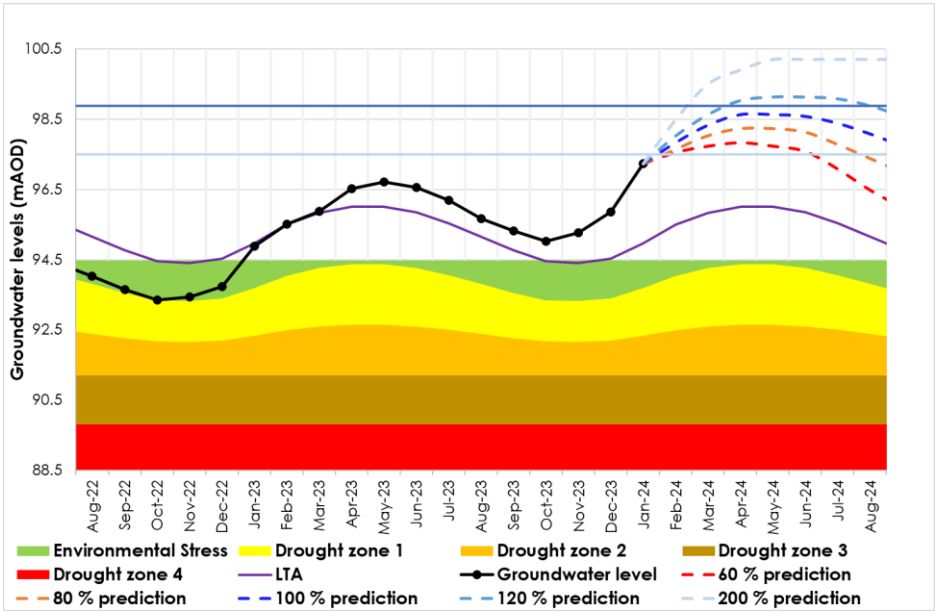
Flood zones 1 & 2

Zone 1: We need to operate at a heightened state of alert

- Issue fortnightly groundwater level briefings with risk assessments
- Undertake a monthly check of production site groundwater levels using alarms on telemetry
- Notify Ops teams when GWLs reach 0 mBHP in non-pumping conditions
- Undertake checks to ensure headworks are sealed at high risk sources

Zone 2: Groundwater flooding is likely

- Issue weekly GWL briefings with risk assessments
- Form an incident team to monitor the situation
- Undertake a fortnightly check of production site groundwater levels using alarms on telemetry
- Run pumps 24/7 if required and make sources baseload
- Reconfigure supply network



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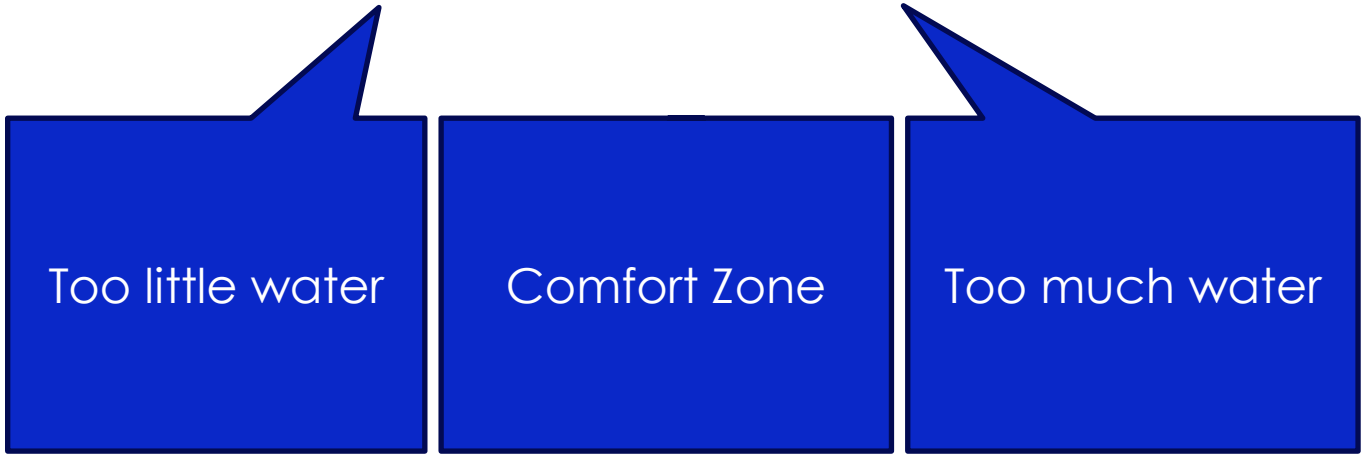
Conclusions & Recommendations

- Droughts that have different characteristics (magnitude, duration)
- Extreme events that seem to occur more frequently
- Changing climate affecting both supply & demand
- Need to maintain & enhance **resilience**
- **New sources** of supply and **transfers** to balance GW reductions where required
- **Adaptability** is key to weather extremes
- **Conjunctive use** of GW & SW to allow optimisation
- **Flexible abstraction licensing regime** would be key



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Thank you for listening – Questions?

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Forecasting groundwater levels

Ineson Lecture 2024

November 2024 (London)

Agenda

1 **Water System Analysis**

…Horse Traits?

2 **Example 1: Drought 2018**

2018: Forecasting ground water recovery

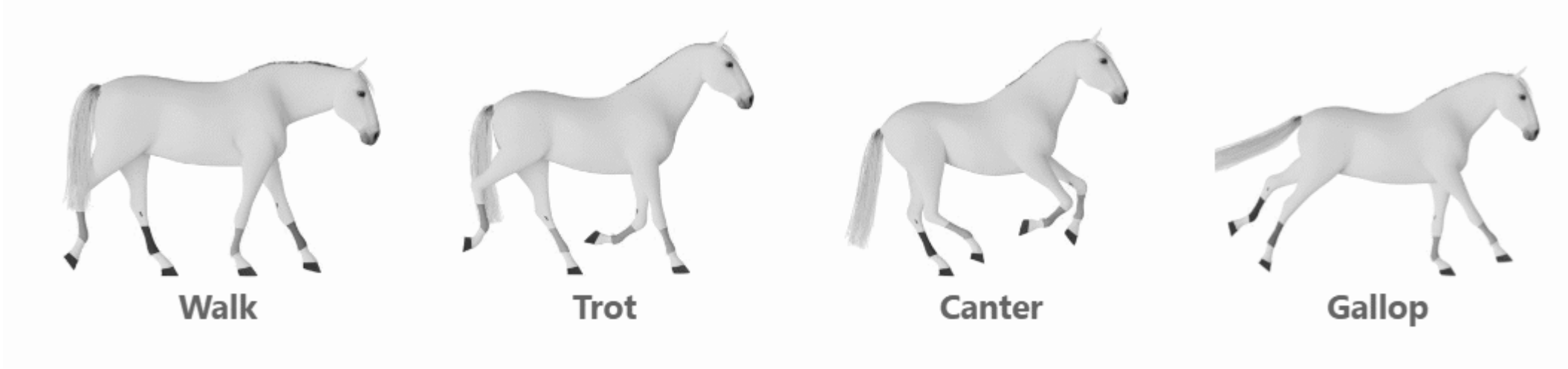
3 **Example 2: Storage Deficit**

Is ground water level a good predictor for storage capacity?
Smart (ground water based) management to prevent flooding

4 **Overall Conclusions**

The importance of fully understanding the groundwater system

1. Water System Analysis
Horse traits?



Several analyzing methods and most ground water models are validated for ‘Normal Circumstances’

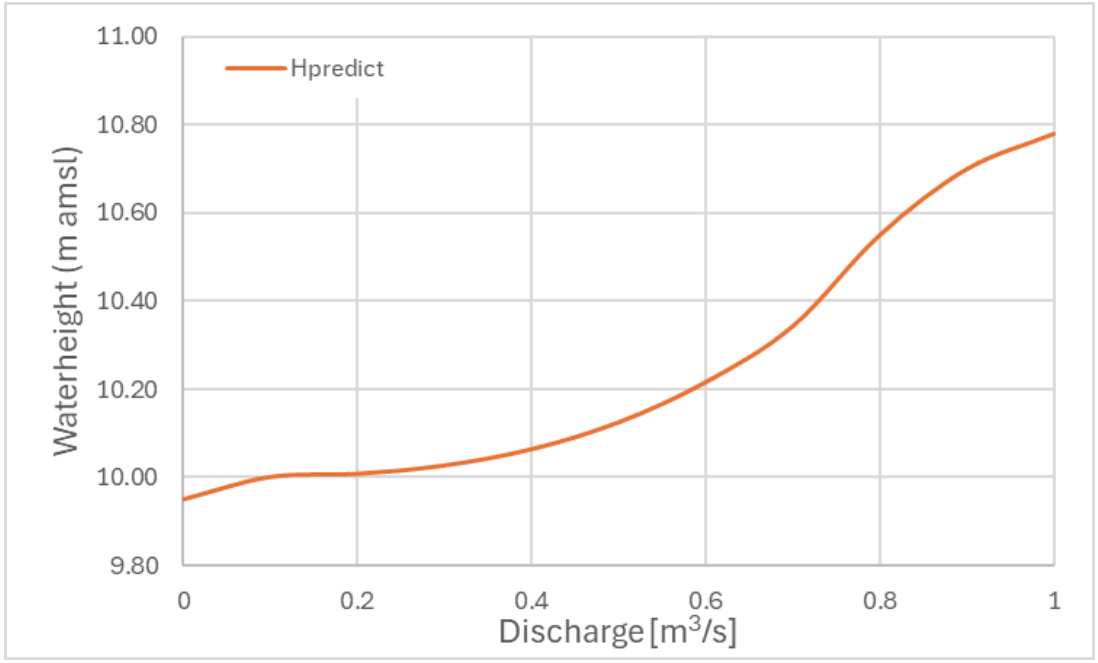
During extremes (Drought, Severe Precipitation), other processes apply!

Theo N. Olsthoorn (Emeritus Professor TU Delft): *… compare this with horse traits… Using a common model will misfit during extreme circumstances because of neglecting important physical processes.*

1. Water System Analysis

Example extreme weather event 2010

The culvert is dimensioned for normal up to high discharge…

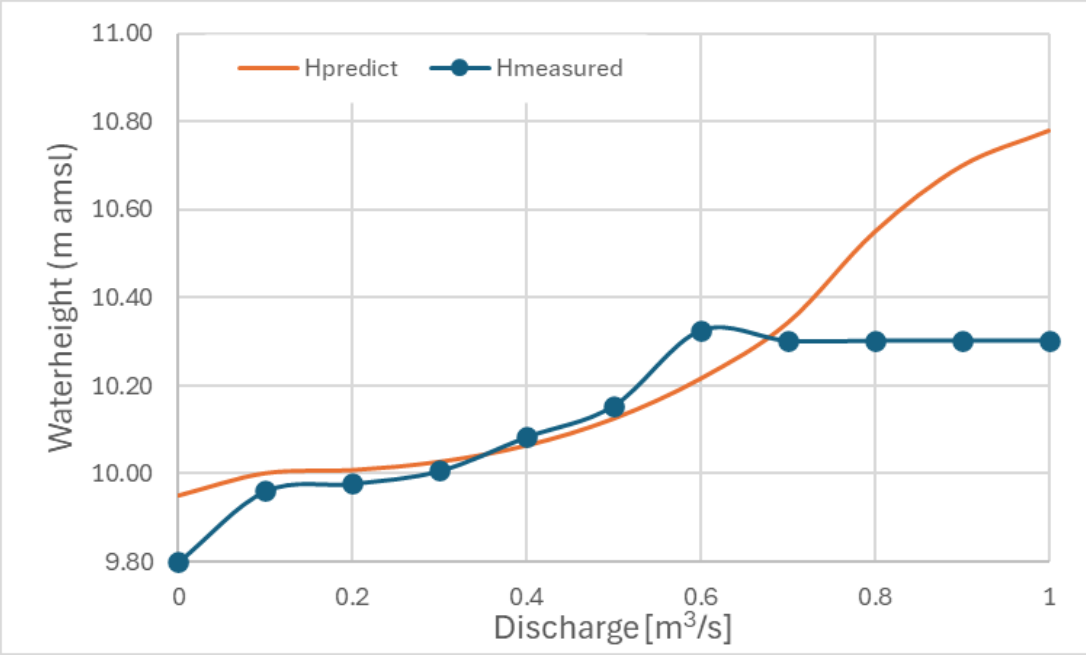


1. Water System Analysis

Example extreme weather event 2010

… but during extreme discharge, the river floods the road.

This also means that water levels do not rise any further. The normal Q → h relations is no longer valid



2. Example 1: Drought 2018

After sunshine comes… Drought!

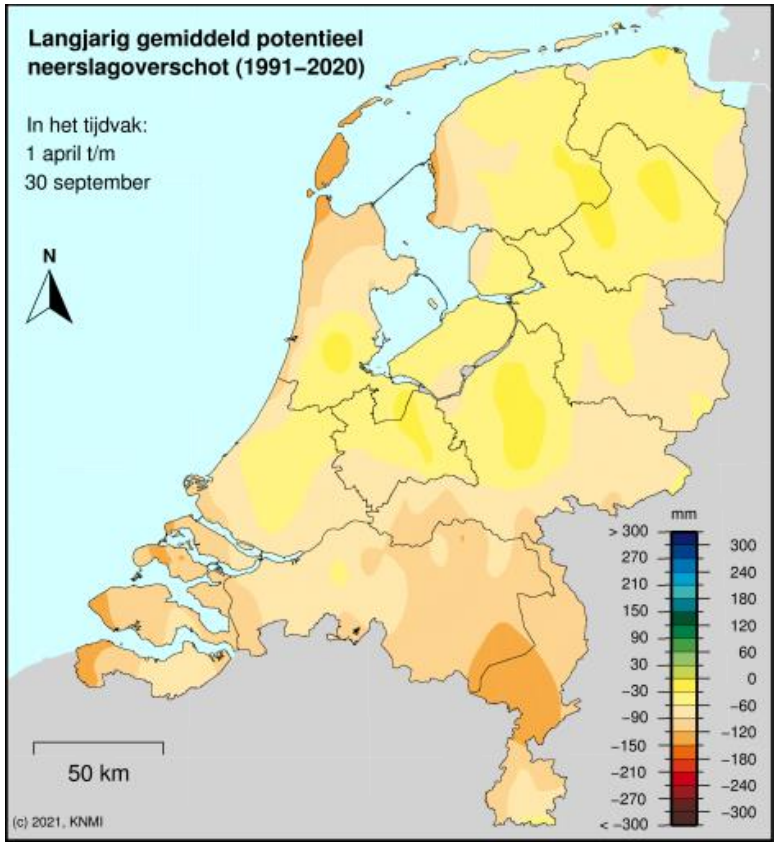
2. Example 1: Drought 2018

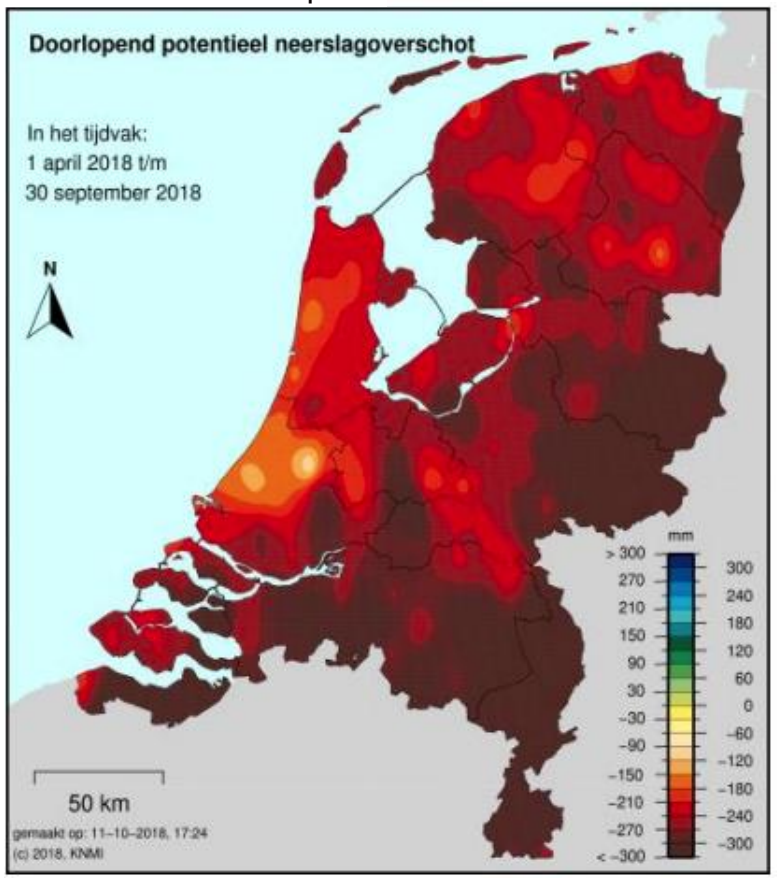
After sunshine comes… Drought!

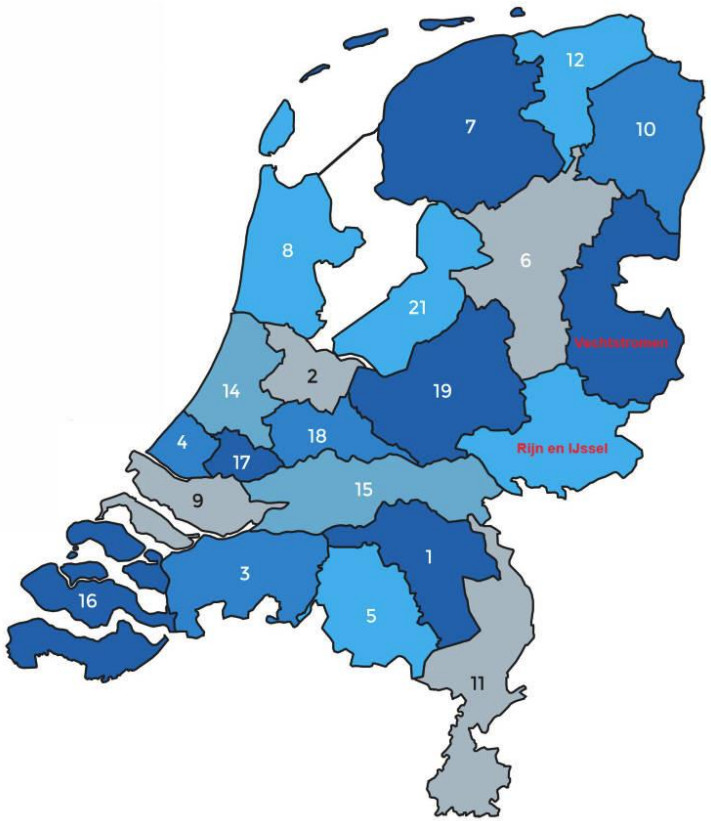
On average: ~100mm *(deficit)*

In 2018: ~300mm *(deficit)*

Cumulative potential precipitation surplus: $P - Et_{pot}$







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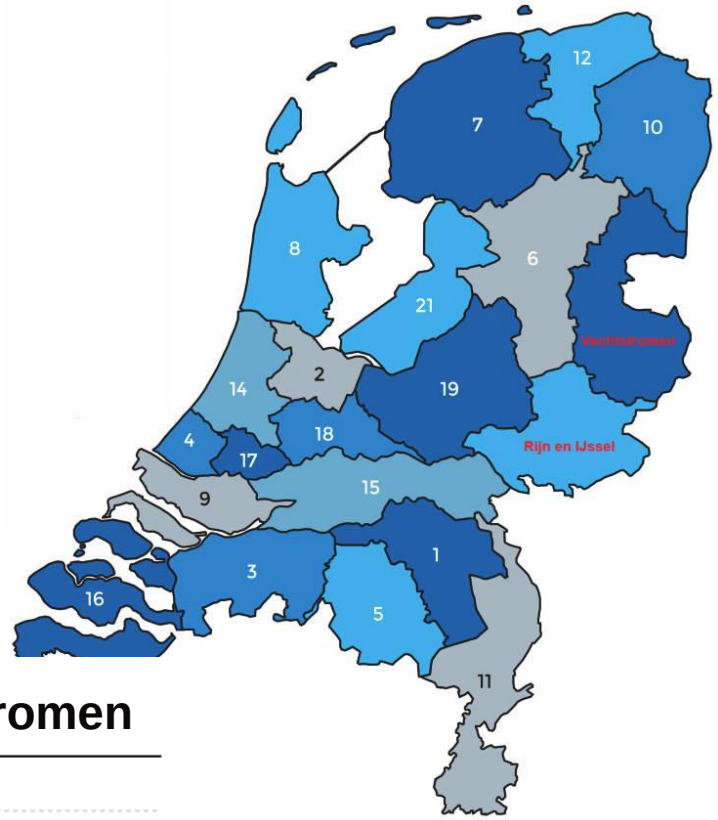
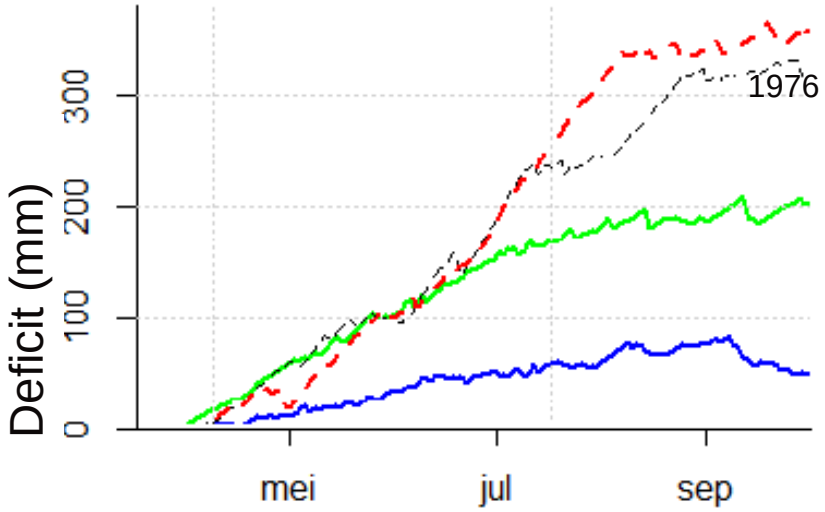
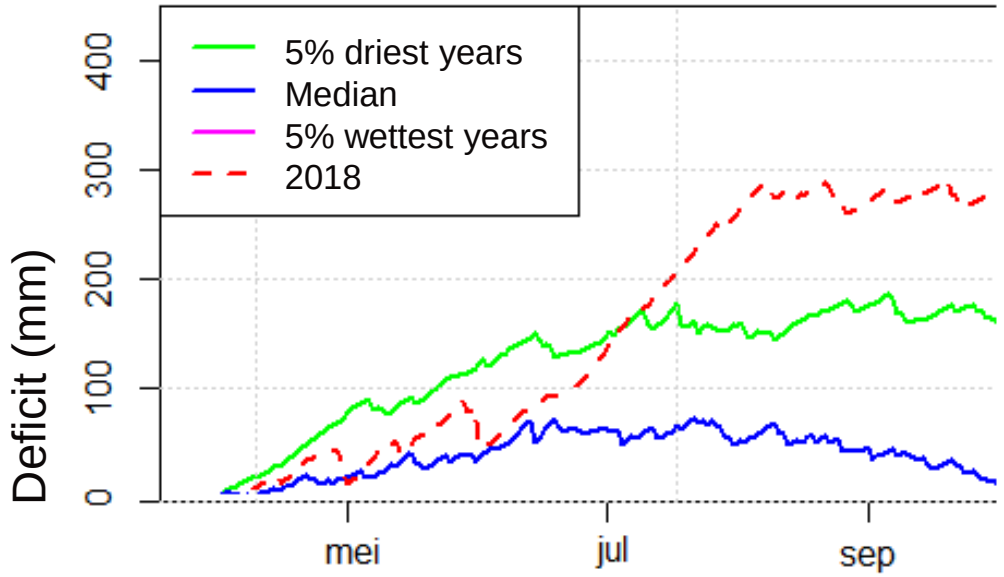
After sunshine comes… Drought!



Precipitation Surplus Ws Rijn en IJssel

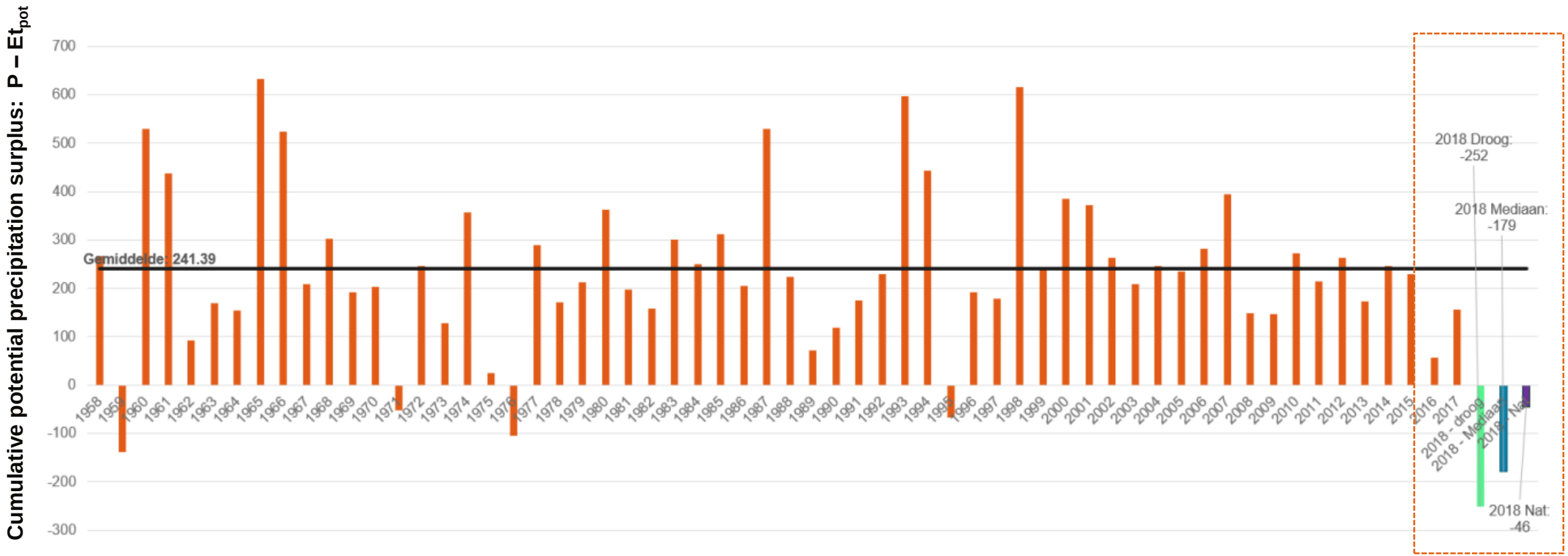


Precipitation Surplus Ws Vechtstromen



2. Example 1: Drought 2018

After sunshine comes… Drought!



2. Example 1: Drought 2018

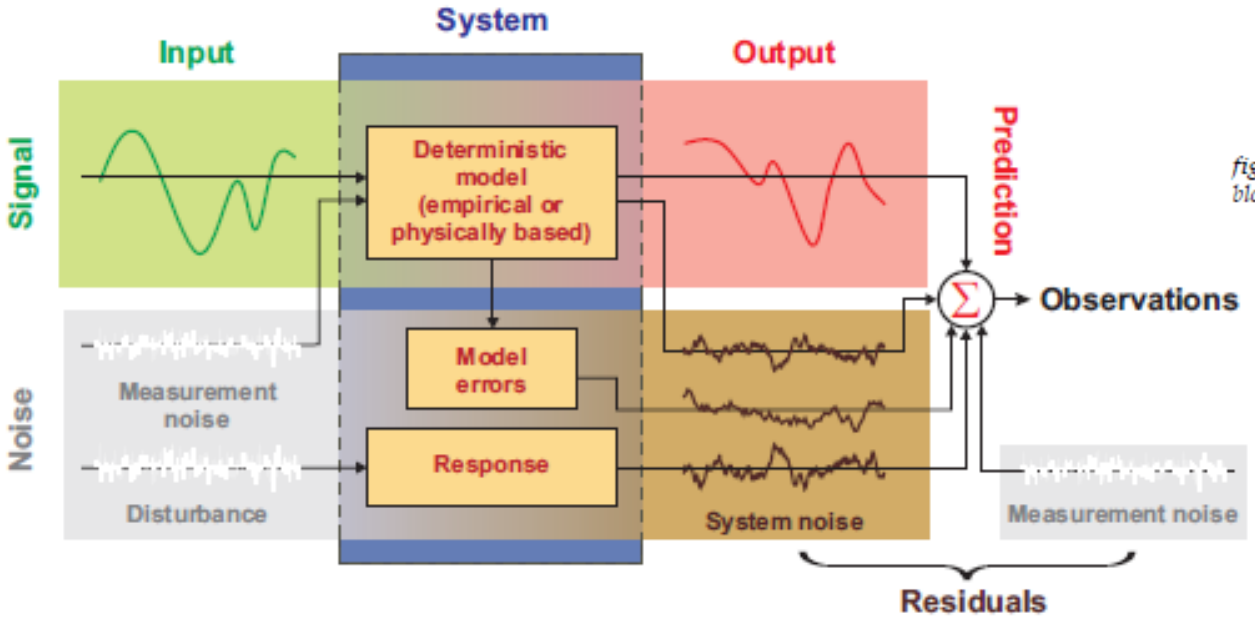


figure 2.10: Sources and effects of noise in models of (linear, open) systems.

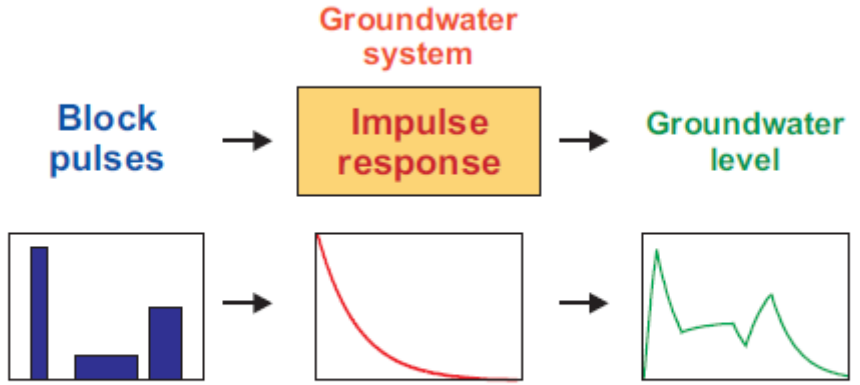
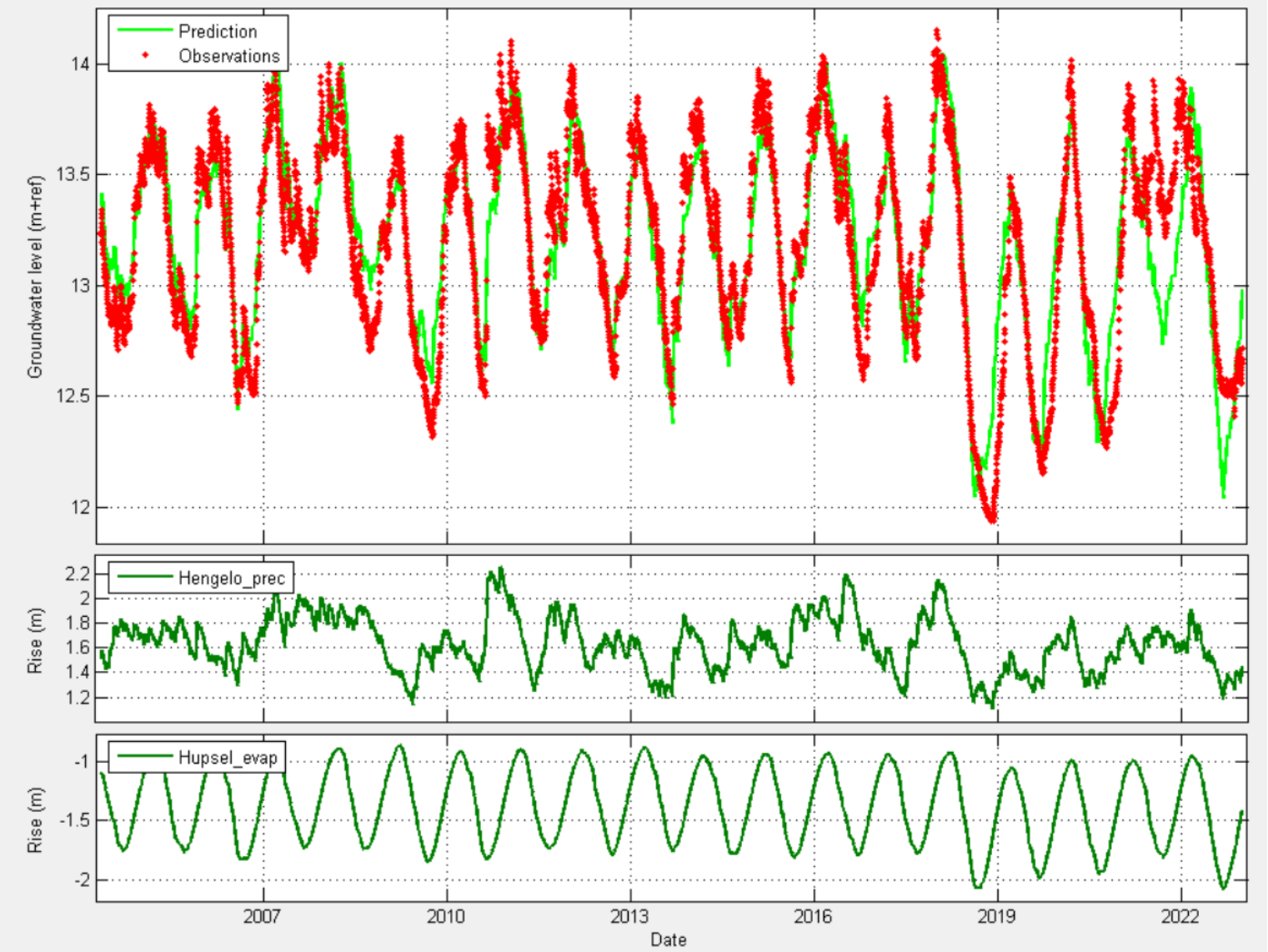


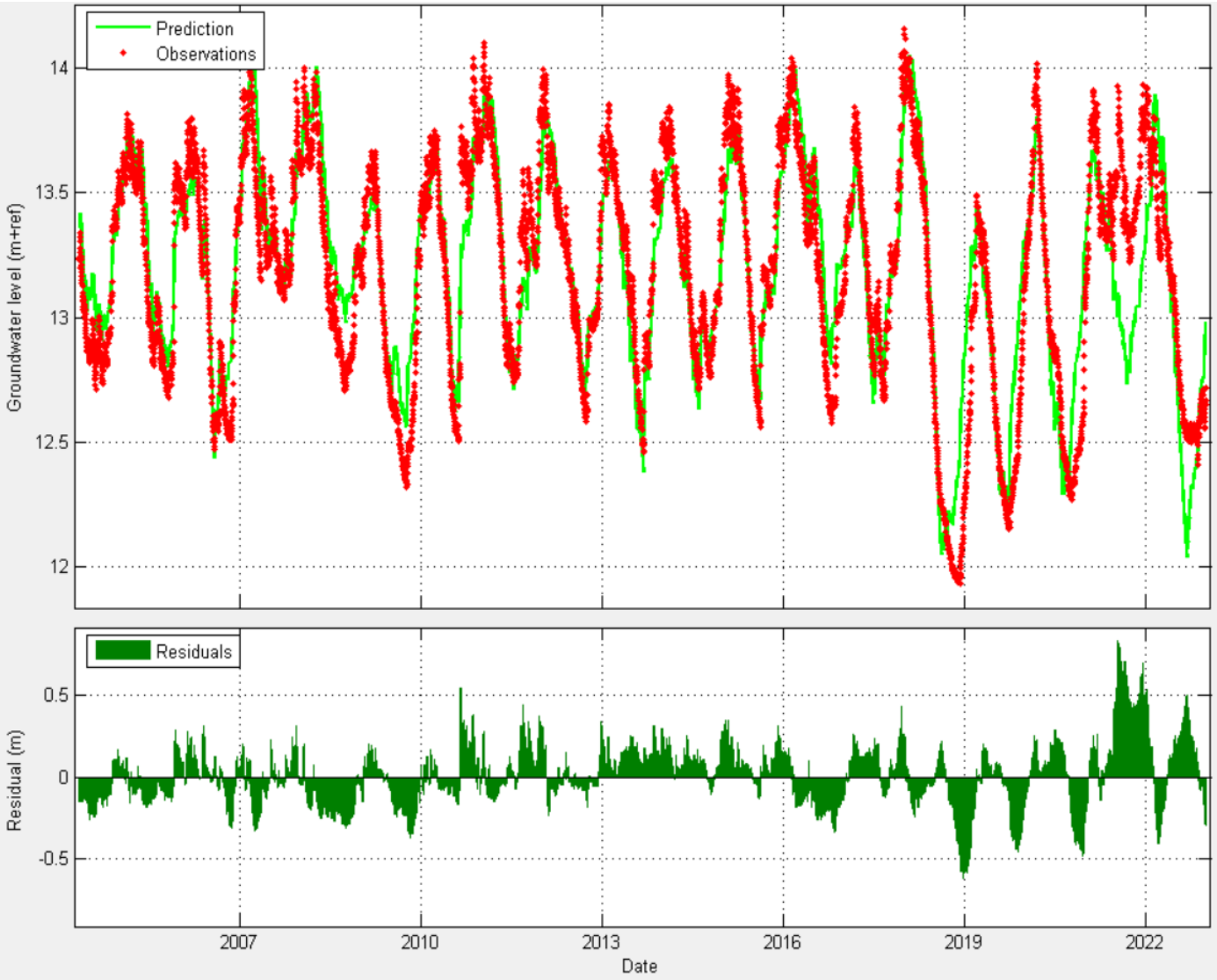
figure 2.14: Transformation of input to output in case of an exponential impulse response and three block pulses of different height and duration.

Jos van Asmuth (2012): *Groundwater System Identification through Time Series Analysis*

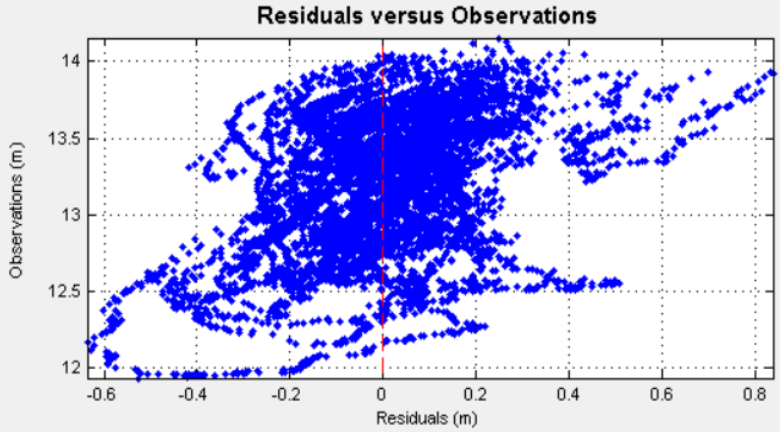
2. Example 1: Drought 2018



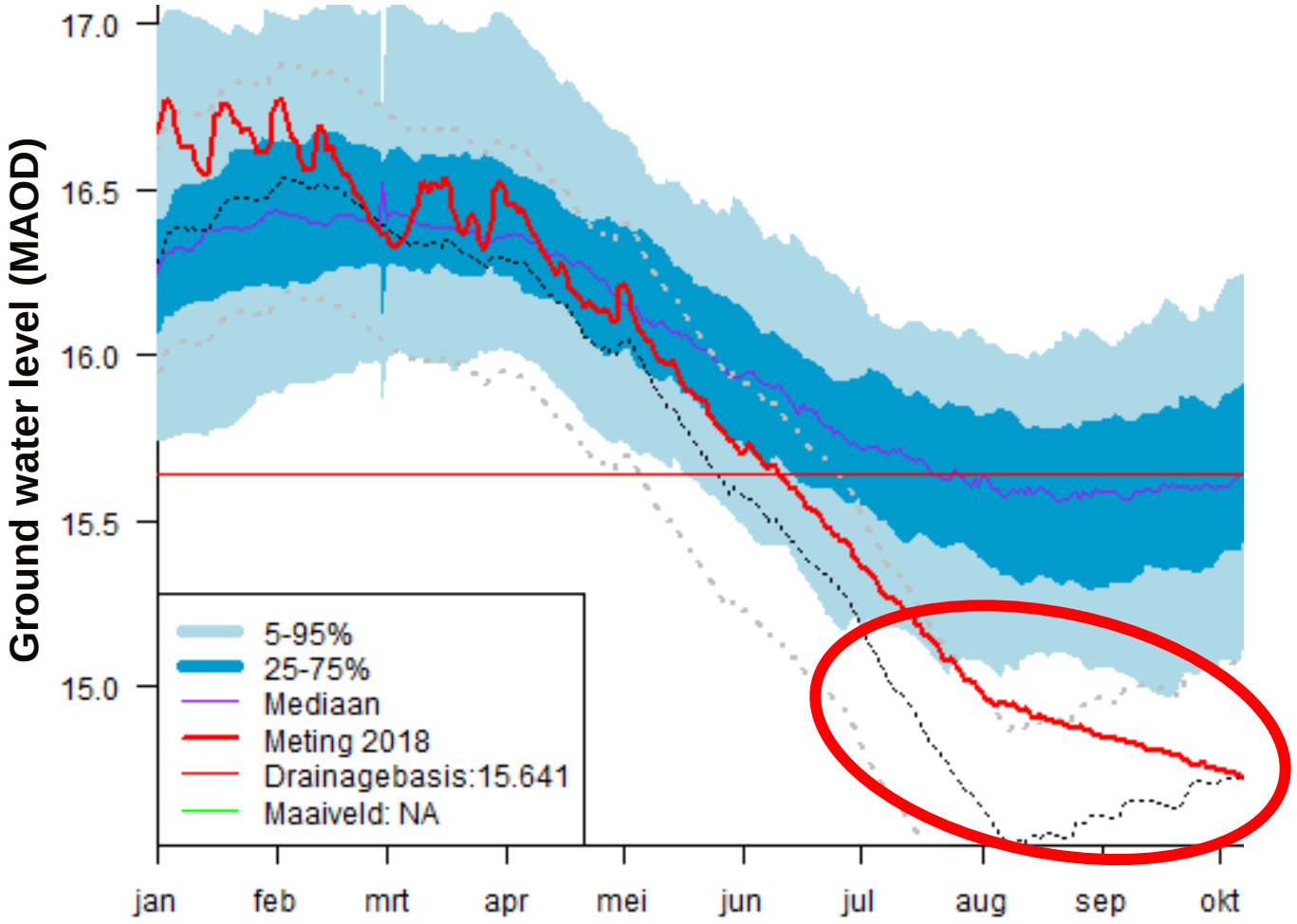
2. Example 1: Drought 2018



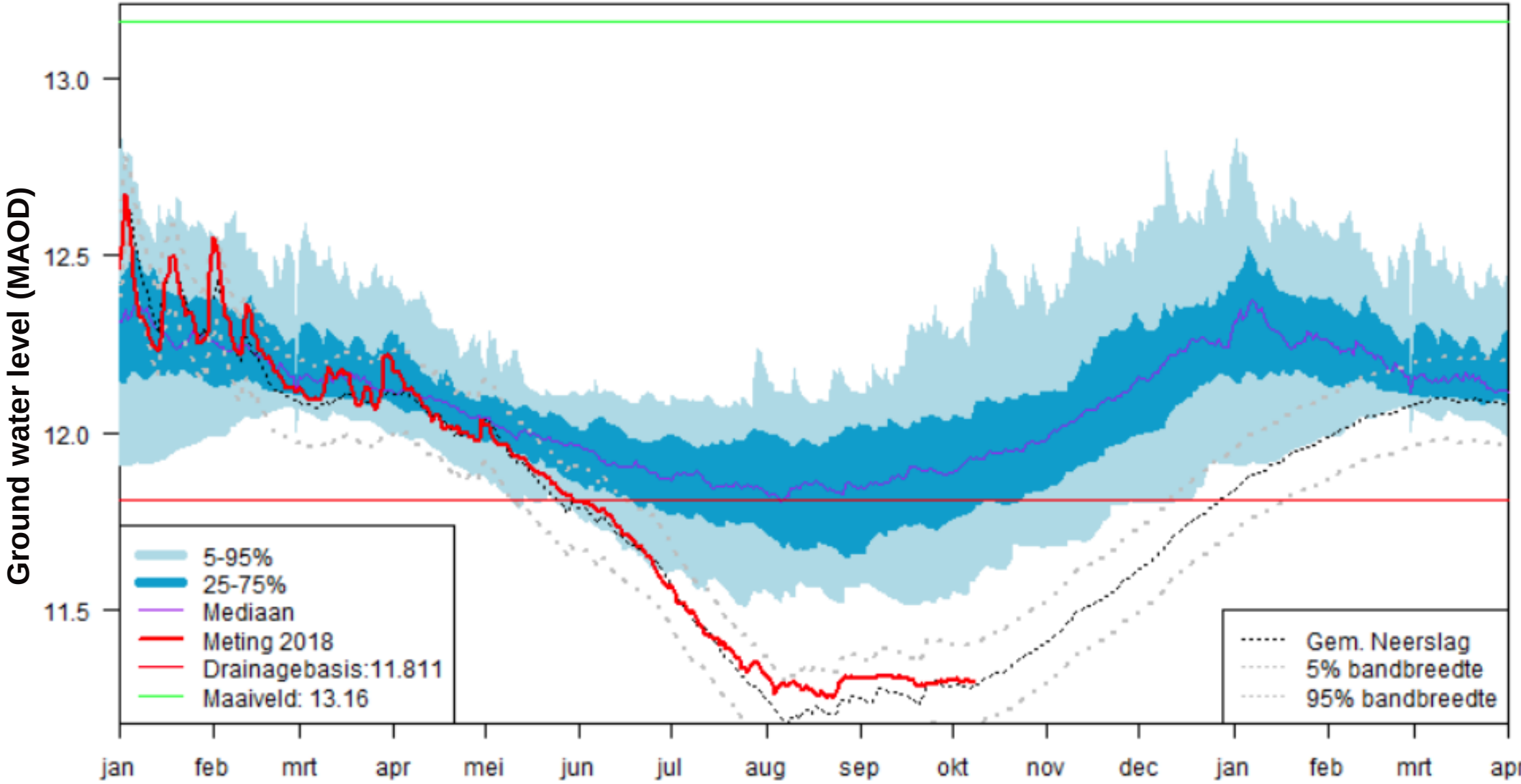
1	**Explained Var (%)**	82.03	
2	**Mean Abs Error (cm)**	14.5	
3	**RMSE (cm)**	19.2	
4	**Drainage level (m)**	12.9	
5			
6	**Factor**	**Parameter**	**2*sdev**
7	PREC M0	749.4	22.8
8	PREC MU	168.0	6.4
9	Evaporation factor	1.10	0.04



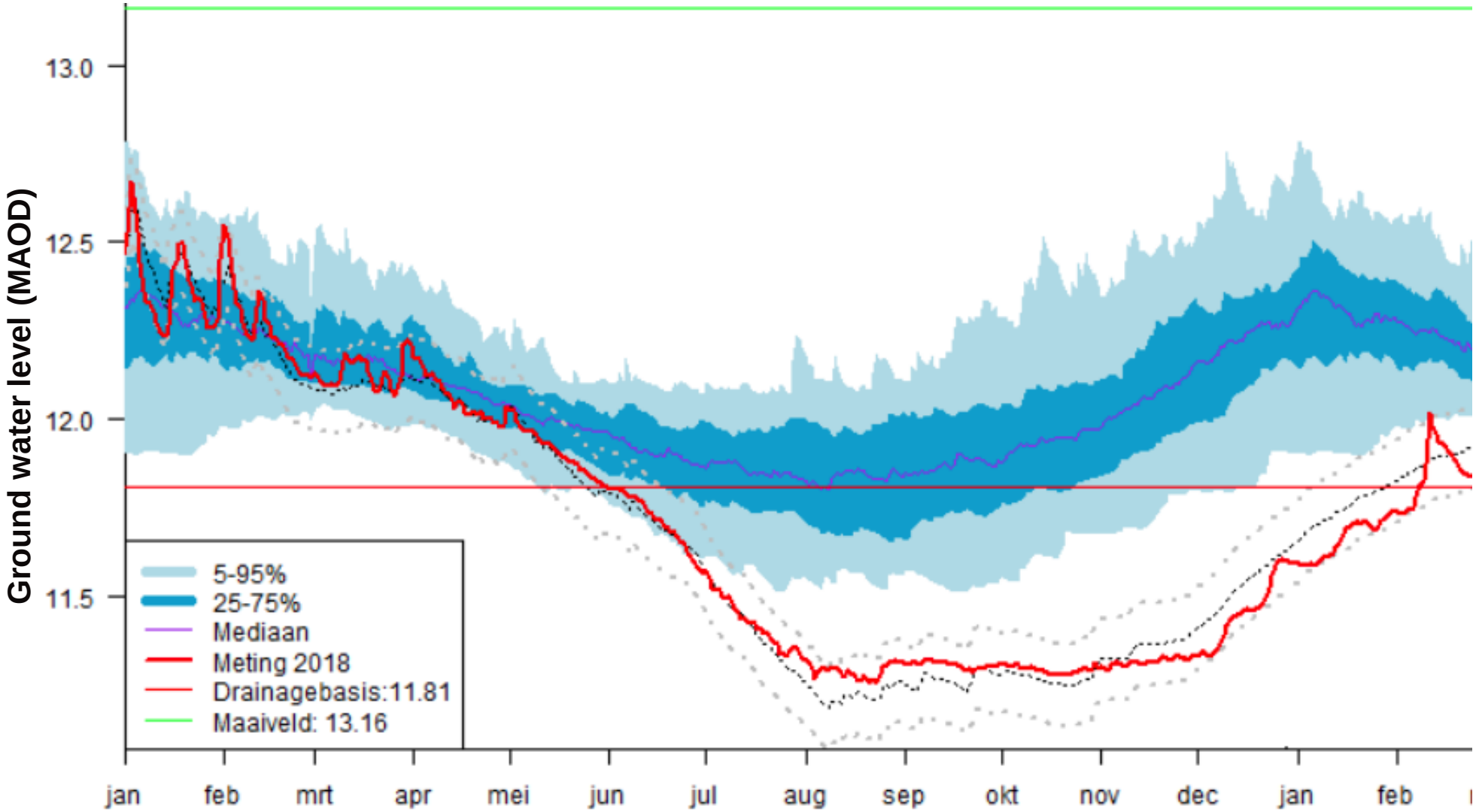
2. Example 1: Drought 2018



2. Example 1: Drought 2018



2. Example 1: Drought 2018



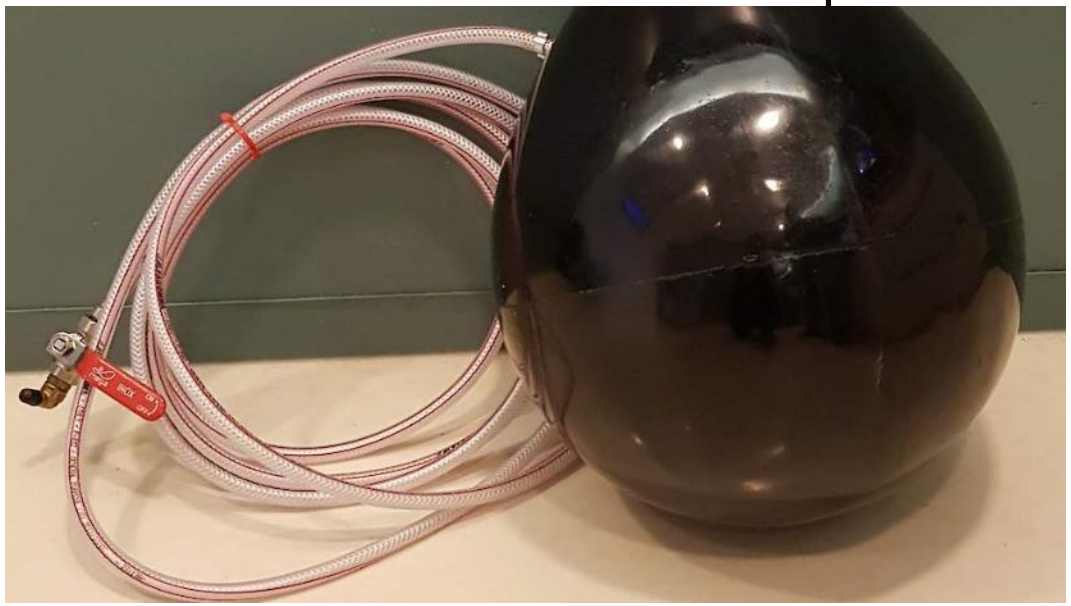
2. Example 1: Drought 2018

Conclusions

The extreme drought resulted in lower ground water levels and ground water reserves.

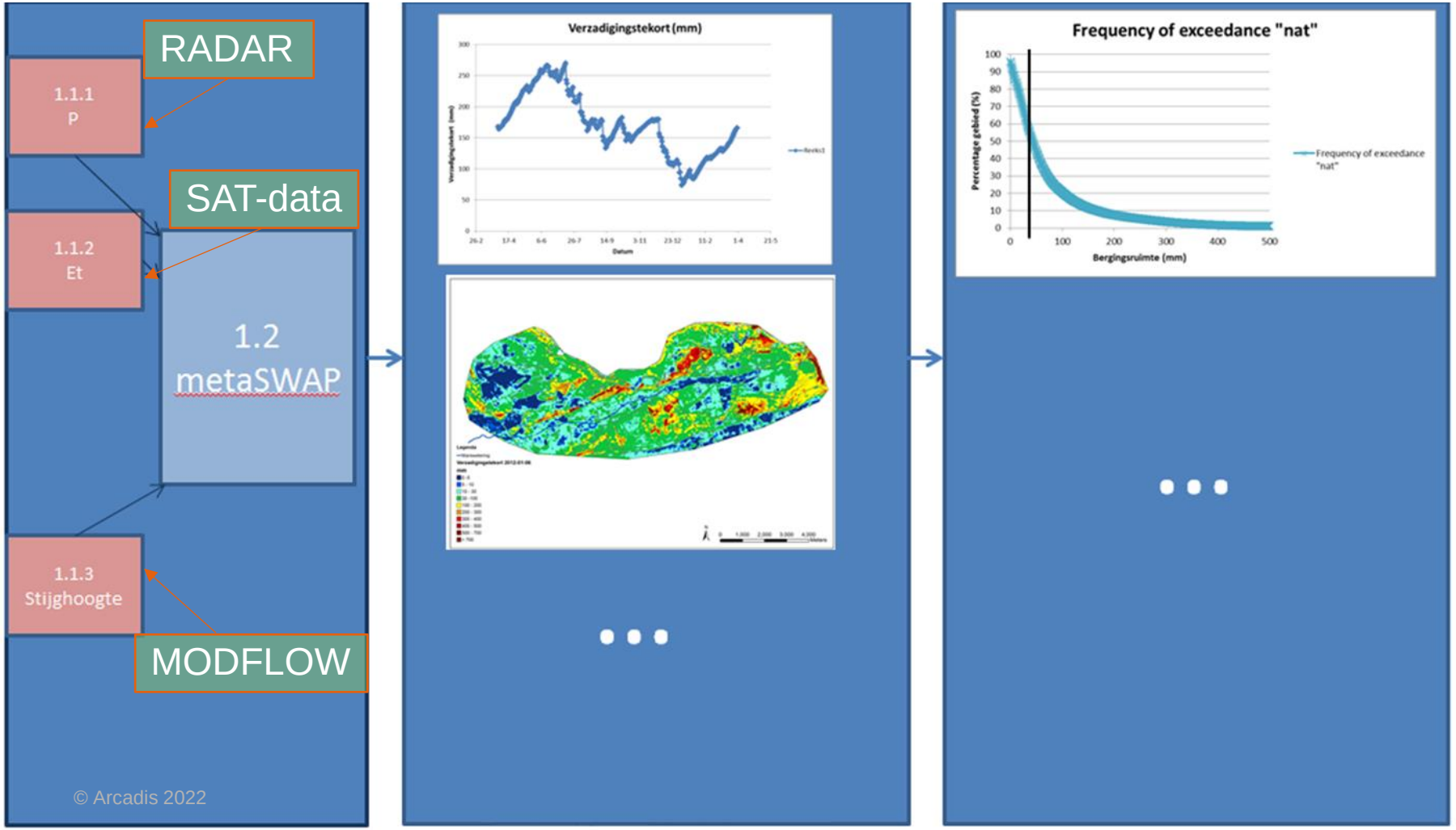
→ The forecast indicated a dry to very dry start of the next growing season, even after wet winter conditions!

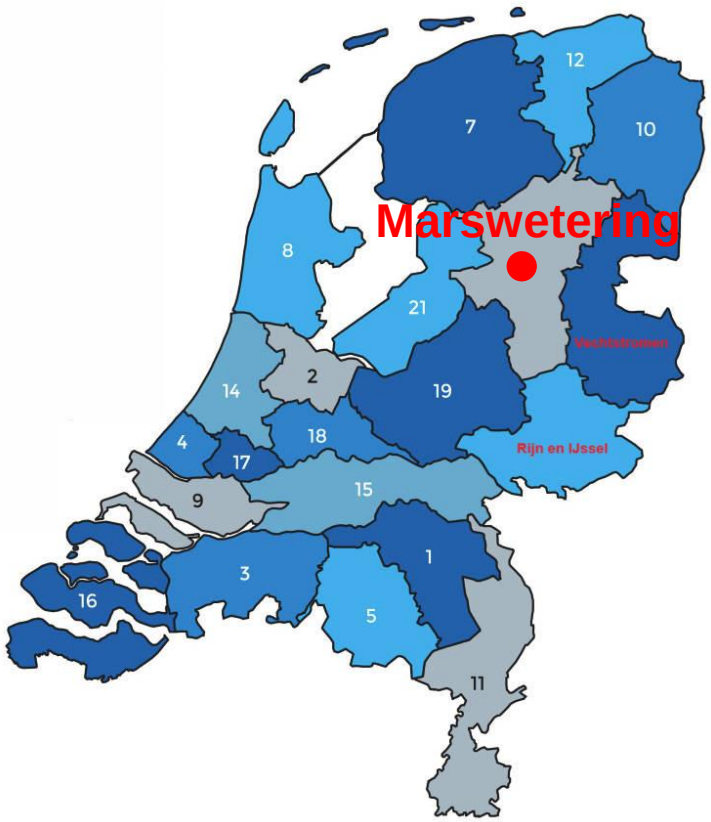
The waterboard was advised to preserve as much (precipitation)water as possible.



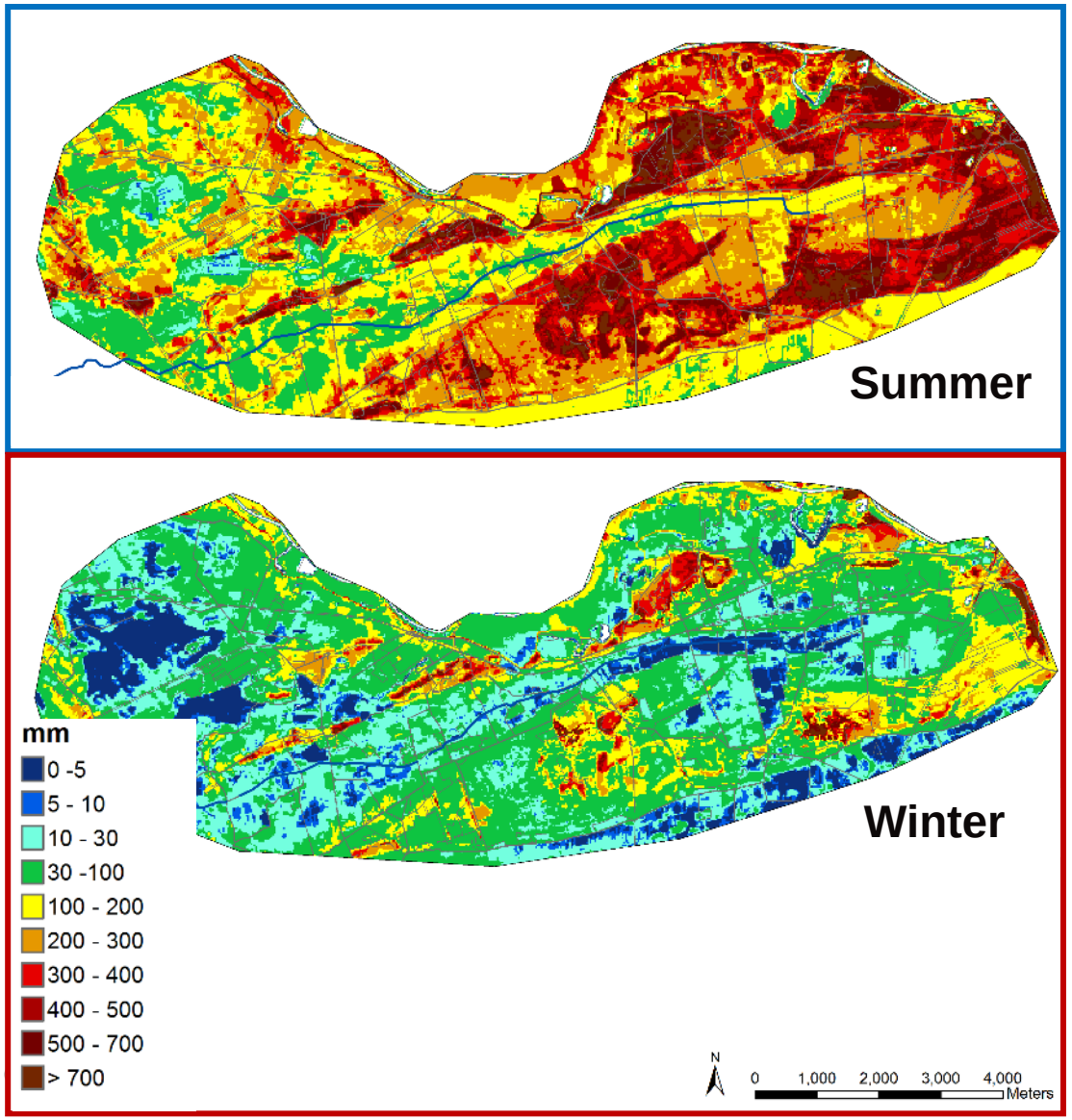
3. Example 2: Storage Deficit

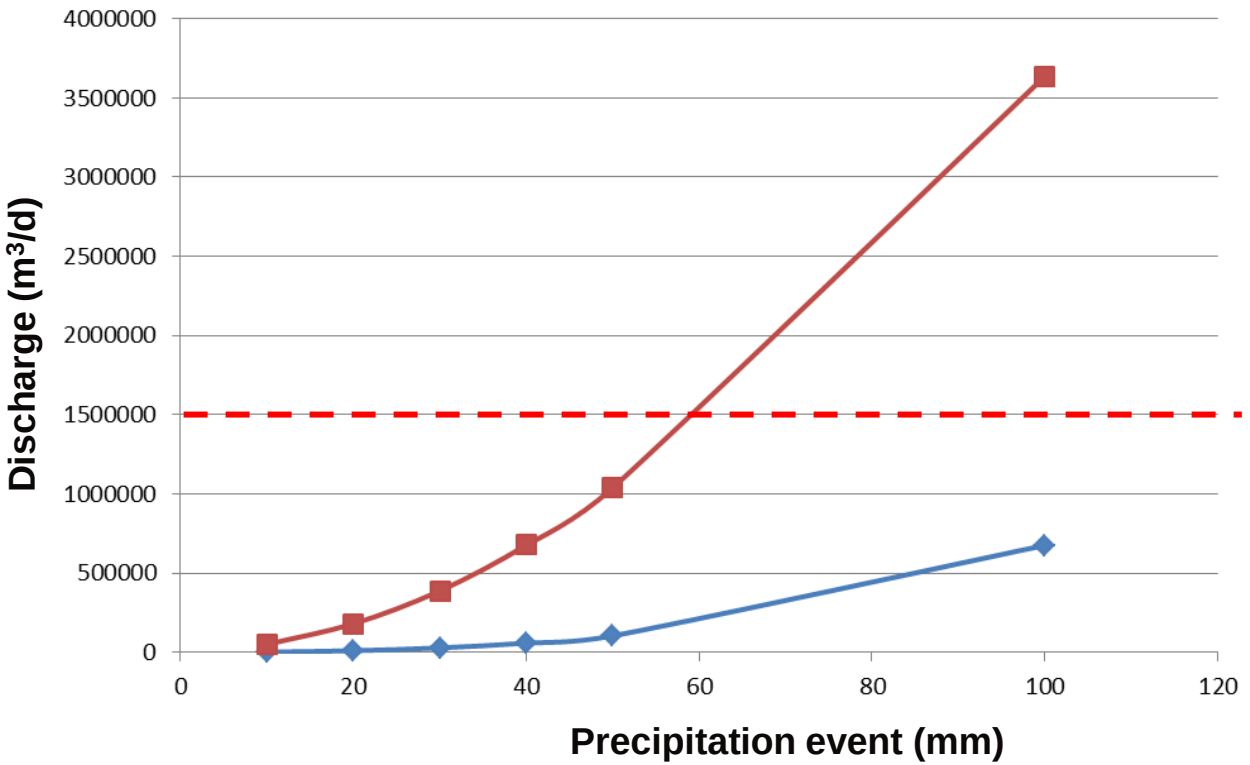
1. Model (now casting) **2. Interpretation and presentation** **3. Accumulation (fore casting)**





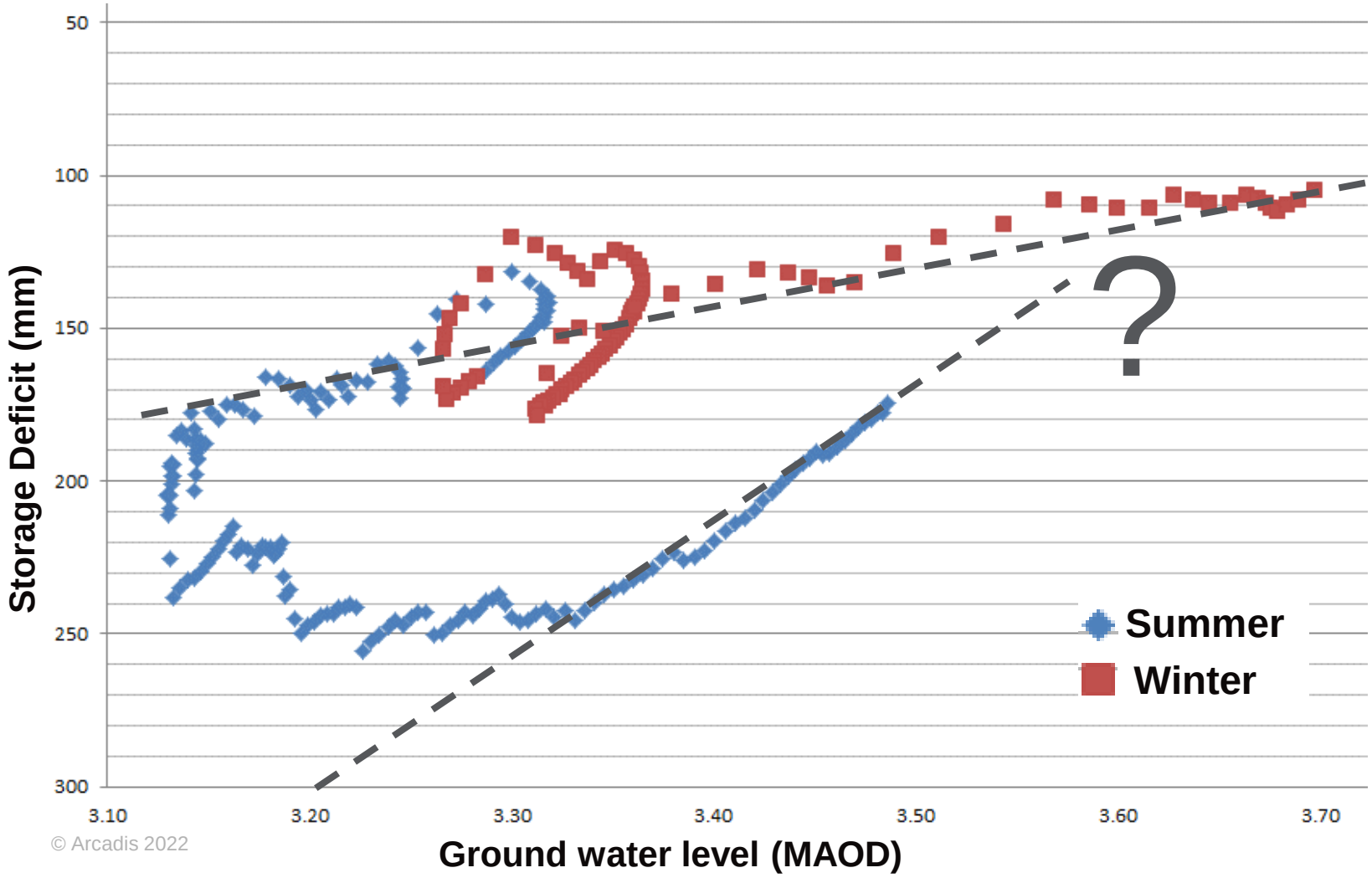
3. Example 2: Storage Deficit





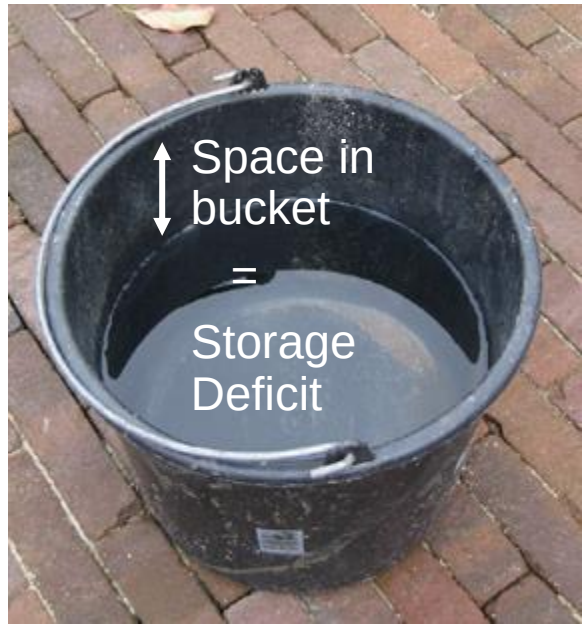
3. Example 2: Storage Deficit

Is ground water level a good predictor?



Bucket size = Ground water level

Bucket: unsaturated zone



3. Example 2: Storage Deficit

Conclusions

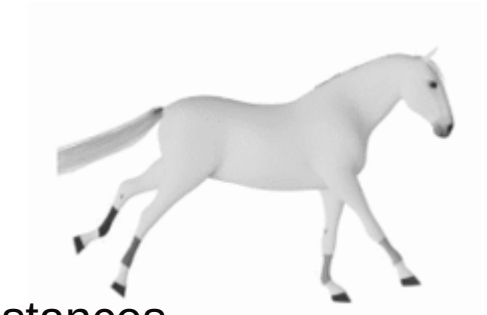
Is ground water level a good predictor? *NO*

- With a combined ground water model (MODFLOW) and unsaturated zone model (MetaSWAP), storage deficit can be calculated (now casting)
  - Better results are established when using high resolution (spatial and temporal): radar and satellite data

- The now casted storage deficit is a good measure for the ability to store a precipitation event. In combination with a flow model, active measures in water management can be taken.

→ When the weather forecast for tomorrow is 60mm, is it useful to lower the weirs or turn up pumping stations?

Overall Conclusions



- Always remember the ‘Horse Traits’!
  → first fully understand the hydrological system during common *and* rare circumstances

- Use suitable instruments (e.g. models) and validate on specific (extreme) events.
  → More than normally explain the results in bandwidths and probabilities.

- Use the best data available, especially for the input that matters the most.
  → during extreme events: Precipitation, evaporation, ….

- **Climate is changing: this means that current extreme events happen more often *and* new circumstances will occur.**
  → understand the hydrological system (impulse, response, …). Reproduce events, now casting.,. Fore casting

Any questions?

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Senior Hydrologist

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GeoSmart Information

Towards a more complete flood risk model for Britain: The role of groundwater

Mark Fermor

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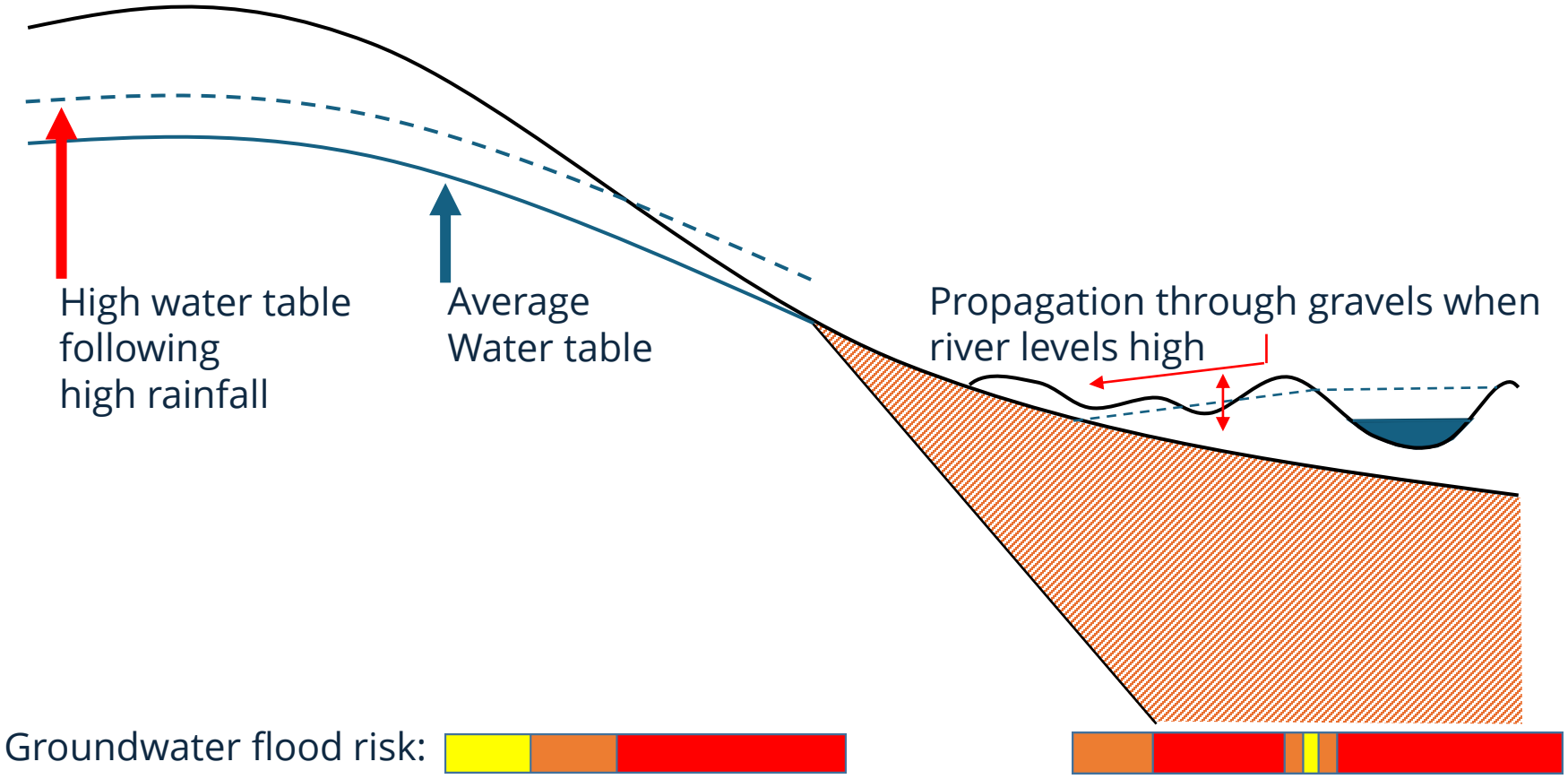
Datchet near Windsor Berkshire February 2014

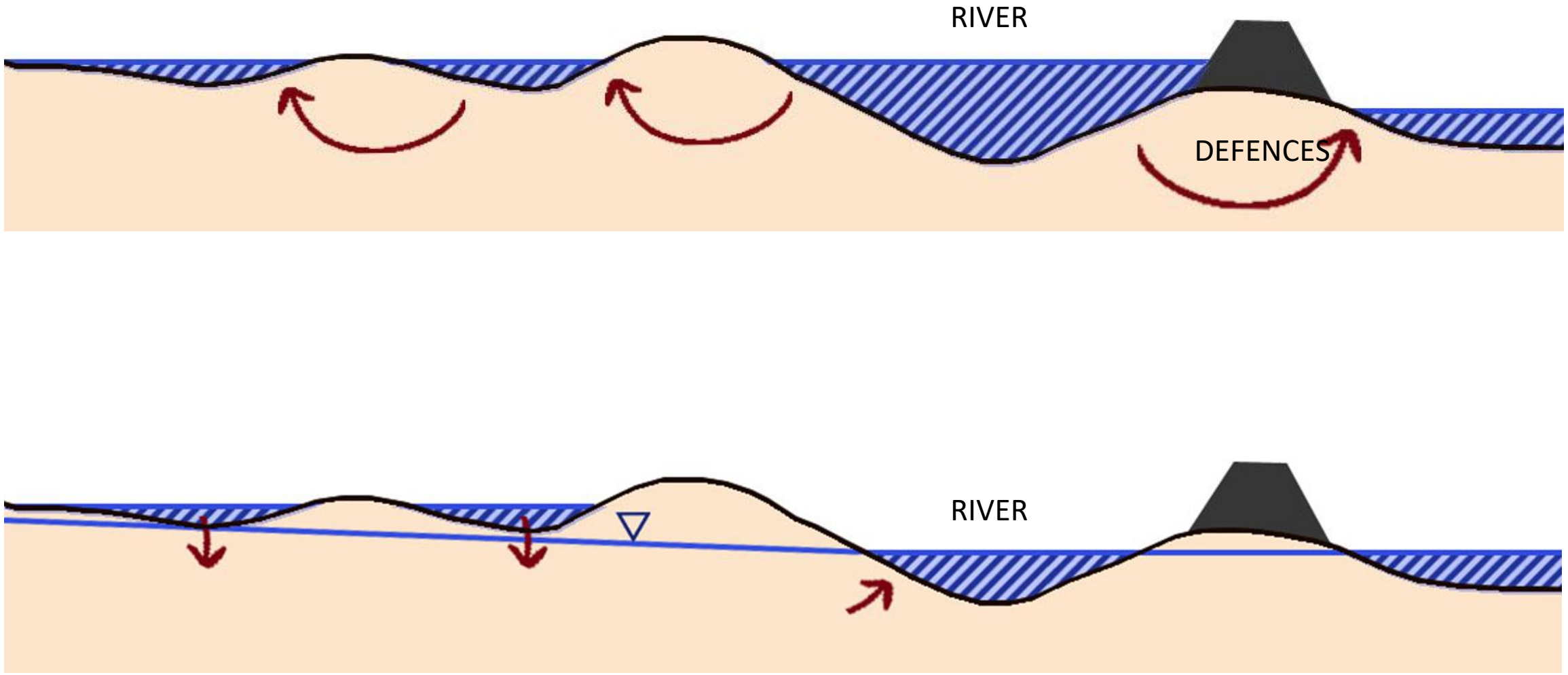
GeoSmart Information

Cross section showing groundwater flood mechanisms

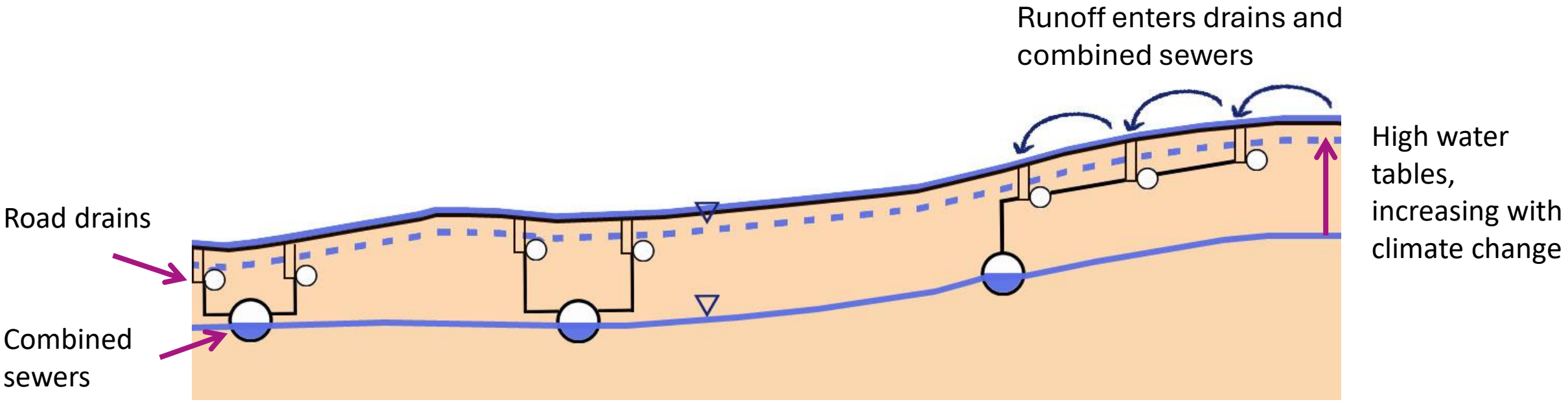


GeoSmart Information

River driven groundwater flooding

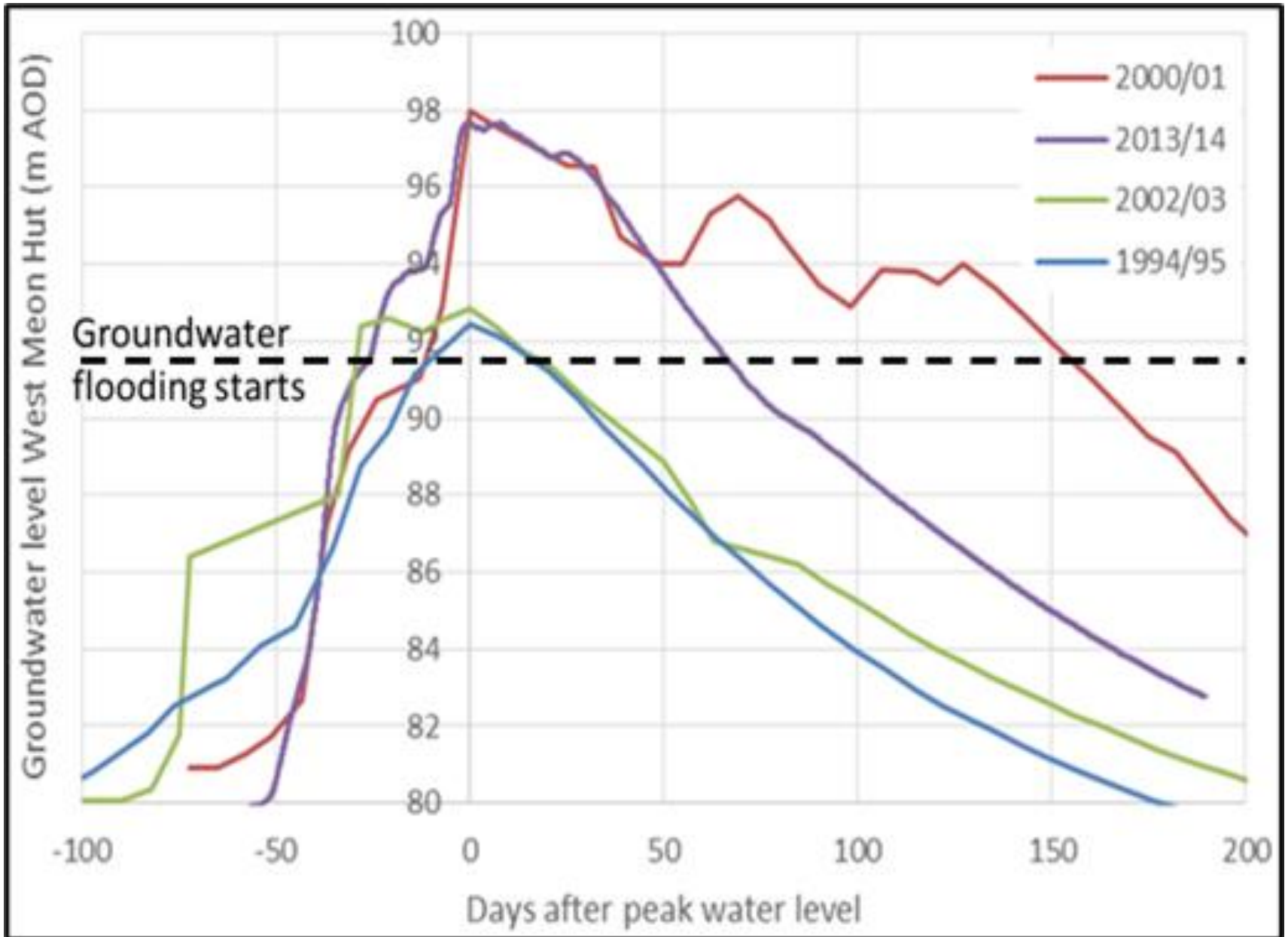


Groundwater driven sewer and drain flooding

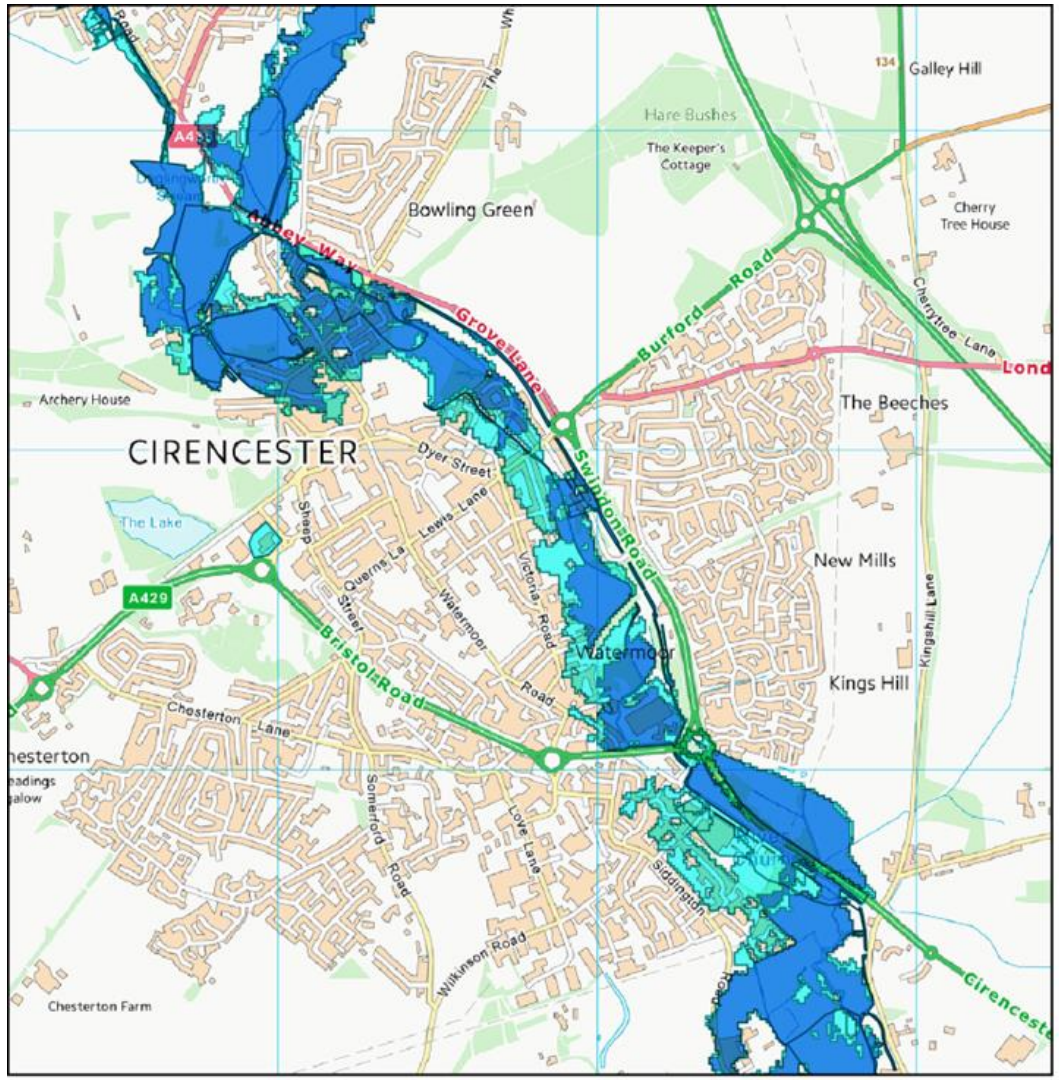


GeoSmart Information

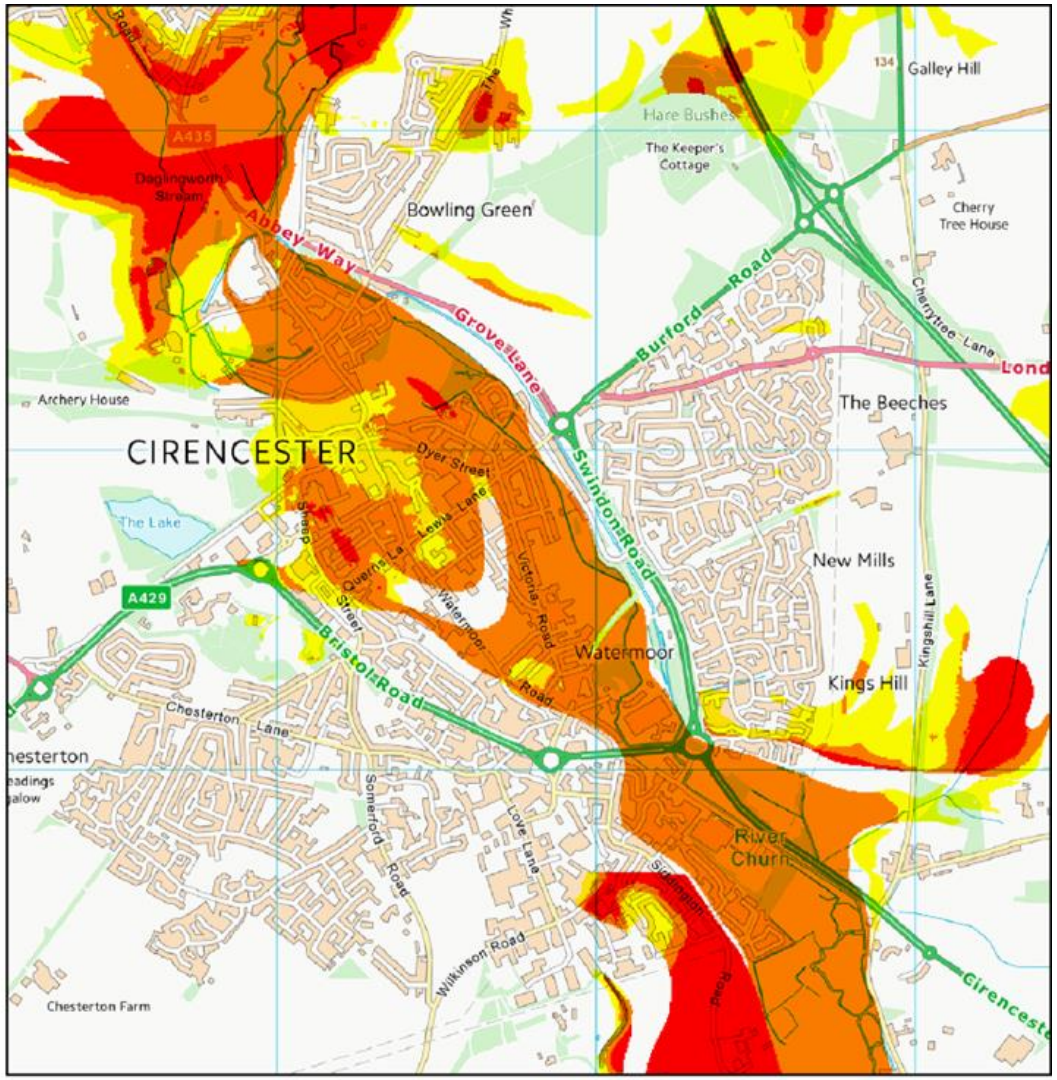
Groundwater flooding



Groundwater driven flooding



Map shows Environment Agency river flooding zone 2 (aqua) and zone 3 (blue)

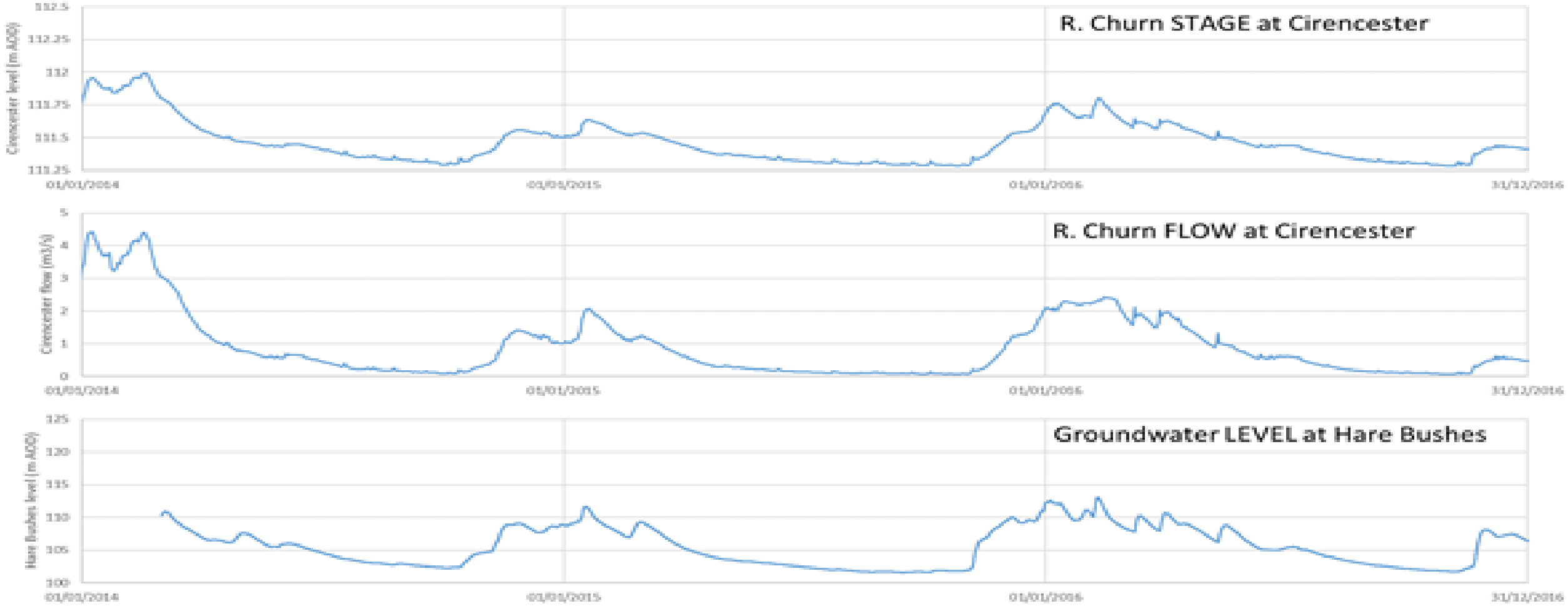


Map shows GeoSmart GW5 groundwater flooding risk zones from high (red) to low (yellow)

GeoSmart Information

Stage and flow forecasting – Cirencester gauge

R. Churn stage and flow at Cirencester are strongly correlated to groundwater levels at the Hare Bushes borehole

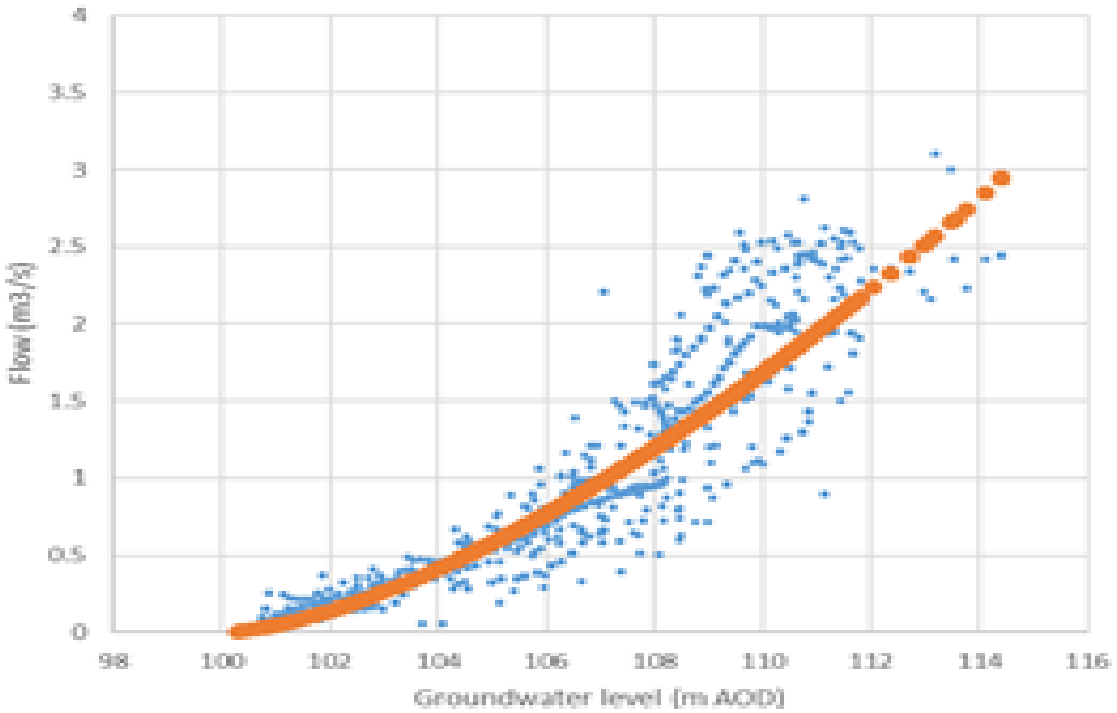


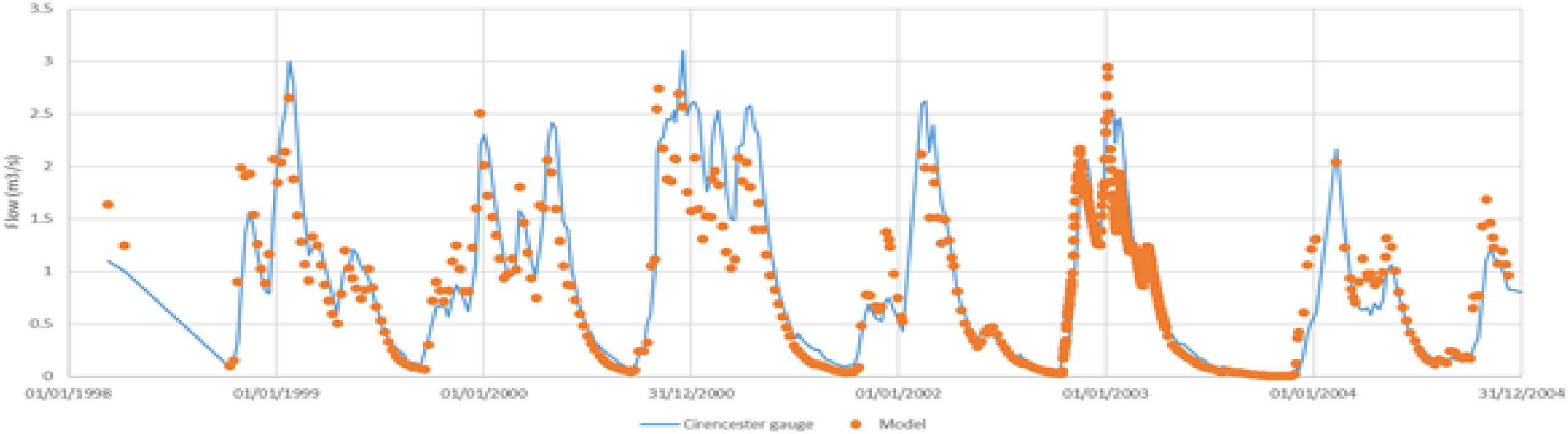
GeoSmart Information

Flow forecasting

Cirencester Flow-Head relationship

$$\text{Flow} = 0.0522\ (\ 100.1 + \text{head})^{1.515}$$





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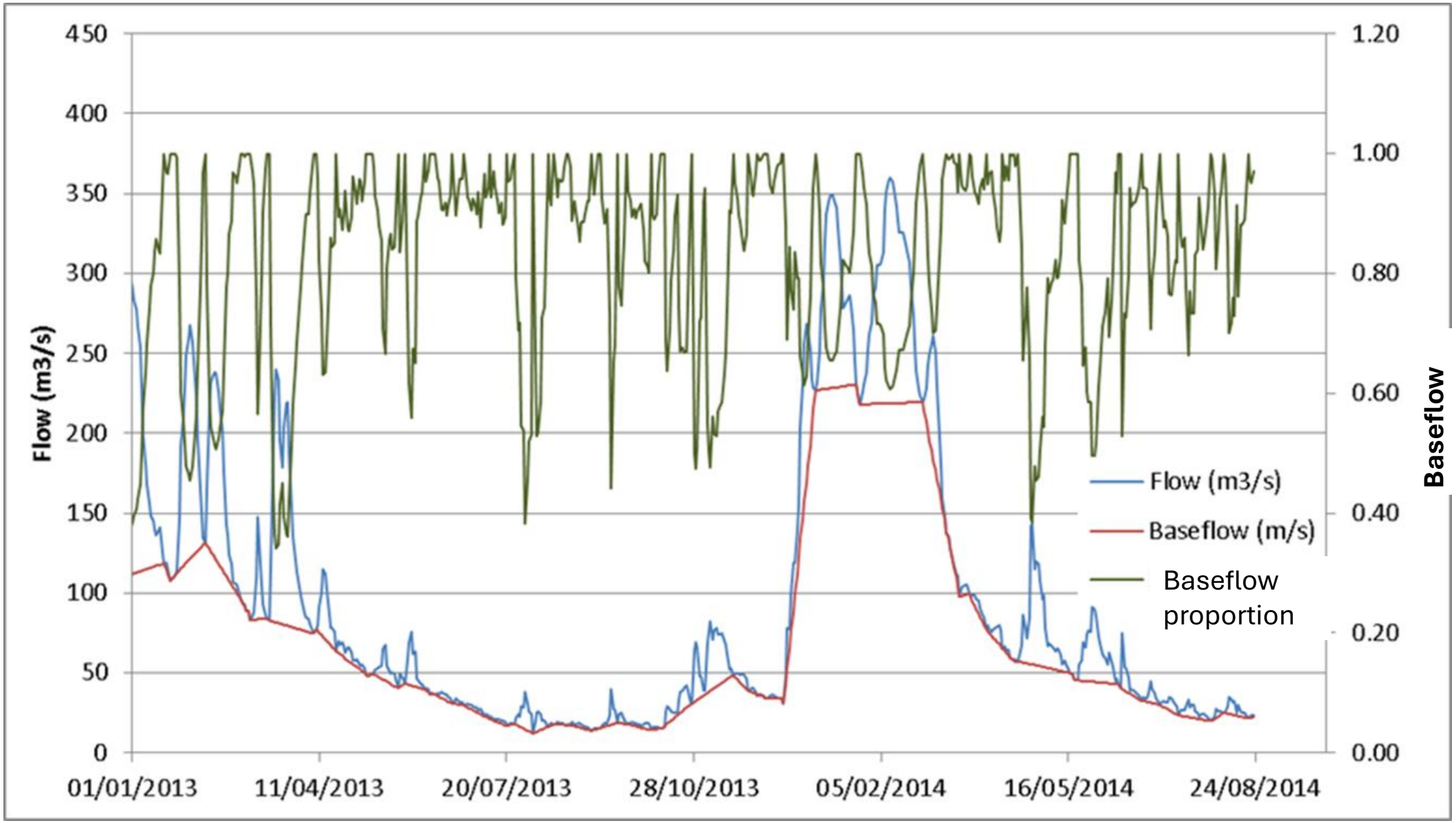
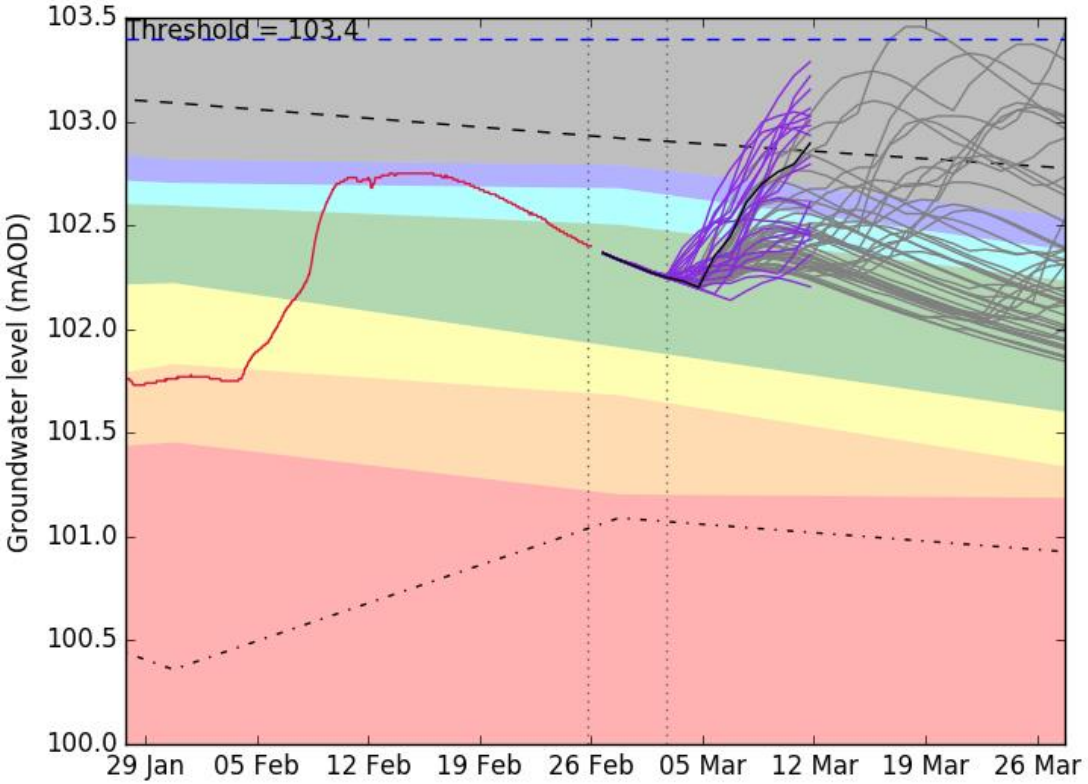
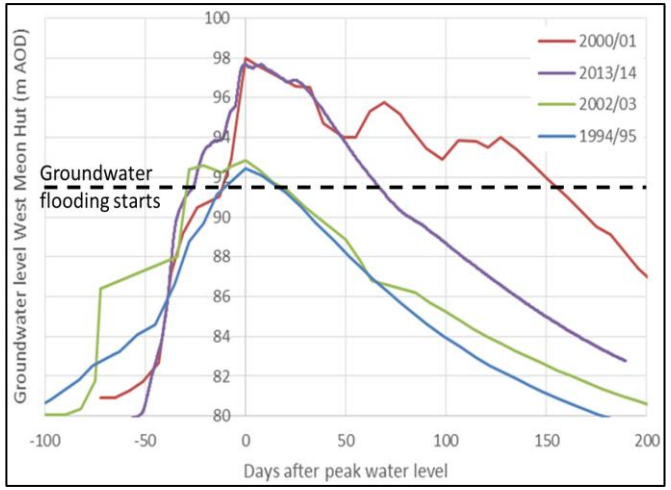
River Thames naturalised flow at Kingston

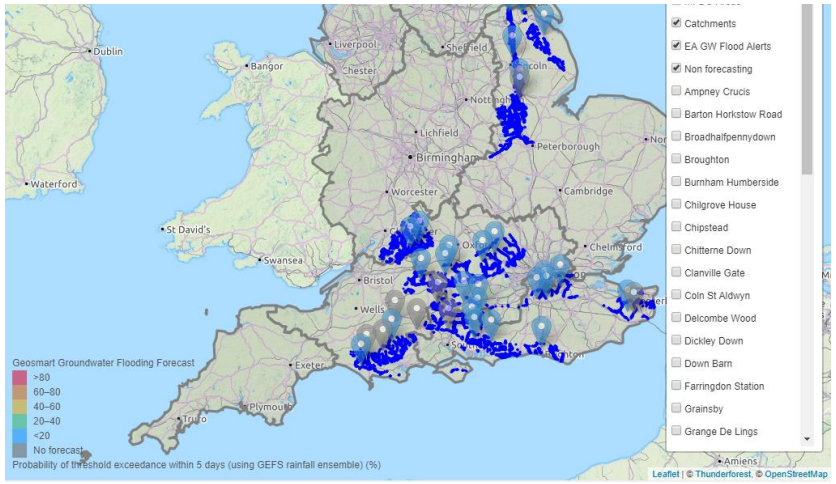


Groundwater – predictable long duration flooding

- Groundwater flooding is of significantly longer duration, **months**, than other types of flood and causes significantly (x2.5) more damage than for flooding from other sources at similar depths.
- A Groundwater flood risk forecasting model can provide advance, > **30 days warning** of when groundwater flooding will occur and when antecedent conditions will increase risk from other flood sources.







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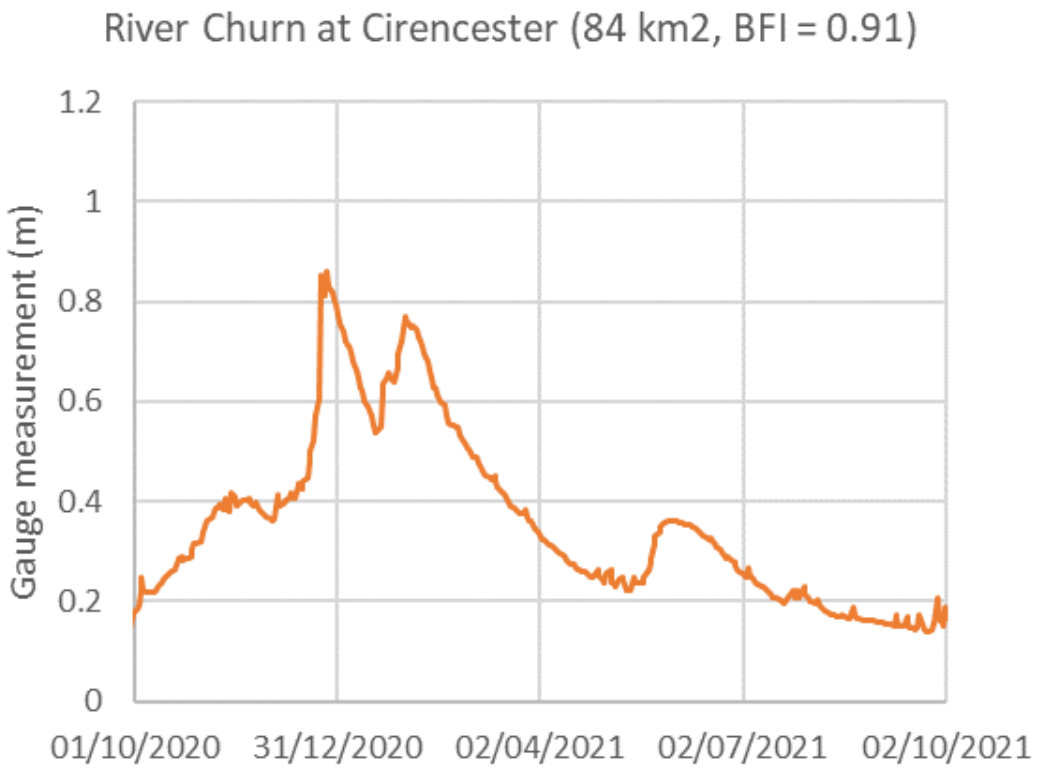
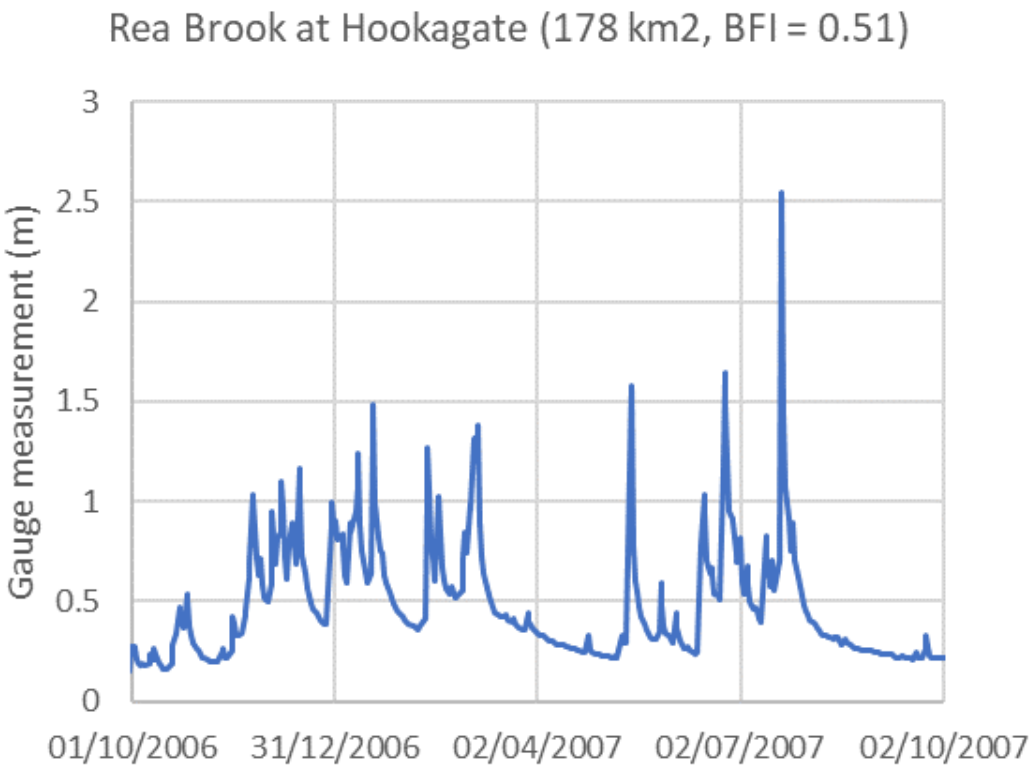
Baseflow effects on flooding





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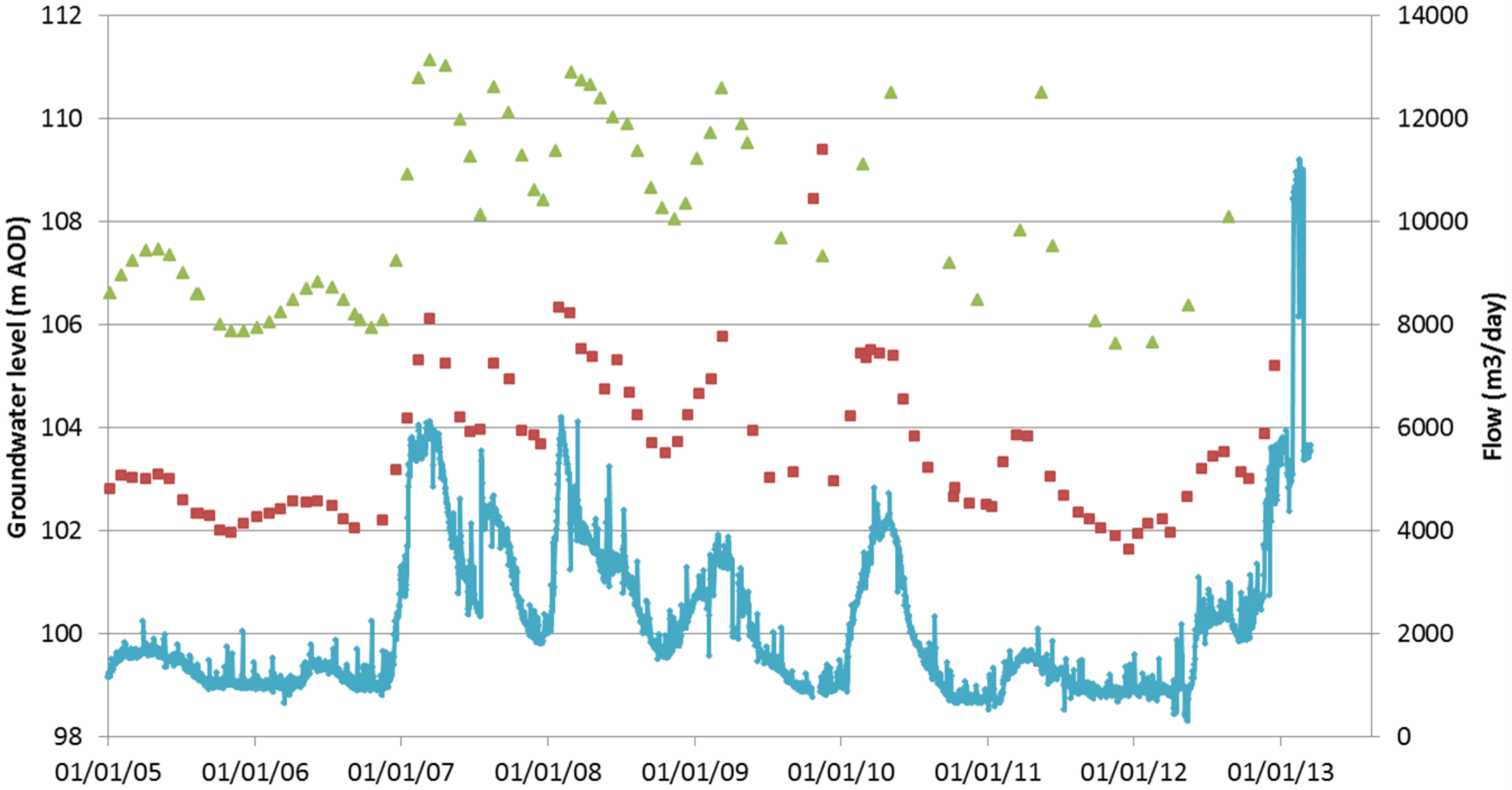
Groundwater levels and sewage works flows



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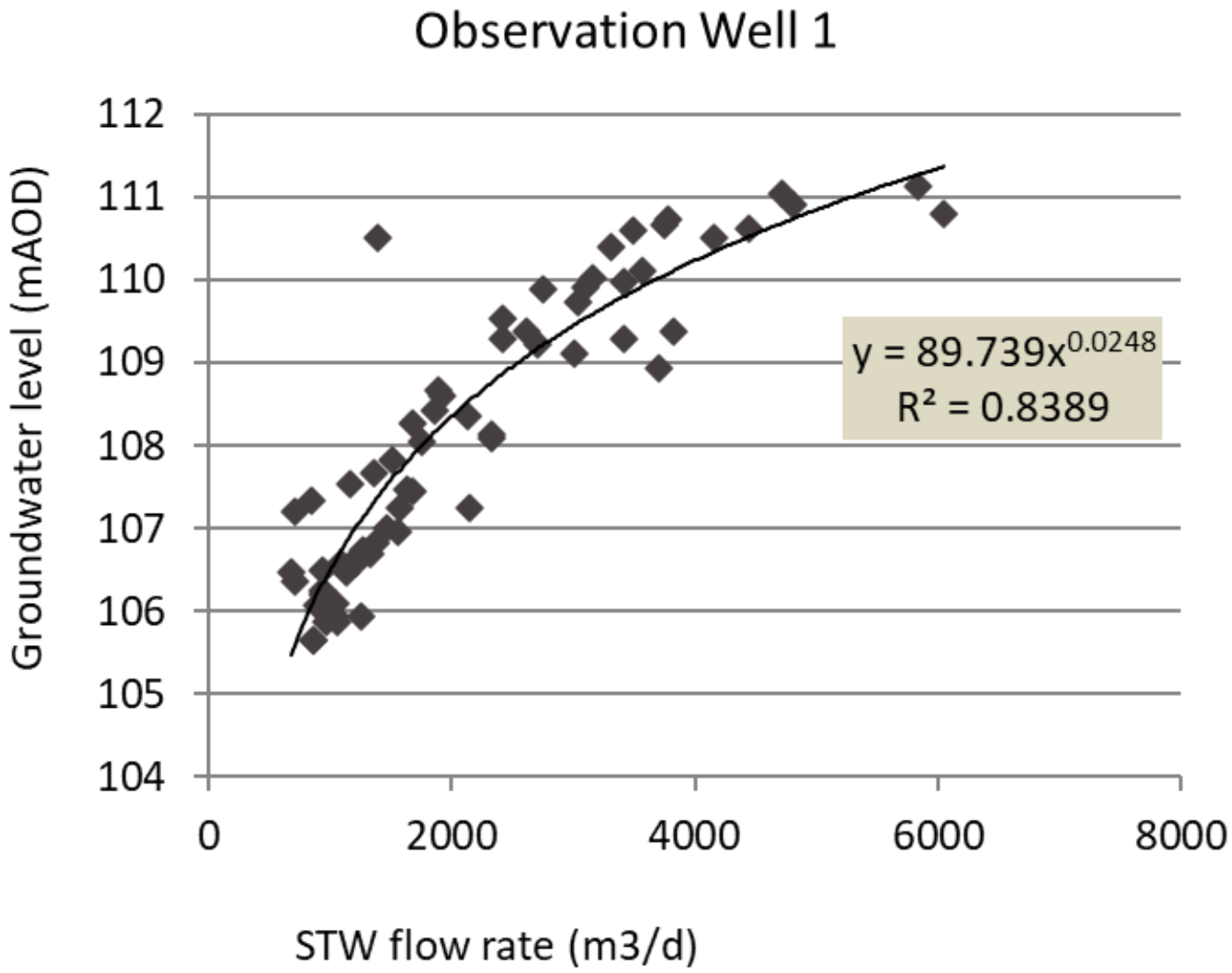
Groundwater levels and STW flows correlation



FloodSmart **Analytics**

Client portfolio data

Flooding from All Sources
Depths and Extents

Pluvial
Fluvial
Tidal
Groundwater

Other GIS reference data

FloodSmart Analytics
Engine

Flooding from All Sources
Average Annual Damages

Pluvial
Fluvial
Tidal
Groundwater

Damages in £'s

Flooding from All Sources
Climate Change Scenarios

Pluvial
Fluvial
Tidal
Groundwater

2030's, 2050's, 2080's
RCP 2.6, 4.5, 8.5

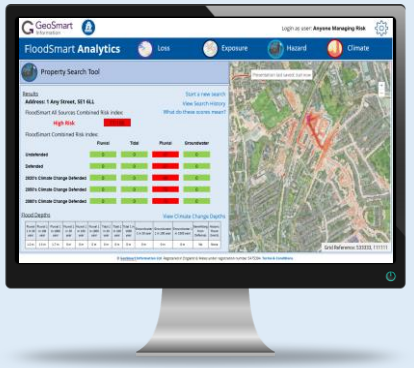
FloodSmart Analytics
Full Property Database

Linked to Property UPRN

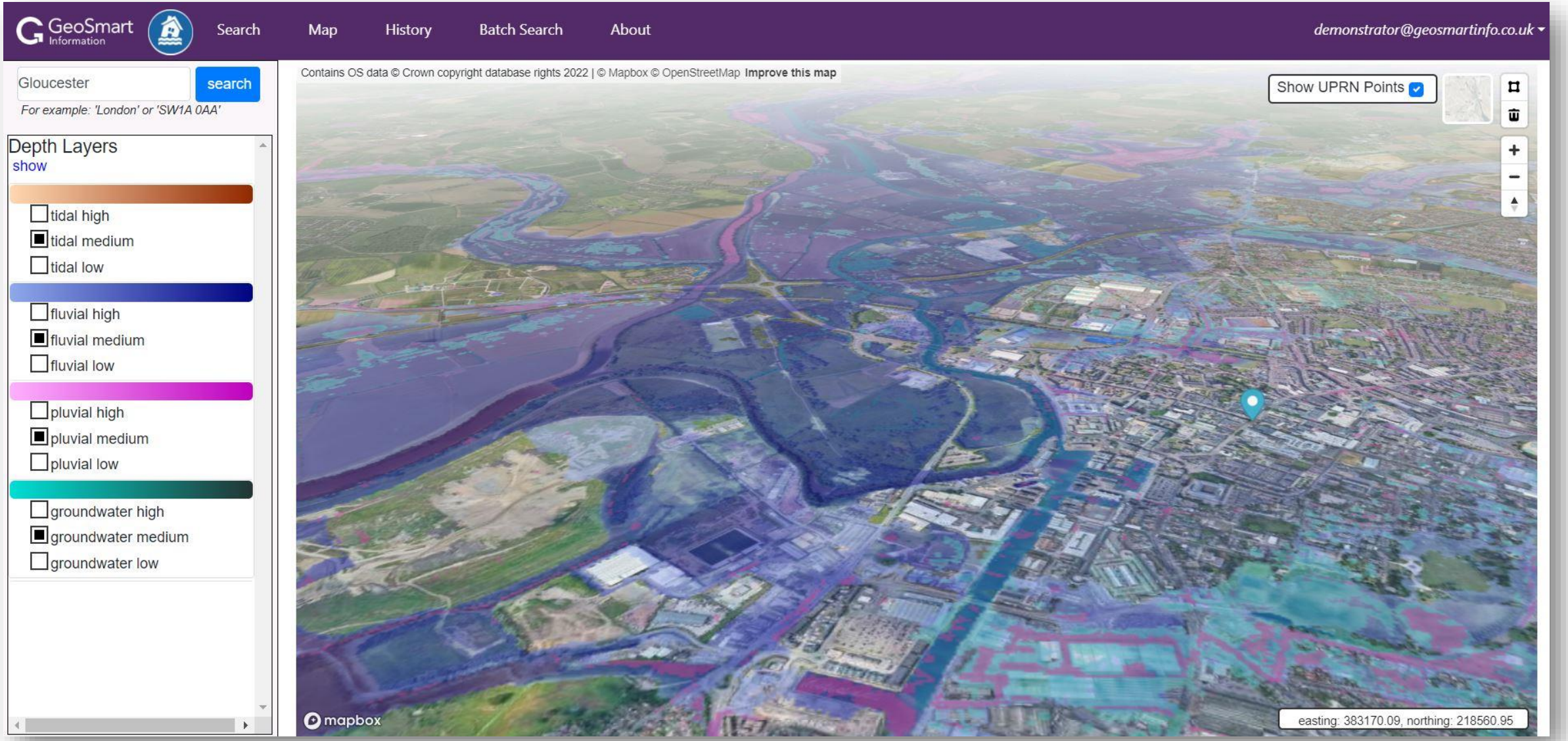
FloodSmart Analytics
Custom Client Database

Linked to client exposure

FloodSmart Analytics
Web Applications



FloodSmart Analytics



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Current estimated risk for homes in Britain

Flood source	% of GB properties within areas at risk	Average annual loss contribution	Properties at risk, where losses are exacerbated by groundwater
Rivers (defended)	1.8%	23%	78.7%
Groundwater	3.2% *	13%	-
Surface water	14.5%	53%	15.0%
Coastal (defended)	0.5%	11%	16.2%

* Groundwater flooding does not impact all properties within risk zones because it is often mitigated by building design or natural and artificial drainage systems which act to lower water tables

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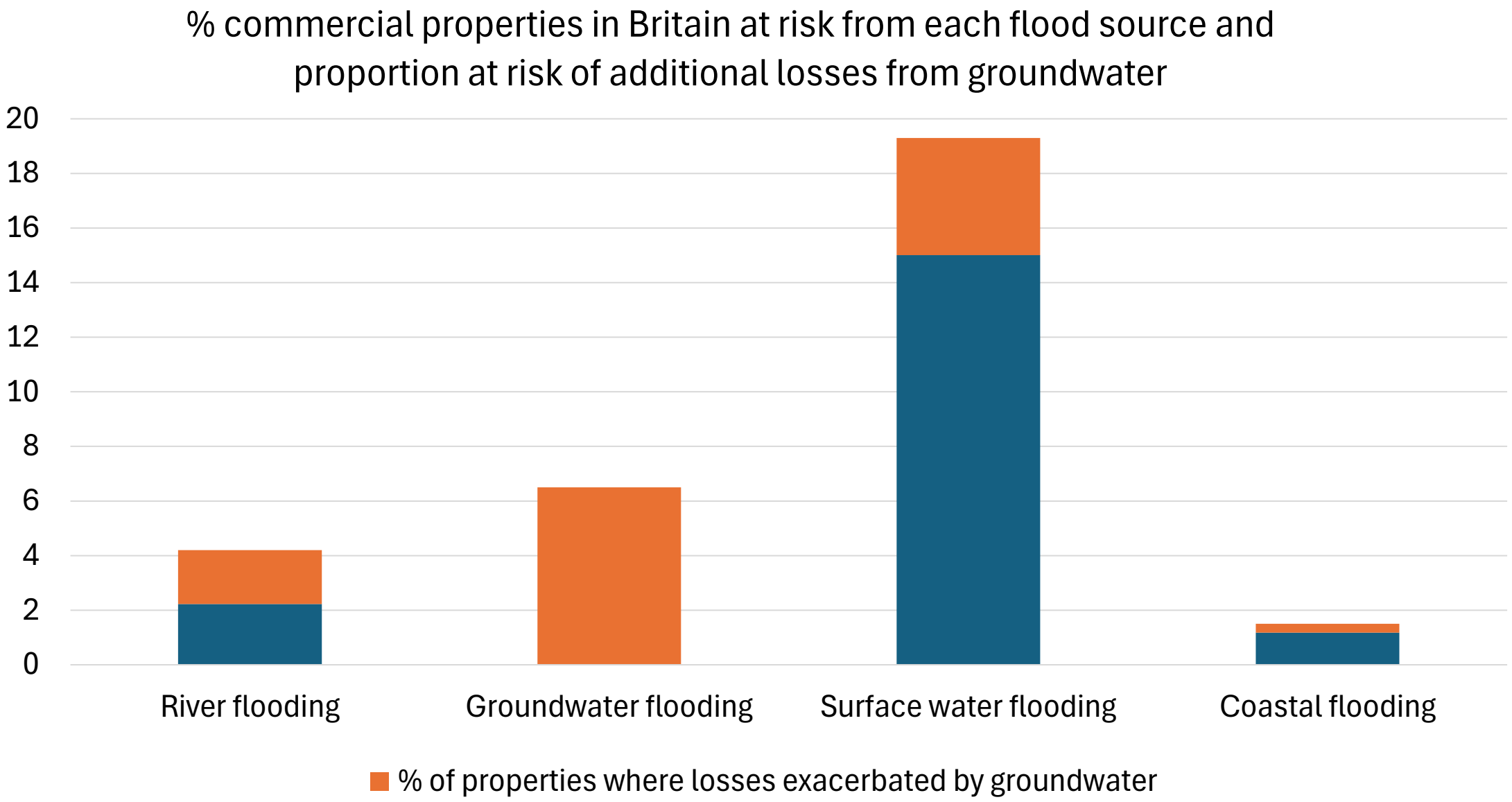
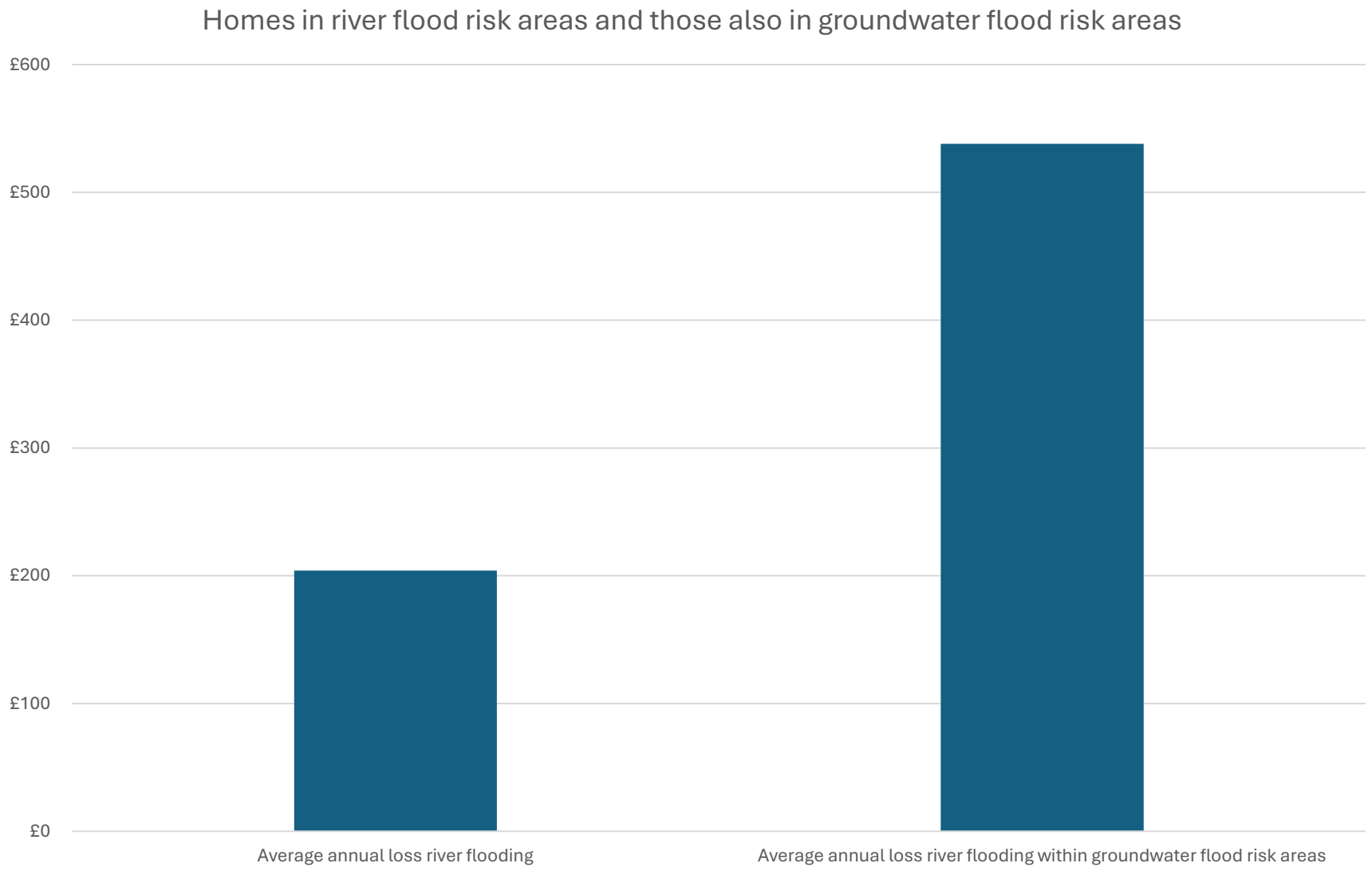


Typical AAL at residential property



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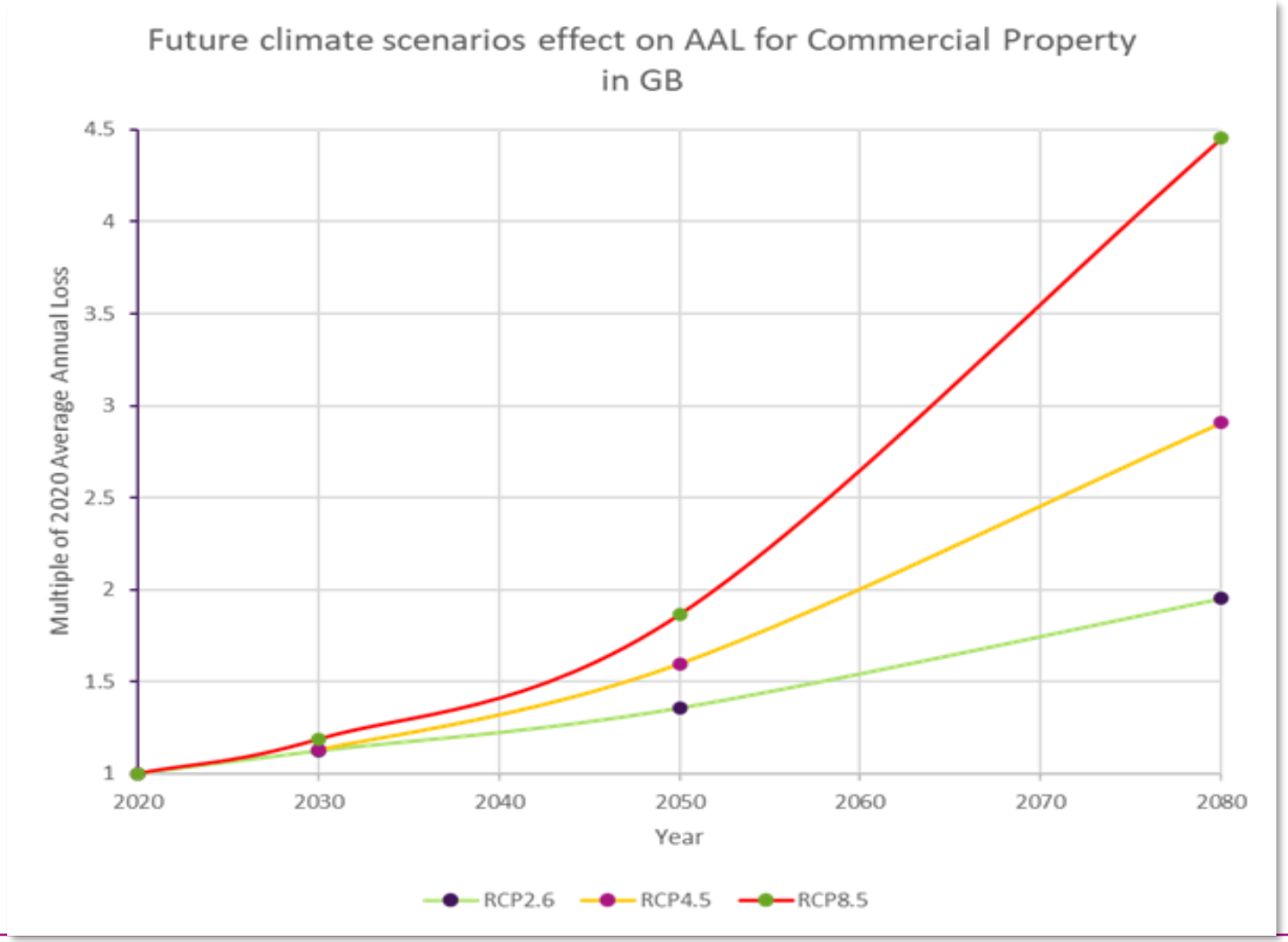
Climate change



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Joint Probability

$P(A,B) = P(A) \times P(B)$

High permeability catchment floods result from two events.

Event A = groundwater recharge leading to high baseflow over days and weeks

Event B = the storm that leads to rising limb of river hydrograph over hours and days, coinciding with Event A at vulnerable river setting.

Groundwater frequency analysis combined with traditional flood hydrology quantifies risk.

A coincidence of 100 year events could lead to catastrophic unprecedented flooding.

Flood and Water Management Act 2010

“local flood risk” means flood risk from—

(a)surface runoff,

(b)groundwater, and

(c)ordinary watercourses.

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Conclusions

In high permeability catchments floods result from two events

Event one is the groundwater priming the catchment for future storms, and event two is the storm.

Groundwater is not local flooding. It is a core and integral part of the catchment flow system.

Floods are very significantly primed by groundwater conditions and it helps to consider floods result from two independent events.

Groundwater driven flooding often lasts much longer and this increases damage on average 2.5x other flooding.

Flood risk assessment based on all four main sources of flooding brings a more complete flood risk model that delivers increased forecasting ability, better estimate of duration and costs of flooding.

GeoSmart Information

Thank You.

Mark Fermor

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Quantifying floods and droughts in rapidly changing human-water systems

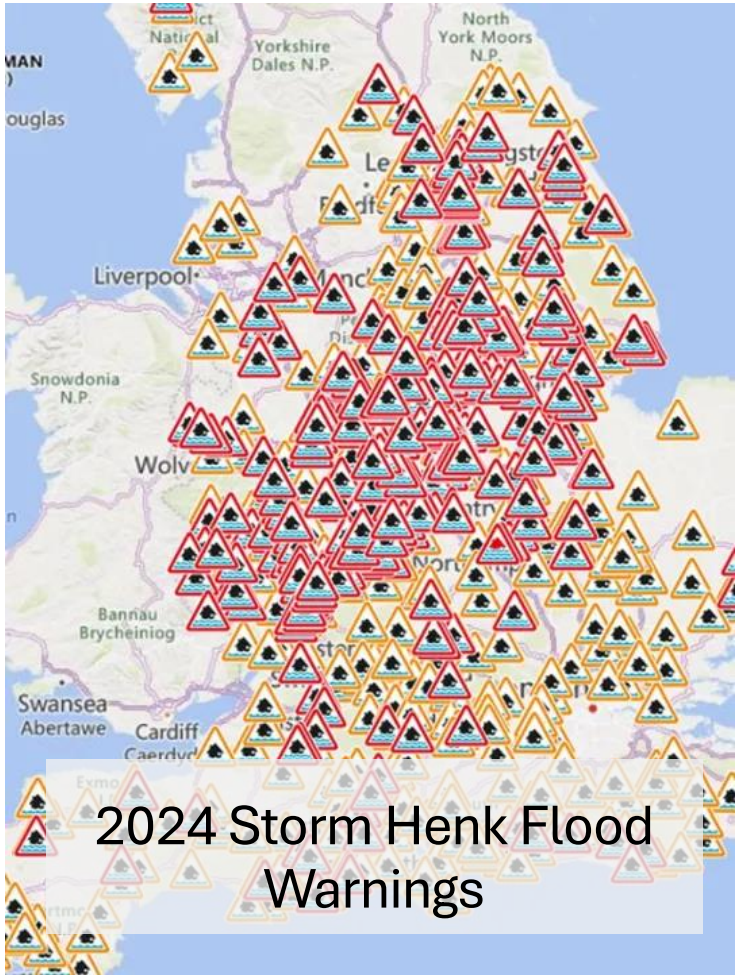
Gemma Coxon

University of BRISTOL

UKRI Natural Environment Research Council

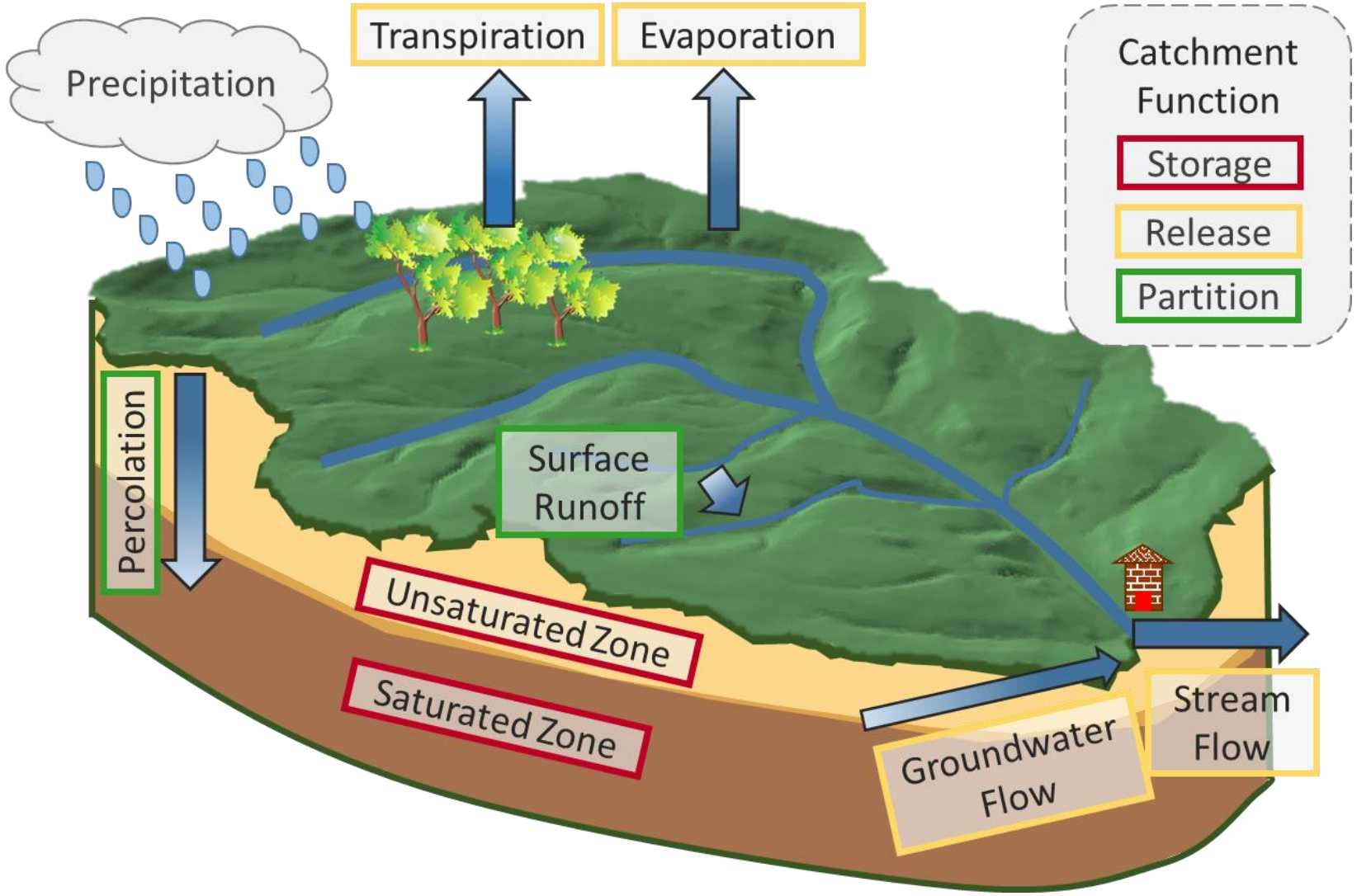
Hydrological extremes are increasing in their frequency, severity and duration

© Sentinel 3, ESA

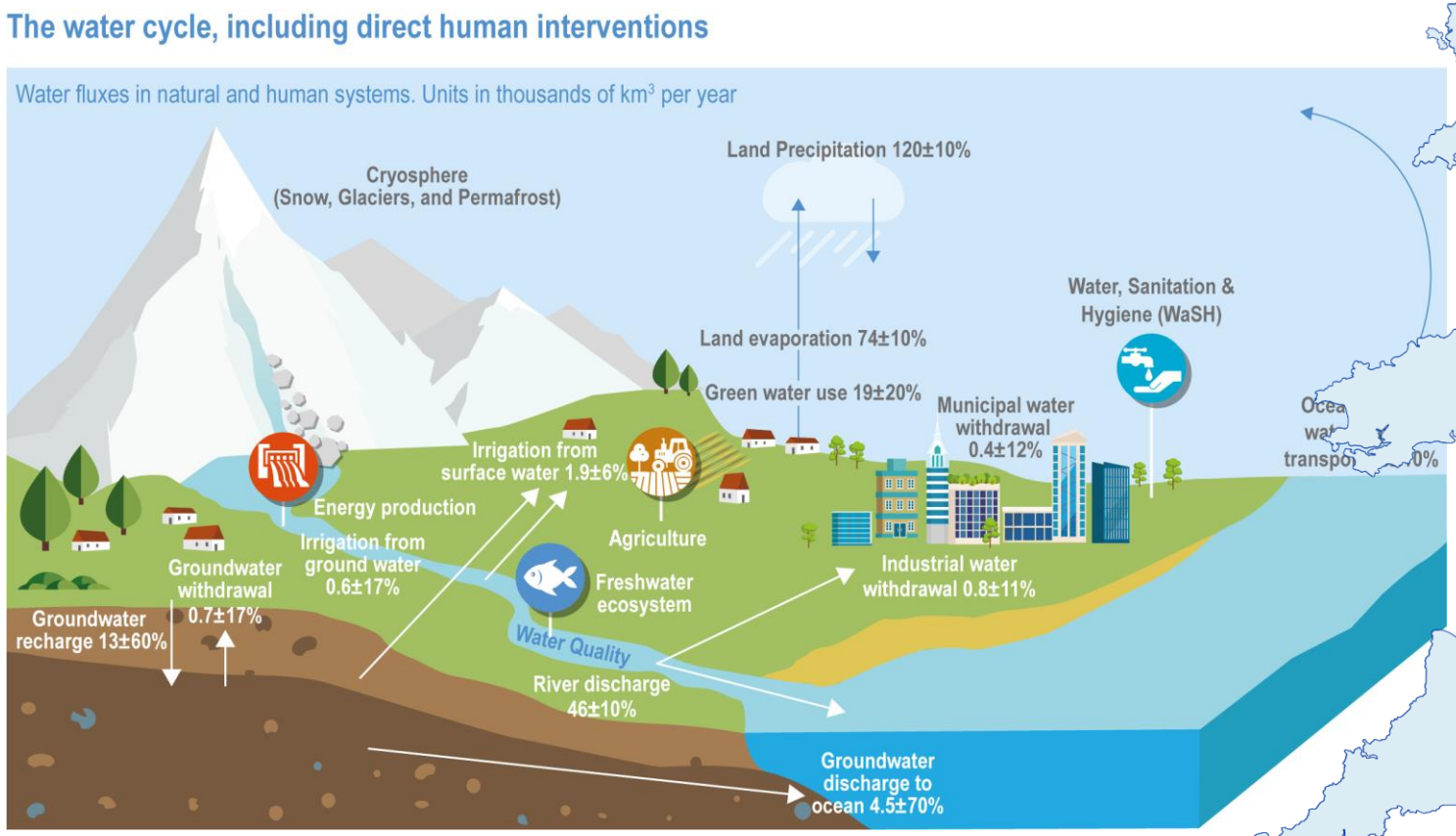


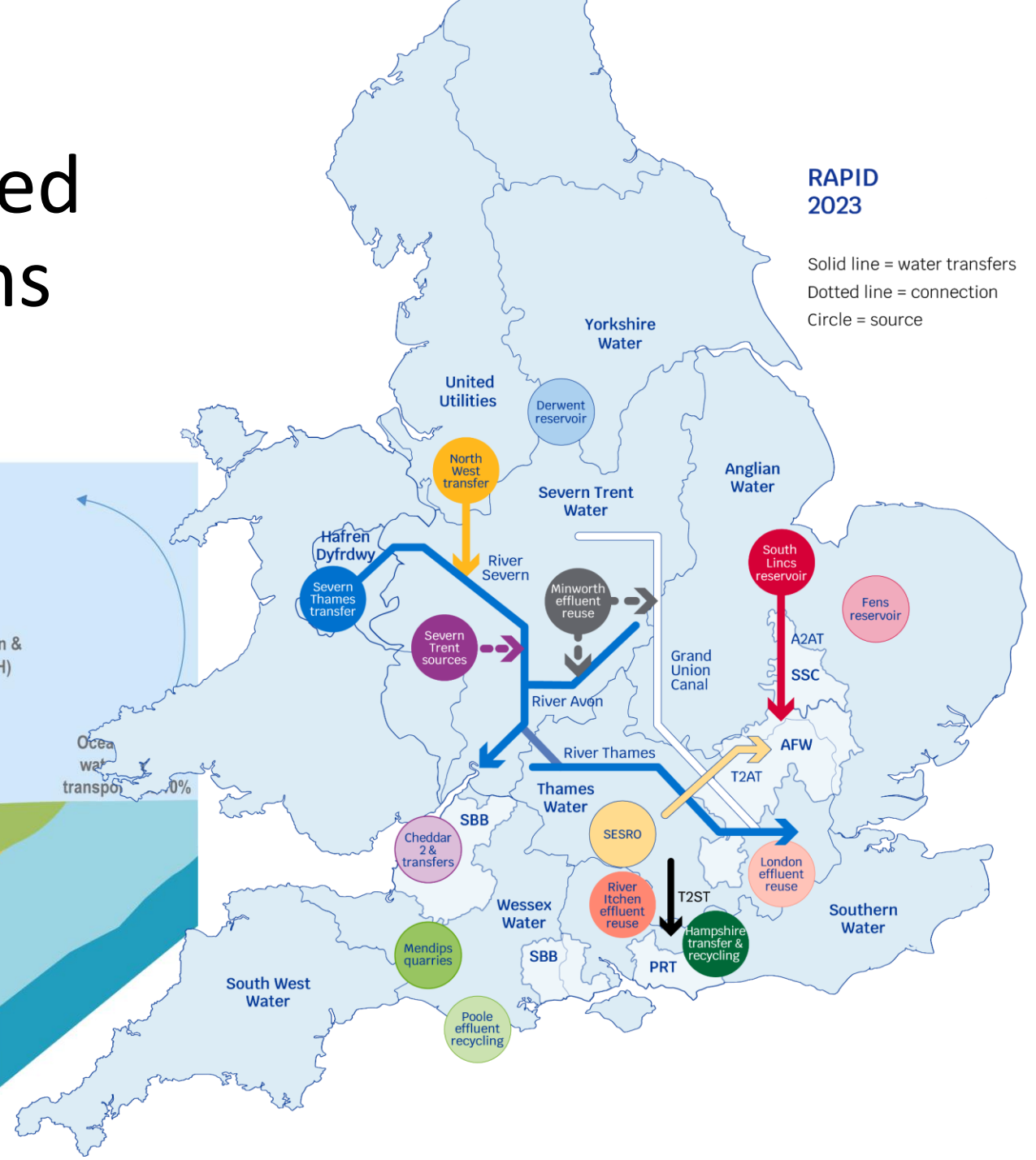
© Environment Agency

Catchment-scale hydrological modelling and analyses underpin the management and sustainability of future water resources



Yet, catchments are (increasingly) interconnected across wider water systems





Quantifying floods and droughts in rapidly changing human-water systems

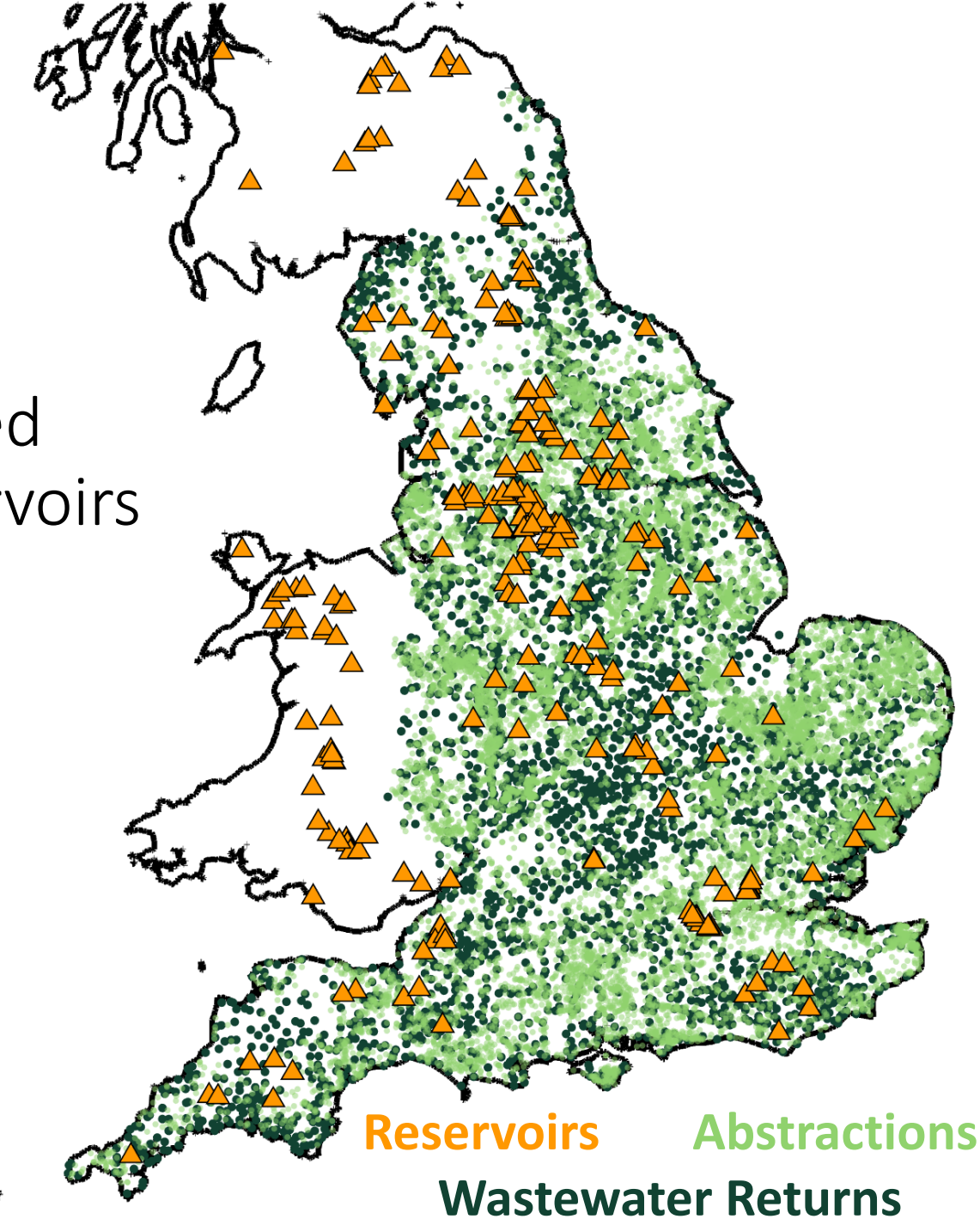
1) **How do humans impact river flows?**
2) Building integrated hydrological modelling frameworks
3) Where do we go next?

Complex network of reservoirs, abstractions and wastewater returns

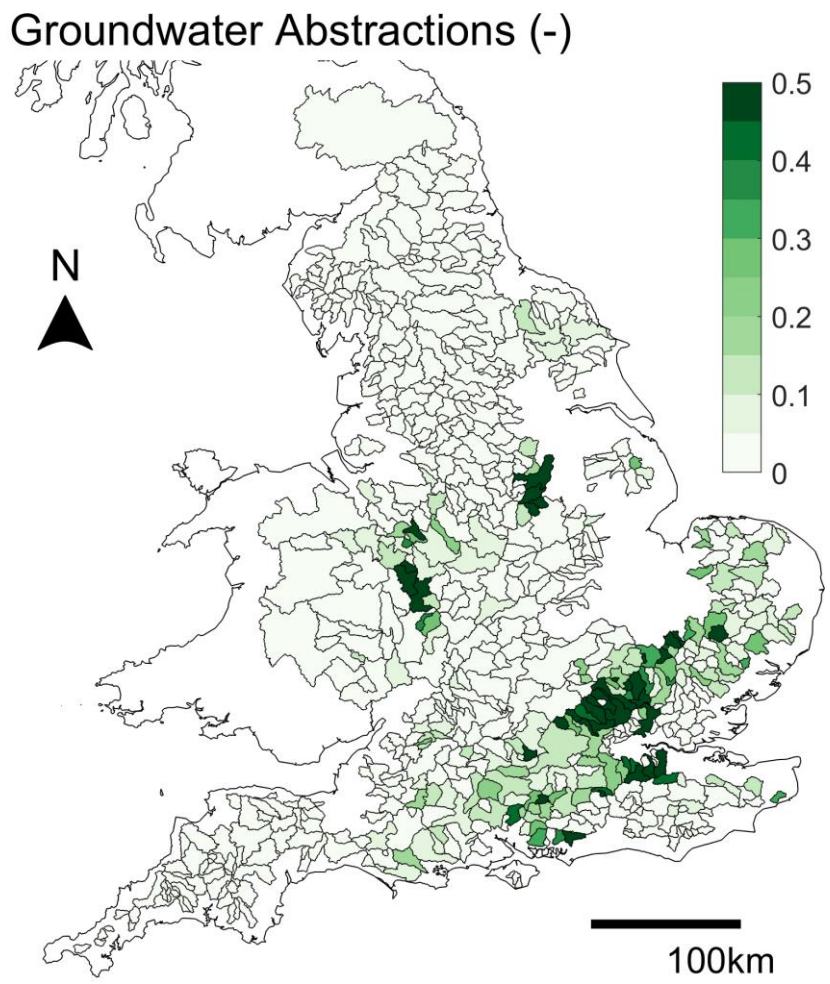
8.7 million ML/year abstracted
2.5 million ML stored in reservoirs

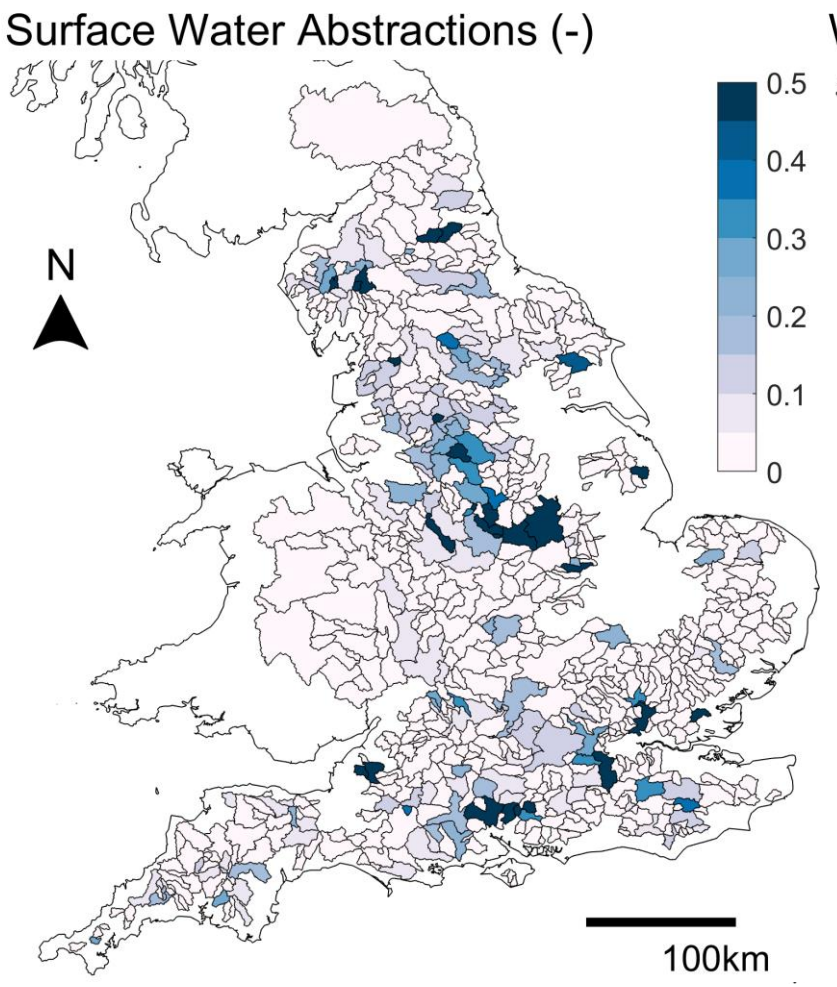
75% total volume abstracted is from surface waters

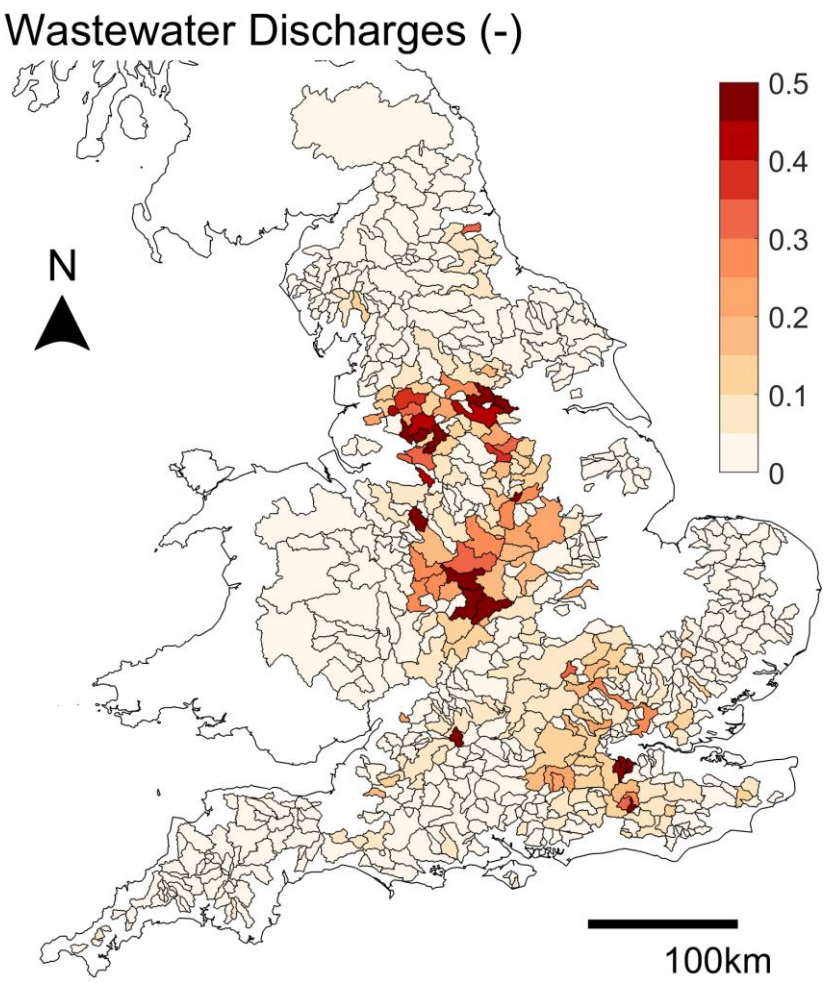
60% total volume abstracted is for public water supply



Significant component of flow regime and varies spatially

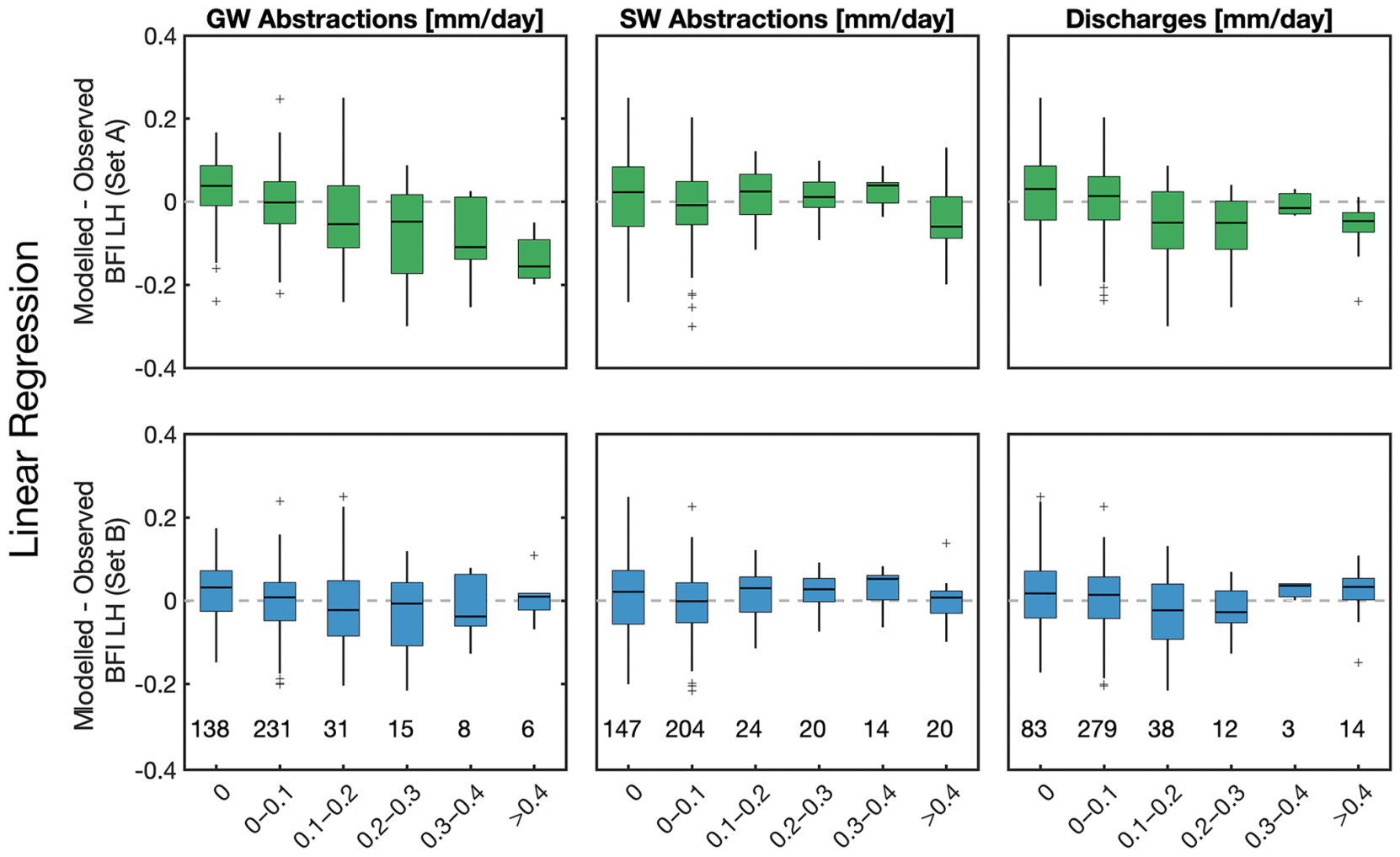






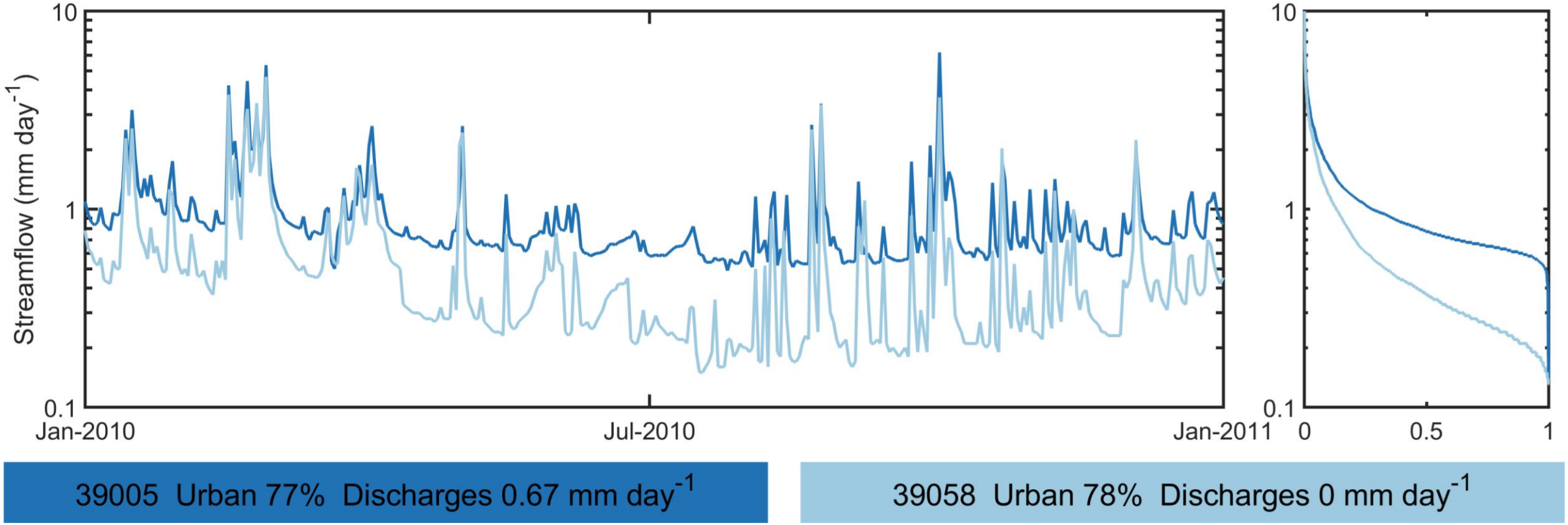
Water resource management practices affect baseflow

Groundwater abstraction is the most influential of these practices, with a positive correlation between abstraction and baseflow



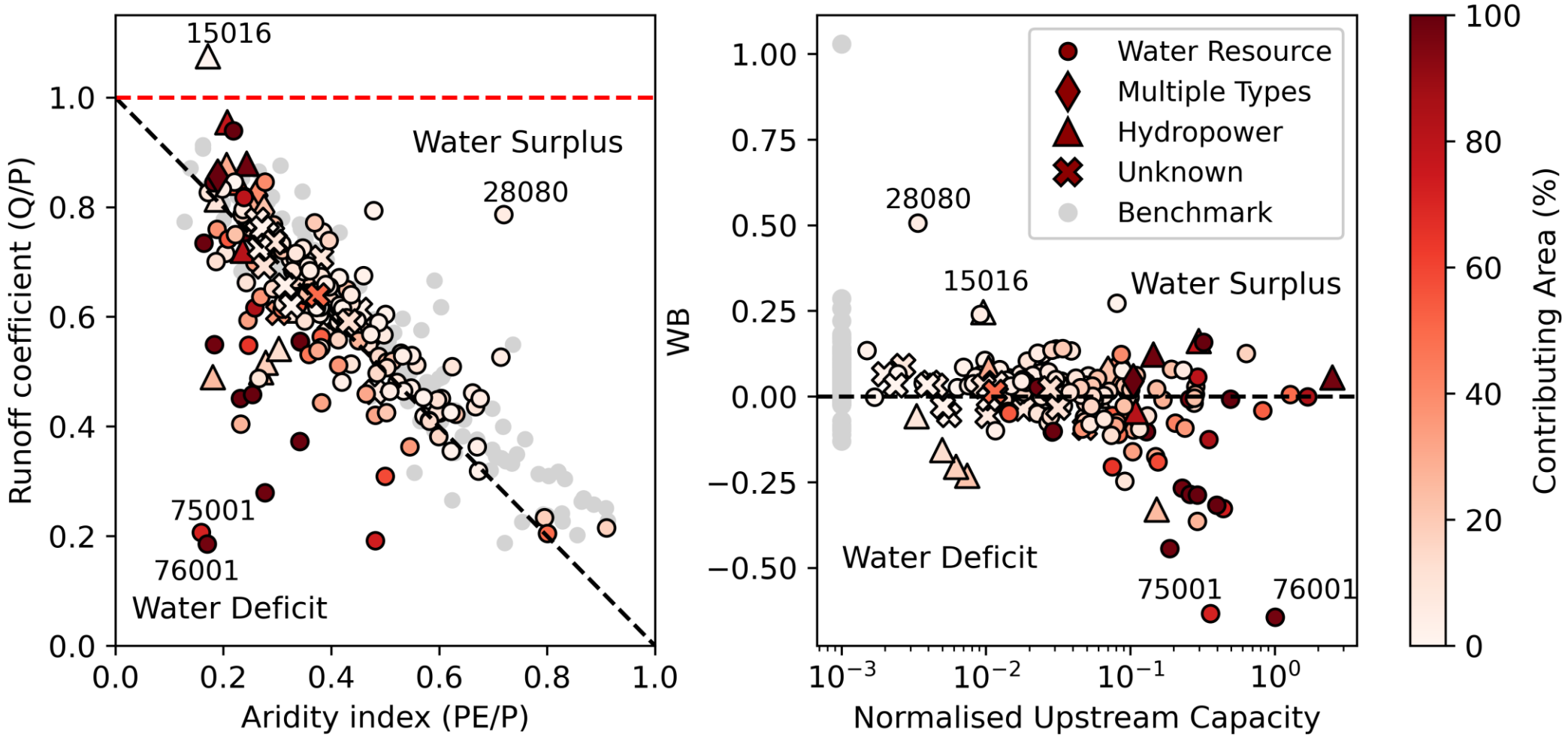
Bloomfield et al (2021), https://doi.org/10.5194/hess-25-5355-2021

Wastewater discharges increase flow magnitudes and reduce flashiness



Coxon et al (2024) Wastewater discharges and urban land cover dominate urban hydrology signals across England and Wales

Reservoirs significantly alter the catchment water balance

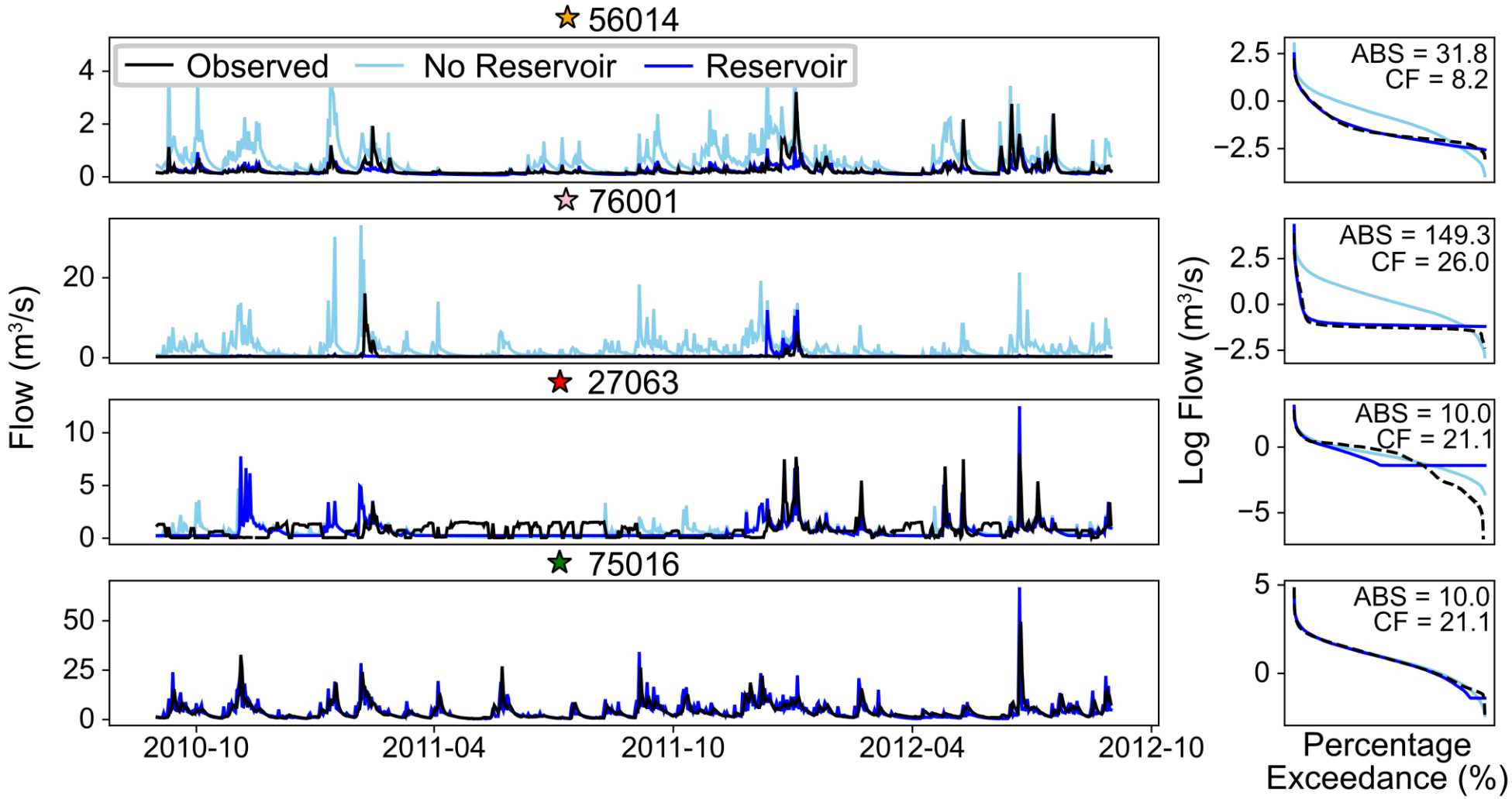


Salwey et al (2023) National-Scale Detection of Reservoir Impacts Through Hydrological Signatures, WRR

Quantifying floods and droughts in rapidly changing human-water systems

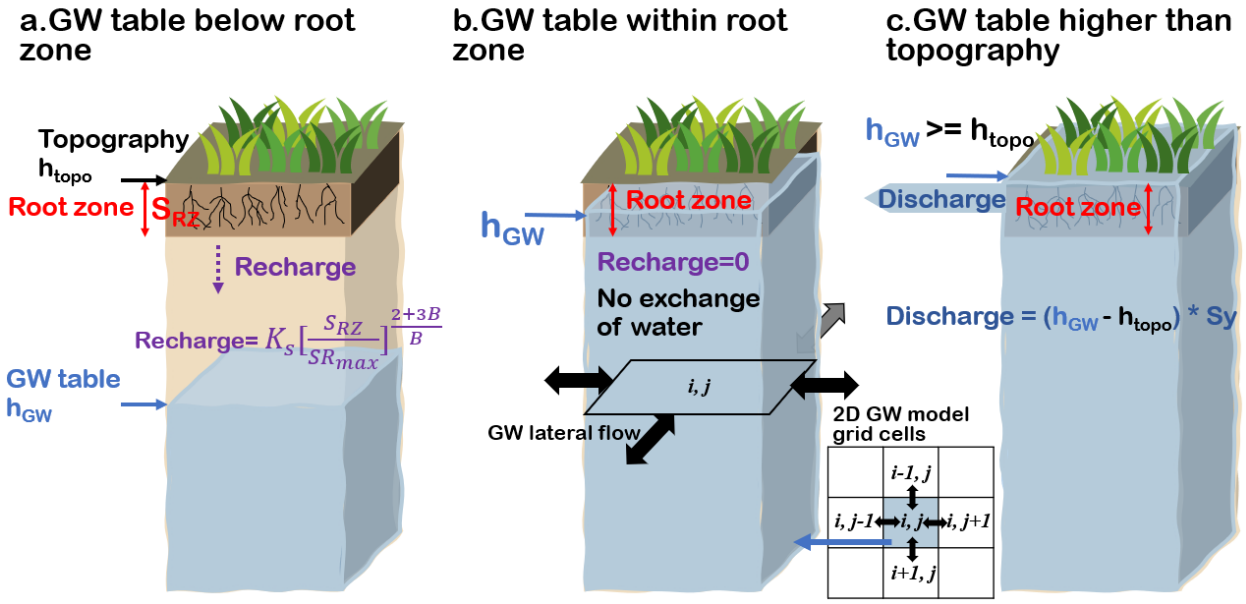
1) How do humans impact river flows?
2) **Building integrated hydrological modelling frameworks**
3) Where do we go next?

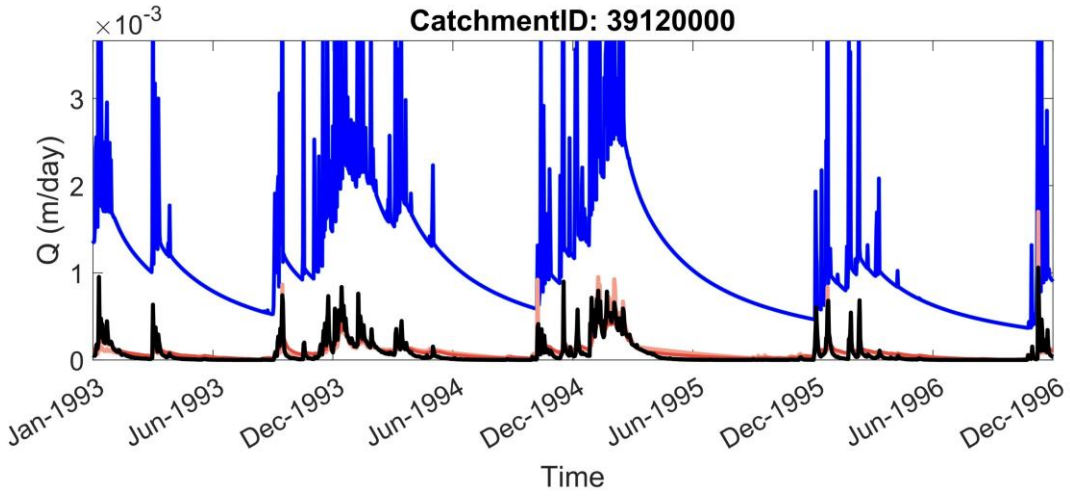
Developing water supply reservoir operating rules for large-scale hydrological modelling



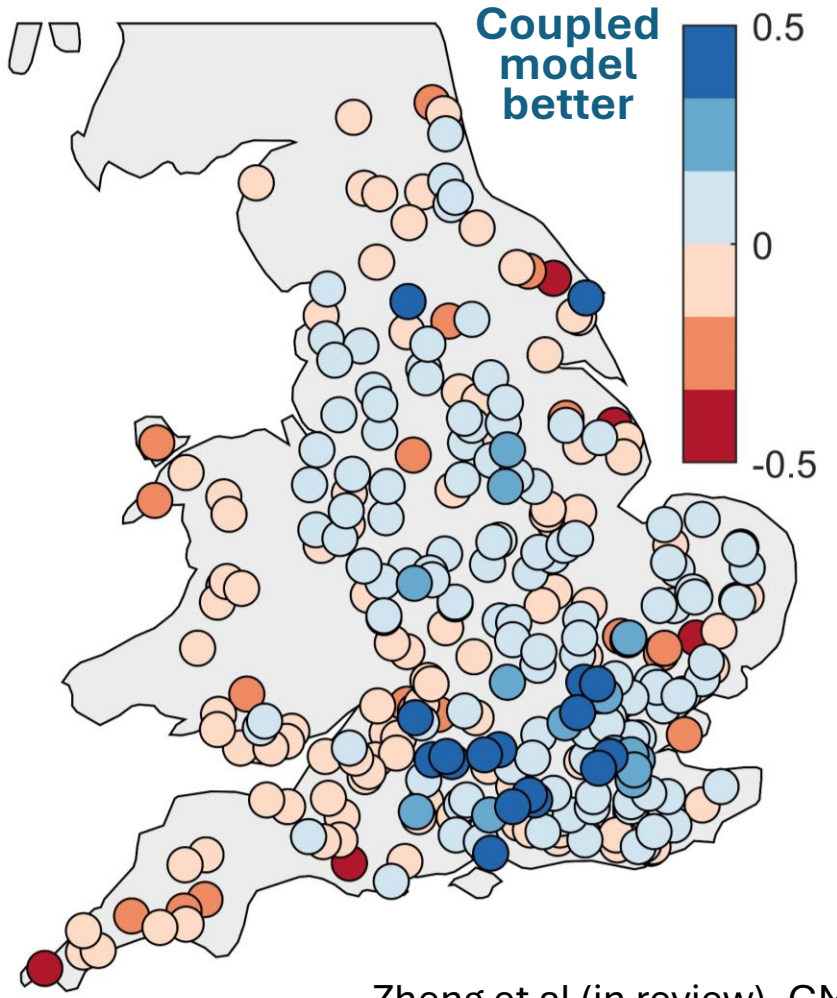
Salwey et al (2024), HESS

DECIPHeR-GW v1: A coupled hydrological model with improved representation of surface-groundwater interactions



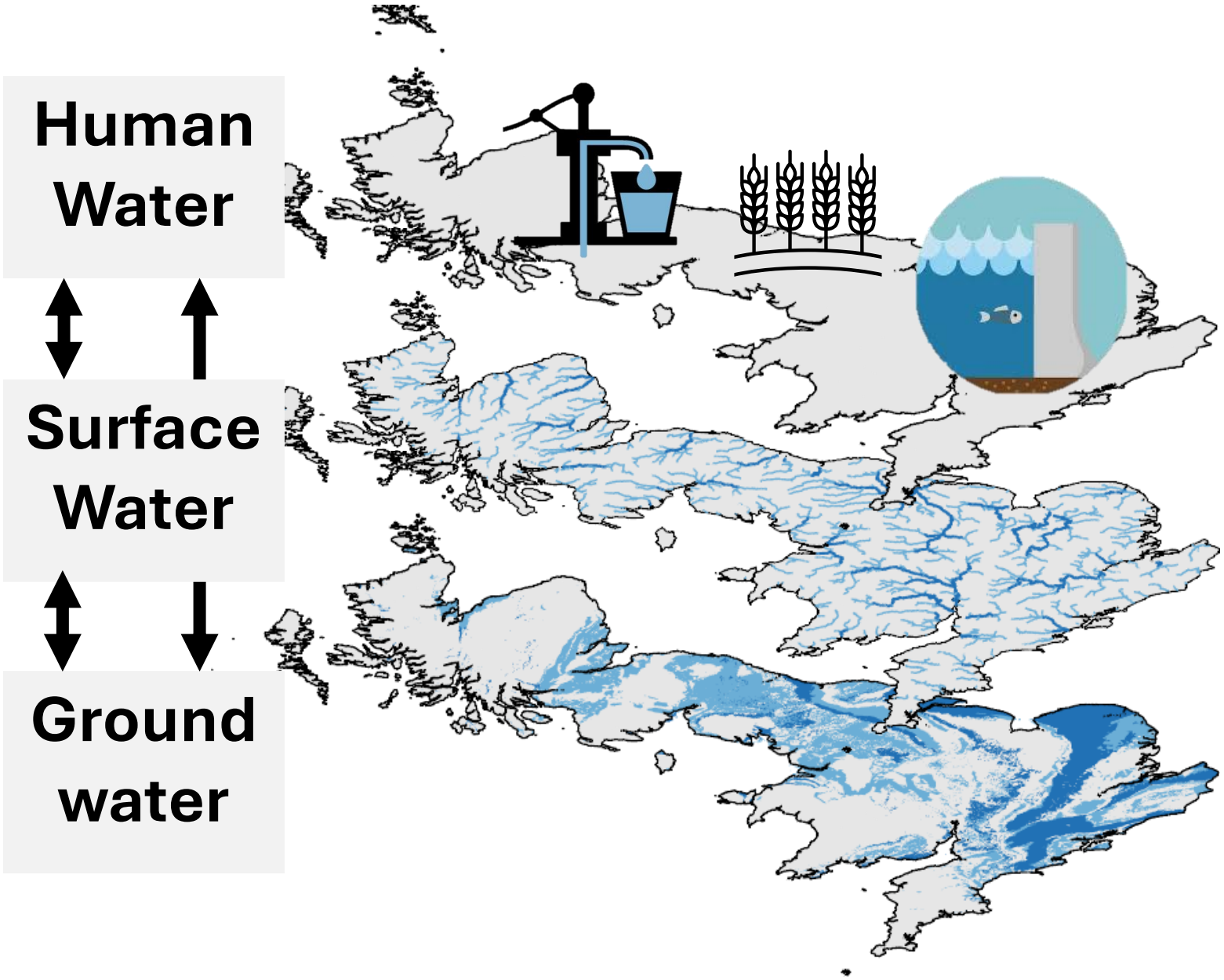


Difference in two models



Zheng et al (in review), GMD

Quantifying floods and droughts in rapidly changing human-water systems



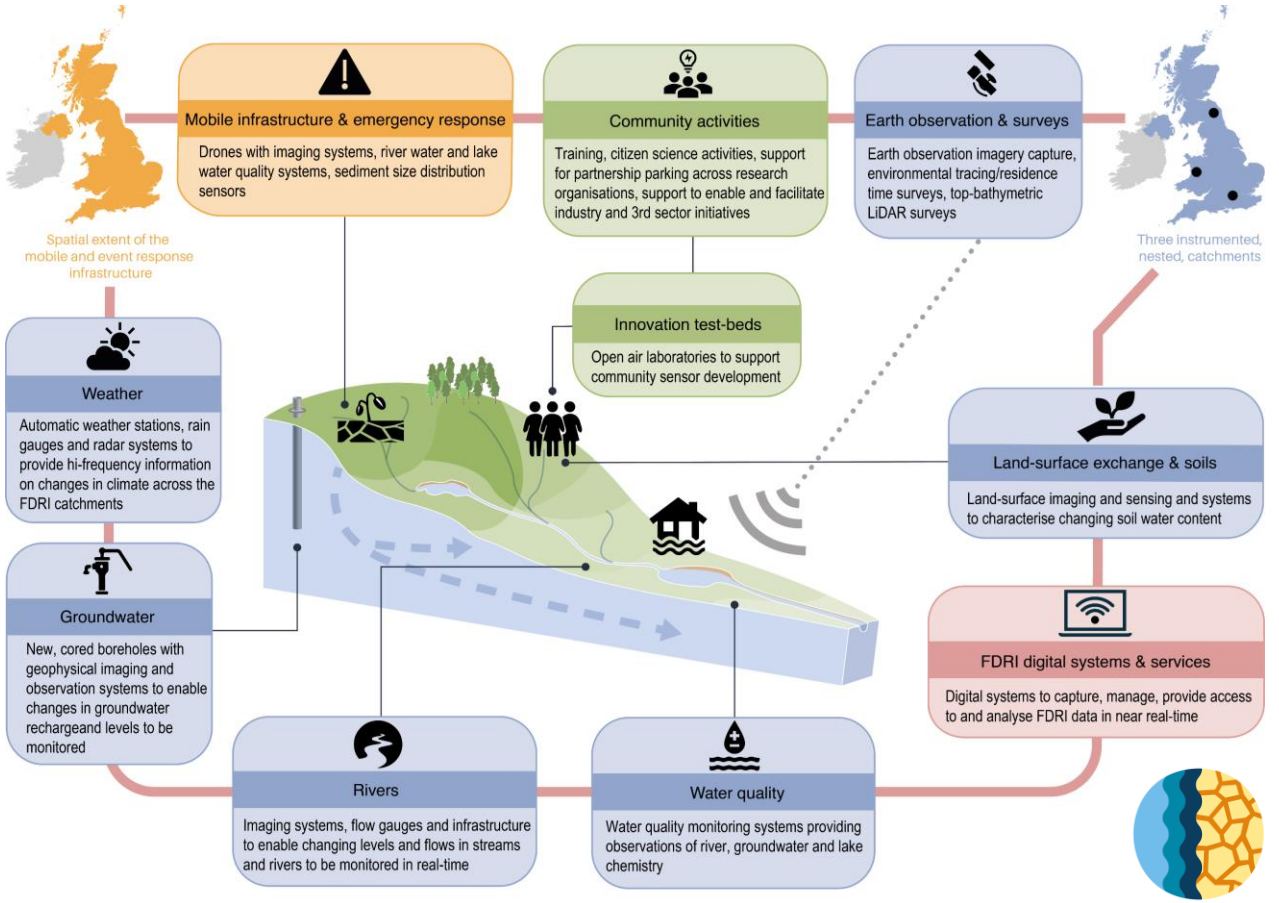
Quantifying floods and droughts in rapidly changing human-water systems

1) How do humans impact river flows?
2) Building integrated hydrological modelling frameworks
3) **Where do we go next?**

Looking Ahead: Community and collaboration

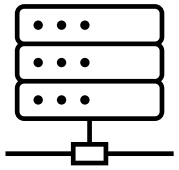
Open access data, modelling and platforms

- Network of coordinated observatories
- Unique integration of **mobile** and **fixed** infrastructure
- National-scale physical and **digital** infrastructure
- **Innovative** infrastructure
- **Community building** **at its core**



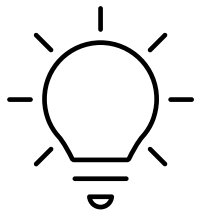
FDRI
FLOODS & DROUGHTS RESEARCH INFRASTRUCTURE

Looking Ahead: Community and collaboration



Open access data, modelling and platforms

Interdisciplinary partnership working to resolve community questions



New collaborative funds? Highlight topics? UKHydro-MIP? Community review?

Quantifying floods and droughts in rapidly changing human-water systems

Gemma Coxon

University of BRISTOL

UKRI Natural Environment Research Council

DR JOHN BLOOMFIELD
BRITISH GEOLOGICAL SURVEY & UNIVERSITY OF READING

Understanding hydrogeological extremes in a non-stationary world

International Association of Hydrogeologists
BRITISH NATIONAL CHAPTER

The Hydrogeological Group

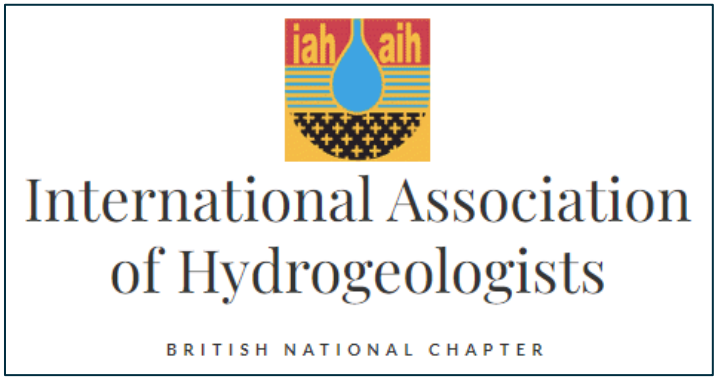
BGS British Geological Survey

Acknowledgements

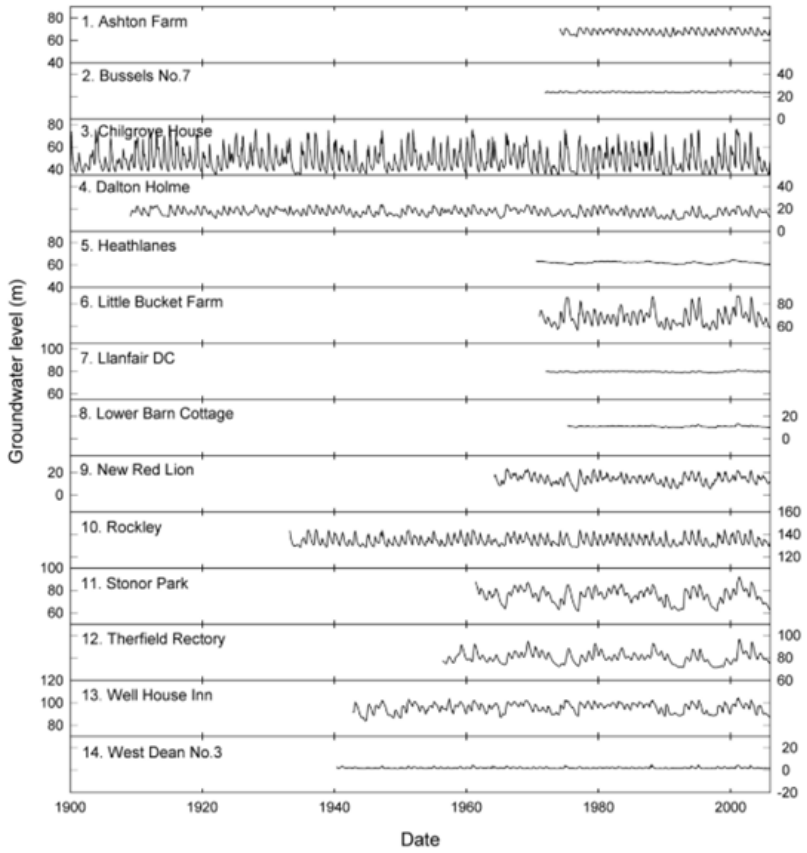
- Throughout the talk I've drawn on others work I hope this is acknowledged appropriately – if not please let me know!
- I'd like to thanks colleagues
  - in NERC's Centre-Surveys, particularly at the BGS and in UKCEH
  - in academia who have been so generous with their time and ideas and happy to be inclusive
  - in industry, and the regulatory and third sectors for interesting dialogues, and for the technical challenges that they set us
  - and colleagues in NERC and the other funding agencies that play such an important part in enabling our science
- I'd specifically like to acknowledge some colleagues who I've worked with over the last couple of decades, in no particular order:
  - Ben Marchant, Bentje Brauns, Matt Ascott, Chris Jackson, Jon Mackay, Andrew McKenzie, Emily Crane, Lei Wang, and everyone on the BGS groundwater data team (BGS); colleagues in the NRFA at UKCEH; Gareth Old and the FDRI Team at UKCEH; Gemma Coxon and Doris Wendt (Bristol); Ian Holman and Will Rust (Cranfield); David Hannah (Birmingham) and Anne Van Loon (Vrije Universiteit Amsterdam)
- Thanks also to the IAH committee and the HydroGroup of the Geol. Soc. for convening and hosting today's meeting and of course to all the today's speakers

(almost) 50 years of the Hydrogeology Group at Wallingford

- I also want to acknowledge the importance of the work of the **Hydrogeology Group of the British Geological Survey, Wallingford** over the last 50 years.
- I'm grateful to have spent my career within the collaborative, nurturing environment of this Group and it's a matter of great regret that it is being closed this December.
- One measure of the impact of this Group is the number of eminent hydrogeologists and hydrogeochemists who have presented previous Ineson Lectures, and I'm honoured and humbled to be entrusted by the IAH Committee to deliver this year's Ineson Lecture
  - Dick Downing (1992)
  - Stephen Foster (1999)
  - David Grey (2000)
  - Mike Edmunds (2001)
  - John Barker (2003)
  - Denis Peach (2009)
  - Pauline Smedley (2018)



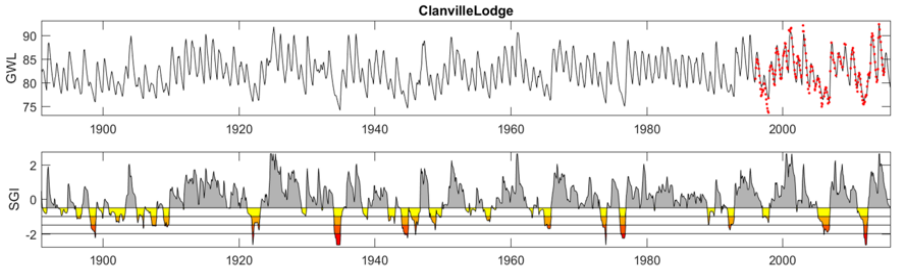
Scope of presentation

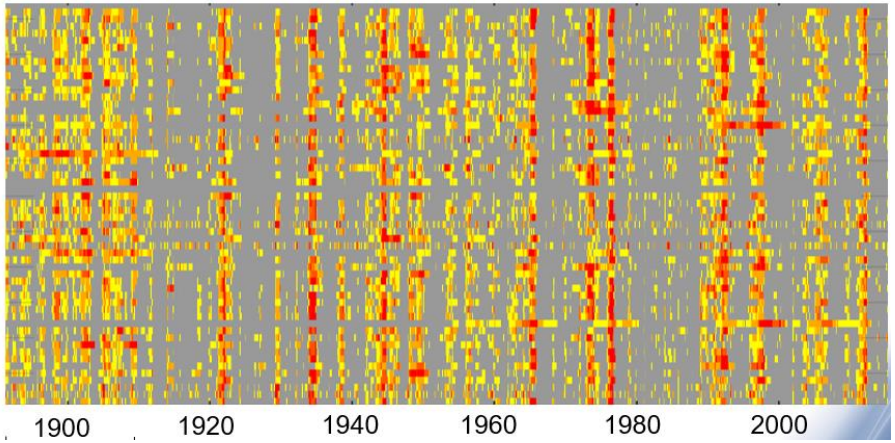


- It is not about how we measure and acquire groundwater level data, or how that is used for reporting of groundwater status.
- It is not about how that data is used for short-term (1-month to 12-month) forecasting, nor for decadal to centennial-scale modelling of groundwater levels under change.
- It is not about management responses to or planning for hydrogeological extremes.
- It's not about specific process understanding.
- **It's about the phenomenology of changing groundwater levels over a range of spatio-temporal scales, in response to a diverse range of drivers of change, and, importantly, how they relate to changes in the wider terrestrial water cycle.**

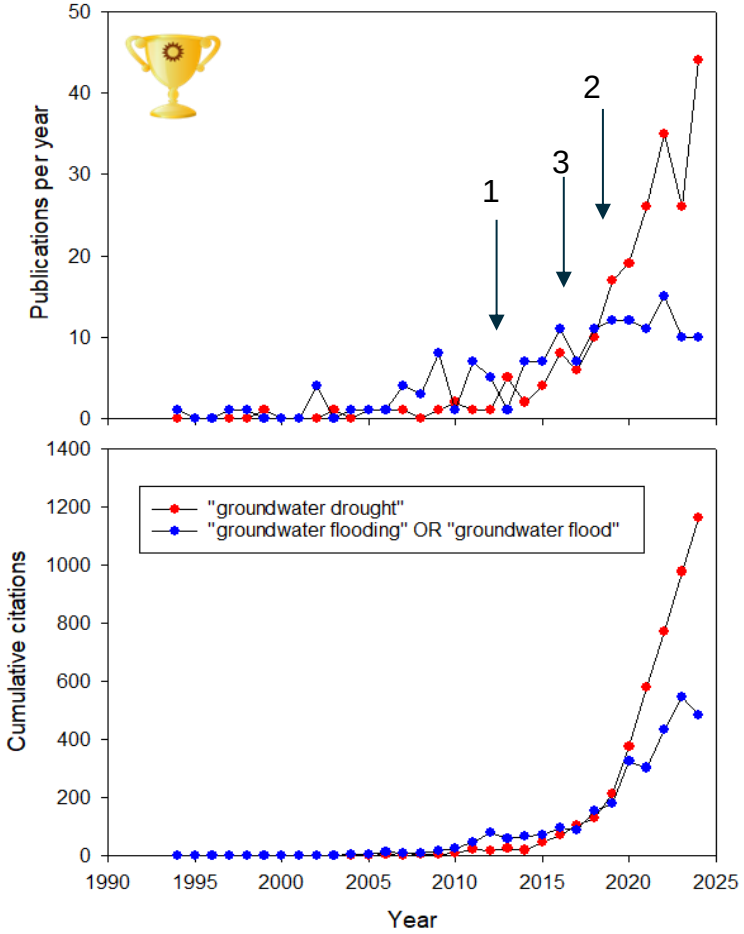
Outline of the talk

- **Introduction**
  - Context
  - Hydrogeological non-stationarity
  - Phenomenology of hydrogeological extremes
    - Spatial & temporal scales
    - Propagation of climate signals
- **Eight case studies**
  - Methodological development (x3)
  - Regional & continental scale examples (x2)
  - Long term (>100 years) variations in extremes (x2)
  - Analysis of impacts of extremes (x1)
- **Lessons learnt & future directions**
- **Audience participation (x5)**





Context - publications in peer-reviewed literature (data from Web of Science)



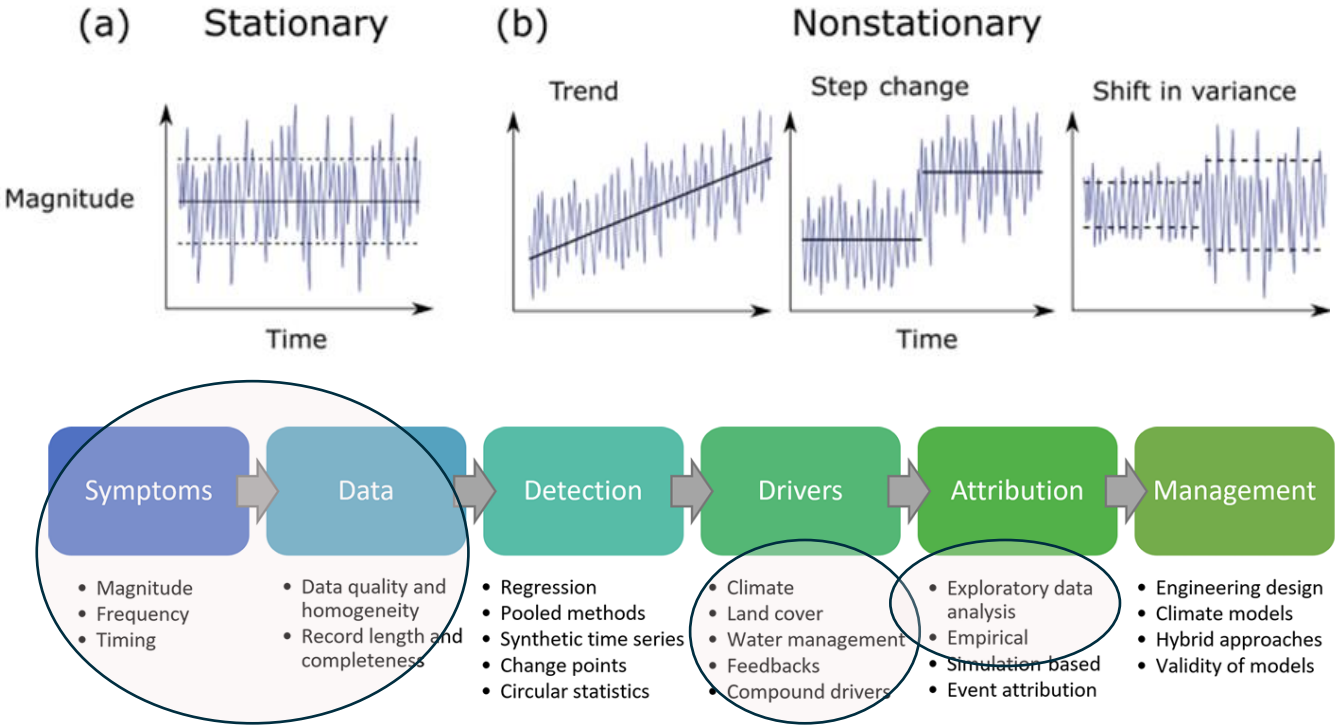
- "Groundwater drought": 212 publications and 4522 citations since 1999
- "Groundwater flooding" OR "Groundwater flood": 152 publications and 3042 citations since 1994
- Three most highly cited (~ 20% of all citations):

  1. Bloomfield & Marchant (2013) - Standardised Groundwater level Index
  2. Li et al (2019) - Global GRACE Data Assimilation for Groundwater and Drought Monitoring
  3. Thomas et al (2017) - GRACE Groundwater Drought Index: Evaluation of California Central Valley groundwater drought

- but there have been ~147,000 "drought" and ~160,000 "flood" OR "flooding" publications since 1994 (**about two orders of magnitude more!**)

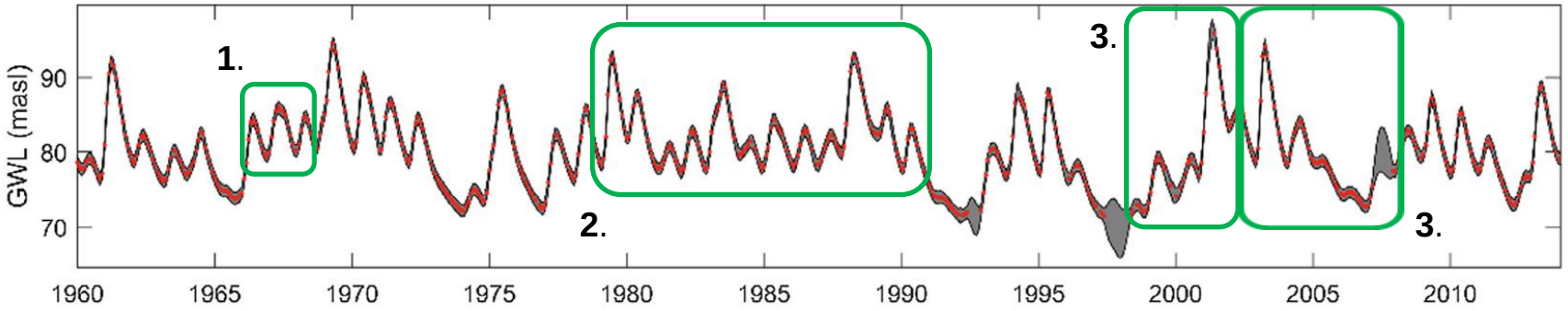
Stationarity – a working definition

A **stationary process** is a stochastic process whose **probability distribution does not change when shifted in time**. Consequently, parameters such as the **mean and variance of the series do not change over time**



Slater et al 2021. Nonstationary weather and water extremes: a review of methods for their detection, attribution, and management

Stationarity - Groundwater level fluctuations



- The Thirfield Rectory record has not been formally assessed for stationarity, but from visual inspection we can see:
  - periodic fluctuations (in this case typically annual fluctuations),
  - periods of short-term stationarity (in the illustrated case over a few years), and
  - periods of non-stationary over a few years
  - while the record as a whole may be stationary (no apparent change in variance).
- **Stationarity may be a function of the period and length of observation**

Table 6.2 Summary of Mechanisms That Lead to Fluctuations in Groundwater Levels

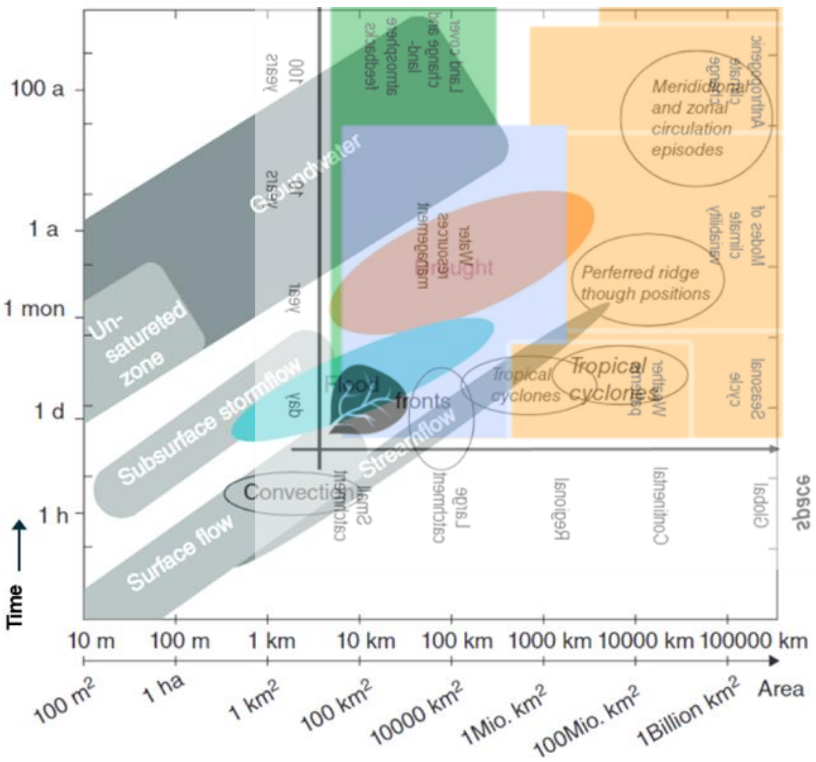
	Uncon-fined	Confined	Natural	Man-induced	Short-lived	Diurnal	Seasonal	Long-term	Climatic influence
Groundwater recharge (infiltration to the water table)	✓		✓				✓		✓
Air entrapment during groundwater recharge	✓		✓		✓				✓
Evapotranspiration and phreatophytic consumption	✓		✓			✓			✓
Bank-storage effects near streams	✓		✓				✓		✓
Tidal effects near oceans	✓	✓	✓			✓			
Atmospheric pressure effects	✓	✓	✓			✓			✓
External loading of confined aquifers		✓		✓	✓				
Earthquakes		✓	✓		✓				
Groundwater pumpage	✓	✓		✓				✓	
Deep-well injection		✓		✓				✓	
Artificial recharge; leakage from ponds, lagoons, and landfills	✓			✓				✓	
Agricultural irrigation and drainage	✓			✓				✓	✓
Geotechnical drainage of open pit mines, slopes, tunnels, etc.	✓			✓				✓	

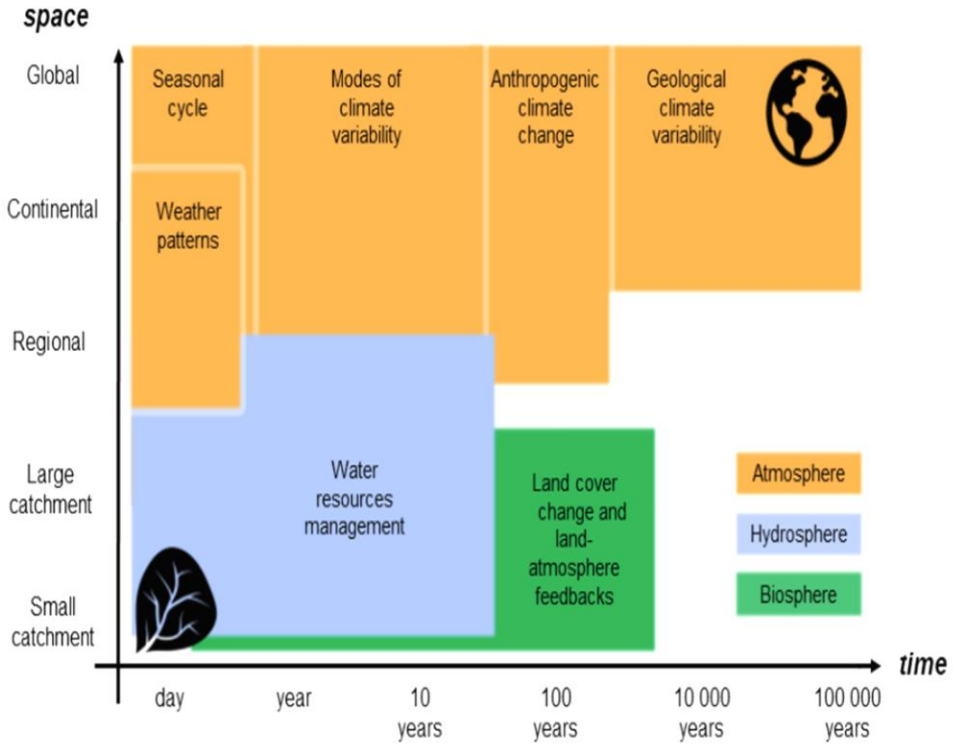
Freeze & Cherry 1979

Stationarity – controls on GW levels at different time frames

	"Natural" mechanisms									"Anthropogenic" mechanisms				
	Air entrapment	ET & phreatic consumption	Atmospheric pressure effects	Earthquakes	Tidal effects	Bank storage	GW recharge	Recent climate variability	Geological time climate variability	ASR	Deep-well injection	GW abstraction	Land cover change	Anthropogenic climate change
Sub-daily														
Diurnal														
Seasonal / annual														
Decadal														
Centenial														
Greater than centenial														

Mechanisms that are influential over longer periods typically also effect larger areas

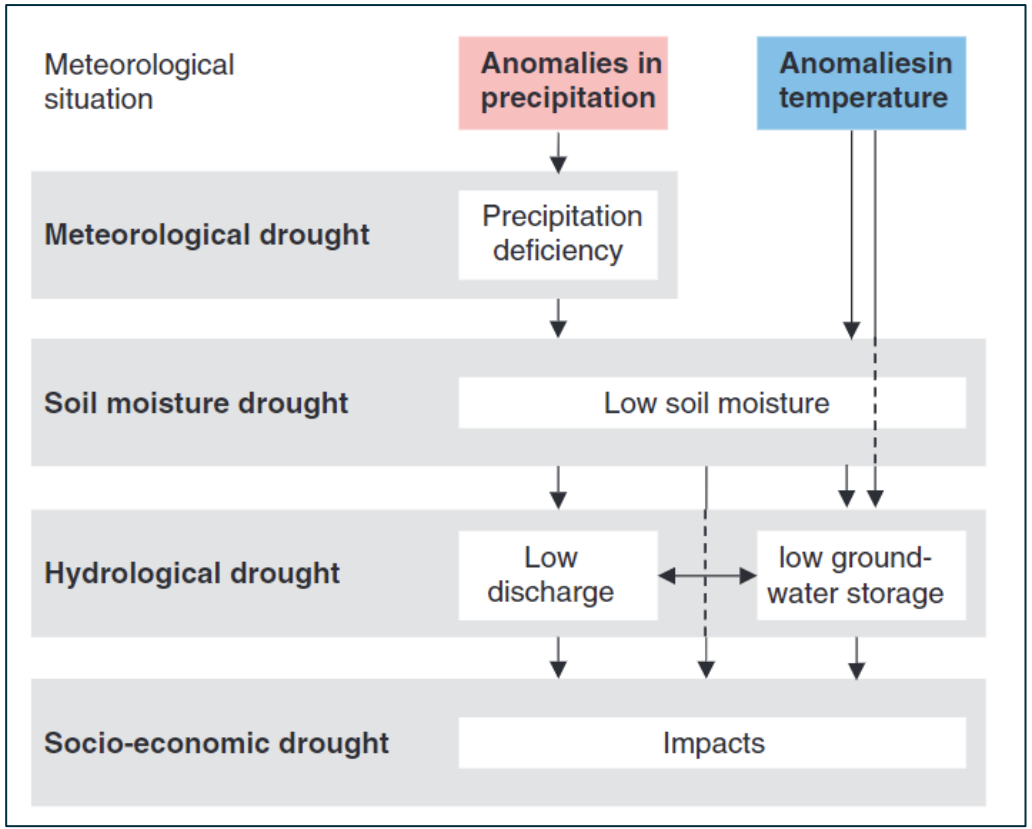




Hydrological processes (floods & droughts), their climate **drivers** and the **domains** that are affected (Van Loon, 2015)

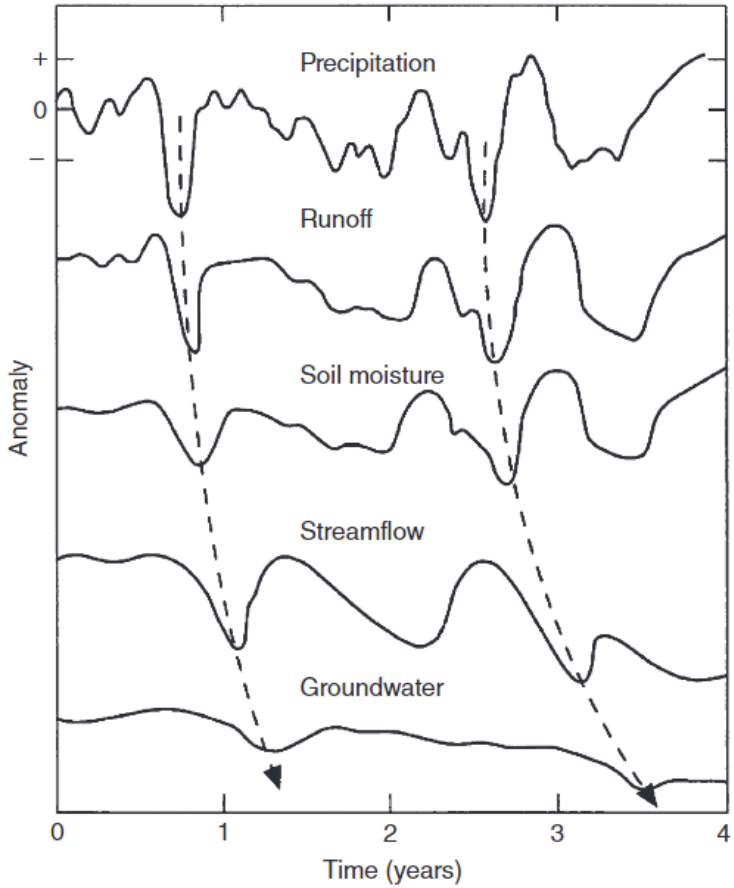
Drivers of non-stationary water extremes (Slater et al ., 2021)

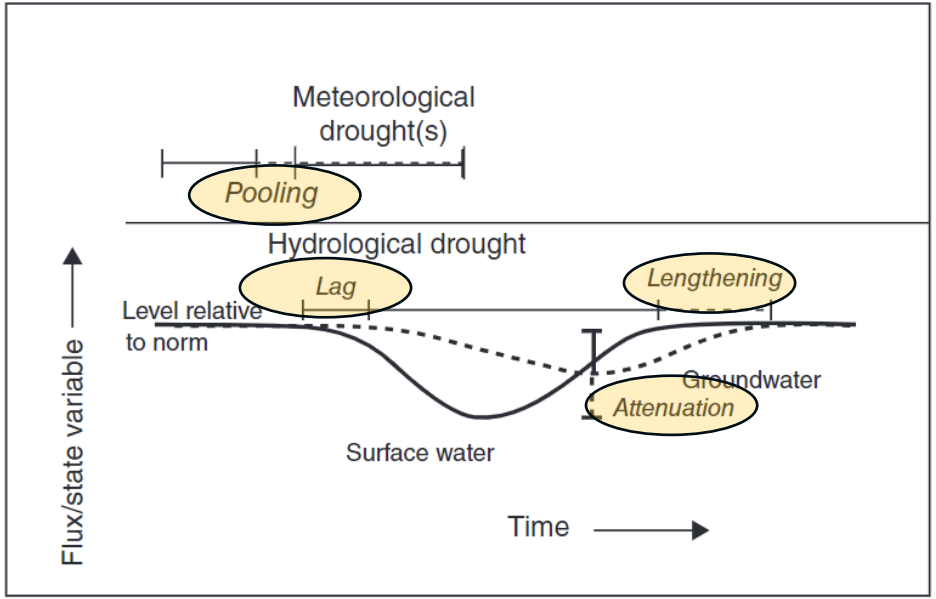
Hydrogeological extremes - drought



Van Loon 2015

Hydrogeological extremes - drought





Van Loon 2015

Eight case studies

Methodological development

- Standardised Groundwater level Index (**SGI**) methodology
- Application of a standardised index (**SGFI**) to characterise groundwater flooding
- Correlation with other hydrological standardised indices (e.g. **SSI**)

Regional to continental scale examples

- Regional (Lincolnshire) analysis of groundwater drought using cluster analysis of SGI timeseries
- European groundwater drought analysis

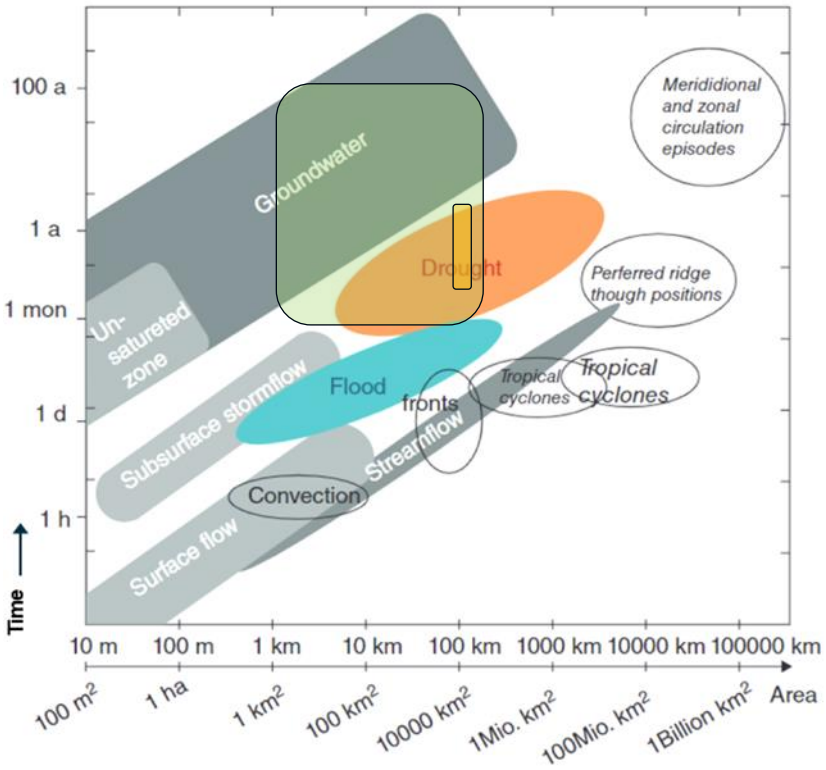
Long-term (>100 years) variations in extremes

- Reconstruction of historic droughts
- Signals of climate change in groundwater droughts?

Impacts of extremes

- Analysis of impacts of hydrological extremes

Methodology #1 – SGI



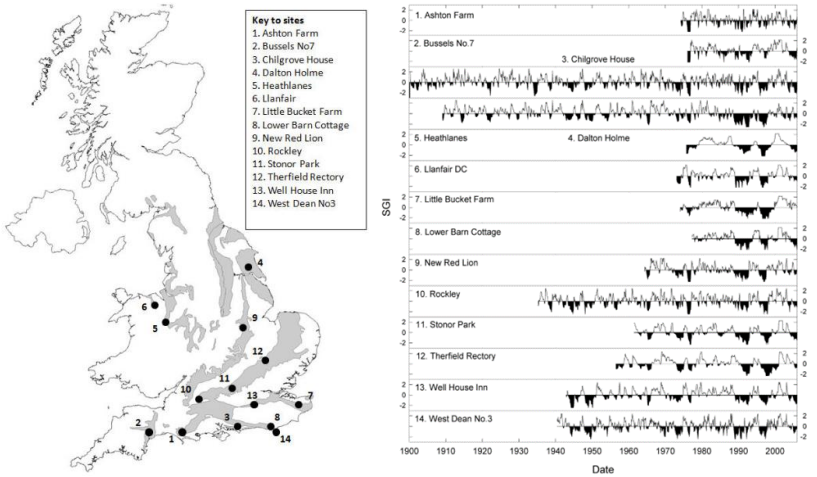
after Van Loon 2015

Analysis of groundwater drought building on the standardised precipitation index approach

J. P. Bloomfield[1] and B. P. Marchant[2]

Hydrol. Earth Syst. Sci., 17, 4769–4787, 2013
www.hydrol-earth-syst-sci.net/17/4769/2013/
doi:10.5194/hess-17-4769-2013

Hydrology and Earth System Sciences
Open Access



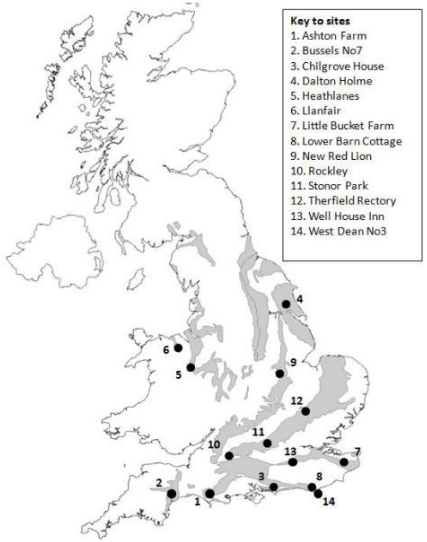
Study area: 1 km² – 134,000 km²
Temporal range: 1 month to 100 years
Drought area: ~100,000 km²
Drought duration: 3 months – 2 years

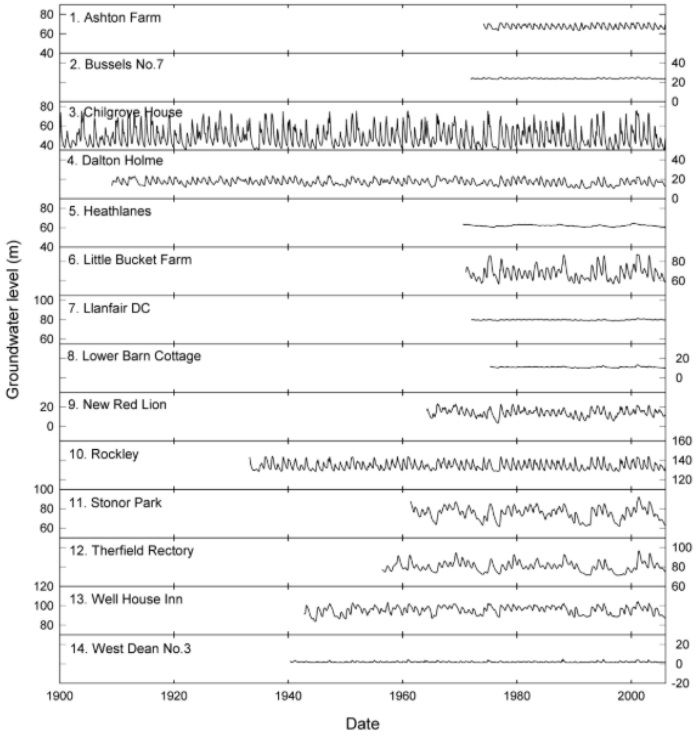
Analysis of groundwater drought building on the standardised precipitation index approach

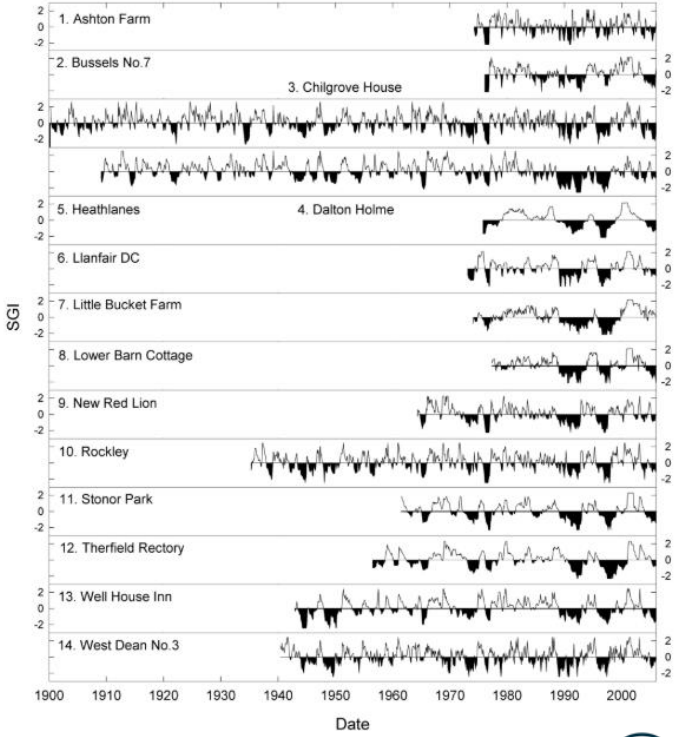
J. P. Bloomfield[1] and B. P. Marchant[2]

Hydrol. Earth Syst. Sci., 17, 4769–4787, 2013
www.hydrol-earth-syst-sci.net/17/4769/2013/
doi:10.5194/hess-17-4769-2013

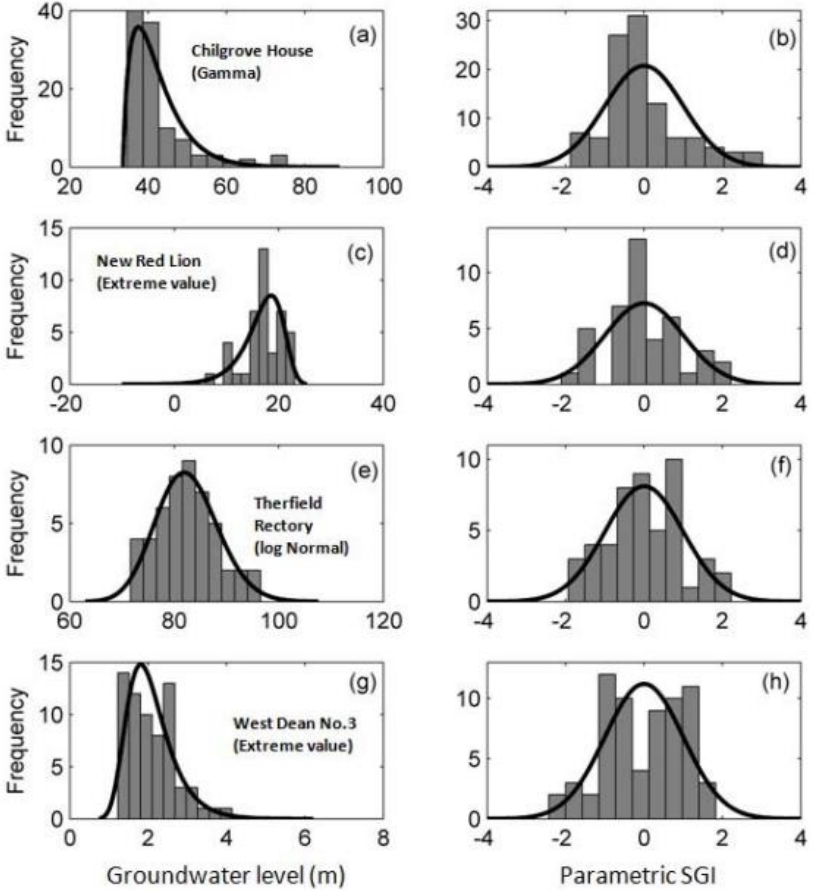
Hydrology and Earth System Sciences
Open Access







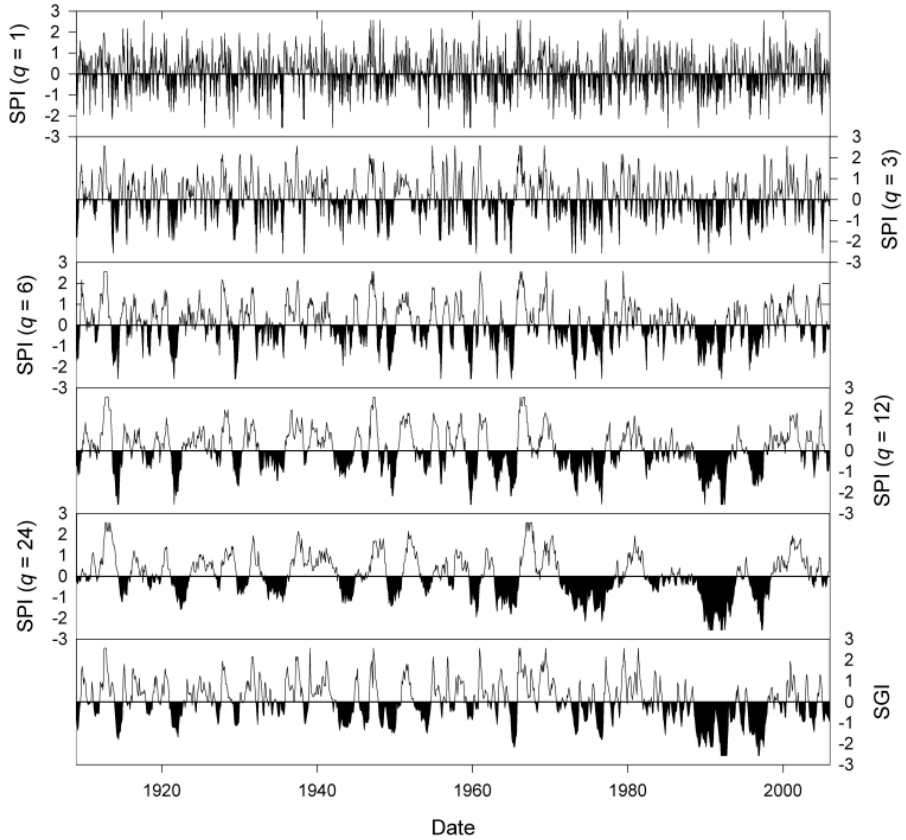
Standardised Groundwater level Index - SGI



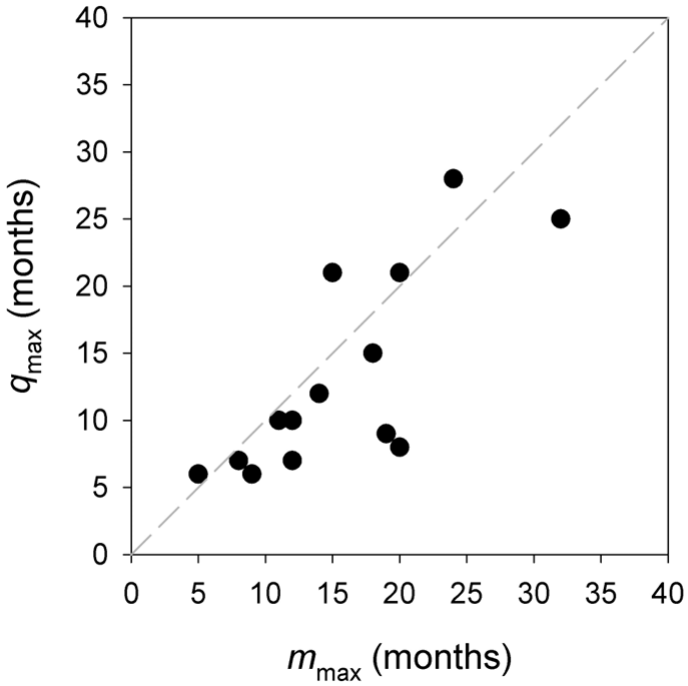
The normal scores transform is undertaken by:

- applying the inverse normal cumulative distribution function to n equally spaced p_i values ranging from $1/(2\,n)$ to $1 - 1/(2\,n)$.
- The values that result are the SGI values.
- They are then re-ordered such that the largest SGI value is assigned to the i for which p_i is largest, the second largest SGI value is assigned to the i for which p_i is second largest and so on.

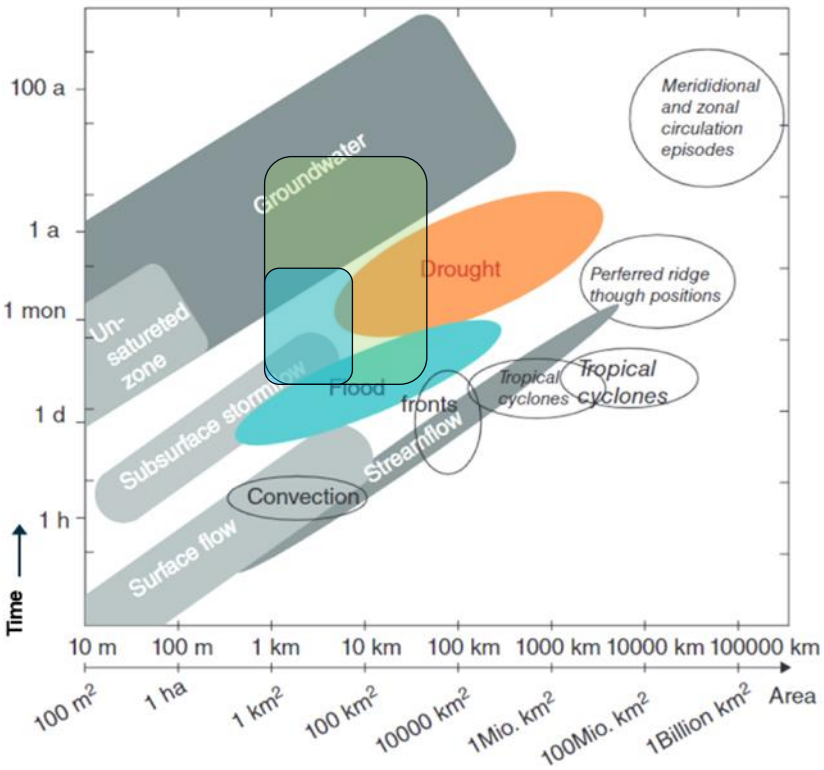
SGI autocorrelation & correlation with climate variables



SPI_n and SGI time series for Dalton Holme



Methodology #2 – SGFI



after Van Loon 2015

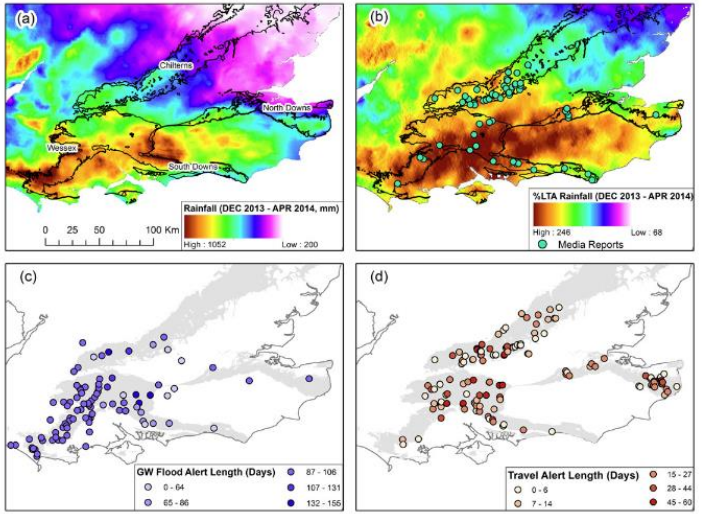
Hydrological Processes

Volume 31, Issue 25
15 December 2017
Pages 4586-4599

RESEARCH ARTICLE | Full Access

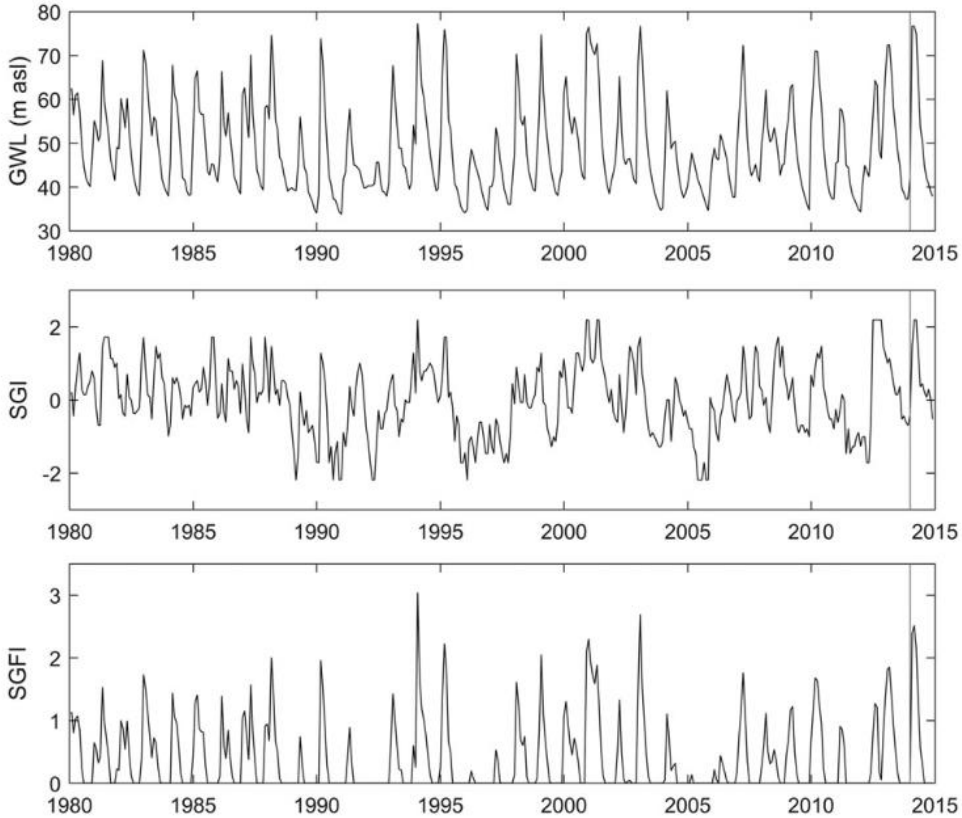
Improved understanding of spatio-temporal controls on regional scale groundwater flooding using hydrograph analysis and impulse response functions

Matthew J. Ascott, Ben P. Marchant, David Macdonald, Andrew A. McKenzie, John Paul Bloomfield



Study area: <1 km² – 19,000 km²
Temporal range: 1 week to 35 years
Flood area: <1 km² - ~10 km²
Flood duration: 1 week to 6 months

Standardization to characterise groundwater flooding



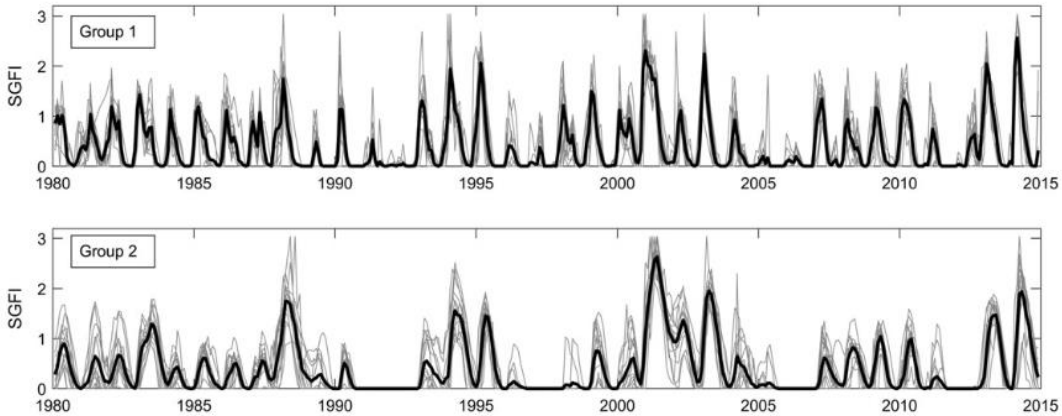
Chilgrove House hydrographs.
Ascott et al 2017. Hydrological Processes, 31, 4586-4599

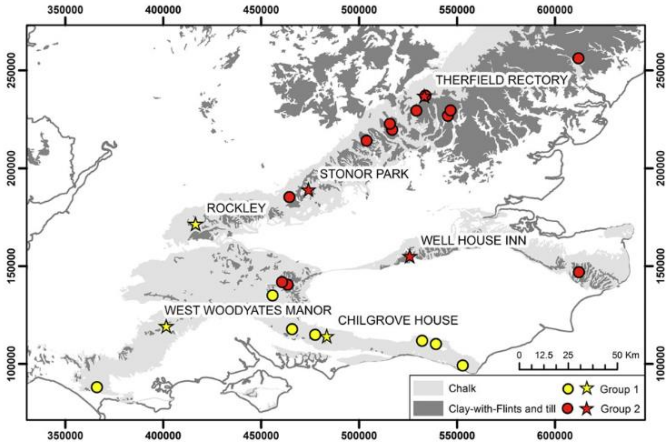
Standardized Groundwater Flood Index (SGFI)

Apply normalization to the entire set of groundwater level measurements so the index reflects the absolute rather than de-seasonalized groundwater level (because groundwater flooding is related to the absolute level of groundwater).

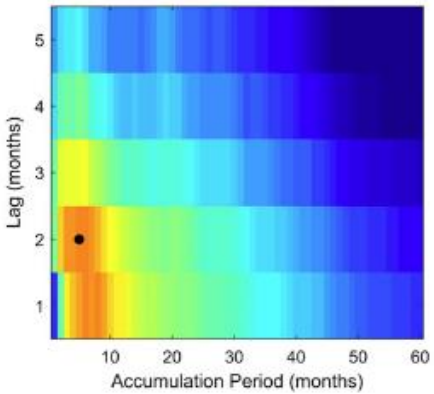
All **negative normalized values set to zero** to focus upon periods where the groundwater levels were higher than their median. **This was done because of the non-linear relationships between precipitation and groundwater levels previously documented by Eltahir and Yeh (1999),** and they were specifically interested in possible correlations between precipitation and incidences of flooding associated with high groundwater levels.

SGFI & groundwater flooding

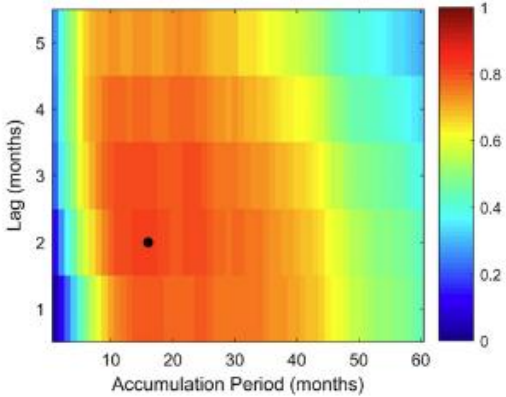




Grouping SGFI series using k-means cluster analysis and cross-correlation of SGFI cluster centroids with SPI revealed two spatially coherent groups of standardized hydrographs that responded to precipitation over different timescales.

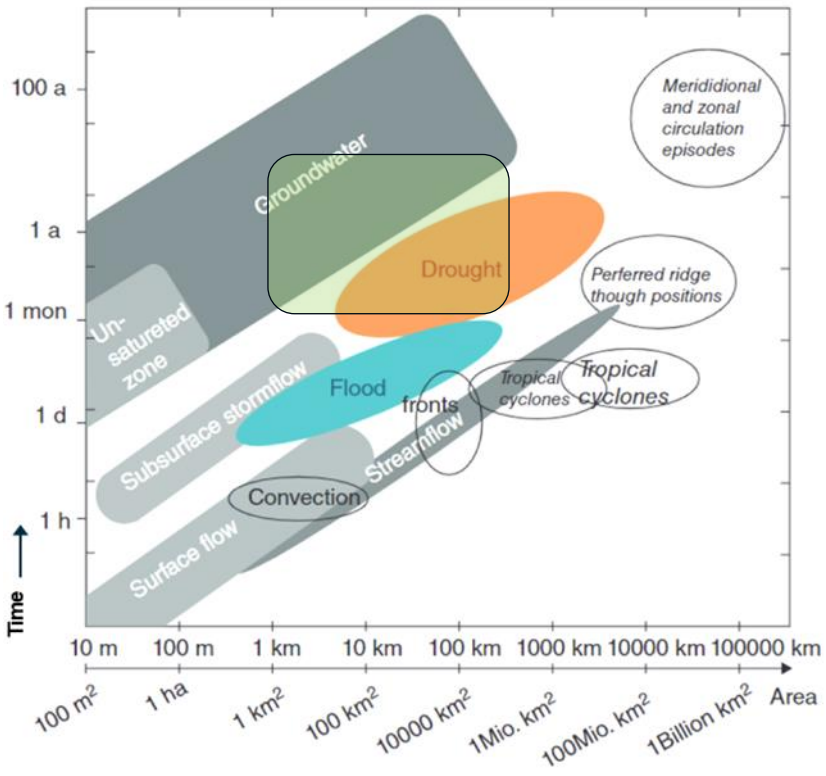


Group 1: SPI_5



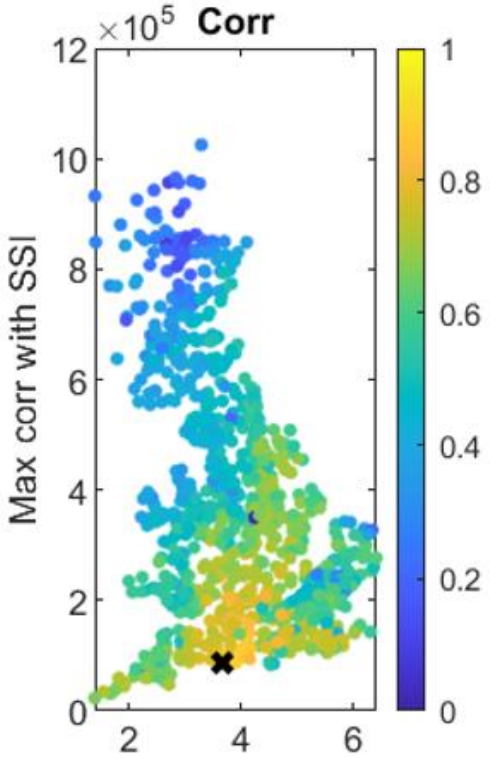
Group 2: SPI_{16}

Methodology #3 – SGI & SSI



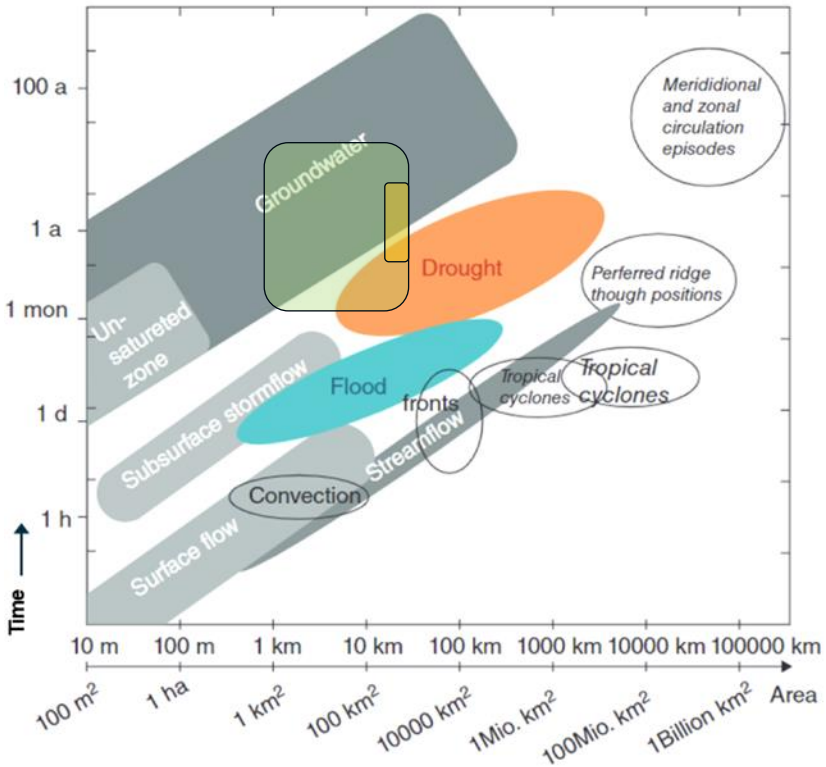
after Van Loon 2015

Links between SGI & SSI
Ben Marchant & Matt Ascott (in prep)



Analysis area: 1 km² – 240,000 km²
Temporal range: 1 month to 20 years

Regional analysis of drought



after Van Loon 2015

Regional analysis of groundwater droughts using hydrograph classification

J. P. Bloomfield[1], B. P. Marchant[2], S. H. Bricker[2], and R. B. Morgan[3]

Hydrol. Earth Syst. Sci., 19, 4327–4344, 2015
www.hydrol-earth-syst-sci.net/19/4327/2015/
doi:10.5194/hess-19-4327-2015

Hydrology and Earth System Sciences
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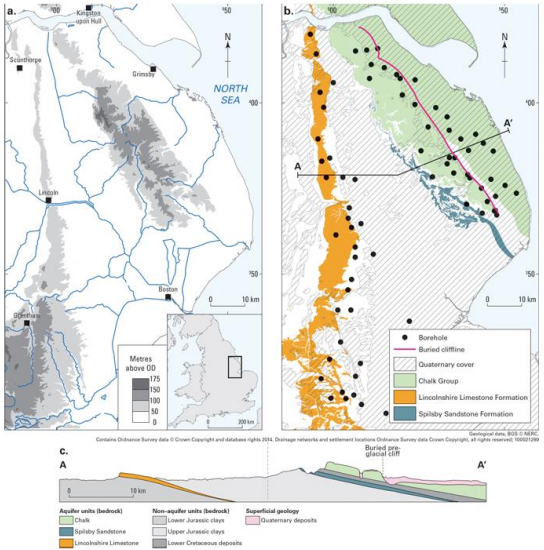
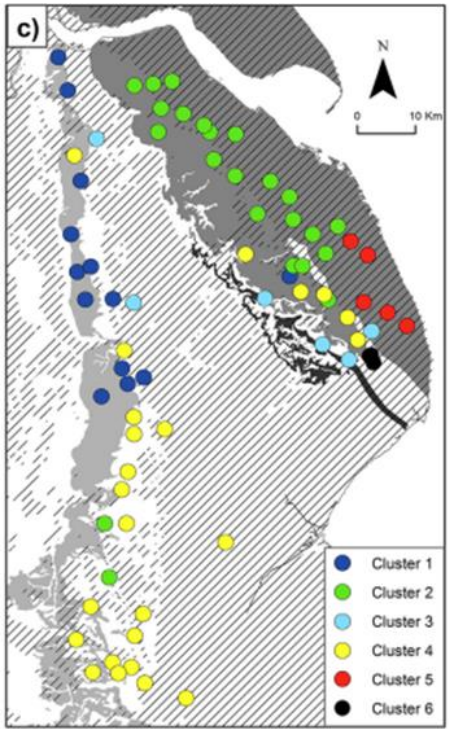
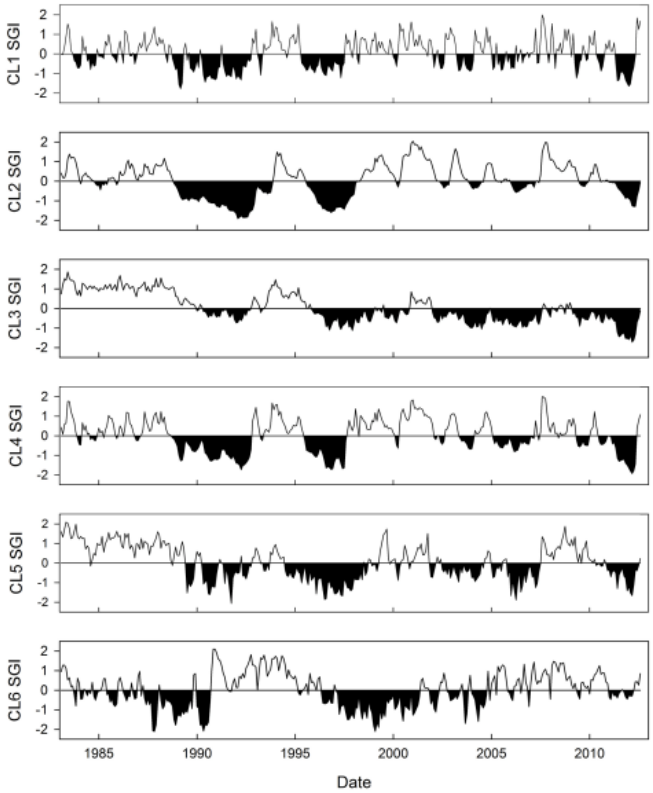
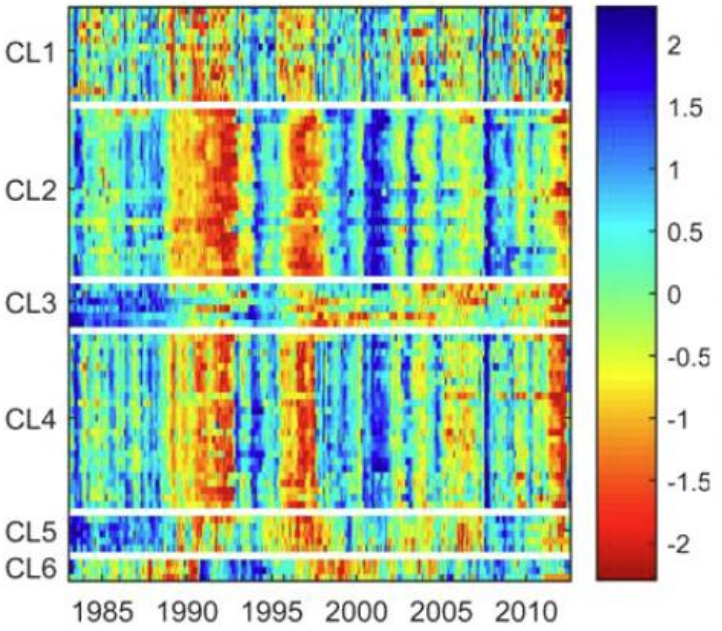


Study area: 1 km² – 7,000 km²
Temporal range: 1 month to 30 years
Drought area: ~7,000 km²
Drought duration: 3 months – 2 years

Regional groundwater drought characterization







Regional groundwater drought characterization

	CL1	CL2	CL4
Number of drought events	39	15	18
Mean duration (months)	4.6	11.3	9.1
Maximum duration (months)	27	61	49
Mean event magnitude	−2.9	−7.9	−6.6
Mean event intensity	−0.43	−0.28	−0.4
Maximum event intensity	−1.1	−1.05	−1.13
No. of events where $I < -1$	3	2	2

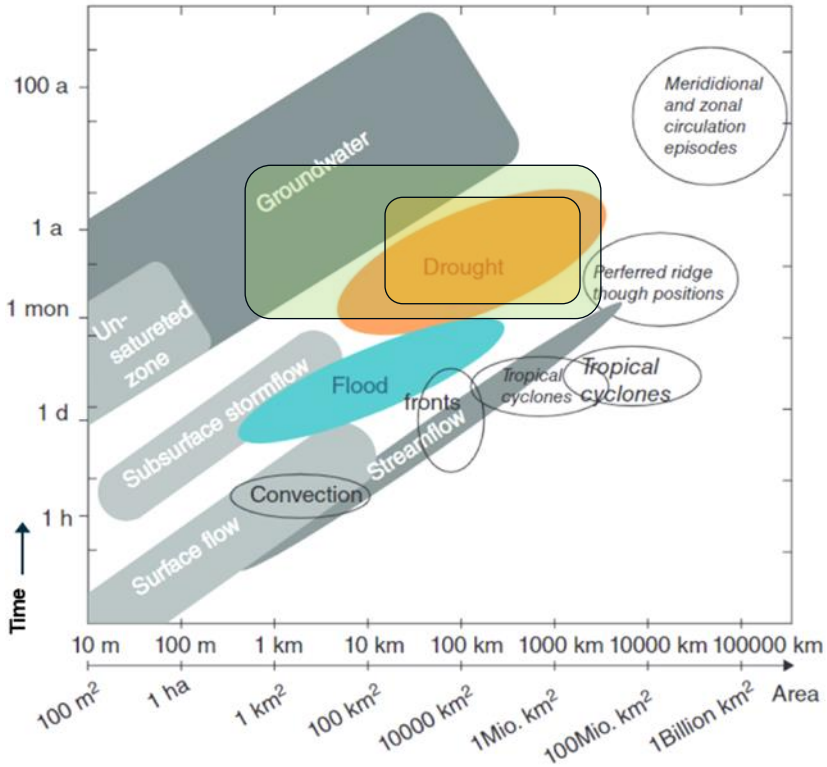
Summary of drought statistics for cluster means

Drought episode	Drought index	Regional SPI_{12}	Mean SGI CL1	Mean SGI CL2	Mean SGI CL4
1988 to 1993	Start date	Dec 1988	Oct 1988	Nov 1988	Oct 1988
	End date	Oct 1992	May 1993	Nov 1993	May 1993
	D_{event}	47	56	61	56
	M_{event}	−56.8	−37	−63.6	−41.6
	I_{event}	−1.2	−0.7	−1.0	−0.7
1995 to 1998	Start date	May 1995	May 1995	Aug 1995	Jul 1995
	End date	Oct 1997	Jul 1997	Feb 1998	Aug 1997
	D_{event}	30	27	31	26
	M_{event}	−34.3	−18.7	−32.4	−29.3
	I_{event}	−1.1	−0.7	−1.0	−1.1
2010 to 2012	Start date	Jan 2011	May 2011	Jan 2011	Jul 2010
	End date	Apr 2012	May 2012	Aug 2012	May 2012
	D_{event}	16	13	20	23
	M_{event}	−16.1	−13.9	−11.7	−21
	I_{event}	−1.0	−1.1	−0.6	−0.9

Summary of drought statistics for individual drought episodes

Continental-scale analysis of drought

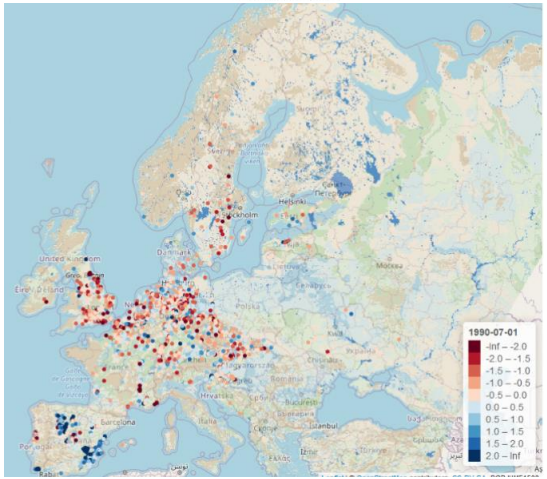
Proc. IAHS, 383, 297–305, 2020
https://doi.org/10.5194/piahs-383-297-2020



after Van Loon 2015

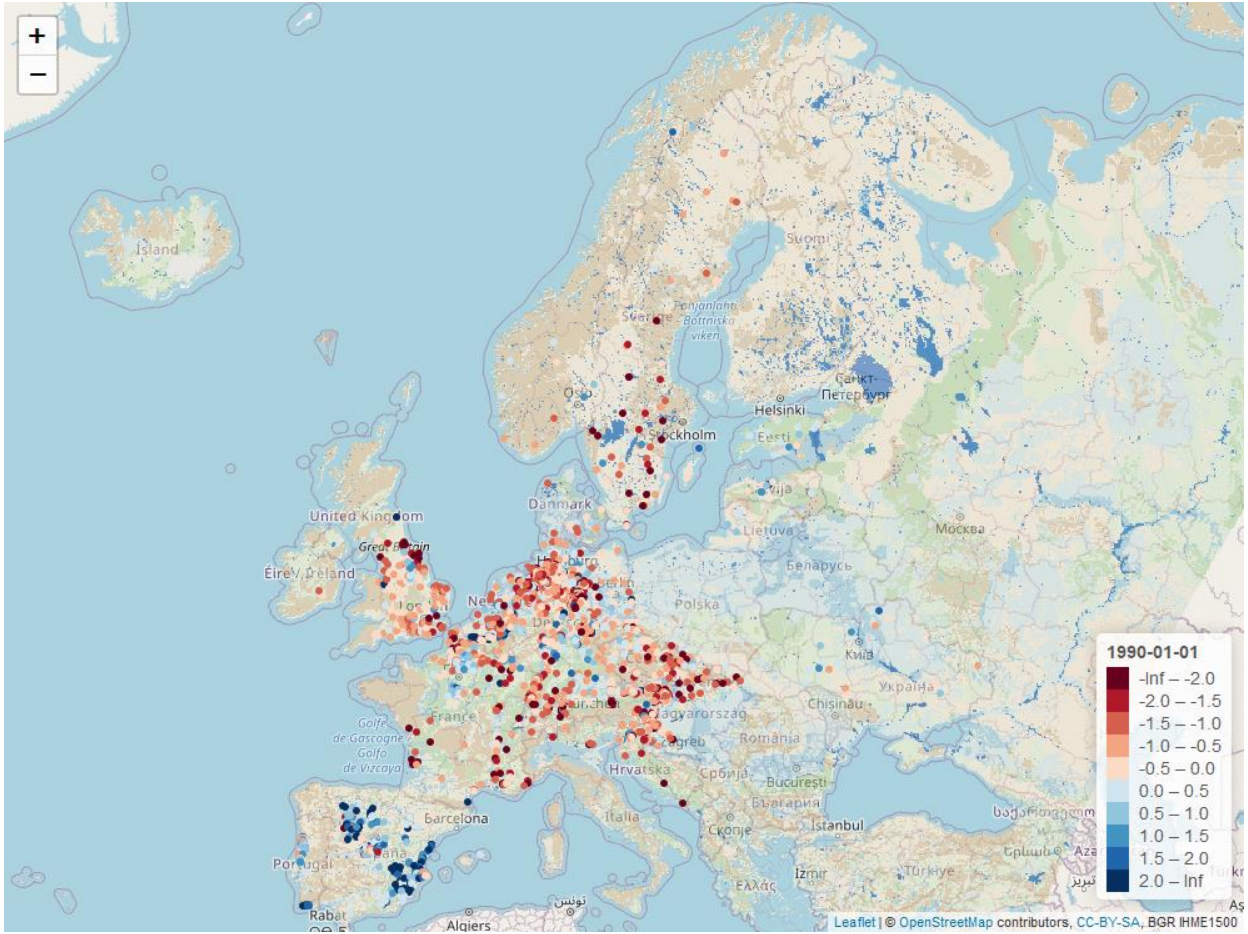
The Groundwater Drought Initiative (GDI): Analysing and understanding groundwater drought across Europe

Bentje Brauns[1], Daniela Cuba[1], John P. Bloomfield[2], David M. Hannah[3], Christopher Jackson[1], Ben P. Marchant[1], Benedikt Heudorfer[3], Anne F. Van Loon[3,a], Hélène Bessière[4], Bo Thunholm[5], and Gerhard Schubert[6]

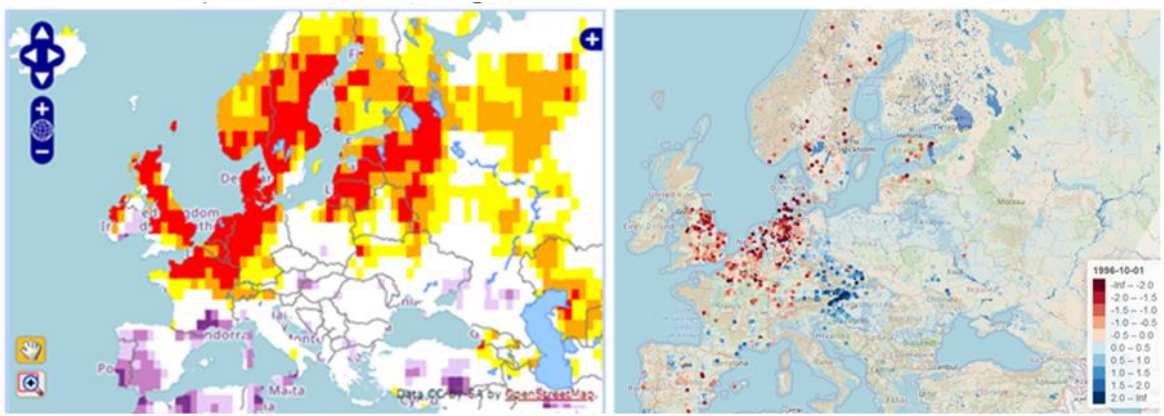


Study area: 1 km² – 10,000,000 km²
Temporal range: 1 month to 20 years
Drought area: 1,000 km² - 1,000,000 km²
Drought duration: 3 months – 2 years

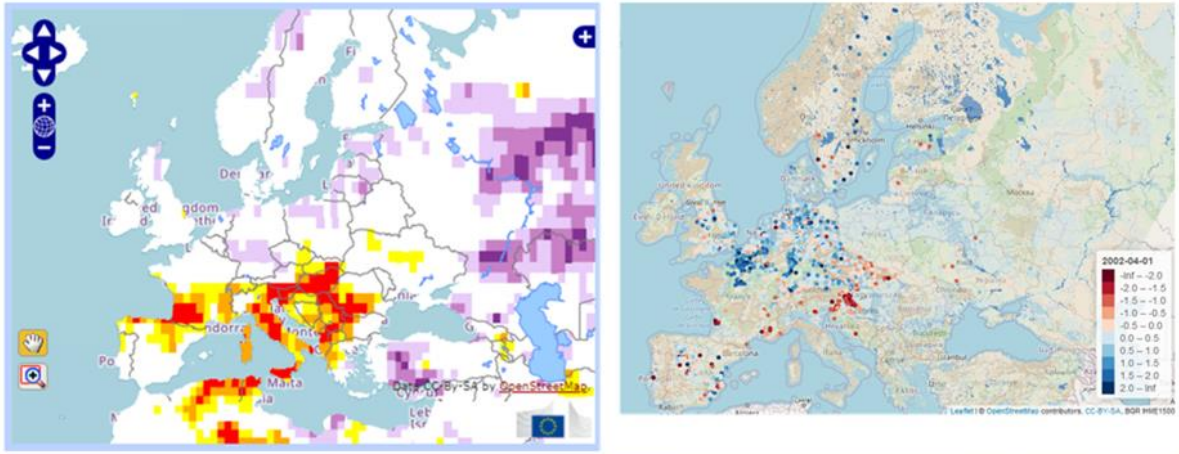
Continental scale groundwater drought propagation



Continental scale groundwater drought propagation



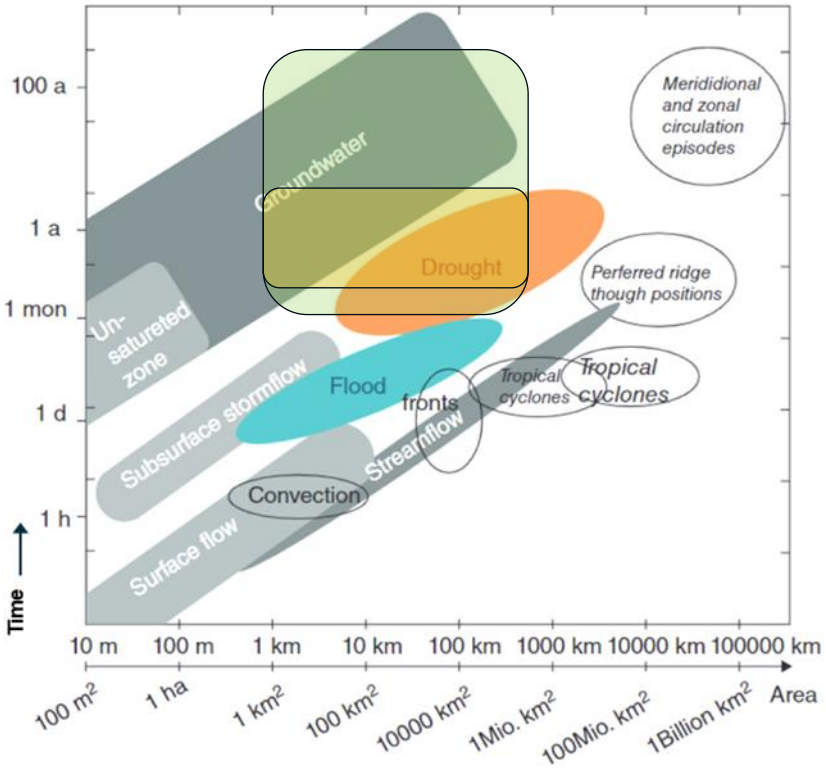
SPI_{12} Sept 1996 & SGI Oct 1996



SPI_{12} Mar 2002 & SGI April 2002

European Drought Observatory - https://drought.emergency.copernicus.eu/

Reconstruction of historic droughts

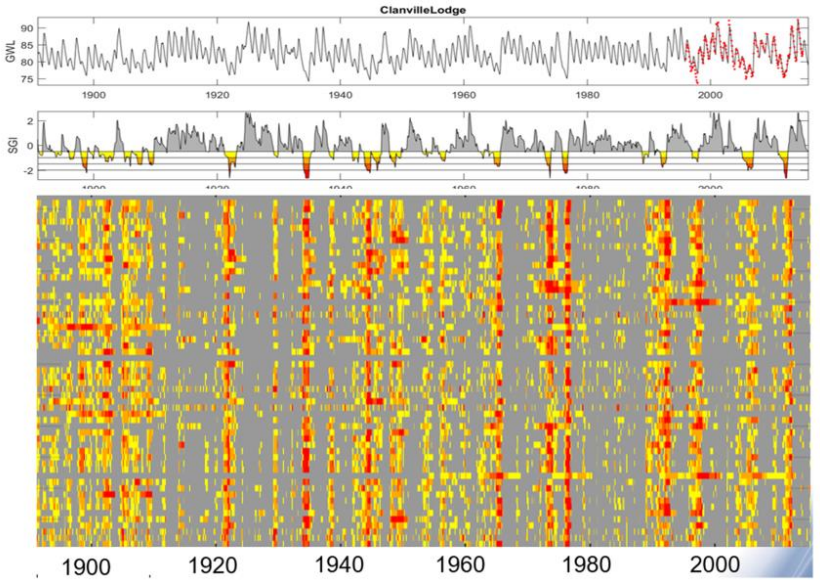


after Van Loon 2015

Bloomfield, J.P.; Marchant, B.P.; Wang, L.

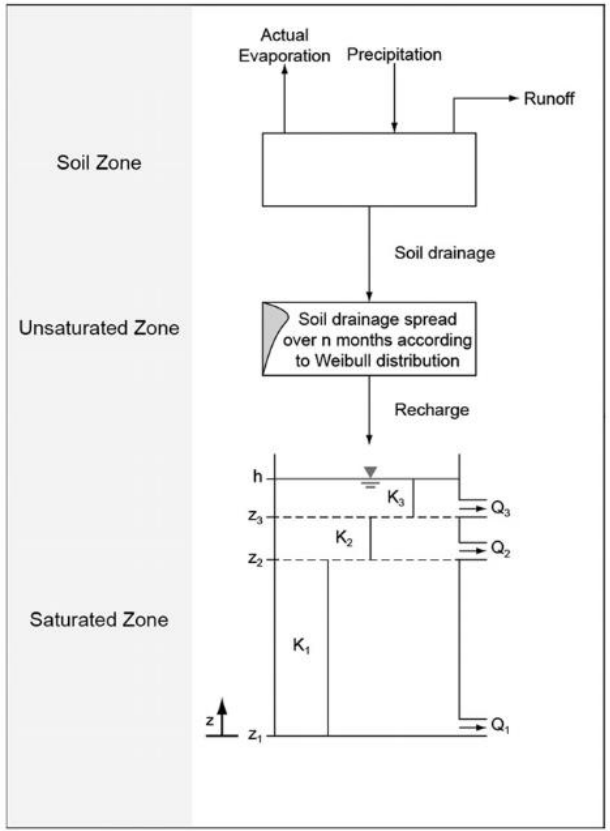
Historic Standardised Groundwater level Index (SGI) for 54 UK boreholes (1891-2015)

https://doi.org/10.5285/d92c91ec-2f96-4ab2-8549-37d520dbd5fc

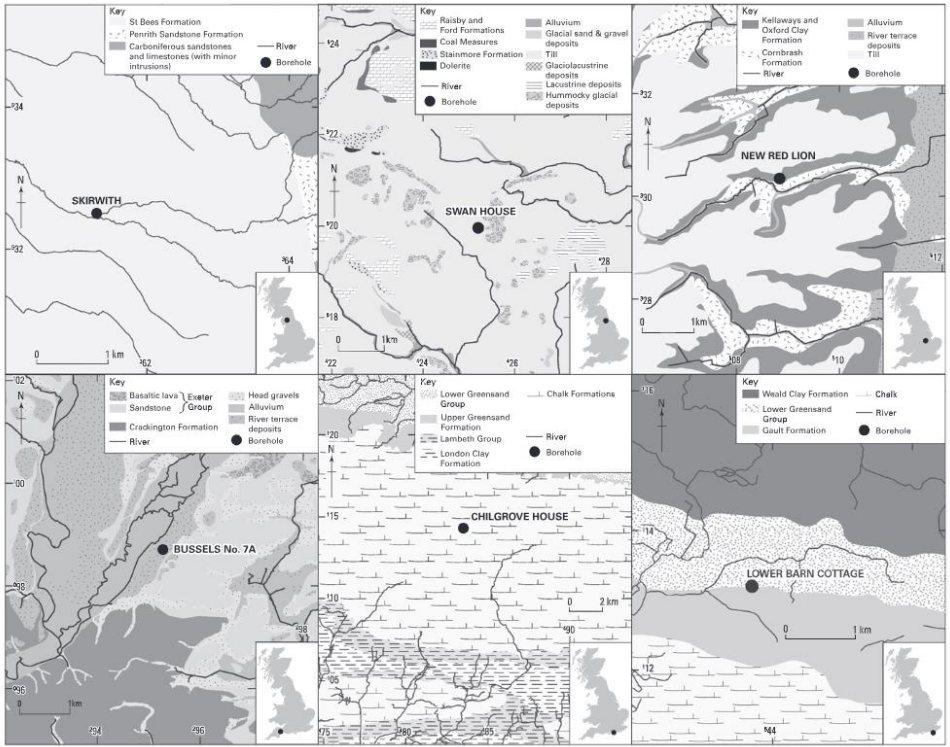


Study area: 1 km² – 134,000 km²
Temporal range: 1 month to 125 years
Drought area: 1 km² – 134,000 km²
Drought duration: 3 months – 2 years

Groundwater level reconstruction for drought analysis

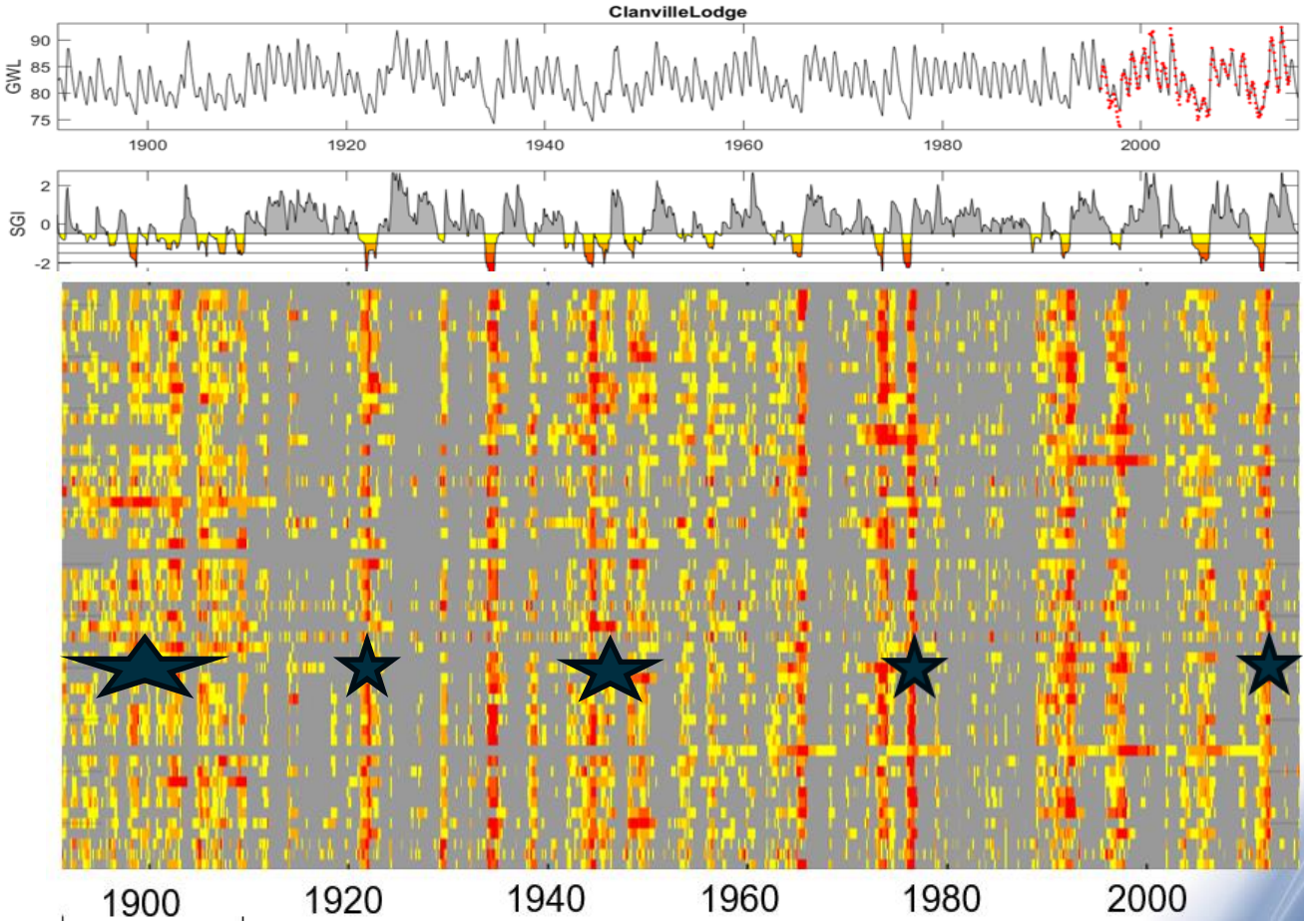


Using a method developed by Jackson et al (2016)

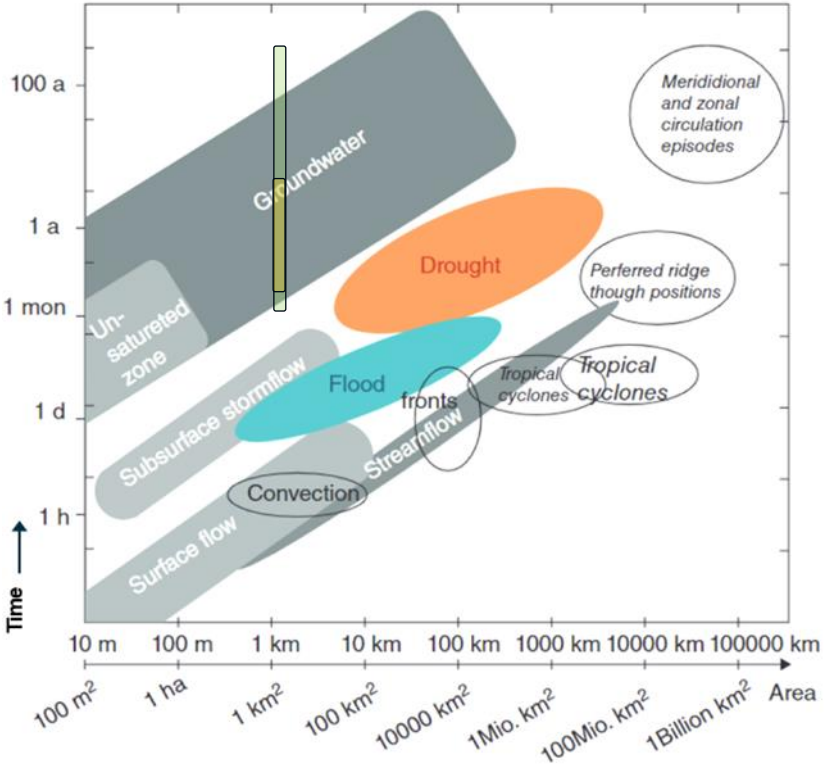


Jackson et al. 2016. Hydrological Processes, 30, 3107-3125

Groundwater level reconstruction for drought analysis



CC & groundwater drought



after Van Loon 2015

Hydrol. Earth Syst. Sci., 23, 1393–1408, 2019
https://doi.org/10.5194/hess-23-1393-2019

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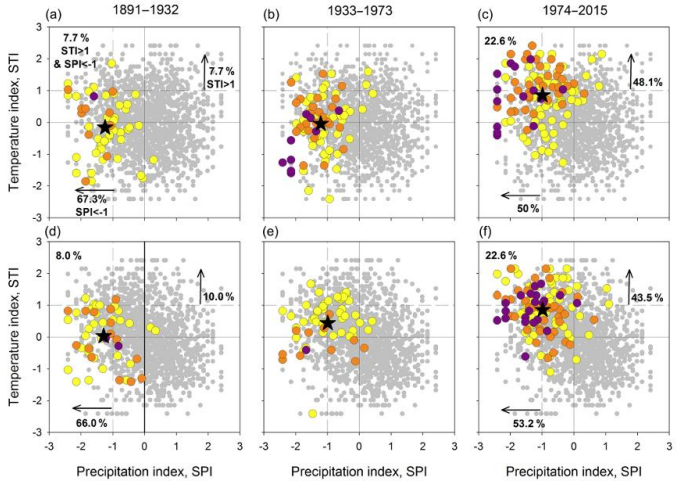
Changes in groundwater drought associated with anthropogenic warming

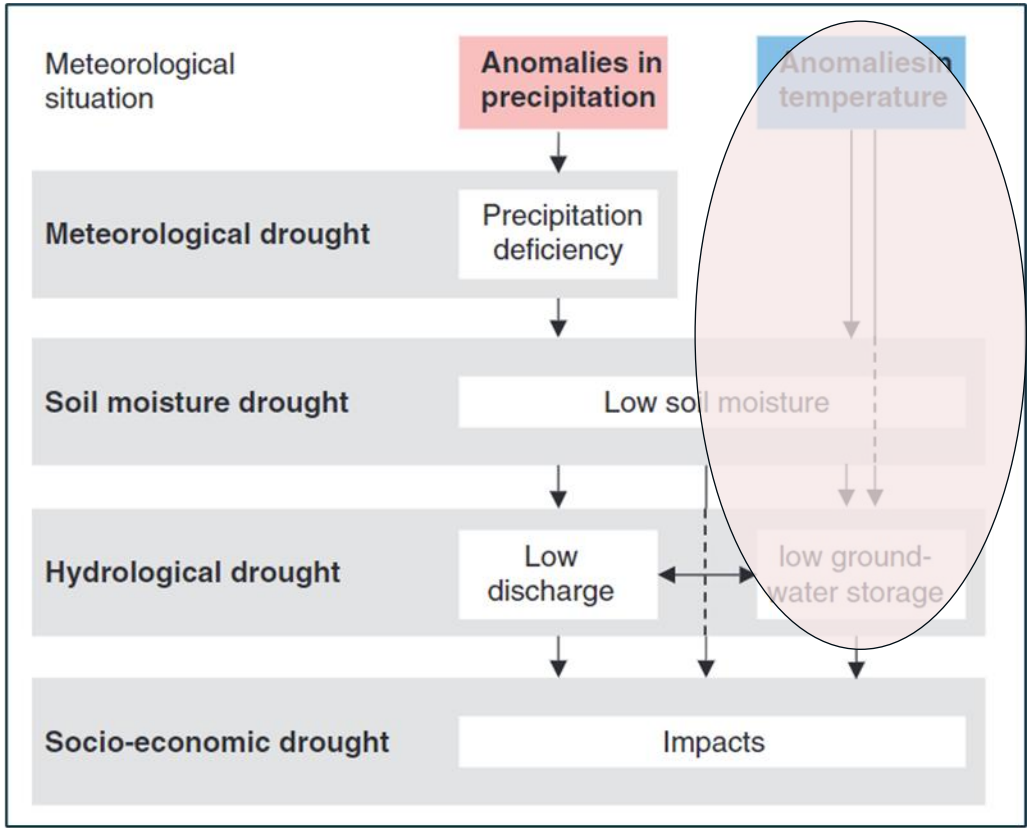
John P. Bloomfield[1], Benjamin P. Marchant[2], and Andrew A. McKenzie[1]



Study area: 1 km²
Temporal range: 1 month to 125 years
Drought area: 1 km²
Drought duration: 3 months – 2 years

BGS

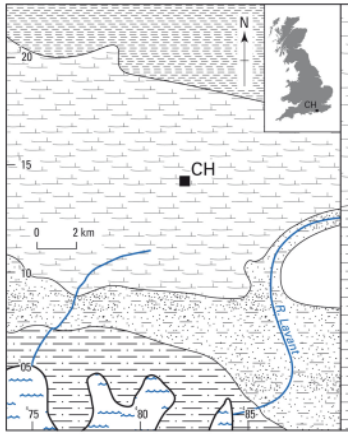
Does CC effect groundwater drought in the UK?



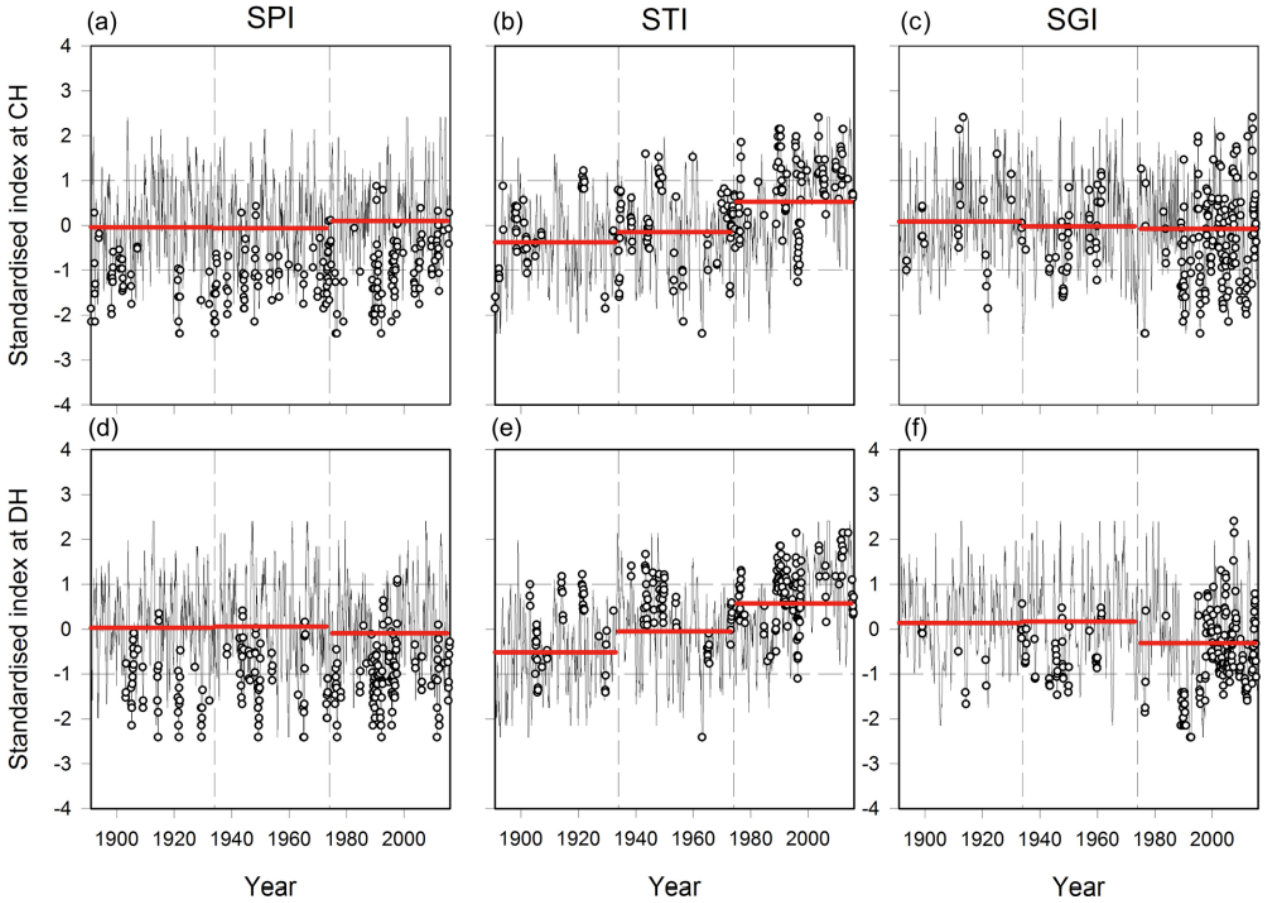
Van Loon 2015

Does CC effect groundwater drought in the UK?

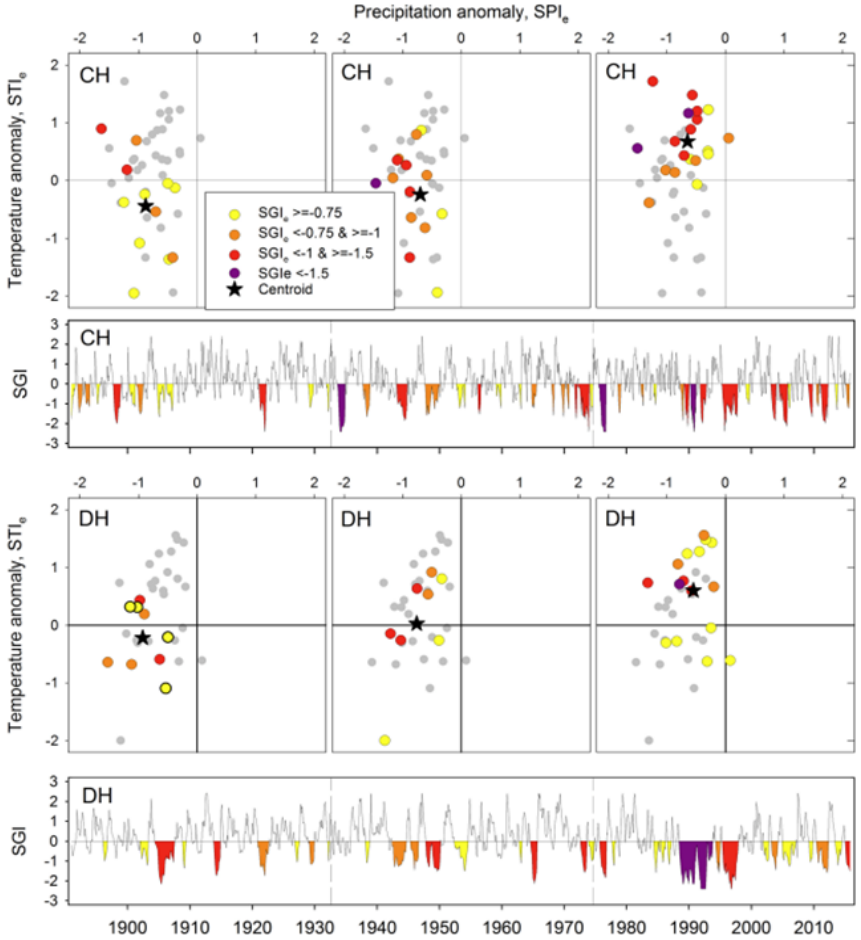
Chilgrove House



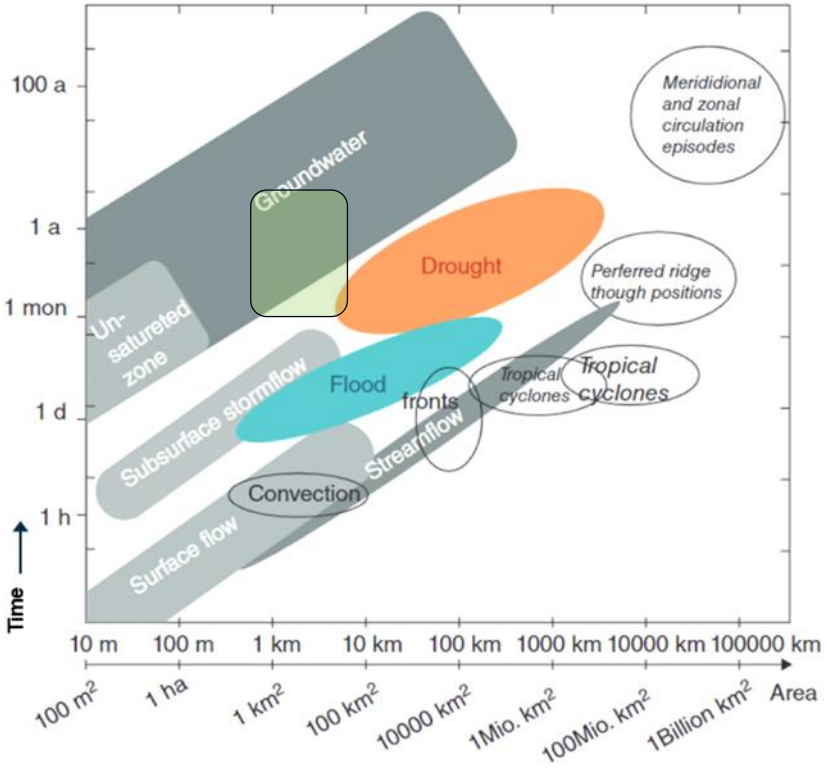
Dalton Holme



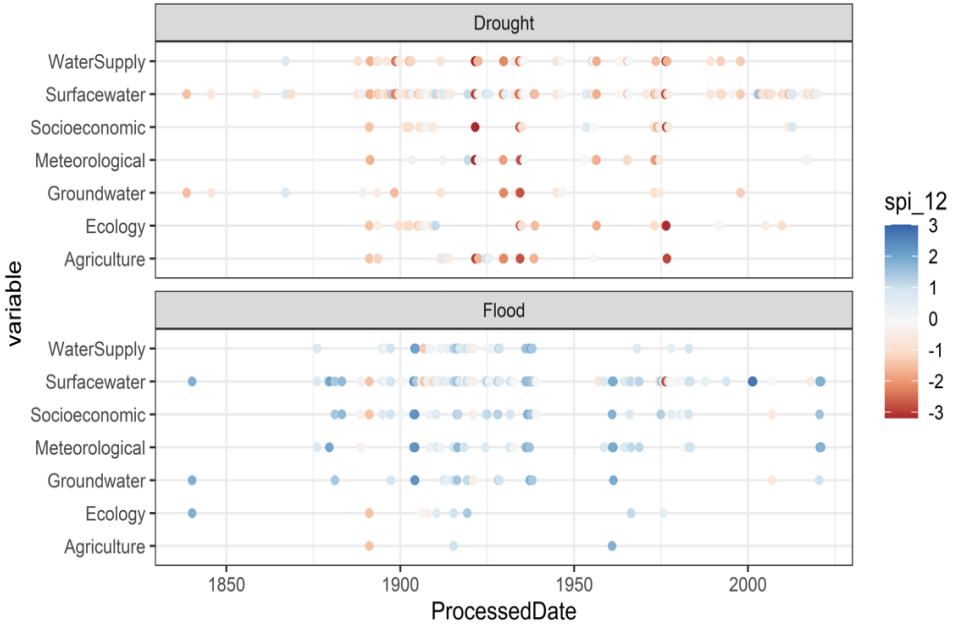
Does CC effect groundwater drought in the UK?



Impacts of GW extremes



Impacts of groundwater extremes
Matt Ascott & Ben Marchant (in prep)



Preliminary results appear to show an increased probability of drought impacts in summer

Area: 1 km² – 100 km²
Time: 1 month - 2 years

Some lessons learnt

Hydrogeology Journal (2021) 29:921–924
https://doi.org/10.1007/s10040-020-02249-0

ESSAY

Managing groundwater supplies subject to drought: perspectives on current status and future priorities from England (UK)

M. J. Ascott[1] · J. P. Bloomfield[1] · I. Karapanos[2] · C. R. Jackson[3] · R. S. Ward[3] · A. B. McBride[4] · B. Dobson[5] · N. Kieboom[6] · I. P. Holman[7] · A. F. Van Loon[8] · E. J. Crane[1] · B. Brauns[3] · A. Rodriguez-Yebra[3,5] · K. A. Upton[9]

- Observations from Ascott et al (2021)
  - integration of drought definitions;
  - enhanced fundamental monitoring;
  - integrated modelling of groundwater in the water cycle; and
  - better information sharing.

Some future research directions

- **Five opportunities:**
  - A **systematic review of research on hydrogeological extremes**, but particularly groundwater drought, would be timely
    - identify research priorities going forward
  - Establish **conceptual framework for relationships between spatio-temporal scales of processes, drivers and domains**
    - Use this to map and analyse metadata from systematic review
  - Bring **together reconstructed, observed and modelled groundwater extremes** (incl. assoc. uncertainty bounds) to characterise changes in groundwater extremes over ~200 year period from late 1800s to 2100
    - trends and aquifer- or region-specific phenomena?
  - **Investigate processes that are T-sensitive and lead to groundwater drought intensification**
    - quantifying these effects in the context of the strong warming signal
  - **Develop a common approach to the quantification of impacts of groundwater extremes and collect the data** so that there is suitable inputs for future impact modelling

Thank you for listening!

I’m happy to take questions

j.bloomfield@pgr.reading.ac.uk
jpb@bgs.ac.uk

Superb Ant-Hill Hoverfly
Xanthogramma pedissequum