FORECASTING RISKS OF ENVIRONMENTAL EXACERBATION OF DISSOLVED ORGANIC MATTER – BUILDING CLIMATE CHANGE RESILIENCE (FREEDOM-BCCR)

Don Monteith (UKCEH) and Fraser Leith (Scottish Water)

4th November 2020

UK Centre for Ecology & Hydrology

UNIVERSITY OF LEEDS

United Utilities
Water for the North West

Dŵr Cymru Welsh Water

Met Office

Scottish Water
Trusted to serve Scotland

YorkshireWater

UKRI UK Research and Innovation

UK CLIMATE RESILIENCE PROGRAMME

The FREEDOM-BCCR Team

UK Centre for Ecology & Hydrology:
Heidrun Feuchtmayr, Amy Pickard, Bryan Spears, Justyna Olszewska, Phil Taylor, Jenny Williamson, Doug Clarke, Semeena V. Shamsudheen, Chris Barry, Alan Radbourne, Peter Henrys, Chris Evans & Don Monteith.
University of Leeds: Pippa Chapman & Cat Moody (NERC Fellow)
University of Glasgow: Susan Waldron
Irish Water: Lorraine Gaston
Scottish Water: Fraser Leith, Nic Booker, Graeme Moore, Stewart Sutherland & Jonathan Moses
United Utilities: Clare Bullen & Carmel Burke
Welsh Water: Tara Froggatt, Sophie Straiton, Rupert Perkins
Yorkshire Water: Jenny Banks

Importance and implications of upland catchments for the UK drinking water supply

- 70 % of the UK's upland drinking water supply is derived from upland catchments
- Upland catchments are often characterised by soils rich in organic matter – including peats
- Dissolution by rainfall forms Dissolved Organic Matter (DOM).
- DOM contributes brown colouration
- **The water industry must reduce DOM to low levels to minimise Taste and Odour problems and the formation of potentially carcinogenic disinfection byproducts (DPBs) during disinfection**

UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

What is Dissolved Organic Matter?

Dissolved Organic Mattter (DOM)

- All organic matter passing through a fine filter (e.g. 0.45 µm)

Dissolved Organic Carbon (DOC)

- The amount of carbon contained within DOM
- Determined by high temperature oxidation and spectrometric analysis of resulting CO_2

Also quantified colorimetrically, i.e. Colour (units = Hazens).

- DOC and colour in upland waters normally tightly correlated.

DOM "quality" and treatability

	DOM origin		
	soil organic matter		water
properties	decaying plant material		algal, plant and bacterial exudates
	T1	T2	T3
molecular weight	high	low	low
UV absorbance	high	moderate	low
degradability by light	high	low	low
prone to coagulation	high	low	low
prone to biodegradation	low	low	high

For T1-T3 concept see Anderson et al., 2019. Biogeochemistry

UK Centre for Ecology & Hydrology

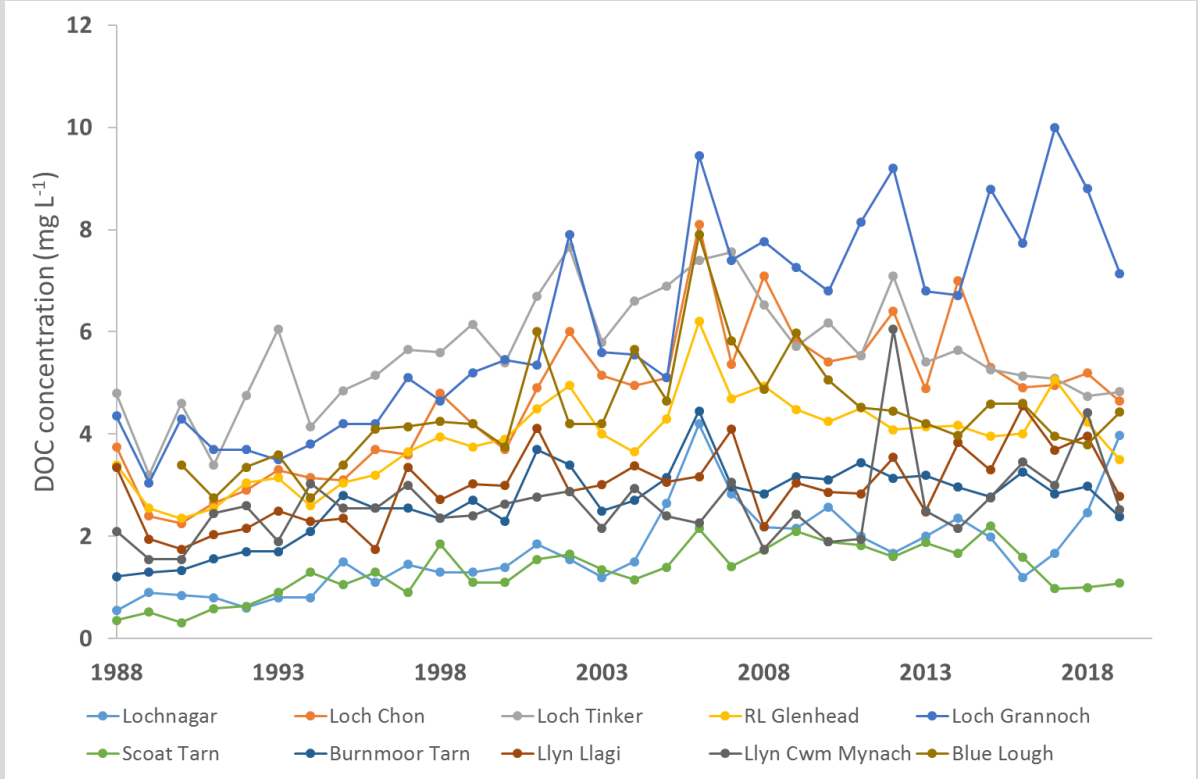
Met Office

UK Research and Innovation

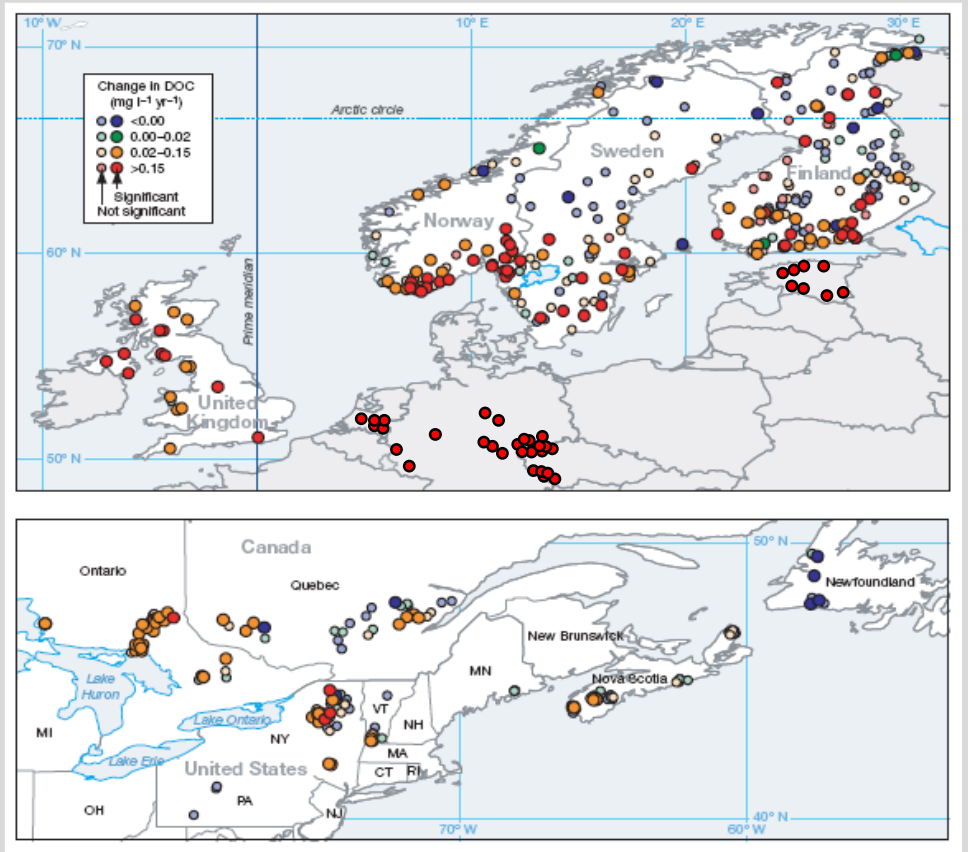
DOM concentrations in upland waters have been rising for several decades

UK CLIMATE RESILIENCE PROGRAMME

Trends in Dissolved Organic Carbon in UK Upland Waters Monitoring Network lakes (1988 – 2016)



% change in Dissolved Organic Carbon (1990 – 2004)



Adapted from Monteith et al. 2007. Nature

UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

DOM dependence on climate – temperature

Temperature control on microbial decomposition of soil organic matter regulates DOC production

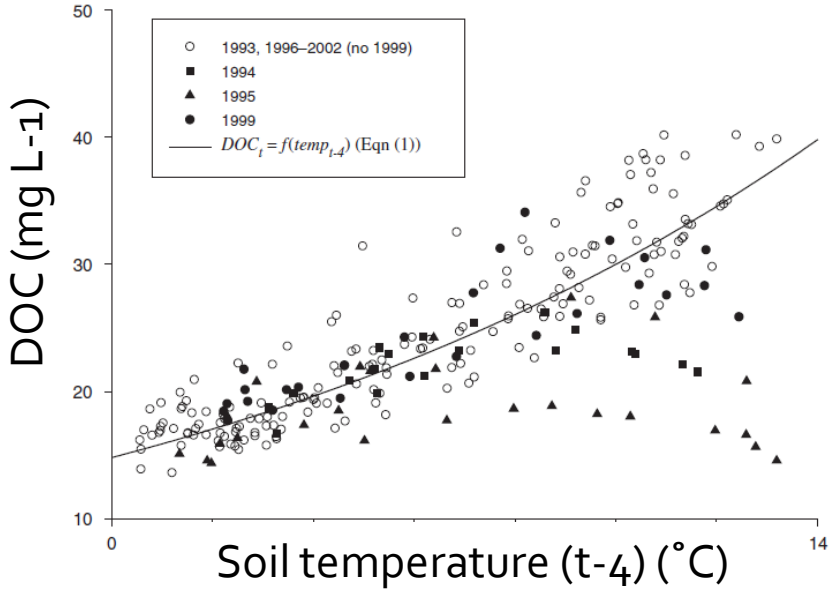
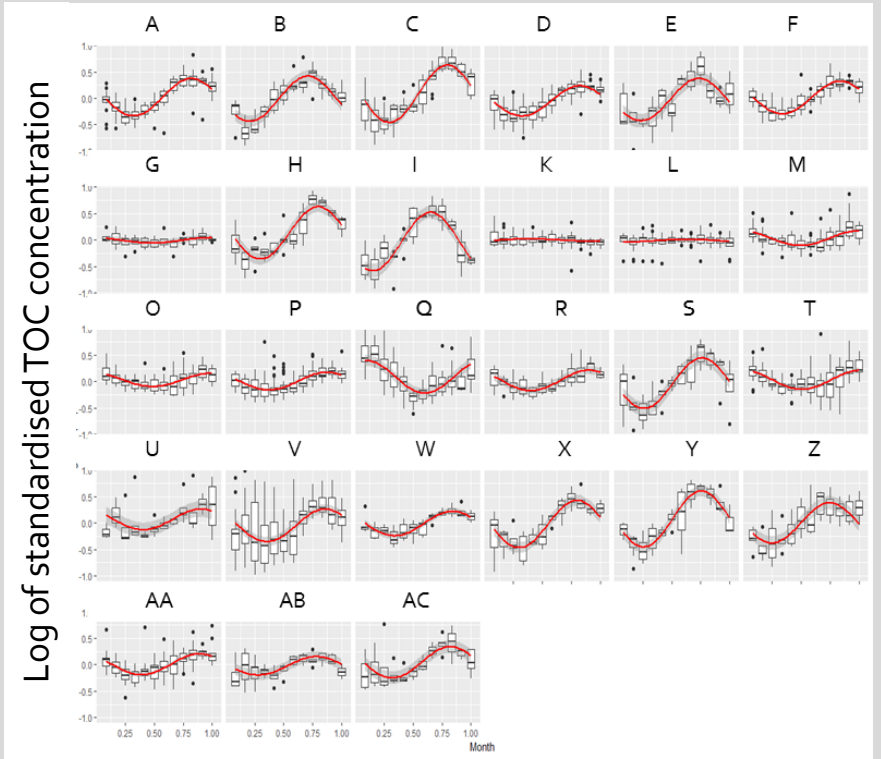


Fig. 3 Relationship between DOC and soil temperature ($t-4$). Regression line shown (Eqn (1)) fitted to data from 1993, 1996–2002 (excluding 1999).

From Clark et al. 2005 – Global Change Biology

Seasonal TOC variation in 27 Scottish Water Source Waters



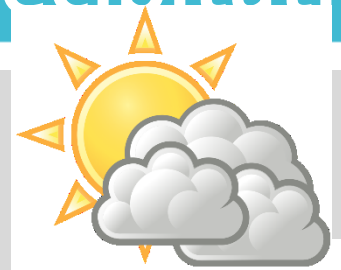
month of the year

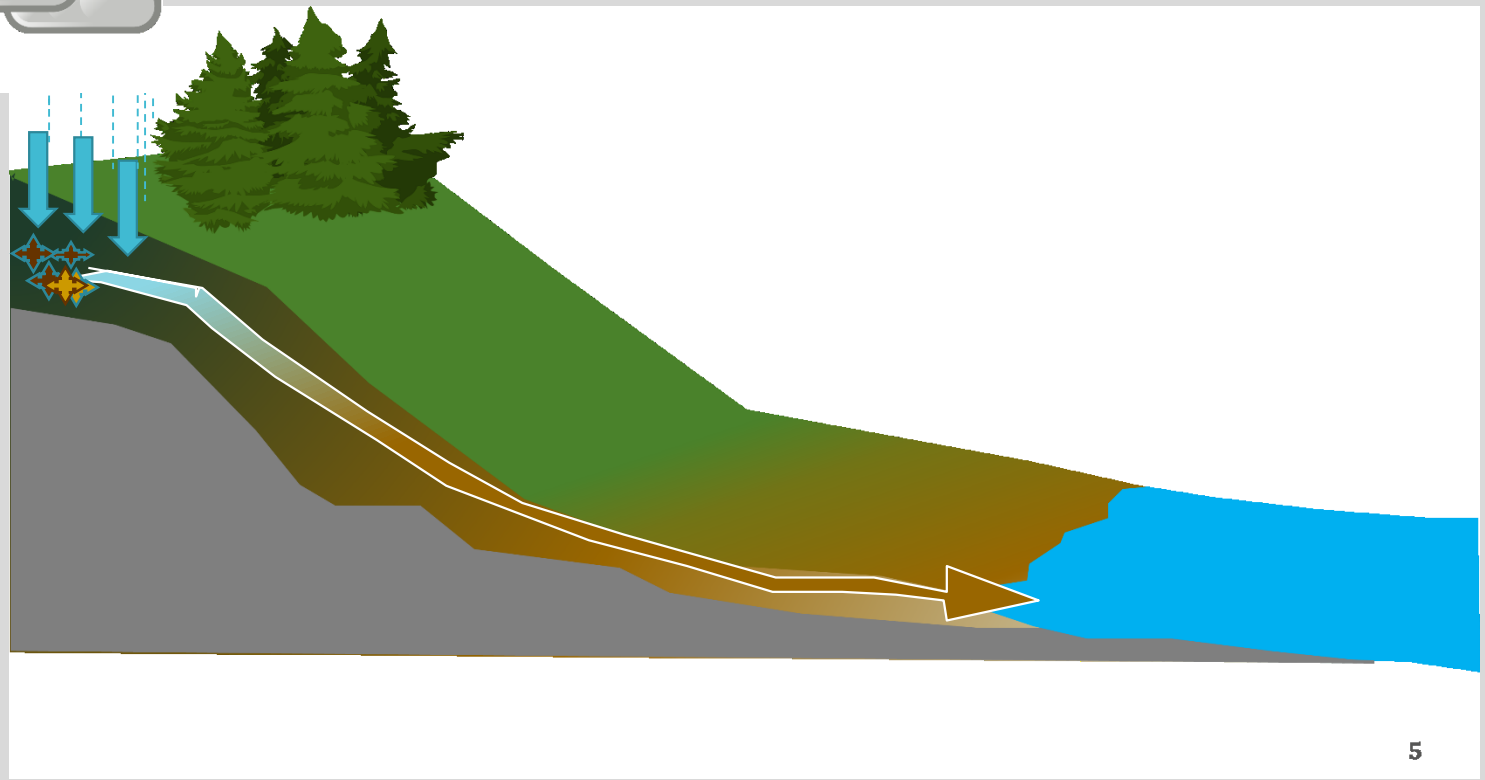
UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

DOM dependence on climate – precipitation and soil moisture



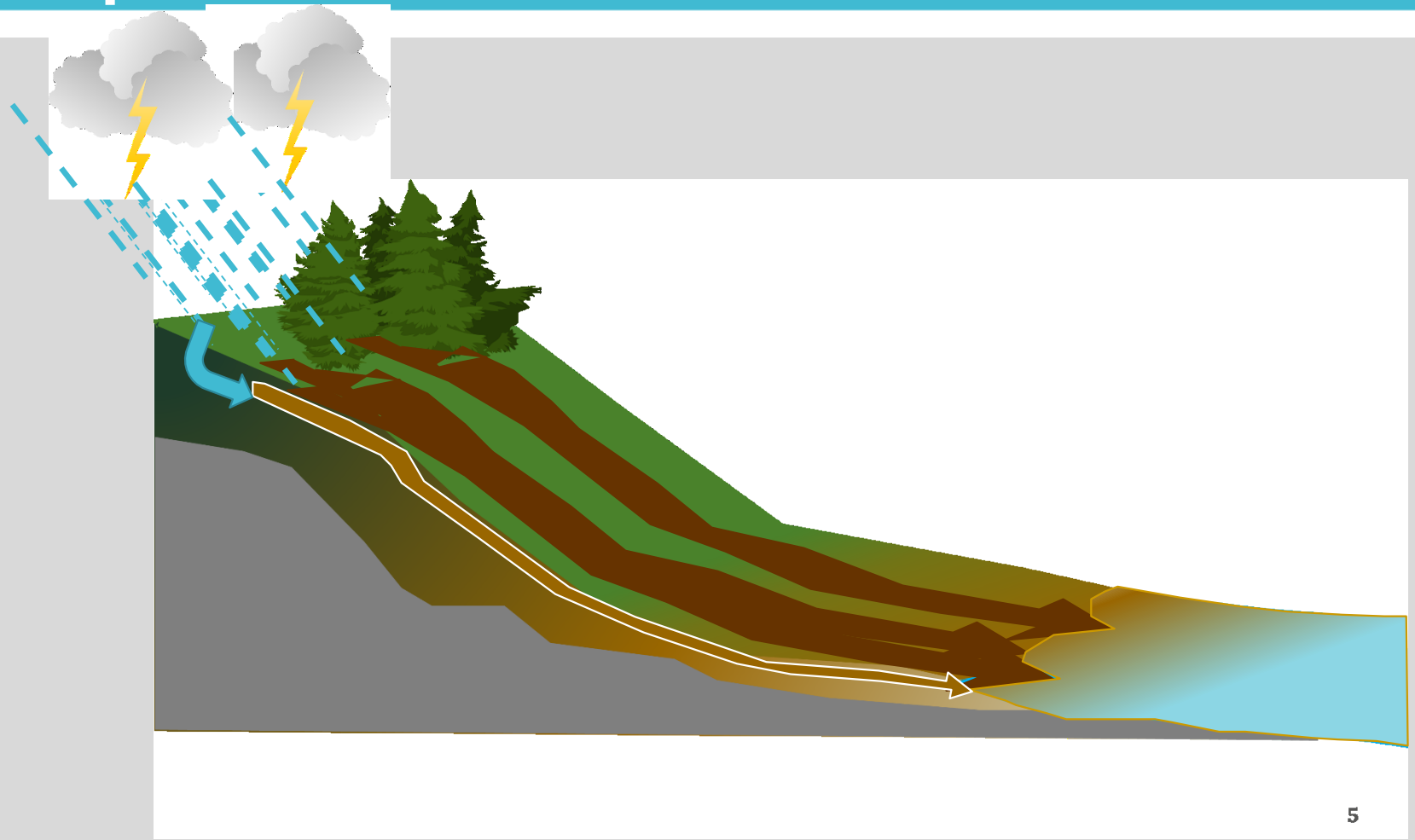


UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

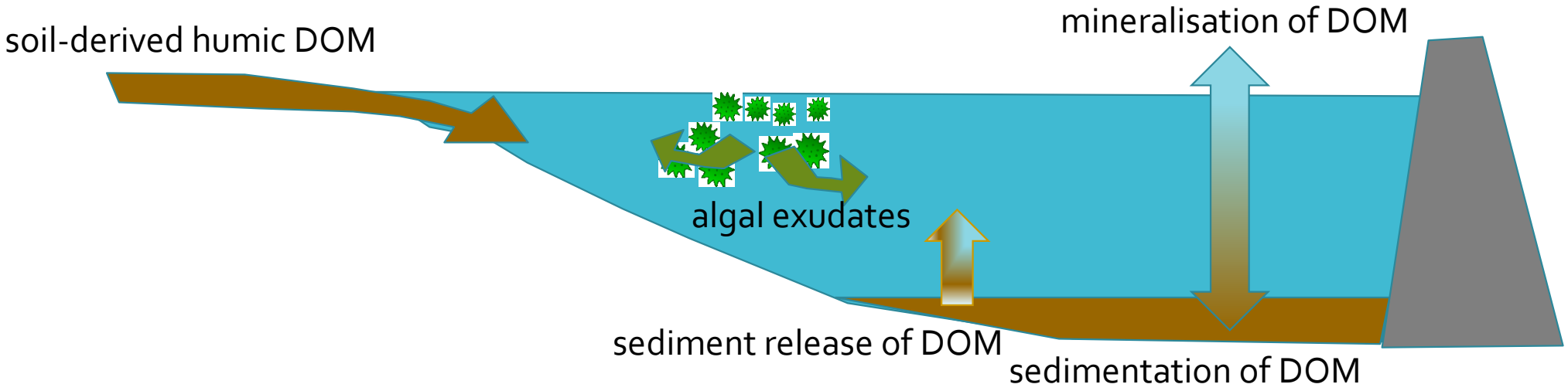
DOM dependence on climate – precipitation and soil moisture



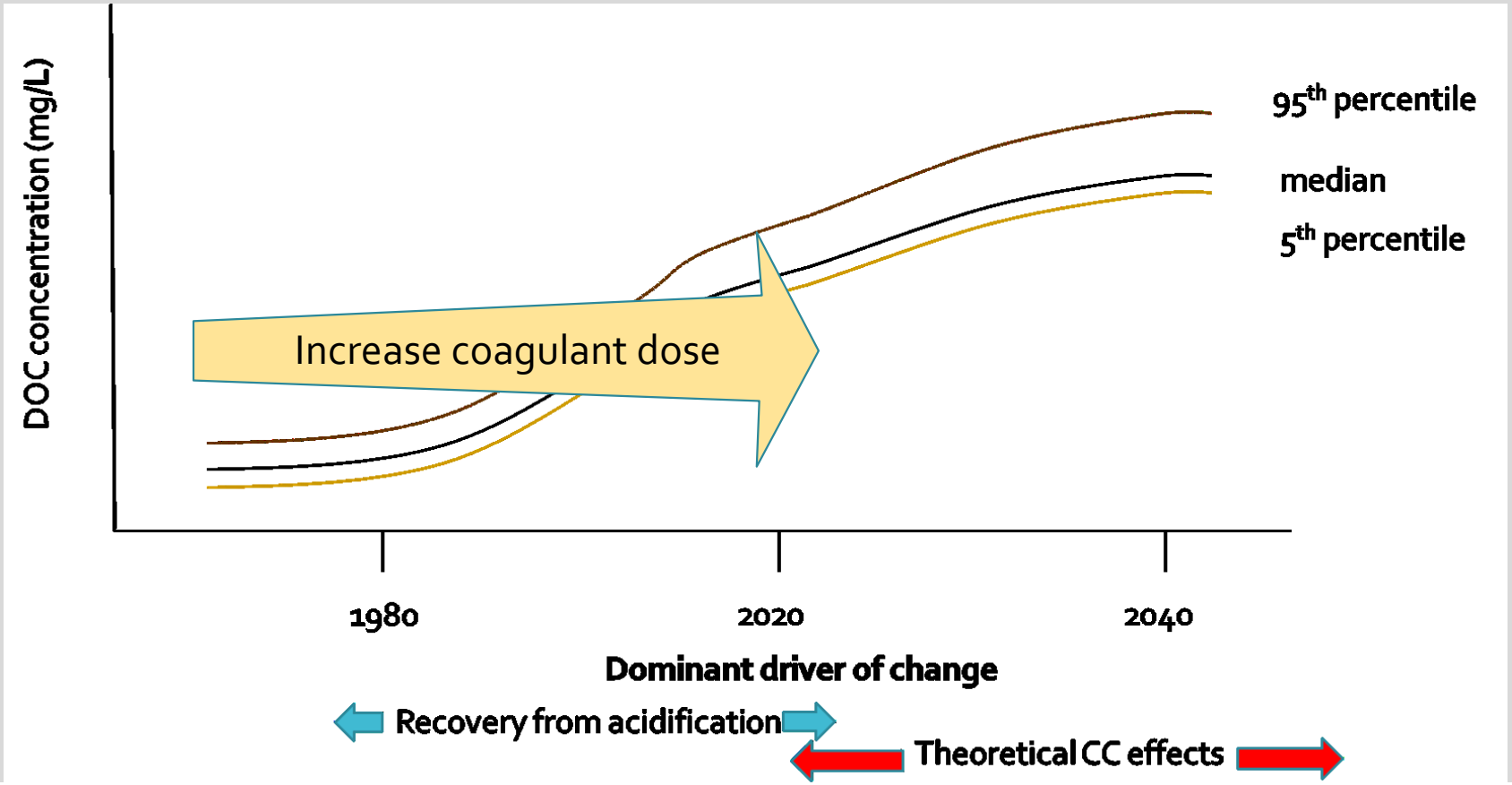
UK Centre for Ecology & Hydrology
Met Office
UK Research and Innovation

DOM dependence on climate – within reservoir processing

- **Precipitation - evaporation:** water throughput rate
- **Temperature + wind:** algal production rates, thermal stratification intensity and duration
- **Solar radiation:** photo-degradation



Water treatment works have their limits

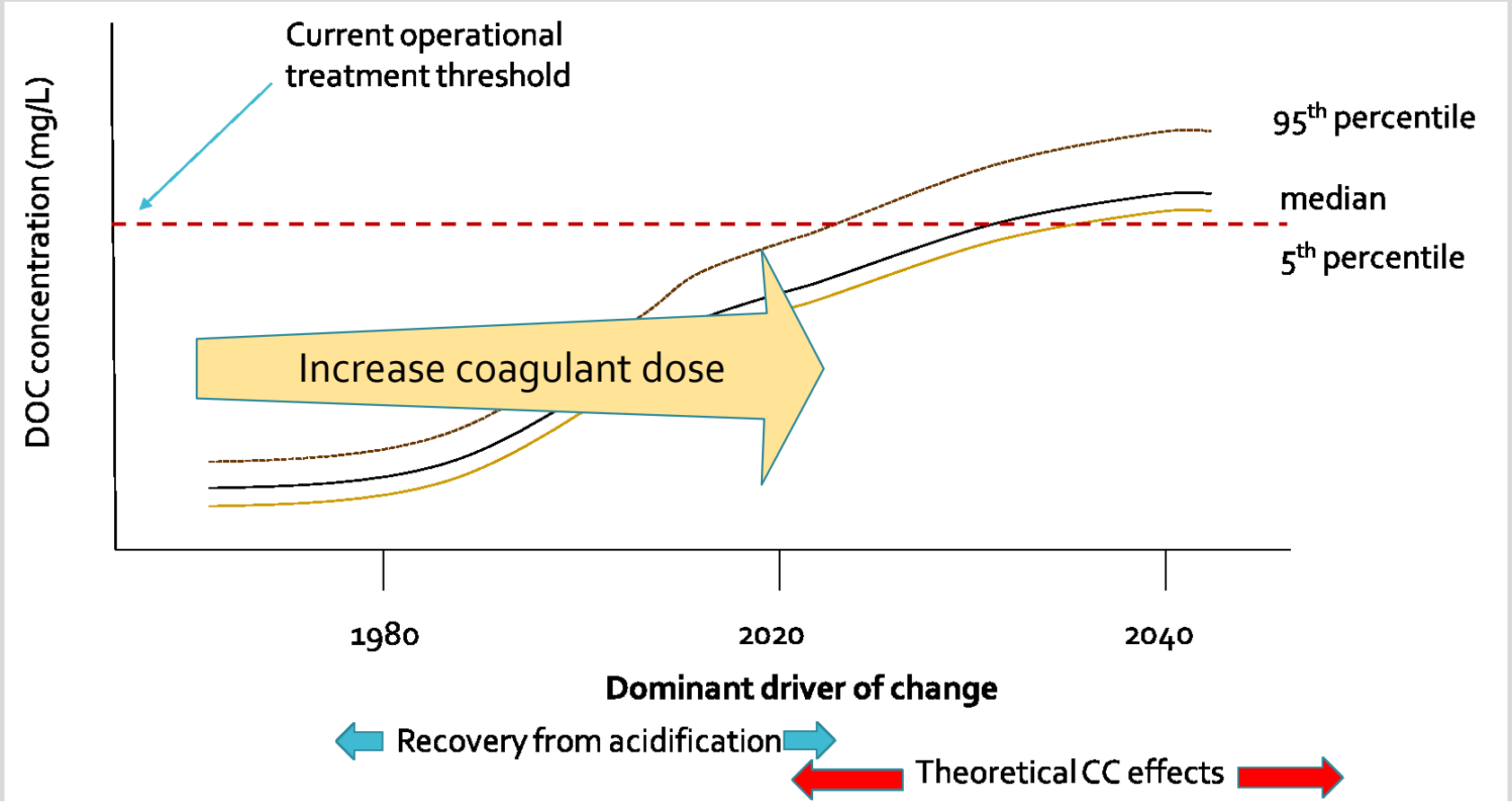


UK Centre for Ecology & Hydrology

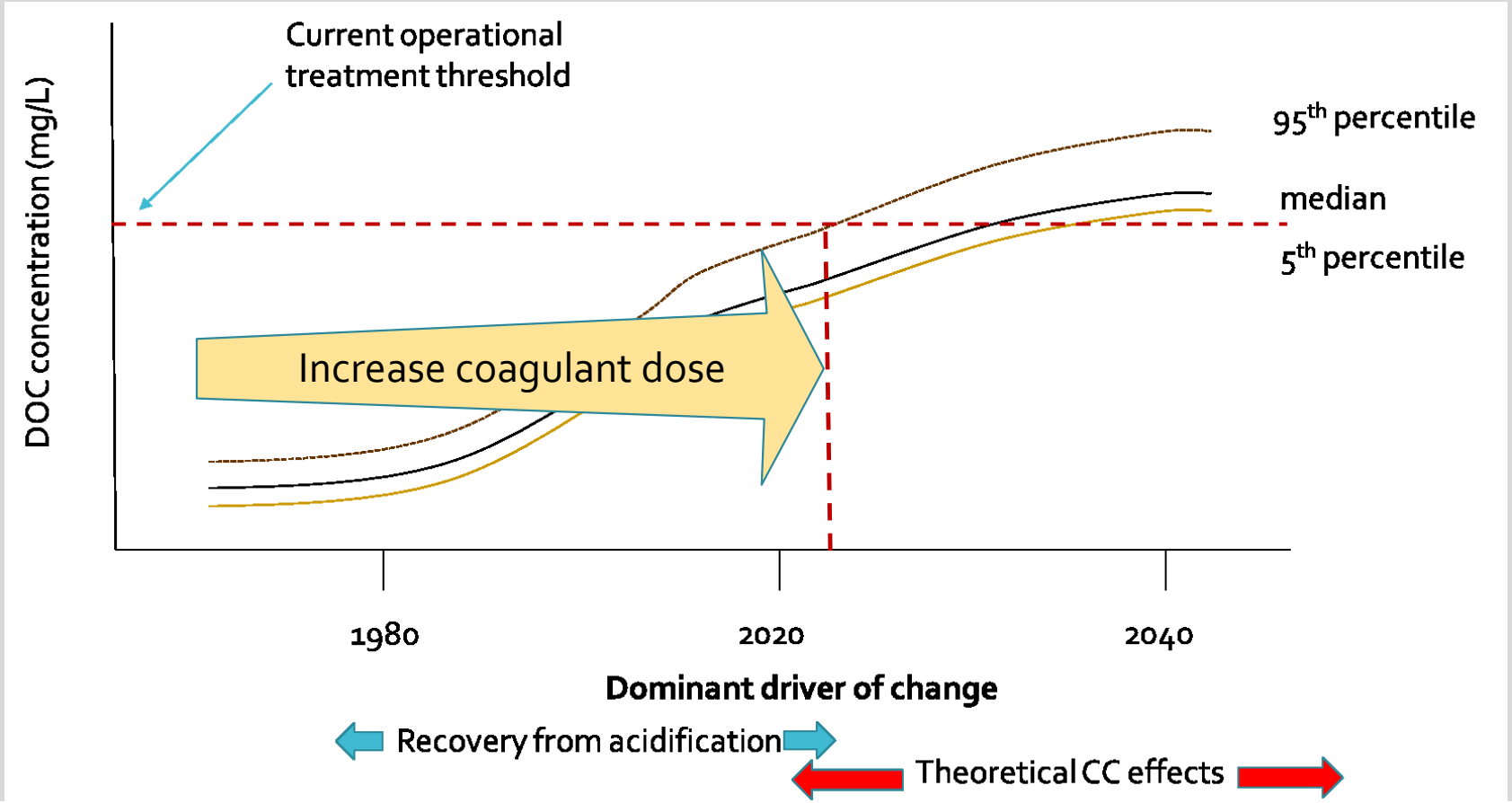
Met Office

UK Research and Innovation

Water treatment works have their limits



Water treatment works have their limits



UK Centre for Ecology & Hydrology

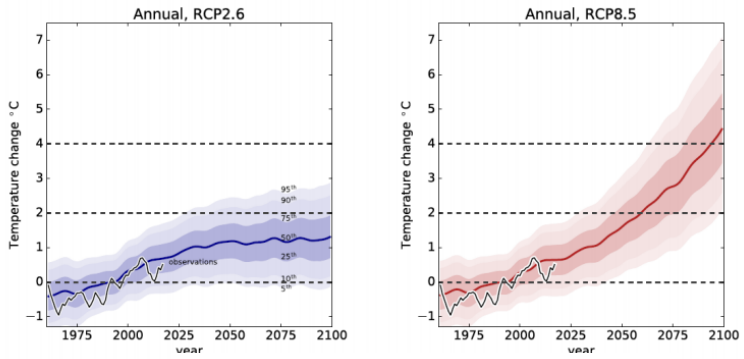
Met Office

UK Research and Innovation

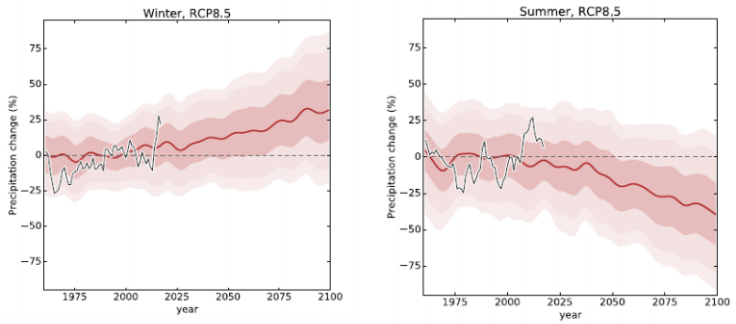
What are the likely implications of forecast changes in climate for upland surface drinking water sources?

UK CLIMATE RESILIENCE PROGRAMME

Future UK temperatures



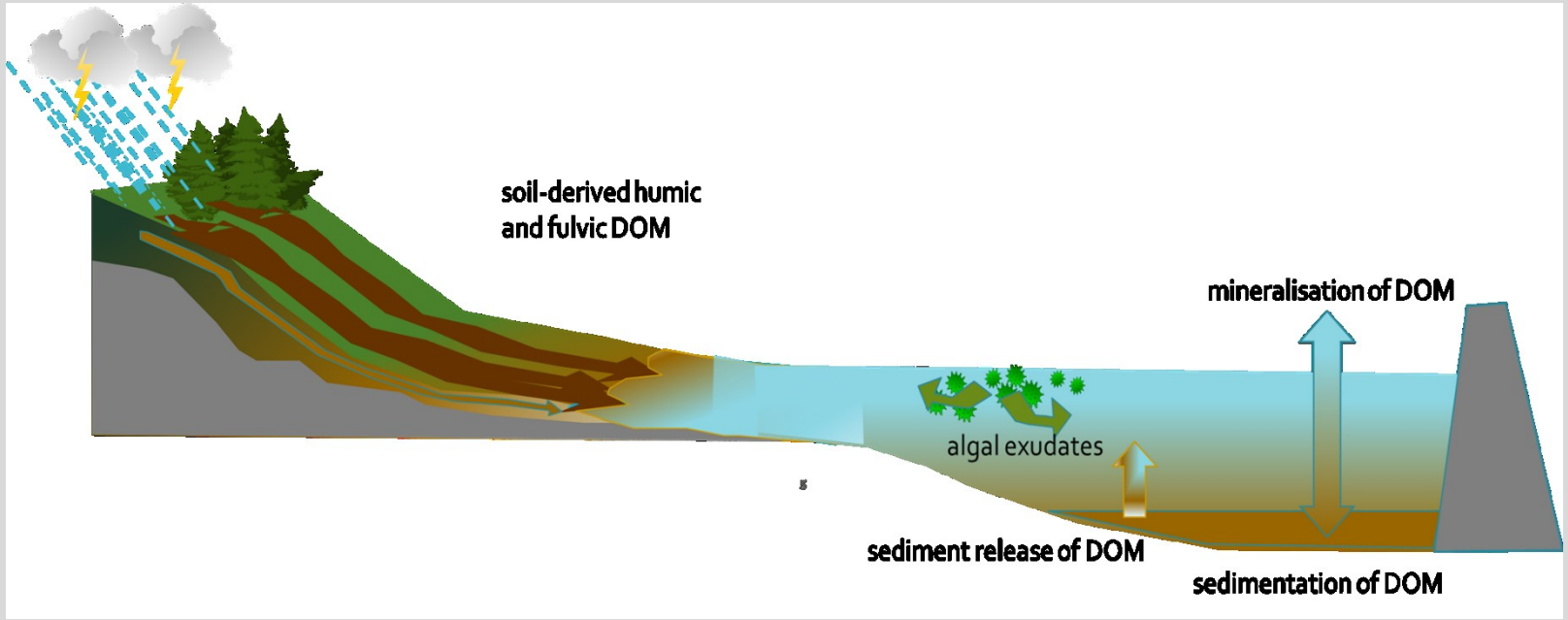
Future UK precipitation



Department for Environment Food & Rural Affairs | Department for Business, Energy & Industrial Strategy | Met Office Hadley Centre | Environment Agency

Working together on UK Climate Projections

www.metoffice.gov.uk



UK Centre for Ecology & Hydrology

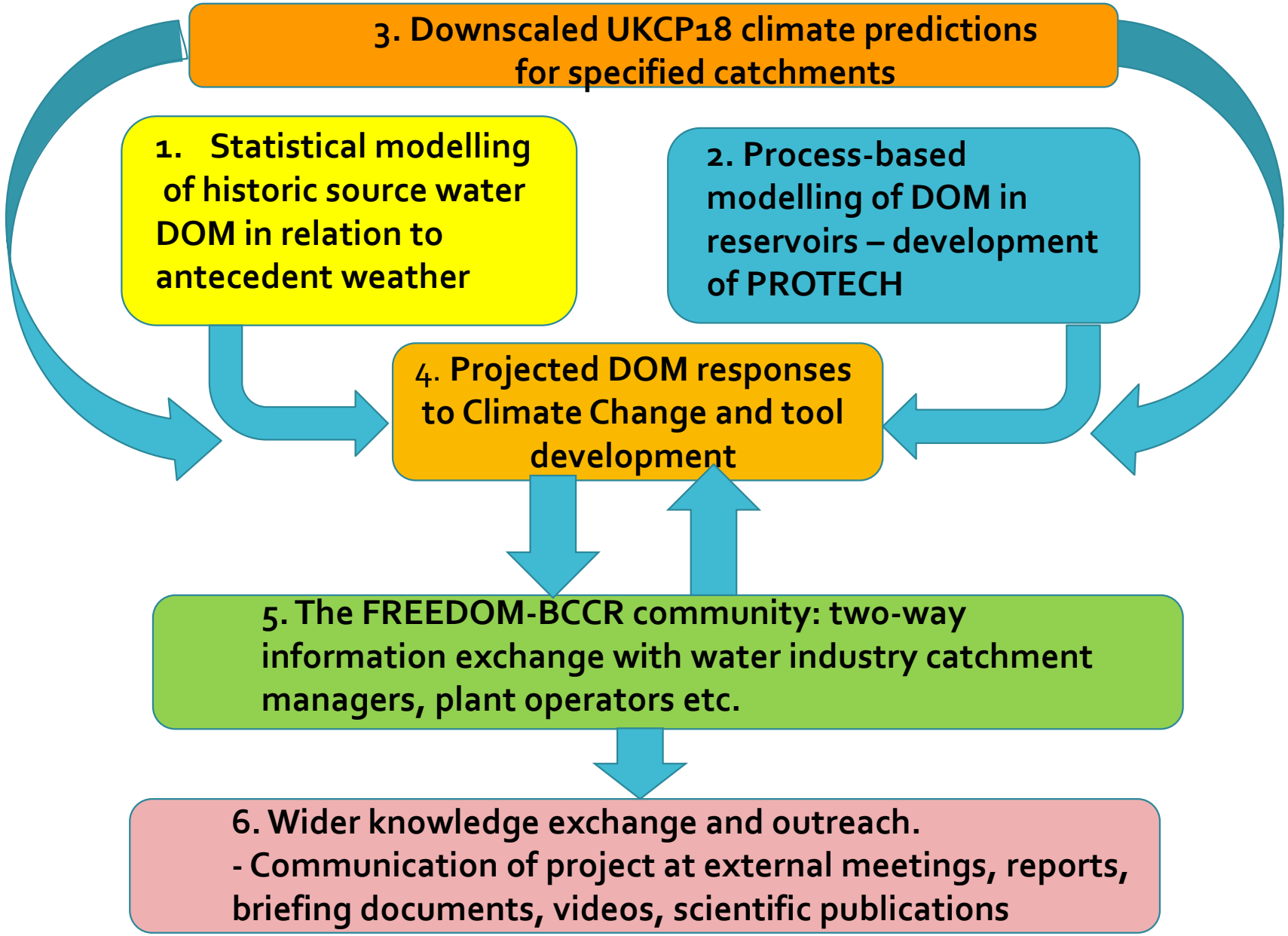
Met Office

UK Research and Innovation

FREEDOM-BCCR: Objectives

- Provide the water industry with a clearer understanding of risks posed by CC to future DOM levels to inform mitigation and adaptation strategies.
- Facilitate long-term two-way research-industry dissemination of knowledge necessary to build resilience.
- Create key Performance Indicators (KPIs) to inform impact on industry resilience.
- Support development of a DOM predictive tool, to provide a central means of communicating CC risk and uncertainty.

FREEDOM-BCCR Project structure



UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

1: Statistical analysis of TOC variation in drinking water sources as function of climate

UK CLIMATE RESILIENCE PROGRAMME

Datasets

"Source water" TOC data for 30 Scottish Water source waters (2013-17)

1 km gridded interpolated daily:

- Air temperature (CHESS)
- Precipitation (GEAR)
- Soil moisture (JULES)

Site-specific linear models

TOC ~ antecedent air temperature + antecedent precipitation + antecedent soil moisture. (periods 2, 10, 30, 60, 90 & 180 days

Additional explanatory variables

- Soil type (Soil Map of Scotland)
- Land cover and catchment area (UKCEH Lakes Portal)
- Reservoir volume (Scottish Water)

UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

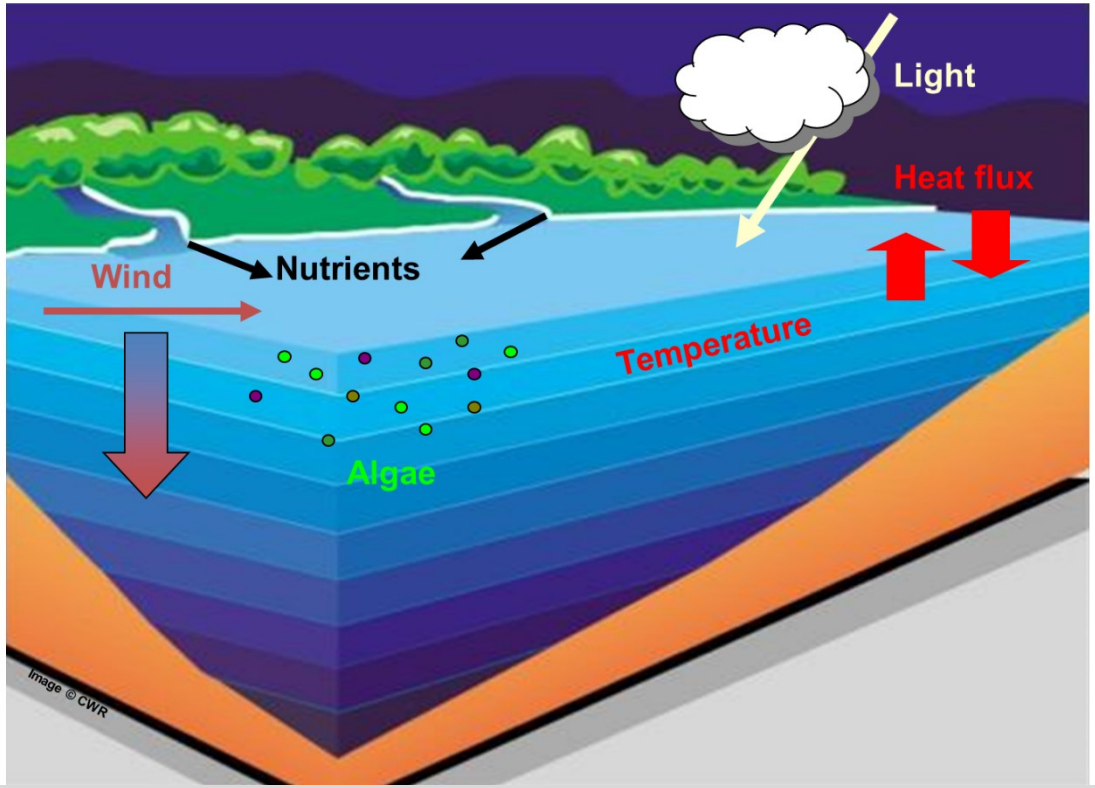
Regional statistical analysis: outcomes

Positive effect

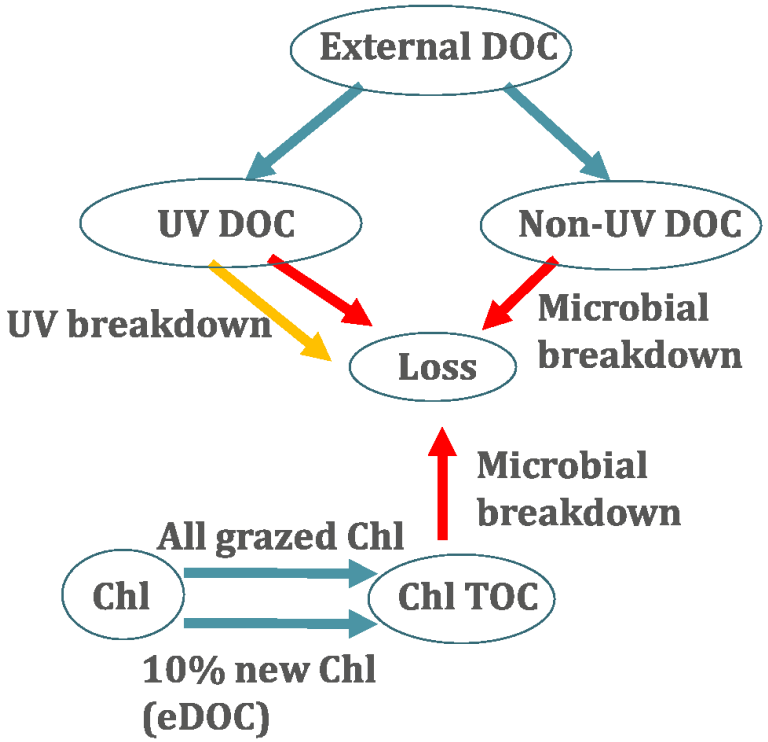
Negative effect

	variable			
Water source	Temperature	Precipation	Soil moisture	
	antecedent period (days)			R^2
A	186	180	60	0.51
B	96	90	180	0.70
C	159	180	90	0.70
D	183	180	2	0.31
E	110	10	60	0.56
F	190	90	90	0.45
G	192	180	NA	0.73
H	NA	180	2	0.17
I	169	180	2	0.67
J	57	60	180	0.77
K	260	180	60	0.12
L	NA	90	60	0.03
M	260	90	30	0.28
N	260	180	30	0.23
O	210	180	180	0.30
P	NA	30	60	0.36
Q	260	90	60	0.32
R	260	10	30	0.50
S	240	180	10	0.49
T	133	180	180	0.64
U	260	30	90	0.26
V	NA	90	180	0.26
W	205	180	90	0.29
X	NA	10	180	0.34
Y	157	30	NA	0.60
Z	127	180	60	0.81
AA	142	90	2	0.49
AB	243	180	30	0.31
AC	NA	180	180	0.16
AD	167	NA	180	0.44

2. Process-based modelling of DOM in reservoirs – development of PROTECH



The DOC model

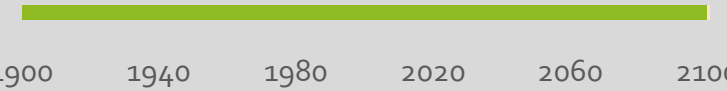


UK Centre for Ecology & Hydrology

Met Office

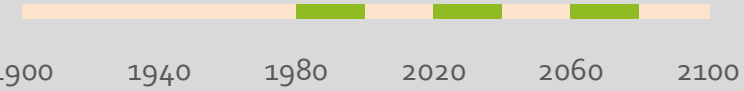
UK Research and Innovation

3: UKCP18: RCP 8.5 scenarios - RCM and CPM



RCM: 12 km Europe12 HadGem3-GC3.05

Downscaled to 1.0 km UK



UK Centre for Ecology & Hydrology

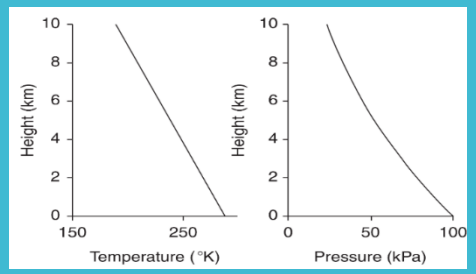
Met Office

UK Research and Innovation

CHESS methodology applied to UKCP18 12 km

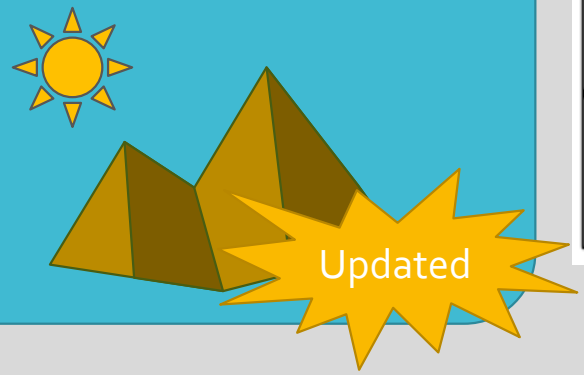
UK CLIMATE RESILIENCE PROGRAMME

Topographic corrections

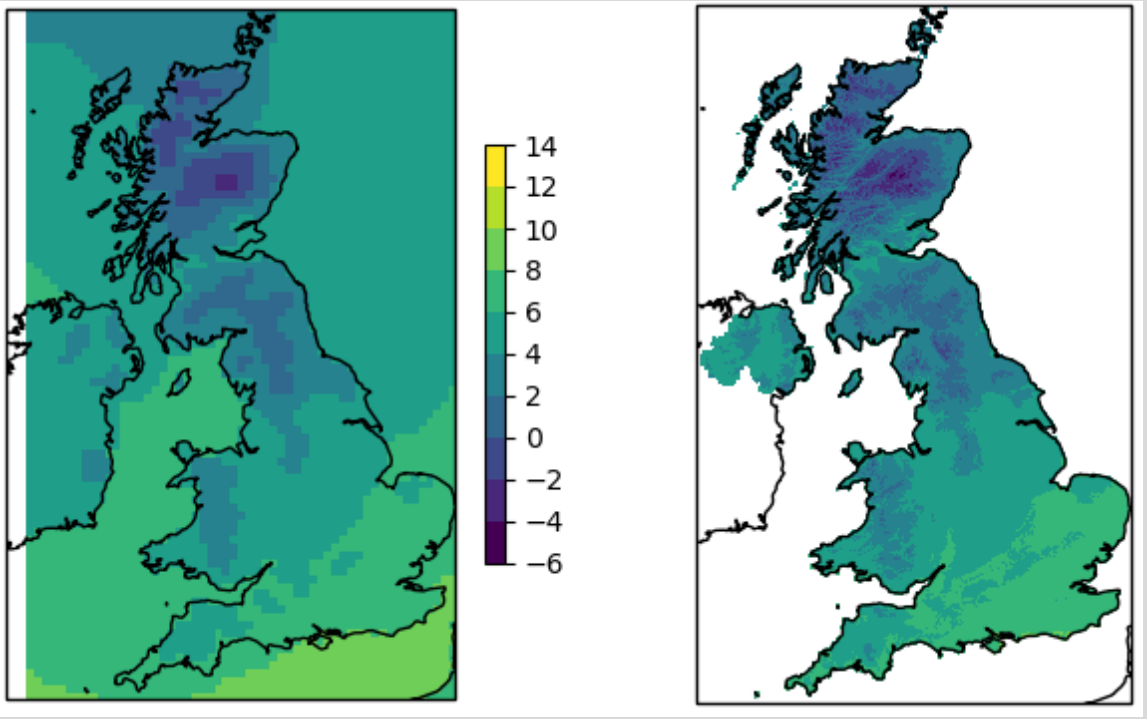


Shuttleworth, Terrestrial Hydrometeorology

Radiation corrections



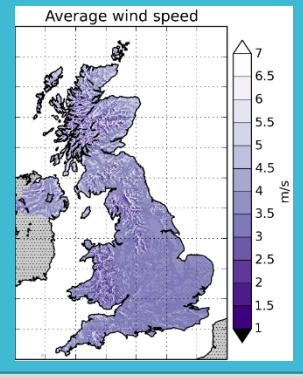
Air Temperature (°C)



Robinson et al, 2017 doi:10.5194/hess-21-1189-2017

Rainfall corrections

Wind corrections



UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

Four ensemble runs generated

Daily time series (1980-2080)

extracted for selected catchments

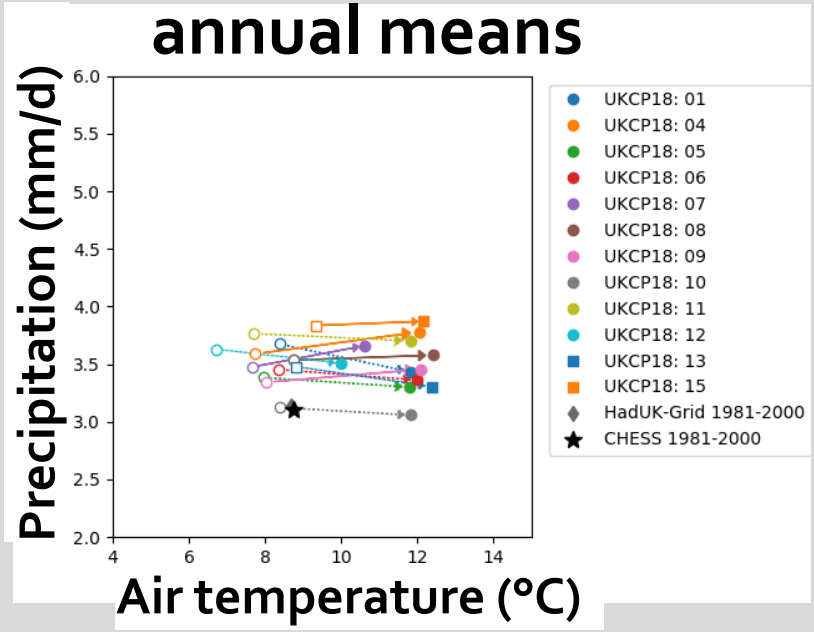
Variables	Name	units
pr	Precipitation	kg/m²/s
rlds	**Downward** longwave radiation	W/m²
rsds	**Downward** shortwave radiation	W/m²
sfcWind	10m wind speed	m/s
tas	Daily mean air temperature	K
uas	Eastward 10m wind	m/s
vas	Westward 10m wind	m/s
runoff	**Surface runoff**	
t_soil	**Soil temperature**	**K**
smcl	Soil moisture content	K

EM01 - Median warming

EM06 - Median warming + largest decrease in summer precipitation

EM04 - Most warming

EM15 - Least warming



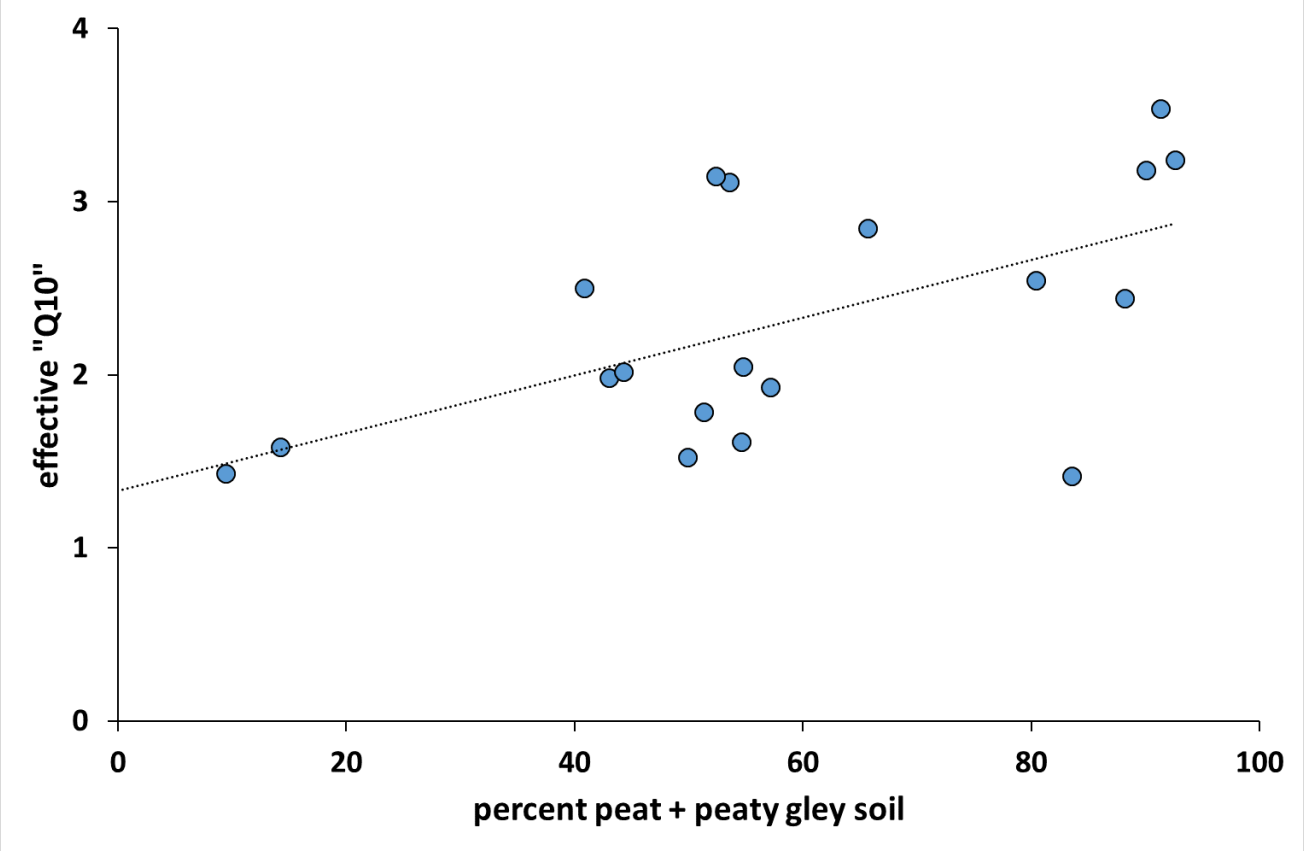
UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

Key observations from statistical modelling

- Warming will exert a significant positive effect on DOM production in peaty catchments.
- Effects will be most marked in catchments with the high cover of peat and waters with the shortest residence times
- Less rainfall during spring and summer in very peaty catchments likely to have a concentrating effect on DOM
- Catchments dominated by better drained organo-mineral soils less susceptible to temperature, while DOM concentrations could decline in drier summers.



UK Centre for Ecology & Hydrology

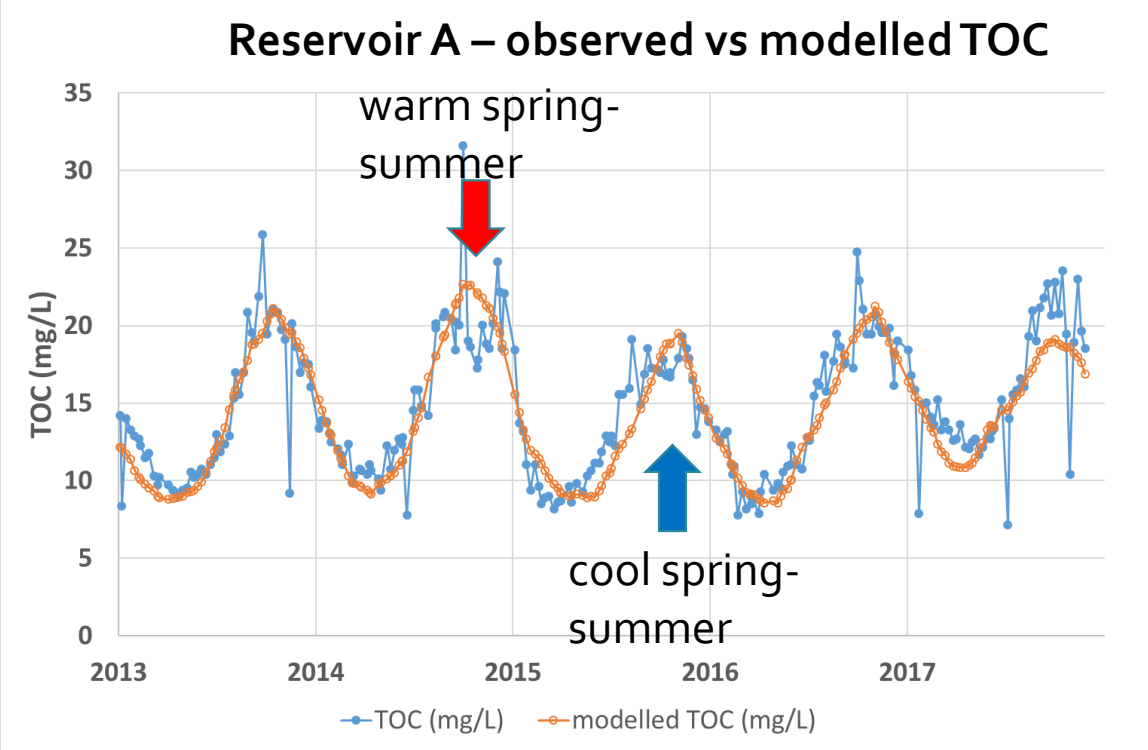
Met Office

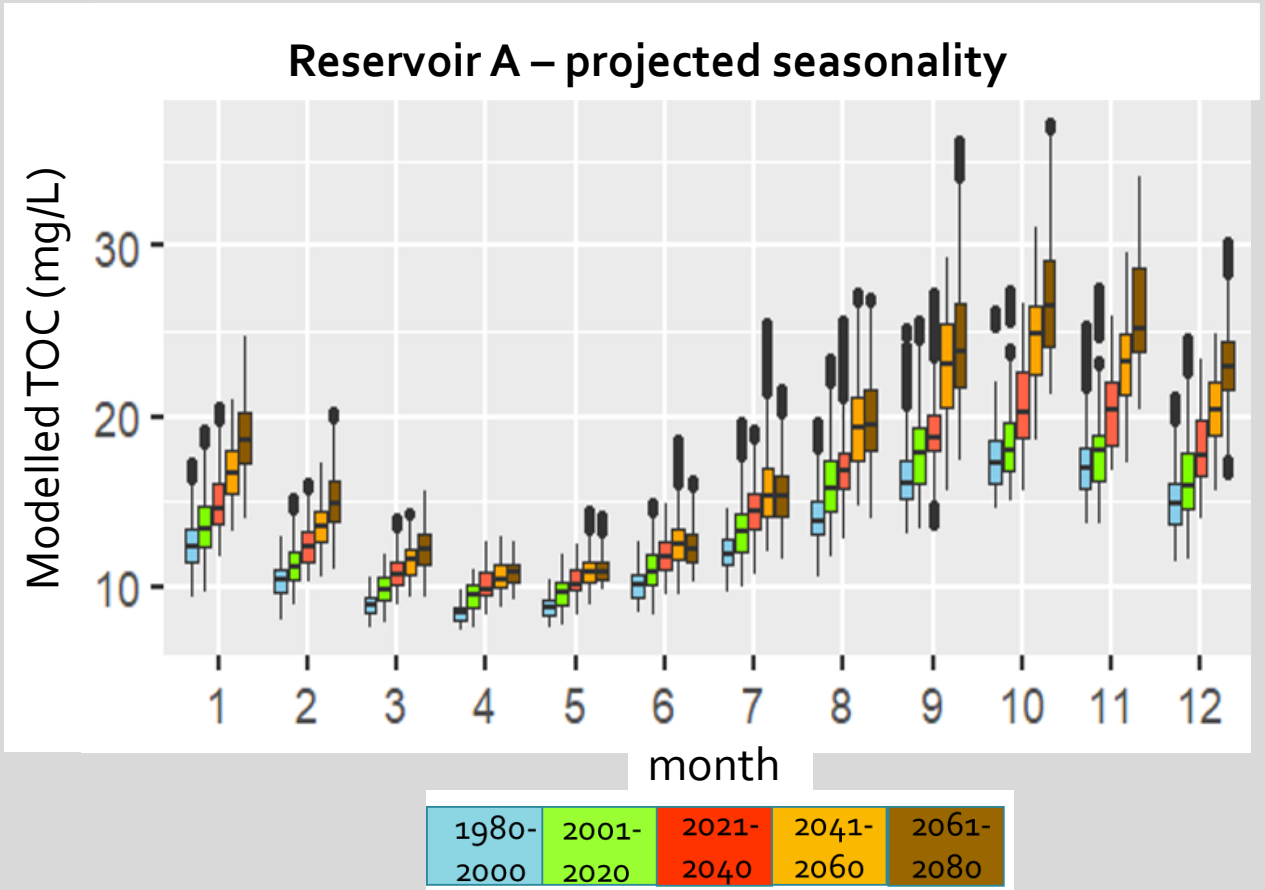
UK Research and Innovation

Key observations from PROTECH modelling

- Low algae reservoirs: warmer water should increase terrestrial DOM breakdown.
- Net removal of DOM in more eutrophied waters will be smaller due to enhanced algal production
- Measures to reduce nutrient loads to reservoir will enhance the reservoir's ability to be a DOC sink

4. Projected climate responses



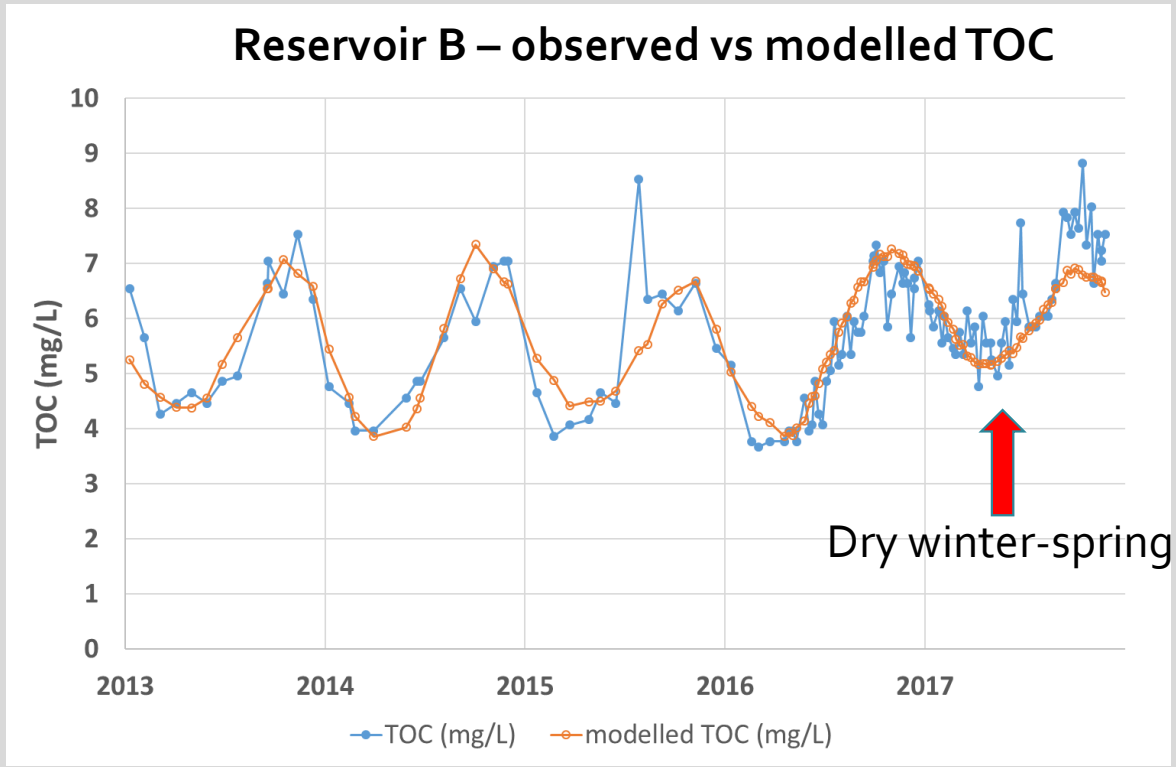


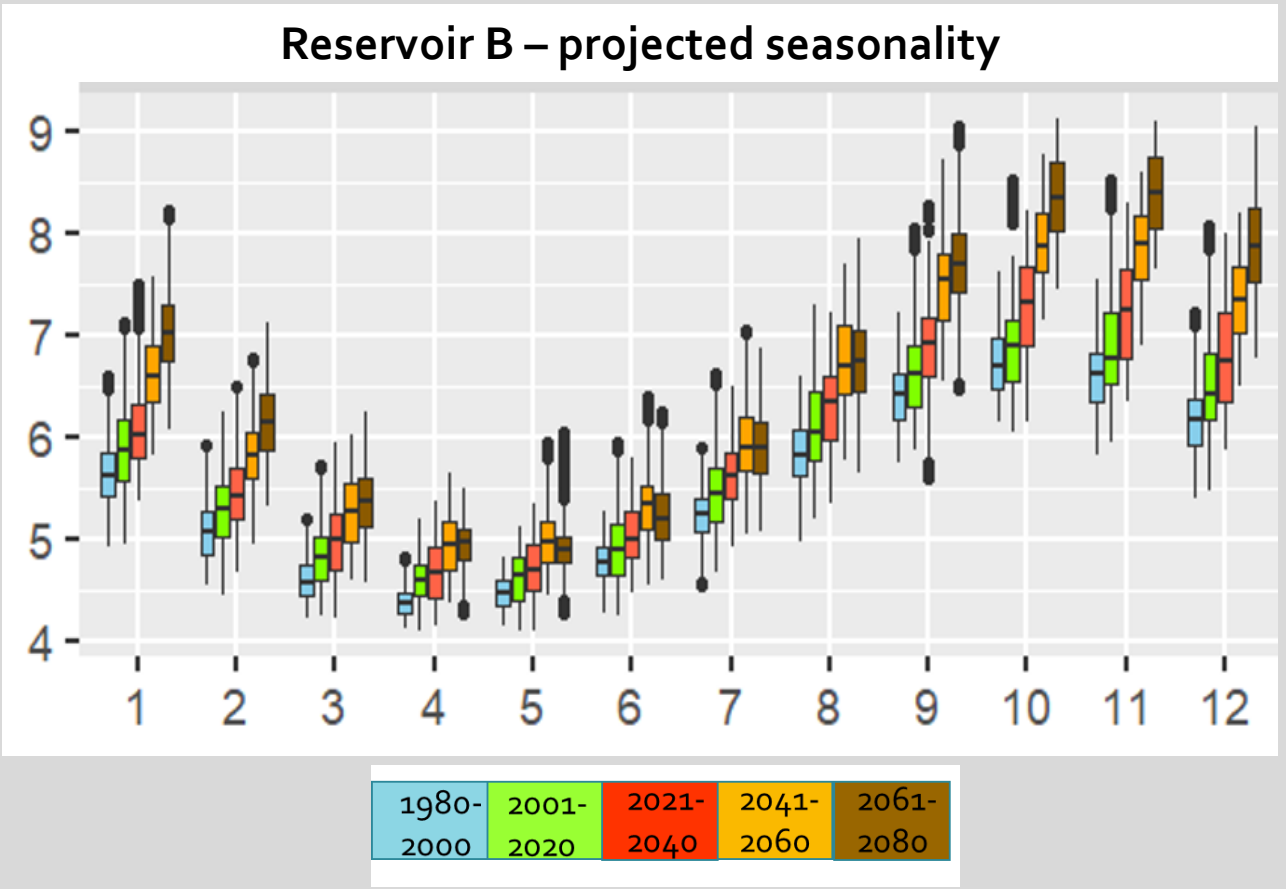
UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

4. Projected climate responses





UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

Tentative future DOM change under RCP 8.5 scenario

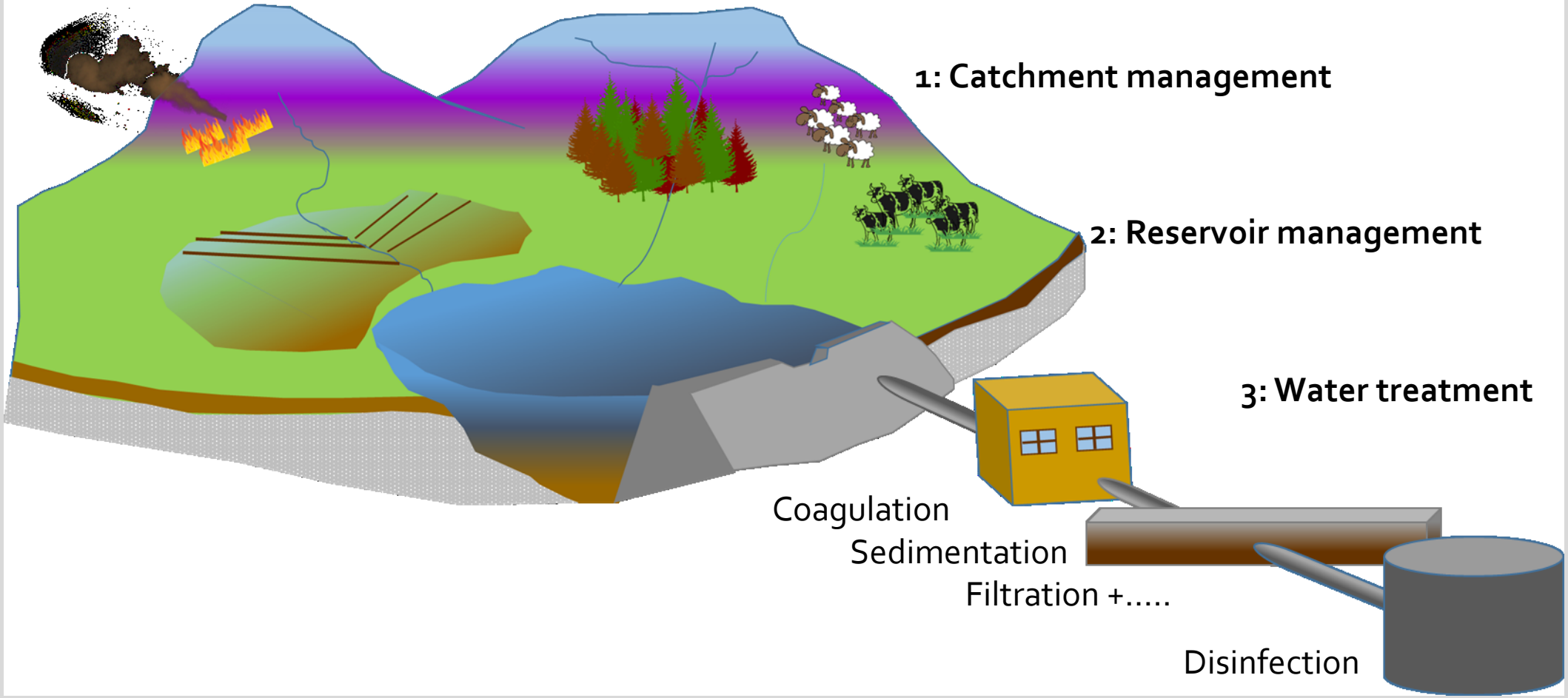
	Residence time (months)	Rising temperature	Falling summer rainfall	Net effect on DOM concentration
100% Organo-mineral	3			
100% Organo-mineral	18			
50% Organo-mineral - 50% peat	3			
50% Organo-mineral - 50% peat	18			
100% peat	3			
100% peat	18			

UK Centre for Ecology & Hydrology

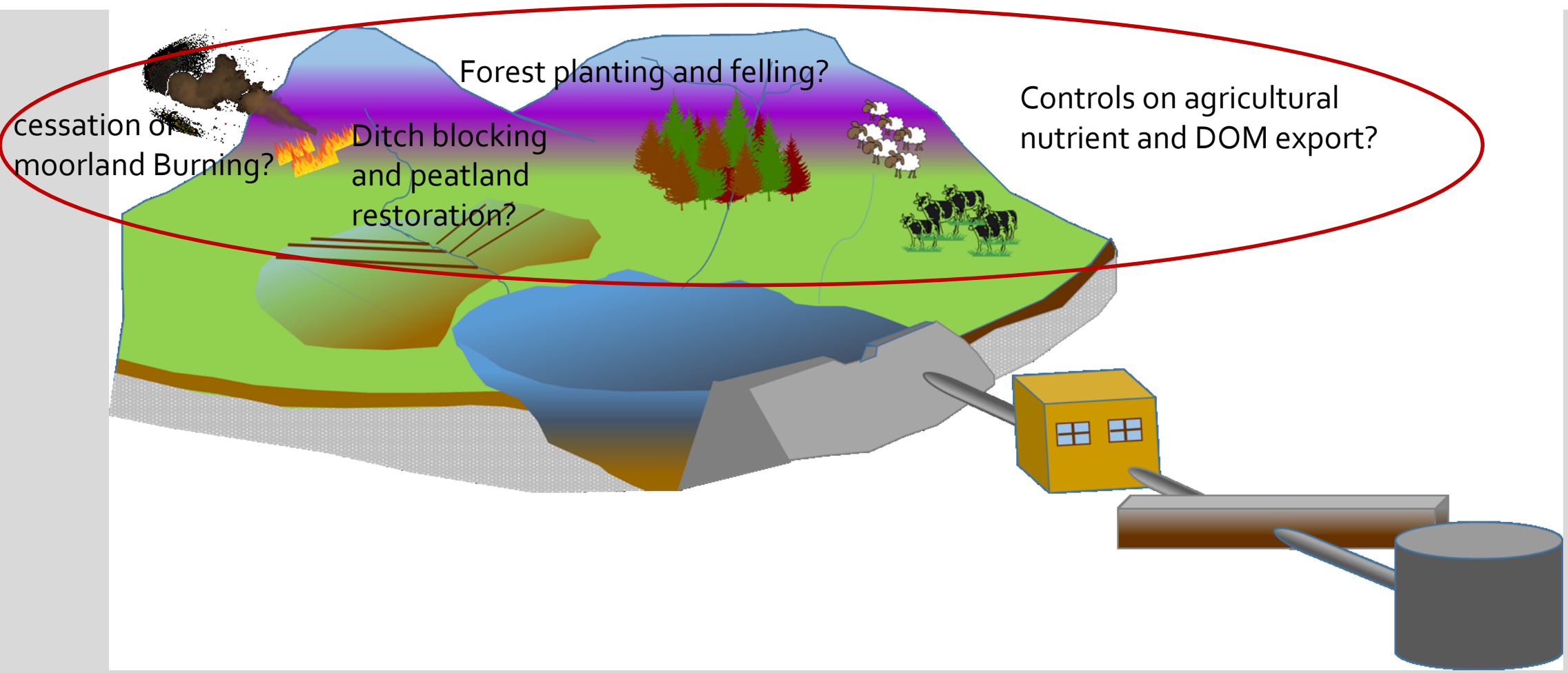
Met Office

UK Research and Innovation

5: The FREEDOM-BCCR community: the concept of the DOM intervention chain



the DOM intervention chain:
1) Catchment Management

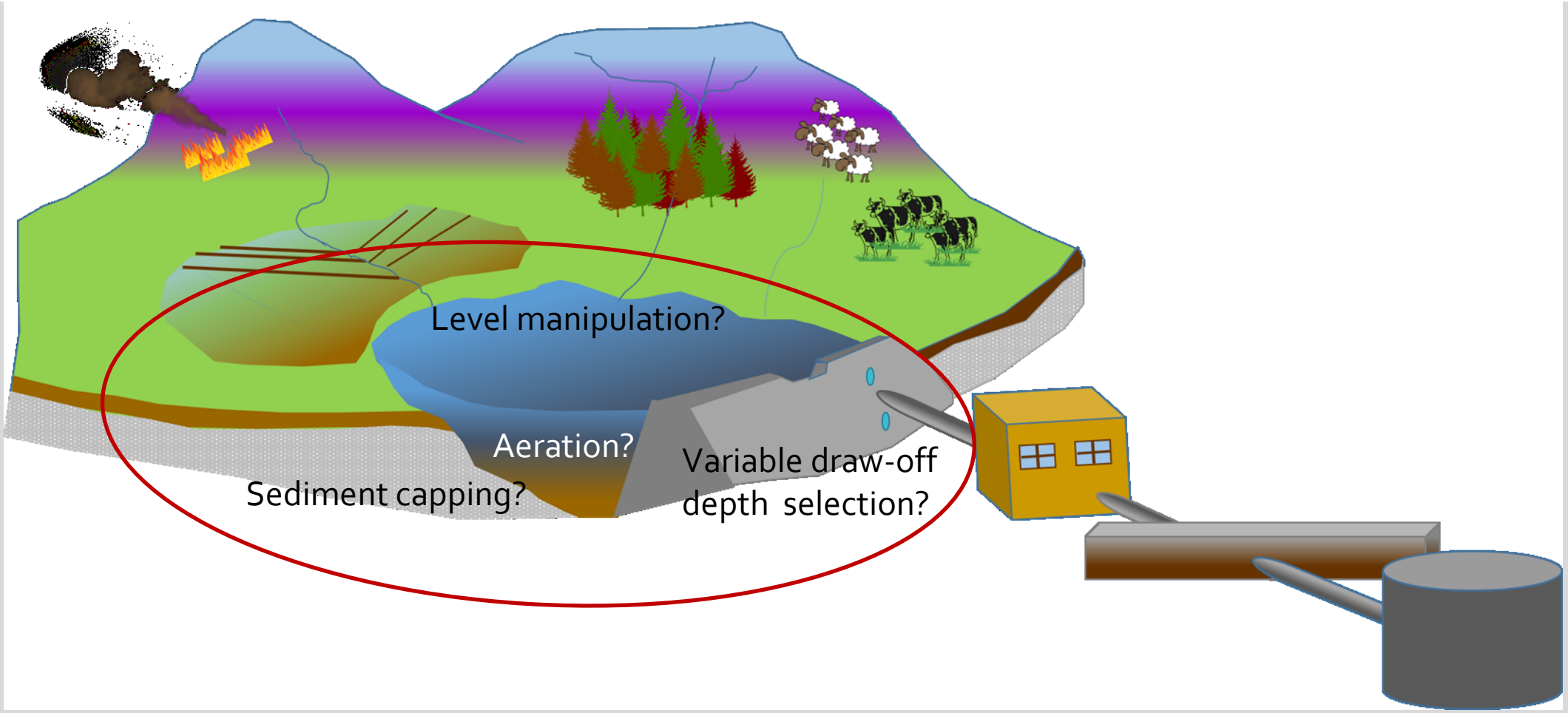


UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

the DOM intervention chain:
2) Reservoir Management

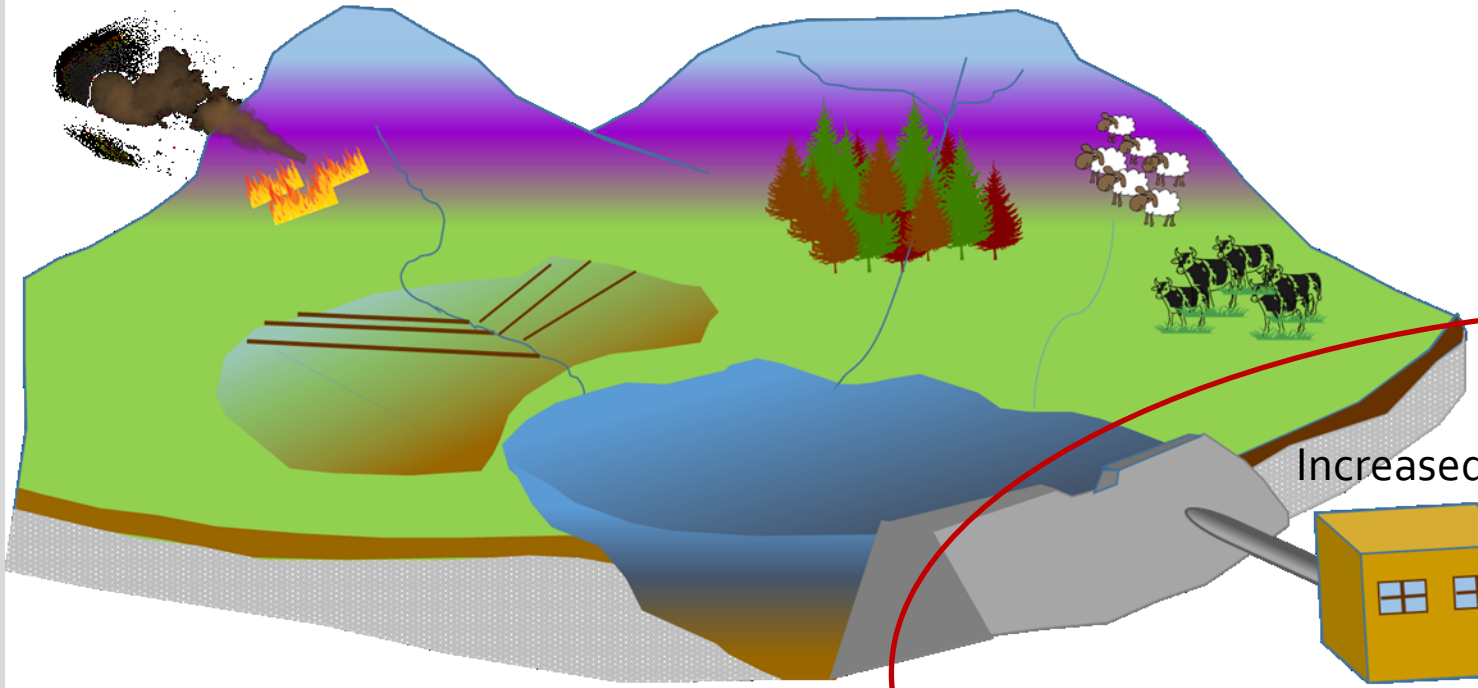


UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

the DOM intervention chain:
3) Monitoring & Treatment Options



Increased coagulant dosing?

Real-time monitoring / identification of risk via DOM quality monitoring informing tailored treatment

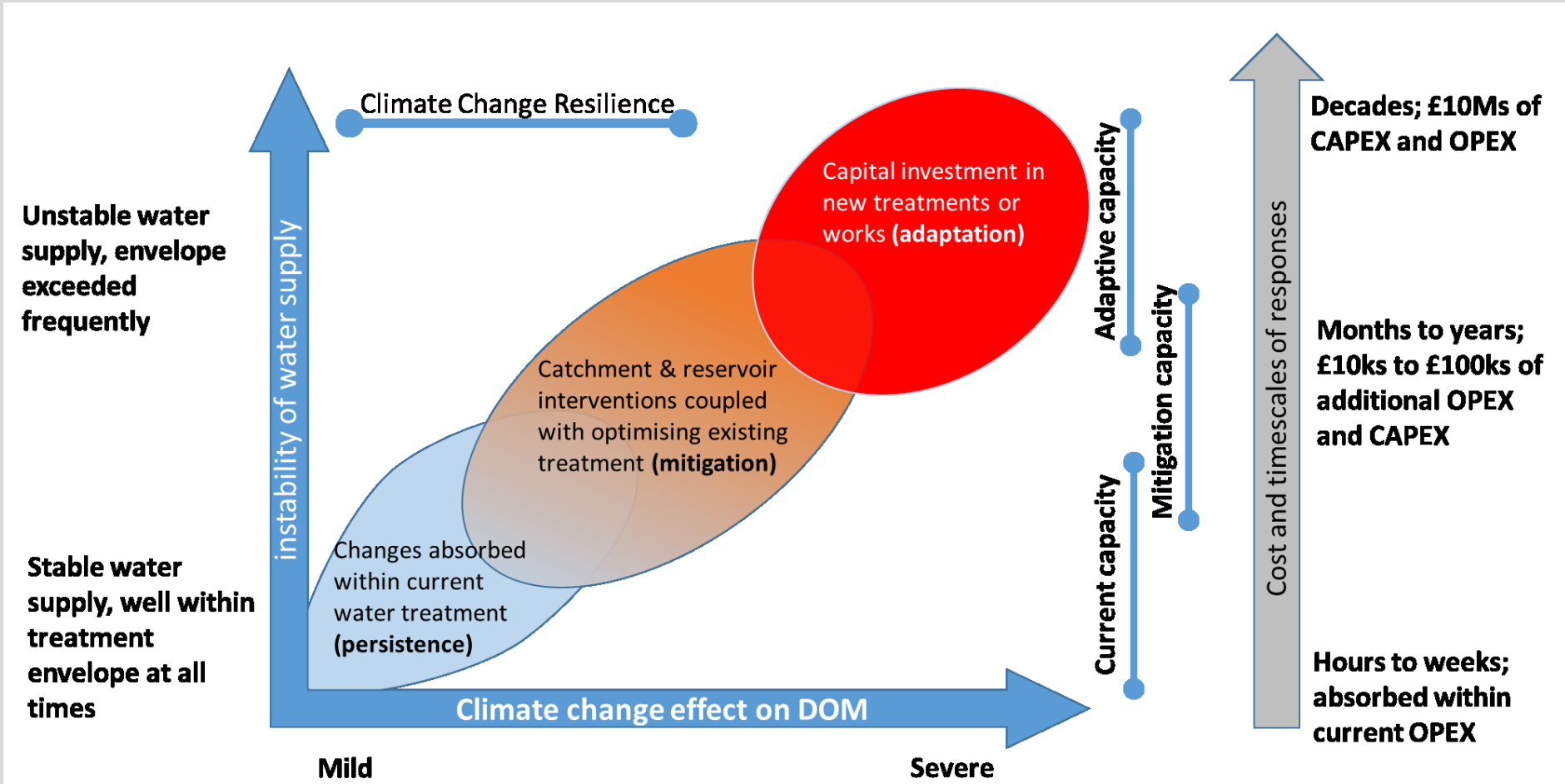
Installation of new plant, e.g. Magnetic Ion Exchange

UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

FREEDOM-BCCR: conceptual resilience model

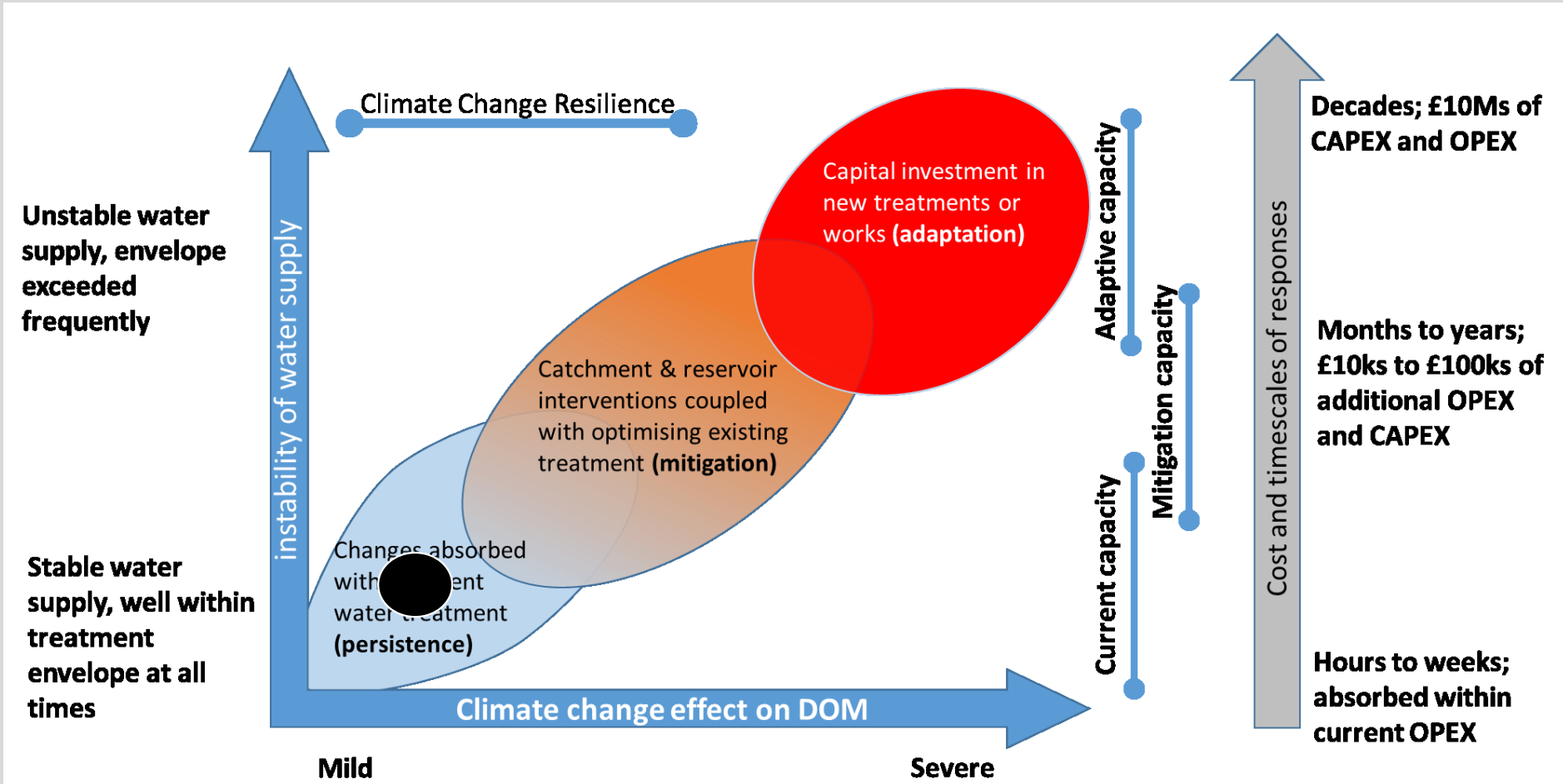


UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

FREEDOM-BCCR: conceptual resilience model

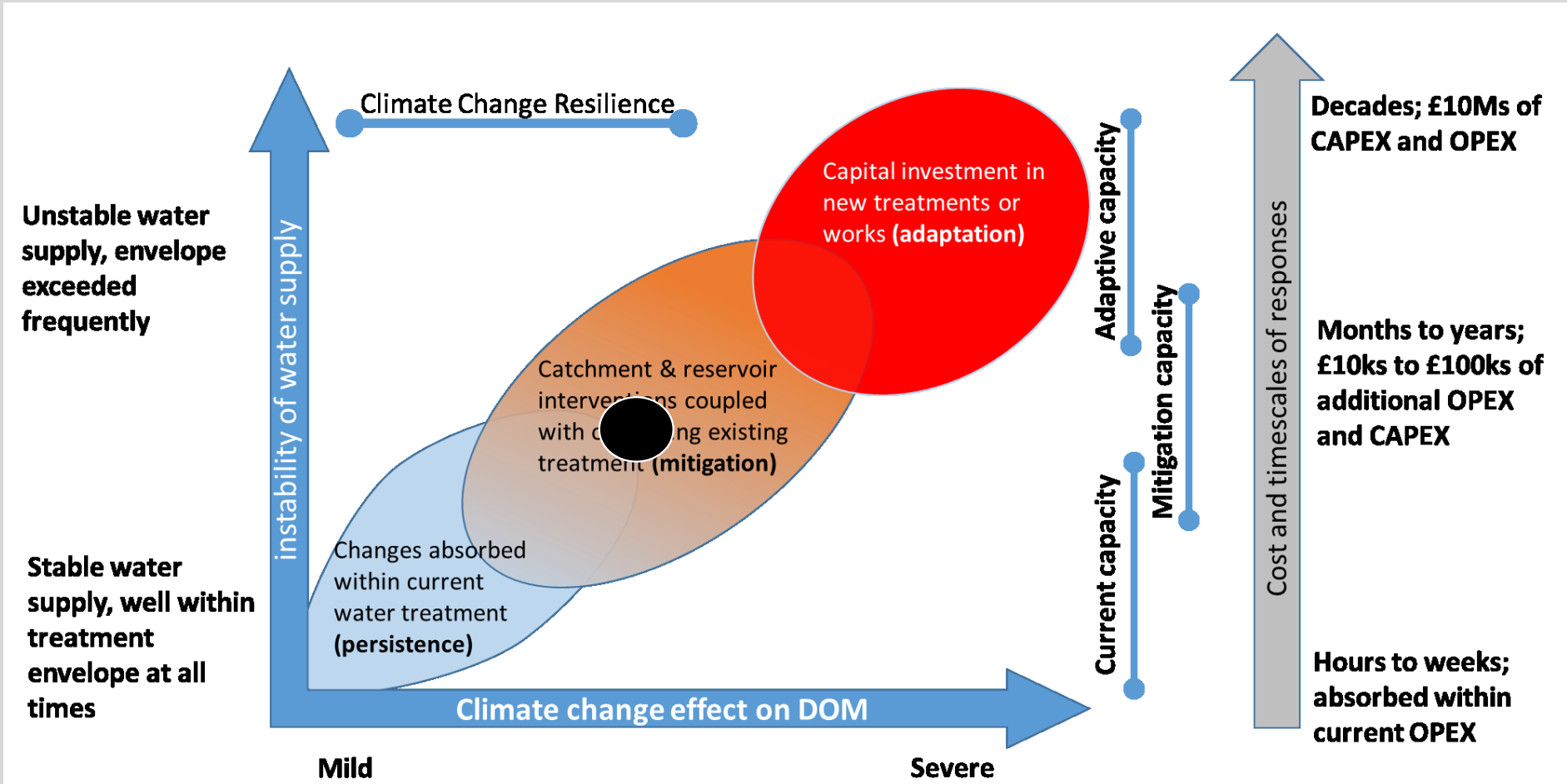


UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

FREEDOM-BCCR: conceptual resilience model

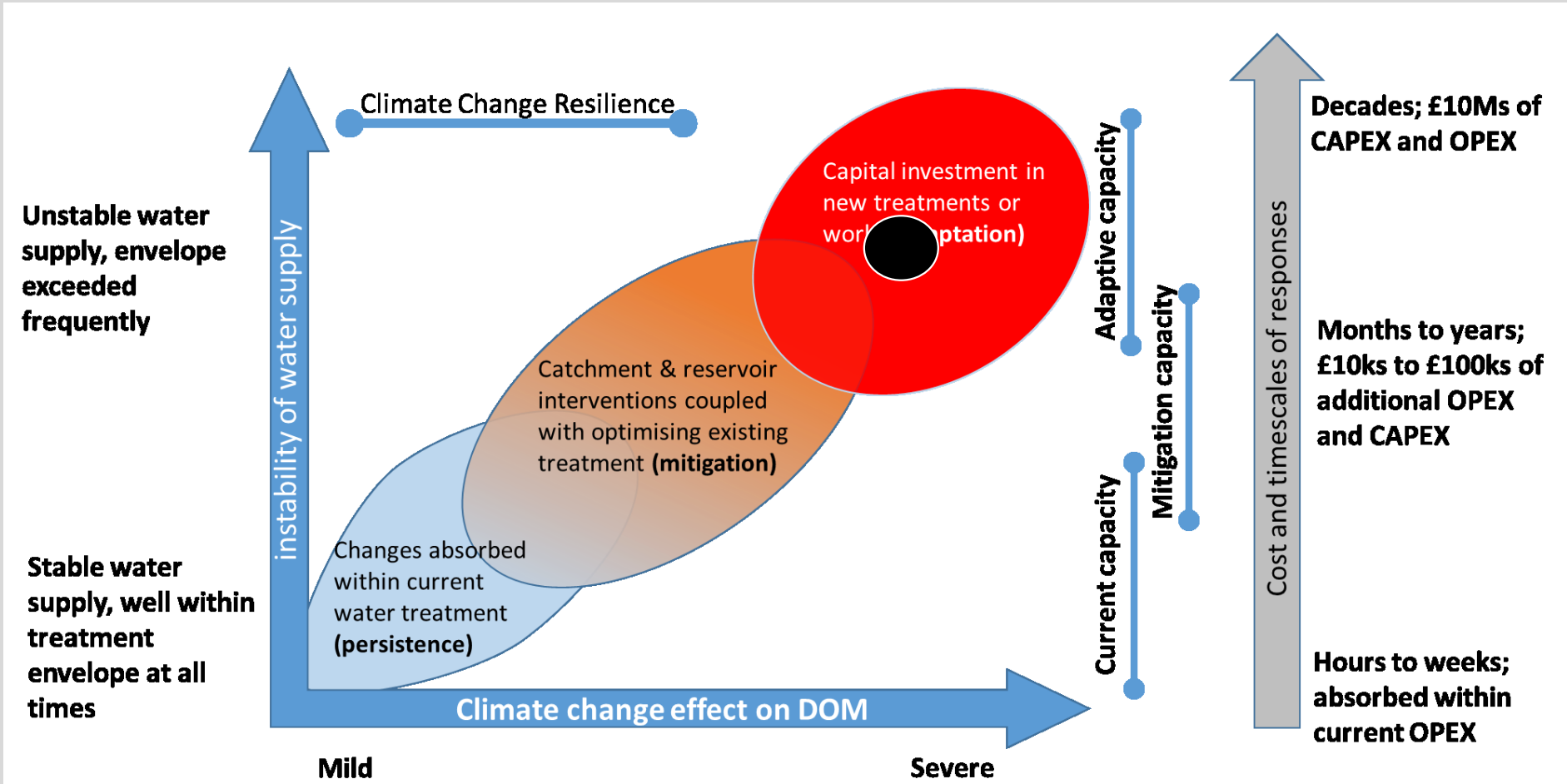


UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

FREEDOM-BCCR: conceptual resilience model



UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

FREEDOM-BCCR Outputs

- External presentations to the water industry-focussed sector
- Intervention chain report to industry
- Industry focussed briefing notes and short videos
- Peer reviewed publications:
  - Opinion pieces
  - Modelling approaches and projections


UK Centre for Ecology & Hydrology

Is there potential to manage dissolved organic matter concentrations within upland reservoirs?

One of three FREEDOM-BCCR project briefing notes considering options to increase resilience in the water industry to climate change impacts on Dissolved Organic Matter

Dissolved Organic Matter (DOM) in upland drinking water sources poses an increasing challenge to the water industry as concentrations have risen substantially in recent decades. Work undertaken during the FREEDOM-BCCR* has highlighted the potential of future climate change to exacerbate concentrations further, with important implications for water treatment. Reservoirs draining catchments dominated by peat soils are considered most vulnerable to the effects of warming.

The UK water industry has a history of intervening within reservoirs in order to control water quality issues such as algal blooms, excessive manganese levels, and deterioration in taste and odour.

In contrast, options to manage reservoirs in order to mitigate rising DOM concentrations are rarely considered. However, reservoirs can act as either a sink or a source of DOM (Figure 1), depending on the relative importance of various physical, chemical and biological processes. It is worth considering whether there are ways of modifying, or exploiting, these processes in order to reduce DOM concentrations in raw water outtakes.

Drinking water supply reservoirs vary considerably in physical characteristics, e.g. depth, volume, wind exposure and residence time, and the quality of water they receive. Understanding how such properties influence the production and removal of DOM is critical in determining the potential for in-reservoir mitigation options.

Warming across the UK resulting from global climate change will result in warmer soils and warmer reservoir water. Microbial decomposition of soil organic matter will increase as soils warm, and peaty soils particularly are expected to release greater quantities of DOM into reservoirs.

Increases in water temperature will enhance rates of microbial breakdown of DOM, hence at least partly offsetting increased DOM inputs. However,

UK Centre for Ecology & Hydrology

Met Office

UK Research and Innovation

Summary

- The FREEDOM-BCCR project set out to develop a scientist-practitioner community to asses the potential threats of climate change on dissolved organic matter to the upland drinking water supply in the UK.

- The project has involved the free sharing of ideas and data, resulting in a much clearer understanding of the likely scale of the problem and the options open to the industry to increase resilience of the supply.

- Elements of the predictive work still need to be finalised, but it is clear that climate change does impose a significant risk, particularly to smaller and more peat dominated catchments and their treatment works.

- While modelling has been effective in capturing much of the DOM behaviour in these systems, a major outstanding area is with respect to response to extreme events – particularly intense rainfall events – that will require more intensive monitoring. The current community is well placed to explore these issues further.

FREEDOM and FREEDOM-BCCR: a water industry reflection

Dr Fraser Leith

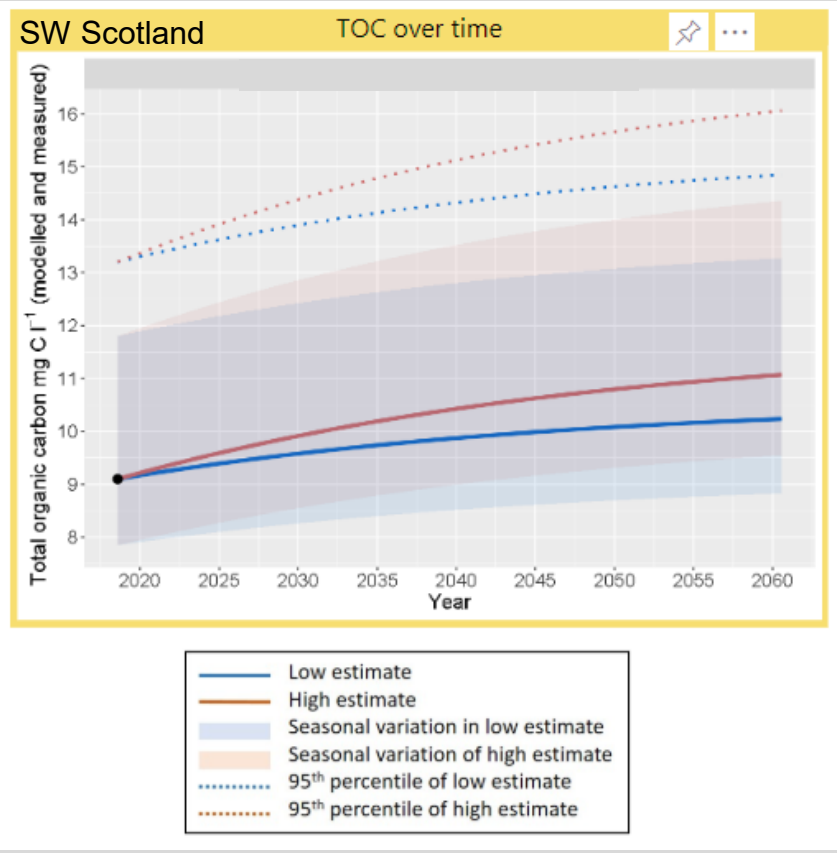
Met Office

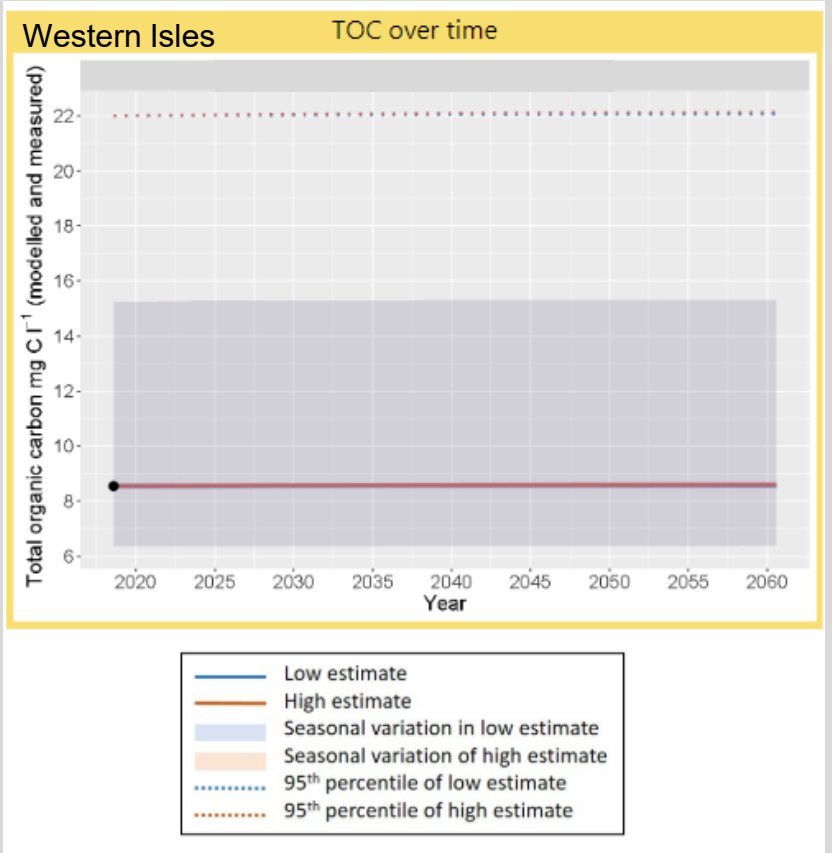
Scottish Water
Trusted to serve Scotland

UK Research and Innovation

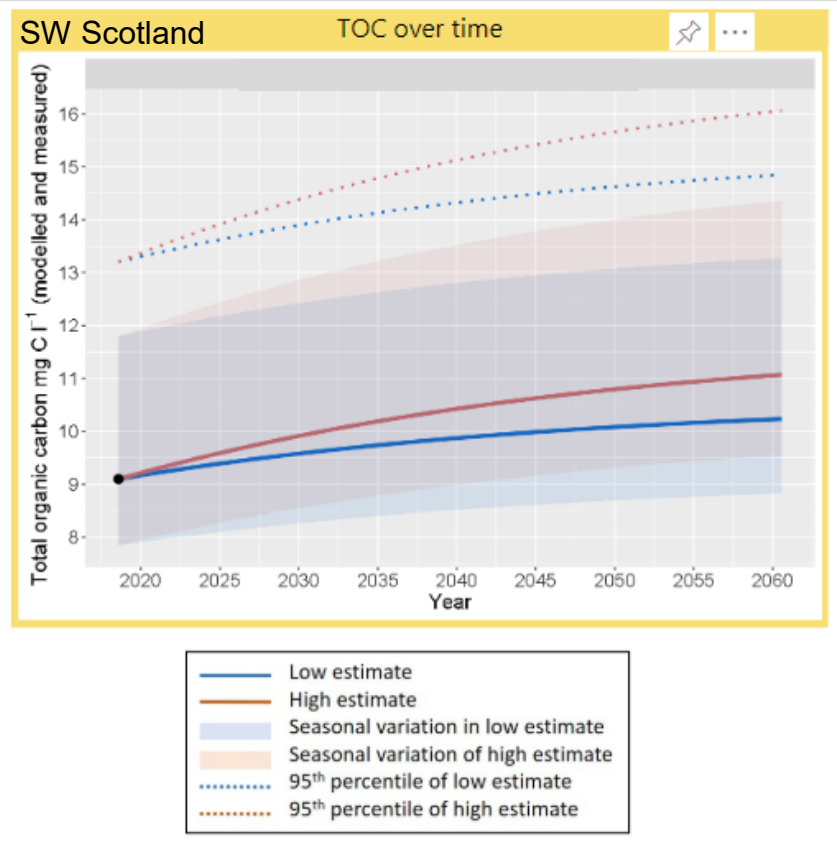
UK CLIMATE RESILIENCE PROGRAMME

FREEDOM Decision Support Tool





FREEDOM Decision Support Tool

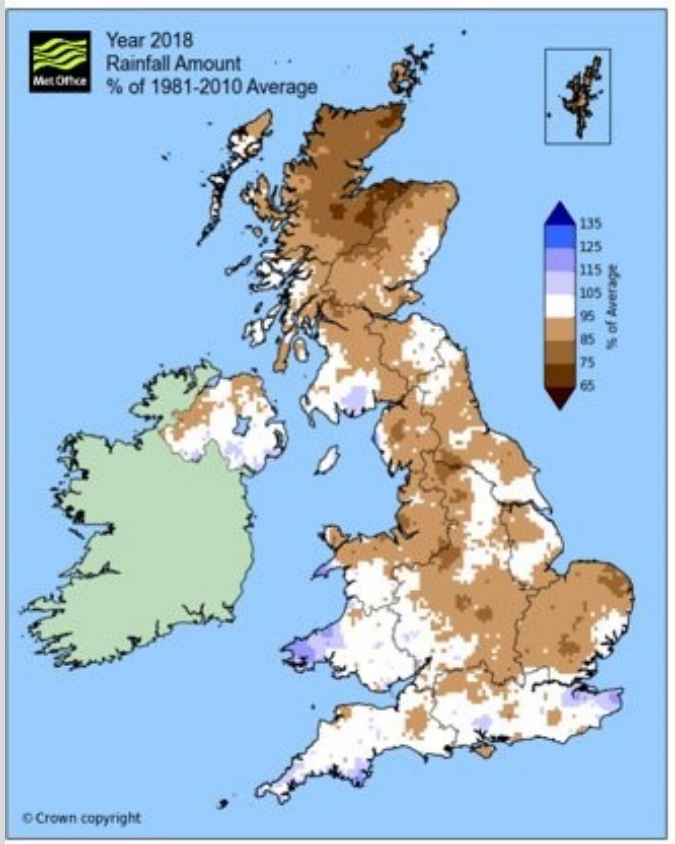


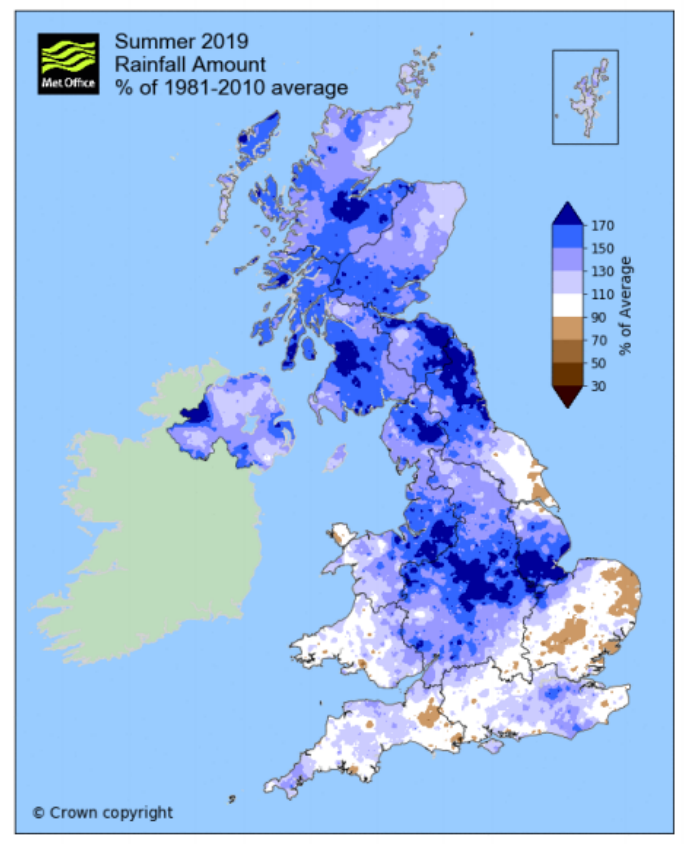
Scottish Water
Trusted to serve Scotland

Met Office

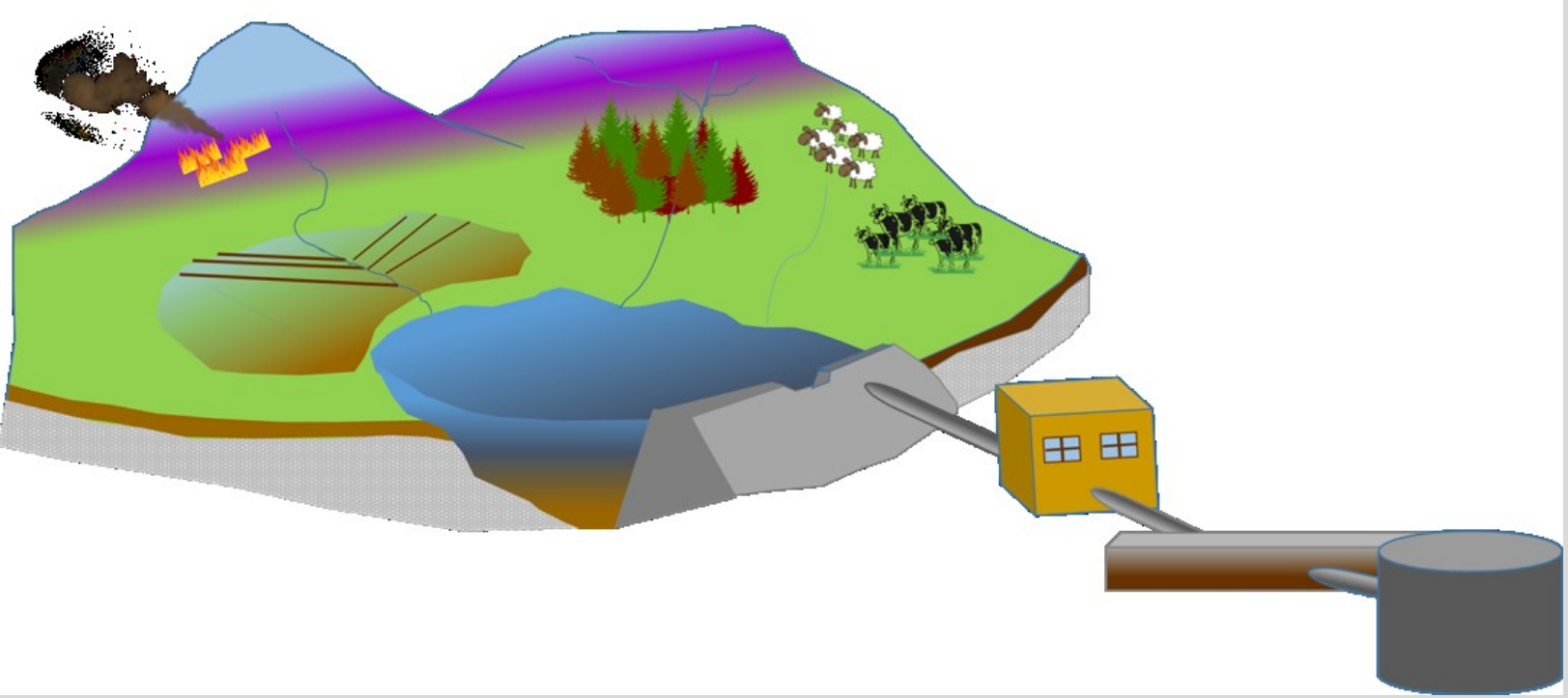
UK Research and Innovation

What will FREEDOM-BCCR add?





Water industry decision metrics



- Catchment, reservoir, or treatment options
- Most effective catchment management options
- New information on reservoir management options

Scottish Water
Trusted to serve Scotland

Met Office

UK Research and Innovation

Next steps

- Strength - linking research and industry across specialisms
- Extremes
- Improved decision-making metrics and tools

The FREEDOM project

FREEDOM is funded by the Natural Environment Research Council (NERC) and Scottish Water, and involves water and catchment scientists at the Centre for Ecology & Hydrology, the University of Glasgow, and the University of Leeds. Over 2018, the team have been working to establish the main drivers of changes in DOM in Scottish Water's drinking water sources, and the physical and biological processes that affect DOM levels within reservoirs. The resulting knowledge is being incorporated within a tool to equip catchment managers, plant operators and strategic planners with a better understanding of where, and by how much, DOM concentrations are likely to change in future in order to inform future management decisions.

Building climate change resilience: FREEDOM-BCCR project

A follow-on project, funded by UK Research and Innovation (UKRI), involving the same research team but a wider range of UK water companies, is seeking to further develop the application of the FREEDOM tool, focussing specifically on the potential impacts of climate change on DOM. FREEDOM-BCCR (Building Climate Change Resilience) aims to develop a community of scientists and industry practitioners focused on building the resilience of the UK's drinking water resources, by developing a clearer understanding of the DOM risks posed by climate change and identifying a range of adaptation and mitigation options available to manage them.

The 12 month FREEDOM-BCCR project started in February 2019. The aims of the project will be communicated to the water industry during the spring via a webinar and further workshops are planned for later in the year to encourage an exchange of views and needs and to disseminate the main outcomes from both projects.

Partners

Funded by

Scottish Water
Trusted to serve Scotland

Met Office

UK Research and Innovation

Scottish Water

Trusted to serve Scotland

Contact details

Website: www.ukclimateresilience.org

Twitter: @UKCRP_SPF

YouTube: UK Climate Resilience programme

The UK Climate Resilience programme is supported by the UKRI Strategic Priorities Fund.
The programme is co-delivered by the Met Office and NERC on behalf of UKRI partners AHRC, EPSRC, ESRC.