Report – Stakeholder engagement

D2 – Future water resources for water intensive energy infrastructure

October, 2023

UK Government

CS-NOW

Climate services for a net zero resilient world

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About CS-N0W

Commissioned by the UK Department for Energy Security and Net Zero (DESNZ), Climate Services for a Net Zero Resilient World (CS-N0W) is a 4-year, £5 million research programme, that will use the latest scientific knowledge to inform UK climate policy and help us meet our global decarbonisation ambitions.

CS-N0W aims to enhance the scientific understanding of climate impacts, decarbonisation and climate action, and improve accessibility to the UK's climate data. It will contribute to evidence-based climate policy in the UK and internationally, and strengthen the climate resilience of UK infrastructure, housing and communities.

The programme is delivered by a consortium of world leading research institutions from across the UK, on behalf of DESNZ. The CS-N0W consortium is led by **Ricardo** and includes research partners **University College London (UCL)**; **Tyndall Centre for Climate Change Research;** and institutes supported by the **Natural Environment Research Council (NERC)**, including the British Antarctic Survey (BAS), British Geological Survey (BGS), National Centre for Atmospheric Science (NCAS), National Centre for Earth Observation (NCEO), National Oceanography Centre (NOC), Plymouth Marine Laboratory (PML) and UK Centre for Ecology & Hydrology (UKCEH).

Contents

1. Introduction

In 2022, Work Package D2 (WPD2) of the CS-N0W programme ran two online stakeholder events. These events were to inform key stakeholders about the modelling work being done to project future water resources for water intensive energy infrastructure, and to seek feedback from stakeholders on the project plans:

- **Knowledge Sharing Webinar,** 'Future water availability for water-intensive energy infrastructure', on Thursday 13th October 2022; and an
- **Interactive Workshop,** 'Scenarios and indicators of future water availability for water-intensive energy infrastructure', on Thursday 10th November 2022.

This report summarises the attendees, the material presented, the key outcomes and the feedback gained from stakeholders from the two events. This information subsequently was used to shape WPD2's analysis of future water resources in England, in particular the analysis of the future projections (described in Tanguy et al. 2023). The intelligence has also fed through into the subsequent WPF2 stakeholder engagement work on the communication and visualisation of the CS-N0W outputs via a Portal.

This report is one of four reports summarising the outcomes of WPD2. The four reports are:

- Stakeholder engagement (Barker et al., 2023, this report)
- Approaches to construct scenarios of future water demand (Baron et al., 2023)
- Hydrological modelling and artificial influences: performance assessment and future scenarios (Bell et al., 2023)
- Analysis of Future Scenarios (Tanguy et al, 2023)

2. Knowledge Sharing Webinar

The first event, a knowledge sharing webinar held on Thursday 13th October 2022, was publicised widely using the flyer shown in Figure 1. A target list of stakeholders was assembled through liaison between the D2 team and the Environmeny Agency. The objective of this event was to inform key stakeholders about the CS-N0W water availability modelling, methods and approaches, and was aimed at anyone with an interest in future water availability in England.

Figure 1 Flyer for CS-N0W D2 knowledge sharing webinar 13th October 2022

The agenda for the webinar is shown in Table 1 and the slides shown are available in Appendix 1 – Knowledge Sharing Webinar Slides.

The webinar was attended by a total of 118 participants, including twelve presenters and CS-N0W project staff. A breakdown of organisations attending the webinar is shown in Figure 2, 'Other' organisations were those with only one representative attending were:

- BP
- British Beer and Pub Association
- British Geological Survey
- Carbon Capture and Storage Association
- Dairy UK
- EDF Energy
- Energy UK
- Food and Drink Federation
- ITM Power
- JBA Consulting
- Maltsters Association Of Great Britain
- Progressive Energy
- Net Zero East
- RWE
- SSE
- Uniper Energy
- UK Power Networks
- United Utilities

Table 1 Agenda for the CS-NOW D2 knowledge sharing webinar on 13th October 2022

Introduction to CS-NOW	Chris Thorpe, Ricardo
Project overview	Jamie Hannaford, UKCEH
Modelling methodology	Vicky Bell, UKCEH
Future demand scenarios	Helen Baron, UKCEH
Q&A on modelling and scenarios	
Analysis and visualisation	Jamie Hannaford, Matt Fry UKCEH
Uses of the CS-NOW dataset	Stuart Allen, Environment Agency
Q&A on outputs and applications	
Wrap-up and Next steps	Jamie Hannaford, UKCEH

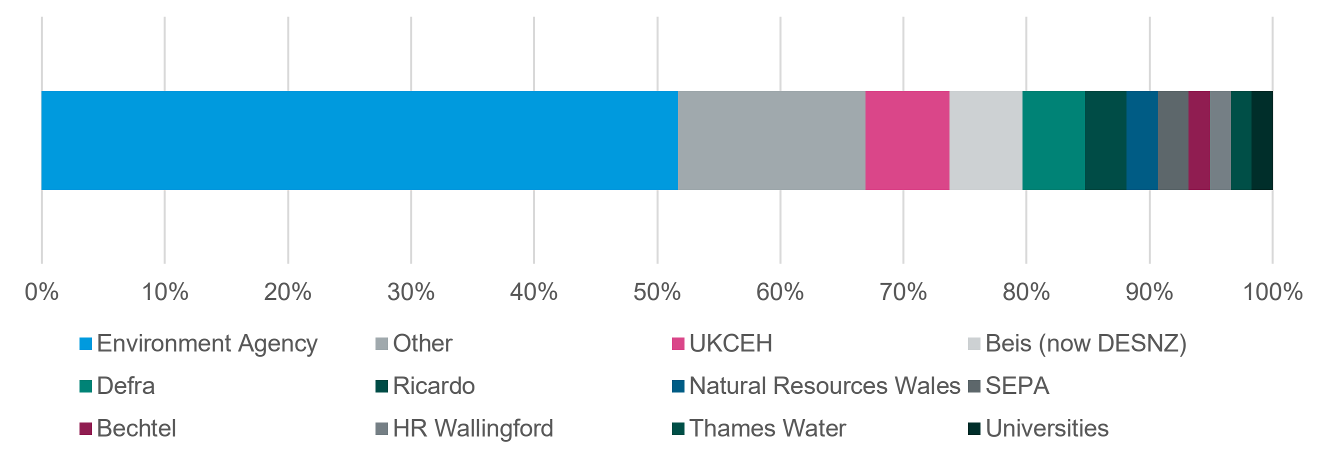

Figure 1 Breakdown of organisations attending CS-NOW D2 knowledge sharing webinar (total of 118 participants), organisations with one attendee are listed as 'Other'

Summary of Presentations

In the webinar introduction, Chris Thorpe (Ricardo) gave an overview of the wider CS-NOW programme. This was followed by a more detailed introduction to the D2 work package by Jamie Hannaford (UKCEH). This overview highlighted the need for data and information on future water resources that considered the latest climate and water demand scenarios.

Vicky Bell (UKCEH) then described the modelling approach, which is using the national scale 1km resolution model Grid-to-Grid (G2G) to model future naturalised and influenced river flows. She also described the modelling approach being used by British Geological Survey to model future groundwater resources. Helen Baron (UKCEH) detailed the outcomes of a literature review on previous efforts to develop future water demand scenarios and presented (at a high level) a basis for how new scenarios of future water demand could be constructed in CS-N0W. More information on the modelling approach and the new future water demand scenarios can be found in other WP2 reports, specifically Bell et al. (2023) and Baron et al., (2023).

Jamie Hannaford (UKCEH) then discussed the outputs of the D2 modelling, highlighting the added value of the dataset for future water resources assessments, over other existing hydrological data products (e.g. eFLaG (Hannaford et al. 2023), MaRIUS (Bell et al. 2019), etc.):

- Naturalised and influenced river flows
- High spatial resolution (1km)
- Transient simulations (daily data, 2020 – 2080)
- Ensemble of climate projections (12x RCM runs)
- Multiple demand scenarios (3x scenarios)

Following this, the types of analysis that could be done using the output dataset were discussed, as well as how the data could be visualised and made available (linking through to CS-N0W Work Package F2 - Future water resources for water-intensive energy infrastructure – data visualisation). The final presentation was from Stuart Allen (Environment Agency) who described how these outputs and this analysis will help build resilience and inform future planning and adaptation in a changing climate.

Summary of the Q&A sessions

There were two Q&A sessions in the webinar: the first followed presentations on the modelling methodology and future demand scenarios, the second focussed on the outputs and applications. Participants asked questions verbally and in the chat function of MS Teams, and questions in turn were answered both verbally and in the chat. Key themes raised in the Q&A sessions are summarised below. The questions and answers, and resolution to any issues, are given in Appendix 2- Knowledge Sharing Webinar Q&A.

- **Aims of the project**, including possibilities of using outputs to understand impacts of future droughts on nature, project timings
- **Catchments/geographic scope**, including whether cross-border flows were included, possibilities of extending to include Wales and Scotland. While this was not possible within CS-N0W, it is certainly a possible follow-up and the project team continue to engage with partners in organisations in Wales and Scotland.
- **Data**, including use of licenced or actual abstraction data (the latter being the case), whether the impacts of impoundments are included in the model (which they are not at present), representativeness of discharge data (relative to abstractions, which is one key limitation of the data as noted in the appendix and accompanying reports, Baron et al. 2023 and Bell et al. 2023), inclusion of groundwater abstractions (which are included)
- **Scenarios**, including assumptions in predicted growth in water demand due to hydrogen production, impact of water demand for hydrogen production on total demand, data sources for the potential growth of

different net-zero technologies, correlations between weather/flows and abstractions/discharges to develop future scenarios of artificial influences

- **Links with other initiatives**, including the 2024 round of water companies' water resources management plans (WRMP24), the third independent assessment of UK climate risk (CCRA3; CCC21), UK-SSP scenarios, eFLaG.
- **References**: references suggested for reclaimed water strategy – Moores (2021), Industrial & agricultural water use - Wood Environment & Infrastructure Solutions UK Limited (2020), Population scenarios - Cambridge Econometrics (2019).

3. Interactive Workshop

The second event was an Interactive Workshop (webinar) held on Thursday 10th November 2022 (Figure 3). The objective of this event was to get feedback on and discuss CS-N0W analysis plans with key stakeholders. The workshop was aimed at anyone with an interest in shaping and using scenarios of future water resources in England, and invites were extended to the key stakeholders identified by EA/DESNZ. The workhsop aimed to:

- Introduce the scenarios of future water demand and use in more detail, and ensure they are fit for purpose
- Discuss and identify the indicators of future water resources needed to support decision making

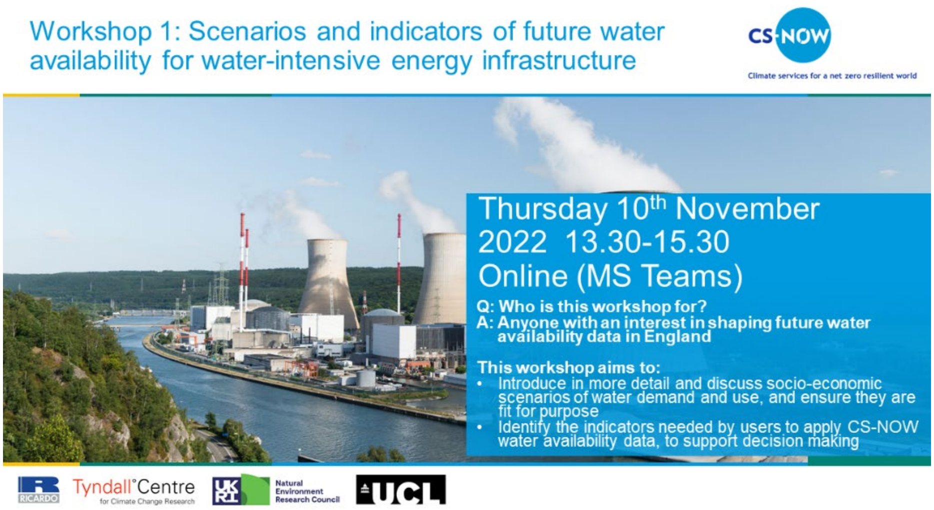

Figure 3 Flyer for CS-N0W D2 Interactive Workshop 10th November 2022

The workshop was structured around two main presentation sessions where more detailed material on the scenarios and then indicators was presented. The presentation sessions were then followed by an interactive session which was run using Mentimeter (https://www.mentimeter.com/) in order to vote on options, to help prioritise and select scenarios and indicators.

The workshop was attended by a total of 78 participants, including 10 presenters and CS-N0W project staff. A breakdown of organisations attending the webinar is shown in Figure 4, 'Other' organisations were those with only one representative attending were:

- BP
- British Beer and Pub Association
- British Geological Survey
- Carbon Capture and Storage Association
- Dairy UK
- Energy UK
- Equinor
- HS2
- MOSL (Market Operator of Englands Non Household Water Market)
- Net Zero East
- Progressive Energy
- RWE
- SSE
- TFL Tube
- Thames Water
- Uniper Energy
- Unknown
- Welsh Water
- Yorkshire Water

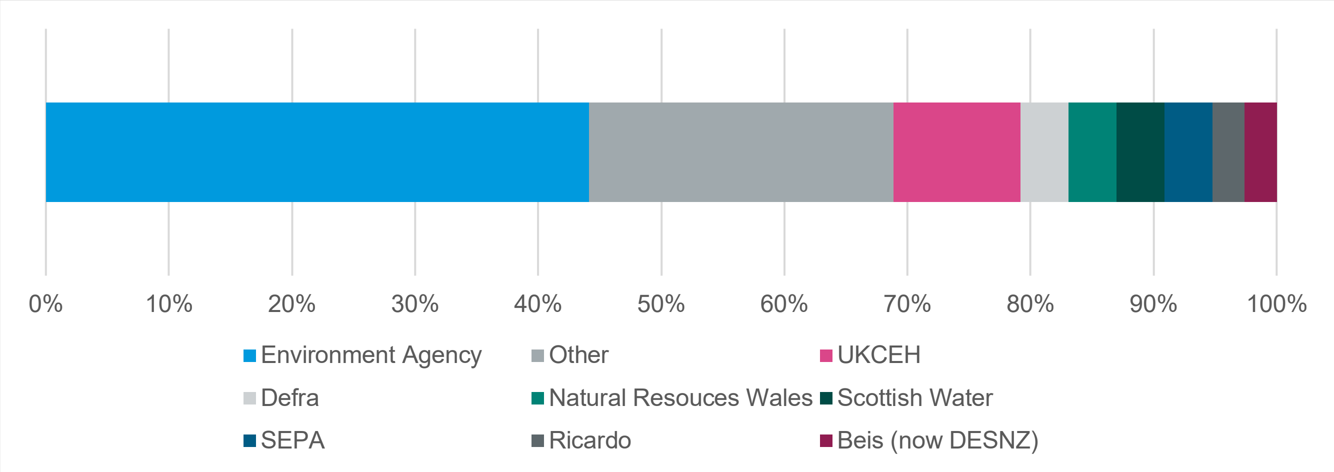

Figure 4 Breakdown of organisations attending CS-N0W D2 Interactive Workshop (total of 78 participants), organisations with one attendee are listed as 'Other'

Summary of Presentations

The slides presented at the webinar can be seen in Appendix 3. In the first instance, Jamie Hannaford (UKCEH) gave an overview of the materials presented in the Knowledge Sharing Webinar (see Section 2), which included a summary of the CS-N0W programme and an overview of the modelling approach and methods – more detail on which can be found in Bell et al., (2023). Jamie outlined the aim of the analysis being done within CS-N0W D2 to assess and analyse changes in future water availability at the catchment and regional scale for artificially impacted future flows. The 'eFLaG' project was briefly introduced which produced future flow and groundwater level projects for the UK using UKCIP18 climate projections. CS-N0W advances the data produced by eFLaG by providing projections for ungauged locations allowing for improved regional scale simulations and, crucially, producing both naturalised and impacted future flows for three different water use scenarios by building on the artificial influence (abstractions and discharges) layer that was built into G2G in the MaRIUS project.

Helen Baron (UKCEH) then gave an overview of the water demand scenarios developed in CS-N0W, the aim of which are to create an envelope of potential future demand scenarios and combine best estimates of future demand over different sectors to form a coherent national picture and to use these scenarios to model future influenced flows, providing gridded estimates of future water availability. The three scenarios (here named 'Upper', 'Central' and 'Lower', but since renamed to 'Economic Growth', 'Business As Usual' and 'Sustainability', respectively) are summarised in Figure 5. Helen then presented some options that could be implemented in the scenarios around the power, industrial and spray irrigation water use, which were explored directly in the interactive session (summarised below). Finally, Helen discussed how environmental flows could be implemented in the CS-N0W modelling and data. Due to uncertainty in applying Hands Off Flows (HOFs) into the future, HOFs were not included in the modelled water availability, but Environmental Flow Indicators (EFIs) can be run as a post processing step, which could show how abstraction sensitivity bands may change and how much water is available at these bands in the future. An example of how environmental flows could be presented is shown in Figure 6.

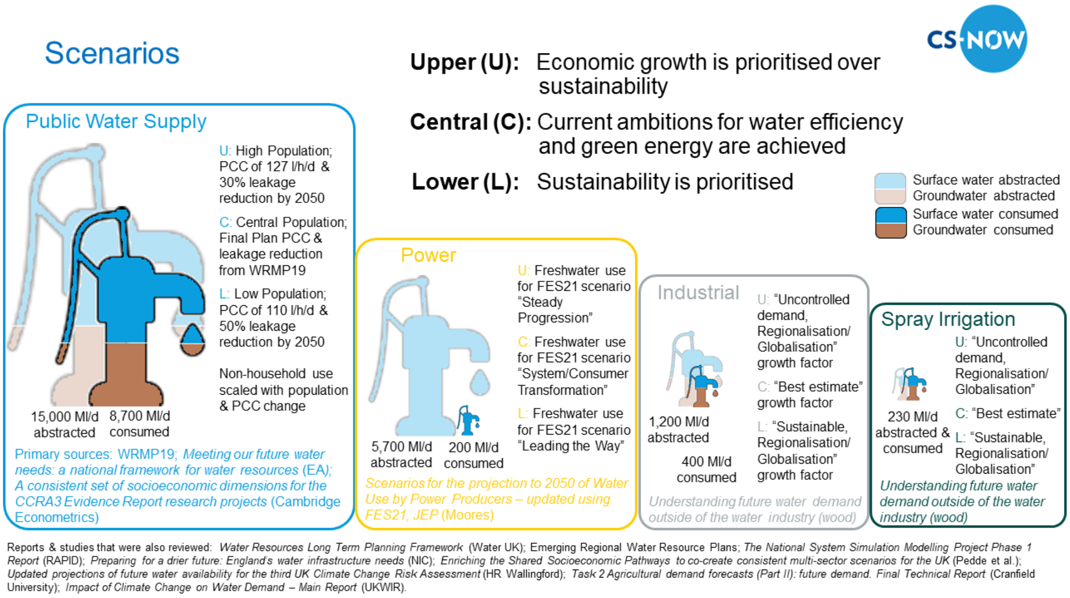

Figure 5 Summary of the three water use scenarios across the public water supply, power, industrial and agriculture (spray irrigation) sectors presented at the Interactive Workshop.

The third section of the presentation materials focused on the specifics of the planned analysis and the types of indicators to use to assess future water resources, presented by Jamie Hannaford and Lucy Barker (UKCEH). The CS-N0W proposal set out that the design and definition of these indicators and flow metrics should be stakeholder-led and provide a consistent foundation for strategic planning of water use and availability across water-intensive sectors, e.g. energy, agricultural and industrial abstractors.

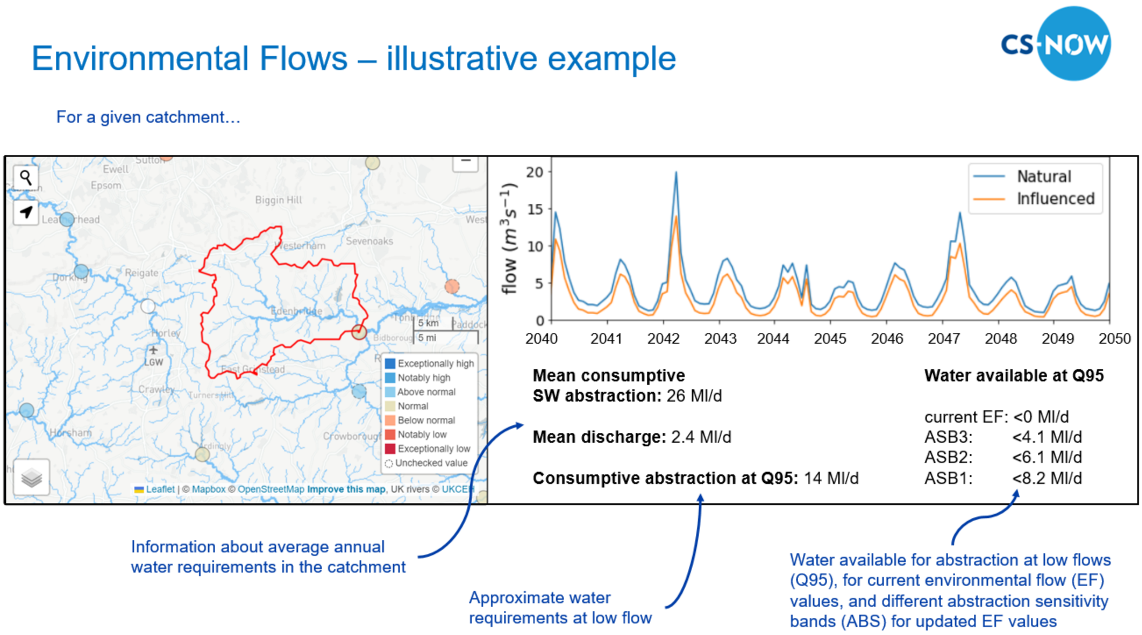

Figure 6 Illustrative example of how environmental flows information and data could be visualised in CS-N0W

Introductory materials were presented to provide options and context for the key questions explored in the interactive session that followed:

- Which flow indicators?
- Which drought indicators?
- What spatial scales?
- What timescales (i.e. how to show changes in future)

The options presented and the results of the interactive activity are discussed in the sections below.

Overview of Interactive sessions

The interactive sessions were hosted online using Mentimeter ('Menti'), such that the modelling and analysis teams at UKCEH could pose specific questions and choices to the participants and understand their needs and priorities. Full results of the interactive sessions are available in Appendix 4 – Interactive Workshop Menti Results.

Summary of Menti interactive voting

As a starting point, participants were asked some introductory questions about their sector and whether they are currently having to plan for future water resources – 77% of the participants were having to plan (57 responses), with most participants being from Government, regulation/regulator, water, energy sectors.

Water use scenarios

When asked how the water use scenarios presented fit into their current and/or future planning needs, respondents on the whole noted that they were a positive step in bringing different strands of information together into one dataset that could support planning needs in the water resources, energy, policy and regulation, and in the transition to net zero. The fine spatial resolution was noted as a benefit as was the systematic nature with which the scenarios had been produced and that they can be used to compare against their own or other existing scenarios.

A number of participants noted that it was hard to say exactly how scenarios might be used until more details were provided (e.g. on leakage, per capita consumption etc.) and especially on what they showed in terms of future water resources. A number of responses focussed on the possible future inclusion of WRMP24 plans and assumptions, which would improve their utility. Some noted other aspects which could be included in future, to enhance the scenarios' utility, including: agricultural demand with changing crop types, abandonment of current water sources, e.g. groundwater sources due to saline intrusion, woodland restoration, and other adaptation strategies and inclusion of different climate scenarios (e.g. RCP 2.6 or 4.5; IPCC, 2021)

When asked what the CS-N0W projections add to what they currently use for future planning, responses generally focussed on the higher resolution and the ability to visualise differences and changes regionally, and the representation of more sectors, beyond just water supply.

Specifics of the scenarios

Participants were asked two questions about the specifics of the scenarios. Firstly, for the energy sector whether the 'Central' scenario should use the 'Future Energy Scenario' (FES21, Moores et al. 2021) scenario for system transformation or consumer transformation. Answers were evenly split between 'system transformation' and 'no particular view' (46% each) with the remainder selecting consumer transformation (37 responses in total). Secondly, for industrial and spray irrigation water use, whether the regionalisation or globalisation scenarios should be used. Around two-thirds of responses were for the 'regionalisation scenario' (64%), with 31% having 'no particular view', the remainder selecting the 'globalisation scenario'. More information on the scenarios can be found in Baron et al., (2023).

Data gaps

WRMP24 was raised as a key data gap to address if the exercise of creating the scenarios was repeated in the future, in addition to the inclusion of cross-border flows and other countries within the UK. Other suggested gaps included: private water supplies, different crop types, projected changes in land use (including urbanisation), and the impact of nature based solutions and/or policies and subsidies.

Two-thirds of respondents noted that data was already being collected or produced to fill these gaps (N.B. only 6 responses), for example: abstraction data in other parts of the UK, urban development plans, land use mapping and private water supply data.

Environmental flows

Participants were asked how the baseline period for the environmental flows should be calculated, around two-thirds selected a 30-year 'moving window' baseline (i.e. a 30 year baseline that is updated every 10 years) (64%), with 21% selecting 'don't know'. The remainder of participants selected 'apply the current baseline period to the future (9%), 'no particular view' (3%) and 'other' (3%).

An example of how the environmental flows could be presented was shown (see above and Figure 6), with over three-quarters (78%) of respondents saying that the data and information shown in this example would be useful for future planning, the remaining responses varied from 'no particular view' (13%), 'no' (6%) and 'don't know' (3%, total of 32 responses).

Analysis plans

As a start, participants were asked about their primary reasons for analysing future changes in water resources. Participants could select and rank multiple answers, with the most popular responses being: 1) water resources planning, 2) regulation/environmental flows, 3) water quality/ecological impacts/conservation. The next question asked what other future climate/water resource products they currently use, with 32 responses, 22% of selected 'not relevant for me', 20% for both 'Future Flows (2011)' and 'eFLaG (2022)', 17% 'other(s)', 10%

‘MaRIUS’, 7% ‘Atkins Regional Climate Products (2020)’ and 5% ‘I don’t use any future hydrology, only climate products I run through my own hydrological models’.

General flow indicators

When asked about the general flow metrics of interest, those calculated at the monthly (42%) and seasonal scale (28%) were the most popular. When considering low flow metrics in particular, low flow percentiles were the most popular choice (60%) followed by n-day mean annual minima (25%).

Drought indicators

The threshold level method and associated extracted drought event characteristics (duration, intensity, severity) was the most popular choice for analysing changes in future drought (50%), with around a third having ‘no particular view’ (34%).

Spatial scales

Participants were asked what spatial scale(s) the analysis should be done at and could select and rank multiple answers, with the most popular responses being: 1) catchments, 2) river basin districts, 3) water resource zones and 4) regional groups. In addition, participants were asked if they were interested in the spatial coherence of droughts/low flows between regions, with 94% answering ‘yes’.

Visualising and analysing change

When asked about the approach that should be taken to assess future change, 33% selected warming levels (e.g. 1.5^{o}C, 2^{o}C etc.), 29% selected time slices (e.g. baseline, near future, far future) and 22% transient changes (i.e. continuous moving windows). The remainder selected ‘decadal changes’ (15%) and ‘no particular view’ (2%).

Other approaches

The final questions briefly considered other options for analysis around other aspects of flow variability (e.g. drought termination, timing of high/low flows, seasonality etc.) and visualisation of uncertainty; there was not enough time in the session to address these in detail.

4. OUTCOMES OF CS-N0W D2 STAKEHOLDER ENGAGEMENT ACTIVITIES

Analysis of future water resources

Table 3 summarises the most popular selection for each multiple-choice question on the analysis plans presented in the Interactive Workshop. Further information on the analysis of future water resources in England undertaken in CS-N0W D2, following these stakeholder workshops, can be found in Tanguy et al., (2023).

Table 3 Summary of most popular multiple choice questions relating to the CS-N0W analysis of future water resources

Question	**Most popular answer** *Second most popular answer*	Number of responses
For water use in the power sector, should the CS-N0W central scenario use the FES21 scenario for System or Consumer Transformation?	**46% System Transformation** **46% No particular view** *8% Consumer Transformation*	37
For water use in industry and spray irrigation, should the CS-N0W upper and lower scenarios use the Regionalisation or Globalisation scenarios?	**64% Regionalisation** *31% No particular view*	36
How should the environmental flows baseline period be calculated?	**64% Apply a 30-year moving window that is updated every 10 years** *21% Don't know*	33
Which 'general' flow metrics would you like to see us investigate in our analysis within CS-N0W?	**42% Monthly average flows** *28% Seasonal average flows*	32
Which low flow metrics would you most like to see us investigate in our analysis within CS-N0W?	**60% Flow percentiles (Q95, Q70 etc.)** *25% N-day minima (7-day, 30-day etc.)*	29
What approach should we take to analyse droughts?	**50% Threshold level methods (extracted droughts with intensity, duration, volume)** *34% No particular view*	32
What spatial scales should we analyse?	**Catchments** *River Basin Districts*	33
Are you interested in looking at the spatial coherence of drought/low flows between regions?	**94% Yes** *3% No* *3% Don't mind*	31
What approach should we take to look at future change?	**33% Warming levels (e.g. 1.5 deg, 2 deg, 2.5 deg)** *29% Time slices (e.g. Baseline 1989-2018), Near future 2020-2049, Far future 2050-2079)*	28

Links to CS-N0W F2: Data exploration and visualisation tool

The outcomes of the CS-N0W D2 interactive workshop were used as the starting point to ask potential users of the CS-N0W projections how they would like to be able to explore and visualise the data in the tool developed within in CS-N0W Work Package F2 (WPF2). More information on the data exploration and visualisation tool can be found in WPF2 report Barker et al., (2023).

5. SUMMARY: OVERALL ASSESSMENT AND LEARNING POINTS

Below we provide a summary assessment of the workshop outcomes, remaining challenges and learning points:

Overall assessment of the workshop outcomes:

- The two workshops were successful in raising awareness about CS-N0W among the community, gathering community views on the scenarios and datasets and helping provide direction and specific stakeholder decisions for the D2 analysis. The first workshop raised awareness and primed potential users, whereas the second workshops used an interactive methodology to capture stakeholder preferences for several elements of the scenarios, and for all the key decisions for the D2 analysis (on which spatial scales, temporal scales, choices of indicators and so on). These directly fed into the finalized scenario design (Baron et al. 2023) and the subsequent D2 analyses presented in Tanguy et al. (2023).
- The two workshops also provided an important foundation and mobilized a stakeholder community for the more concerted engagement efforts of F2. The workshops were co-organised and delivered by the F2 team, and the F2 sub-project has taken forwards much of this intelligence on stakeholder preferences, but sought to build on it with closer directed working with a smaller stakeholder group. The F2 super users group was also defined using the attendees from the engagements summarized here as a starting point.
- Overall, there was a great deal of interest in the planned CS-N0W outputs, and a lot of positive support for the initiative, as well as a recognition of what the 'added value' is of the planned outputs compared to previous hydrological products. Users voiced a particular support for the inclusion of abstractions/discharges and use of future socioeconomic scenarios, and the plans to deliver high-resolution gridded outputs. Many voiced enthusiasm for these developments and could see value in the products for their applications. However, there was also a lot of uncertainty as to just how far the D2 outputs would go as they stand in meeting those needs – perhaps unsurprising given the limited time in these workshops, and the available detail on the outputs – this underscores the importance of the longer-term and hands-on stakeholder engagement planned in F2.

Limitations and learning points:

- While the audience was a relatively diverse group of water users, there was inevitably a bias towards the EA. This is appropriate given they are commissioners of the work and key users, but it would have been beneficial to have a greater representation from other key user groups (e.g. more DESNZ and other energy sector users) at the second workshop. We did engage with these organisations and used our key contacts to reach out within their networks and organisations, but perhaps this could have been done more systematically and with greater lead-times – the F2 team have considered this in their engagement strategy.

- The workshop design and interactive elements worked well for capturing user preferences on the analysis methods and specific aspects of the scenarios, which was really the key brief for D2. However, the workshops were less effective at capturing the wider discourse, in particular stakeholders' views on the scenarios and wider research design of D2. In part this was by design, as the scenarios and plans for modelling had already largely been defined and developed beforehand (through a bilateral co-development process with the EA as the key users). At the same time, it was perhaps a missed opportunity to explore user feedback on some key aspects which were covered only at very high level (e.g. the potential for looking at future environmental flow constraints, scope for extending to other parts of the UK). They were captured here and passed into the F2 analysis, but we did not really explore user preferences in detail. Much of this discussion (e.g. the Q&A in Appendix 2 and free-text answers in appendix 4) is for potential developments way beyond the scope and resources of CS-N0W D2/F2 but provides useful intelligence for potential future updates, and for new avenues of research that can build on the foundation of D2/F2.
- In part this last learning point can be generalized into a key challenge with the D2 workshops (and later also in F2): we were necessarily engaging users about potential 'datasets and products' while still having some uncertainty as to exactly what they would be, and specifically whether those datasets and products would actually be available to the user community, given the ongoing uncertainties around licensing for CS-N0W outputs.
- One important issue that was raised during the workshop concerned terminology (see Q&A, Appendix 2). Some users raised concerns about the use of 'water availability' which has a precise definition within the EA and wider regulatory community, being water available for abstraction after environmental flow requirements have been considered. Given that this is not being included explicitly in the future D2 projections (see Barron et al. 2023 and Bell et al. 2023), the use of this term could be misleading. This observation was taken through into the F2 user engagement, and following agreement from EA and other users, it has been agreed that 'Future Water Resources' would be used to describe the tools and datasets emerging from D2 and F2 from CS-N0W.

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Parry, S., Mackay, J., Chitson, T., Hannaford, J., Bell, V.A., Facer-Childs, K., Kay, A., Lane, R., Moore, R.J., Turner, S., Wallbank, J. (2023) Divergent future drought projections in UK river flows and groundwater levels. Hydrology and Earth System Sciences, In Revision, https://doi.org/10.5194/hess-2023-59

Rameshwaran, P., Bell, V., Brown, M., Davies, H., Kay, A., Rudd, A., Sefton, C. (2022) Use of Abstraction and Discharge Data to Improve the Performance of a National-Scale Hydrological Model. Water Resources Research, 58 (1), https://doi.org/10.1029/2021WR029787

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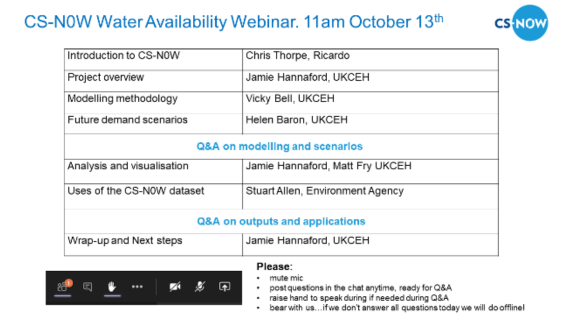
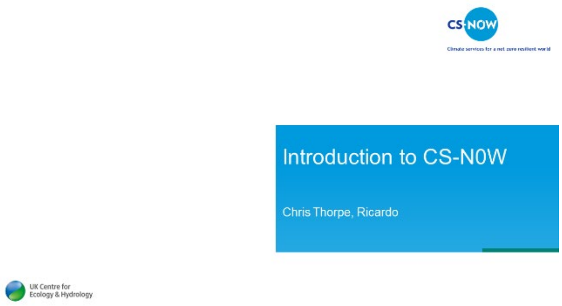
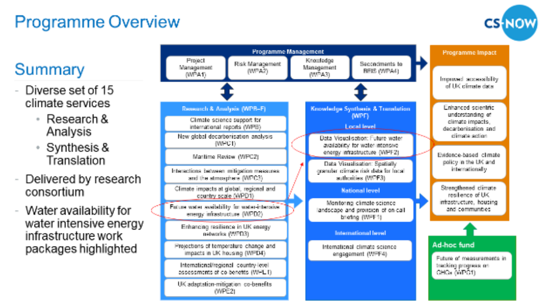
Wood Environment & Infrastructure Solutions UK Limited (2020) Understanding future water demand outside of the water industry, Defra, London.

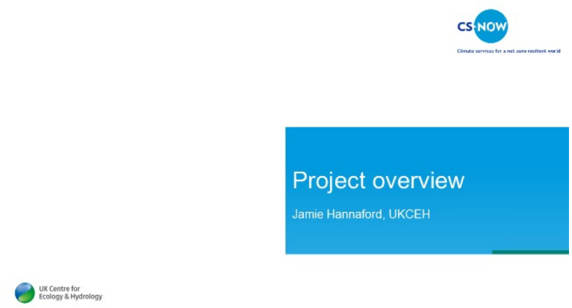
Appendix 1 – Knowledge Sharing Webinar Slides

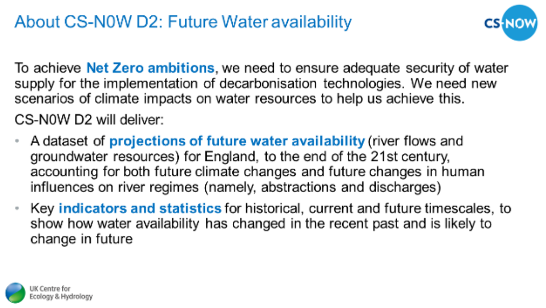
Slides from the CS-N0W D2 knowledge sharing webinar on 13th October 2022:

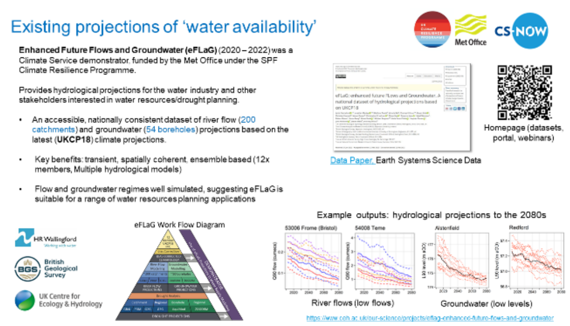


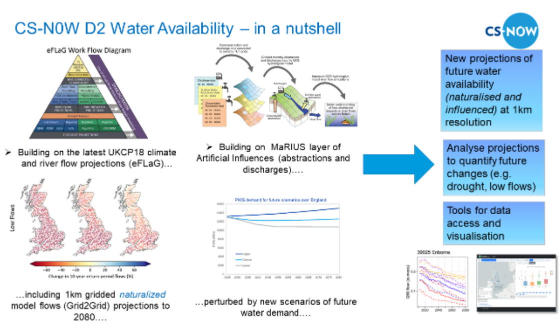




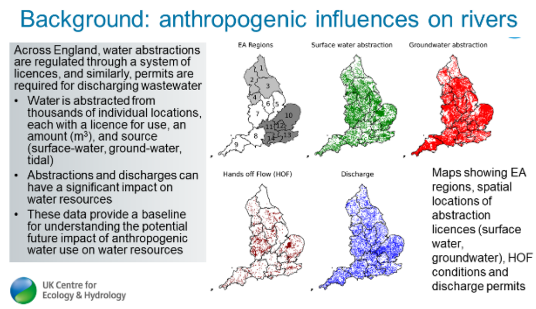


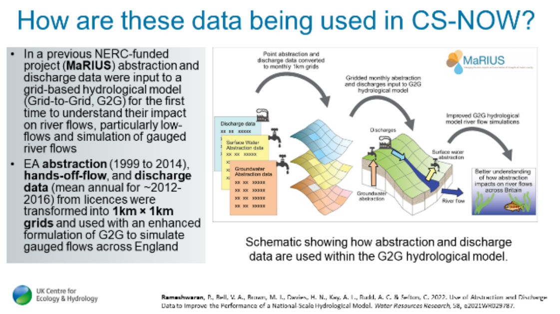


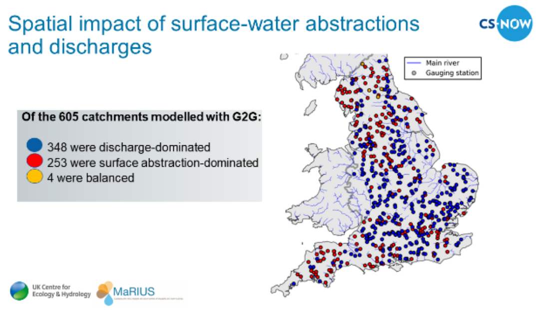


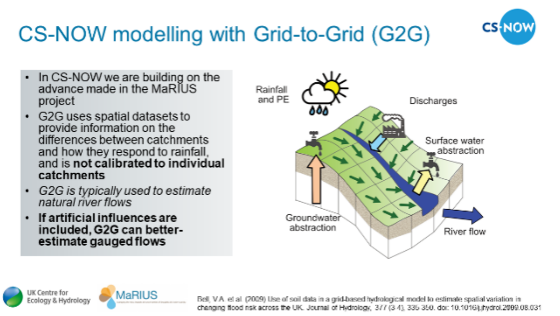


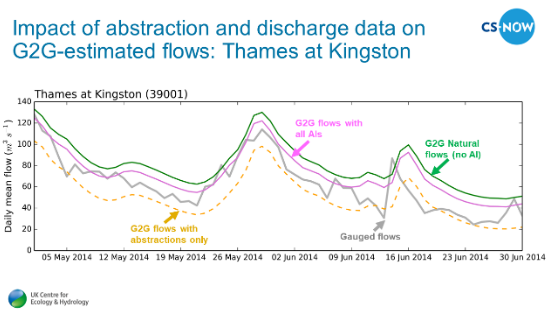

Modelling methodology
Vicky Bell
Ponnambalam Rameshwaran
Helen Davies
UK Centre for Ecology & Hydrology

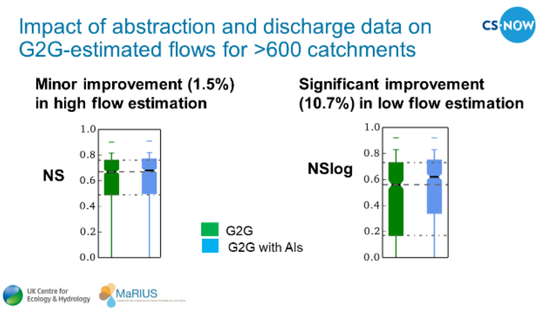

Background: anthropogenic influences on rivers
Across England, water abstractions are regulated through a system of licences, and similarly, permits are required for discharging wastewater
• Water is abstracted from thousands of individual locations, each with a licence for use, an amount (m3), and source (surface-water, ground-water, tidal)
• Abstractions and discharges can have a significant impact on water resources
• These data provide a baseline for understanding the potential future impact of anthropogenic water use on water resources
EA Regions
Surface water abstraction
Groundwater abstraction
Hands off Flow (HOF)
Discharge
Maps showing EA regions, spatial locations of abstraction licences (surface water, groundwater), HOF conditions and discharge permits
UK Centre for Ecology & Hydrology

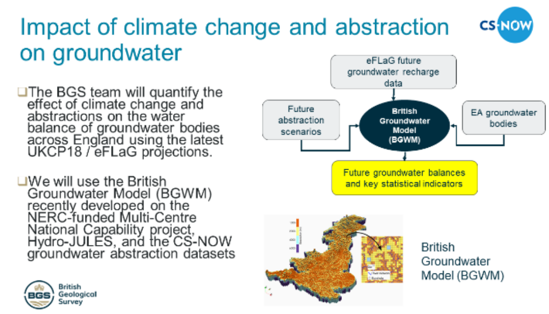

How are these data being used in CS-NOW?
• In a previous NERC-funded project (MaRIUS) abstraction and discharge data were input to a grid-based hydrological model (Grid-to-Grid, G2G) for the first time to understand their impact on river flows, particularly low-flows and simulation of gauged river flows
• EA abstraction (1999 to 2014), hands-off-flow, and discharge data (mean annual for ~2012-2016) from licences were transformed into 1km × 1km grids and used with an enhanced formulation of G2G to simulate gauged flows across England
MaRIUS
Schematic showing how abstraction and discharge data are used within the G2G hydrological model.
UK Centre for Ecology & Hydrology

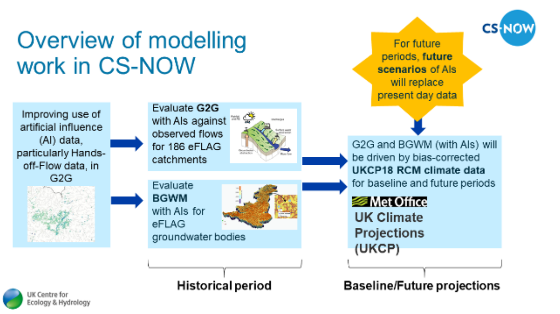

Spatial impact of surface-water abstractions and discharges
Of the 605 catchments modelled with G2G:
348 were discharge-dominated
253 were surface abstraction-dominated
4 were balanced
Main river
Gauging station
UK Centre for Ecology & Hydrology
MaRIUS

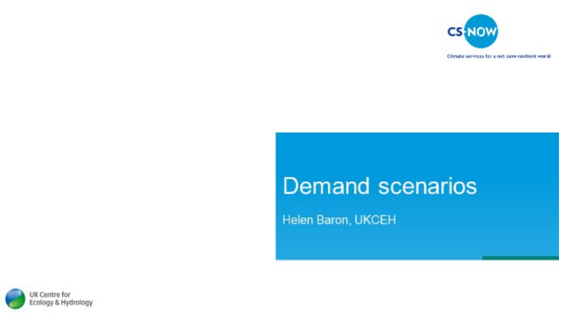

CS-NOW modelling with Grid-to-Grid (G2G)
• In CS-NOW we are building on the advance made in the MaRIUS project
• G2G uses spatial datasets to provide information on the differences between catchments and how they respond to rainfall, and is not calibrated to individual catchments
• G2G is typically used to estimate natural river flows
• If artificial influences are included, G2G can better-estimate gauged flows
Rainfall and PE
Discharges
Surface water abstraction
Groundwater abstraction
River flow
UK Centre for Ecology & Hydrology
MaRIUS


Impact of abstraction and discharge data on G2G-estimated flows: Thames at Kingston
Thames at Kingston (39001)
Daily mean flow (m3 s-1)
G2G flows with all AIs
G2G Natural flows (no AI)
G2G flows with abstractions only
Gauged flows
05 May 2014
12 May 2014
19 May 2014
26 May 2014
02 Jun 2014
09 Jun 2014
16 Jun 2014
23 Jun 2014
30 Jun 2014
UK Centre for Ecology & Hydrology


Impact of abstraction and discharge data on G2G-estimated flows for >600 catchments
Minor improvement (1.5%) in high flow estimation
Significant improvement (10.7%) in low flow estimation
NS
NSlog
G2G
G2G with AIs
UK Centre for Ecology & Hydrology
MaRIUS

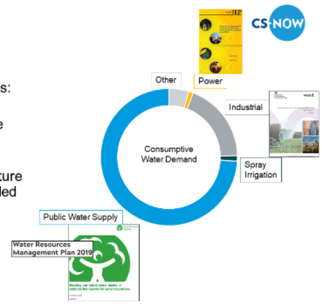

Impact of climate change and abstraction on groundwater
The BGS team will quantify the effect of climate change and abstractions on the water balance of groundwater bodies across England using the latest UKCP18 / eFLaG projections.
We will use the British Groundwater Model (BGWM) recently developed on the NERC-funded Multi-Centre National Capability project, Hydro-JULES, and the CS-NOW groundwater abstraction datasets
eFLaG future groundwater recharge data
Future abstraction scenarios
British Groundwater Model (BGWM)
EA groundwater bodies
Future groundwater balances and key statistical indicators
British Groundwater Model (BGWM)
British Geological Survey


Overview of modelling work in CS-NOW
For future periods, future scenarios of AIs will replace present day data
Improving use of artificial influence (AI) data, particularly Hands-off-Flow data, in G2G
Evaluate G2G with AIs against observed flows for 186 eFLAG catchments
Evaluate BGWM with AIs for eFLAG groundwater bodies
G2G and BGWM (with AIs) will be driven by bias-corrected UKCP18 RCM climate data for baseline and future periods
Met Office
UK Climate Projections (UKCP)
Historical period
Baseline/Future projections
UK Centre for Ecology & Hydrology


Demand scenarios
Helen Baron, UKCEH
UK Centre for Ecology & Hydrology

Scenarios

- Create an envelope of potential future demand scenarios: upper, central, and lower
- Combine best estimates of future demand over different sectors to form a coherent national picture
- Use these scenarios to model future **influenced** flows, providing gridded estimates of future water availability

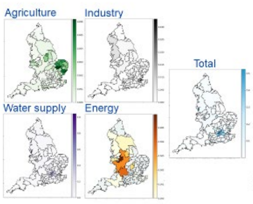


Suggested water demand projections

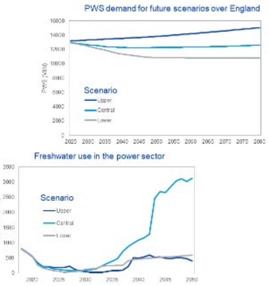
	PWS				Non-PWS			
Scenario	**Population[1]**	**PCC**	**Leakage**	**Non-household**	**Industry[2]**	**Energy[3]**	**Agriculture[2]**	**Environment**
Upper: Economic growth is prioritised over sustainability	High scenario	127 l/p/d by 2050, fixed 2050-2080	30% reduction in leakage by 2050	Current estimates scaled with local population and PCC change	"Uncontrolled demand, Regionalisation" growth factor	Freshwater use for FES21 scenario "Steady Progression"	"Uncontrolled demand, Regionalisation" growth factor	HoF maintained at current levels (model results processed to inform future HoF limits)
Central: current ambitions for water efficiency and green energy are achieved	Central scenario	Final Plan PCC from WRMP19, fixed at final value	Final Plan leakage from WRMP19, fixed at final value	WRMP19 estimates, fixed at final value	Best estimate growth factor	Freshwater use for FES21 scenario "System Transformation"	Best estimate growth factor	HoF maintained at current levels
Lower: Sustainability is prioritised	Low scenario	110 l/p/d by 2050, fixed 2050-2080	50% reduction in leakage by 2050	Current estimates scaled with local population and PCC change	"Sustainable, Regionalisation" growth factor	Freshwater use for FES21 scenario "Leading the Way"	"Sustainable, Regionalisation" growth factor	HoF maintained at current levels (model results processed to inform future HoF limits)

1. Cambridge Econometrics, "A consistent set of socioeconomic dimensions for the CCRA3 Evidence Report research projects," Cambridge Econometrics, Cambridge, 2019.
2. Wood Environment & Infrastructure Solutions UK Limited, "Understanding future water demand outside of the water industry," DEFRA, London, 2020.
3. Moores, "Scenarios for the projection to 2050 of Water Use by Power Producers - updated using FES21," JEP, 20221.

Spatial pattern of current consumptive abstractions



Future demands over time



Q&A on modelling and scenarios

Climate services for a net zero resilient world

Climate services for a net zero resilient world

Outputs: analysis and visualisation

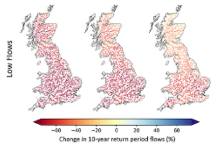
Jamie Hannaford, Lucy Barker (UKCEH)

UK Centre for Ecology & Hydrology

Outputs: the CS-N0W projections

Added value of this dataset for future water availability assessment:

- Naturalised and influenced river flows
- High spatial resolution (1km)
- Transient simulations (daily data, 2020 – 2080)
- Ensemble of climate projections (12x RCM runs)
- Multiple demand scenarios (3x scenarios)



Example of previous high-resolution low flow projections using Grid2Grid (Lane and Kay, 2021)

Timescale: projections delivered to BEIS in spring 2023
Availability via public interfaces to be addressed in subsequent stakeholder work 2023 - 2024

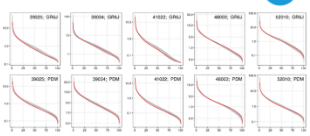
26

Analysing the projections

- We will analyse future projections (naturalised and influenced) using a range of river flow and groundwater metrics.
- Options for customisation to look at further scenarios and options (e.g. future changes in sustainability requirements)

Question: which key metrics would you prefer?

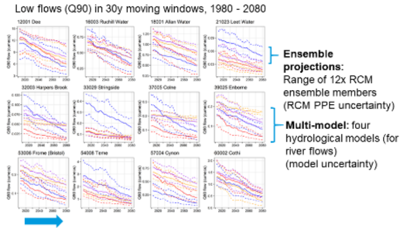
- Annual and seasonal means
- Flow Duration Curves
- Low flows (Q95, 7-day minimum)
- Drought indicators (e.g. duration, intensity)
- Variability (Coefficient of variation)
- And so on….



Analysis Example: Flow Duration Curve metrics from eFLaG (Hannaford et al. 2022).
Red: based on observations
Grey: lines showing range of RCM projections

27

Analysis – examples from eFLaG

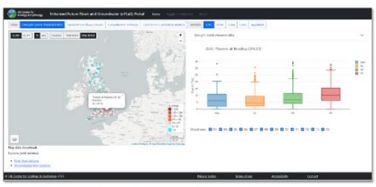


Transient: look at interannual and interdecadal variability rather than time-slices

28

Parry et al. In prep (HESS)

Analysis and visualisation – examples from eFLaG



Analysis Example: eFLaG Portal screenshot, showing future changes in maximum drought deficit for the river Thames

Boxplots show ensemble means and range of projections across ensemble of climate model runs

https://eip.ceh.ac.uk/hydrology/eflag/

WPF2: Data delivery

CS-N0W is focussed on making data accessible, relevant and useable to end users

We will focus on helping water users to understand and access the information coming from the data

- New indicators
- Spatial representation
- Visualisation

30

User engagement for data delivery

Three virtual user engagement activities with potential users around **indicators** and **visualisation**
- Workshop 1 (10th November): discuss scenarios in detail, select indicators for CS-N0W analysis
- Workshop 2 (17th November): Explore indicators and requirements for decision making
- Workshop 3 (8th December): Finalise indicators, identify visualisation requirements

Use these outputs to define the overall requirements.

Development work will happen through 2023, involving some "super-users" for regular feedback (Agile, iterative development)

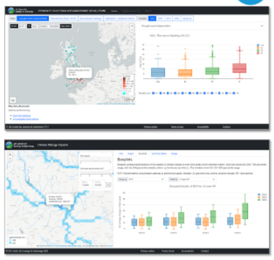
Please let us know if you are keen to join this stakeholder engagement activity! lucybar@ceh.ac.uk

31

Indicators of future water availability

Aim to:
- Move beyond simple %-change, etc.
- Include changes in extremes
- Make use of uncertainty information

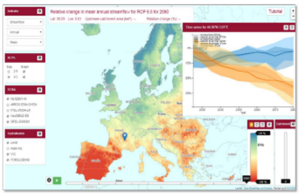
Ensuring indicators are relevant to any existing / future decision making processes will be key.



32

Visualisation and data access

Aim to:
- Deliver visualisation tools / portal
- Spatial / temporal data
- Enable understanding and exploration of complex outputs



33

Uses of the CS-N0W dataset

Stuart Allen, Environment Agency

Climate services for a net zero resilient world

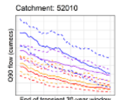
UK Centre for Ecology & Hydrology

Why do we need CS-N0W?

Chief Scientist's Group · Environment Agency

What does CS-N0W give?

- Builds on eFLaG
- Freely available
- High resolution (1km grid)
- Artificial influences
- Nationally consistent
- Accessible



Chief Scientist's Group · Environment Agency

How will CS-N0W help?

Chief Scientist's Group · Environment Agency

CS-N0W: In summary

- The climate is changing
- We need research on the probable impacts
- CS-N0W gives that and will help users adapt
- Thank you

Chief Scientist's Group · Environment Agency

Q&A on outputs and uses

Climate services for a net zero resilient world

Webinar: Future water availability for water-intensive energy infrastructure

Climate services for a net zero resilient world

Thank you all for listening and participating

Reminder: let us know if you are interested in participating in stakeholder engagements

Further updates on projections and analyses in early 2023

Questions/follow-up: jaha@ceh.ac.uk

Tyndall Centre for Climate Change Research · UKRI Natural Environment Research Council · UCL · UK Centre for Ecology & Hydrology · British Geological Survey

APPENDIX 2 – KNOWLEDGE SHARING WEBINAR Q&A

Questions asked in the chat at the Knowledge Sharing Webinar on the 13th October 2022 are recorded here, with the questions given in bold and answers in italics. The questions have been split into themes around data, geographic scope, links with other projects/initiatives, scenarios, references, aims and outputs.

Data

Are you using licensed quantities or actual abstraction data?
We are using actual abstraction values. For more information see Bell et al., (2023).

Are the impacts of impoundments included?
Impacts of impoundments are not included in the modelling, just abstractions, discharges and Hands Off Flows. *For more information see Bell et al., (2023).*

In relation to baseline discharges; how comfortable are you that the discharges are comparable & representative given the difference in data availability compared to abstraction data? (both time period difference and availability of actual compared to consented, and/or the need to estimate dry weather flow)
The discharge data is considered 'best available' – in fact, it is the only available dataset for England. There are undoubtedly some limitations given the time period available, and we will acknowledge these in our reporting. We have liaised with the EA through the project to try and secure improved discharge data and will continue to do so, but given timescales it is unlikely there will be improved discharge data available. See Bell et al., (2023) for more information.

AI in G2G looks very interesting!! May have missed this, but are the abstractions and discharges based on point input data, or gridded (or was gridded developed from point data or something)? Would it be possible to map flows to EA water bodies? This seems like the kind of thing that could influence something like WRGIS and inform, e.g., IMPFAC values which will inform things like EFI calcs?! Big potential link to Env. Destination, given the opportunity for climate change impact modelling...!
This is all based on point abstractions and discharges, but we used this to produce a gridded dataset. Regarding the potential uses of the data for mapping to EA water bodies, and influencing EA decision-making, we will record this comment and feed through to the EA and into the F2 task that is engaging users on data access and visualisation. See Bell et al., (2023) for more information.

Is the model flow reactions to the inclusion of abstraction data not reflecting the degree to which English rivers are heavily under management? Weirs, dams etc. dictate create a cliff edge of 'low flow'. Including abstraction improves model reaction at low flow because you are catching periods when flow drops below this cliff edge. At higher flows abstraction doesn't matter much because flood prevention and other management actions control flow irrespective of abstraction. This would still be super useful to understand but creates issue when showing data in an aggregate manner.

Yes, we did not expect the introduction of AIs to improve high flow estimation in Grid-to-Grid *(G2G), our aim was to improve low-flow estimates, Rameshwaran et al (2022) provides more detail on the use of abstraction and discharge data to improve the performance of the model.*

If groundwater abstractions are being included, how will these be applied in the model and how will the fact that impacts are often not limited to the location of abstraction be handled
Please see Rameshwaran et al. (2022) for more details on how groundwater abstractions are included in G2G.

Geographic scope

How are you dealing with catchments that cross between Wales and England in the modelling?
Only catchments with a modest overlap with Welsh and Scottish borders have been included in the modelling as only English artificial influences data have been obtained and processed for CS-N0W. See Bell et al., (2023) for more information.

It was mentioned that cross border catchments had been excluded - does this also extend to the Severn?
In addition to the above, five catchments that cross the border into Wales have been included that have a modest overlap into Wales: 54001 – Severn at Bewdley, 54032 – Severn at Saxons Lode, 54057 – Severn at Haw Bridge, 54029 and 54008 – Teme at Tenbury have a modest overlap into Wales. Note that abstractions and discharges for these five border-crossing catchments are likely to be underestimated as we do not have AI data for Wales. See Bell et al., (2023) for more information.

Will you be taking account of potential cross border water transfers?
We are not able to take account of cross-border transfers in this work. It could be something to consider in future work though.

Will there be scope to extend this work to Scotland and Wales?
There are no plans to extend to Scotland, Northern Ireland and Wales in CS-NOW, but if suitable AI data are available for these regions, we'd very much like to extend our work.

Links with other projects/initiatives etc.

The 2019 WRMPs will be somewhat out of date with draft WRMP24s just submitted to EA on 3rd October 2023, there is much more demand reduction in the latest plans.
This was unfortunately too late to include WRMP24 in the CS-N0W scenarios, however they could be included in the future if the activity was repeated. See Baron et al., (2023) for more information on the scenarios.

On demand: can you not use the new scenarios from the UKCR-funded UK-SSPs project? https://www.ukclimateresilience.org/products-of-the-uk-ssps-project/

The population projections we are using are from the Cambridge Econometrics dataset which are consistent with CCRA3, but the industrial and power sector projections may not be.

I was wondering more about the climate change scenarios used i.e. looking at 2 or 4 degrees global warming levels or pathways or RCPs

The climate scenarios used are UKCP18 RCM climate projections, a 12-member ensemble, all at RCP8.5. These are the same climate scenarios as those used in the (previous) eFLaG project, see Hannaford et al., (2023) for more information on the eFLaG data.

Scenarios

Can you expand on the assumptions made behind the predicted growth in water demand due to future hydrogen production?

I would refer you to the JEP report for that information, where it is covered in detail (Moores et al., 2021).

What data are you using on potential growth of different net zero technologies - will be a range of pathways to net zero using different techs - some will be more water hungry than others.

Are you looking at the correlation between weather/flow and abstractions/discharges and if so how?

This is one of many approaches we are considering to help us develop future scenarios of artificial influences. There is work that Cranfield have done on this for agricultural demand that might be useful if you can have access to that. The variability in these demands with weather can be very marked.

References

Please could you type the name of the documents referenced to develop the scenarios?

- *Freshwater power use: Moores, A. (2021) Scenarios for the projection to 2050 of water use by power producers - updated using FES21, RWE Generation UK for Joint Environmental Programme. Available at: https://www.energy-uk.org.uk/publications/jep21wt02-scenarios-for-the-projection-to-2050-of-water-use-by-power-producers-updated-using-fes21/*
- *Industrial & agricultural water use: Wood Environment & Infrastructure Solutions UK Limited (2020) Understanding future water demand outside of the water industry, Defra, London.*
- *Population scenarios: Cambridge Econometrics (2019) A consistent set of socioeconomic dimensions for the CCRA3 Evidence Report research projects, Cambridge Econometrics, Cambridge. Available at: https://www.ukclimaterisk.org/wp-content/uploads/2020/07/Socioeconomic-Dimensions-Final-Report_CE.pdf*

Aims

As well as understanding future water projections for net zero, could this work also help with understanding impacts on nature for example from flows/drought?

Absolutely. And although it will be an advance by bringing human impacts in, the current eFLaG dataset is also ready-to-go and can be used to look at future droughts:

- *eFLaG dataset: Hannaford et al., (2022)*
- *eFLaG data paper: Hannaford et al., (2023)*
- *Analysis of future drought: Parry et al., (2023)*
- *eFLaG project information: https://www.ceh.ac.uk/our-science/projects/eflag-enhanced-future-flows-and-groundwater*

Outputs

Just a comment - Providing outputs that can be used in all spatial planning decision making is really important. How development is designed and the wider contribution it makes to the environment (hopefully environmental improvement!) will play a big role in what water usage scenario we end up following (from the second presentation), as well as ensuring new development is resilient and sustainable.
We will be working to understand how this data could be used in such decision making processes and trying to make sure the outputs are as directly useful as possible.

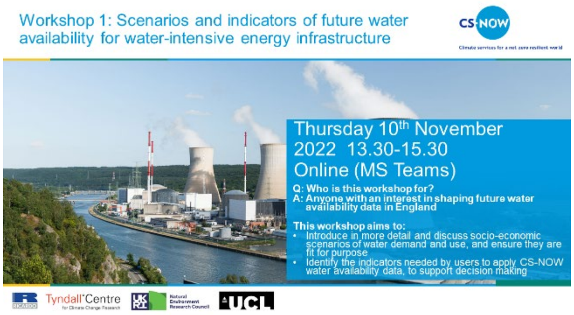
Data will be provided at a range of spatial scales within the CS-N0W F2 Future Water Availability Explorer and Visualisation Tool currently being developed, see Barker et al., (2023) for more information.

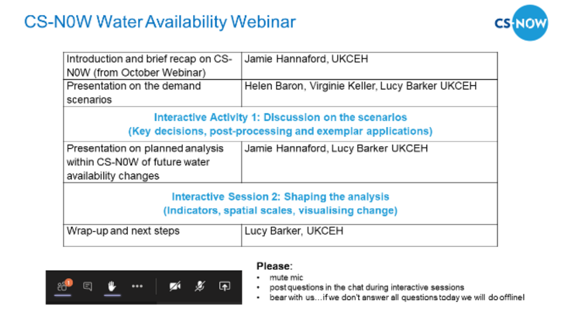
It's a fantastic piece of work which will show future flow scenarios and will be very helpful when looking at water resources planning for different sectors. However, I think that the term "water availability" could well be misleading. The EA needs to protect the full licensed quantities of abstraction licences. These, along with environmental needs feed into our assessments of water availability. It would be wrong to suggest that water is available for further licences to be granted based on an assessment based on actual abstraction and how that may change in the future.
This is a good point and something to be considered for the communication of this work, particularly under CS-N0W F2. Water availability has a wide range of potential meanings and definitions but we agree we should consider the terminology to avoid misunderstandings about the purpose of the work.

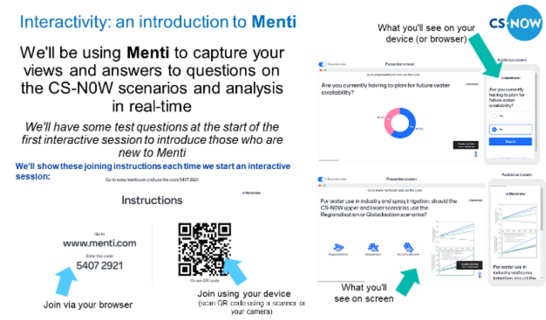
- *Post-hoc note: following the F2 user engagement, this issue was bought up again in the early user groups. Hence, a decision was taken in autumn 2024 to use the term 'future water resources' in the key outputs from this work (i.e. future public-facing datasets and portals)*

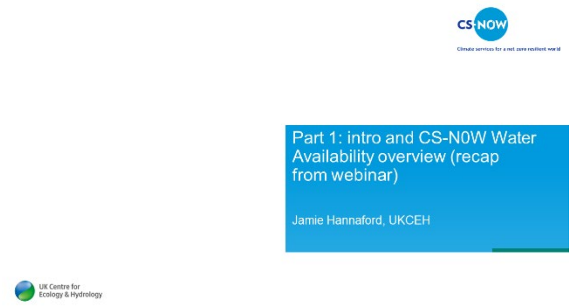
Appendix 3 – Interactive Workshop Slides

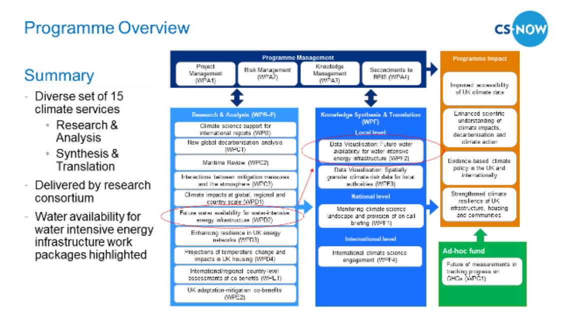
Slides from the CS-N0W D2 interactive workshop on 10th November 2022:

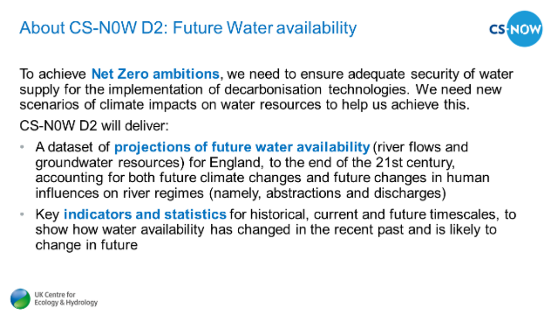


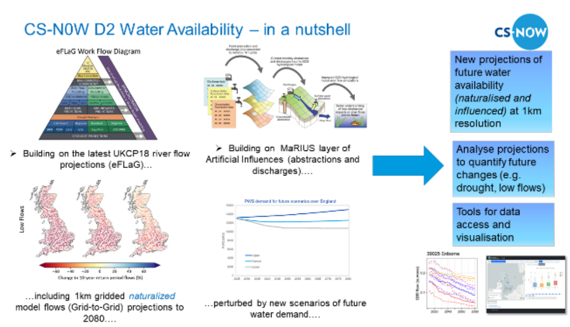


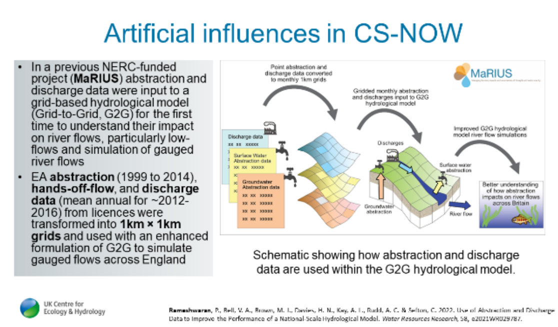






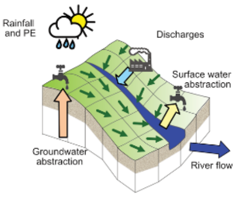






CS-NOW modelling with Grid-to-Grid (G2G)

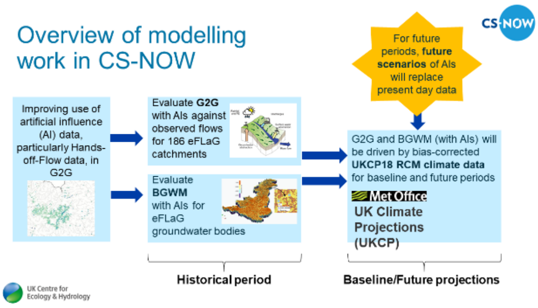
- In CS-NOW we are building on the advance made in the MaRIUS project
- G2G uses spatial datasets to provide information on the differences between catchments and how they respond to rainfall, and is **not calibrated to individual catchments**
- *G2G is typically used to estimate natural river flows*
- **If artificial influences are included, G2G can better-estimate gauged flows**



UK Centre for Ecology & Hydrology · MaRIUS

Bell, V.A. et al. (2009) Use of soil data in a grid-based hydrological model to estimate spatial variation in changing flood risk across the UK. Journal of Hydrology, 377 (3-4), 335-350. doi: 10.1016/j.jhydrol.2009.08.031

Overview of modelling work in CS-NOW



UK Centre for Ecology & Hydrology

What are these workshops all about?

Three virtual user engagement activities with potential users around **indicators** and **visualisation**

- Workshop 1 (10th November): discuss scenarios in detail, select indicators for CS-N0W analysis
- Workshop 2 (17th November): Explore indicators and requirements for decision making
- Workshop 3 (8th December): Finalise indicators, identify visualisation requirements

Use these outputs to define the overall requirements.

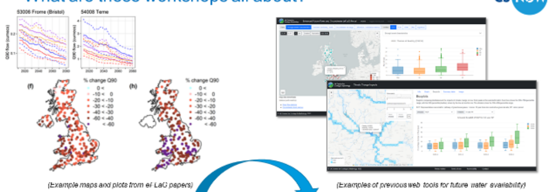
Development work will happen through 2023, involving some "super-users" for regular feedback (Agile, iterative development)

Please let us know if you are keen to join super-user groups!

lucybar@ceh.ac.uk

11

What are these workshops all about?



(Example maps and plots from eFLaG papers)

(Examples of previous web tools for future water availability)

Workshop 1: 10th November 2022:
Help us decide on an approach for a first national scale analysis of CS-N0W outputs
(e.g. Indicators, methods, spatial scales, time periods).
➢ **Output: CS-N0W papers and reports**

Workshop 2&3: 17th Nov, 8th Dec – and into 2023
Co-design with us tools for accessing and visualising CS-N0W outputs in a way that meets the decision-making needs of a wide community.
➢ **Output: CS-N0W web tools and platforms**

Climate services for a net zero resilient world

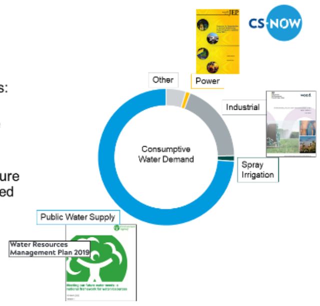
Demand scenarios

Helen Baron, UKCEH

UK Centre for Ecology & Hydrology

Scenarios

- Create an envelope of potential future demand scenarios: upper, central, and lower
- Combine best estimates of future demand over different sectors to form a coherent national picture
- Use these scenarios to model future **influenced** flows, providing gridded estimates of future water availability



Scenarios

Requirements:

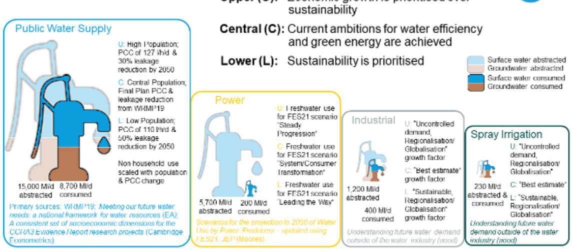
- National & spatially coherent.
- Extending from 2020 to 2080.
- Based on available data.
- Feasible (within project timescales).
- Minimising uncertainty.

Inputs:

- Collaboration with EA & energy sector.
- Review of existing reports.
- In-team experience.

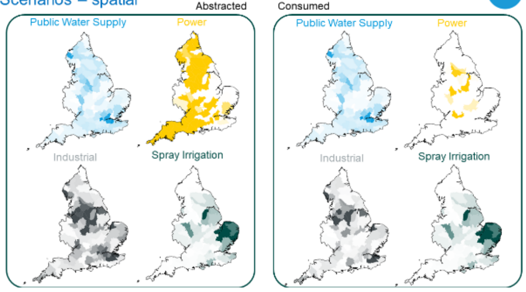
Scenarios

Upper (U): Economic growth is prioritised over sustainability
Central (C): Current ambitions for water efficiency and green energy are achieved
Lower (L): Sustainability is prioritised



Reports & studies that were also reviewed: Water Resources Long Term Planning Framework (Water UK); Emerging Regional Water Resource Plans; The National System Simulation Modelling Project Phase 1 Report (RAPID); Preparing for a drier future. England's water infrastructure needs (NIC); Enriching the Shared Socioeconomic Pathways to co-create consistent multi-sector scenarios for the UK (Pedde et al.); Updated projections of future water availability for the third UK Climate Change Risk Assessment (HR Wallingford); Task 2 Agricultural demand forecasts (Part II): future demand. Final Technical Report (Cranfield University); Impact of Climate Change on Water Demand – Main Report (UKWIR).

Scenarios – spatial



Scenarios - options

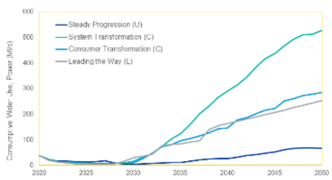
Upper (U): Economic growth is prioritised over stainability
Central (C): Current ambitions for water efficiency and green energy are achieved
Lower (L): Sustainability is prioritised

Power

U: Freshwater use for FES21 scenario "Steady Progression"
C: Freshwater use for FES21 scenario "System/Consumer Transformation"
L: Freshwater use for FES21 scenario "Leading the Way"

System Transformation, achieving net zero carbon by 2050 by changing energy generation and supply:
- Hydrogen for heating
- Consumers less inclined to change behaviour
- Lower energy efficiency
- Supply side flexibility

Consumer Transformation, achieving net zero carbon by 2050 by changing energy use:
- Electrified heating
- Consumers willing to change behaviour
- High energy efficiency
- Demand side flexibility



Scenarios for the projection to 2050 of Water Use by Power Producers – updated using FES21, JEP (Moores), 2021

Scenarios - options

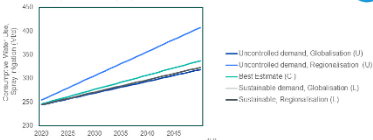
Upper (U): Economic growth is prioritised over stainability
Central (C): Current ambitions for water efficiency and green energy are achieved
Lower (L): Sustainability is prioritised

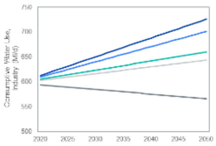
Industrial & Spray Irrigation

- U: "Uncontrolled demand, Regionalisation/Globalisation" growth factor
- C: "Best estimate" growth factor
- L: "Sustainable, Regionalisation/ Globalisation" growth factor

Figure 12.3 of wood report: Socio-economic scenarios (adapted from Water Resources East, Atkins (2017)

Understanding future water demand outside of the water industry (wood), 2020





Environmental Flows

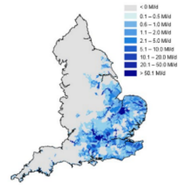
Table 1: Percentage allowable abstraction from natural flows at different sensitivity bands and at different flow snapshots (Q30 is the highest and Q95 is the lowest flow)

	Q30	Q50	Q70	Q95
ASB3 'high'	24%	20%	15%	10%
ASB2 'moderate'	26%	24%	20%	15%
ASB1 'low'	30%	26%	24%	20%

Table 2: Describes compliance and non-compliance at different abstraction sensitivity bands.

Abstraction Sensitivity Band	Compliant with EFI	Non-compliant Band 1 (up to 25% below the EFI at Q95)	Non-compliant Band 2 (25-50% below the EFI at Q95)	Non-compliant Band 3 (up to 50% below the EFI at Q95)
ASB3 'high'	<10% lower than natural flow	<35% lower than natural flow	<60% lower than natural flow	>60% lower than natural flow
ASB2 'moderate'	<15% lower than natural flow	<40% lower than natural flow	<65% lower than natural flow	>65% lower than natural flow
ASB1 'low'	<20% lower than natural flow	<45% lower than natural flow	<70% lower than natural flow	>70% lower than natural flow

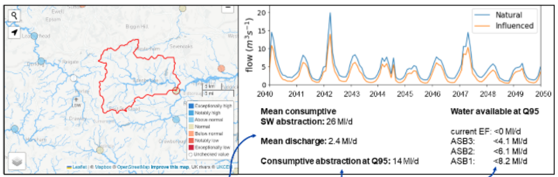
Available water resource for abstraction at low flows (Q95) in 2050 if surface water flows are protected for the environment at current volumes. Figure 2 from Appendix 4 (EA)



Environment Agency, 2020, National Framework report, Appendix 4: Longer term environmental water needs.

Environmental Flows – illustrative example

For a given catchment...

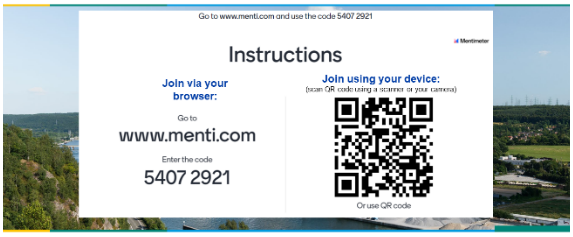


Information about average annual water requirements in the catchment

Approximate water requirements at low flow

Water available for abstraction at low flows (Q95), for current environmental flow (EF) values, and different abstraction sensitivity bands (ABS) for updated EF values

Interactive Session: Scenarios



Climate services for a net zero resilient world

Part 3: Analysis

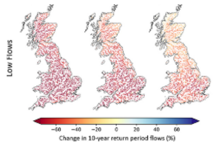
Jamie Hannaford, Lucy Barker (UKCEH)

UK Centre for Ecology & Hydrology

Outputs: the CS-N0W projections

Added value of this dataset for future water availability assessment:

- Naturalised and influenced river flows
- High spatial resolution (1km)
- Transient simulations (daily data, 2020 – 2080)
- Ensemble of climate projections (12x RCM runs)
- Multiple demand scenarios (3x scenarios)



Example of previous high-resolution low flow projections using Grid-to-Grid (Lane and Kay, 2021)

Timescale: projections delivered to BEIS in spring 2023
Availability via public interfaces to be addressed in subsequent stakeholder work 2023 - 2024

Why are we doing this analysis?

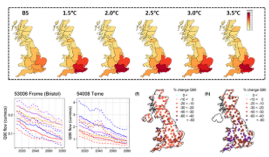
From CS-N0W Proposal:

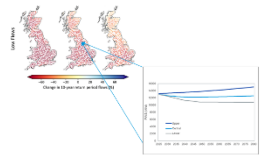
Task 5: Analysis and provision to other tasks/WPs. This task will involve **analysis of future water availability** using the CS-N0W outputs.

For a selected sub-set of the eFLaG catchments, future assessments will be made of **naturalised and AI-impacted flows** across the flow regime using selected **stakeholder-agreed indicators** (e.g. Q95, Q90, mean 7-day annual minima) and **drought metrics** (Standardised Streamflow Index, etc.), as already used in eFLaG.

Regional scale assessments based on the underlying gridded data will also be made (focusing on the water company regional groups also used in the National Framework).

How does this compare to eFLaG?

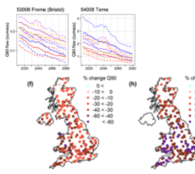




Similar: characterise future water availability at Catchment, regional to national-scale using widely-used indicators of river flow

Key Differences: projections for 'ungauged' locations => improved regional scale simulations. **Naturalized vs Impacted** futures, for **3x socio-economic scenarios**

Outcome: paper(s) and briefings showing future catchment to regional/national scale changes in water availability given both anthropogenic and socio-economic changes



(Example maps and plots from eFLaG papers)

(Examples of previous web tools for future water availability)

Workshop 1: 10th November 2022:
Help us decide on an approach for a first national scale analysis of CS-N0W outputs
(e.g. Indicators, methods, spatial scales, time periods).
- Output: CS-N0W papers and reports

Workshop 2&3: 17th Nov, 8th Dec – and into 2023
Co-design with us tools for accessing and visualising CS-N0W outputs in a way that meets the decision-making needs of a wide community.
- Output: CS-N0W web tools and platforms

Today is about making some pragmatic decisions on indicators/regions for a first analysis….
Subsequent engagement will be about building more flexible tools that allow user customisation

"Bridging the gap"

Pictures from Oct webinar
Thanks to Stuart Allen, EA

- Bridges a gap between large-scale regional water resources planning and fine-scale regulatory planning.
- Sets out to provide, for this first time, a consistent foundation for strategic planning of water intensive future energy developments, alongside wider consideration of other water uses, using the same standard climate impact projections.
- But is designed primarily for high-level regional- or national-scale strategic planning and policy rather then underpinning local operational decision-making.

Why engage stakeholders?

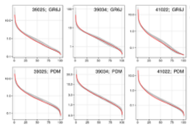
- eFLaG has already asked stakeholders – but with a focus on the water industry (which will also benefit from CS-N0W)
- CS-N0W aims to support NetZero implementation, including planning of water-intensive energy infrastructure
- By looking at **water availability (natural and impacted)** CS-N0W could be of benefit to wide community including **agriculture, industrial abstractors**, etc

How should we do our analyses?

We will analyse future projections (naturalised and influenced) using a range of river flow and groundwater metrics.

We would like your input to help shape the following aspects, as shown in the next slides

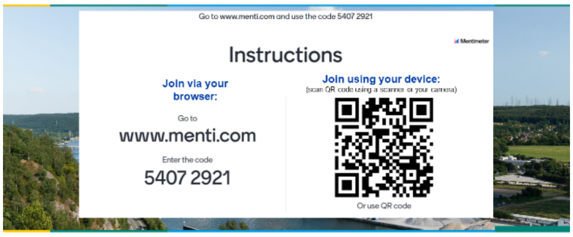
1) Which flow indicators?
2) Which drought indicators?
3) What spatial scales?
4) What timescales (i.e. how to show changes in future)



Analysis Example: Flow Duration Curve metrics from eFLaG (Hannaford et al. 2022).
Red: based on observations
Grey: lines showing range of RCM projections

'Other future water availability products are available'

Interactive Session: Analysis Plans



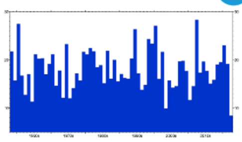
Climate services for a net zero resilient world

3a: General flow indicators

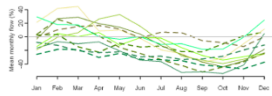
UK Centre for Ecology & Hydrology

General Indicators

Average flows for:
- Annual (calendar year, water year)
- Seasonal (DJF, MAM, JJA, SON)
- Monthly



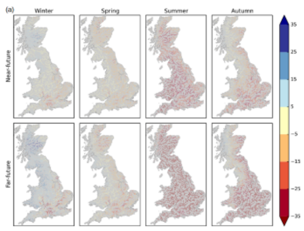
Average annual flows for the river Taw (Devon)



Example of future changes in monthly flows for 2050s (Future Flows, Prudhomme et al. 2013)

General Indicators

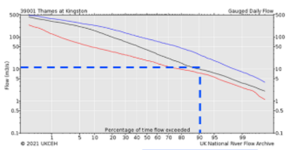
Average flows for:
- Annual (calendar year, water year)
- Seasonal (DJF, MAM, JJA, SON)
- Monthly



Future changes in seasonal river flows (Kay et al. 2021)

Low flow Indicators

- Low flow indicators quantify dryness at one time or duration
  - Q_{90} = flow exceeded 90% of the time (flow duration curve)
  - 7-day minimum flow (AM7) = lowest 7-day average flow

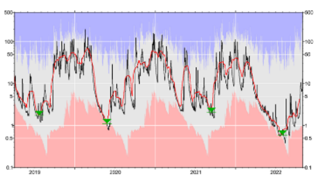


$Q_{90} = 10\ m^3/s$

Low flow metrics: simple and easy to interpret….and can cover the whole regime (high flows!)

Low flow Indicators

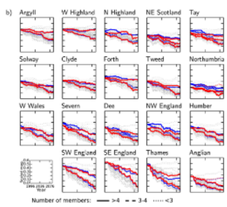
- Low flow indicators quantify dryness at one time or duration
  - Q_{90} = flow exceeded 90% of the time (flow duration curve)
  - 30-day minimum flow (AM30) = lowest 30-day average flow



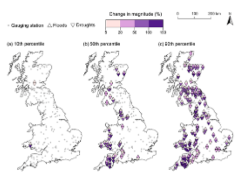
Daily hydrograph (black), 30-day average (red), Annual 30-day minimum (green)

Can also fit low flow frequency curves to derive Return Periods (e.g. 1 in 20-year low flow)

Low flow Indicators: examples



Changes in the 20-year Return Period low flow for 7-day (red) and 30-day (blue) average low flows, 1990s – 2080s (Kay et al. 2021)



Change in magnitude of 10th, 50th, 90th percentile flows (Collet et al. 2018)

Interactive Session: Analysis Plans

Go to www.menti.com and use the code 5407 2921

Instructions

Join via your browser:

Go to

www.menti.com

Enter the code

5407 2921

Join using your device:

(scan QR code using a scanner or your camera)

Or use QR code

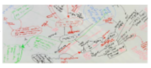
3b: Drought indicators

UK Centre for Ecology & Hydrology

Drought Indicators: down the rabbit hole….

Workshops in 2015 - 2020

→ Delegates from government, environmental regulators, public water suppliers, farmers, power generation & public health



Different sectoral needs (e.g. timescales) **but some similarities** (e.g. historical benchmarks)

Types of drought e.g. meteorological, agricultural, hydrological…. 'whisky', 'salmon', 'navigational'?

Importance & diversity of **impacts** but not systematically collected

Translation of national scale tools to local-scale impacts & decision making needed

Consistent messaging helps with drought management & communication

Hannaford et al. 2019. Weather Climate and Society. https://doi.org/10.1175/WCAS-D-18-0042.1

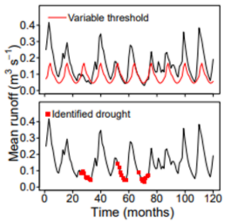
Barker et al. 2022. Frontiers in Environmental Science https://www.frontiersin.org/articles/10.3389/fenvs.2022.752201/full

Historic Droughts IMPETUS driver

Drought Indicators

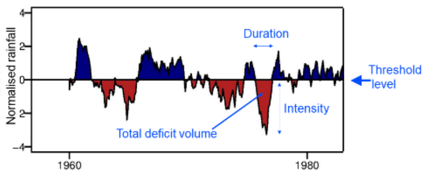
Threshold Level Method (TLM)

- **Key concept:** when river flow falls below threshold, this is a drought
- The most commonly used concept to define droughts
- Accounts for the seasonality of drought



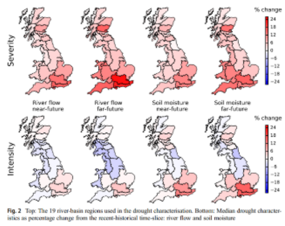
Threshold methods: three main drought quantities

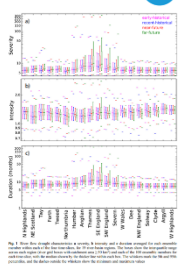
- Drought **intensity** (Q_{min}), **duration** (d) and total deficit (**volume**, V; or **Severity**, S)



Threshold methods: can extract event properties to look at changes in drought characteristics
BUT: some subjective decisions (e.g. on 'pooling' droughts together)

Threshold methods: indexing change



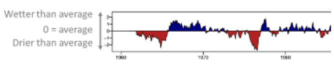


% change in severity and intensity of droughts between 1980s and 2030s/2050s (Rudd et al. 2019)

Drought Indicators: Standardized Indices

Standardised Precipitation Index (SPI)

- Variations for river flow, groundwater (etc)
- Comparable over time and space
- User-defined accumulation periods (1, 3, 6 months etc.)
- Indicates drought severity and probability



Indicator value	Drought severity category
0 - -0.99	Mild
-1.00 - -1.49	Moderate
-1.50 - -1.99	Severe
≤-2.00	Extreme

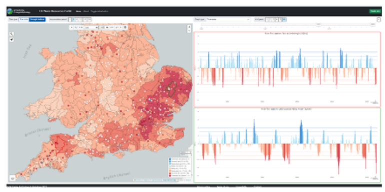
Standardised Precipitation Index

Standardised Precipitation Evapotranspiration Index

Standardised Streamflow Index

Standardised Groundwater Index

Drought Indicators: standardized indices

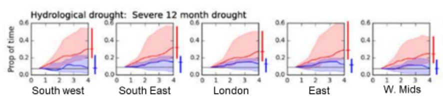


Map: SPI-3 and SSI-3, July 2022. Plots: SSI3 time series for the Taw (Devon) and Little Ouse (Norfolk/Suffolk)
From: https://eip.ceh.ac.uk/hydrology/water-resources/

Standardized Indicators: widely used drought indices (WMO recommended), can readily compare across seasons and geographies

BUT: Can be difficult to interpret and 'back-transfer' to water availability. Challenges of fitting statistical distributions and dealing with trends

Standardized Indices: an example



Change in English regional climate risk indicators with increase in global mean temperature relative to pre-industrial levels. Red = HadGEM3, Blue: CMIP5

Arnell et al. 2021.

3c: Spatial Scales

UK Centre for Ecology & Hydrology

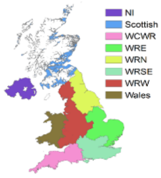
Spatial Scales: catchments?

eFLaG (200) catchments:

- National-scale representativeness (rainfall, soil, elevation, principal aquifers)
- Spatial distribution
- Balance of 'near natural' and disturbed catchments
- Previous stakeholder engagement on network selection
- Already have eFLaG model runs for other models

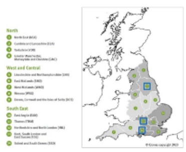
51

Spatial Scales: examples



Regional Groups

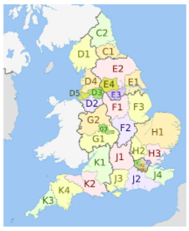
Water Resources Zones
(spatial scale of demand scenarios)



Environment Agency Areas

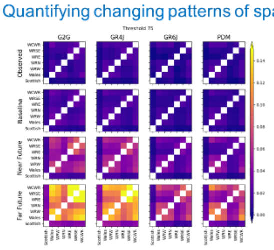
Spatial Scales: examples

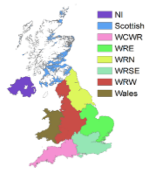
River Basin districts
(also UK Climate Projections)
(Kay et al. 2021 and many others)



'ITL2' (formerly NUTS2) Regions
(Wikipedia)

Quantifying changing patterns of spatial coherence

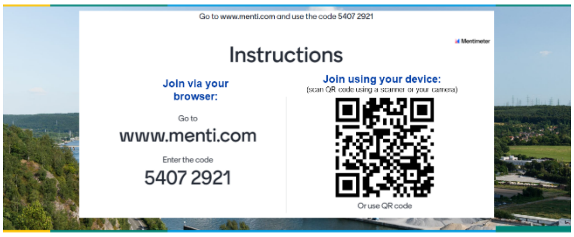




Joint probability of UK regions being 'in drought' in the eFLaG ensemble
Tanguy et al, in prep

Interactive Session: Analysis Plans

Climate services for a net zero resilient world

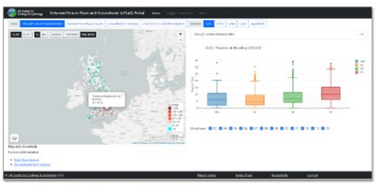


Climate services for a net zero resilient world

3d: Analysing and visualising changes

UK Centre for Ecology & Hydrology

Analysis and visualisation – examples from eFLaG

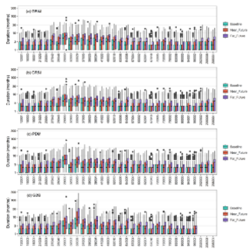


Analysis Example: eFLaG Portal screenshot, showing future changes in maximum drought deficit for the river Thames

Boxplots show ensemble means and range of projections across ensemble of climate model runs

https://eip.ceh.ac.uk/hydrology/eflag/

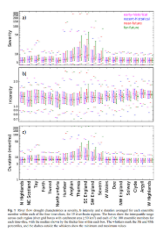
Time Slices



Baseline, 1989-2018
Near Future, 2020-2049
Far Future, 2050-2079

Boxplots containing **drought durations** for all droughts (threshold method, Q70) extracted from all 12 RCM ensembles

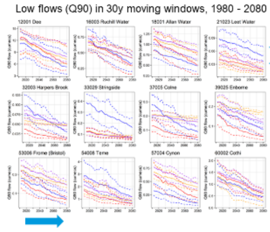
Parry et al. In prep (HESS)



Rudd et al. 2019

Transient Changes

Low flows (Q90) in 30y moving windows, 1980 - 2080



Ensemble projections: Range of 12x RCM ensemble members (RCM PPE uncertainty)

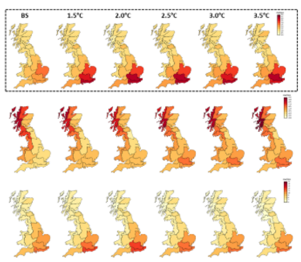
Multi-model: four hydrological models (for river flows) (model uncertainty)

Transient: look at interannual and interdecadal variability rather than time-slices

Parry et al. In prep (HESS)

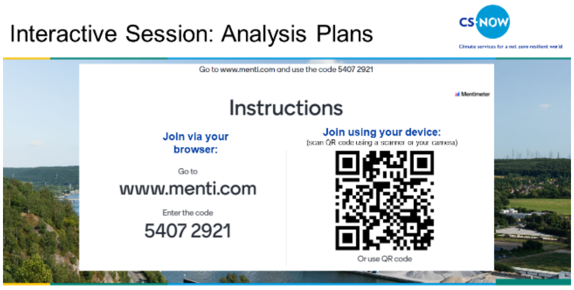
59

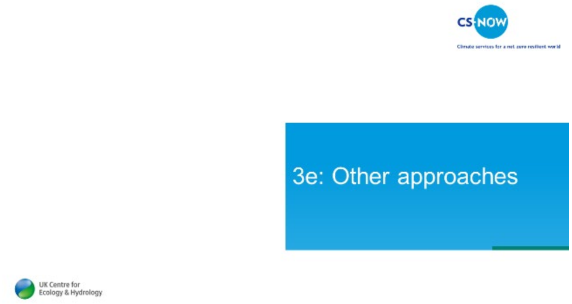
Warming Levels

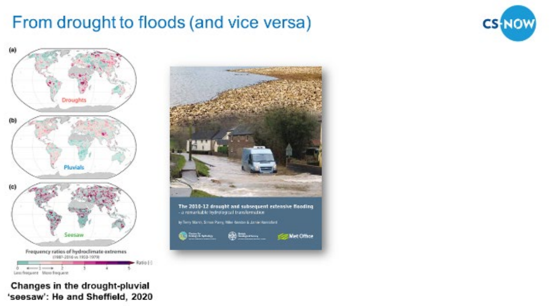


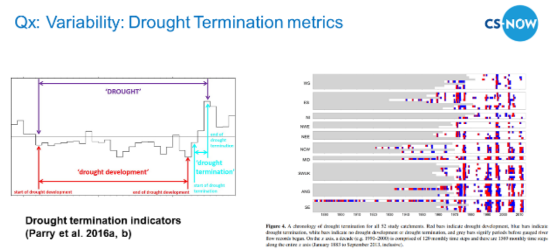
Drought Severity at different warming levels using eFLaG

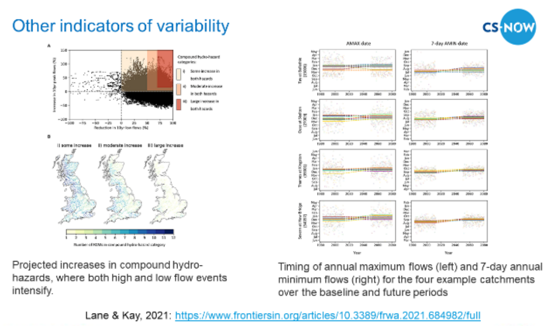
Ali Rudd, in press (Presented at BHS symposium, 2022)

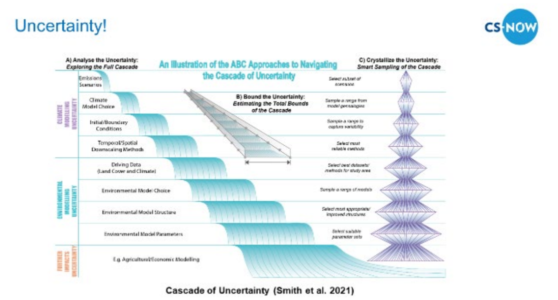

Interactive Session: Analysis Plans
Go to www.menti.com and use the code 5407 2921
Instructions
Join via your browser:
Go to
www.menti.com
Enter the code
5407 2921
Join using your device:
(scan QR code using a scanner or your camera)
Or use QR code

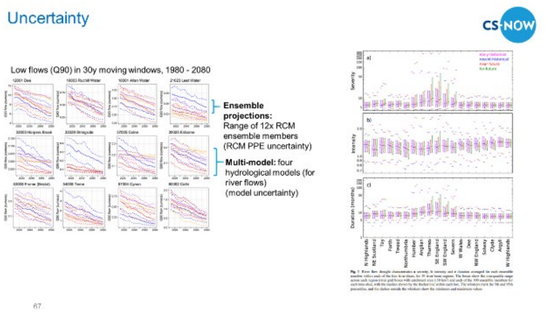

3e: Other approaches
UK Centre for Ecology & Hydrology

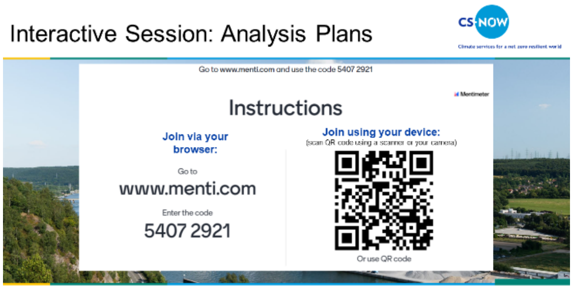

From drought to floods (and vice versa)
Changes in the drought-pluvial 'seesaw': He and Sheffield, 2020


Qx: Variability: Drought Termination metrics
'DROUGHT'
'drought development'
'drought termination'
Drought termination indicators
(Parry et al. 2016a, b)


Other indicators of variability
Projected increases in compound hydro-hazards, where both high and low flow events intensify.
Timing of annual maximum flows (left) and 7-day annual minimum flows (right) for the four example catchments over the baseline and future periods
Lane & Kay, 2021: https://www.frontiersin.org/articles/10.3389/frwa.2021.684982/full


Uncertainty!
An Illustration of the ABC Approaches to Navigating the Cascade of Uncertainty
Cascade of Uncertainty (Smith et al. 2021)


Uncertainty
Low flows (Q90) in 30y moving windows, 1980 - 2080
Ensemble projections: Range of 12x RCM ensemble members (RCM PPE uncertainty)
Multi-model: four hydrological models (for river flows) (model uncertainty)
67

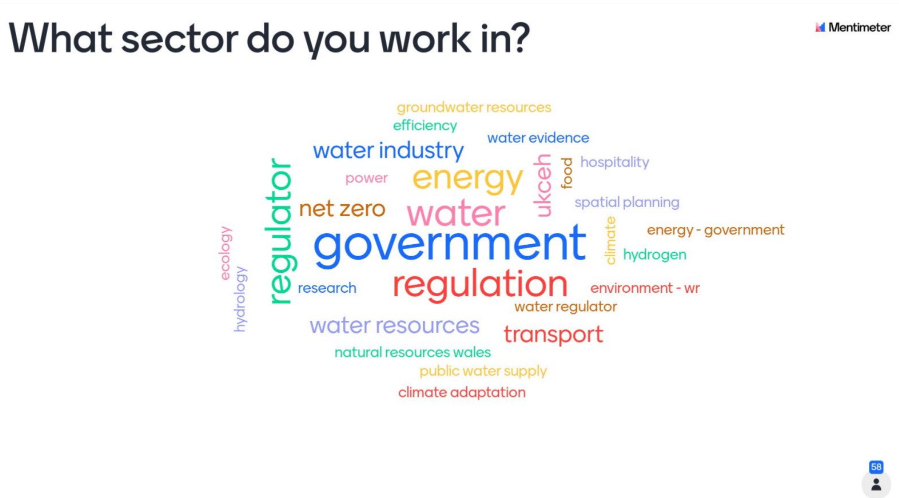

Interactive Session: Analysis Plans
Go to www.menti.com and use the code 5407 2921
Instructions
Join via your browser:
Go to
www.menti.com
Enter the code
5407 2921
Join using your device:
(scan QR code using a scanner or your camera)
Or use QR code

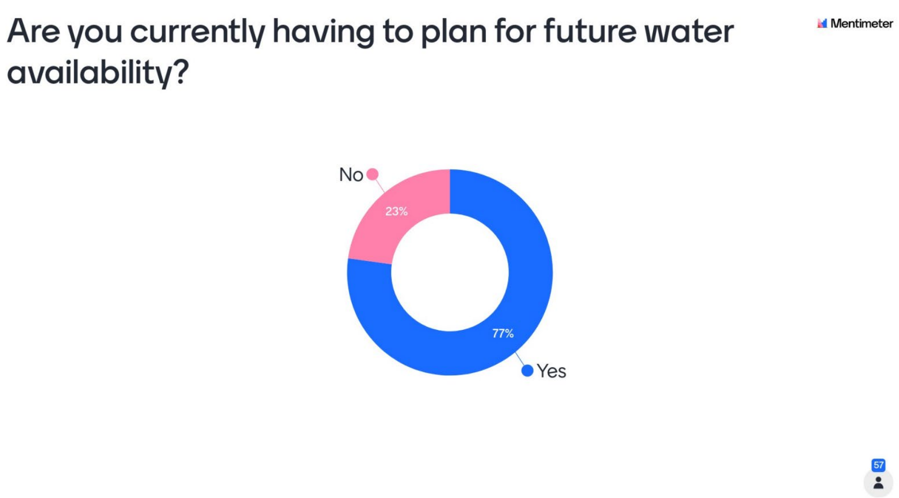

Webinar: Future water availability for water-intensive energy infrastructure
Thank you all for listening and participating
Reminder: let us know if you are interested in participating in stakeholder engagements
Further updates on projections and analyses in early 2023
Questions/follow-up: jaha@ceh.ac.uk

Appendix 4 – Interactive Workshop Menti Results

This section lists the questions asked via Menti during the Interactive Workshop on Thursday 10th November 2022. Voting was split into two main sections, the first on the scenarios and the second focused on the analysis plans.

Introductory questions





Scenarios

How do these scenarios of future water demand fit in with your current and/or future planning needs?

- Relevant but need more detail
- Not sure to how align with current process
- More information is needed but I can see how they could impact abstraction licensing
- Uncertain how aligns with existing methods, guidance and other projections. Is it comparable, to be adopted across sectors or generally another data set to aid choice?
- We have to fit in with what is available when we submit planning
- Very useful to see. We haven't thought about specific sector impacts just general climate projections. Can see it being useful for TCFD analysis etc.
- Don't currently fit in but have potential for the future
- In Water Resources we need to have an idea of what is available in the future to balance all the needs with the environment. I'm

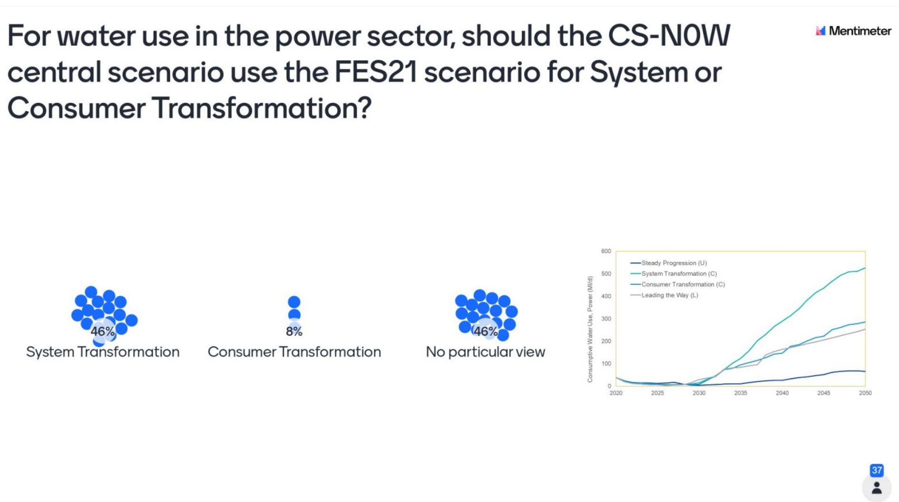
especially interested in the energy needs as we need to move to net zero.

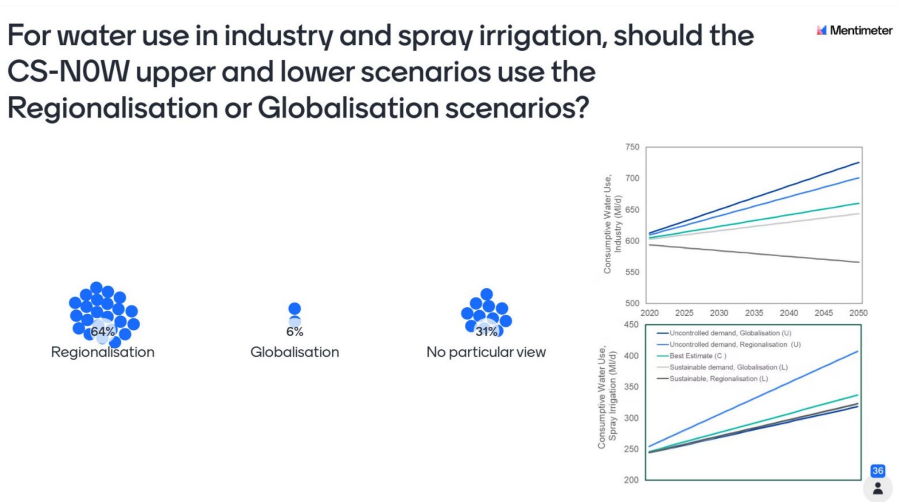
- Closely aligned, would like more detail on the leakage and PCC assumption in the central scenario.
- The EA needs to achieve sustainability of water resources to protect the environment. Understanding future pressures is integral to this.
- Need to account for WRMP24 and the different policies on demand going forwards
- Look like they will be useful by bringing together a range of different sectors.
- Currently ewe tend to use scenarios related to future warming and how they will change weather and climate
- They fit in and seem useful. I wonder if we have sufficient understanding of the impacts of net zero yet.
- Scenarios largely align with planning need
- More details necessary before we can comment of this moment
- Close but not the same. We have to assume what is situated by guidelines – re. PCC etc.
- Water demand for Net Zero land use change is still unknown, but at some stage we need to start thinking about them
- Need a consistent approach across the UK for climate change impact assessment and for adaptation requirement
- Useful but a shame WRMP24 data will not be used – could this be updated?
- Important to understand future pressures. Need to understand what these scenarios are saying better
- Useful together with sector planning to shape policy
- Need to align with WRMP24 demand assumptions
- The scenarios aren't binary there might be a bit of all. Hydrogen production seems to be centred on industrial clusters near estuaries rather than inland – ditto carbon capture. We also perhaps need to think [about] water quality as it could be unusable.
- Working with 4 future scenarios on water condition and pressure similar themes
- Scenarios could be used in water resources modelling to investigate uncertainty around meeting future water needs
- We see future water availability as the main challenge for the different levels of future hydrogen economy 2030 and the wider sector
- Would need to base planning needs on WRMP24 scenarios
- Interesting to better understand how future variability across sectors is considered i.e. agricultural demand due to changing crop types
- It's important to understand how climate change will affect water availability in isolation to other factors, so scenarios that do this are important alongside these scenarios
- Potential for the future – I work in Scotland so not directly applicable, but could be a basis for the future.
- Possible change of future HOF is huge uncertainty that will need to be addressed. What policy will regulators adopt?
- What impact will WRMP24 and subsequent WRMPs have on these results
- Part of the picture in assessing the pressure on water in the future and nature and type of the hydrometric network to measure it
- Need to plan for both climate and non-climate scenarios – so starting with climate projection type scenarios (2&4, RCPs) but then dovetailing in different abstraction/discharge scenarios
- Provide scenarios for understanding of potential impacts and of comparison to own
- We might need to factor in the abandonment of current sources especially groundwater due to saline intrusion so inland sources come under pressure
- Not sure why future availability higher in the south and east compared to north and west
- Helpful to consider as a climate adapted spatially coherent flows profile. Informing future availability/planning decisions on water - possibly
- Not sure if woodland restoration is considered as part of adaptation strategy
- We require it for water resources
- They look more systematic with finer grain
- Useful to identify the future needs for the transition to net zero
- I'm not really sure as we use a lot of these data sets – however bringing them together may help and the spatial information will be useful. If updated with WRMP24 they will be extremely useful
- Consistency across all sectors – potentially one version of the truth
- Flows add to current water quality so we get a more holistic picture of true impact and water available for dilution of effluent
- Useful information mindful of EA's role in licensing
- So far it's been hard to get hold of any site specific data so this offers much better locational data
- Currently difficult to forecast 25 years ahead. Forecasting to 2080 seems very optimistic

- Good to visualise differences between regions and impacts on sectors

What do they add to what you currently use for future planning?

- Better spatial detail
- Adding in other sectors beyond water supply
- Will this take account of cross border planning scenarios
- Scenarios and higher resolution
- Information on other sectors demand
- My sector is generally regarded as non-consumptive, but water availability and water temperature is important for future planning
- Granularity is important
- Account for needs of all water users (NPWS and PWS)
- Incorporation of artificial influences across sectors
- Greater spatial detail will be helpful and if updated they will be very useful
- Collaboration with multi-sector spatial data and identify the opportunities across sectors
- Provide better information on future demand for energy sector
- Less uncertainty
- Agricultural and golf course abstractions tend to be seasonal. Is that taken into account as such for future scenarios
- Great that accounted for a range of sectors – very helpful! Especially for future scenarios!
- Comparison to our use of WFD Waterbodies
- Good to visualise differences regionally
- There isn't anything available for spatial planning decision making, they provide a useful perspective for policy makers
- Spatial scale – but need to understand better what other sector demands add to data used in national framework for water resources other sector demand work
- Includes groundwater
- Interesting to see what assumptions ae – although as said scope does have limits, e.g. not UK



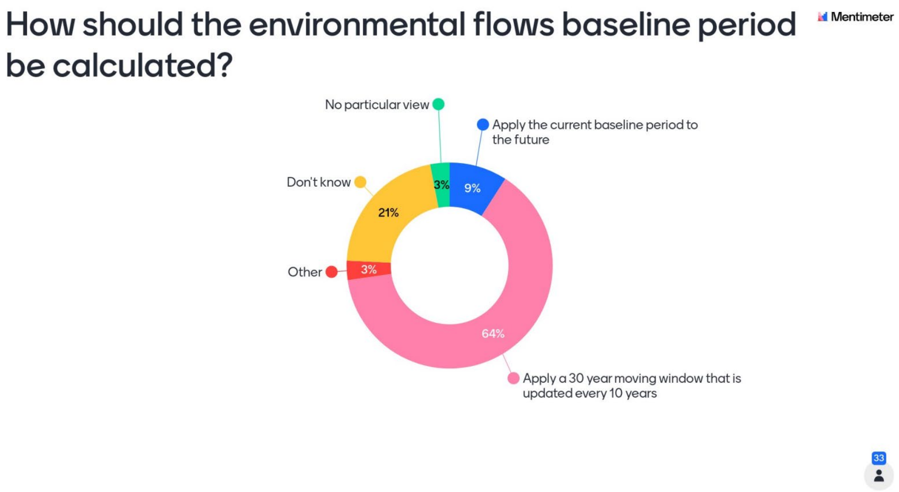


Are there any remaining data gaps that would need to be filled if this exercise was repeated in the future?

- WRMP24
- Wales – given planning is cross border – include Wales and align WRMP24
- How can we incorporate future WRMPs
- WRMP24 in future updates using same methodology
- Regional water resources plans
- Update river flows and EFIs
- Agriculture/farming
- Other geographical areas of the UK
- The impact of urbanisation on runoff
- Wales, Scotland and NI
- Multisector assumptions – private water supplies etc.
- Other UK areas
- Expand to over rest of UK
- Projections on pumped water volumes (as a renewable energy source?)
- More detailed standard industry classification
- Private water supplies?
- Crop types?
- Links to policy drivers and assumptions
- Updated water industry data and private water supplies
- Groundwater and groundwater quality – need to consider water quality of discharges to an extent
- Water transfers – stream support, etc.
- Do you currently incorporate predicated land use change?
- Aligning with future WRMP
- WRMP24
- Private water
- Wales
- Cover UK wide
- Impact of Nature Based Solutions (likely to be positive)
- Matching CC assumptions requirements to WC plans
- WRMP24, regional plan data especially for other sectors
- Updated scenarios
- UKCCRA
- Influence of future policies or subsidies
- Future land use plans – planning, development, nature recovery
- Updated scenarios FES and CCC

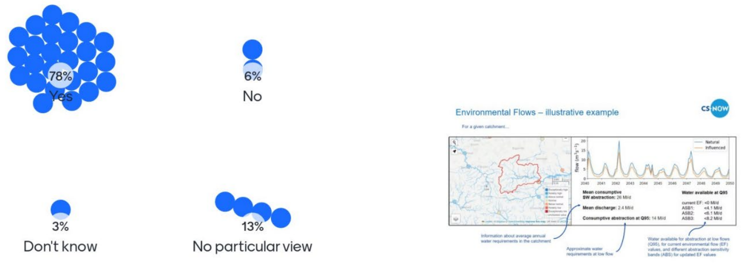
What data are being collected or produced at the relevant spatial scales to fill the gaps?

- Natural capital accounting
- Woodland/forestry regeneration mapping
- Planning and development e.g. Cambridge and Oxford arc etc. will influence demand
- Crop consensus data
- Peatland restoration
- SEPA hold returns data for shorter timescale than England – but this set is growing there are likely to be quality issues associated with the data
- Private water supply data to understand volume and timing of their demands
- EST Energy report Wales
- SEPA hold daily abstraction data
- SUDS
- WRMP tables, AR tables



Would the data included in the illustrative example be useful/interesting? What else would be useful (assuming the analysis is possible)?

Mentimeter



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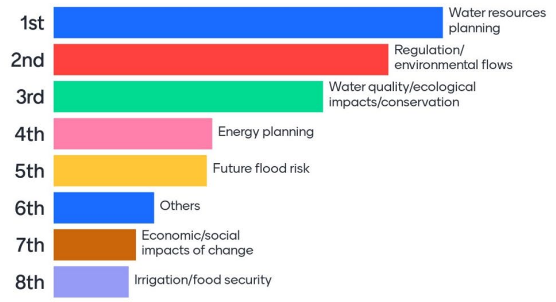
Analysis plans

What are your primary reasons for analysing future changes in water availability in your area of interest?

Mentimeter



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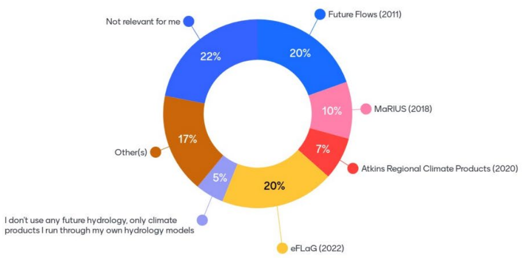
What other future climate/water availability products do you use at the moment to investigate future water availability?

Mentimeter



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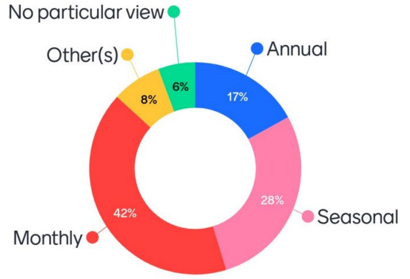
Which 'general' flow metrics would you like to see us investigate in our analysis within CS-N0W? i.e. averages of:

Mentimeter



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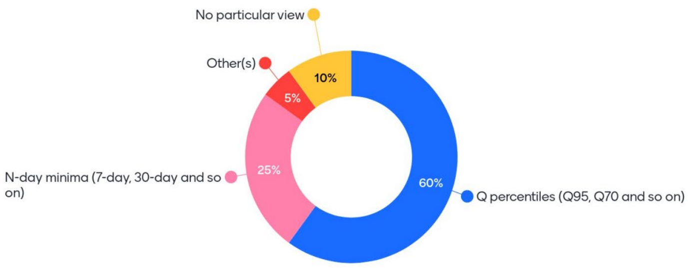
Which low flow metrics would you most like to see us investigate in our analysis within CS-N0W?

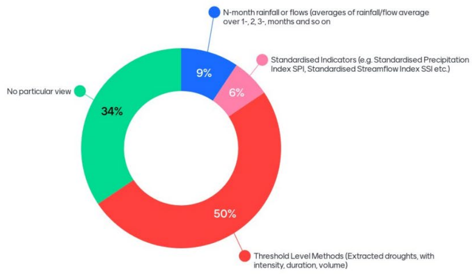
Mentimeter



29

What approach should we take to analyse droughts?

Mentimeter



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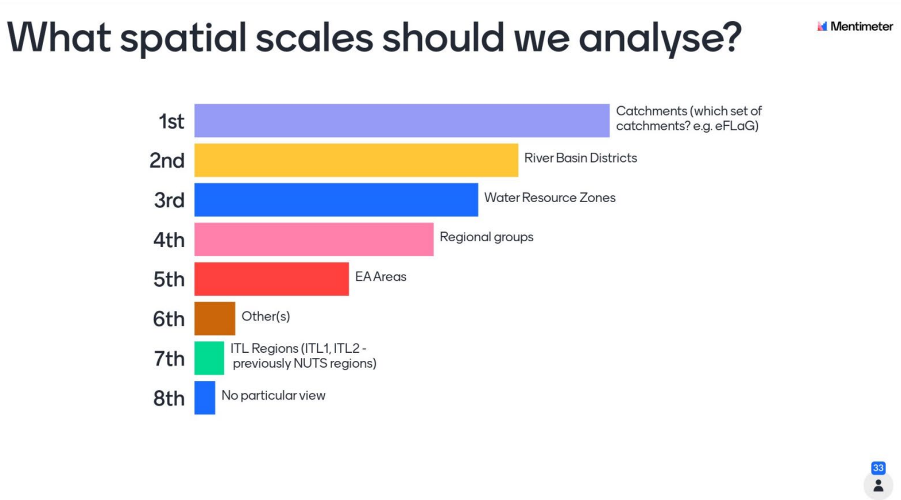

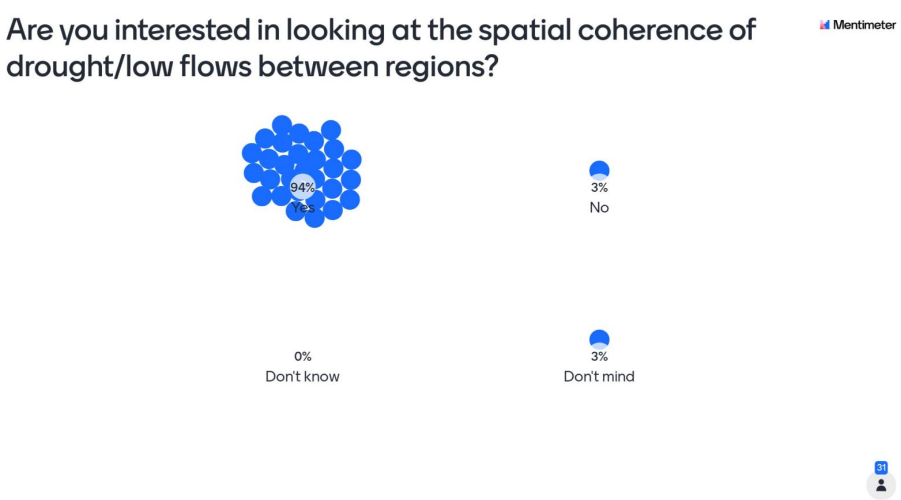

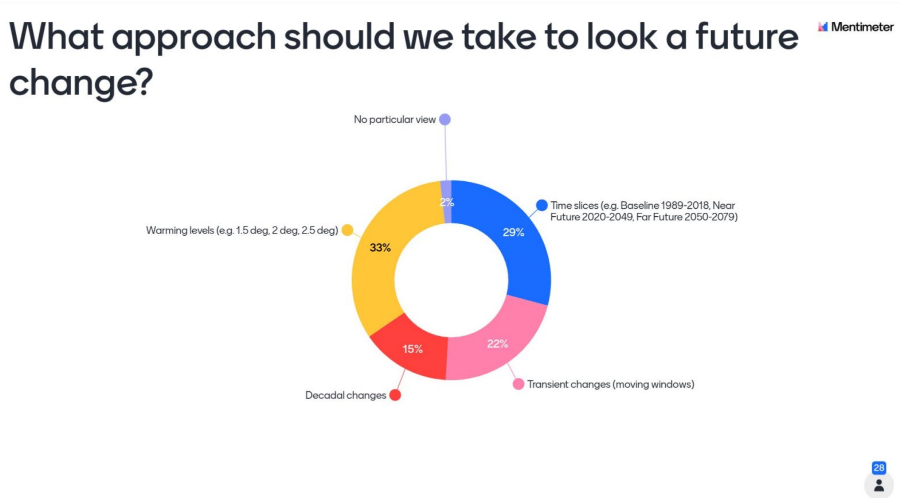

* Do you have any other comments on our approach to analysing river flows – are we missing anything?
* Are you interested in variability across the flow range (e.g. swings from high to low flows and vice versa)?
* Do you have any views on how we should present uncertainty in our analysis?
* *Questions not asked due to time restraints*

UK Government

CS-NOW

Climate services for a net zero resilient world