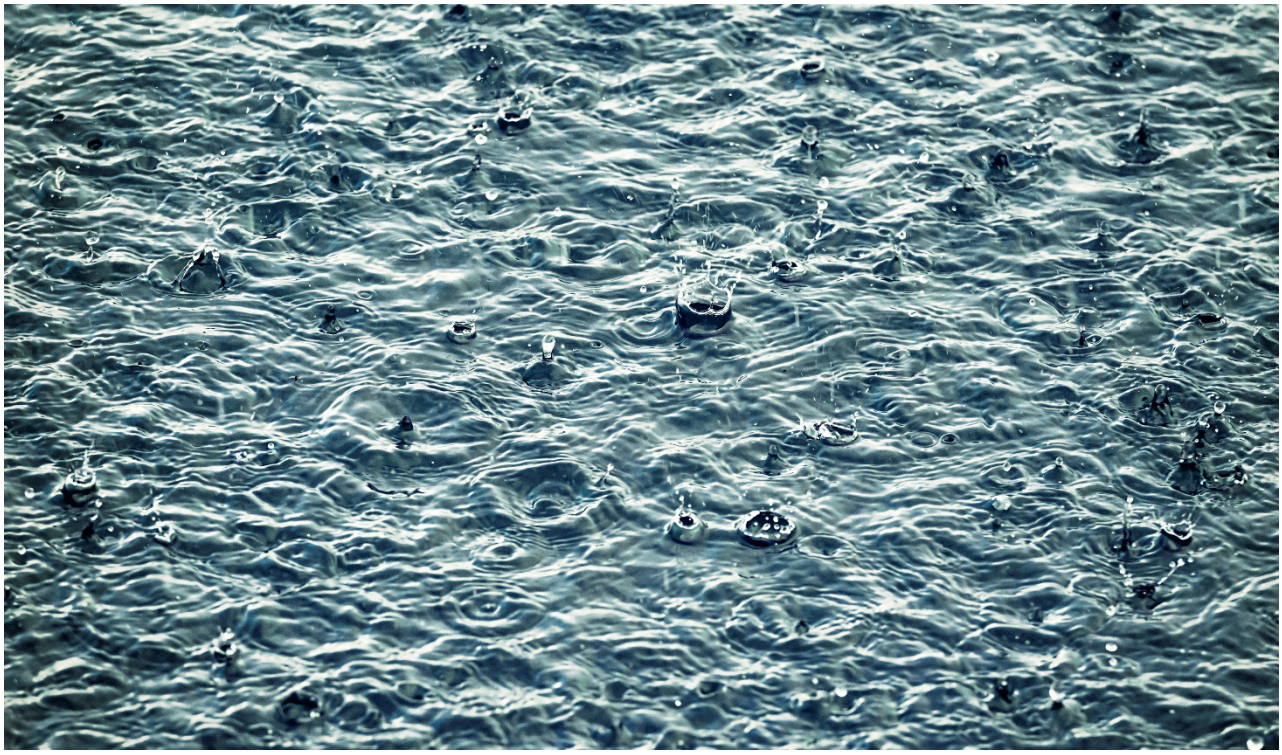
HR Wallingford
Working with water

# eFLaG: Enhanced Future and Groundwater

## User Needs Specification and Research Requirements



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# Contents



## Tables

# 1 Introduction

This document sets out the User Needs Specification for the project 'Enhanced Future Flows and Groundwater' (eFLaG), a project funded within Lot 5 of the Met Office SPF Climate Resilience Call.

This research project is seeking to develop a prototype Climate Service that will enhance the resilience of the water sector to drought events. This will be addressed through first scoping the information needed to achieve enhanced resilience, along with an assessment of the main benefits from doing so. A pilot Climate Service will then be developed for providing nationally-consistent hydrological projections to enable assessment of drought risk. Finally, the value of the Climate Service for supporting improved planning methods to enhance drought resilience will be demonstrated through case studies.

eFLaG is in effect a successor to the Future Flows and Groundwater Levels (FFGWL) dataset (Prudhomme et al. 2013). FFGWL is widely used within the water industry to provide insight into the future evolution of river flows and groundwater levels through the 21st century. In Future Flows, The 11-member ensemble was generated by driving a suite of hydrological models with an ensemble of bias-corrected climate projections drawn from the HadRM3 Perturbed Physics Ensemble (PPE), one of the key products from the UKCP09 projections.

Further details of the research project can be found in the Research Method Specification (Hannaford et al., 2020).

This document outlines the current water industry practice, which frames the user needs highlighted through the stakeholder engagement activities undertaken as part of the eFLaG project, as well as information taken from other sources. These information sources are described, before detailing the user needs, and the subsequent research requirements that fulfil these user needs. The document serves to summarise the stakeholder engagement activities and findings, and act as an input into the method statement for the demonstration case studies.

## 1.1. Current water industry practice

Recent studies (Water-UK 2016, NIC 2018, HR Wallingford 2015; 2020) have highlighted the challenges faced by the UK in providing secure and reliable supplies of water into the future. They have presented ideas to help improve drought resilience through a twin track approach of reducing demand and increasing supply, including through the sharing of water.

The approach to longer-term water resources planning is based around Water Resource Management Plans (WRMPs), published every five years, which set out how security of water supplies will be maintained as sustainably as possible into the future. Drought Plans (DPs), also developed by water companies, are nearer-term planning documents setting out the operational steps a company will take as a drought unfolds. Adaptation to future climate change and the consideration of a range of potential droughts are key components of these planning processes.

To assist water companies in their assessment of climate change, the Environment Agency developed guidance (Environment Agency 2013; 2017a; 2017b) in the form of tiered approaches of increasing complexity based on research that followed the publication of the UKCP09 projections (Christierson et al. 2012, Environment Agency 2013). This guidance has recently been updated by the Environment Agency (2020a), in part due to the release of UKCP18, but the underlying methods have remained broadly unchanged since 2013.

One key change reflected in the recent updates to the water resources planning guidance (Environment Agency, 2020b; 2020c) require water companies in England and Wales to consider assessing their supply

forecast against a predefined resilience standard of 1 in 500 years (i.e. it represents the amount of water available such that standpipes and rota cuts are not required more than once every 500 years on average). As part of this, water companies will be encouraged to use water resource system stress metrics rather than meteorological or hydrological metrics to estimate return periods due to the non-linearities in response. This in turn will be informed by simulation modelling of large stochastically generated climate datasets through hydrological and water resource system models.

Evaluating the implications of climate change on drought resilience (and hence on natural climate variability) has previously been considered by water companies and regional planning groups using a delta-change approach typically based on mean monthly climate factors from the UKCP09 probabilistic projections (water company scale assessments) or using the Spatially Coherent Projections from Future Flows (water company scale, for some companies and regional assessments for regional groups). This approach has been retained for the current (WRMP24) planning cycle (but not prescriptive as to the choice of UKCP18 product(s) to use) and to be combined with the stochastically generated datasets described above, with the guidance stating that companies, "…should demonstrate that the selected events are still reasonably reflective of a 1 in 500 level of risk once climate change perturbations have been applied", with no explanation as to how this might be achieved. The choice of climate change product(s) used within analysis can also be influenced by the expectations of regulators (e.g. Ofwat, 2021, expecting the use of probabilistic projections), and may also be dependent on external factors, such as the ability to align impacts across different sectors and regions.

The current stochastically generated climate datasets being used by water companies and regional groups to consider natural climate variability have been designed to be alternative realisations of the historical period 1950-1997. The current Environment Agency (2021c) suggests that these 'replicates' should be considered as individual time series, and analysis across the industry has highlighted that they reflect a large range of uncertainty around severe to extreme droughts up to the industry required resilience standard of the 1 in 500 year return period event. When these replicates are perturbed with climate change factors, as required by the Environment Agency guidance (2021a), the future uncertainty is likely to become larger, due to the uncertainty in the baseline 1 in 500 drought events being amplified through the application of change factors. Due to the statistical nature of the stochastic weather generator, the subsequent application of mean change factors (either from probabilistic climate change projections, or from regional climate models) and the water resource modelling process, the end results are not attributable to particular events. This contrasts with storyline approaches, where physically plausible events similar to those experienced historically are used to explore climate change impacts (e.g. van der Wiel et al., 2021; Shepherd et al., 2018).

## 1.2. Information sources

As part of the eFLaG project, stakeholder engagement activities have been undertaken to help shape the research and make it relevant to questions required by the UK water industry. The stakeholders engaged as part of the workshop are listed in Table 1.1. The respondents to the survey are given in Appendix B. At the time of writing, this stakeholder engagement has taken the form of:

- Workshop 1 – A series of short presentations on eFLaG-related projects, including UKPC18, WRSE climate change dataset, EA gridded PET dataset, and EA climate change and stochastic dataset guidance, followed by a summary of the eFLaG project and a section for discussions. The workshop design, schedule, and questions raised and how they were answered is included in Appendix A.
- Workshop 1 questionnaire – A survey monkey questionnaire issued to all Workshop 1 attendees that covered key questions related to the case studies, hydrological and hydrogeological outputs. The results of this questionnaire and insight gained is given in Appendix B.

Additional key information sources that have informed the user needs specification are:

- UKCP18 climate projections;
- eFLaG research specification;

- WRMP24 climate change guidance (Environment Agency, 2020); and,
- Current industry practices and datasets, including regional climate datasets.

The eFLaG datasets will be based primarily on the UKCP18 Regional Climate projections and will sit within a wider context of existing (UKCP09 projections, Future Flows, UKCP18 projections) and emerging climate datasets (WRSE Regional Climate Datasets Framework (undertaken by Atkins), Met Office RCP2.6 Global projections, EA gridded Potential Evapotranspiration (PET) dataset) and regulatory guidance (WRMP24 Stochastics, Adaptive Planning and WRMP29; Climate Change Assessment for WRMP24).

The UKCP18 Regional Projections are only available at the RCP8.5 emissions scenario, which is considered to be a plausible worst-case outcome. RCP8.5 represents the 90th percentile of the no-policy baseline scenarios available at the time (van Vuuren et al., 2011). Furthermore, it is argued (e.g. Hausfather and Peters, 2020) that the likelihood of RCP8.5 is reducing due to efforts to reduce emissions but the latest observations of atmospheric carbon concentrations continue to demonstrate recent rises consistent with the RCP8.5 scenario (e.g. Wuebbles et al., 2017). It is worth noting that future projects (e.g. EuroCordex , UKCRP, 2021) may provide additional scenarios to complement the UKCP18 regional projections but are not available at this time.

Responses to question 2 of the workshop 1 questionnaire (Appendix B.1) demonstrate that there is an increased preference for comparison of outputs of this project with the widely used UKCP18 Probabilistic Projections and the Regional stochastics and climate change dataset currently being used in regional planning. The requirement for screening datasets and dataset comparison means that this user requirement extends from a comparison of climatology through to the impact on water supply systems.

Table 1.1: Individuals engaged as part of stakeholder activities

| Individuals name | Organisation | Secondary Organisation |
|---|---|---|
| Susannah Rae | SEPA | |
| Jonathan Dennis | Environment Agency | RAPID team |
| Paul Crockett | Environment Agency | National Framework (Water Resources Planning) Operations Catchment Services |
| Stuart Allen | Environment Agency | Climate Change Research Team |
| Richard Davis | Environment Agency | Senior Advisor, Hydrology |
| Owen Bramwell | Scottish Water | |
| Miranda Foster | Yorkshire Water | Water Resources North |
| Geoff Darch | Anglian Water | Water Resources East |
| Anne Bravery | Anglian Water | |
| Chris Hutton | Wessex Water | Water Resources West Country Group |
| Meyrick Gough | Water Resources South East | |
| Richard Blackwell | United Utilities | Water Resources West |
| Peter Blair | Thames Water | |
| Richard Amos | DCWW | |
| Adrian Brookes | Defra | |
| Tracey Dunford | NRW | |
| Marie-Louise Wise | Ni Dept for Infrastructure | |
| Conor Courtney | NI Water | |
| Lorraine Gormley | Scottish Government | |
| James Dowling | Welsh Government | |
| Mike Keil | CCWater | |
| Jean Spencer | Water-UK | |

| Individuals name | Organisation | Secondary Organisation |
|---|---|---|
| Kathryn Brown | Committee for Climate Change | |
| Nicholas Adjei | OFWAT | |
| Aaron Burton | Waterwise | |
| Michael Jones | Thames Water | Water Resources Modelling Lead |
| Mark Whiteman | Environment Agency | Technical Advisor (Groundwater Resources) |
| Steven Wade | Atkins | |

# 2 User needs

Building on previous discussions during the previous two water resources planning cycles (WRMP14, WRMP19 for which the UKCP09 climate change projections were used), the user needs have been developed through identification of core principles of a climate change dataset. These were identified from discussions with stakeholders during the workshop and through responses to the stakeholder questionnaire. These core principles have been broken down into user needs, before being further subdivided into research requirements which represent more specific user needs that can be passed directly to the method statement.

The core principles of a climate change dataset for use in UK water resources are those that have been identified as being of most value to the water resources industry. The outputs from eFLaG need to:

- be directly applicable to water resources and drought planning across the UK;
- provide evidence with regards to future drought severity;
- be compared to datasets already being used in the industry and the research community; and,
- be accompanied by demonstration case studies signposting how the eFLaG datasets should be used.

In order to start developing specific research requirements based on user needs, these core principles have been broken down into user needs based on information gathered from sources outlined in Section 1.2. These user needs and the justification for their inclusion is given in Table 2.1.

Table 2.1: User needs

| User need | Justification | MoSCoW prioritisation |
|---|---|---|
| 1. Comparison of hydrological models and modelling uncertainty generally, but also when using climate change projections. | The stakeholder response to Question 8 (Appendix B.2) demonstrates that there are a large number of hydrological models used across water resource planning in the UK. There is therefore a requirement to understand how these models perform to different hydrological conditions. A response to Question 8 indicates that a number of the hydrological models listed are not those used by water companies and regulators. The case studies therefore need to provide a link between these, by using water company hydrological models driven by the eFF climatology to compare with the eFF hydrology. | Must Have |
| 2. Comparison of climate change projection datasets. | The stakeholder response to Question 2 (Appendix B.1) highlights a requirement to compare other datasets with the eFLaG outputs. This step is critical in understanding what new information is contained within the outputs that has not been modelled before, and hence may have different system implications. | Could have |

| User need | Justification | MoSCoW prioritisation |
|---|---|---|
| 3. Explore climate change assessment methods beyond the use of change factors. | This user need has been highlighted in Question 3 of the stakeholder questionnaire (Appendix B.1). It will allow comparison of direct climate model outputs and perturbed historical and stochastic sequences. | Must have – to be covered as part of additional scope and development of potential methods will depend on research findings |
| 4. Explore methods different to linear scaling through the planning horizon. | This user need has been highlighted in Question 4 of the stakeholder questionnaire (Appendix B.1). | Must have - development of potential methods will depend on research findings |
| 5. What does the information in climate model outputs tell us about future droughts? | It is critical that outputs from a climate dataset are understood with respect to their future drought characteristics. This need has been identified through development of the WRMP24 climate change guidance and discussions with water companies. | Must have |
| 6. How can drought metrics be used to screen climate change datasets for droughts that test system resilience? | The breadth of drought metrics mentioned in Questions 11 and 12 in Appendix B.2 indicates an interest in metrics as a way of quickly determining the potential system implications of model outputs. It also highlights the use of different metrics for different systems. | Could have – depends on outputs from |
| 7. Specification for future work and necessary datasets | New datasets are being released and used by water companies and research studies throughout planning cycles. Often these are contrasting in methodological approach with previous or current datasets e.g. response to Question 2 in Appendix B.1. A specification for future work would signpost where methods should focus on dataset characteristics, and where research is required to improve methods. | Should have – insight for future user needs |

There is a need to place climate projections within a wider context to understand the water resource system implications of different emissions scenarios, and the investment required to adapt to an uncertain future. The latest draft Environment Agency climate change guidance (Environment Agency, 2020) requires, for highly vulnerable systems, water companies to undertake such a contextualisation using the range of products available from UKCP18, with the depth of analysis dependent upon the system vulnerability to climate change, level of climate change driven investment and change in evidence when looking at UKCP18 products compared to those used in previous assessments. Consequently, there is a user requirement to understand the UKCP18 projections and those products derived from them, such as those generated by this project, and compare them to those used in the previous WRMP planning cycle (Future Flows and Groundwater Levels, UKCP09 projections, MaRIUS), as well as those being used as part of WRMP24 analyses (Regional stochastics and climate change, Atkins, 2021).

To meet these evolving needs of the water industry following publication of UKCP18, requires access to a consistent, spatially coherent climatological and hydrological dataset. Furthermore, evaluation of the UKCP18 regional climate projections in terms of evidence on how severe to extreme droughts may evolve in the future due to climate change could provide valuable insights to the industry in developing investment plans. This dataset needs to be considered alongside the existing climate datasets and methods used by the industry to provide context and this study needs to demonstrate how it could be used to underpin future investment planning.

The user needs in Table 2.1 are general requirements that relate to both the use of the eFLaG outputs themselves and how to use them, and the information contained within the outputs and how the demonstration case studies can be used to explore this climate change information. These user needs can be further subdivided into research requirements identified through stakeholder engagement that answer specific questions related to each need. Table 2.2 identifies some of these specific questions, relates them to the corresponding user need(s) and provides a description of the requirement. This will aid in the development of the method statement for the demonstration case studies and the questions they can answer, tying the research outputs directly back to identified user needs. Due to project time constraints, not all aspects of user needs will be able to be addressed as part of this project, however they should provide a snapshot of UK water resource needs for further investigation.

Table 2.2: Research requirements

| User need | Research requirement | Requirement description |
|---|---|---|
| 1 | Assessment of water resource impacts using eFF climatology and different hydrological models using industry standard models and contrasting case studies. | This will help highlight differences between hydrological models and aid understanding of where there are uncertainties, and how these might be considered, or reduced through model selection. It will also help water companies understand where eFLaG outputs are useful to their supply area. |
| 2 | Assessment of water resource impacts using eFF hydrology and WRMP19 and WRMP24 hydrology using industry standard models and contrasting case studies. | This will help highlight differences between the eFF hydrology datasets and datasets used as part of WRMP19 and WRMP24. Analysis and outputs from this will be used to assess where differences occur and why they occur, enhancing trust in the dataset and allowing water companies to determine if there is information within the eFF datasets that may be useful to their system analysis. |
| 3 | How much do water resource model outputs vary between a change factor approach and running transient climate model outputs through water resource models? How might this influence strategic planning decisions? | Current UK water resource approaches rely on the use of change factors, which alter the severity and duration of droughts they are used to perturb, but may ignore issues such as consecutive dry winters. Using climate model outputs in a transient way, and comparing the outputs against the change factor approach will highlight differences between the approaches, draw out commentary on the projections themselves and signpost areas for further work. This will be particularly relevant for groundwater systems and surface water system susceptible to longer duration droughts. This requirement also examines the use of a 1:500 year plus climate change event when compared with the transient bias-corrected outputs. |
| 3 | Does the eFLaG bias-corrected timeseries data say anything different about spatial coherence compared to a change factor approach and perturbing historic / stochastic droughts? | Change factor approaches rely heavily on the spatial coherence and patterns of the droughts being perturbed. Spatial analysis of the difference in outputs between a change factor approach and the bias-corrected climate outputs will highlight differences and help understand what additional information is available within the bias-corrected outputs, as well as how the change factor approach represents future droughts. |
| 4 | What do the bias-corrected eFLaG outputs show in terms of varying regional climate change signal that | Linear scaling of impacts from a single point in time assumes that climate change impacts are annually incremental, and equal through the time horizon. It therefore also assumes that these impacts occur at |

| User need | Research requirement | Requirement description |
|---|---|---|
| | may indicate the appropriateness of linear scaling in regional planning? | the same point in time from one region to the next. Understanding how appropriate this is will highlight where improvements could be made to scaling impacts and what is important when considering regional connectivity. |
| 4 | What alternatives are there to linear scaling? | Linear scaling is known to have limitations. Through a spatial analysis of regional climate change signal, what alternatives are there to linear scaling (e.g. temperature scaling as used in CCRA3, HR Wallingford, 2020) using climate model information, and what are the limitations of these approaches? |
| 5 | What can the bias-corrected regional projections tell us about future extreme droughts? | Climate models contain physically-based information, rather than historical, or historically derived information, and therefore may tell us about the evolution of future extreme droughts. Given the ensemble size, it is possible that information garnered from the bias-corrected regional projections can only tell us about less-extreme future droughts, however this question seeks to understand if there is some information that can be used from the projections that isn't currently contained within historical or historically-generated droughts. |
| 2 / 5 | Demonstrate how the spatial coherence of the transient eFLaG outputs compare with those of the regional stochastic datasets currently being used in the sector. | Stochastically generated datasets rely on statistical modelling of driving historic climate processes. The regional climate models that underpin the bias-corrected datasets contain may contain information on droughts that varies from that of the stochastic or historic datasets, therefore providing information that would be helpful for regional transfer assessments. |
| 6 | Demonstrate drought metric suitability with system specific stress metrics. | An assessment of the coherence of drought metrics based on either rainfall or hydrological / hydrogeological models with water resource system stress will help pull out where particular metrics perform well (in relation to both hydrological models and the drought metrics themselves). |
| 6 | Demonstrate the use of drought metrics as a screening tool for selecting droughts that may test system resilience. | Screening climate change datasets for droughts that may test system resilience is often a useful tool to focus modelling effort and reducing model run times. This requirement seeks to determine whether system-relevant drought metrics are suitable for use in selecting drought events. |

# 3 Summary

The user needs set out in this document are related to both the projections themselves and how the case studies demonstrate the use of the eFLaG outputs. Some research requirements are related to longer timeframe issues such as those related to the use of change factor approaches and the use of linear scaling, however there are some requirements, such as those relating to the spatial coherence of the underpinning regional climate model and the evidence within the projections themselves that are of immediate interest. The research requirements will feed into the demonstration case study method statement.

# 4 Acknowledgements

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# Appendices

# A Workshop 1 design, schedule and question summary

## A.1 Workshop design

### A.1.1 Workshop philosophy

The eFLaG datasets sit within a wider context of existing (UKCP09 projections, Future Flows, UKCP18 projections) and emerging climate datasets (WRSE Regional Climate Datasets Framework (undertaken by Atkins), Met Office RCP2.6 Global projections, EA gridded Potential Evapotranspiration (PET) dataset) and regulatory guidance (WRMP24 Stochastics, Adaptive Planning and WRMP29; Climate Change Assessment for WRMP24). In order to be of the greatest value to stakeholders and the eFLaG project, it is proposed to provide time-slots for presentation of those datasets and guidance updates yet to be published within the workshop, with the aim of providing context and discussion around key projects and topics. The intention is that the workshop will act as a hub for all aspects of climate change related discussion in the Water Industry, rather than solely a discussion around the eFLaG datasets and dissemination, and should ensure that the industry fully understand where the eFLaG datasets sit within the past, current and emerging climate datasets.

There is limited scope for stakeholders to change some aspects of the methodology (e.g. selection of hydrological and groundwater models, bias correction method) that underpins the eFLaG datasets. The workshop and stakeholder engagement will, however, allow stakeholders to shape how outputs are made available to the industry and guide how best to integrate the datasets into industry. This will ensure outputs are understood (e.g. limitations of methods, how Water Companies might report results) and subsequently used in an appropriate way by industry. This is going to be critical in their uptake, particularly given the public scrutiny all inputs and methods will be required to withstand where they are used for making significant investment decisions.

The workshop therefore has two themes: context setting (which will provide stimuli for discussion on issues directly relevant to the eFLaG project); and the eFLaG project itself (including summary of proposed work, and focussed stakeholder input). It is proposed that these two themes will be intertwined through the workshop, but with clear questions for the stakeholders that are directly related to the eFLaG project (to ensure stakeholder inputs are relevant). This workshop layout will be finalised through the agenda.

### A.1.2 Context setting

Slots for ~5 minute presentations (pending agreement with relevant organisations) as follows:

- Met Office presentation on UKCP18 and new Global Projections RCP2.6 dataset.
  - Provide introduction to UKCP18 datasets and the latest dataset releases.
- Atkins presentation on WRSE climate change dataset.
  - Help to frame the discussion around the UKCP18 Regional Projections, bias correction.
- Richard Davis presentation on EA gridded PET dataset.
  - Provide information on the latest PET dataset that may have implications for hydrological model calibration for Water Companies.
- HR Wallingford presentation on EA Climate Change Assessment for WRMP24 Guidance.

- Atkins presentation on EA WRMP24 Stochastics, Adaptive Planning and WRMP29 Guidance.

### A.1.3 eFLaG discussions

The points for discussion have been identified based on improving understanding of the eFLaG datasets within the Water Industry and how they can make use of the modelling being undertaken in the eFLaG project. It is anticipated that discussion will also come out of the presentation of the proposed methodology. The key areas for both presentation and discussion are as follows:

**Presentation of methodology. Discussion to include the following:**

- Selection of catchments and boreholes.
- Overview of groundwater and hydrological models.
- Best ways to clearly disseminate the following:
  - Hydrological model benchmarking (e.g. limitations of model selection in geographic areas, features of particular models) and guidance for using research grade models for industry applications.
  - Bias correction method (e.g. limitations and potential future work).
  - Approach to handling the issue that climate models produce time-series based on 360 day years and how these are processed to 365/6 day years.
  - Model evaluation (e.g. groundwater model performance in different hydrogeological settings).
- Where aspects of the methodology could be developed in the future.

**Analysis of future drought characteristics. Discussion to include the following:**

- Metrics of interest to Water Companies.
  - Metrics of interest may vary based on spatial and temporal differences across the UK, and water resource model system responses.
  - Guidance on how to interpret likelihoods and understand the interplay between natural variability and climate change signal.

**Overview of Demonstration Case Studies. Discussion to include the following:**

- Hydrology and groundwater outputs.
  - Best way to demonstrate differences between datasets used for WRMP19 and eFLaG.
- Water resource model outputs.
  - Best way to demonstrate differences between system responses for WRMP19 and eFLaG datasets.
- Implications of the datasets.
  - How they might be used, what information might need to be provided where differences occur (e.g. a result of RCP8.5 emission scenario, a result of hydrological models used) and the cascade of uncertainty.

**Overview of dataset delivery. Discussion to include the following:**

- Data formats.
  - .csv, NetCDF etc.
- Dataset access.
  - Website, supporting information etc.

### A.1.4 Workshop delivery

Owing to the current Covid-19 situation, there is a great deal of uncertainty surrounding the organisation of a workshop in the coming months. Whilst it is the project teams preference for a face-to-face workshop over a

virtual one (they often seem to stimulate more discussion), there is much more certainty in organising a virtual workshop. In order to improve engagement during a virtual workshop, we are currently reviewing what are effective means of stakeholder engagement (e.g. setting up quick surveys with voting options, using Slido), and will update this document during April with more details of specific tools we would use to facilitate such a workshop.

## A.2 June workshop schedule

Total time: **90 minutes**

Introduction and wrap-up: **15 minutes**

Context setting presentations: **25 minutes**

eFLaG presentations: **50 minutes**

The aim of the June workshop is to provide more information on parts of the project where stakeholder input is required, some of the industry relevant context, and ask questions of the stakeholders, which will be discussed at the following workshop in mid-late July (date TBC).

### Workshop delivery

- Video conference (Microsoft Teams).
- All of questions we ask, as well as all questions asked by stakeholders are to be captured on the Teams chat and will be captured post-meeting. We plan to record the meeting.
- Workshop questionnaire capturing all questions for stakeholders (using SurveyMonkey or similar) to be sent out shortly after workshop.

### Introduction to workshop (HR Wallingford)

- Overview of session (10 minutes – Mason Durant, HR Wallingford).

### Context setting presentations (Chris Counsell to "chair")

Context setting presentations (25 minutes – 20 minutes presentations, 5 minutes buffer). No time is set aside for questions here, as this workshop isn't about these separate projects, however stakeholders can type questions into slido:

- UKCP18 and new Global Projections RCP2.6 dataset (5 minutes – Fai Fung, MO).
- Industry regional climate change datasets (5 minutes – Steven Wade, Atkins).
- EA PET dataset (5 minutes – Richard Davis, EA).
- EA and NRW Climate Change Assessment for WRMP24 Guidance (5 minutes – Mason Durant, HR Wallingford).

### eFLaG presentations (CEH to "chair", Matt Ascott to "chair")

Put a few overarching questions up at the start and ask stakeholders to think about these as we go through the presentations and take them away, ready for a discussion at the following workshop. Each presentation may also have specific questions (e.g. site selection) which can be asked in each presentation and captured within responses and discussion at the follow on workshop.

*Overarching questions* - these should be answered through the lens of both this research study and also the longer-term direction of travel for how the industry might consider climate change as part of water resources planning into the future:

- In the longer term, what are the industry's primary needs from a climate change dataset? What would be its key attributes and features?
- How can the outputs from this research best contribute to progress towards this ambition?

- What outputs do you require (a list they can rank in order of importance, to cover drought metrics, raw outputs, guidance on use)?
- What should the case studies focus on? What outputs would you want to see from the case studies?
  - Comparisons with Regional Stochastics and UKCP18 change factors?
  - Inform industry as to choice of products and how impacts might best be integrated into the wider WRMP?
    - Central impact + distribution for Target Headroom?
    - Separate 'plans' for different futures trajectories?

*eFLaG presentations* to cover an introduction, four sections of eFLaG outlined in the workshop design and questions. For information on content of each, please refer to the Workshop Design document:

- Introduction to eFLaG (5 mins – CEH).
- Methodology (15 mins - CEH, BGS).
  - UKCP18 products and bias-correction.
  - Hydrological modelling inventory and site selection.
  - Groundwater modelling and site selection.
- Future drought characteristics (10 mins - CEH, BGS).
  - Metrics.
  - Extreme Value Analysis.
- Demonstration Case Studies (10 mins – Chris Counsell, HR Wallingford).
- Dataset delivery (10 mins - CEH).
- Questions (10 mins - CEH) – questions for this session should be aimed at giving the stakeholders the information they need to be able to answer the questions we are getting them to take away, rather than detailed feedback on the specific questions.

**Workshop wrap-up**

- Overview of session (5 minutes – Mason Durant, HR Wallingford).

## A.3 Workshop 1 questions

- Steven Wade: Question to Fai - Will the ET product include different assumptions on stomatal resistance and plant responses to higher CO2 etc?
- Paul Crockett: Comment on Mason's presentation - The size of WRZ varies the 15% includes some big WRZ.
- Mark Sampson: Richard [Davis] - do you know timeframe for updating EA GW models with EA dataset - months or over the next few years?
- Fai Fung: In reply to Steven Wade, no it won't. In more detail...the set of results using the Met Office climate model in UKCP Global (60km) does not include an interactive carbon cycle and has prescribed vegetation distributions.
- Steven Wade: CEH colleagues can you share the methodology pdf in the meeting chat?
- Mike Jones: Richard [Davis], what's the current view on the potential magnitude of impact PET changes will have on catchment water balances?
- Stuart Allen: How much consistency is there please between the proposed catchments and the original FF catchments?

- Mark Sampson: Jamie - re use of GR4J, our work has indicated that GR6J outperforms the 4 parameter version for our selected catchments (natural and modified) used for scoping.
- Jamie Hannaford: HI Stu: PDM and AquiMod are the links to the original FFGWL.
- Chris Counsell: Richard's response to Mark's question on EA GW models, "Given the resources required to do this, it will be over the next few years."
- Jamie Hannaford: Mark Sampson: we are looking into this - Katie has done some comparisons with GR6 and is revisiting those, It's a long story though, so happy to follow up!
- Stuart Allen: Will the GW recharge work be continuous to 2080 or time-slices similar to previous?
- Steven Wade: CEH: Can you share the Rudd et al 2019 paper?
- Jamie Hannaford: Hi Steve - will add links to the ppt before sharing it. Can also send PDFs for any that are less readily available, but most will be open access.
- Steven Wade: JH: Agreed on sensitivity of EVA - we could spend a lot of resources at Public Inquiries arguing about 1 in 500 year droughts!!!
- Chris Jackson: Hi Stuart, we will be putting the transient projections through the national recharge model.
- Steven Wade: Instead let’s just test systems to a sensible range of droughts. Stochastic data sets are useful for this purpose.
- Jamie Hannaford:
- Hi Stu, re: set of catchments. We have tried to ensure significant overlap with FFGWL as well as others like Historic Droughts.
- Hi Steve - agreed on EVA. Definitely good to bring convergence of evidence from stochastics, climate models, .... (as well as emerging work on improving understanding of past rainfall e.g. rescue, recovery, documentary, etc).
- Hi Steve - re: Bias Correction we are engaging with Met Office about possible avenues like this within scope of eFLaG. But also mindful of constraints.
- re: methodology PDF - currently in draft so perhaps will share offline on request and then share full version more widely when in final draft.
- Steven Wade: eFlag: All good stuff. My only concern is coming out with a big data set AFTER the industry has completed their plans?

# B Workshop 1 questionnaire results

Following Workshop 1 on 29/06/2020, a survey was sent out to attendees, as well as those who could not make Workshop 1, but want to attend Workshop 2, to gather information on the three strands of the project – the demonstrator case studies, river flow modelling, and groundwater level and recharge modelling. The survey was kept deliberately concise in an attempt to maximise stakeholder engagement. The responses to the questions will be used to frame the discussions at Workshop 2.

There were 11 respondents, with representation from Water Companies in all four home nations, regional planning, and regulators at the Environment Agency and Natural Resources Wales. The breakdown of respondents is given in Table B.1.

Table B.1: Survey respondents

| Respondent name | Organisation |
|---|---|
| Tracey Dunford | Natural Resources Wales |
| Mark Whiteman | Environment Agency |
| Owen Bramwell | Scottish Water |
| Conor Courtney | NI Water |
| Miranda Foster | Yorkshire Water |
| Geoff Darch | Anglian Water |
| Meyrick Gough | Water Resources South East |
| Michael Jones | Thames Water |
| Chris Hutton | Wessex Water |
| Richard Davis | Environment Agency |
| Richard Amos | DCWW (Welsh Water) |

This note provides a summary of the question responses across the three project strands as well as a brief overview of any insight.

## B.1 Demonstrator case studies

There was an overwhelming interest in eFLaG exploring methods other than linear scaling to quantify climate change impacts through the planning horizon, as well as exploring methods that look beyond the use of change factors. Both of these are topics that may have significant implications for Water Companies' assessments of future water availability and resilience. Both the regulators (the Environment Agency and Natural Resources Wales) and Water Companies (with the exception of NI Water) expressed interest in eFLaG exploring these topics. However, the majority of respondents anticipated including climate change in Target Headroom for both WRMP24 and WRMP29, indicating that they don't anticipate using adaptive pathway-type approaches where climate change uncertainty is intrinsic to the path taken. Respondents most want the eFLaG outputs to be compared against the UKCP18 Probabilistic Projections and the Atkins' produced regional stochastic and climate change datasets, indicating a preference for datasets that are perhaps likely to be used in WRMP24 and potentially WRMP29 assessments. All Water Company respondents have water resources systems where climate change is a significant, if not the most significant source of uncertainty in their investment plan.

**Q1 – Should the emphasis of the case studies (outputs due summer 2021) be targeted at WRMP24 or WRMP29?**

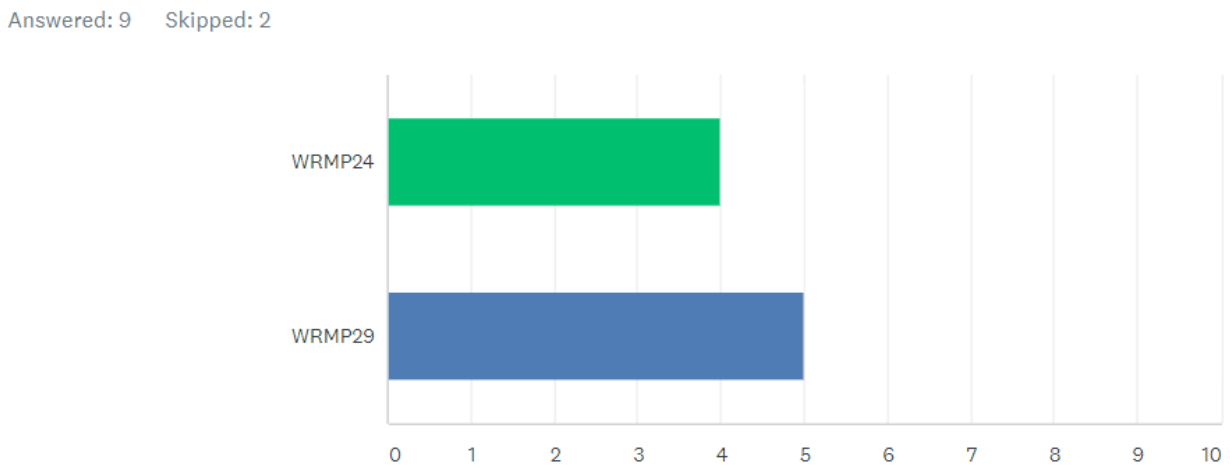


Figure B.1: Question 1 response

**Q2 – What other datasets would you like eFLaG outputs (climate / flows) compared to?**

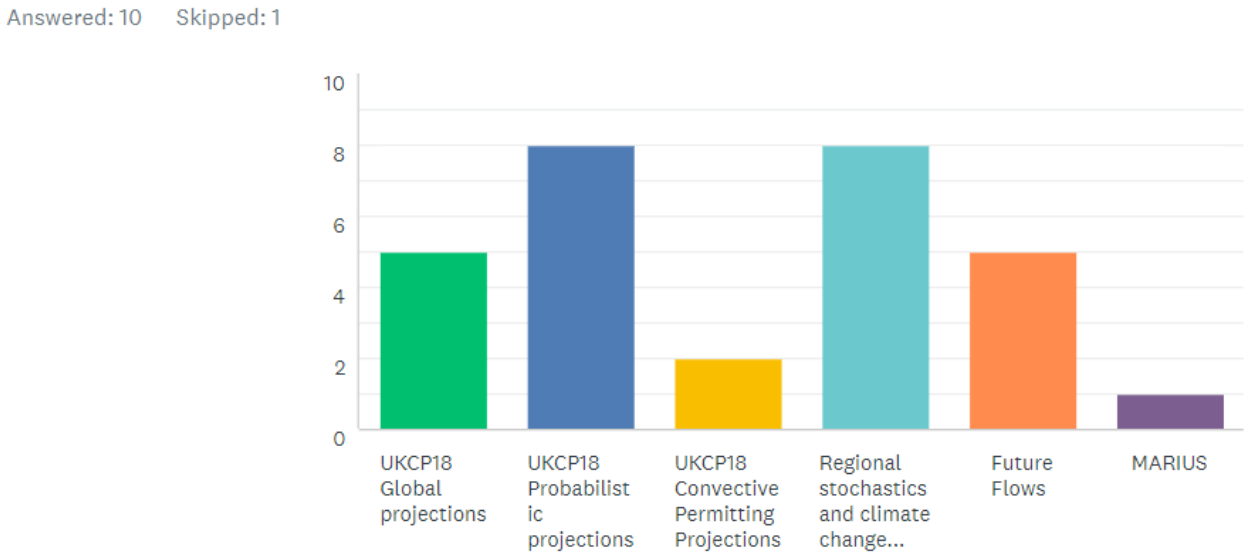


Figure B.2: Question 2 response

Table B.2: Question 2 comments

| Respondent | Additional comments |
|---|---|
| Geoff Darch (Anglian Water) | New stochastic weather generator output from Met Office (EDE) |
| Mark Whiteman (EA) | Compare recharge to Environment Agency groundwater model outputs |

**Q3 – What is your interest in eFLaG exploring climate change methods that look beyond the use of change factors?**

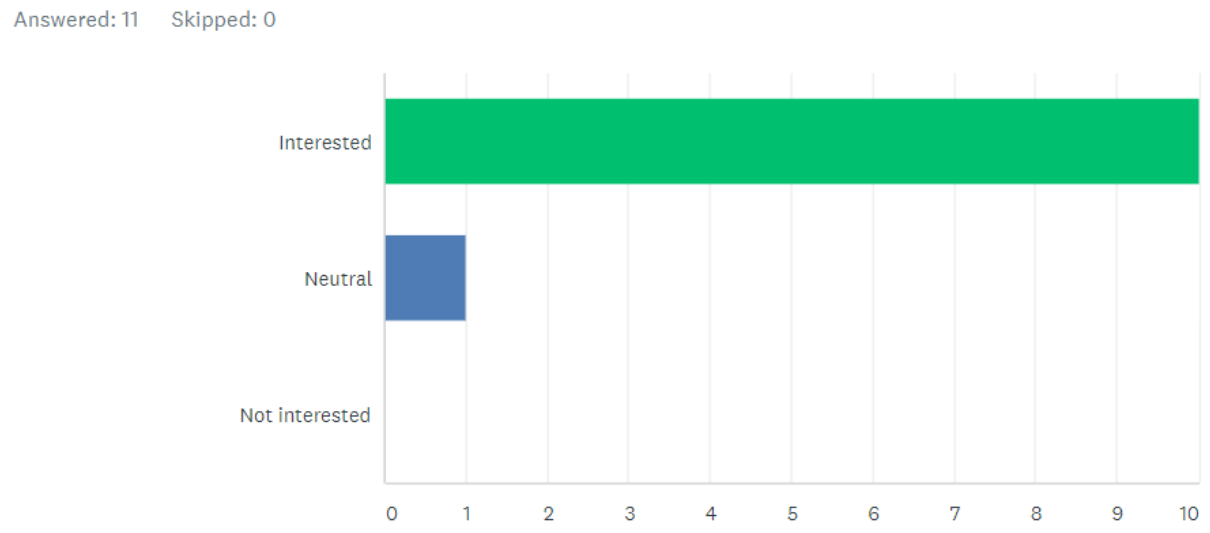


Figure B.3: Question 3 response

**Q4 – What is your interest in eFLaG exploring methods other than linear scaling to quantify climate change impacts through the WRMP planning horizon?**

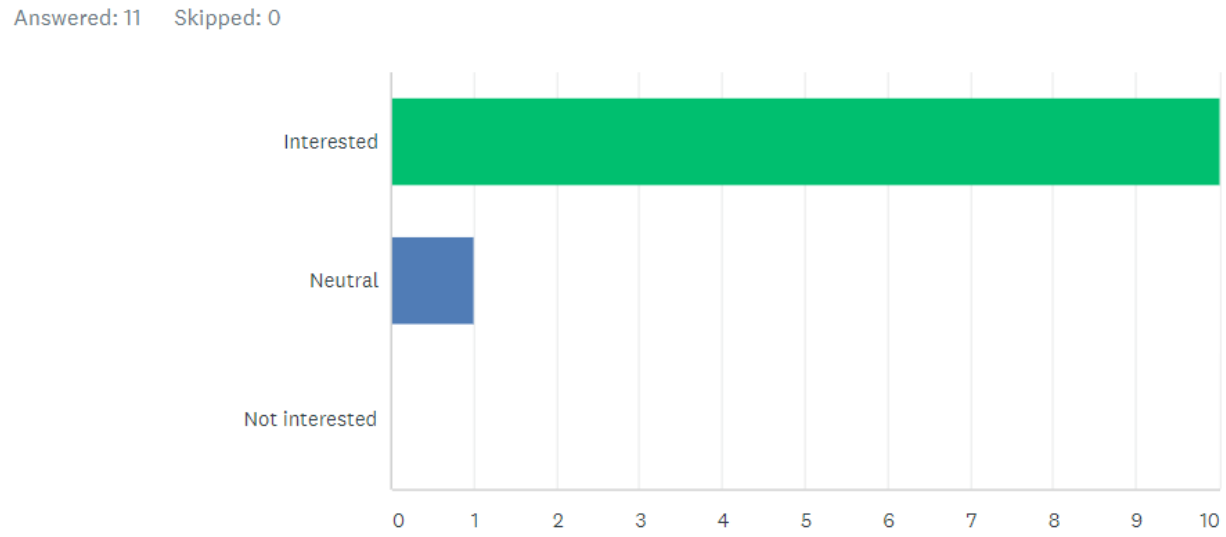


Figure B.4: Question 4 response

**Q5 – [Water Companies only] What is the significance of climate change (relative to other sources of uncertainty) to your investment planning?**

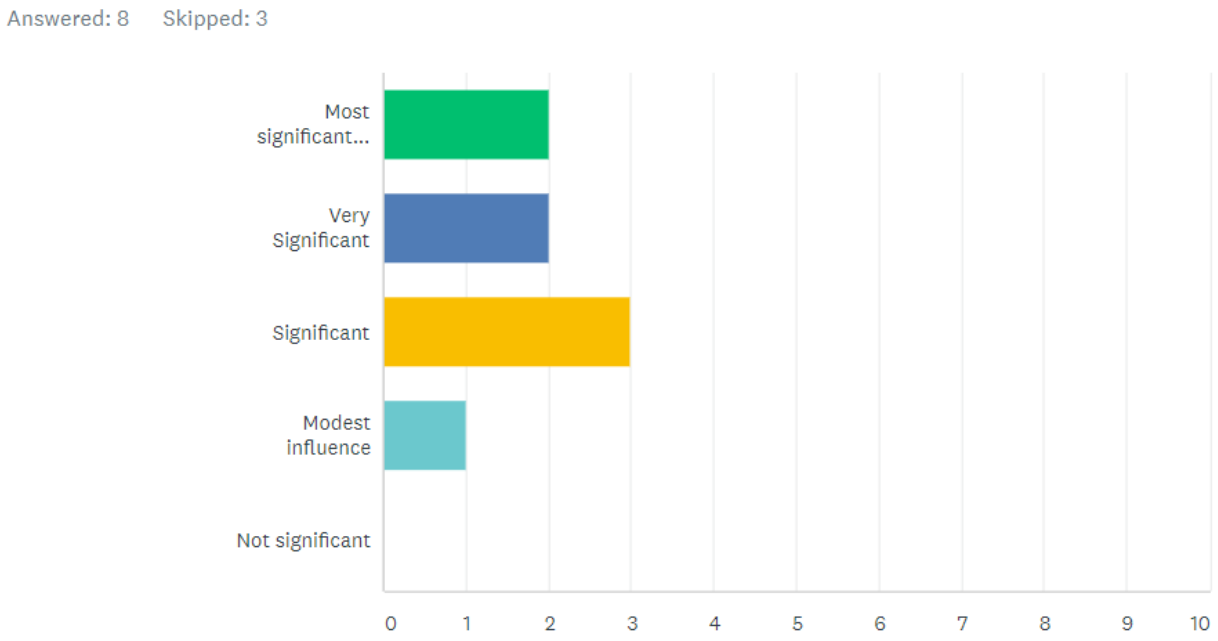


Figure B.5: Question 5 response

**Q6 – [Water Companies only] Do you anticipate including climate change uncertainty in Target Headroom for WRMP24 or 29?**

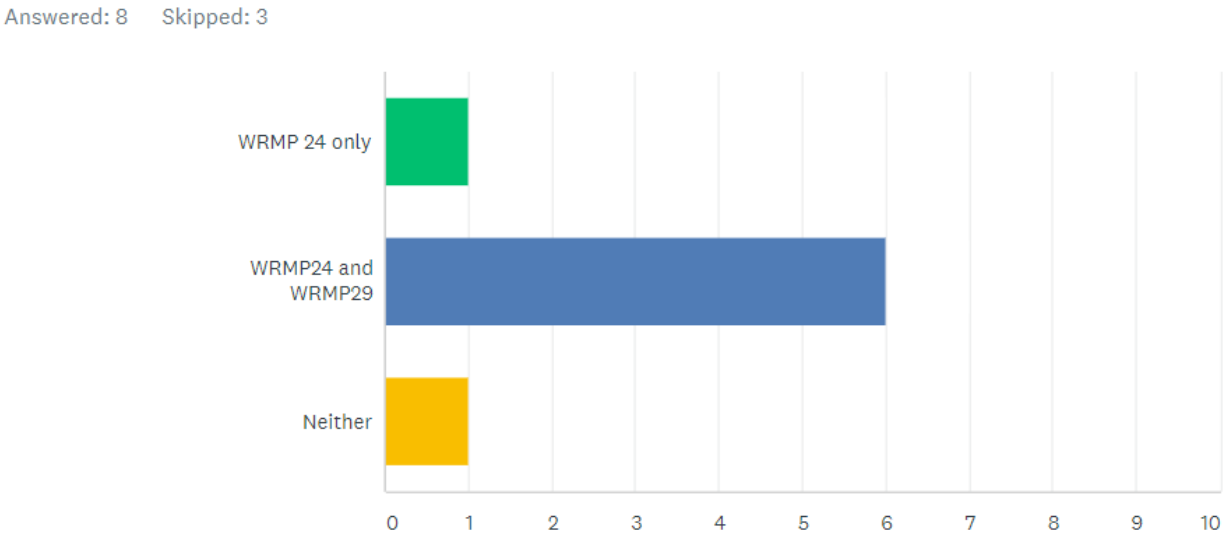


Figure B.6: Question 6 response

**Q7 – [Water Companies only] Which of the case study water companies is most relevant to your system and its vulnerabilities to drought and climate change?**

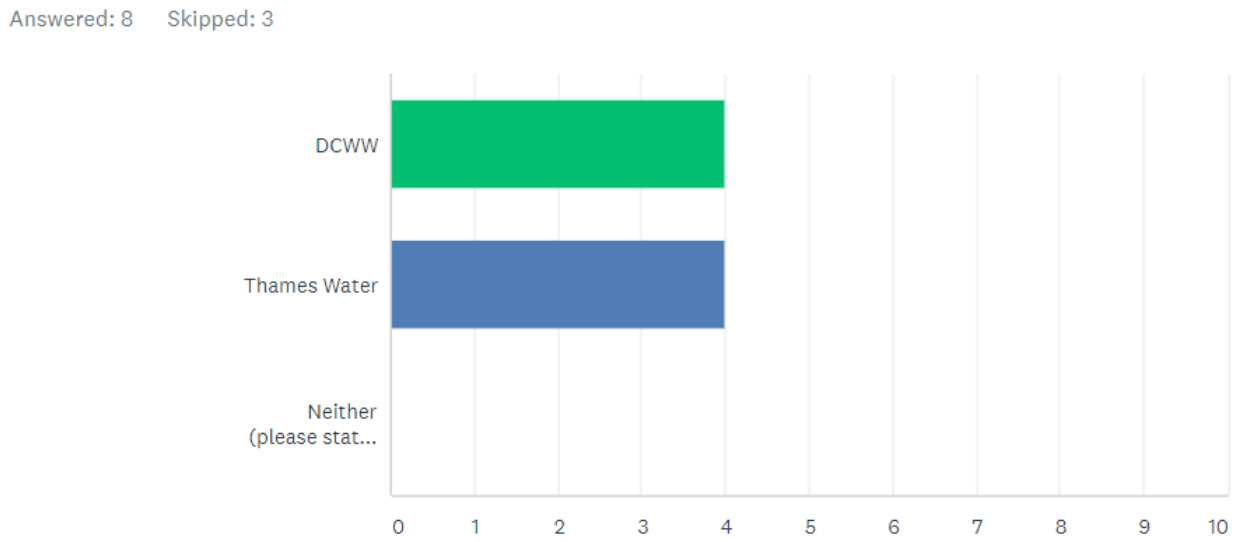


Figure B.7: Question 7 response

## B.2 River flow modelling

A number of respondents suggested additional catchments that are of interest to their work. The split in drought metrics being requested pre and post WRMP24 is perhaps an indicator of the eFLaG outputs being more useful post WRMP24, with all metrics scoring either the same, or higher, for inclusion post WRMP24, with no change in relative preference with the exception of low streamflow metrics. For this question, flow threshold metrics were of more relative use post WRMP24 than n-day minimum flows. CatchMOD and HYSIM represent the greatest share of hydrological models, however both PDM and GR6J are used more than any other single model.

### Q8 – Which of these hydrological models do you currently use?

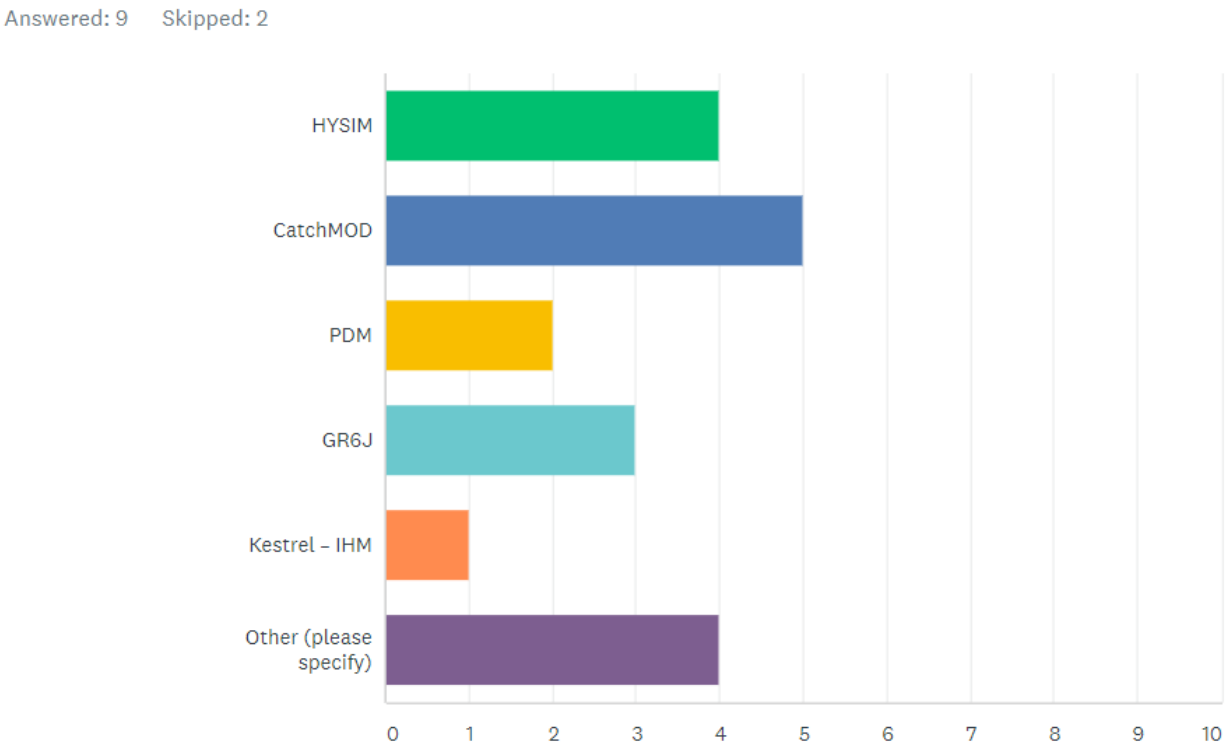


Figure B.8: Question 8 response

Table B.3: Question 8 comments

| Respondent | Comment |
|---|---|
| Mark Whiteman (EA) | We use MODFLOW and 4R (EA or SWaC) recharge model to simulate river flows in groundwater dominated catchments; |
| Miranda Foster (Yorkshire Water) | We mostly use gauged river flows, and water balances for reservoir inflows. Where these are not appropriate, we currently use Hysim for hydrological models, but investigating the use of GR6J; |
| Geoff Darch (Anglian Water) | SIMFLOW; TETIS; (and groundwater models); |
| Richard Davis (EA) | This is a comment for Question 9. None of the primary models you are using (PDM, GR6J or G2G) are used within operational Water Resources Hydrology either within the regulator nor by water companies. Unless the climate inputs are provided there will be limited operational use of the data from the project. |

### Q9 - eFLaG will use 3 RR models (PDM, GR4J and G2G) across ~ 200 catchments. Some will be in the demonstrator regions (Thames, Wales) along with a core national network of c.120 sites. If resources allow, are there other key sites that should be considered?

Table B.4: Question 9 site suggestions

| Respondent | Site |
|---|---|
| Mark Whiteman (EA) | Chalk streams – Chilterns e.g. Ver, Chess, Misbourne |
| Miranda Foster (Yorkshire Water) | 27089 Wharfe at Addingham (as well / instead of at Wetherby – more useful as HOFs based on this gauge) |
| Miranda Foster (Yorkshire Water) | 27007 Ure at Kilgram (as well / instead of at Westwick – more useful as HOFs based on this gauge) |

| Respondent | Site |
|---|---|
| Miranda Foster (Yorkshire Water) | 26002 Hull at Hempholme (although / because this is a tricky one – strange tilting weir at tidal limit) |
| Richard Amos (DCWW) | 102001 |
| Richard Amos (DCWW) | 66011 |
| Richard Amos (DCWW) | 56007 |
| Geoff Darch (Anglian Water) | Nene to Wansford |
| Geoff Darch (Anglian Water) | Bedford Ouse to Offord |
| Geoff Darch (Anglian Water) | Wensum to Cottessey / Norwich |

### Q10 – What type of outputs would be of benefit for you to have access to?

Answered: 10 Skipped: 1

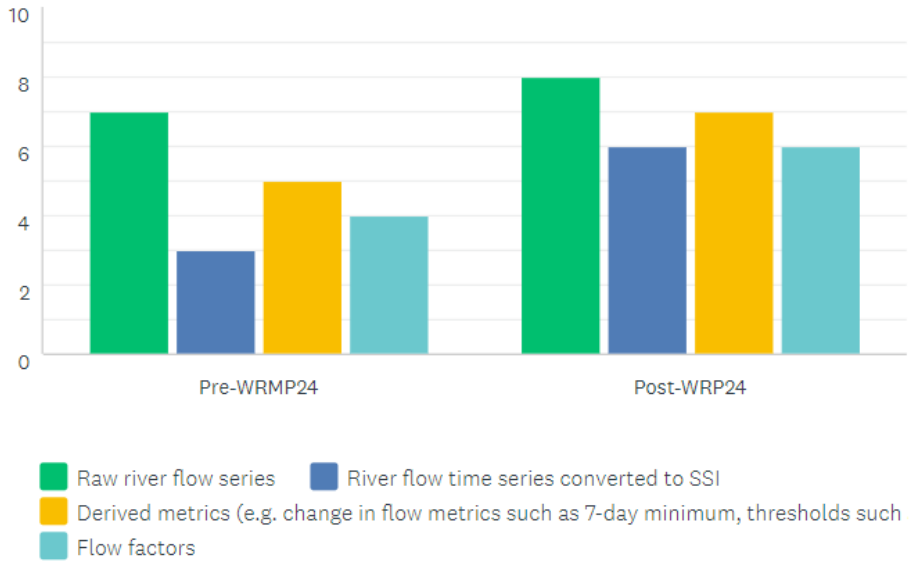


Figure B.9: Question 10 response

Table B.5: Question 10 comments

| Respondent | Comment |
|---|---|
| Mark Whiteman (EA) | Need to check on timescales for PR24 – that might influence my answer! |
| Miranda Foster (Yorkshire Water) | Summer 2021 is too late for inclusion in WRMP24, so all outputs only relevant to post WRMP24 |
| Richard Davis (EA) | The raw climate datasets which can be input into the regulators and water companies own models |

**Q11 – Which of the following drought analysis metrics would you prefer to see us use to explore how hydrological drought risk changes in future?**

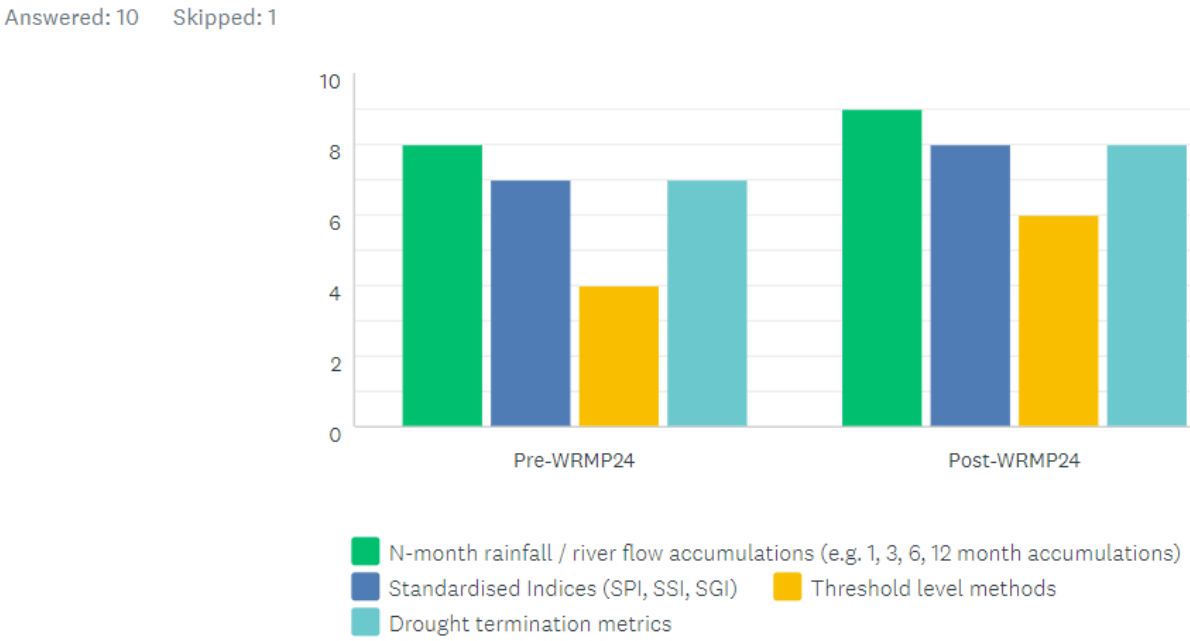


Figure B.10: Question 11 response

Table B.6: Question 11 comments

| Respondent | Comment |
|---|---|
| Richard Amos (DCWW) | Number of consecutive dry days in a drought period |
| Miranda Foster (Yorkshire Water) | As before, summer 2021 is too late for WRMP24 inclusion |
| Geoff Darch (Anglian Water) | Ensure sufficiently long durations e.g. 24, 36 month |
| Richard Davis (EA) | Up to 36 months for rainfall assessments |

**Q12 – We also plan to look at changes in low streamflows. Which would you prefer:**

Answered: 10 Skipped: 1

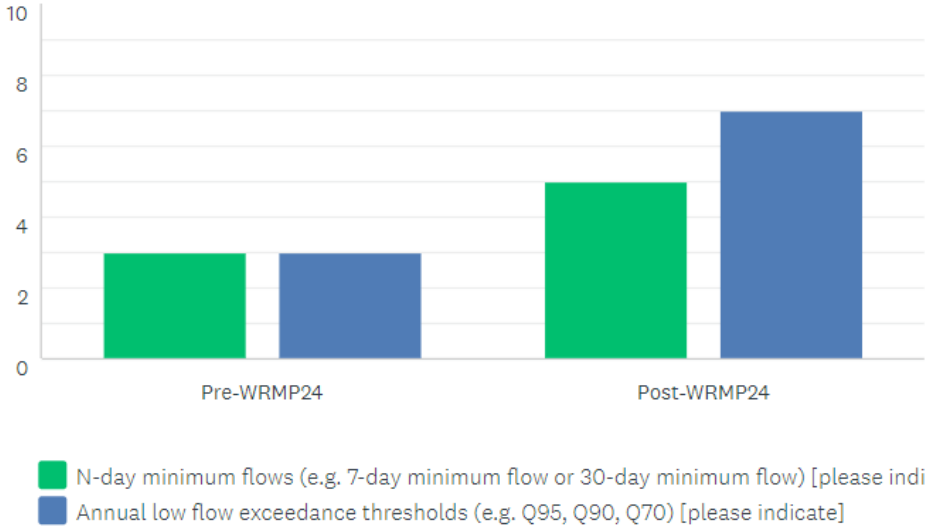


Figure B.11: Question 12 response

Table B.7: Question 12 metric preference comments

| Respondent | Minimum flow metric |
|---|---|
| Richard Amos (DCWW) | Preference for 7 day minimum |
| Geoff Darch (Anglian Water) | N-day period preference is highly site dependent. Generally key low flow is Q95 but also site dependent |
| Richard Davis (EA) | Continuous number of days below particular thresholds |

**Q13 – eFLaG will be delivering the datasets (flows, groundwater and derived indices) as a large dataset to the EIDC for free access. We do not have resources to develop a tool or portal for spatial / temporal exploration of the dataset but would be keen to know if you would like to see this sort of capability being made available in the future.**

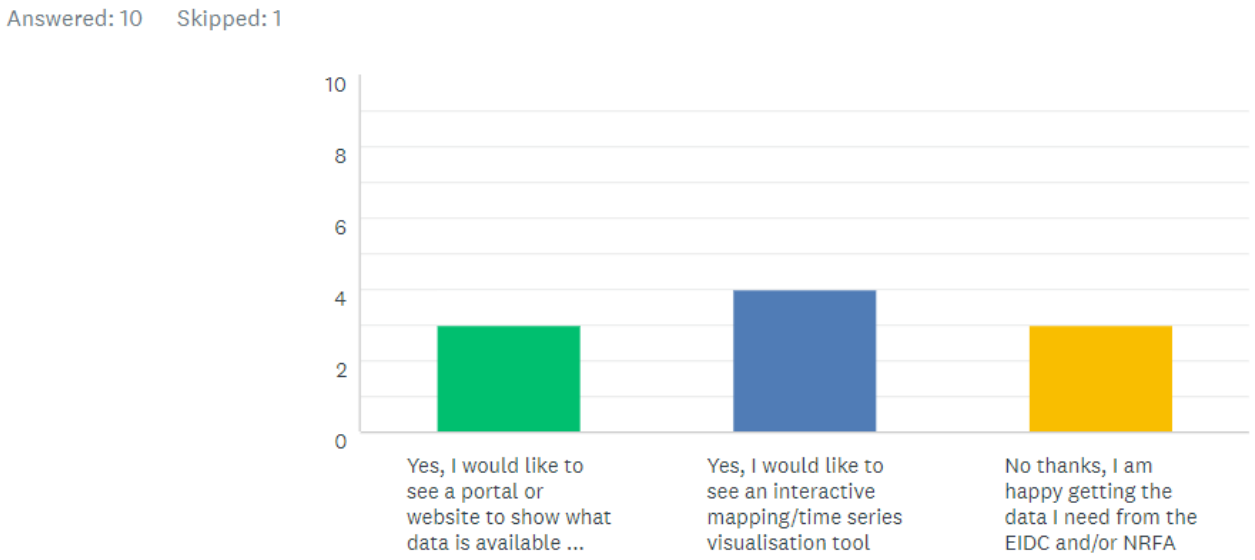


Figure B.12: Question 13 response

## B.3 Groundwater level and recharge modelling

A number of respondents suggested additional observation boreholes that are of interest to their work. The split in drought metrics for recharge and groundwater level being requested pre and post WRMP24 is perhaps an indicator of the eFLaG outputs being more useful post WRMP24, with all metrics scoring either the same, or higher, for inclusion post WRMP24.

**Q14 - Groundwater level time series at 60 observation boreholes will be simulated using the lumped parameter model AquiMod. Are there additional observation boreholes that would be of benefit to you to be modelled if resources allow?**

Table B.8: Question 14 site suggestions

| Respondent | Site |
|---|---|
| Miranda Foster (Yorkshire Water) | Ralph Nook |
| Miranda Foster (Yorkshire Water) | Pincheon Green long record in the Sherwood Sandstone |
| Miranda Foster (Yorkshire Water) | Broughton Corallian |
| Geoff Darch (Anglian Water) | Any in East Anglia e.g. confined chalk or crag |
| Mike Jones (Thames Water) | Sweeps Lane, Darent-Cray Chalk |
| Mike Jones (Thames Water) | Frith Cottage, Wey Lower Greensand |
| Mike Jones (Thames Water) | Lilley Bottom, Upper Lee Chalk |
| Chris Hutton (Wessex Water) | Allington borehole (near Chippenham) |

**Q15 – The AquiMod models will be used to simulate continuous daily groundwater level time series over historic and future (up to 2100) time periods. With this in mind, what types of outputs would be of benefit to you?**

Answered: 9 Skipped: 2

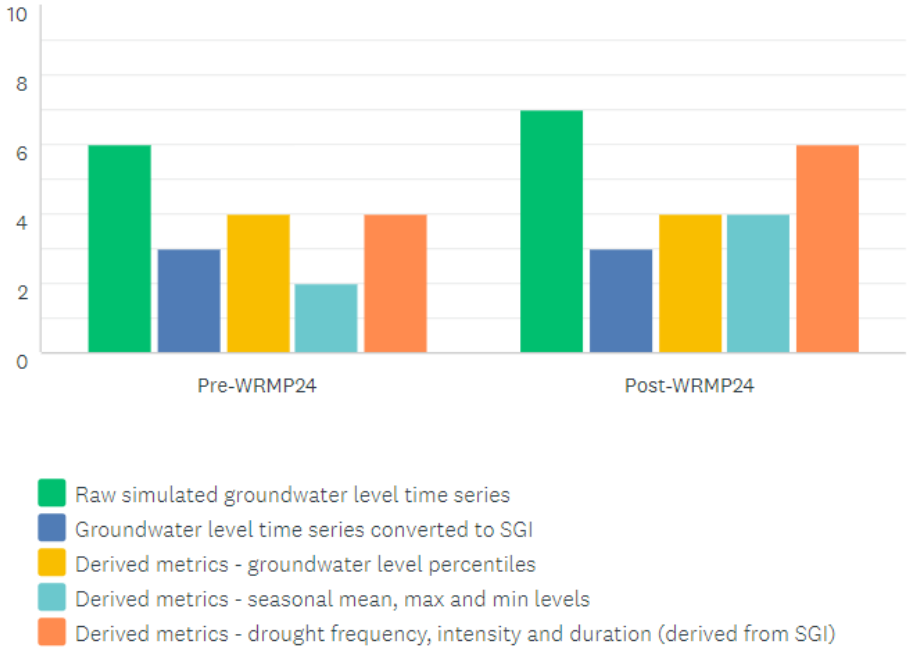


Figure B.13: Question 15 response

Table B.9: Question 15 comment

| Respondent | Comment |
|---|---|
| Richard Davis (EA) | Continuous number of days below particular thresholds |

**Q16 - The national recharge model, ZOODRM will be used to produce gridded recharge time series over Great Britain. If time allows, would provision of recharge files from ZOODRM recharge model for use in the regional models be useful?**

Answered: 7 Skipped: 4

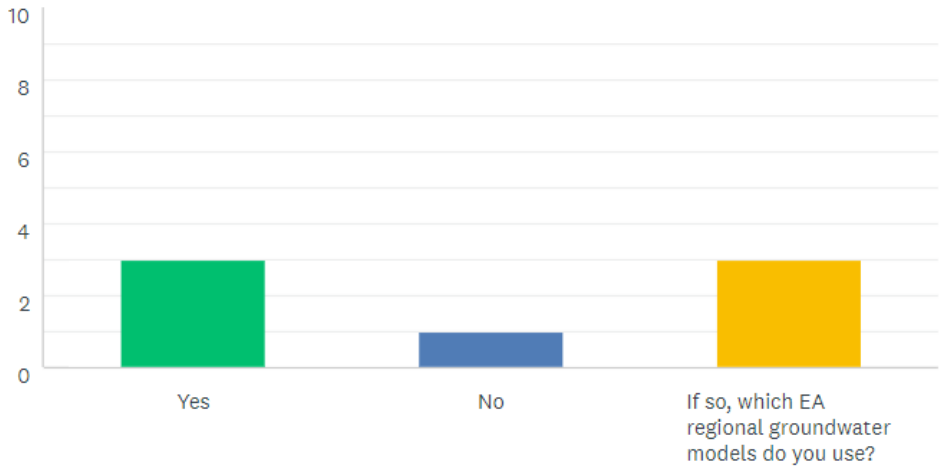


Figure B.14: Question 16 response

Table B.10: Question 16 groundwater models

| Respondent | Groundwater models |
|---|---|
| Miranda Foster (Yorkshire Water) | Yorkshire chalk model, East Midlands, Yorkshire models (for Sherwood Sandstone) |
| Mike Jones (Thames Water) | Cotswolds, Kennet, Herts Chalk, London Basin Aquifer Model, Mole |
| Chris Hutton (Wessex Water) | Wessex Basin model |

**Q17 - ZOODRM will be used to produce continuous 2 km daily recharge time series over historic and future time periods. With this in mind, what types of outputs would be of benefit to you?**

Answered: 8 Skipped: 3

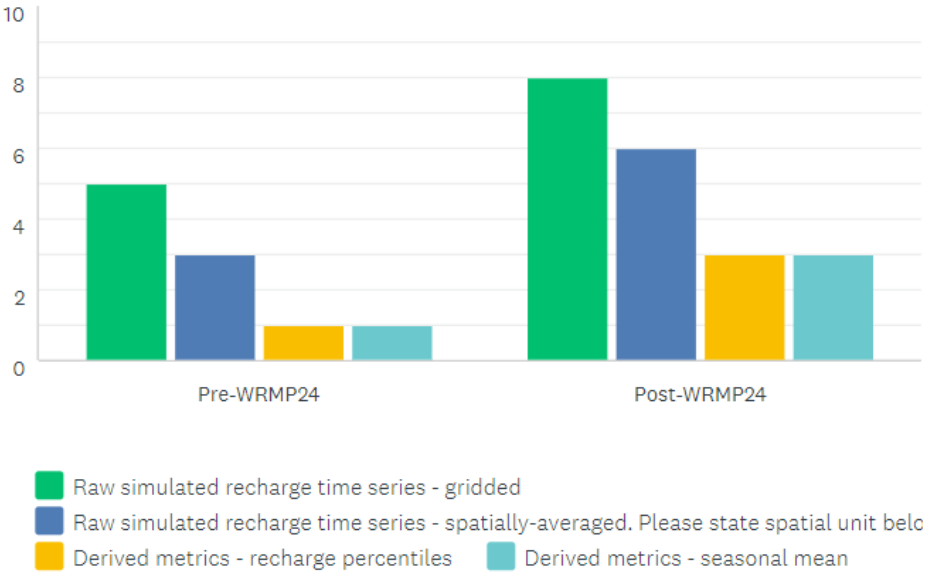


Figure B.15: Question 17 response

Table B.11: Question 17 comments

| Respondent | Comment |
|---|---|
| Miranda Foster (Yorkshire Water) | Aquifer level for spatial averaging |
| Geoff Darch (Anglian Water) | We could compare this with the WRE recharge model (SWaCMOD) |
| Meyrick Gough (WRSE) | Whilst this dataset is interesting it cannot be used by industry as each groundwater model has been calibrate on different recharge models. It would have been better to use the original recharge models for some of the more accurate groundwater models e.g. Brighton and Worthing Block model |
| Mike Jones (Thames Water) | Averaged by hydrometric area |

### Q18 – Is there any groundwater specific drought analysis that would be of benefit to you?

Answered: 9 Skipped: 2

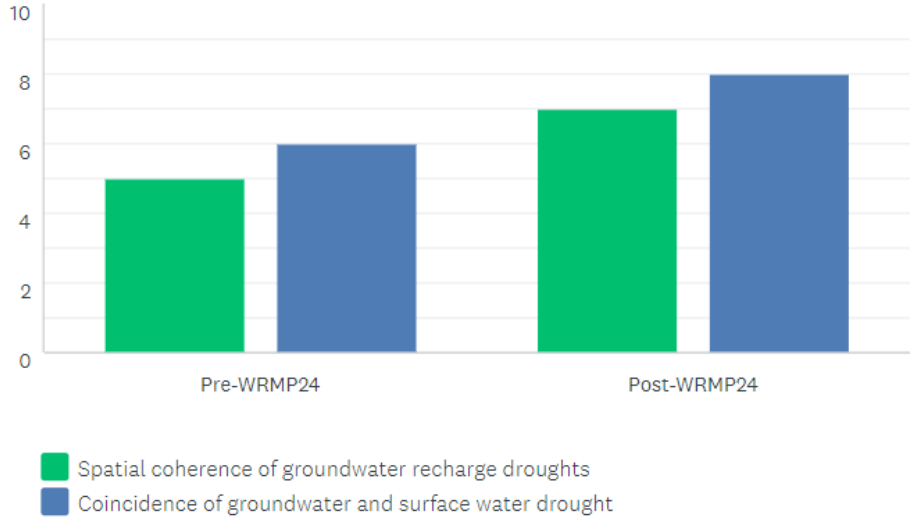


Figure B.16: Question 18 response

Table B.12: Question 18 comment

| Respondent | Comment |
|---|---|
| Richard Davis (EA) | Particularly between surface water and groundwater dominated parts of the country |

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