# Final Draft Water Resources Management Plan 2024

# Annex 10: Regional plan methodologies used

Submission date: May 2025

WATER for LIFE

from Southern Water

# Method Statement: Environmental Assessment

## Consultation version

## July 2020

| Title | Method Statement: Environmental Assessment |
|---|---|
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| **Author** | Nick Price |
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| **WRSE Director Approval** | Meyrick Gough |

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# Table of Contents

# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

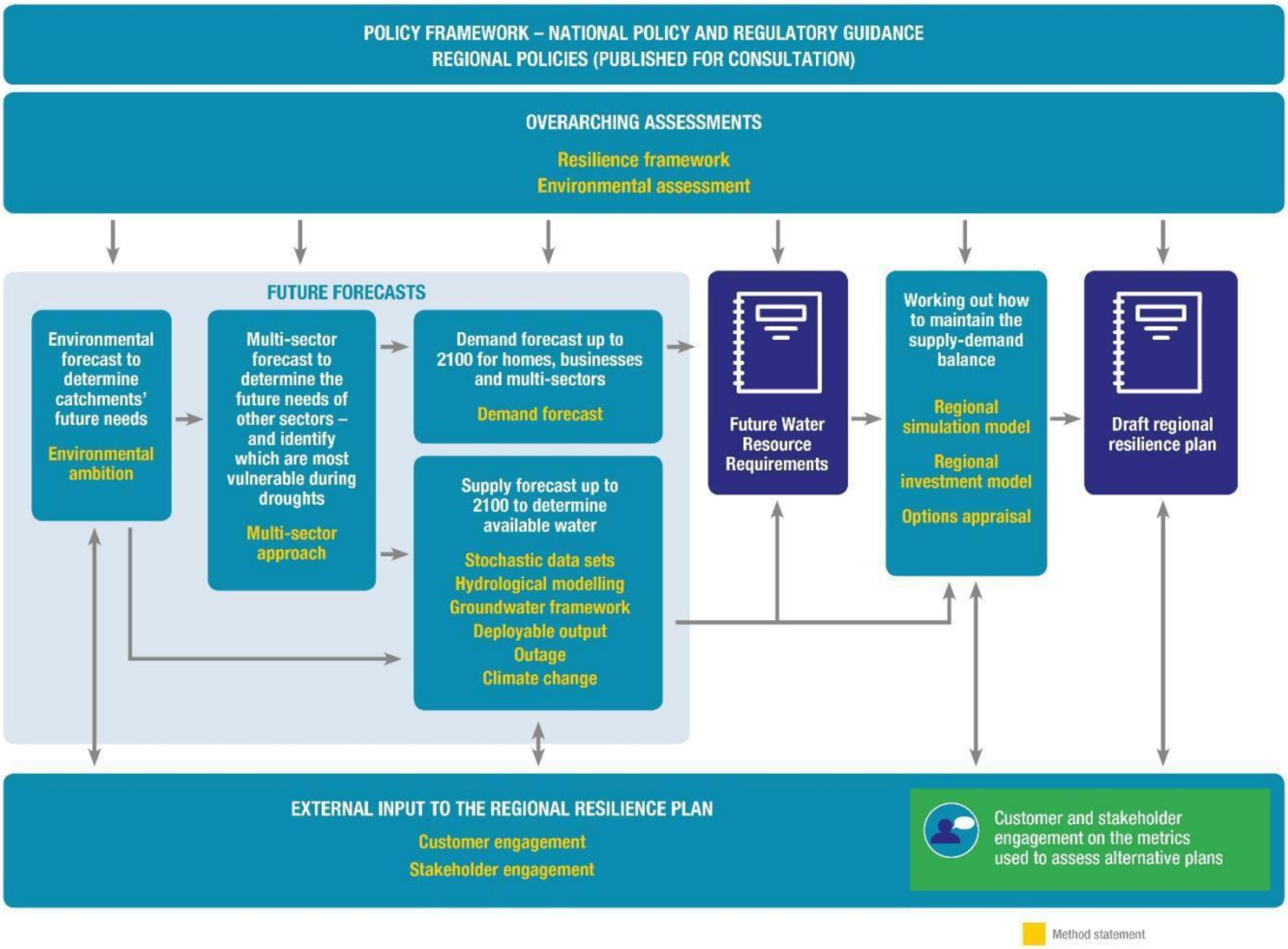
We have prepared method statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We are consulting on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this environmental assessment method statement will contribute to the preparation process for the regional resilience plan.

This method statement sets out the approach to how environmental impacts and benefits will be evaluated and used to inform an environmentally compliant and best value regional plan. The approach outlined within the method statement is also designed so it can be undertaken at the scale of the regional plan but then also applied to individual water company water resources management plans.

A separate method statement sets out how the regional plan will achieve environmental enhancements in the long term (our environmental ambition) for the benefit of everyone.

**Figure ES1: Overview of the method statements and their role in the development of the WRSE regional resilience plan**



# 1 Method Statement

## Background and purpose of statement

1.1 The Water Resources South East (WRSE) group is developing a regional resilience plan for the South East of England which will set out the long term water needs for the region and the interventions required to address these needs. The need for regional plans is set out in the Environment Agency's Water Resources National Framework which explores the long-term needs of all sectors that depend on a secure supply of water. We have produced a series of method statements to explain the approach we are taking to develop the regional plan.

1.2 This environmental assessment method statement describes the approach to be taken to assess environmental effects in the development of the Water Resources South East (WRSE) Regional Plan. The approach to environmental assessment is closely linked to two other environmental work streams in the WRSE work programme which are key to the development of the regional plan as shown in Figure 1 below – the environmental ambition and environmental engagement work streams - these are covered in more detail in a separate WRSE environmental ambition method statement.

## Development of methodology

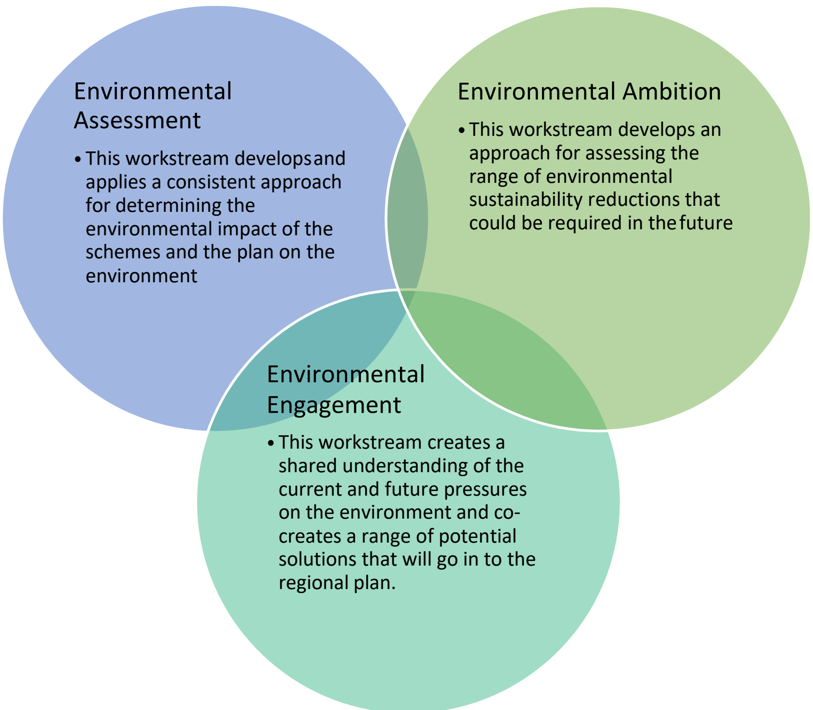
1.3 Previously environmental evaluation has predominantly been undertaken through the Strategic Environmental Assessment (SEA) process both at the level of individual water company water resources management plans (WRMPs) and through a combined and cumulative assessment undertaken on the regional plan. In addition Water Framework Directive (WFD) assessments and Habitats Regulation Assessments (HRA), where necessary, have been undertaken by water companies as part of their options appraisal and selection processes for their plans and to ensure compliance with environmental legislation.

1.4 It was recognised that the development of an integrated resilience plan for the South East to meet the requirements of the Environment Agency's Water Resources National Framework would need to be informed through a bespoke environmental assessment approach that identifies both environmental impacts and opportunities. Recent government and regulatory publications have made it clear that companies are expected to maximise the wider social and environmental values delivered through provision of their services and therefore the approach needs to identify the opportunities afforded in this area through different alternative strategies.

1.5 Initially a scoping study WRSE Environmental Appraisal Framework Scoping Report was commissioned by WRSE to review best practice in terms of understanding of SEA, Ecosystem Services and Natural Capital assessments in order to propose an initial environmental assessment framework. A review of available mechanisms for evaluating environmental and social value using literature searches was undertaken and in total 29 tools and approaches to environmental appraisal and valuation were reviewed. In addition, 13 organisations were interviewed to gather views on existing approaches and options for a newframework approach. The proposed framework was a step towards meeting stakeholder expectations, building on existing approaches but it presented challenges in terms of how it could be automated for the scale of assessment needed for the whole of the South East. Whilst the scoping study was being finalised in early 2020 new draft guidance emerged from the Environment Agency which also needed to be considered (see section 1.8 below).

1.6 It has become increasingly clear that an innovative and leading-edge environmental assessment approach is required given the emerging regulatory guidance and the significant water resources infrastructure that will be required to address the supply demand deficit in the region as set out in our publication [Future water resource requirements for South East England (March 2020)]. The approach needs to be applied at a regional level but should also be flexible enough to be implemented at a sub-regional level. This will involve providing a common source of readily accessible data that all water companies can use to support their planning. The focus of the current phase of works is to develop a consistent approach for environmental assessment which incorporates environmental valuation techniques such as Biodiversity Net Gain (BNG), Natural Capital (NC) and ecosystem services assessment. The aim is to apply this across WRSE water companies so that wider environmental and social impacts and benefits can be consistently accounted for across the regional options in determining a best value resilient regional plan. In addition, it will incorporate climate change resilience through modelling of options.

**Figure 1: WRSE environmental workstreams**




1.7 WRSE subsequently commissioned the development of a new integrated environmental appraisal process to provide a consistent framework for environmental assessments for WRMP24. The method outlined in the WRSE Regional Plan Environmental Assessment Methodology Guidance (June 2020) has been developed taking into account the new guidance from the Environment Agency and uses an integrated approach covering:

- Strategic Environmental Assessment (SEA)
- Habitats Regulations Assessment (HRA)
- Water Framework Directive (WFD) Assessment
- Natural Capital (NC) Assessment
- Biodiversity Net Gain (BNG)

1.8 The proposed environmental assessment process takes into account the following new and emerging guidance for water resources planning:

- Water Resources Planning Guideline (WRPG): Working version for WRMP24 (version 4.2) (Environment Agency, Natural Resources Wales, Ofwat)
- A Green Future: Our 25 Year Plan to Improve the Environment, DEFRA

1.9 A review of the environmental and natural capital elements of the new water resources planning guidance (section 1.8) and its alignment to the proposed environmental assessment approach for the WRSE Regional Plan has been undertaken and is presented in the Technical Note Review of Draft WRPG – Environmental and Natural Capital Review (May 2020).

1.10 A series of GIS tools for the environmental and ecosystem services assessments of the regional plan are being developed. The aim of these tools is to enable a more consistent and complex assessment of the individual options, improve the consistency between environmental assessment methods used by individual companies and provide a strong platform for WRSE to build on in the future. The GIS system will be designed around existing ESRI applications and software such as ARCGIS dashboard and ARC online. The GIS system development will focus on three specific areas:

a. Enabling the environmental assessment and associated valuation of a large number of options quickly and accurately to meet the programme requirement. This will also reduce the work needed by individual water companies when undertaking their own WRMP assessments.
b. The visualisation and analysis of individual option environmental impacts and the combined impact of the overall regional plan with the incorporation of climate change scenarios. This information will also inform the cumulative assessments of individual WRMP assessments.
c. Improved consistency across the individual assessment workstreams and between the water companies' environmental assessment techniques and provide environmental values that can be used when undertaking options appraisal. Thereby integrating the two processes.

1.11 The approach to the environmental assessment methodology is presented in Figure 2 and is aligned to the new draft guidance from the Environment Agency. The figure shows the key interactions between the environmental appraisal and the options decision-making and plan development as part of an integrated and iterative process.

1.12 It is anticipated that the environmental assessment methodology will be used as a framework for water companies when undertaking their WRMP24 statutory environmental appraisals. A large amount of the supporting information required for WRMP24 will be produced as part of the regional plan environmental assessments which will be available for use by the individual water companies. Figure 3 shows the interactions and information that will be available from the regional plan environmental assessment to support the water company WRMP24 development process. The approach aims to reduce the amount of work individual water companies need to undertake during WRMP24, streamline the environmental assessment process, and ensure consistency across water company environmental assessments. Further information is included within the roles and responsibilities section below.

# Summary of proposed methodology

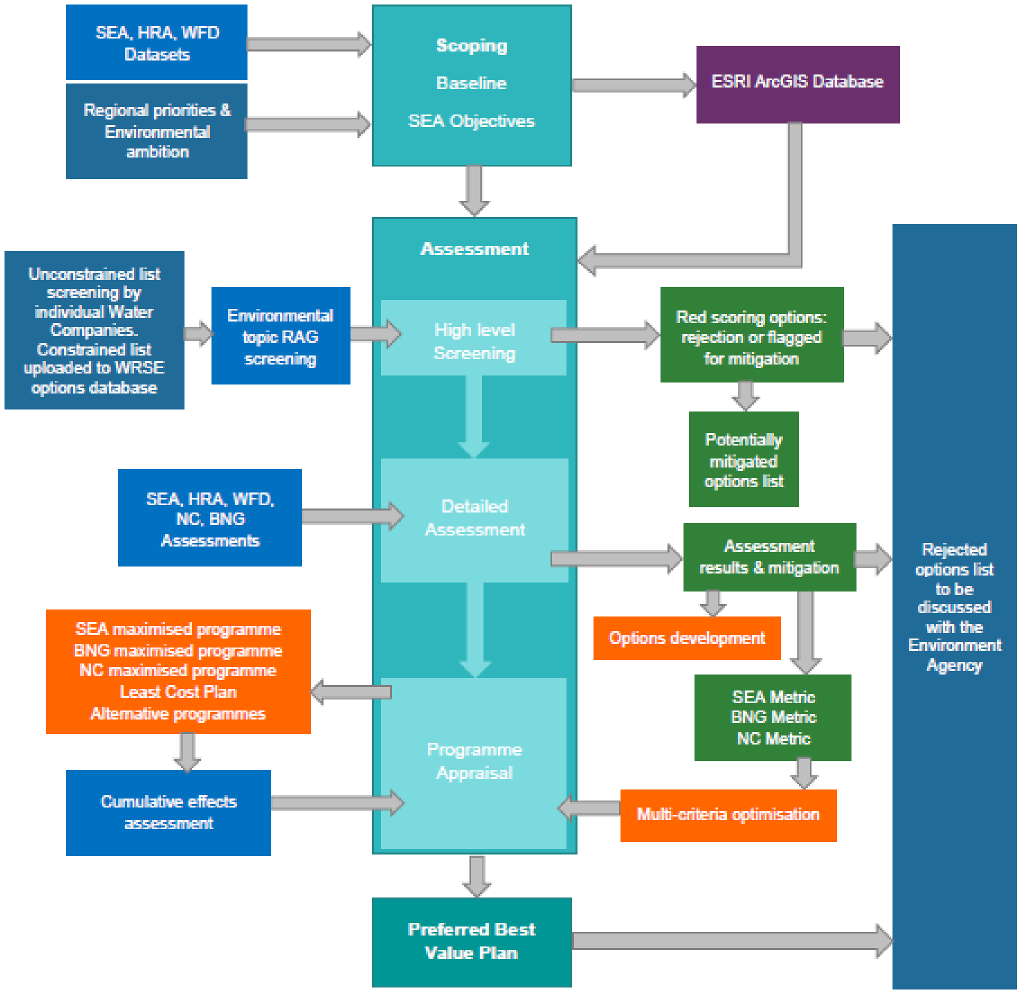
1.13 The WRSE Regional Plan Environmental Assessment Methodology Guidance sets out the approach in more detail and should be read in conjunction with this methodology statement. The aforementioned guidance sets out the process as three steps covered as separate chapters:

- Stage 1 – Scoping
- Stage 2 – Assessment
- Stage 3 – Reporting and consultation

These steps build upon the established statutory SEA process by incorporating HRA, WFD assessments, Natural Capital assessments and Biodiversity Net Gain, whilst ensuring the formal requirements for an SEA are also met.

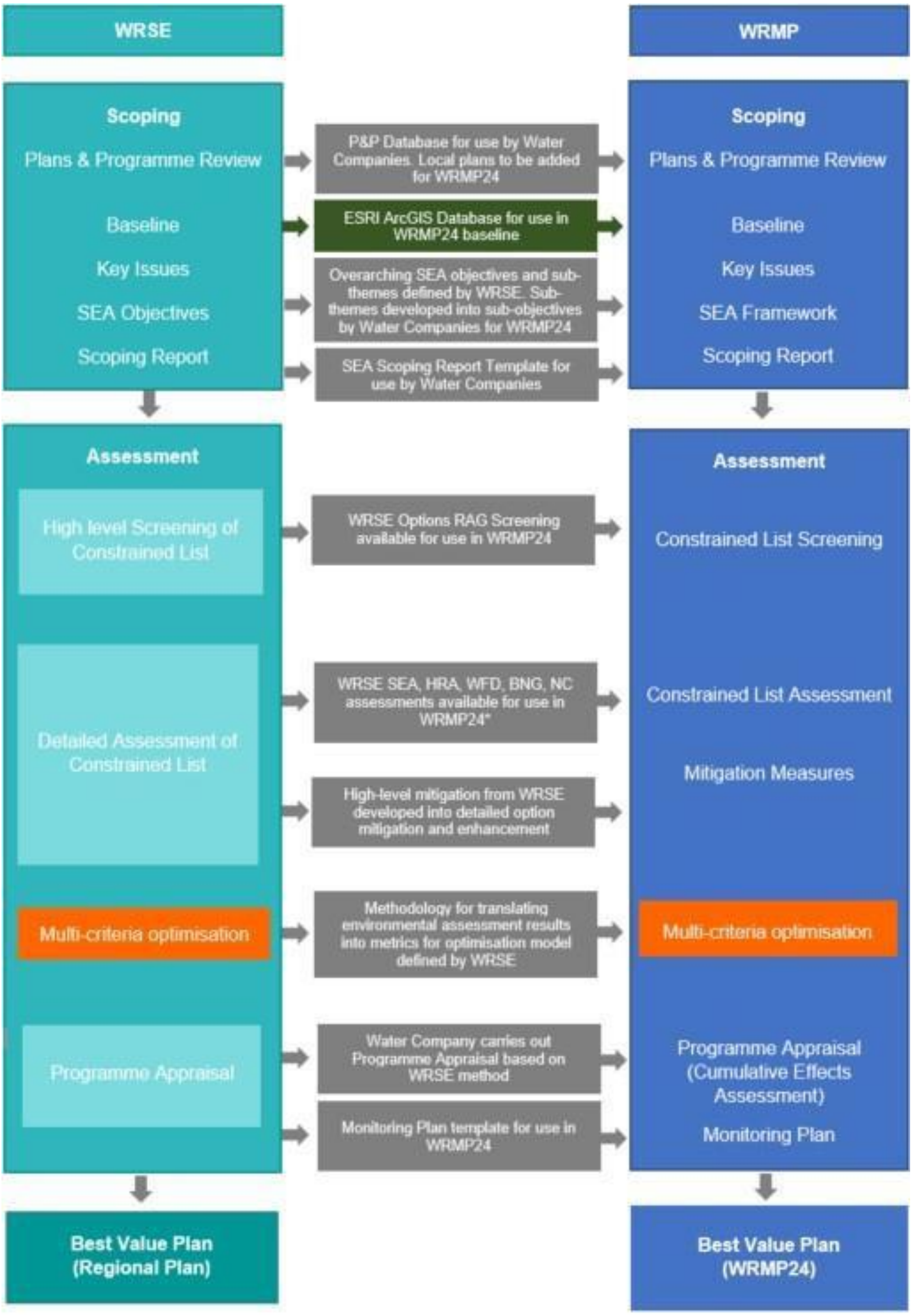
1.14 The scoping stage will include the review of all International, European, national, regional and local policies on the environment and sustainable development. The purpose of the plans and programme review is to ensure the WRSE environmental assessment supports wider environmental policy and objectives and legislation. A database of reviewed plans and legislation will be kept divided into policy level (e.g. International, national, local) and environmental topic (e.g. biodiversity, human health) and will be used primarily for WRSE however, it is anticipated that it could also be used by individual water companies for their WRMP24 SEA to streamline the plans and programme review process.

Figure 2: Environmental assessment approach




1.15 Stage 1 scoping will also include the collection of the baseline information that is required by Schedule 2 (2) of the SEA regulations. This will be captured in an environmental database, with the spatial information held in an ESRI ArcGIS Environmental Database. The environmental database will include data required for the SEA, HRA and WFD assessments and any other data files required for other aspects of the assessment. The database is being developed for WRSE for the Regional Plan, however, it is anticipated that individual water companies will be able to use the database for their WRMP24 assessments and add additional local level data if required.

## Figure 3 Relationship between WRSE and WRMP environmental appraisal processes




* Options would only need to be re-assessed by Water Companies if the option elements changed from those assessed as part of the regional plan, an unconstrained option was brought forward that wasn't on the regional plan constrained list, or additional local level baseline was included (this would only require re-assess of the relevant SEA objective)

1.16 The methodology recognises the importance of an evolving baseline without the implementation of the Regional Plan (as required by the SEA Directive and Regulations) and due to the long timescale of the Regional Plan period the baseline is likely to change, therefore, the future effects of the plan may change as well. One or two future time slices will be considered to cover the length of the plan period. These time slices will be agreed with WRSE and information such as climate projections and growth forecasts can be included to look at effects on the baseline.

1.17 It is proposed that an overarching set of SEA objectives are developed for WRSE. These will be linked to the SEA Directive topics and key priorities for WRSE and informed by the review of the six water companies' SEA objectives. These overarching objectives will be used to assess the WRSE regional plan using the environmental datasets. The overarching objectives could then be used as a framework for WRMP24 with sub-objectives chosen by each water company to reflect the issues and priorities in their areas.

1.18 A two-stage options assessment process is planned to comprise:

a. A high-level environmental screening assessment
b. Detailed assessment (including SEA, HRA, WFD, NC, BNG)

1.19 The high-level screening will be undertaken on the constrained list of options provided by the water companies. The purpose of the screening will be to act as a validation for the unconstrained list screening that water companies have undertaken to ensure environmentally damaging options are not considered further and to flag options with high environmental risk, that can still be considered, but where mitigation will be needed.

1.20 The detailed assessment will include the SEA, HRA, WFD, NC and BNG assessments. The SEA objectives on biodiversity, flora and fauna, and on water will be informed by the results of the HRA and WFD assessments, and an environmental metric covering all three will be developed to feed into options decision-making.

1.21 The detailed assessment will be carried out on the options uploaded by the water companies in September 2020. Details of embedded mitigation will be included in the upload details and the detailed assessment will be based on this information. The methodology recognises that not all options will be developed to include mitigation which could lead to biases when translating results into metrics. Therefore, following the detailed assessment, the mitigation identified will be fed back to water companies to review and update their options for the March 2021 upload period.

1.22 The WRSE Regional Plan Environmental Assessment Methodology Guidance explains how the multi-criteria optimisation approach set out in the new Environment Agency guidance reflects the proposed approach for WRSE, where the outcomes of the environmental assessments are translated into metrics to feed into the multi-criteria optimisation for options selection and the programme appraisal. The results of the assessments will be translated into the following metrics in line with the new Environment Agency guidance:

- SEA metrics – one for positive effects and one for negative effects
- BNG metric
- Natural Capital metric

There will also be a need to include latest Environment Agency guidance on chalk rivers and invasive species.

1.23 A proof of concept (PoC) assessment of the environmental assessment methodology has been undertaken on four different types of options to demonstrate its applicability. The WRSE Proof of Environmental Assessment Concept Overview Document (June 2020) report shows how each of the five environmental assessment approaches have been applied to the four options. The assessment has successfully demonstrated how the approach can be applied and has made some recommendations for improving the approach which are currently under review.

# Roles and responsibilities

1.24 The WRSE Programme Management Board (PMB) has nominated technical leads for each work stream which makes up the programme of work to develop the regional resilience plan. The PMB technical lead for the environmental aspects of the plan is responsible for ensuring the work stream delivers against the regional plan work programme. The PMB technical lead is also responsible for ensuring PMB is kept informed of progress through liaison with the programme manager (section 1.25) and the WRSE PMB environment subgroup (section 1.26).

1.25 A programme manager for the environment work stream has been appointed to manage the various tasks within the work stream and ensure it is integrated with other work streams within the overall regional plan work programme. The programme manager will liaise directly with suppliers who are delivering each task in the work stream.

1.26 A WRSE PMB environment subgroup has been formed to report to the WRSE PMB via the WRSE PMB environment technical lead (section 1.24). This subgroup consists of environmental specialists and managers in each water company and the Environment Agency to ensure environmental technical specialists are contributing their expertise to the development and application of the environmental assessment approach.

1.27 In order to support the environmental assessment aspects of the regional plan and their own water resources management plans, water companies will be responsible for:

a. Collection, analysis and presentation of locally relevant plans and programmes to supplement the WRSE plans and programmes database;
b. Collection, analysis and presentation of local baseline information to supplement the environmental datasets defined under the SEA topics;

c. Identify, develop and/or select local relevant assessment sub-objectives to provide a tailored assessment;

d. Complete a SEA Scoping Report for consultation on the scope of the SEA for the WRMP24;

e. Complete a separate HRA assessment of the WRMP24, as it will be the responsibility of the water company, as the plan author, to ensure Habitat Regulation requirements have been met, when publishing the final plan;

f. Complete a separate WFD assessment of the WRMP24, as it will be the responsibility of the water company, as the plan author, to ensure WFD requirements have been met, when publishing the final plan;

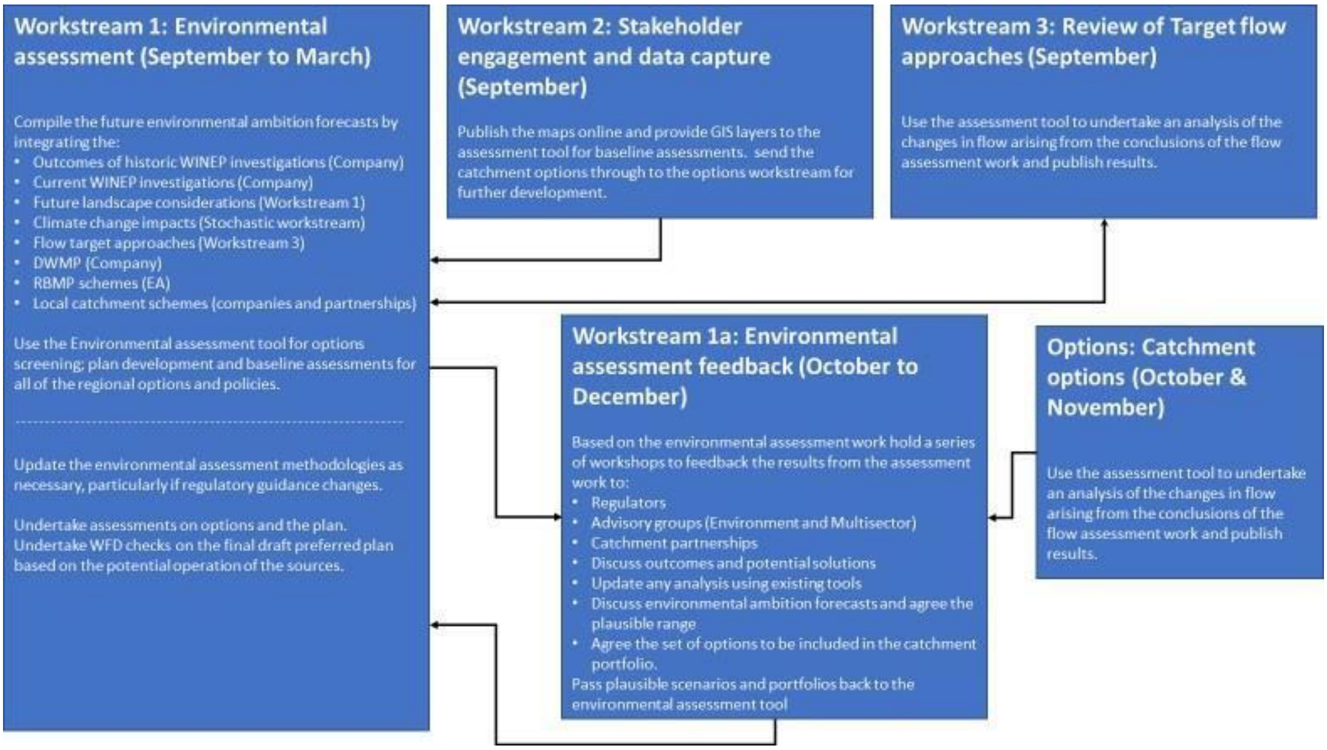
g. Complete a separate NCA of the WRMP24 options, in order to meet the requirements of the EA guidance.

# Timeline and outputs

1.28 The proposed key milestones in the environmental assessment approach are set out below and Figure 4 shows the interaction between key activities and outputs from each of the environment work streams.

- **Milestone 1:** End August 2020 – Submission of scoping report for consultation period.
- **Milestone 2:** End of 2020 - Options full environmental assessments completed and option metrics ready for upload to investment model for the test run in January 2021. Mitigation from assessments fed back to water companies.
- **Milestone 3:** March 2021 – Second upload of options information by water companies. Review of assessment scoring and translation of results into final metrics for the investment model.
- **Milestone 4:** April – July 2021 – Programme appraisal. This is dependent on the timing of the outputs of the investment model. The programmes of options from the investment model will be needed to undertake the environmental programme appraisal. Following this the chosen best value plan will undergo assessment.
- **Milestone 5:** November 2021 - Environmental Report submission for consultation period
- **Milestone 6:** June 2022 – Finalise Environmental Report
- **Milestone 7:** August 2022 - SEA Post-Adoption Statement

Figure 4: Environmental workstreams – activities and outputs



# 2 Summary

2.1 This method statement describes the approach to be taken to assess environmental effects in the development of the regional plan. The approach to environmental assessment is closely linked to two other environmental work streams in the WRSE work programme which are key to the development of the regional plan – the environmental ambition and environmental engagement work streams.

2.2 The approach outlined in this method statement has been developed to meet the specific requirements of emerging guidance for WRMP24 and to ensure that a consistent approach can be applied at the scale of the regional plan as well as individual company WRMPs. This method statement summarises the WRSE Regional Plan Environmental Assessment Methodology Guidance (June 2020) which takes into account the new guidance from the Environment Agency and uses an integrated approach covering Strategic Environmental Assessment (SEA), Habitats Regulations Assessment (HRA), Water Framework Directive (WFD) Assessment, Natural Capital (NC) Assessment and Biodiversity Net Gain (BNG).

2.3 This method statement should be read in conjunction with the WRSE environmental ambition method statement which considers the long term aims for enhancing the environment and the WRSE options appraisal method statement given the important role of environmental assessment on options appraisal and the selection of a best value resilience plan.

# 3 Next steps

3.1 We are consulting on this method statement from 1st August 2020 to 30th October 2020. Details of how you can make comments can be found here – (consultation website).

3.2 We will take into account the comments we receive during this consultation process, in updating the Method Statement. Alongside this, the Environment Agency will shortly be publishing its Water Resource Planning Guidelines (WRPG) on the preparation of regional resilience plans. We may need to update parts of our method statements in response to the WRPG. We have included a checklist in Appendix 1 of this method statement which we will use to check that our proposed methods are in line with guidance where applicable.

3.3 If any other relevant guidance notes or policies are issued then we will review the relevant method statement(s) and see if they need to be updated.

3.4 When we have finalised our Method Statement, we will ensure that we explain any changes wehave made and publish an updated Method Statement on our website.

# Appendix 1 Checklist of consistency with the Environment Agency WRMP24 Checklist

The Environment Agency published its WRPG on XXXXXX 2020, including the WRMP24 Checklist. The following table identifies the relevant parts of the checklist relating to this Method Statement, and provides WRSE's assessment of its consistency with the requirements in the Checklist.

| No. | Action or approach | Method Statement ref: | WRSE assessment of consistency |
|---|---|---|---|
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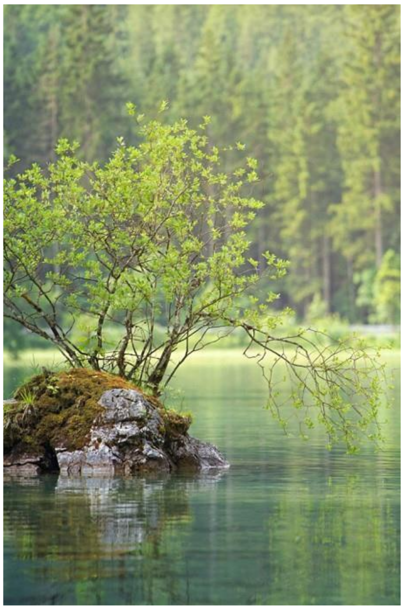

# Method Statement: Environmental Assessment

## Post-consultation version

## November 2021

| Title | Method Statement: Environmental Assessment |
|---|---|
| Last updated | October 2021 |
| Version | Version 2.0 October 2021 – post-consultation version |
| History of Changes made to this version | 28 July 2020 – v1.0 updated to take account of comments from:<br>• Environment Agency (Sarah Wardell)<br>• Portsmouth Water (Wood via Liz Coulson)<br>• South East Water (Emma Goddard via Andrew Halliday)<br>• Thames Water (Yvette de Garis)<br>October 2021 – v2.0 updated to take account of consultation comments from:<br>• River Thames Society<br>• Cotswold Canals Trust (Ken Burgin)<br>• Water Level (Malcom Jeffery)<br>• Roger Turnbull (East Hen Parish Council)<br>• Planning Policy Waverley<br>• Benjamin Williams (RWE)<br>• GARD<br>• Historic England<br>• Environment Agency<br>• Oxfordshire County Council<br>• Vale of White Horse district Council<br>• Ofwat |
| Author | Nick Price, Jacqueline Fookes |
| Approved by | Meyrick Gough, Sarah Green |
| WRSE Director Approval | Meyrick Gough |

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For the full library of WRSE Method Statements, please visit www.wrse.org.uk/library

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

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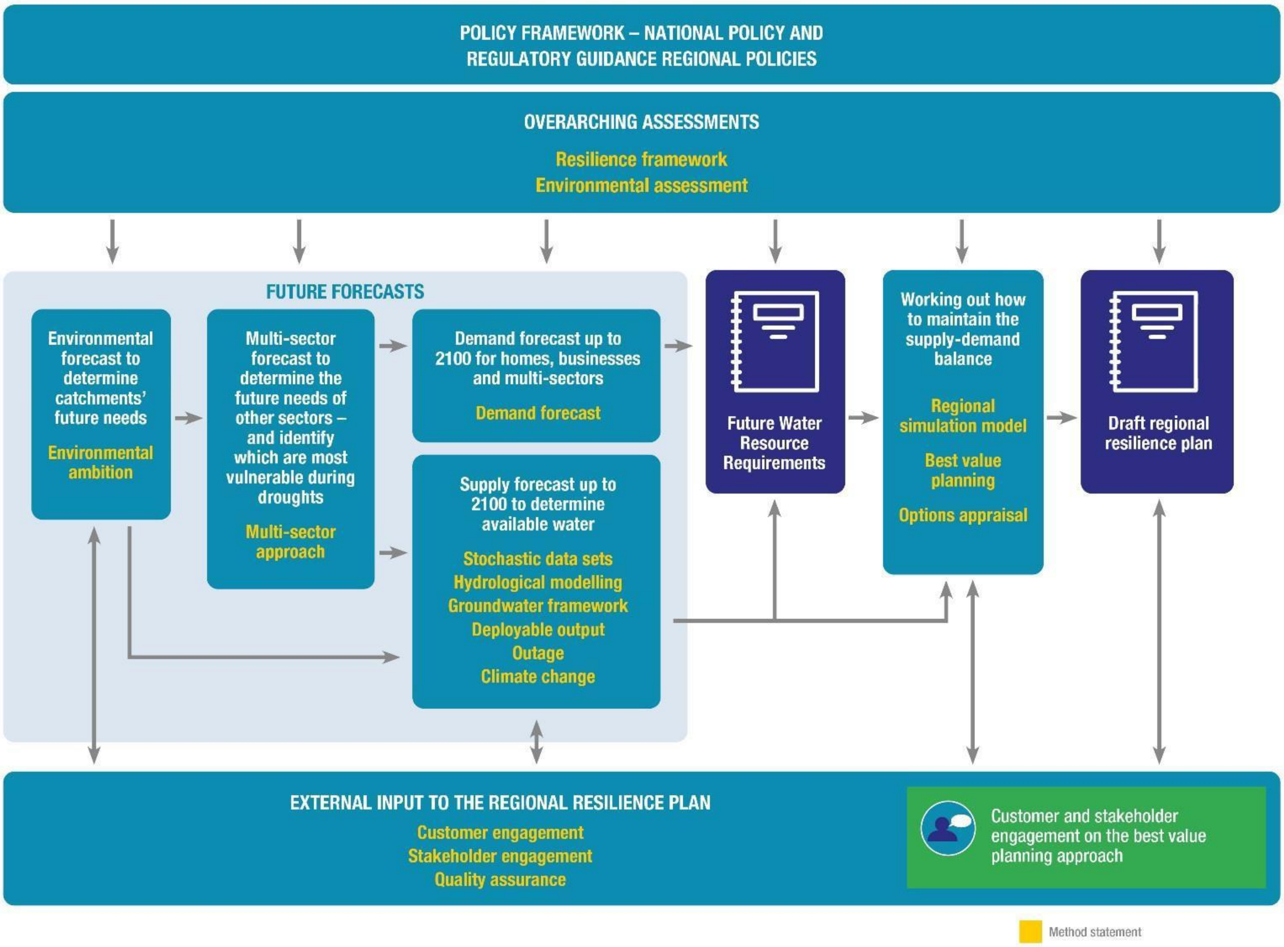
A separate Method Statement sets out how the regional plan will achieve environmental enhancements in the long term (our environmental ambition incorporating environmental destination scenarios) for the benefit of everyone.

A separate environmental scoping report for the Strategic Environmental Assessment has been produced and consulted upon. This provides in detail the processes that will be undertaken during the assessment period. The Scoping Report (consultation version) is available at the WRSE website document library.

**Figure ES1: Overview of the Method Statements and their role in the development of the WRSE regional resilience plan**



# 1 Method Statement

## Background and purpose of statement

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Figure 1: WRSE environmental workstreams

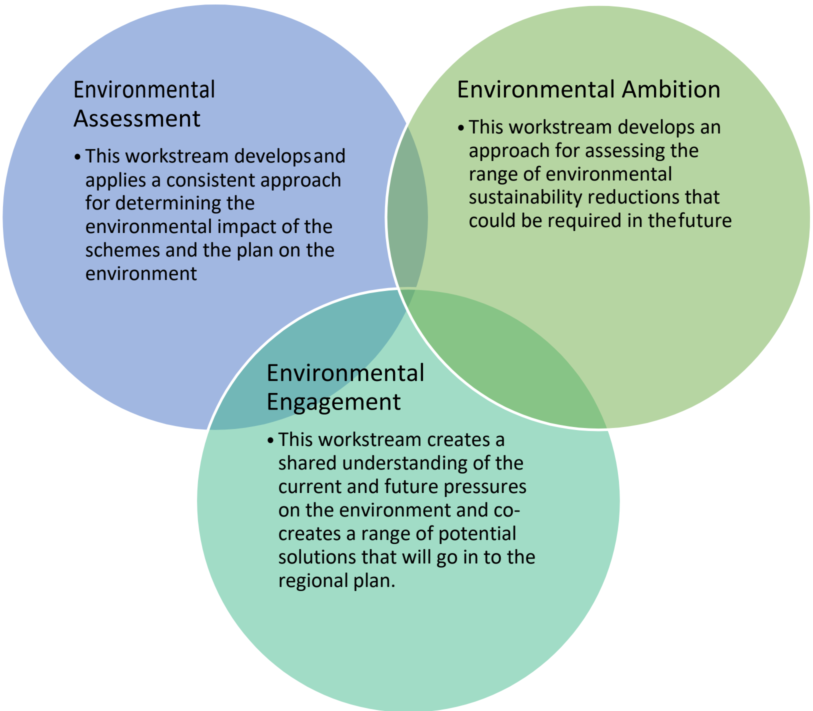

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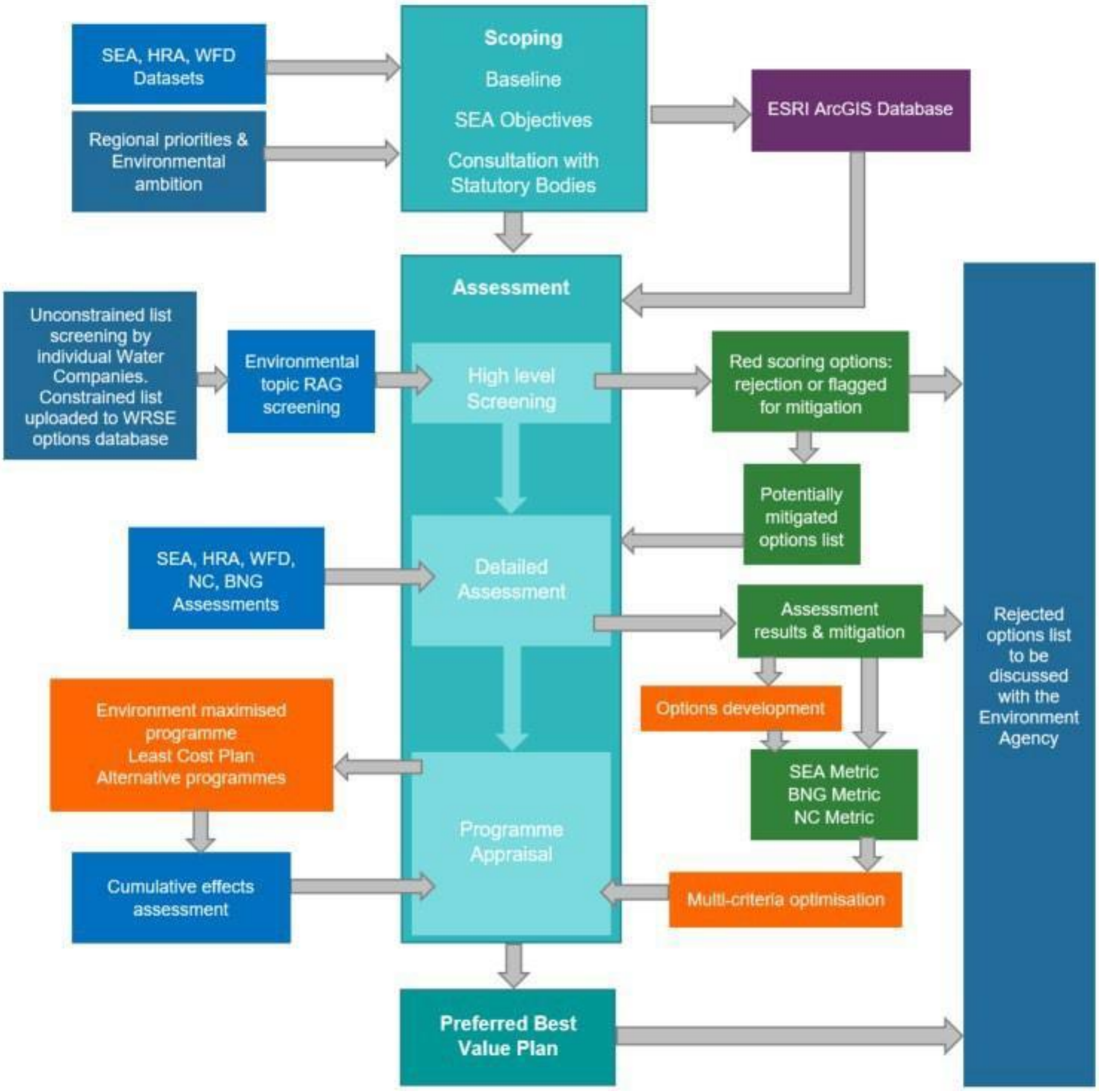
Figure 2: Environmental assessment approach

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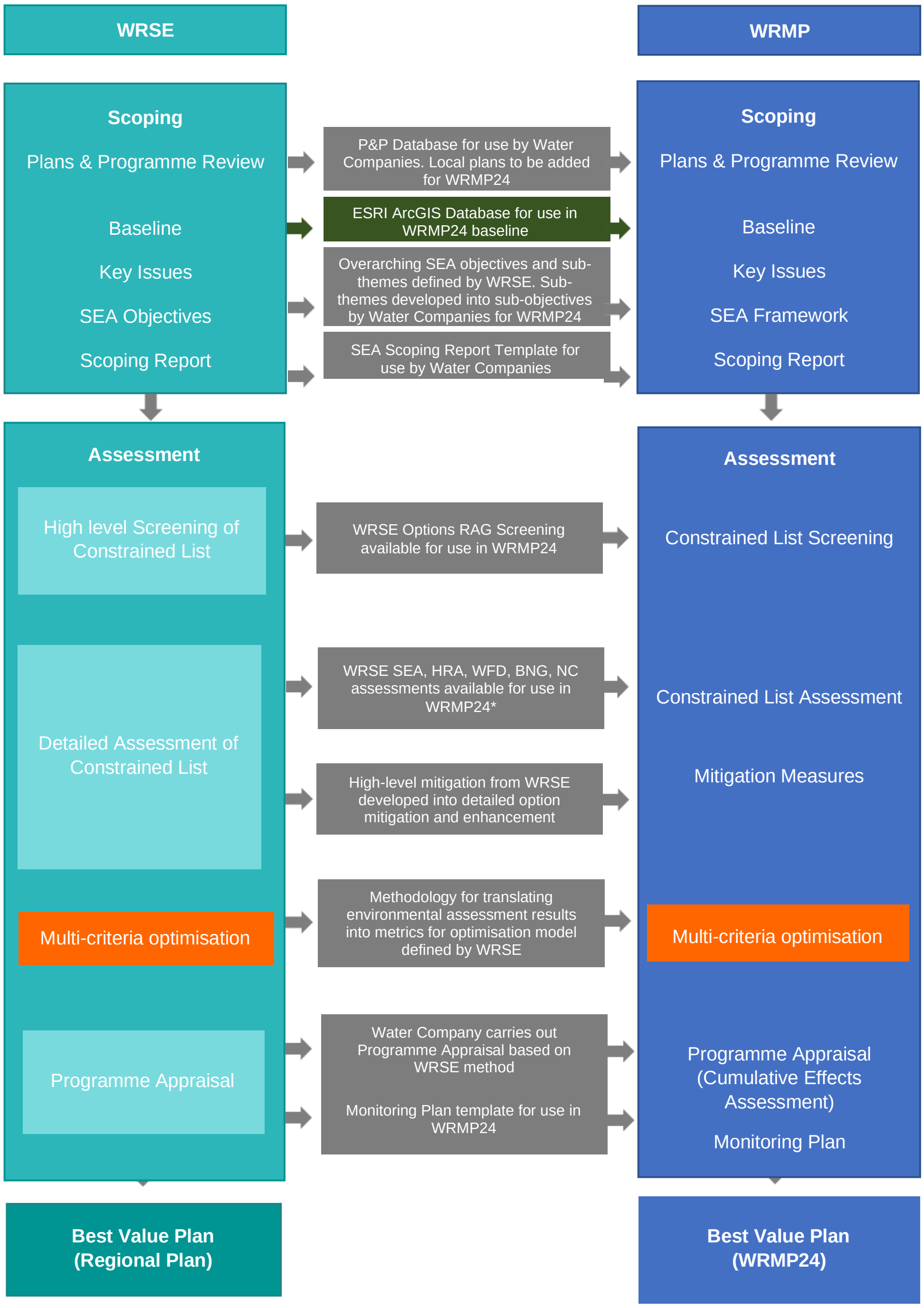
## Figure 3 Relationship between WRSE and WRMP environmental appraisal processes

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- Stage 3 – Reporting and consultation

1.14 These steps build upon the established statutory SEA process by incorporating HRA, WFD assessments, Natural Capital assessments and Biodiversity Net Gain, whilst ensuring the formal requirements for an SEA are also met.

1.15 The scoping stage will include the review of all International, European, national, regional and local policies on the environment and sustainable development. The purpose of the plans and programme review is to ensure the WRSE environmental assessment supports wider environmental policy and objectives and legislation. A database of reviewed plans and legislation will be kept divided into policy level (e.g. International, national, local) and environmental topic (e.g. biodiversity, human health) and will be used primarily for WRSE however, it is anticipated that it could also be used by individual water companies for their WRMP24 SEA to streamline the plans and programme review process.

1.16 It is proposed to include the following themes for assessment of the regional plan within the SEA. The main themes, messages and objectives from the policies, plans and programmes review that are considered relevant to the WRSE regional plan are presented below. These are as follows:

- Conserve flora and fauna and their habitats
- Conservation and wise use of wetlands and their resources
- Protection of Habitat Sites
- Halt overall biodiversity loss
- Protection of landscape character and quality
- Improve water quality as set out in the Water Framework Directive
- Prevent or limit inputs of pollutants into groundwater and surface water
- Promote efficient use of water
- Reduce and manage the risks of flooding
- Reduce greenhouse gas emissions
- Adapt to the impacts of climate change
- Increase resource efficiency and reduce natural resource use and waste
- Promote social inclusion and community participation
- Protect cultural heritage assets including archaeology and built heritage
- Protect best quality soils and agricultural land

- Make space for water and wildlife along rivers and around wetlands
- Restore natural processes in river catchments, including in ways that support climate change adaptation and mitigation

1.17 In addition, the regional plan will support the UK Government's 25 Year Plan to Improve the Environment by:

- Using and managing land sustainably – including embedding a "biodiversity net gain" principle into development (as supported by the draft Environment Bill 26/05/2021).
- Recovering nature and enhancing the beauty of landscapes
- Connecting people to the environment to improve health and wellbeing
- Increase resource efficiency and reducing pollution
- Securing clean, healthy and productive and biologically diverse seas and oceans
- Protecting and improving the global environment

1.18 The themes and messages will be incorporated into SEA objectives which will provide an input into the process of identifying key issues and opportunities and for developing the SEA framework which will support development of the regional plan.

1.19 The scoping stage also includes the collection of baseline information that is required by Schedule 2 (2) of the SEA regulations. This is captured in an environmental database, with the spatial information held in an ESRI ArcGIS Environmental Database. The environmental database includes data required for the SEA, HRA and WFD assessments and any other data files required for other aspects of the assessment. The database is being developed for WRSE for the regional plan, however, it is anticipated that individual water companies will be able to use the database for their WRMP24 assessments and add additional local level data if required. A table showing the environmental datasets and their sources are provided in the WRSE Environmental Assessment Methodology Guidance and were downloaded in September 2020 for use in the assessment process.

1.20 The methodology recognises the importance of an evolving baseline without the implementation of the Regional Plan (as required by the SEA Directive and Regulations) and due to the long timescale of the Regional Plan period the baseline is likely to change, therefore, the future effects of the plan may change as well. One or two future time slices will be considered to cover the length of the plan period. These time slices will be agreed with WRSE and information such as climate projections and growth forecasts can be included to look at effects on the baseline.

1.21 It is proposed that an overarching set of SEA objectives are developed for WRSE. These will be linked to the SEA Directive topics and key priorities for WRSE and informed by the review of the six water companies' SEA objectives. These overarching objectives will be used to assess the WRSE regional plan using the environmental datasets. The overarching objectives could then be used as a framework for WRMP24 with sub-objectives chosen by each water company to reflect the issues and priorities in their areas.

1.22 The assessment will include the SEA, HRA, WFD, NC and BNG assessments. The SEA objectives on biodiversity, flora and fauna, and on water will be informed by the results of the HRA and WFD assessments, and an environmental metric covering all three will be developed to feed into options appraisal.

1.23 The assessment will be carried out on the options uploaded by the water companies in December 2020. Details of embedded mitigation will be included in the upload details and the detailed assessment will be based on this information. The methodology recognises that not all options will be developed to include mitigation which could lead to biases when translating results into metrics. Therefore, following the detailed assessment, the mitigation identified will be fed back to water companies to review and update their options for the March 2021 upload period.

1.24 The WRSE Regional Plan Environmental Assessment Methodology Guidance explains how the multi-criteria optimisation approach set out in the new Environment Agency guidance reflects the proposed approach for WRSE, where the outcomes of the environmental assessments are translated into metrics to feed into the multi-criteria optimisation for options selection and the programme appraisal. The results of the assessments will be translated into the metrics in line with the new Environment Agency guidance:

1.25 To generate the SEA metrics for each option, one for positive environmental effects and one for negative environmental effects, the assessment will include the effects generated by each potential option on the SEA Objectives (as developed during the scoping process and set out in the WRSE SEA Scoping Report):

- Biodiversity, Flora, Fauna: Protect and enhance biodiversity, priority species, vulnerable habitats and habitat connectivity (no loss and improve connectivity where possible), impacts on chalk rivers and the risk of the spread of invasive non-native species.
- Soil: Protect and enhance the functionality, quantity and quality of soils.
- Water: i) Increase resilience and reduce flood risk, ii) protect and enhance the quality of the water environment and iii) water resources and deliver reliable and resilient water supplies.
- Air: Reduce and minimise air emissions.
- Climate Factors: i) Reduce embodied and operational carbon emissions, and ii) reduce vulnerability to climate change risks and hazards.
- Landscape: Conserve, protect and enhance landscape, townscape and seascape character and visual amenity.
- Historic Environment: Conserve, protect and enhance the historic environment, including archaeology.
- Population and Human Health: i) Maintain and enhance the health and wellbeing of the local community, including economic and social wellbeing, and ii) maintain and enhance tourism and recreation.
- Material Assets: i) Minimise resource use and waste production, and ii) avoid negative effects on built assets and infrastructure.

1.26 The SEA metrics will include the results of the HRA and WFD assessments and have both positive and negative scores associated with an option. In addition, a score will be generated for biodiversity net gain (BNG) or required replacement which will be a percentage of habitat lost. The natural capital metric will be a monetised value.

1.27 Natural capital metrics will be generated using DEFRA, (2020) Enabling a Natural Capital Approach. The ecosystem services scoped in are those proposed by the current WRMP guidance the addition of recreation and amenity and food production, to assess the impact on natural capital, they include:

- Carbon sequestration (Climate regulation)
- Natural Hazard management
- Water purification * Quantitative
- Water Regulation
- Biodiversity and Habitats * Biodiversity net gain.
- Air pollutant removal
- Recreation & amenity value
- Food production

1.28 Biodiversity & Habitats will be assessed separately using a quantitative methodology (Defra 2.0). The provision of public water supply has been excluded from all assessments to avoid potential double accounting of benefits within the multi-criteria optimisation. The value of leaving the water in the environment and the benefit this will provide to biodiversity, and other current and future abstractors, will be assessed through the WRSE environmental ambition work package.

1.29 During the assessment process when metrics are being generated there will be continuous review by water companies to ensure the assessments reflect the current understanding of the option and the associated environmental sensitivities.

1.30 The Regional Plan SEA will include proposed mitigation and will develop a programme of monitoring of significant environmental effects of the plan's implementation with the purpose of identifying unforeseen adverse effects at an early stage and being able to undertake appropriate remedial action. In accordance with the SEA Regulations monitoring arrangements may comprise or include arrangements established for other purposes. This is of particular relevance to water reuse schemes where water quality and quantity is a key component to the maintenance of healthy ecosystems. The effectiveness of options where mitigation is key to their adoption in the regional plan would also be candidates for a monitoring regime.

1.31 A proof of concept (PoC) assessment of the environmental assessment methodology has been undertaken on four different types of options to demonstrate its applicability. The WRSE Proof of Environmental Assessment Concept Overview Document (June 2020, not yet in the public domain) shows how each of the five environmental assessment approaches have been applied to the four options. The assessment has successfully demonstrated how the approach can be applied and has made some recommendations for improving the approach which have been taken into account.

1.32 Stakeholder engagement is a key part of the environmental assessment process. The WRSE Project Management Board (PMB) has an environment sub-group where consultation with water company specialists and appropriate statutory bodies is undertaken. Further details can be found in **Method Statement 1327 WRSE Stakeholder Engagement**.

## Roles and responsibilities

1.33 The WRSE PMB has nominated technical leads for each work stream which makes up the programme of work to develop the regional resilience plan. The PMB technical lead for the environmental aspects of the plan is responsible for ensuring the work stream delivers against the regional plan work programme. The PMB technical lead is also responsible for ensuring PMB is kept informed of progress through liaison with the programme manager and the WRSE PMB environment sub-group.

1.34 A programme manager for the environment work stream has been appointed to manage the various tasks within the workstream and ensure it is integrated with other workstreams within the overall regional plan programme. The programme manager will liaise directly with suppliers who are delivering each task in the workstream.

1.35 A WRSE PMB environment sub-group has been formed to report to the WRSE PMB via the WRSE PMB environment technical lead. This sub-group consists of environmental specialists and managers in each water company and the Environment Agency to ensure environmental technical specialists are contributing their expertise to the development and application of the environmental assessment approach.

1.36 In order to support the environmental assessment aspects of the regional plan and their own WRMPs, water companies will be responsible for:

a. Collection, analysis and presentation of locally relevant plans and programmes to supplement the WRSE plans and programmes database.
b. Collection, analysis and presentation of local baseline information to supplement the environmental datasets defined under the SEA topics.
c. Identification, development and/or selection of local relevant assessment sub-objectives to provide a tailored assessment.
d. Completion of an SEA for WRMP24.
e. Completion of a separate HRA assessment for WRMP24, as it will be the responsibility of the water company, as the plan author, to ensure Habitat Regulation requirements have been met, when publishing the final plan.
f. Completion of a separate WFD assessment for WRMP24, as it will be the responsibility of the water company, as the plan author, to ensure WFD requirements have been met, when publishing the final plan.
g. Completion of a separate NCA of the WRMP24 options, in order to meet the requirements of the EA guidance.

# Timeline and outputs

1.37 The proposed key milestones in the environmental assessment approach are set out below.

- **Milestone 1:** End August 2020 – Submission of Scoping Report for consultation period.
- **Milestone 2:** End of 2020 - Options full environmental assessments completed and option metrics ready for upload to investment model for the test run in January 2021. Mitigation from assessments fed back to water companies.
- **Milestone 3:** March 2021 – Second upload of options information by water companies. Review of assessment scoring and translation of results into final metrics for the investment model.
- **Milestone 4:** April – July 2021 – Programme appraisal. This is dependent on the timing of the outputs of the investment model. The programmes of options from the investment model will be needed to undertake the environmental programme appraisal. Following this the chosen best value plan will undergo assessment.
- **Milestone 5:** December 2021 - Environmental Report submission for consultation period.
- **Milestone 6:** April 2022 – Finalise Environmental Report.
- **Milestone 7:** August 2023 - SEA Post-Adoption Statement.

# 2 Summary

2.1 This Method Statement describes the approach to be taken to assess environmental effects in the development of the regional plan. The approach to environmental assessment is closely linked to two other environmental workstreams in the WRSE work programme which are key to the development of the regional plan – the environmental ambition and environmental engagement workstreams.

2.2 The approach outlined in this Method Statement has been developed to meet the specific requirements of new guidance for WRMP24 and to ensure that a consistent approach can be applied at the scale of the regional plan as well as individual company WRMPs. This Method Statement summarises the WRSE Regional Plan Environmental Assessment Methodology Guidance (June 2020) which takes into account the new guidance from the Environment Agency and uses an integrated approach covering Strategic Environmental Assessment (SEA), Habitats Regulations Assessment (HRA), Water Framework Directive (WFD) Assessment, Natural Capital (NC) Assessment and Biodiversity Net Gain (BNG).

2.3 This Method Statement should be read in conjunction with **Method Statement 1333 WRSE Environmental Ambition** which considers the long term aims for enhancing the environment, and **Method Statement 1328 WRSE Options Appraisal** and **Method Statement 1318 WRSE Best Value Planning** given the important role of environmental assessment on options appraisal and the selection of a best value resilience plan.

2.4 As we continue to develop the regional plan we might revise the approach in order to respond to updated regulatory guidance.

# 3 Next steps

3.1 An initial version of this document was consulted upon between 1st August 2020 to 30th October 2020 and comments received during this time have been incorporated in this version.

3.2 We have also reviewed this document against the final WRPG and supplementary guidance notes issued by the regulators.

3.3 If any other further relevant guidance notes or policies are issued, then we will review this Method Statement to see if it needs to be updated.

3.4 When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

# Method Statement: Options Appraisal

## Updated version

## November 2022

| Title | Method Statement: Options Appraisal |
| --- | --- |
| **Last updated** | November 2022 |
| **Version** | Updated version – post consultation |
| **History of Changes made to this version** | 1.0 Draft 1.1 (June 2020) *internal comments*<br>2.0 Draft 1.2ii (July 2020)<br>3.0 Update (2021) this document incorporating external feedback following on from consultation and updated WRPG<br>4.0 Minor updates for draft regional plan |
| ***Summary of areas where substantive changes have been made as a result of consultation feedback*** | See paragraph 4.2 |
| ***Summary of areas where substantive changes have been made as a result of the revised Water Resource Planning Guidelines (WRPG)*** | None |
| **Author** | Nick Honeyball, Bill Hume-Smith |
| **Approved by** | Sarah Green, Meyrick Gough |
| **WRSE Director Approval** | Meyrick Gough |


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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

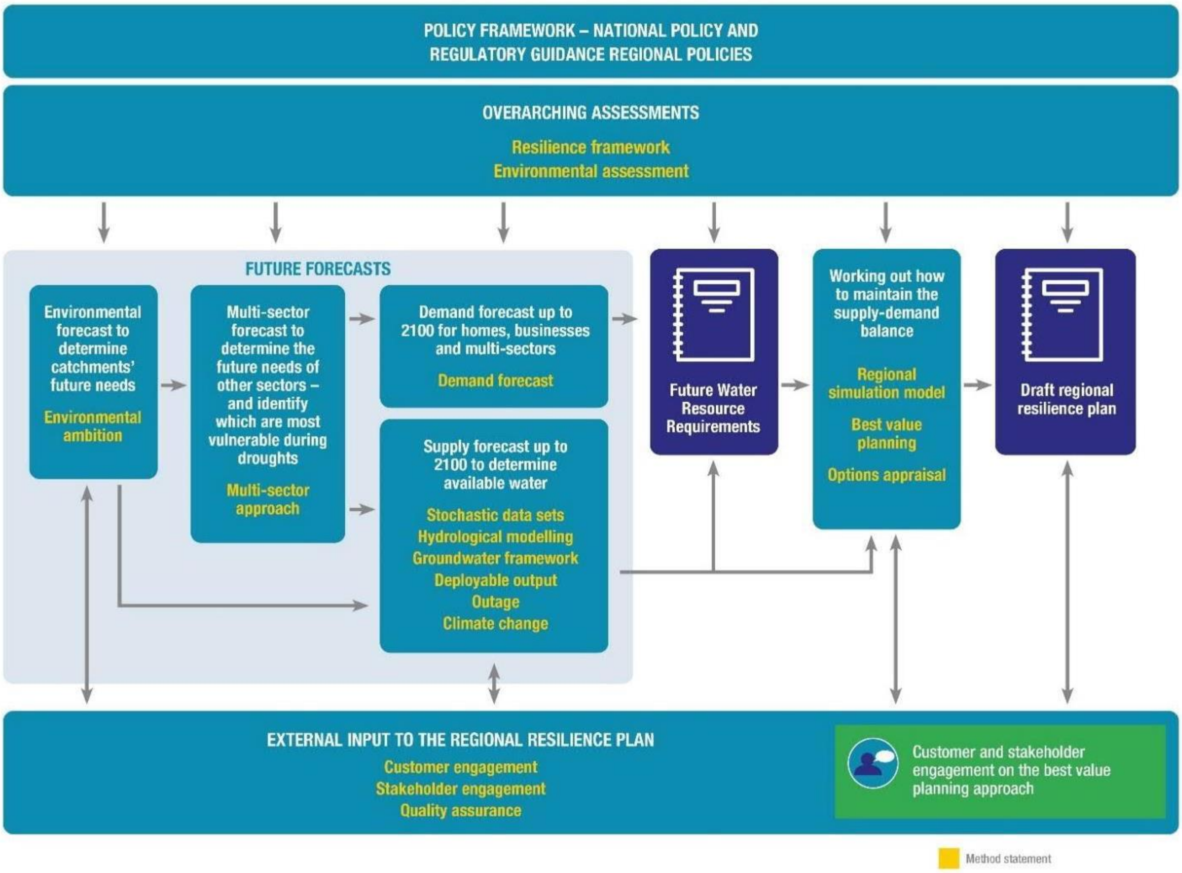
# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

We have prepared method statements setting out the processes and procedures for preparing all the technical elements of our regional resilience plan. We consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

This method statement covers the regional options appraisal and Figure ES1 illustrates how this contributes to the preparation process for the regional resilience plan.

**Figure ES1: Overview of the Method Statements and their role in the development of the plan**



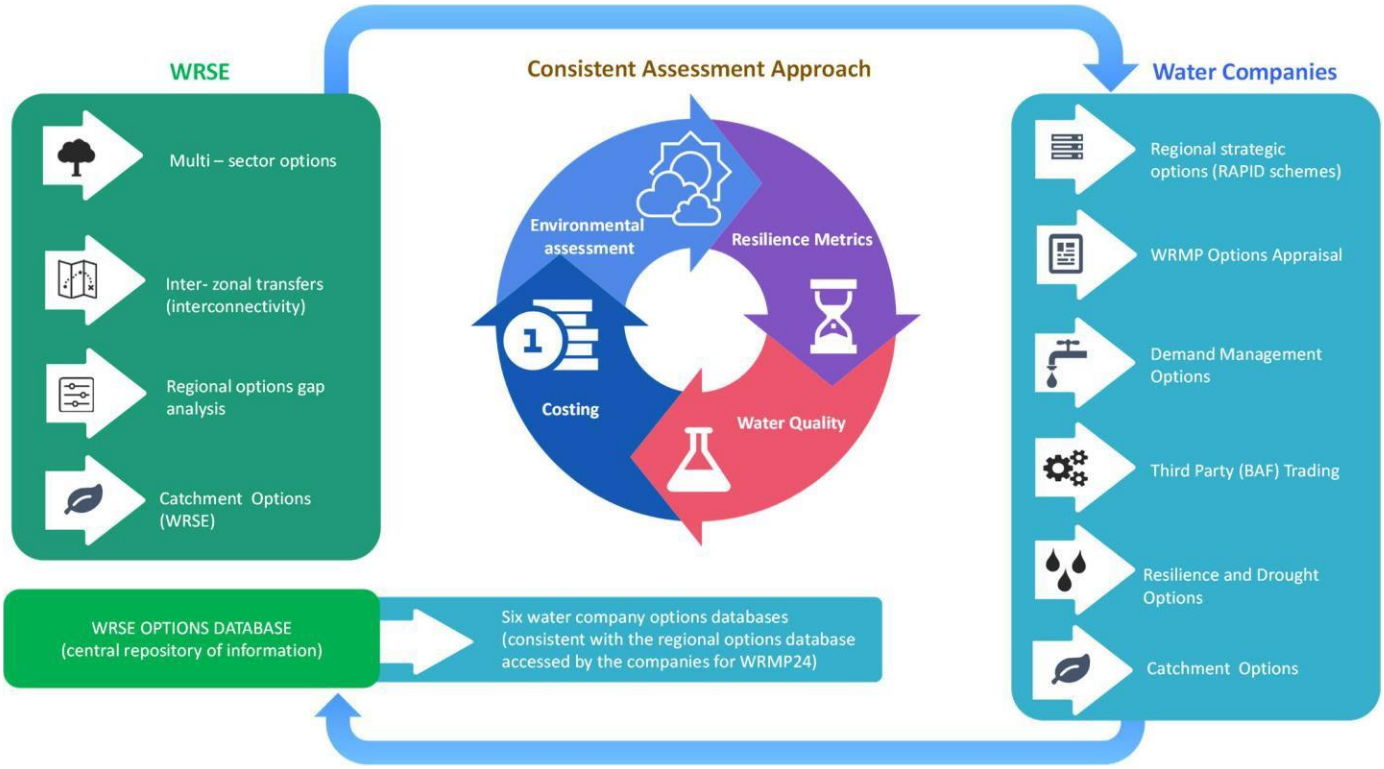
The aim of the options appraisal task is to identify the feasible set of options that will be available for selection to address the future water needs as part of the best value planning process and to improve consistency of option information.

The options information provides the evidence on which we will have to make decisions about which options to include in our regional resilience plan – and what investment to be included in company Water Resources Management Plans (WRMPs) and business plans.

This method statement provides:

- A clear explanation of the background, objectives and components of the options appraisal;
- A high-level outline is provided of how the regional level and WRMP level options assessments inform each other so that they are based on common and consistent information and this is illustrated in an overall process diagram (Figure ES.2); and
- The option types being considered along with the option information being collated to enable the assessment of the options.

**Figure ES.2 WRSE Integrated options appraisal methodology**



# 1 Introduction

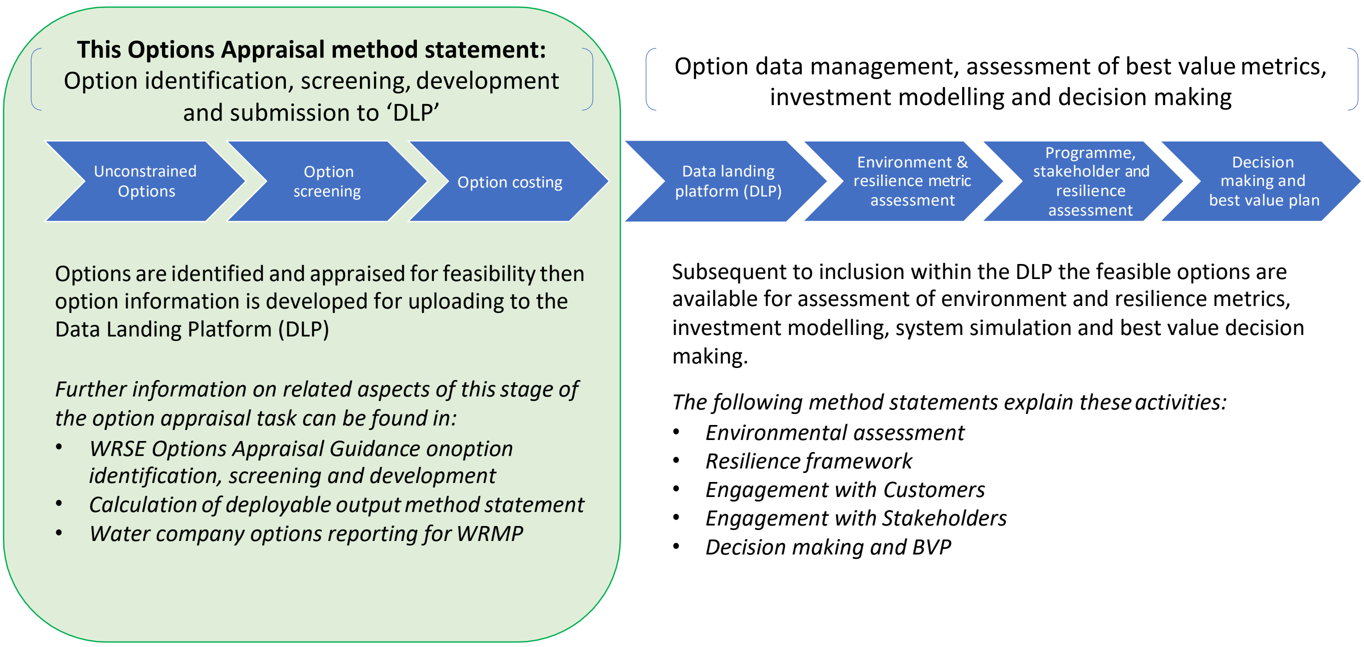
## Overview

1.1 In February 2020 Water Resources South East (WRSE) published its initial Future Water Resource Requirements for South East England, based on the six member companies' WRMP19. In February 2021 WRSE published an update to this and a further summary was published in September 2021, setting out the projected planning challenge that the regional plan will need to meet.

1.2 Ahead of the development of the draft regional plan, WRSE has carried out an appraisal of the water resource options that could be used to address the future deficits in water supplies. This has included existing options and new options which have been identified through WRSE's engagement process. The best value investment planning process will identify which water resource programme – or set of options– will best meet the future water needs of the region. The following phases have been set for the regional options appraisal:

- Phase 1: Scoping phase for the invitation to tender for services
- Phase 2: Options appraisal (between Spring 2020 and March 2021) including option identification, screening, costing and environmental assessment outlined in the Water Resources Planning Guideline (WRPG) Section 8.0. This covers activities up to the upload of data to the WRSE Data Landing Platform (DLP) and before investment modelling, best value plan appraisal of options and decision making, which is covered in other WRSE Method Statements. Figure 1 illustrates the scope of this Method Statement and how it relates to other parts of the process and other Method Statements.
- Phase 3: Continuation tasks (post March 2021) e.g. new options and option updates, refinements.

**Figure 1: Scope of options appraisal method statement within wider process**




1.3 This method statement provides the information to show how as a region, WRSE has and will work collaboratively to undertake the initial appraisal stage of the available options up to the DLP. Theoption appraisal has been developed to meet best practice expectations and to be inclusive for stakeholders, whilst also being carried out in accordance with guidance published by the Environment Agency, e.g. the National Framework for Water Resources and the Water Resources Planning Guidelines, and considering other sector demands.

1.4 To ensure fairness to options from both inside and outside the region, options are assessed consistently, objectively and transparently. The WRSE regional policies consultation undertaken in summer 2020, proposed that potential import options should be assessed to at least the same standards and principles as all other options in the region.

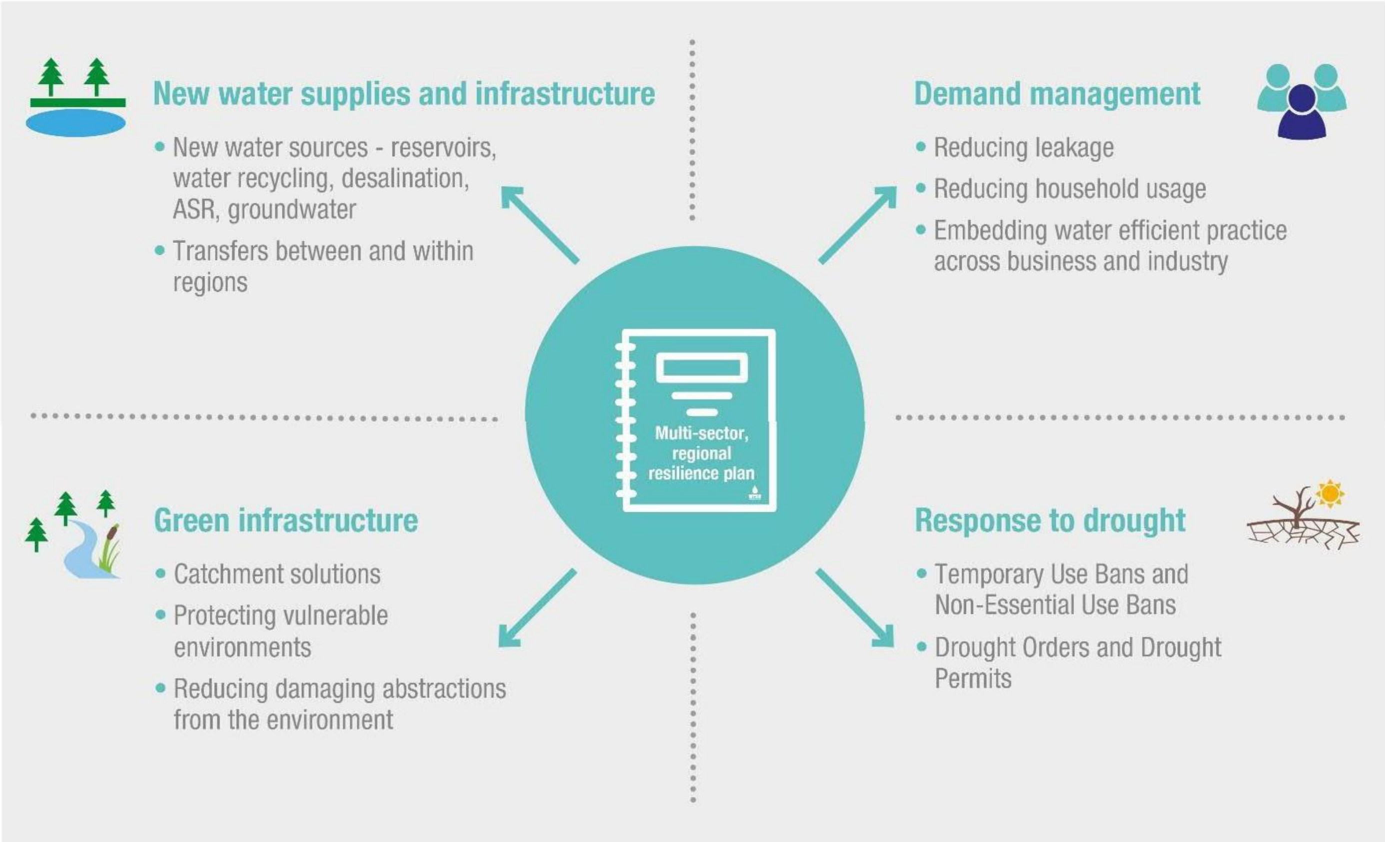
1.5 In most cases the options appraisal and development has been conducted by water companies, however for catchment management and nature-based solutions, multi-sector options and some transfers, initial option development has been conducted at a regional level by WRSE. Where options development and appraisal have been undertaken at regional level this method statement sets out our process to assess options which is balanced, objective and follows the appropriate guidance. We have also clearly signposted to where companies undertook the screening of options, prior to their information submission to WRSE.

## Summary of outputs

1.6 The regional options appraisal workstream involved undertaking a regional options appraisal gap analysis to identify potential gaps in the option set, collating a comprehensive set of existing options, improvements in consistency across option screening and design criteria and the development of new options where the potential was identified.

1.7 An appraisal of Public Water Supply (PWS) and non PWS supply options has been undertaken to address the challenges the region faces between 2025 and 2100. Further, options that will deliver multiple benefits to people, the environment and other sectors are being developed. Options considered include: new water supplies and infrastructure; green infrastructure; demand management; and interventions used to manage drought events. Figure 2 provides further summary information on these option types and Appendix 1 provides a full list of option sub-types under consideration.

Figure 2 WRSE categorisation of options




1.8 **Appendix 3** provides a list of option information that is required for each constrained feasible option to be uploaded into the regional options database for investment modelling. A more limited data set is required for options rejected during screening, but a rejection rationale is required for regulatory reporting from the options database.

1.9 In addition to the option information in **Appendix 3,** WRSE will be assessing the following metrics for each option:

- Environmental metrics – see **Method Statement 1329 WRSE Environmental Assessment**
- Resilience metrics – see **Method Statement 1325 WRSE Resilience**

# Roles and Responsibilities

**1.10** Key roles and responsibilities are as follows:

- WRSE Technical Director: **Meyrick Gough**
  - Overall responsibility and accountability for the technical delivery of the WRSE programme
- WRSE Option Appraisal Manager/Lead: **Nick Honeyball, Affinity Water (WRSE PMB)**
  - Overall responsibility and accountability for the technical delivery of the workstream
  - Overall responsibility for the budget proposal
- WRSE Option type leads: Programme Management Board (PMB) Members
  - Responsible for the scope and delivery of each of the sub-option workstream areas

    - Consultants: Mott MacDonald
    - Consultant Project Principal: Alice Mortimore
    - Consultant Technical Principal: Bill Hume-Smith
    - Consultant Work Package Lead: Rob McNicoll
    - The WRSE options appraisal workstream governance structure contains a RACI (responsibility assignment matrix) structure and the consultants supporting the work have submitted a governance structure to WRSE PMB.
    - The WRSE PMB hold responsibility and accountability for approving all technical works on behalf of WRSE according to the programme requirements and budget.
- WRSE Programme Manager: Sarah Green

# Maintenance of method statement

1.11 Key updates to this method statement

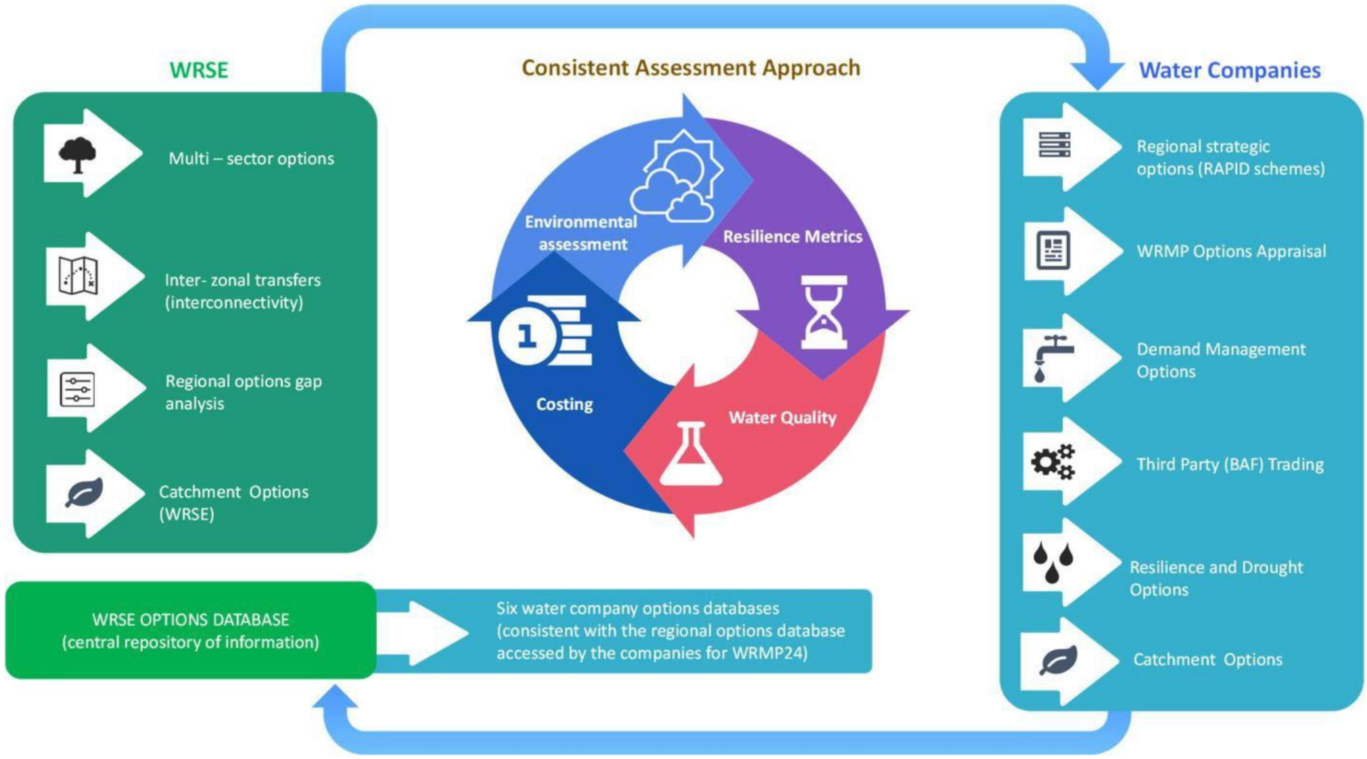
- 1st draft version June 2020
- 2nd draft version July 2020 (to publish online for consultation)
- Revised draft after consultation – (September 2021)
- Minor updates for Draft Regional Plan
- Iterative update/s (to follow where required)

# 2 Options appraisal methodology

## An integrated approach to regional options appraisal

2.1 Figure 3 shows how the WRSE options appraisal is integrated with the water companies' WRMP option appraisal and the wider programme requirements for environmental, resilience and water quality assessments. The methodology has been developed in this way to ensure improvements in consistency across the company approaches so that material options are not overlooked and the inputs to the investment model are consistent. Furthermore, the outputs need to then be suitable for use in water company WRMPs.

**Figure 3: WRSE Integrated options appraisal methodology**




2.2 The options appraisal approach being undertaken by WRSE and the companies promotes integration between the regional and water company WRMP options appraisals, allowing both to actively inform the other.

2.3 A key component of the methodology has also been the work that three of the WRSE companies are progressing with RAPID (the Regulators' Alliance for Progressing Infrastructure Development) which includes Ofwat, the Environment Agency and Drinking Water Inspectorate (DWI). This work includes the development activities for a number of strategic water resource options (SROs) identified by Ofwat in its PR19 Final Determination strategic regional water resource solutions appendix and also the findings of a strategic options gap analysis conducted by Ofwat.

2.4 WRSE prepared guidance[1] for its member companies on the options appraisal process, informed by a review of previous approaches across the WRSE companies. Figure 4 shows the stepped process for the option appraisal in this method statement and identifies those activities undertaken by WRSE at a regional level and those activities conducted by individual water companies.

2.5 WRSE have undertaken a sampled review of each company's rejection register to ascertain the basis for excluding options and have provided guidance on how to strengthen the rationale and audit trails in alignment with the WRMP24 guidance. The rejection registers have been updated by the companies to ensure that there is a robust rejection rationale which is recorded on the WRSE options database.

2.6 As part of the review of the company option screening work from WRMP19, WRSE reviewed the potential for company options to provide wider regional benefit. Where potential for this was identified, companies were informed of the opportunities and when updating option screening, companies were advised to consider the potential needs of neighbouring companies as well as their own needs.

2.7 There are a number of 'decision and hand-off points' between the company and the regional level option appraisals, these start with acceptance of the screening recommendations by the companies and include the following:

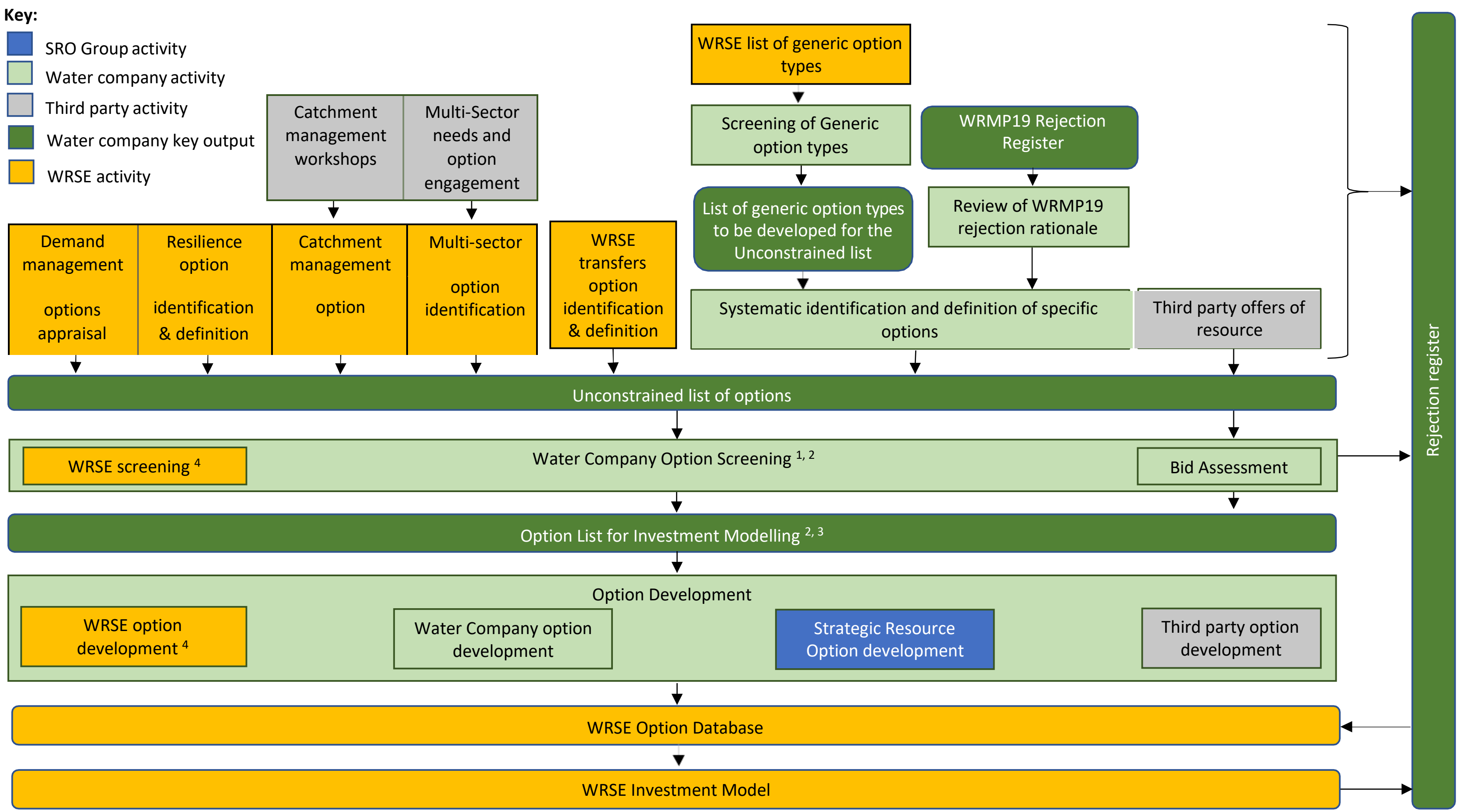
- Re-screened option lists by the companies inclusive of new regional options (either feasible lists, or constrained feasible lists if the feasible list has been subject to further screening)
- Submission of the rejected options with rationale for rejection (included on the unconstrained lists)
- Option information upload to the regional database (option data)
- An information share (as set out in Appendix 4 with the EA/NE) with regulators
- Iterative updates to the regional option database via option 'windows' for new information (third party options, updates to strategic regional options)

2.8 As part of the consultation on this method statement, the EA requested further information in the final version on the 'rationale for rejecting/progressing options'. The rationales for decisions on option progression are subject to the water company screening approaches and will be included in a rejection register that will be published alongside the draft regional plan for consultation.

2.9 It should be noted that the Environment Agency's Water Resources Planning Guideline is now final, and this method statement has been cross checked against this to ensure it is aligned (See **Appendix 5** for check list).

[1] Mott MacDonald (October 2020) Options Appraisal - Guidance on option identification, screening and development

## Figure 4: An overview of the process for identifying and screening options




*Note 1: Screening processes will vary between companies and may include a one or two stage approach, company specific feedback has been provided to improve robustness of option screening*

*Note 2: The Option List for Investment Modelling may be the full Feasible List of options, or a Constrained Feasible List, where this has been agreed with stakeholders (including the EA), provided that care is taken when constraining the Feasible List to ensure options that could benefit other companies are not rejected at this stage.*

*Note 3: Demand management options are represented as strategies comprising baskets of consumption and leakage reduction options combined by Water Companies to achieve different levels of total demand reduction*

*Note 4: WRSE option identification, screening and development activities focused upon catchment management, multi-sector and strategic transfer options*

# Demand side options

## Background

2.10 The National Framework for Water Resources published by the Environment Agency in March 2020 set out the expected targets for leakage and household per capita consumption (PCC) reduction by 2050 in comparison to current figures. These are:

- Leakage - to be reduced by 50%
- PCC – regional level of 110 litres per person per day (a reduction of around 30-35%)

2.11 Demand management (DM) options go beyond traditional approaches of just volumetric savings to consider schemes associated with improving the environment and resilience. DM options include:

- Leakage reduction (distribution network and customer supply pipes)
- Water efficiency (behaviour change and physical interventions at household level)
- Metering (conversion from fixed rate to metered tariff, smart metering)

2.12 The WRSE companies provided a range of demand management strategies (DMS) for leakage and usage reductions, and cost information for different weather scenarios, via a DMS Template, for the purposes of the WRSE investment modelling. It is a requirement that the DMS and option information will be aligned and consistent across companies.

## Approach

2.13 To investigate potential alignment issues, a questionnaire survey was completed that focused on the WRSE water companies' demand forecasting approaches and the methods used for the development of demand management options and strategies. The surveys were followed up with interviews. The information provided was analysed to determine similarities, differences and materiality of the dissimilarities. Some alignment issues were identified and recommendations/proposals[2] were made to address these for the companies to use in populating their DMS templates in a consistent fashion.

## Outputs

2.14 It was determined that the DMS template should be applied at the WRZ level. The template will incorporate three [Low/Medium/High] demand management strategies for consumption and leakage reductions. WRSE has provided guidance on how companies should develop the strategies and definitions for completing the DMS templates. Portsmouth Water have also investigated a High Plus strategy that included universal metering.

2.15 Guidance provided to companies on the use of a consistent framework of methods includes recommendations for forecasting to a planning period of 2100, application of outcome-based uncertainty bands, treatment of savings from water labelling options and DYCP (dry year critical period) forecasting of leakage and usage reduction savings.

[2] Mott MacDonald, March 2021, Task 4e Technical Note, Alignment of Demand Management Strategies & Options

2.16 Guidance was also provided on deriving the DMS, consistent with the regulatory Water Resources Planning Guideline (WRPG), the Environment Agency's National Framework and the period of water efficiency benefit. For the leakage reduction strategies guidance was provided on estimating volumes of water saved from targeted customer supply pipe measures and from application of Active Leakage Control (ALC) innovative/new technologies to fixing leaks.

2.17 For data assurance purposes, a checklist was provided of what should be checked to assess the composition of the leakage and usage reduction forecasts against the WRPG requirement and a note of considerations to avoid double counting of savings from inter-dependencies of individual DM options.

2.18 All companies have looked at potential savings resulting from government led demand management interventions.

## Supply side options

2.19 A regional option gap analysis has been conducted including a review of a sample of rejected options from WRMP19. This identified recommendations on option identification, screening and option development consistency which were provided to the companies. Companies have then updated their options appraisal and uploaded the information back to WRSE.

2.20 WRSE have not applied a minimum size threshold to filter the supply options because even smaller local options can be important to meet demands when aggregated, though schemes of less than 1Ml/d are usually not meaningful at regional scale.

2.21 An important aspect of the WRSE work is to explore opportunities for improvements across the region in inter-connectivity between water resource zones (both with in water companies and between water companies). WRSE has undertaken supply demand balance modelling to identify opportunities not already included in option lists where new transfers could release 'trapped' surplus water or transfer water from new strategic options to other areas of need in the region.

2.22 In order to develop work with other sectors, WRSE set up a strategic working group with the following sectors, agriculture and horticulture (NFU, West Sussex Growers)), energy producers, paper and pulp producers, water cress producers, aggregate industry and golf. The group will assess the future demands of these sectors and work with the options team to ensure where options do emerge, they can be translated into the options appraisal process.

2.23 Another key alternative option type are nature-based solutions within catchments. The scope for these options has focused on a) the incorporation of existing catchment options and b) undertaking catchment workshops to facilitate the identification of new catchment option ideas. The catchment workshops were held in 2020 with catchment partnerships and other local stakeholders. They focussed on identifying catchment solutions. A process was then developed for screening and developing information for catchment management options for inclusion in investment modelling.

2.24 In order to facilitate the promotion and bespoke screening of new multi-sector options, WRSE has developed online facilities to collate and assess new options. Online forms for submitting new options were provided and **Appendix 2** summarises the assessment process.

2.25 The principles we will follow when sharing information with the Environment Agency and Natural England are set out in Appendix 4, and we will seek to undertake this at an optimal time to reduce the burden on all parties involved.

## Strategic resource options (SROs) and the RAPID options (gap analysis)

2.26 Three of the WRSE companies (Affinity, Thames and Southern Water) are working with water companies in neighbouring regions to further develop large scale SROs within the context of the RAPID 'gated process'.

2.27 WRSE is working closely with the companies involved in developing the SROs in the following ways:

- By supporting these companies with a good understanding of the regional programme requirements (option information and timing) – for the inputs to the regional planning process
- By providing these companies with expectations and methods for consistency of approaches – for use in the options assessment work
- By assessing environmental and resilience metrics for SROs
- By working with RAPID where required and understanding the requirements to integrate the work emerging in a timely way into the regional planning options assessment – such as the gap analysis of the current strategic infrastructure schemes
- By undertaking regional needs assessment modelling (to support the gated process requirements) – as inputs to the RAPID gated process.

2.28 This work is necessary to maintain the timely sharing of consistent information and data for the regional plan development, which will read through into statutory WRMPs and which in turn will become the needs assessment for future statutory planning inquiries.

2.29 RAPID also undertook a 'gap analysis' of opportunities for increasing availability and sharing of water resources for resilience that may a) have been discounted in previous WRMPs, b) be in the national and regional interest and not previously considered (including multi-sector options) and c) may be in the interest of future WRMPs. Key findings from the gap analysis that have been taken forward for the WRSE region as potential options include:

- The conversion of a currently active quarry (Mendip Quarries) for use as a water resources reservoir instead of decommissioning it at its end of life for mineral extraction; and
- Development of a strategic grid within the WRSE region to allow surplus resources to be more fully utilised.

## Resilience and drought options

2.30 For previous WRMP options appraisals 'resilience options' have not usually been incorporated within the options appraisals. Resilience options include interventions that do not offer deployable output benefit but can operationally support resilience during events such as loss of assets. Due to the focus on increasing resilience and the development of the resilience framework, WRSE have requested that the water companies collate and submit their resilience options for regional appraisal. For further information relating to the resilience framework application, see **Method Statement 1325 WRSE Resilience**.

2.31 Drought options include Temporary Use Bans (TUBs), Non-Essential Use Bans (NEUBs) and drought orders and permits where agreed with the Environment Agency. Some of the drought options from Company drought plans will be included as options in the regional plan. 'More before 4' options (e.g. tankering, and drought orders and permits with major impacts) included in Drought Plans to delay the introduction of Level 4 restrictions (e.g. rota-cuts and standpipes) have not been included in the option list for investment modelling.

## Water trading options

2.32 WRSE recognises that water companies are working separately with third parties on demand and supply option opportunities through their Bid Assessment Frameworks (BAFs) and that this work may trigger the development of new options (both supply and demand). It is proposed that water companies can include such options via 'update windows' during the plan development, where they can put forward water trading options that may have been identified through this process. By doing so there will be ample opportunity to include water trading innovation in options at regional scale where these may arise.

2.33 Where companies are screening third party proposals, these will be subject to the company BAFs which are aligned with company WRMP screening approaches and should therefore be consistent with the screening of alternative options.

2.34 As well as seeking offers of resource, WRSE is conducting a systematic analysis to identify potential new bulk transfers that may be beneficial within the WRSE area. This work includes:

- Using a simple model of WRZs supply-demand balances in the South East to identify where there could be benefits from additional connectivity between zones and to identify capacity envelopes for the potential new transfers; and
- The identification of start and end points for the potential new transfers, followed by pipeline route selection and development of option information.

# 3 Progressing the options appraisal

## Inputs/requirements

3.1 Regional level (consistency)

- Cross company methods (screening and option development)
- Design and information (consistency method/s)

3.2 WRMP level (option lists)

- WRMP19 options
- Resilience options
- Catchment options

3.3 RAPID (National and regional option gap analysis)

- Findings and implications for WRSE from the RAPID strategic options gap analysis

3.4 Other sectors

- National Framework regional sector demand (Environment Agency's National Framework for Water Resources, and WRSE's Future Water Resource Requirements)
- Existing options and new options at initial concept level (multi-sector group)

## Outputs

3.5 Outputs will include:

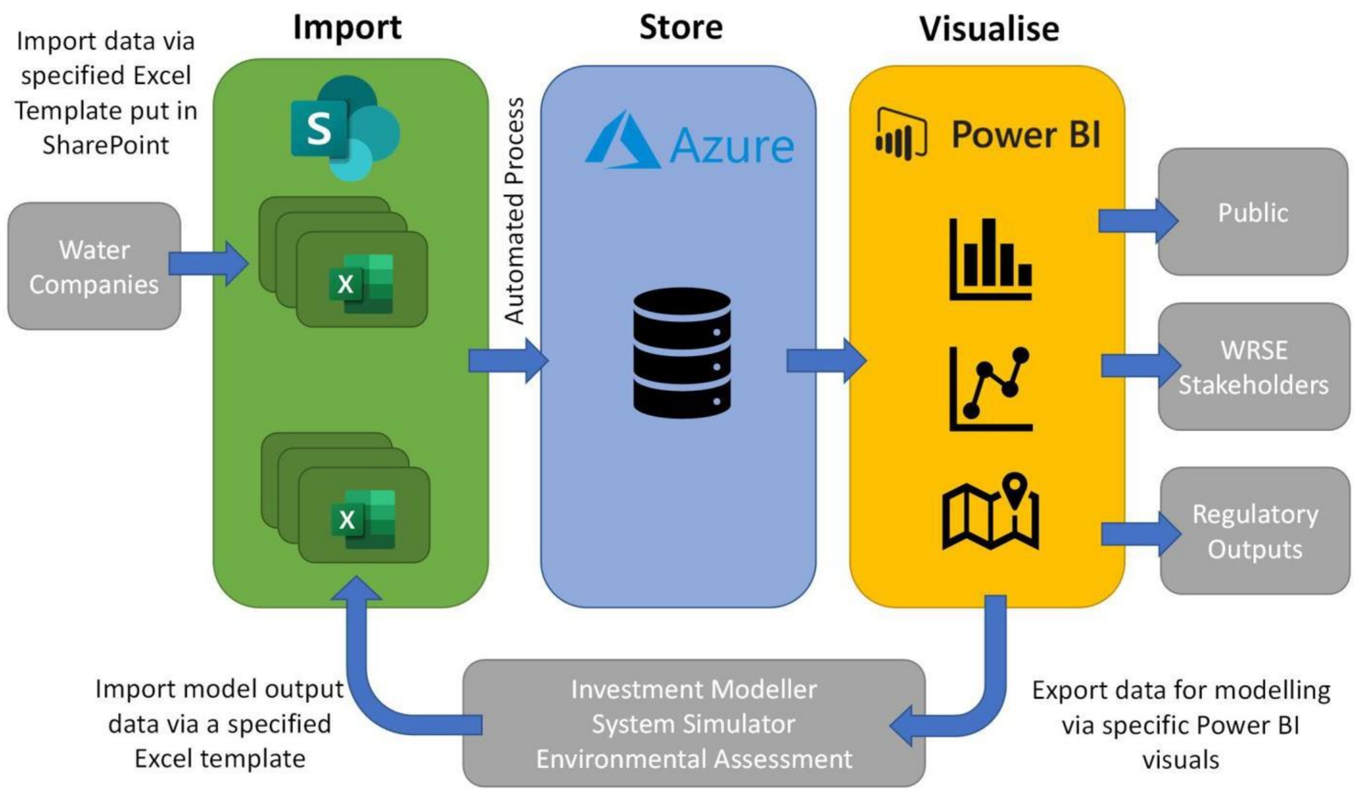
- A central regional options database that contains information that is consistent with company WRMPs (options, lists and information) available for water company WRMP sub lists and databases
- A comprehensive list of options that covers a wide range of generic option types (following the best practice guidance)
- Regional options appraisal reporting to support water company WRMP24 options appraisal studies (to ensure consistency across the approaches and a gap analysis of regional scale options). These include the following reports:
  - WRSE Options Appraisal Task 1 and 2a Technical Note (Review of rejection registers, gap analysis and screening)
  - WRSE Options Appraisal Task 2b Technical Note (inclusive of Task 4 consistency and design principles)
  - WRSE options appraisal guidance on option identification, screening and development (which brings together and updates the guidance from the two reports listed above)
  - A technical report summarising the outputs of the options appraisal and the options uploaded

- Initial options appraisal ‘pre consultation’ stage communication with statutory stakeholders (EA/NE) to support WRMP pre consultation.

## Data definition and assurance

3.6 Options data is uploaded through excel templates to a Microsoft Azure hosted options database. This information can then be viewed and analysed through Power BI dashboards and is linked to the WRSE investment model. Additional information on upload requirements and templates is provided where necessary to those parties tasked with submitting the information.

Figure 5: Overview of options database




3.7 There are two levels of technical assurance on information for input to the regional modelling, which will provide a record of how the data sources have been checked and recorded, these are as follows:

- Water company level (Level 1): water company assurance process for dWRMP24 and, where applicable, consultant supplier assurance processes up to the point at which information is submitted to WRSE
- WRSE regional level (Level 2): From the hand-over point where data is received by WRSE, the WRSE assurance process will be undertaken at regional level for all centralised data and information activities.

3.8 Where there are further iterations and updates to option information between the companies and WRSE, the same two levels of assurance apply.

3.9 The Level 1 assurance process is defined by the water company. An example of this process level might be a 'three line' assurance. Where the company procures expert consultant services to undertake the work on their behalf the first line of assurance would be the quality assurance applied by the consultancy service. The second line would be spot checks and reviews of the data aligned with the WRSE programme deadlines and the third line would be external assurance of the data process to assure the work on behalf of the WRMP and internal company requirements for board assurance.

3.10 Where there is a need for targeted assurance for consistency to meet stakeholder expectations, such as application of the cost consistency methodology by companies, these will be defined as required to meet the assurance needs.

## Key milestones

3.11 Key milestones include:

- Autumn 2020: Initial option data upload to the WRSE option database (phased during the autumn of 2020). Stakeholder engagement on the method statement.
- December 2020: Close of first 'window' for new options
- March 2021: Close of first 'window' for updated option information
- Spring and summer 2021:
  - Regional modelling in progress, any required revisions to option information included
  - Engagement at option level with the EA and NE (continuing through into autumn/winter 2021)
- January to February 2022: Second 'window' for updated option information
- February 2023: Following the update on WRMPs, a third limited opportunity to include option information changes.

# 4 Summary

4.1 This method statement provides a clear explanation of the background, objectives and components of the options appraisal. The method statement and accompanying guidance provides a clear description of the step-by-step process to be undertaken for the regional plan and the steps required to be undertaken by the member water companies.

4.2 We have updated this method statement to ensure that the comments provided by stakeholders have been captured and that it is line with the latest WRPG. A summary of the key revisions is provided as follows:

- A flow process diagram (Figure 1) to show what part of the options appraisal process is contained within this method statement, with signposting to the post DLP stage method statements that cover investment modelling and best value planning (**Method Statement 1318 WRSE Best Value Planning**).
- Clarification that information on the rationale for rejecting options will be published with the draft regional plan.
- The quality assurance process is updated to provide further information.
- We have also provided additional information setting out how multi-sector, resilience, third party, and catchment management options have been identified and appraised.
- We have subsequently agreed the engagement approach with the EA and **Appendix 4** has been updated to reflect this.
- An additional website link is included to help interested parties to navigate to the relevant new information on options on the WRSE website.

4.3 A high-level outline is provided of how the regional level and WRMP level options assessments will inform each other so that they are based on common and consistent information and this is illustrated an overall process diagram.

4.4 The handover points between WRSE and the companies is included, along with the schedule of dates for when these activities will occur (key milestones).

4.5 The list of information required for the options appraisal and subsequent modelling is provided in **Appendix 3** and where cross referencing to other workstreams is required it is provided (e.g. information provision for resilience and environmental assessments).

4.6 The quality assurance and key assumptions are outlined.

# 5 Next Steps

5.1 An initial version of this document was consulted upon between 1st August 2020 to 30th October 2020 and comments received during this time have been incorporated in this version of the method statement.

5.2 We have also reviewed this document against the final WRPG and supplementary guidance notes issued by the regulators. We have included a checklist in **Appendix 5** to ensure our final version of this Method Statement is in line with the guidance.

5.3 If any other further relevant guidance notes or policies are issued, then we will review this Method Statement to see if it needs to be updated.

5.4 When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

5.5 We will update our website with relevant information from time to time to ensure that as new information comes forward stakeholders are kept informed.

# Appendix 1: Option Types

**The screening approach and the list of option types**

An initial generic option list is proposed as follows, developed from the UKWIR Water Resources Planning Tools 2012 Report[3], and categorised according to the WRSE high level option types. Some additional Scheme Types and Sub Types have been added. Text in italics is carried forward from the UKWIR generic option type tables and the 'UKWIR Ref' indicates the table number and scheme type number from the UKWIR tables.

**Table 5.1: Blue – Green Infrastructure Generic Option Types**

| Categories | UKWIR Ref | Task 3: Scheme Type / Sub type |
|---|---|---|
| Catchment management | 5.19 | *Catchment management schemes* - Supporting river flows |
| Catchment management | 5.19 | *Catchment management schemes* - Habitat creation on chalk aquifers |
| Catchment management | 5.19 | *Catchment management schemes* - Flood Storage / Wetland creation |
| Catchment management | 5.19 | *Catchment management schemes* - Reconsider existing fish practices |
| Catchment management | 5.19 | *Catchment management schemes* - River Restoration |
| Catchment management | 5.19 | *Catchment management schemes* - Using SuDs to replenish aquifers |
| Catchment management | 5.19 | *Catchment management schemes* - Nitrate reduction |
| Catchment management | 5.19 | *Catchment management schemes* - Pesticide reduction |
| Catchment management | 5.19 | *Catchment management schemes* - Payments for ecosystem services |
| Catchment management | 5.19 | *Catchment management schemes* - Agricultural Activity |
| Other | 5.18 | *Water quality schemes that may have the coincidental effect of increasing the deployable output (DO) of a source works* |

[3] UKWIR, 2012, Water Resource Planning Tools (Report Ref. No12/WR/27/6) Economics of Balancing Supply and Demand

### Table 5.2: Efficient Use and Management of Water Generic Option Types

| Categories | UKWIR Ref | Task 3: Scheme Type / Sub type | Description |
|---|---|---|---|
| Consumption reduction | 2.1 | *Compulsory metering* - Household | *Households in water-stressed areas, Households where a meter or meter box already exists* |
| Consumption reduction | 2.1 | *Compulsory metering* - Selective | Customers with *swimming pool, outside taps, sprinkler/hose pipe users* |
| Consumption reduction | 2.1 | *Compulsory metering* - Non-household | *Industrial premises, Commercial and public sector premises* |
| Consumption reduction | 2.10 | *Advice and Information on direct abstraction and irrigation techniques* | *Drip vs. spray irrigation, Direct abstraction, Other techniques for reducing evaporation* |
| Consumption reduction | 2.11 | *Advice and information on leakage detection and fixing techniques* | *Industrial, Commercial and public sector, Household, Agricultural* |
| Consumption reduction | 2.12 | *Promotion of water saving devices* - Retrofitting (new or subsidised) | Replacement of existing fittings (e.g. taps, toilets) in existing housing stock. *Appliance exchange programmes - washing machine, dishwasher, water closets or WCs. Company subsidy to appliance manufacturers. Company subsidy to consumers for the purchase of water saving appliances. Limited purchase/use of instantaneous water heaters/boilers*. Installation of low volume shower heads, toilet bag cistern dams, water butts, flush controller for urinals etc. |
| Consumption reduction | 2.13 | *Water Recycling - grey water reuse (existing household and non-household)* | *Encouraging or requiring water recycling (i.e. direct use of untreated 'grey water') - industrial, commercial and public sector, households (e.g. using water from baths/showers/basin for toilet use),, fitting recycling systems to existing houses* |
| Consumption reduction | 2.13 | *Water Recycling* - grey water reuse (new household and non-household) | *Encouraging or requiring water recycling (i.e. direct use of untreated 'grey water') - industrial, commercial and public sector, households (e.g. using water from baths/showers/basin for toilet use), fitting recycling systems in new houses.* |
| Consumption reduction | 2.14 | Sponsoring *Water efficiency enabling activities* by others | *Sponsoring 'waste minimisation' projects, Tradable delivery entitlements, Targeting gardeners for rainwater harvesting, Lobbying for tighter or company-specific water regulations, Improving the enforcement of water regulations, Implement water efficiency research (Waterwise) outcomes, Planning restrictions preventing new development* |
| Consumption reduction | 2.2 | *Enhanced metering* - Household | Where meters are installed compulsorily but then customers encouraged to switch to paying measured charged voluntarily |
| Consumption reduction | 2.2 | *Enhanced metering*, AMI *Smart metering* - For all Customers | *Targeted installation of water meters and a promotional campaign to increase optant rates and change of occupancy switchers* |
| Consumption reduction | 2.3 | *Meter Installation policy* - Water Company Level | *Installation when premises change ownership, Industrial, Commercial and public sector, Households* |
| Consumption reduction | 2.3 | *Meter Installation policy* - Regional / national level | |

| Categories | UKWIR Ref | Task 3: Scheme Type / Sub type | Description |
|---|---|---|---|
| Consumption reduction | 2.4 | *Metering of sewerage flow* - To manage water consumption and water wastage | *Optional scheme, Compulsory scheme* |
| Consumption reduction | 2.5 | *Introduction of special fees* | *Introduction of separate additional fees for, sprinkler users, hose pipe users, outside tap users, swimming pools* |
| Consumption reduction | 2.6 | *Changes to existing measured tariffs* - Drought protection | *Including - seasonal, spot pricing for water stressed areas, drought time tariffs, introducing summer/winter or other seasonal tariffs, introducing daily/peak/off-peak tariffs for at least some seasons,* |
| Consumption reduction | 2.6 | *Changes to existing measured tariffs* - Volumetric charges | increasing the *volumetric charges, introducing rising block volumetric charges, charge only above a defined subsistence level of use (to protect low income families), flow restrictor charging (tariff reduction for a restriction in domestic supply water pressure)* |
| Consumption reduction | 2.6 | *Changes to existing measured tariffs* - Other | *Discontinued declining block rate tariffs, domestic user tariffs and/or commercial user tariffs* |
| Consumption reduction | 2.7 | *Introduction of special tariffs for specific users* | *Introducing interruptible industrial supplies, introducing lower charges for major users with significant storage, introducing higher cost ban-free sprinkler or hose pipe licences, Introducing spot pricing for selected customers* |
| Consumption reduction | 2.8 | *Water use audit and inspection - Household and non-household water efficiency* | *Domestic property water use audit and retrofit, stand alone, Domestic property water use - audit and retrofit, Integrated Demand Management, Domestic property water use - self audit packs, Commercial property water use - audit integrated with Water Regulations Inspection, Commercial property water use audit, Institutional property water use audit and retrofit* |
| Consumption reduction | 2.9 | Awareness campaigns - *Targeted water conservation information (advice on appliance water usage)* | *Industrial customers/bodies, Commercial customers, Households, Public sector (e.g. schools, hospitals, community groups), Recreation facilities (parks and gardens, golf courses), Designers of hot water systems, taps and water using appliances, Purchasers of water-using appliances (i.e. in showrooms), Labelling water consumption of appliances.*<br>Customer education on water saving appliances. Encouraging *greater use of water saving technology in new and/or existing buildings (industrial, commercial, public sector and household). Encouraging fitting of showers, low volume shower heads, limited purchase/use of power showers, low flush toilets, dual flush toilets, fitting new toilets, composting toilets, waterless urinals, retrofitting existing toilets, shallow trap toilets, flush controller for urinals, timing devices, 'people detectors', self-closing taps i.e. push operation taps that cut off this supply after a short time, spray taps, toilet bag cistern dams (by displacing part of the cistern volume, reduce the flush volume), hose activated by a spring loaded trigger mechanism, research and development into water saving technology.* |
| Consumption reduction | New | Home visits to reduce plumbing losses | Assistance in repairing leaking toilets. *Programme of re-washering customers' taps* |
| Consumption reduction | New | Reduction in other consumption | Reduction of distribution system operational use, reduction of legal water use that is unbilled & reduction in illegal water use |
| Loss reduction | 3.1 | *Customer supply pipe leakage reduction* | *Identification of major supply pipe leaks, fixing major supply pipe leaks, at water company expense, at customers' expense or subsidised by water company* |
| Loss reduction | 3.2 | *Leakage reduction* - trunk mains and | *Find & fix leakage in trunk mains and reservoirs including overflows* |

| Categories | UKWIR Ref | Task 3: Scheme Type / Sub type | Description |
|---|---|---|---|
| | | service reservoir leakage reduction | |
| Loss reduction | 3.2 | *Leakage reduction* - Speed and quality of repairs | Changes to policy / organisational setup e.g. fixing of reported and/or detected leaks<br>Increase in repair resources<br>Improved quality of repairs |
| Loss reduction | 3.5 | *Leakage reduction* - *Pressure reduction programmes* | New pressure reduction programmes (installation of PRVs)<br>Optimisation of existing pressure management assets<br>Pressure transient reduction |
| Loss reduction | 3.6 | *Leakage reduction* - (Asset renewal) | Additional leakage-driven mains replacement<br>Small area networks<br>*Distribution capacity expansion* to relieve constraints and manage pressure |
| Loss reduction | 4.1 | *Diagnostic studies* for production losses | |
| Loss reduction | 4.2 | *Improved leakage detection and reduction on raw water mains* | |
| Loss reduction | 3.3, 3.4 | Leakage reduction - *Active Leakage Control* | Changes to policy / organisational setup<br>Increase in leakage detection resources<br>Improved efficiency<br>Innovative techniques and technologies e.g. fast logging, fixed noise logging, smart networks |
| Loss reduction | 4.3, 4.4 | *Increase water treatment works (WTW) efficiency* | *Reduce treatment works losses*<br>*On site wash water recovery* |
| Loss reduction | New | Leakage reduction - Customer engagement / education / incentives | Advice and information on leak identification and fixing techniques to raise awareness and educate customers to report leaks |
| Loss reduction | New | Leakage enabling schemes | e.g. better monitoring and information including night use, investigation to better understand the network, identifying previously unknown consumption, improved meter accuracy and DMA operability, more bulk metering, raw water mains monitoring. |
| Other | 5.16 | *Rainwater harvesting* | *Direct collection and storage of rainwater*. May be at domestic or industrial scale (e.g. airports) |
| Other | New | Sea water for industrial processes and cooling | |
| Outage reduction | New | Interventions to reduce outage risk | Interventions to increase source and system reliability, redundancy, resistance, response and recovery to outage events enabling reduction in elements of outage risk, by changing magnitude, likelihood and duration of impacts. |

**Table 5.3: Hard Infrastructure Generic Option Types**

| Categories | UKWIR Ref | Task 3: Scheme Type / Sub type | Description |
|---|---|---|---|
| Desalination | 5.7 | *Desalination* | *Membrane separation (electrodialysis reversal, reverse osmosis), Thermal processes (multistage flash distillation, multiple effect distillation, mechanical vapour compression)* |
| Groundwater | 5.3 | *Groundwater sources* | *New sources, improve existing sources (with or without licence change), Increase aquifer yield by reducing seawater intrusion into aquifers, by pumping or through introduction of a physical barrier* |
| Groundwater | 5.5 | *Artificial Storage and Recovery wells (or Aquifer Storage and Recovery (ASR))* | |
| Groundwater | 5.6 | *Aquifer recharge /Artificial recharge (AR)* | |
| Other | 5.15 | *Tidal barrage* | |
| Other | 5.20 | *Conjunctive use operation of sources* | |
| Other | 5.21 | *Joint ("shared asset") resource* | |
| Other | 5.22 | *Asset Transfers* | |
| Other | 5.23 | *Options to trade other (infrastructure) assets* | |
| Other | 5.12, 5.17 | *Abstraction licence trading* | Trading of existing licences. *Re-use of existing private supplies taken out of service (Defence establishment sites/Industrial sites)* |
| Removal of constraints | 3.7 | *Distribution capacity expansion* | *Trunk mains, Distribution mains* |
| Removal of constraints | 5.10 | *Redevelopment of existing resources with increased yields* | *Changes to current system operation that may result in relatively cheap and simple operational changes that could yield benefits to the supply-demand balance* |
| Removal of constraints | New | Increase water treatment works (WTW) capacity | |
| Reservoir | 5.2 | *New reservoir* | *On-stream reservoirs, Pumped-storage reservoirs, Flood storage reservoirs, River regulation reservoirs and/or direct supply reservoir, Development of dis-used gravel pits (or redundant quarries) as reservoirs, Dam raising* |
| Reuse | 5.12 | *Reclaimed water, water re-use, effluent re-use* | Include recycling of sewage, surface water, or wastewater treatment works final effluent for direct or indirect reuse. |
| River abstraction | 5.1, 5.4 | *Direct river abstraction* | *New river abstraction (with intake) and with licence application, Transfer of existing river licence to new or existing works, modify existing abstraction licences.* Also includes use of infiltration galleries. |
| Import | 5.8 | *Bulk transfers* into regi*on* | Import of raw or treated water from outside WRSE region. May include *renovation or increase of existing transfer or development of new bulk transfers by canal, river or pipeline* |
| Transfers | 5.8 | *Bulk transfers* within region | Transfer of raw or treated water between WRZ/companies within WRSE region: *Renovation or increase of existing transfer or development of new bulk transfers by canal, river or pipeline* |

**Table 5.4: Response to Regional Events Generic Option Types**

| Categories | UKWIR Ref | Task 3: Scheme Type / Sub type | Description |
|---|---|---|---|
| Drought orders | New | Drought intervention - Drought order | Limitation of other abstractions, and further limit customer use of water |
| Drought permits | New | Drought intervention - Drought permit | Modification or suspension of conditions in abstraction licences |
| Other | 2.15 | *Change in Level of Service to enhance water available for use (WAFU)* | |
| Other | 5.13 | *Imports (icebergs)* | *Towing of icebergs from the Norwegian sea* |
| Other | 5.14 | *Rain cloud seeding* | |
| Other | New | Drought intervention - recommission abandoned sources | |
| Transfers | 5.9 | *Tankering of water* - Road Tankering | |
| Transfers | 5.9 | *Tankering of water* - Sea Tankering | |
| Transfers | New | Drought intervention - Temporary transfer | Transfers between WRZs under mutual aid using existing connections, new transfers, or emergency transfers constructed in drought circumstances |

# Appendix 2: Appraisal of multi-sector options

## Multi-sector options

The National Framework for Water Resources set the objectives for regional plans as follows: *"Regional plans will set out how the supply of water for people, business, industry and agriculture will be managed in the region. The plans will create resilient water supplies for all users, while protecting and enhancing the environment and creating wider social benefits for the next 25 years or more. They will be developed collaboratively by water companies, other large water-using sectors and local organisations with an interest in the water environment, who collectively make up regional water resources planning groups."*

WRSE is responding to these objectives by developing a multi-sector regional resilience plan that will include solutions to address water resources needs for both Public Water Supply (PWS) and Non-Public Water Supply (Non-PWS) users, while ensuring this is done in a way that delivers environmental benefit and wider social and economic benefit. Figure 6 shows how these objectives overlap. The objective of the regional plan is broader than the objective of WRMPs in that the regional plan include Non-PWS needs, as well as PWS needs. Figure 6 also provides examples of different options that map onto these objectives.

To facilitate identification of multi-sector options WRSE developed a Stakeholder Engagement Tool. The tool used a web-based form, accessible through the WRSE Engagement HQ site, to engage sectors with Non-PWS needs. The tool sought information on:

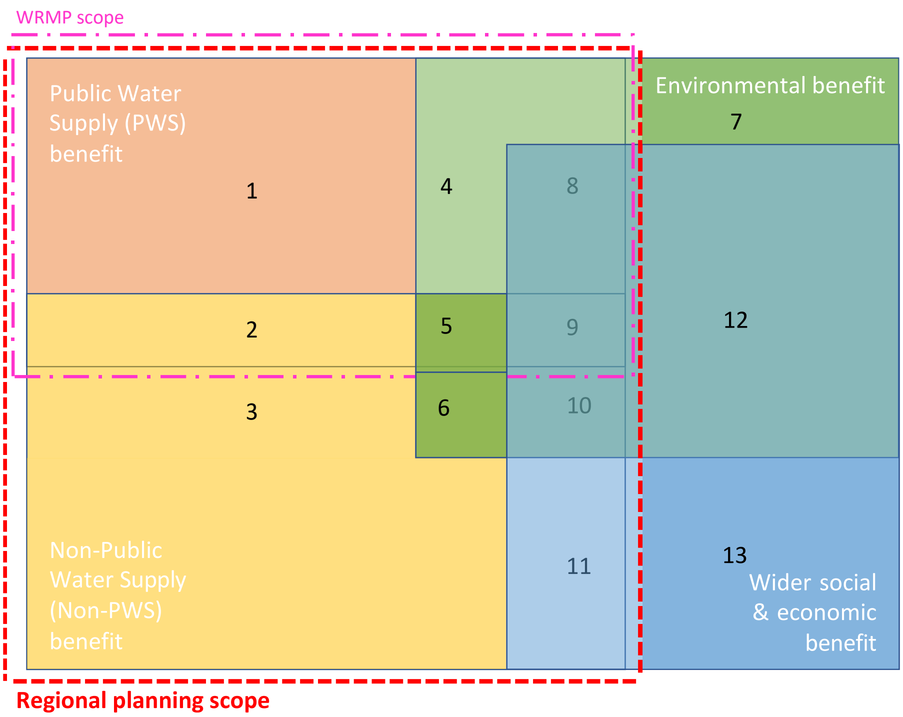
1. Existing abstractors with surplus resources who would be prepared to trade with another sector
2. Existing or potential abstractors with a future increased need
3. Ideas for new multi-sector options

Where surplus resources are identified then potential new trading options can be developed for either PWS or Non-PWS sectors.

Where there are future Non-PWS needs then these can be added to the PWS needs within WRZs to identify the potential for multi-sector solutions to address both needs.

Where new multi-sector options are identified to address joint needs then there are included in the option set provided that the minimum level of information needed can be provided and the options do not overlap with other option types (e.g. water company demand management strategies).

## Figure 6: Characterisation of multi-sector options




Examples of options:

1. Home visits to reduce PWS per-capita consumption/New resource development for PWS/Water efficiency audits for PWS customers
2. Options to help PWS customers make better use of Non-PWS resources, reducing PWS need
3. Option to develop non-PWS for irrigation or industry
4. Catchment management, increasing security of PWS and improving environmental water quality.
5. Catchment management, increasing security of PWS and Non-PWS supplies and improving environmental water quality
6. No till agriculture improving resilience of water in soil profile for agriculture
7. River restoration for environmental improvement alone *(but likely to have social benefits too?)*
8. As 4, (catchment benefits) but also providing significant recreational and employment benefit
9. As 5 (catchment benefits), but also providing improved flood risk management.
10. Wider uptake of regenerative agriculture, landscape scale interventions
11. Non-PWS reservoir with amenity value
12. Natural flood management measures.
13. Flood storage reservoir.

# Appendix 3 Option Information

Information on options is provided to WRSE using a standard template. The information is then uploaded to an options database. For options that have been rejected by companies during option screening only limited information is required including the option name, reference and rejection reason. For feasible (or constrained feasible) options for investment modelling further information is required which is summarised in the tables below including:

- Summary information on the option (see Table 5)
- Option metric profiles for information that varies over the planning period (see Table 6)
- Option metrics that are single point values and do not vary over time and as such do not need to be profiled Option (see Table 7).

**Table 5: Summary of option information**

| Data field | Brief description |
|---|---|
| Option name / ID | Name and WRSE identification reference. Company references can also be added. |
| Option Description | A brief description of the option, including the engineering design |
| Option stage and type | The option stage allows for real option analysis (e.g. planning, construction). Classification (e.g. reservoir, river abstraction, groundwater etc). |
| WRMP19 status and change | Whether an option was selected at WRMP19 and whether it has changed since then, stayed the same, or is a new option. |
| DO Tier | The category of options for Deployable Output (DO) assessment |
| Minimum flow and capacity (Ml/d) | Summary fields on the benefits of the option |
| Cost base | The date for which all costs are current for, indexing will be applied to make all costs consistent |
| Current asset? | If the option represents a currently operational option, or an option under construction |
| Duration (years) | The estimate in years for which how long the option will take to deliver |
| Earliest operational start | The earliest date that water becomes available |
| Location details | NGRs for locations of key start/end points (inclusive of donor/recipient company names if applicable) |
| Rejection details | If scheme is rejected, the reason why and when it was rejected |
| Dependencies | Whether options are:<br>• Mutually exclusive<br>• Mutually inclusive<br>• Reliant of start/completion of another option |

### Table 6: Option metric profiles 75 year (cost and other metrics)

| Metric | Brief description |
|---|---|
| Costs | • Capital costs (capital expenditure, or 'capex') by asset life category<br>• Optimism bias (using consistent cost method)<br>• Costed Risk<br>• Operating cost ('opex') fixed (£/yr) and variable (£/Ml) |
| Deployable Output (DO) | Yearly profile of DO can be input against a number of scenarios:<br>• 1:2 average<br>• 1:10 average & peak<br>• 1:200 average, peak & minimum<br>• 1:500 drought average, peak & minimum |
| Embodied and Operational Carbon | Carbon emissions<br>• Fixed (tCO2e/yr) and variable (tCO2e/Ml) |
| Other | Electricity<br>• Fixed (kWh) / variable (kWh/Ml) |

### Table 7: Option non-profiled metric data (resilience, environmental and other metrics)

| Metric | Brief description |
|---|---|
| Resilience | The scoring method for the following resilience metrics are set out in the Resilience Framework Method Statement (**Method Statement 1325 WRSE Resilience**).<br>• Supply Demand Benefit Uncertainty<br>• Vulnerability to other Hazards<br>• Availability of additional headroom<br>• Catchment / Raw water quality risks<br>• Capacity of Catchment Services<br>• Risk of failure due to exceptional shocks<br>• Soil health<br>• Expected time to failure<br>• Duration of Enhanced Drought Restrictions<br>• Operational Complexity<br>• System Connectivity<br>• Good customer relations for demand management<br>• Scalability & Modularity<br>• Lead Time<br>• Reliance on External bodies<br>• Flexibility of planning pathways<br>• Collaborative landscape management |
| Environmental | The scoring methodology for environmental metrics is set out in the Environmental Assessment Method Statement (**Method Statement 1329 WRSE Environmental Assessment**)<br>• SEA Environmental Benefit Effect<br>• SEA Environmental Negative Effect<br>• Biodiversity Net Gain<br>• Natural Capital |
| Lead time | Time (in years) required to implement the scheme after being included in an approved WRMP. For real options this time may be separated into planning, development and construction stages. |

# Appendix 4 Stakeholder pre-consultation (EA/NE)

This appendix sets out the approach to pre-consultation for the options appraisal including:

- The need for engagement
- The engagement 'ask' from the WRSE options appraisal team
- The principles and proposed approach
- Agreed approaches to sharing information
- Timely release of information and initial timeframe

**The reason for this appendix (the 'need')**

The WRSE options appraisal workstream will require engagement with stakeholders as part of the task delivery. The Environment Agency (EA) and Natural England (NE) are key stakeholders for statutory water company WRMPs and therefore will need early visibility of the activities being undertaken by WRSE (which will inform company WMP24 options appraisals).

The type of information that could be part of the engagement include:

- Technical methods
  - Such as changes to the company WRMP screening methods and approaches through recommendations by WRSE to improve consistency across the company WRMP options appraisals
- Options information
  - Option lists (may change as a result of new information or recommendations made by WRSE)
  - Option scopes and new options may occur (either from WRSE or water company appraisals)

It is recognised that these changes should be managed and organised as efficiently as possible, and that by doing this through WRSE (initially), ahead of WRMP24 pre-consultations we may be able to control the impact on all parties (time and resourcing) and help mitigate the risk of subsequent EA/NE feedback on WRMPs requiring significant changes to the regional plan.

**The engagement 'ask'**

We would like to engage the EA/NE in these two key areas of our options appraisal work therefore and Table 10 provides an initial list of areas of engagement along with a summary of what feedback we would expect to receive.

**Table 10: Engagement areas and anticipated feedback**

| Area of work | Method / Report / Information type | Feedback |
|---|---|---|
| Technical methodology | Phase 1 scoping report<br>Phase 2 regional approach (options appraisal)<br>• Approach to option screening<br>• Approach to option development and consistent information requirements for the constrained feasible list<br>Phase 3 WRSE options appraisal summary report | Does the approach to regional planning set out align with your expectations, including those of the WRPG and National Framework?<br><br>Do you have any comments on the environmental assessment methodology? |
| Options | Lists (option database)<br>• Changes to unconstrained, feasible lists<br>• The rationale for why and which options | Are you satisfied with the application of the approach for options identification and screening?<br><br>Are there options on the constrained feasible list that you think should not be included?<br><br>Are you aware of any gaps in the constrained feasible list? |
| | Option level (information)<br>• Existing option (with new environmental information)<br>• New option creation (and environmental information) | Do you have any comments on specific option information for investment modelling (e.g. environmental metrics, rejection reasonings)? |

**The principles we propose to follow to carry out the engagement**

We recognise that the EA and NE have limited resources available to undertake the engagement, we also recognise that with the current situation (Covid-19) and restrictions in place that face to face contact is not possible. In order to undertake the engagement, we are currently working on the following principles and tools to help manage the engagement effectively.

- That because a single regional database is held, that is consistent with the company options list, that WRSE will be able to organise the initial sharing of information.
- That the data information platforms will be developed in ways to help facilitate this (e.g. data fields which allow for the sorting of information).
- That we will agree beforehand on the information types and feedback required.
- That we will provide the EA/NE with the information and clearly delineate where the feedback should be provided.
- Agree with the EA/NE on a timeframe for the information share and feedback (we will agree beforehand a schedule).

**Summary of agreed approaches to sharing information**

Environment Agency approach:

- That companies will continue to engage with the regional contacts on the methodology and technical reporting at regional level
- That option level information will be made available to local teams via water company WRMP teams and the feedback and workshops be held at local level
- That option level information should also be available at regional level (WRSE) to the Environment Agency for visualisation purposes

Natural England approach:

- That WRSE will organise and make available all relevant regional and option level information via the DLP and visualisation tools in order to make the most efficient use of resources

Data on individual options can be made available to the Environment Agency and Natural England through the following means:

1. A PowerBI dashboard linked to the WRSE options database providing details of the unconstrained list of options, including rejection reasons for options that have not been taken forward and key option information for those options that have been taken forward for investment modelling (i.e. either on the feasible or constrained feasible lists)
2. An ArcGIS Online dashboard showing the location and description of options carried forward, together with the geographical information on the constraints considered in the environmental assessment.

**Initial timeframe - Updated**

The timing for the engagement is best once the initial data uploading and options appraisal screening stages have been undertaken, along with any activities that could create new options. Options have been uploaded to the WRSE options database in Spring of 2021 and public workshops on the options were held in June 2021. Recordings of the workshops are available from the WRSE Engagement HQ website.

The exact protocol for accessing the data will be agreed with the Environment Agency and Natural England by the WRSE PMB once the technical tasks have been completed to allow access in line with the principles set out in this Method Statement.

In terms of technical methods, the Phase 1 and Phase 2 reports are available for review by the EA/NE. These could be passed to the EA/NE representatives on the WRSE PMB when required, subject to agreement.

# Appendix 5 Checklist for consistency with the WRPG

The Environment Agency published its WRPG in February 2021. The following table identifies the relevant parts of the guidance relating to this Method Statement, and provides WRSE's assessment of its consistency with the requirements in the guidance.

| WRPG Section No. | Action or approach | Method Statement ref: | WRSE assessment of consistency |
|---|---|---|---|
| 8.1, 8.2 | Option lists (unconstrained and feasible) | **Paragraph 2.4** (and Figure 4) show how the option lists are generated and integrated into the regional option appraisal<br><br>**Paragraph 2.7** explains the 'hand-off' points in relation to the option lists | Consistent with the requirements to identify options from generic option types and integrated between company and regional levels |
| 8.1.1 | Regional and third- party options | **Paragraph 2.19** references the regional option gap analysis which identifies new regional options (at company level). Figure 3 shows which options are identified at regional level (catchment management, multi-sector and transfers)<br><br>**Paragraph 2.32 and 2.33** reference where third party options can be included within the regional plan (via windows for submission). Where third party option ideas are put forward to WRSE they will be forwarded to water companies. | Shows clearly where regional solutions will be identified. Company level reporting will provide further detail.<br><br>The approach to working with companies on third party options is consistent with the WRPG |
| 8.2, 8.2.1 | Screening and Further screening | **Paragraph 2.4** (and Figure 4) shows how the screening of options is integrated between company and regional levels. | The screening methodologies will be made available via company level.<br><br>The WRSE process promotes and allows for consistency across company level screening |

| | | | |
|---|---|---|---|
| 8.2.2 | Assessing environmental constraints | The option screening employed for company unconstrained lists includes screening for environmental constraints.<br>For options included for investment modelling the environmental assessment of options is contained within the WRSE environmental assessment Method Statement | Environmental screening of unconstrained option lists is undertaken at company level |
| 8.3 | Provision of option information | Option description, DO, lead time, and value metrics (customer, environment and resilience) for the option will all be available via the WRSE DLP<br>Option utilisation will be available post modelling<br>Environmental assessment results will also be available via WRSE (or company level depending on the request) | Some of the option information required for WRMPs will be available from the options database<br>Further information will be needed for company level option dossiers |
| 8.3.1 | Cost information | Guidance to companies on cost consistency provided in WRSE options appraisal guidance that aligns with All Company Working Group guidance for Strategic Resource Options. | Approach aligns with WRPG, although noted that in some cases option development may be at a point where not all environmental and water quality interventions have been identified, however such early-stage options are expected to have a higher optimism bias. |
| 8.3.2 | Carbon | Embodied carbon emissions are included in the information requirements (Appendix 3), together with power requirements for calculation of emissions from electricity. | Requirement to include carbon emissions is addressed. Further consideration needed on potential for mitigations to reduce embodied carbon. |

# Method Statement: Resilience Framework

November 2022

| Title | Method Statement: Resilience Framework |
|---|---|
| **Last updated** | November 2022 |
| **Version** | Updated for Draft Regional Plan |
| **History of changes made to this version** | Updated table of metrics in Section 5 and added update on metrics used for best value planning at end of Section 5 |
| **Author** | Bill Hume Smith (updates only) |
| **Approved by** | Sarah Green |
| **WRSE Director approval** | Trevor Bishop |

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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

An additional consultation on the Resilience Framework has also been undertaken – the consultation response can be found at https://www.wrse.org.uk/media/qybbxsqw/resilience-framework-response-to-feedback-03-august-2020_final.pdf.

# Table of Contents

# Executive summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

We have prepared Method Statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We have consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

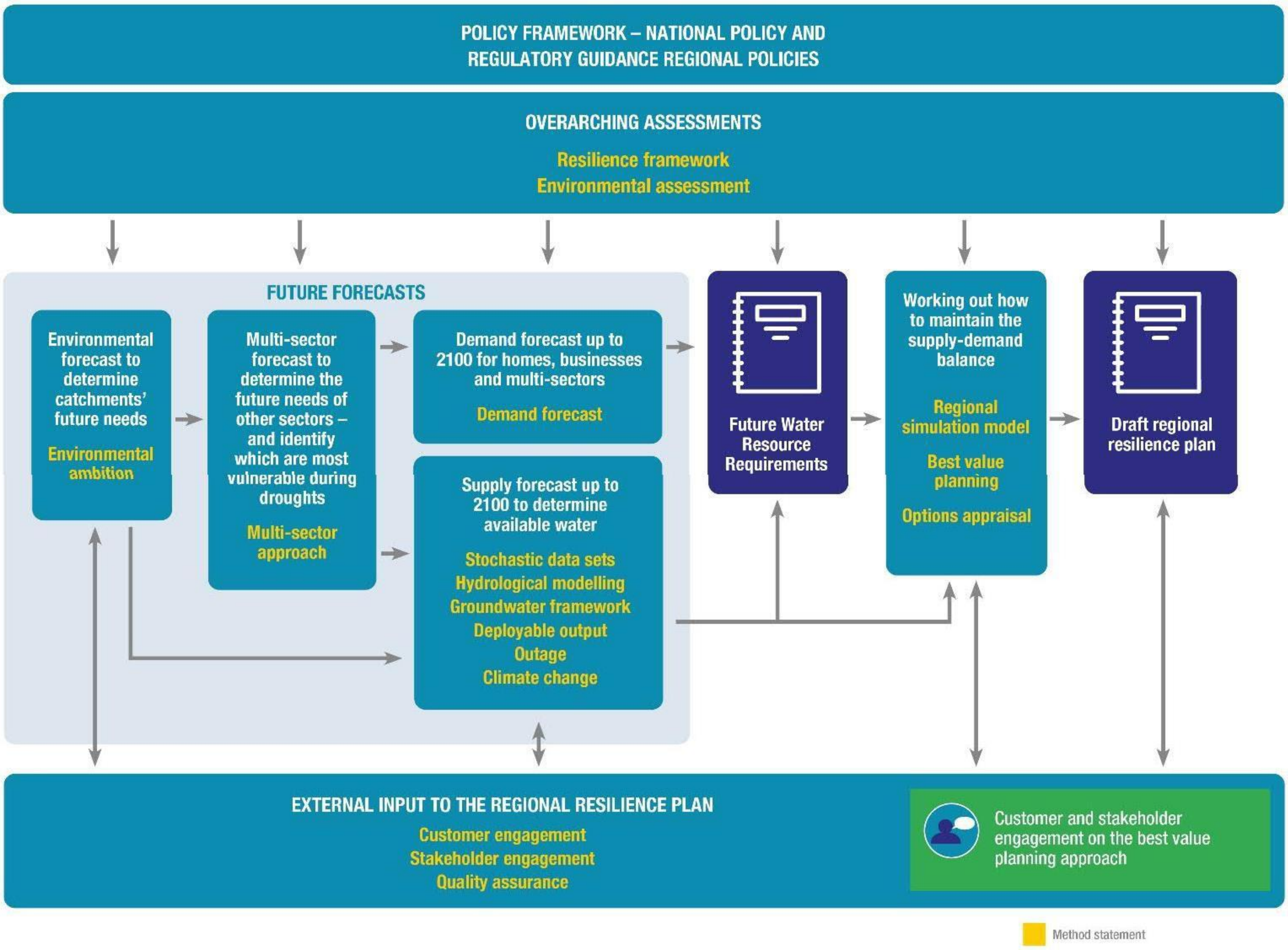
Figure ES1 illustrates how this resilience framework Method Statement will contribute to the preparation process for the regional resilience plan.

To make sure our plan is resilient to future shocks and stresses – both the ones we can forecast and those we can't – we're going to develop and test our plan against a new resilience framework. This will allow us to assess options in terms of greater resilience to short-term shocks and long-term trends, as well as for cost, best value and impact on the environment.

This is a new framework which we have already published for consultation (WRSE Securing resilient water resources for South East England) but our method statement sets out how we have developed it, and how we will use it to assess the resilience of our regional resilience plan.

A specific framework is needed because there are a number of important aspects of `water resource resilience' that are not currently covered by more conventional assessments (and which tend to be economic and environmental -led). We also need to move away from a planning approach that has concentrated on a single 'hazard' – a shortage of water caused by droughts – to one that looks at the resilience of non-public water supplies, the environment and our society and economy more generally.

**Figure ES1: Overview of the Method Statements and their role in the development of the WRSE regional resilience plan**




The Resilience Framework Technical Report Consultation Document and the summary of the response to the consultation can both be found in the document library on the WRSE website.

# 1. Introduction

This Method Statement outlines the final framework approach that Water Resources South East (WRSE) has implemented to allow us to incorporate the concept of 'resilience' into our regional planning process. This framework helps to move us from a focus on securing public water services and managing the risk of droughts, to securing wider resilience across a series of connected water systems.

We recognise that the water resource systems across the South East of England are complex, multi-sector and interlinked, and that risks associated with drought events cannot be viewed in isolation if we are able to address the challenges and identify the opportunities that exist within the domain of water resources within our region. We also understand that future shocks and stresses are uncertain, and the way in which we plan to invest in improvements to our water resource systems needs to reflect that in order to be resilient in themselves.

The framework described within this document is therefore intended to allow us to evaluate and quantify 'resilience' so that we can incorporate the concept into our wider best value planning of water resources for the south east. We consider this is an important step towards a wider, more integrated understanding of water resources planning.

For more information on WRSE and its members, the development and purpose of the regional plan and how it fits into the national picture, please visit wrse.org.uk.

# 2. Feedback on our approach

As laid out in our document: 'Securing resilient water resources for South East England – our response to feedback on our resilience framework', we collated responses on our initial draft framework and have reflected them where appropriate within this document. The key changes we have made as a result of that consultation can be summarised as follows:

- We have carried out a full, systems mapping exercise of the key systems associated with water resources in the south east and ensured that the metrics we have used to measure resilience reflect the most important interactions between those systems.
- We have considered the south-east economic and social system as underlying the other three key systems and looked at how relevant feedback loops might affect our framework. That process specifically identified metrics relating to customer response during drought, and engagement with catchment management, which have been incorporated into the scoring metrics.
- We have clarified how the resilience framework fits in with and interacts with the rest of the best value decision making framework, particularly in relation to environmental value criteria, and we have enhanced the role of supporting catchment services in the resilience framework.
- Links to the national resilience assessment and Cabinet Office definitions of resilience have been made clearer and more explicit. The role of response and recovery is clearly identified, and the ability of investment programmes to evolve and incorporate innovation has been strengthened.
- The interactions with 'shortfalls' in the baseline system resilience, including parts of the public water supply system where there are known or suspected resilience issues, and catchment and soil health deficits for the water environment, have been made clearer.
- The water quality metric has been enhanced to include both the resilience of water resource options themselves, and the impact that changes might have on wider catchment water quality.
- We have implemented a carefully controlled process for managing subjective metric scoring to ensure, as far as is practical, that assessments are consistent and unbiased. This has been subject to an assurance review.
- We have avoided the need for metric or option weighting, with all benefits scaled according to an options contribution to a relevant regional deficit. Inputs relating to hazards and shock events other than drought have been clearly identified within the metrics.

# 3. Summary of the framework

The first question that arises is ‘what do we mean by *resilience* in this context’? There are a multitude of possible definitions and responses to this, and, in line with the National Infrastructure Commission, we have adopted this as a concept rather than a specific definition. In concept:

*‘Resilience is about the ability to continue to function effectively in the face of future challenges. The requirements to achieve it change over time, as challenges alter.’*[1]

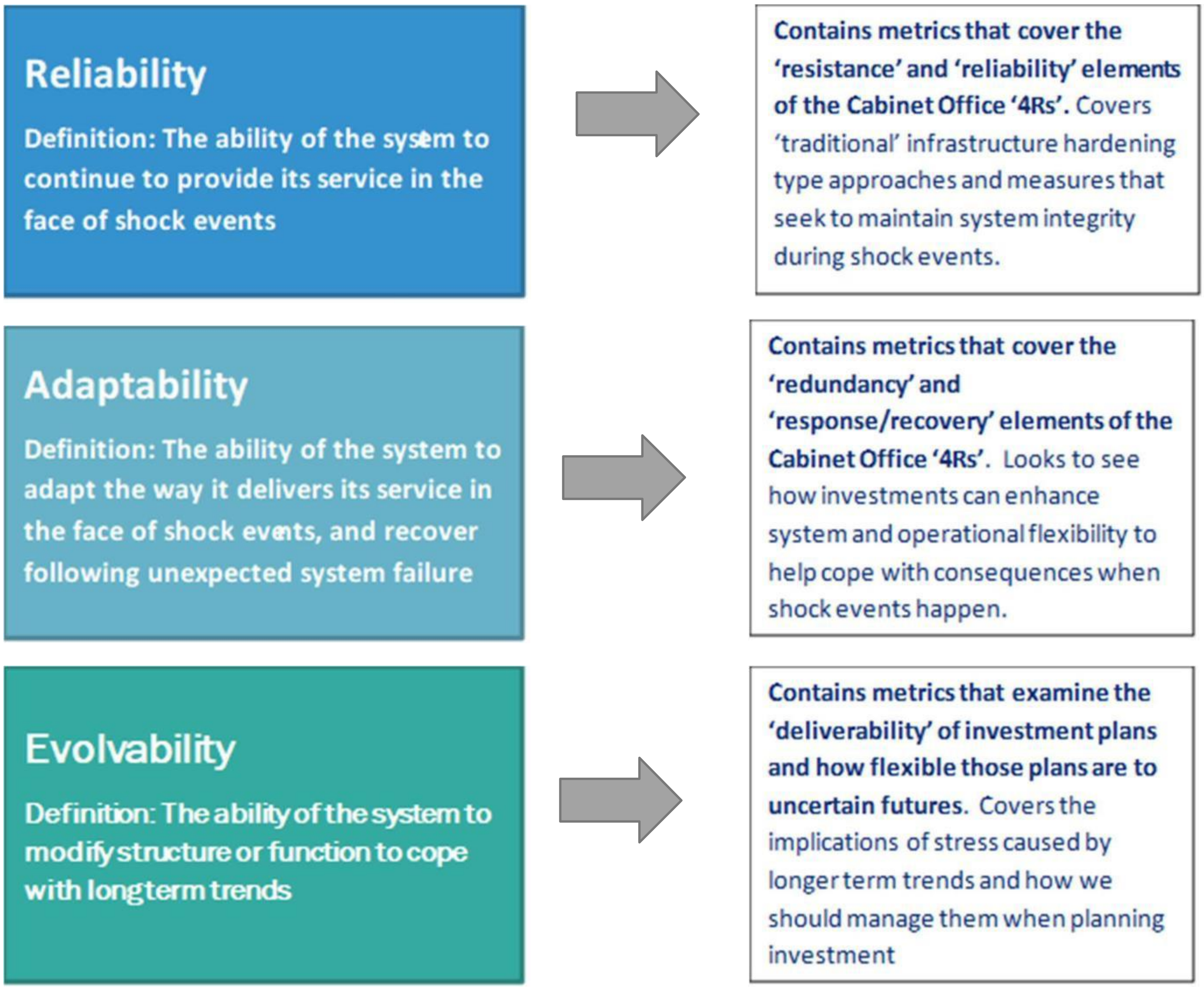
Whether or not a system can be considered to be functioning depends on whether or not it is able to provide the service that we desire from it. We explore the concept of service and how it relates to resilience later in this section.

Our resilience framework is based on the three key attributes of *reliability, adaptability,* and *evolvability.* These describe how our systems are able to cope both in the face of ‘shock’ events (transient events such as drought or pandemic that can act to disrupt the function of the system) and future ‘stresses’ (trends that affect the functioning of the system). These attributes have been modified from the framework proposed by Boltz and Brown’s ‘Resilience by Design’ approach[2], and one of the authors of that paper has been involved as an expert reviewer throughout the framework development.

We have chosen this method because it incorporates the required ‘resilience in the round’ approach recommended by Ofwat, and the 4R’s recommended by the Cabinet Office to understand the resilience of existing systems and extends this to include an assessment of how resilient our investment plans themselves are to future uncertainties. A summary of the three attributes and how they relate to the best practice recommended by the Cabinet Office and Ofwat is provided in the figure below.

[1] National Infrastructure Comission, 2019 Resilience Study Scoping Report

[2] Boltz, F., N.L. Poff, C. Folke, N. Kete, C. Brown, S. Freeman, J. H. Matthews, A. Martinez and J. Rockström. 2019. Water is a master variable: solving for resilience in the modern era. Water Security 8: 1000483. https://doi.org/10.1016/j.wasec.2019.100048




In our case it is important to note that the WRSE resilience framework sits within the wider 'Best Value' decision making framework. Within that framework, all of the value criteria described in the figure below are evaluated and considered when the decisions are being made about the preferred regional plan. That means value criteria such as carbon reduction, and the day-to-day condition of the environment are contained elsewhere within the best value decision making framework (the environment framework in that case). Similarly, societal resilience in the form of cost burden and economic considerations are evaluated elsewhere in the best value decision making framework.

The framework presented here concentrates on the ability of regional water resource systems to respond to shocks and manage long term stresses that might affect our ability to invest in and improve that response. Factors such as natural capital, biodiversity net gain, carbon emissions and affordability are not included in this resilience framework as that would mean they are double counted within the best value framework.


Covered by this framework

As well as the over-arching concept and definitions of the three resilience attributes, there are two further key concepts that inform our resilience framework.

# Systems approach.

In accordance with accepted best practice, our approach to resilience is *systems based*. That is, we evaluate the resilience of the systems of interest as a whole, with a view as to understanding how well they can continue to provide the required service in the face of shock events and long-term stresses. In this case there are three primary systems of interest: the **public water supply (PWS) system,** the **water environment (environment) system** and the **non-public water supply (non-PWS) system** (i.e., other sectors that use water from sources other than the public utilities). We have undertaken a detailed process of **systems mapping** to identify how these systems interact with each other and how they interact with the wider **south east regional socio economic system**, and used this understanding when developing our scoring metrics (see below) and the approach to implementation described in the next section.

## Scoring metrics.

The three core attributes (reliability, adaptability and evolvability) of the resilience framework are not specific enough to allow us to measure them directly, so we apply a number of *metrics* that allow us to evaluate the resilience of the existing systems and proposed investment plans. These metrics have been identified through a process of *systems mapping* and are deigned to allow us to quantify the impact that potential options for regional investment might have on the resilience attributes for each system.

Our resilience framework therefore looks at the three systems and examines how well different water resource programmes that are being considered by WRSE might help those systems provide the resilient service that we want from them, as summarised in the figure below.

| What is the SYSTEM? | What does it (typically) include? | What is the *service* we want? |
| --- | --- | --- |
| Public water supply | Operation, infrastructure and supply chain associated with abstraction, treatment, and bulk network distribution, plus the nature of water demand on the system | Secure supplies that maintain availability to customers irrespective of hazards that might affect water resources |
| Non-Public Water Supply (other Sectors) | Management and infrastructure for abstraction and economic activities that rely on that water (crops, industrial processes etc) | Predictably available water resources that support relevant social and economic activities |
| Water environment | Catchments, including soils and hydrological processes, along with water bodies and their ecology | Catchments and water bodies that are able to help maintain water quality and ecology during and after shock events |

We carried out *systems mapping* to understand how these three interact within the south east regional context ('system of systems') and make sure we are measuring all those metrics that describe the relevant interactions

We defined the service we want to understand how different options and investments help avoid failure of the service (i.e. promote resilience). We measure this through our option metrics

In summary, our resilience framework is designed to allow us to:

- Define the three systems that we need to consider, and understand how they interact within the wider south east context.

- Define the service that we desire from these three systems and the attributes of resilience that we consider will help to maintain this service over the long term.
- Understand how all of the water resource options that we have identified as being potential investments for the regional ~~P~~lan can contribute to our three resilience attributes, in the context of the three systems that we have identified.
- Identify metrics through which we can score the resilience contribution of each option and potential investment portfolio, based on the systems mapping that we have undertaken in the context of the wider south-east region.
- Evaluate the benefits that the plan has on the baseline regional resilience (the 'resilience shift'), in terms of the number, type and extent of known pre-existing resilience issues that are addressed by the planned water resources enhancements.

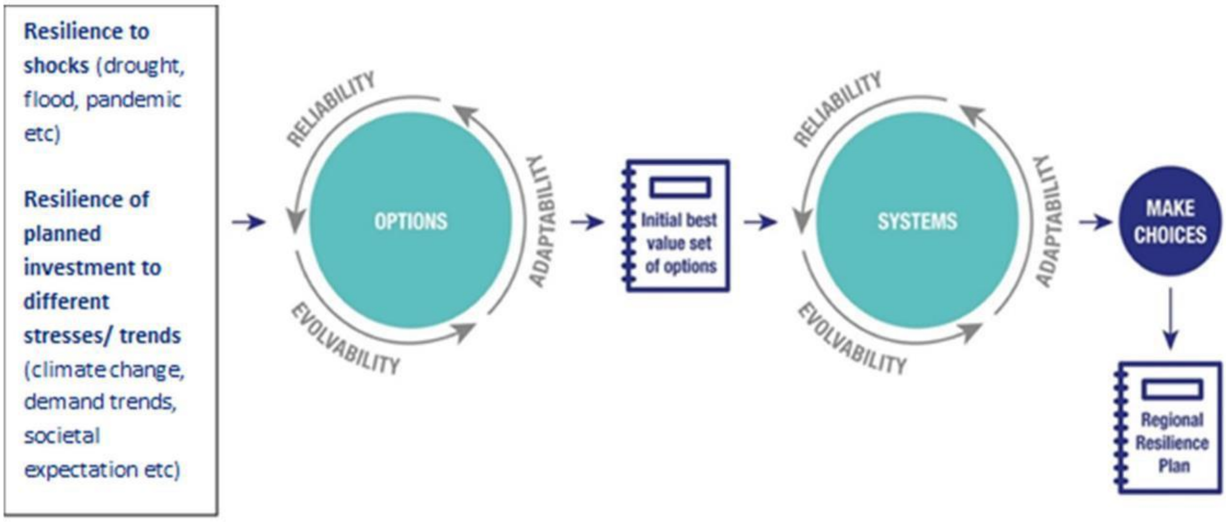
# 4. How we have applied the framework

## Concept and purpose of the framework application

The resilience framework was designed to allow WRSE to consider how all the options, schemes and strategies that have been identified as potentially contributing to water resources in the region might affect the resilience of the PWS, non-PWS and water environment systems. Not all options/schemes will affect all aspects, but the metrics have been designed to ensure that all reasonable benefits have been captured, and the scoring system is designed to allow different options, strategies and schemes to be compared on a reasonably consistent basis. It is meant to be comparative, not absolute, and we recognise that there will be more variability for some metrics. That is an expected outcome of the framework, i.e. it helps us understand how and where the regional plan can affect the resilience of water resources in the region.

Because the framework is designed to score resilience in a consistent, comparable way, we can use it to compare the overall resilience of potential water resource programmes that we identify during the best value decision making process. The framework is essentially applied in two stages:

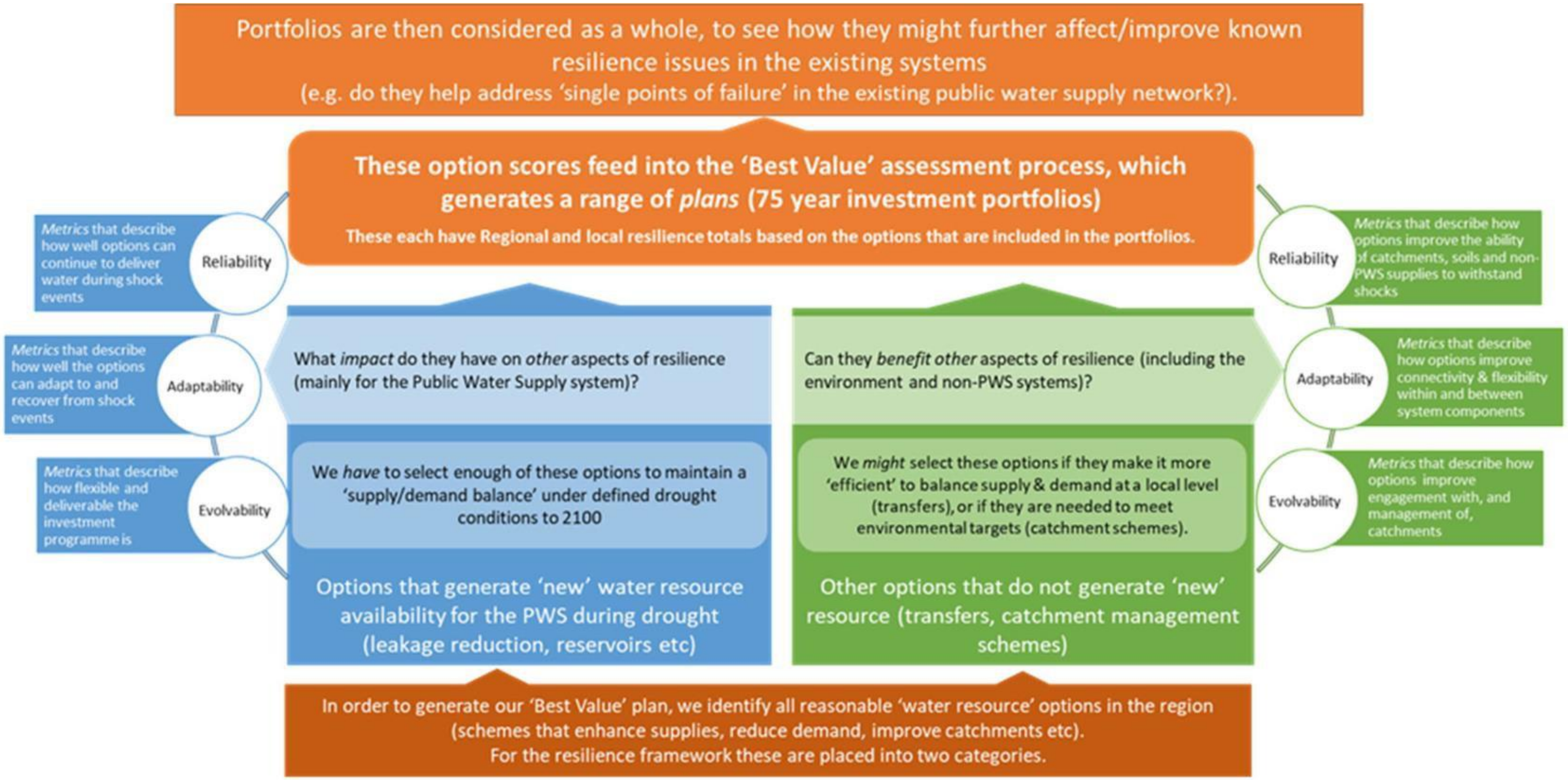
1. As a scoring method for individual options that the regional plan could consider to address its identified water resource needs
2. At a ‘portfolio’ level (i.e. as a whole across the proposed investments within a water resource programme and the existing systems) once a range of potential plans have been identified. This is summarised in the figure below.




One of the main points that we had to account for in the framework was that the majority of options have been designed to address a specific requirement, primarily related to drought resistance (supply/demand benefit) or environment (enhancing natural capital, biodiversity net gain etc), but those options also have a potential impact on our resilience metrics, and this could occur across more than one system. We also had to account for options that either directly, or as a result of their nature, helped to address existing resilience deficits within the *existing* PWS, non-PWS and environment systems. For example, a catchment management scheme may be designed to enhance water quality specifically for PWS supply capability, but in doing so it might also help to improve known soil health issues in the catchment and help promote public involvement in the catchment, which, in turn, enhances customer co-operation during drought events.

The framework addresses this by compartmentalising and scoring individual options prior to the generation of candidate best value water resource programmes, and then by evaluating those programmes against existing known system issues, as shown in the Figure overleaf.

# Summary of the process used to generate resilience scores for candidate water resource programmes



# 5. How we have measured resilience for options and programmes

As indicated above, the performance of options (covering demand management strategies, supply options, transfers and catchment schemes) in relation to resilience is scored through the use of metrics. Further metrics are then scored once candidate investment programmes have been identified. Details of the scoring process and guidance are provided in the Technical Appendix to this Method Statement.

These metrics were identified and then refined through an extensive process of systems mapping, which identified the key contributors to water resource resilience, and the interactions between the systems. This systems mapping is described in the WRSE report 'WRSE Resilience Phase 2: Multi-Sector and Systems Approaches'. A summary of all of the resulting metrics that were identified, separated according to the benefitting system and the type of resilience effect that they have, is provided below. To clarify, the metrics themselves are indicated by the 'R1, R2, R3..' type descriptors below. The sub-headings (e.g. 'uncertainty of performance') have been included purely to give a high level conceptual description of the nature of the metrics contained in that sub-heading

*Overall metric summary table*

| System attribute | RELIABILITY | | ADAPTABILITY | | EVOLVABILITY | |
|---|---|---|---|---|---|---|
| System Indices | | UNCERTAINTY OF PERFORMANCE | | TIMING AND WARNING OF EVENTS | | FLEXIBILITY AND DIVERSITY OF OPTIONS |
| Metric | R1 | Uncertainty of supply/demand benefit | A1 | Expected time to failure (PWS) | E1 | Scalability and modularity of interventions |
| Metric | R2 | Breaches of flow and level proxy indicators | A2 | Duration of enhanced drought restrictions | | |
| System Indices | | ABILITY TO PERSIST WITH PLANNED FUNCTIONS | | ABILITY TO RESPOND TO AND RECOVER FROM UNEXPECTED FAILURES | | DELIVERABILITY OF PLANNED CHANGES |
| Metric | R3 | Risk of failure due to physical hazards | A3 | Operational complexity and flexibility | E2 | Intervention lead times |
| Metric | R4 | Availability of additional headroom | A7 | Customer engagement with demand restrictions | E3 | Reliance on external bodies to deliver change |
| System Indices | | RESILIENCE OF SUPPORTING SERVICES | | SYSTEM CONNECTIVITY AND EASE OF SYSTEM RECOVERY | | MONITORING AND MANAGEMENT OF CHANGE |
| Metric | R5 | Catchment / raw water quality risks | A5 | PWS system connectivity | E4 | Flexibility of planning pathways |
| Metric | R6 | Capacity of catchment services | A4 | WRZ connectivity | E5 | Collaborative landscape management |
| | | | A6 | Inter-catchment connectivity | | |
| Metric | R7 | Risk of failure of supporting service due to exceptional events | | | | |
| Metric | R8 | Soil health | | | | |

**Metric applied to:**
- PWS: Public water supply
- N-PWS: Non-public water supply
- ENV: Environment

★ Evaluated for the baseline system as well as for investment options

**Metric calculated by:**
- Semi-qualitative subjective scale
- Calculated (at option and portfolio level)
- Calculated (only as part of portfolio)

In accordance with the overall concept, the approach to scoring has been carefully designed to allow the resilience impacts of options to be simply added together without any need for subjective weighting to generate an overall score for each investment portfolio. At the same time, it is important that the resilience scores generated for different portfolios can be compared on a consistent basis. These objectives have been achieved through the application of two over-arching principles to the scoring process:

1. All metrics are described according to the same 5-point scale approach, ranging from 'notably less resilient (2 points below an average), through to 'notably more resilient' (2 points above average). There is a variety of ways in which metrics have been scored, from quantitative to semi-qualitative, as detailed in the technical appendix, but the key point is that impacts are all scored on a comparable basis.
2. The *impact* that individual options have on the overall metric scoring across the region is scaled according to the size of benefit they provide to the relevant key regional need. For example, if a water supply option can contribute 100Ml/d to an overall regional supply/demand deficit of 1,000Ml/d, then its *impact* value for a given metric (e.g. R1) is equal to its metric score * 100/1000. Using this 'scaling approach' means that all option impacts can be added in a consistent way to generate overall resilience scores for regional investment programmes.

These two principles mean that any potential investment programme that is being considered within the best value decision making process can be compared on a meaningful basis, against any other programme according to a single overall attribute score, which is equal to the sum of the impact values from options and strategies in that programme. Each of the resilience attributes (reliability, adaptability and evolvability) has this single overall attribute score for each programme, and the contribution of any individual scheme/option is visible based on the impact value it has for each metric.

The actual process for scoring resource options, demand management strategies and catchment schemes has been carefully managed and assured to address the risk of bias or misinterpretation when scoring has been carried out. This process is described in the relevant assurance report. The key elements can be summarised as follows:

- For water company supply schemes, relevant metrics were all initially evaluated by the WRSE team on a generic basis according to type (e.g. desalination plant feeding a system with limited/no storage). The generic scores were then challenged in an open workshop format across all companies and amended where appropriate logical/conceptual cases were made and accepted. The WRSE team then met with water companies on an individual basis to define 'bespoke' scores for individual schemes, mainly for larger options. Again, this was carried out on a challenge/accept basis, where changes to the generic scoring were only accepted by the WRSE team where appropriate logical and conceptual representations were made.

- For demand management strategies, relevant metrics were scored centrally by the WRSE team, based on the type of demand management initiatives contained within that strategy.
- Catchment and soils enhancement schemes (metrics R6, R8, E5) were evaluated according to the amount of movement that they provided towards the desired standard, according to the 5-point scale described above. This was done by the WRSE team using the baseline assessment as described in the next section.
- Additional programme level benefits (metrics R4 and A4) were evaluated using the investment model. For the draft regional plan the portfolio level metric assessments were not included for metrics R2, A1, A2, A6 and E4, while A5 was only used as part of assessment of the benefits of plans in addressing baseline resilience hotspots.

# 6. Evaluating impacts on baseline resilience issues

The resilience framework was not only designed to allow an evaluation of the level of resilience associated with the 'new' water resource that is provided by water resource options and demand management strategies. The existing PWS, non-PWS and environment systems were evaluated to understand where there may be deficiencies in the existing systems in relation to the metrics covered by the framework. This is important because the investments proposed by the regional plan can affect these pre-existing issues, and the assessment of how proposed regional investment programmes might affect these existing issues is an important part of the programme level scoring process. Baseline assessments were therefore carried out on the following aspects of the existing systems:

- For the PWS systems, interviews were held with all water companies to understand where there are likely to be concerns in the base year (2025) within their existing networks relating to metrics R3 (vulnerability to physical shocks), R5 (water quality risks), R7 (vulnerability to other exceptional events), A3 (system flexibility and complexity) and A5 (system connectivity). These interviews were used to generate a geographically based 'hotspot' assessment, similar in nature to the approach used in long term wastewater management planning. The initial regional 'candidate' portfolios were then reviewed to determine which schemes and combinations of schemes have the potential to feature in the final Regional Plan. These were then reviewed against the 'hotspot' assessment to understand where scheme combinations might benefit the existing supply system and enhance the overall resilience score for those portfolios that contain such beneficial scheme combinations.
- For the environment system the work carried out on catchment strategies for the environmental framework was used to determine where those strategies might benefit existing catchment resilience issues. This generated the scores for metric R6. Similarly, a regional assessment was carried out to determine the soil quality for all major catchments, and the potential benefits that catchment management schemes could have on areas of degraded soils. This generated the scores for metric R8.
- Although discussions were held with non-PWS system (multi-sector) representatives and important qualitative understanding was taken from those discussions, the outputs were not sufficiently detailed to allow a quantitative baseline impact assessment in the same way as the PWS and environment systems.

# 7. Next steps

An initial version of this document was consulted upon between 1st August 2020 to 30th October 2020 and comments received during this time have been incorporated in this version.

We have also reviewed this document against the final WRPG and supplementary guidance notes issued by the regulators.

If any other further relevant guidance notes or policies are issued then we will review this Method Statement to see if it needs to be updated.

When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

# Appendix 1: WRSE Updated Resilience Technical Appendix

## Introduction

The purpose of this document is to provide clear guidance and advice for practitioners or stakeholders seeking to technically understand the Resilience Framework as part of the best value modelling process. This will ultimately ensure that the resilience framework is applied consistently and as intended by WRSE.

This document is related to the WRSE Resilience Method Statement (2021). The method statementis intended to provide a detailed description of the resilience conceptual model we are using and why we have selected it. In addition, the method statement provides an overview of our engagement relating to the resilience framework, highlighting how we have incorporated feedback in iterations of the framework. Practitioners or organisations reading this document should read the method statement document first.

This document covers the following sections:

1. **Introduction**: Provides an overview of the document purpose and structure as well as its relationship to other documents.
2. **Background**: Provides an overview of WRSE's definition of resilience and overall approach to resilience.
3. **Guidance for organisations**: Provides an overview of the key information for different organisations and where it is located in the report.
4. **Metrics** – provides an overview of the resilience framework and a schedule of all metrics, including definitions / descriptions. This section also describes the scoring approach for each metric.
5. **Amalgamating metric scores** – this section provides summary guidance for amalgamating individual metric scores to produce attribute level scores.

- **Appendix A: Aggregation of metrics for EBSD modelling –** this appendix provides a detailed description the mathematical approach to scoring, scaling and aggregating metrics for each of the three resilience attributes for the PWS system.
- **Appendix B: Detailed metric scoring guidance** – this appendix provides detailed guidance for scoring individual metrics.
- **Appendix C**: **Mapping to other Resilience Frameworks** – this appendix provides detailed guidance on mapping to other frameworks.

# Background and Systems Mapping

We have been developing our resilience framework to support the best value regional plan since late 2019.

In our approach to the development of the resilience framework, we have used the following working definition:

> *Resilience is the ability of a system to reliably maintain, recover, adapt and evolve system performance in face of shocks and trends that would disturb it.*

In addition to this, our ambition for resilience spans water across the whole south east. This is something we articulated in our consultation on the draft resilience framework in the summer of 2020. In the consultation we also emphasised that achieving this ambition requires a perspective which is broader than public water supply (PWS) alone. Therefore, the WRSE conceptual framework for resilience addresses water in the context of the four following main systems:

- Society and economy
- Multi-sector e.g. agriculture, industry.
- Public water supply system
- Environment (which underpins and supports the other systems)

As we developed the resilience framework, we have mapped the interconnections and interdependencies of these systems. In doing this, we chose to refine the scope of our outlook on resilience to focus more specifically on the resilience of water supply services in relation to these systems. We have therefore adjusted the list above to the following, which has formed the basis of the framework of metrics we describe in **Section 4** of this report.

- Public water supply system (PWS)
- Non-public water supply system (non-PWS)
- Environment system

The high-level systems mapping that was carried out to evaluate the relationships and measurement metrics that are appropriate for the Resilience Framework against the south east regional system and PWS system are replicated in Figure 1 and Figure 2. A more comprehensive version of the system maps, providing detail on systems in the environment, multi-sector systems and more information on the PWS, is available in the report 'WRSE Resilience Phase 2: Multi-sector resilience and systems approaches'. Figure 1 shows value creation and transfer across the systems. The orange lines indicate value flows that could be measured in terms of the six capitals framework. The blue lines are also multi-capital flows, but are coloured blue to indicate that the principal value is the provision of water. Black lines indicate the relevance of the resilience framework to the system. System resilience enables the system to maintain health and deliver its function in delivering valuable outputs. Figure 2 provides a high level PWS system map. Arrows indicate influence of upstream nodes on downstream nodes. The gold node is the key system function which is the supply demand balance. The yellow nodes represent outcomes to the social and economic system. The red node represents regional coordination.

*Figure 1 Systems Mapping of the Water Resources Related Value Chain Across the South East of England*

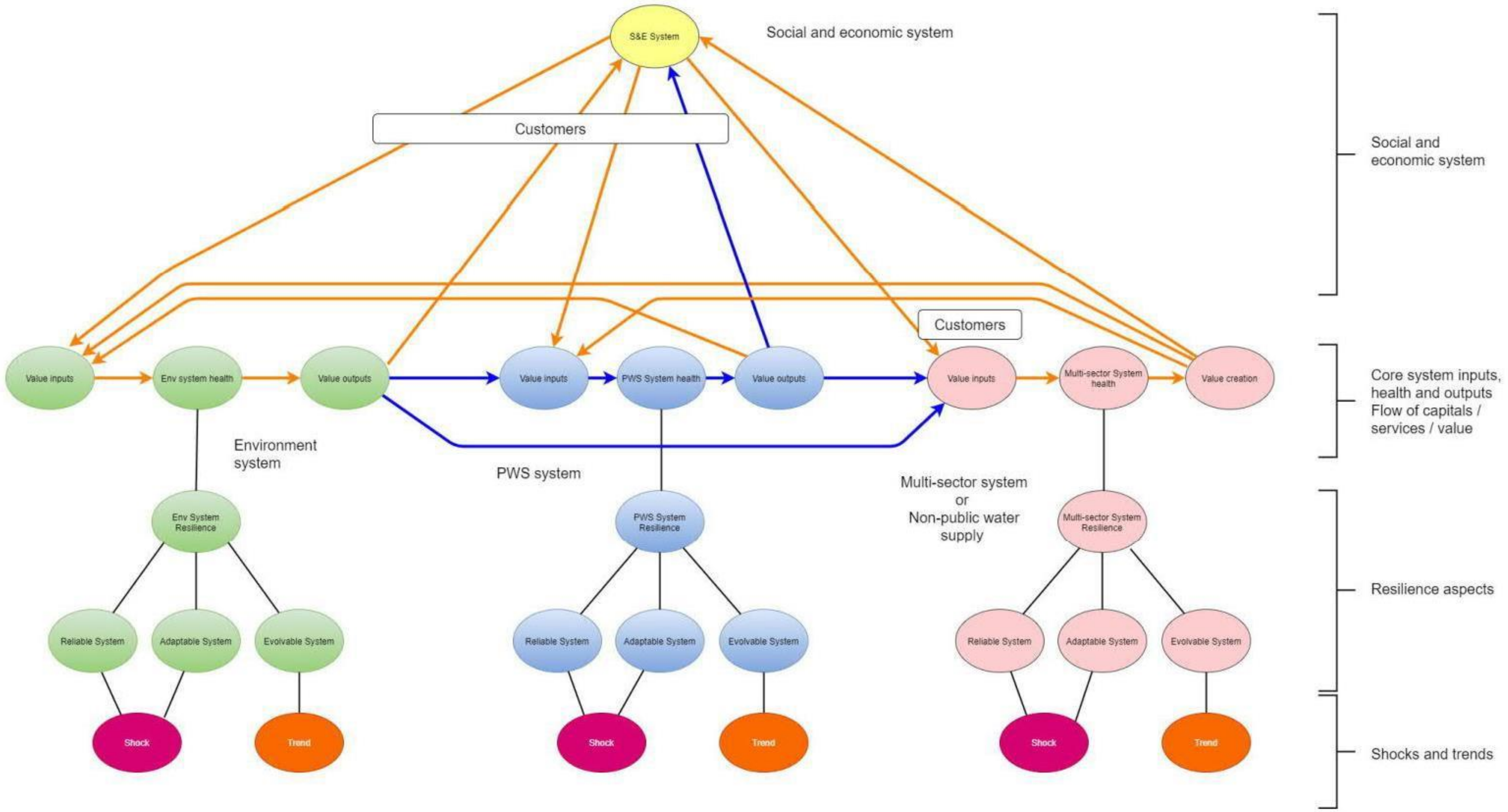
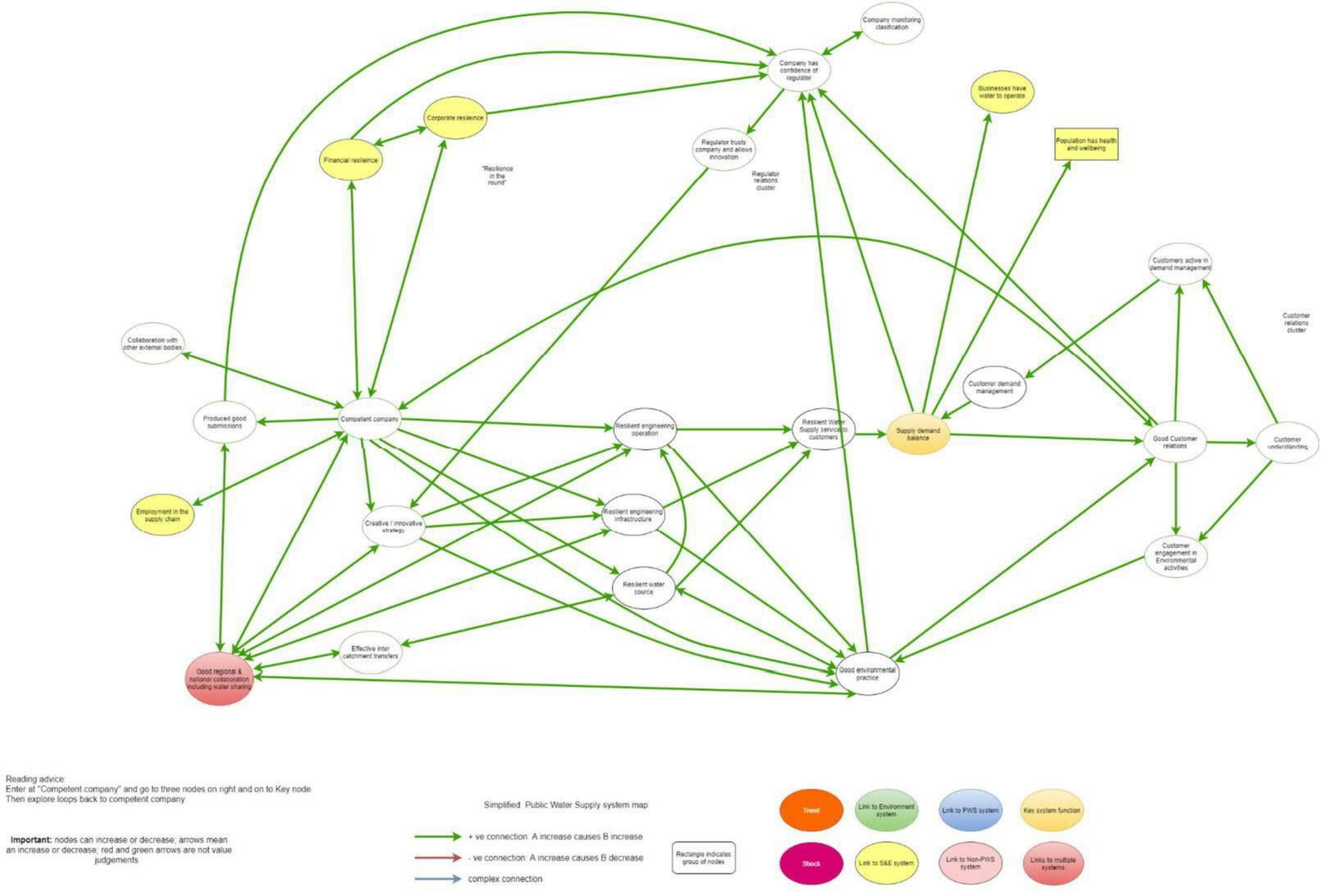
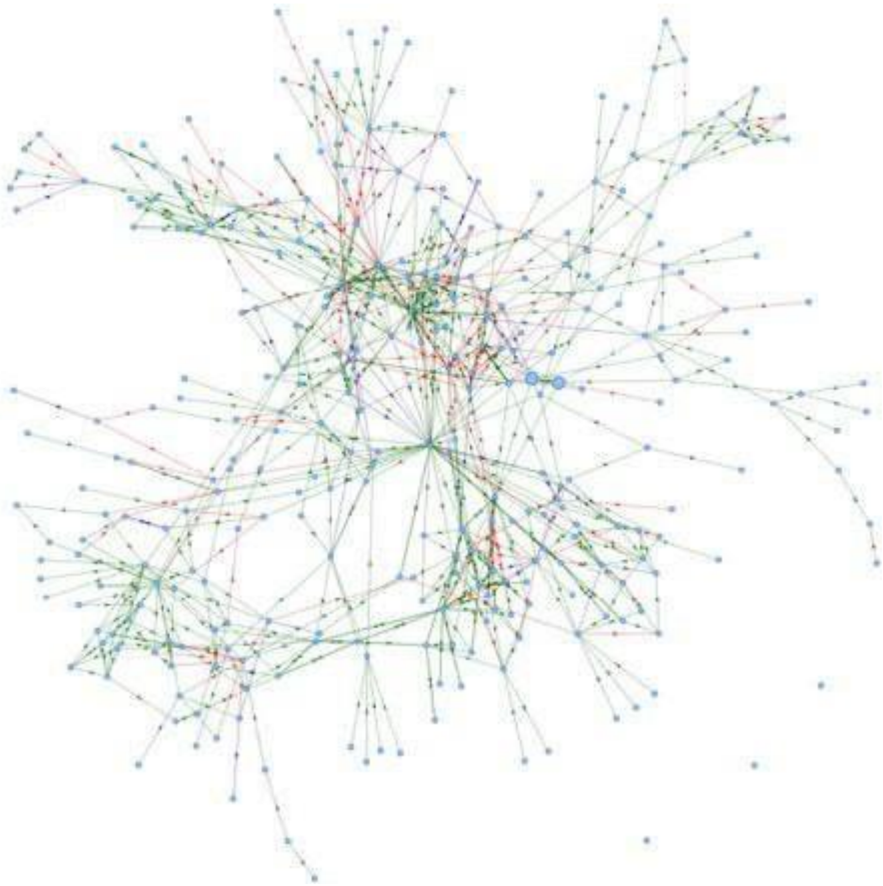


*Figure 2 High Level Systems Map of the Public Water Supply System*



As described in the main Resilience Framework method statement, the south east regional 'social and economic' system has not had resilience metrics or scores identified, rather the system mapping was used to identify the interaction between systems in the context of the south east regional 'system of systems'. The approach and relevant analysis are described in report 'WRSE Resilience Phase 2: Multi-Sector and Systems Approaches'. An integrated tool was used in the systems mapping, and node and connection analysis was carried out based on a fully linked 'system of systems'. The complexity of the network developed in that tool is illustrated in Figure 3 below.

*Figure 3 Replication of the Full Integrated Systems Map Developed for WRSE*



This map shows all of the PWS, multi-sector and environment system nodes and connections that were mapped and integrated for the Phase 2 analysis

This mapping was used to check the applicability and comprehensiveness of the metrics that had been developed for Phase 1. From this process, additional metrics relating to soil health, catchment planning and customer responsiveness to drought interventions were identified as being relevant and required for the WRSE Regional Plan.

# Metric Scoring and Assessment Guidance

In order to evaluate and quantify the resilience impacts of the different investment portfolios that can make up the Regional Plan, it is necessary to score the benefits using 'metrics'. This section provides an overview of where key information and guidance relating to the description, scoring and amalgamation of metrics is located in this document. These components form the technical elements of the Resilience Framework.

## Concept, Schedule and Description of metrics

- A full schedule of metrics, including descriptions, is provided in Table 1 in **Section 4: Metrics**
  - Metrics relevant to the public water supply (PWS) system are indicated with a blue ellipse on Table 1 and are described in Table 2
  - Metrics relevant to the environmental system are indicated with a green ellipse on Table 1 and are described in Table 3.
  - Metrics relevant to the non-public water supply system are indicated with a pale pink ellipse on Table 1 and are described in Table 4.

## Metric scoring

- Guidance for the scoring of metrics, including scales for subjectively scored metrics is provided in **Appendix B**.
  - Subjectively scored metrics are identified in **Section 4: Metrics**.

## Developing scores for the 3 resilience attributes

- The detailed approach and methodology for generating scores for each of the three resilience attributes is provided in **Section 5: Amalgamating metric scores** and **Appendix A.**

## Evaluation of Options Primarily Benefitting PWS

- These organisations had to consider the metrics in Table 2 in **Section 4: Metrics.**
  - If there are elements of the scheme which relate to the environmental system organisations will need to consider Table 3 also.

## Evaluation of Options Primarily Benefitting Non-PWS Water users

- These organisations had to consider the metrics in Table 4 in **Section 4: Metrics.**
  - If there are elements of the scheme which relate to the environmental system organisations will need to consider Table 3 also.

**Note:** In some cases, metrics are repeated across tables. This is because they are relevant to assessment in the context of more than one of the systems.

For further detail on the development of the resilience framework and how we have incorporated feedback from our engagement activities into our approach to resilience please refer to the main method statement.

# Metrics

## Overarching concept and hierarchy

The framework we have developed to assess and characterise the resilience of our three systems of interest (PWS, NPWS, Environment), is designed according to the following logical model and hierarchy. Figure 4 below outlines the framework elements, actions needed and descriptions.

In addition to this, it is worth noting that the 'Attributes' and 'Groupings' elements of the framework are relevant across all of the WRSE external systems (PWS, Non-PWS and Environment). Some 'Metrics' may be relevant across different systems, **however not all metrics are relevant to each system.** The relevant metrics for each system are shown on Tables 1,2,3,and 4.

## Attributes

Figure 4 below outlines the three resilience attributes of the framework.

*Figure 4 Summary of the Three Attributes that form the Resilience Framework*

### Reliability

**Definition:** The ability of the system to continue to provide its service in the face of shock events

For the PWS system, this is the ability of the water supply system to continue or re-start operating as planned in the face of shock events

PWS example: good quality, confined groundwater source that is protected from pollution events and is not vulnerable to drought or climate change.

### Adaptability

**Definition:** The ability of the system to adapt the way it delivers its service in the face of shock events, and recover following unexpected system failure

For the PWS system, this is the ability of the water supply system to change operations to continue service in the face of shock events and recover after unexpected failures

PWS example: a cross company bulk supply transfer that can be easily mixed with the existing network water quality and provides backup capacity in the event of an emergency

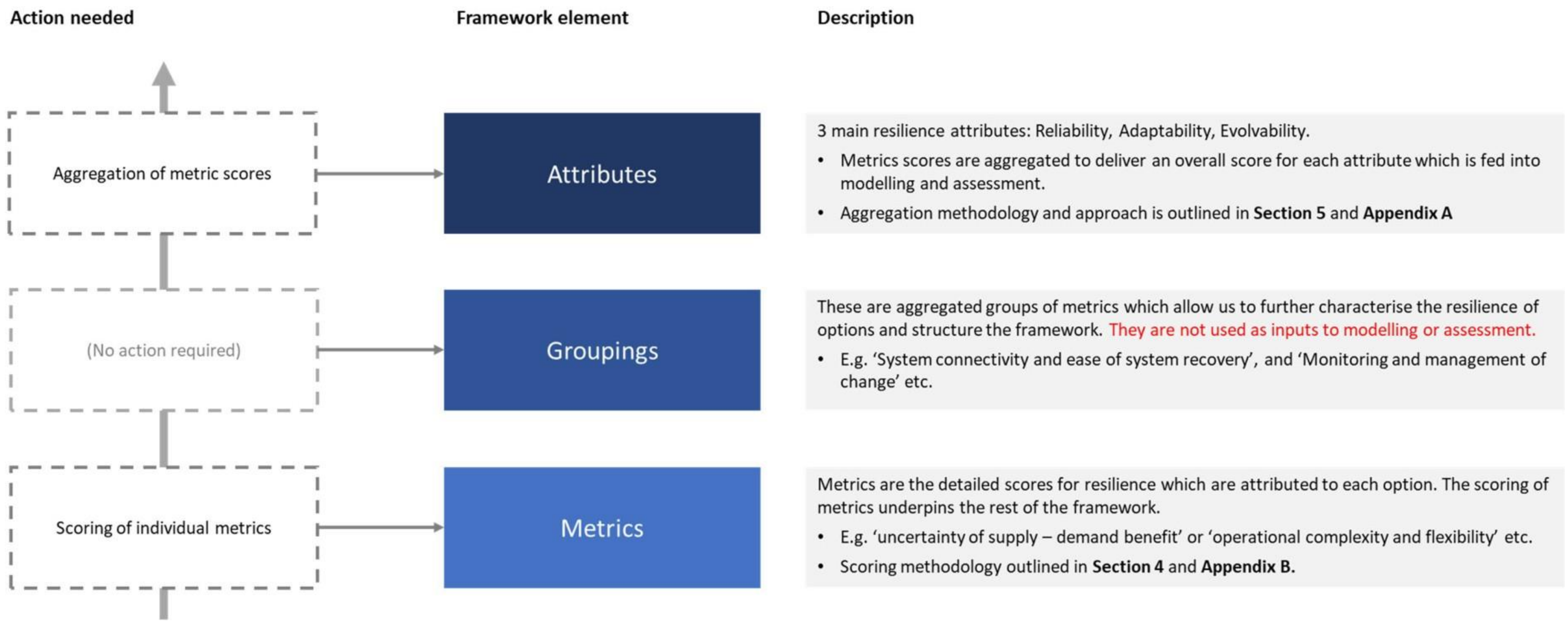
### Evolvability

**Definition:** The ability of the system to modify structure or function to cope with long term stresses or trends

For the PWS system, this is the ability to deliver and adapt water supply investments in the face of uncertain futures and changing trends

PWS example: a smart metering based demand management strategy that contains staged plans for behaviour change and reducing customer wastage, with backup elements to address any shortfalls against targets

*Figure 5: Framework concept*



## Metrics

There are the following general observations to consider regarding the metrics of the resilience framework:

- Most metrics used for the PWS system are only applicable to it, although there is a small amount of overlap with metrics for other systems.
- The metrics used for Non-PWS and Environment are largely common across both systems.
- **Note:** For the environmental system there are a large number of metrics associated with SEA, biodiversity net gain and carbon emission that are included in the WRSE Best Value modelling but do not form part of this *operational resilience* framework.

All of the metrics in the framework, across all of the systems, can be characterised according to 3 main categories of assessment method:

1. Metrics that require evaluation at the option (intervention) level and require a guided but subjective semi-qualitative assessment:
    - These metrics are indicated with an orange box on Table 1 and orange shading in Tables 2,3,4 .
2. Metrics that require evaluation at the option (intervention) level but can be objectively analysed through modelling or use of existing data sets.
    - *In a number of cases the evaluation is only required for strategic level options, and the metric is re-calculated at a latter stage for the investment portfolio as a whole.* These metrics are indicated with a salmon pink box on Table 1 and salmon pink shading in Tables 2,3,4 .
3. Metrics that are evaluated at the portfolio level only.
    - These metrics are indicated with a blue box on Table 1 and blue shading in Tables 2,3,4 .

★ Starred metrics are evaluated for the baseline system as well as options/portfolios. This is because the benefits from options/portfolios are either calculated based on the degree of change from the baseline, or there are synergistic opportunities for the option/portfolio to address identified resilience concerns in the baseline system. .

The outline descriptions of the metrics, grouped according to system, are provided in Tables 2 to 4 below.

*Table 1 Overall metric table*

| System attribute | RELIABILITY | | ADAPTABILITY | | EVOLVABILITY | |
|---|---|---|---|---|---|---|
| System Indices | | UNCERTAINTY OF PERFORMANCE | | TIMING AND WARNING OF EVENTS | | FLEXIBILITY AND DIVERSITY OF OPTIONS |
| Metric | R1 PWS | Uncertainty of supply/demand benefit | A1 ★ PWS | Expected time to failure (PWS) | E1 PWS | Scalability and modularity of interventions |
| Metric | R2 ★ N-PWS ENV | Breaches of flow and level proxy indicators | A2 ★ PWS N-PWS ENV | Duration of enhanced drought restrictions | | |
| System Indices | | ABILITY TO PERSIST WITH PLANNED FUNCTIONS | | ABILITY TO RESPOND TO AND RECOVER FROM UNEXPECTED FAILURES | | DELIVERABILITY OF PLANNED CHANGES |
| Metric | R3 ★ PWS ★ | Risk of failure due to physical hazards | A3 ★ ★ PWS | Operational complexity and flexibility | E2 PWS | Intervention lead times |
| Metric | R4 PWS | Availability of additional headroom | A7 PWS | Customer engagement with demand restrictions | E3 PWS | Reliance on external bodies to deliver change |
| System Indices | | RESILIENCE OF SUPPORTING SERVICES | | SYSTEM CONNECTIVITY AND EASE OF SYSTEM RECOVERY | | MONITORING AND MANAGEMENT OF CHANGE |
| Metric | R5 ★ PWS N-PWS ★ | Catchment / raw water quality risks | A5 ★ PWS | PWS system connectivity | E4 PWS | Flexibility of planning pathways |
| Metric | R6 ★ ENV | Capacity of catchment services | A4 PWS | WRZ connectivity | E5 N-PWS ENV | Collaborative landscape management |
| | | | A6 N-PWS ENV | Inter-catchment connectivity | | |
| Metric | R7 ★ PWS | Risk of failure of supporting service due to exceptional events | | | | |
| Metric | R8 ★ N-PWS ENV | Soil health | | | | |

**Metric applied to:**
- PWS Public water supply
- N-PWS Non-public water supply
- ENV Environment

★ Evaluated for the baseline system as well as for investment options

**Metric calculated by:**
- Semi-qualitative subjective scale
- Calculated (at option and portfolio level)
- Calculated (only as part of portfolio)

## Key Note on PWS Option and Portfolio Scoring

It should be noted that PWS development options form four distinct groups for the purposes of assessment:

1) Options that provide a 'supply/demand' benefit. These options are scored against all metrics *except* R6, R8 and A4. The score is evaluated for the scheme elements that are required to *generate* the benefit (supply DO, or demand reduction), and general score on a 5 point scale depending how resilient they themselves are. If the scheme is separated into stages of development, then the associated DO is assigned to each stage. The scheme needs to be scored overall according to the point of output – in most cases the 'weakest link' will dictate the score, but where there are storage elements (e.g. feed into a reservoir) then this can be mitigated. Where there are 'resilience' bulk transmission schemes that are enabled by water resource options (i.e. they are only possible once the associated resource is built), then these are evaluated as additional benefits (based on the existing system resilience problems that they address) and *added* to the DO scheme scores (e.g. if the DO scheme scores a 3 against R3, but there is an associated pipeline supply that addresses an existing very significant 'hotspot' problem, then the cost of the pipeline scheme can be added and the R3 score for the DO option is increased to a '5').
2) Intra regional transfer schemes. These are not scored, but instead provide a benefit against metric A4 – i.e. they enhance the connectivity of the PWS system across the south east.
3) Options that provide primarily environmental benefits (e.g. catchment management). These score primarily against metrics R6, R8 and E5, and generally add to the overall score of a portfolio, increasing by up to +2 points. Where they do have a notable DO benefit then they *also* score against the other metrics, as described for the other supply/demand balance schemes above
4) 'Resilience only' options that do not provide a supply/demand benefit, but address known problems in the baseline resilience for either the PWS or non PWS systems. These reflect the value of the underlying 'hotspot' problem that they address (assessed for metrics R3, R5, R7, A3 or A5), generating additional benefits of +1 or +2 to that metric.

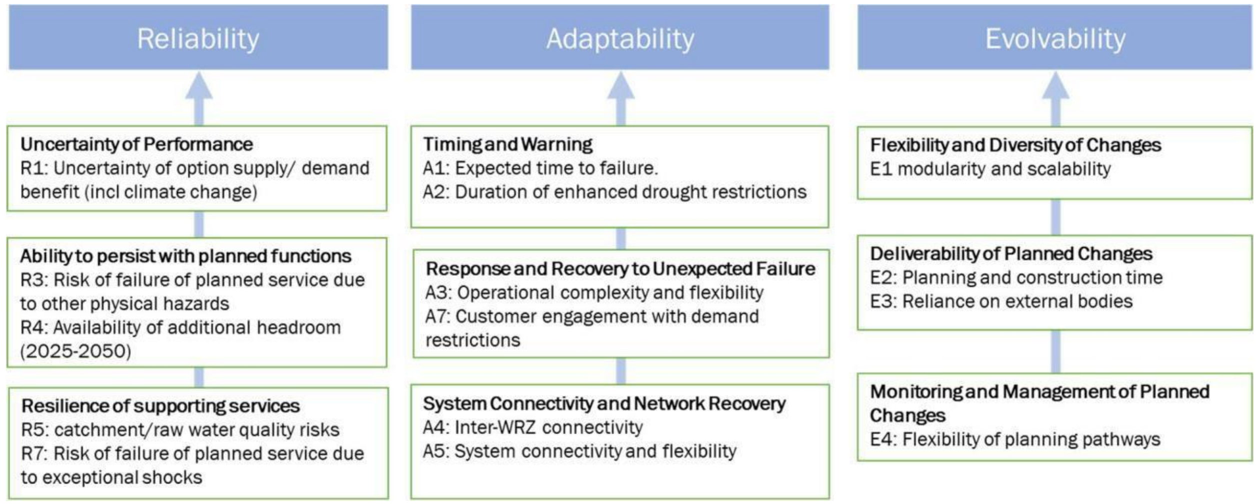
The portfolio level benefits are calculated where appropriate (R2, R4, A1, A2, E4) through the WRSE process, either using the Regional System Simulator (RSS), or the EBSD optimisation model.

## Key Note on Environmental and non-PWS Scoring

As described in Section 5, these are assessed as beneficial metrics, either as an additional benefit provided by PWS options that are primarily intended to generate supply/demand (drought) improvements, or, more commonly, as schemes that are intended to deliver environmental enhancements. This means that the scoring is generally evaluated as 0 (no impact) through to +2. This is equivalent to the PWS approach, as they are scaled according to the area or river length etc that is not achieving the required state in the baseline, so a +2 will generally relate to a change from the default, poor condition to a ';'good' condition for that metric. See Section 5 for more information on how metrics are amalgamated and how we have ensured that benefits are comparable across metrics.

*Table 2 PWS Metric descriptions*

[A summary of the metrics that support the PWS system is shown in advance of the table, followed by the metric description and assessment colour coding]




| Metric | Scoring | Description | Scoring Approach |
|---|---|---|---|
| R1: Uncertainty of options supply/demand benefit | Modelled data Option and Portfolio level | Baseline uncertainty in yield or reduction in demand from DM options. In the interests of simplicity this should be the combined uncertainty taking into account underlying factors (hydrological modelling etc) and climate change 90% confidence interval at 2050. N.B. this does not represent double counting with Target Headroom in the investment planning, as there is no allowance for option uncertainty in the Target Headroom included in the EBSD Real Options modelling. | For each option a 90% confidence interval range is evaluated and the range fed back as guidance to companies. They then assign a 1-5 score for each option. . |
| R3: Risk of failure of planned service due to other physical hazards | Subjective Scales | Relative risk of loss of service due to a physically based shock event that is likely to occur when availability of water resources is already stressed (e.g. during drought, freeze/thaw etc). This includes hazards such as flooding, extreme weather - excessive cold, ice, snow, or heat, fire, terrorism / vandalism, geotechnical instability. Need to consider availability of storage and planned redundancy of assets that are designed to mitigate exposure, although it is important to note that potential for network and operational workarounds is covered by A5 below. Need to account for routine and planned recovery measures e.g. back-up power generation. | 5 point scale relative to the current 'typical' exposure and vulnerability of available options (1 = notably at risk, 2=higher than typical risk, 3=typical, 4=lower than typical risk, 5 = notably less at risk). Consider key vulnerable points, passive storage and availability of routine re-start capability. See Appendix B for further information.<br><br>The resilience of demand management measures will be primarily related to the vulnerability of the measures contained in the strategy to variations in weather (hot weather and freeze/thaw). |
| R4: Availability of additional headroom | Modelled at Portfolio/System Level Only | Based on EBSD modelling. Indication of the amount of 'incidental' surplus generated by interventions (the plan still seeks to balance, but there will be periods of surplus). | Used as a modifier to the sum of the individual scores from other metrics for a given EBSD model portfolio output. Applies a percentage uplift to the score based on the calculation as detailed in Appendix A |
| R5: Catchment & raw water quality risks | Modelled data Option and Portfolio level | Risk represented by transient water quality events occurring in the catchment beyond those that are adequately covered by outage (e.g. high colour/turbidity/metaldehyde affecting multiple sources during runoff events, algal blooms causing widespread treatment problems). Represents the net impact that the option has on the risk to service – if this causes benefit or detriment to the existing risk for abstractors during shock events then this should be included in the scoring assessment. This can be mitigated by option components, but only where these represent 'failsafe' elements that mean outages>24 | 5 point scale based primarily on DWSP catchment risk assessment without control measures (1= notable increase in risk, 3 = 'typical', 5 = notable decrease in risk). Demand measures score in the neutral category (3) by default. Although this is a quantified metric based on catchment risk assessment scores, the standard DWSP approach allows flexibility between companies, so guidance is required - See Appendix B for further information.<br><br>Where an option changes the raw water quality risk within a catchment (e.g. catchment management scheme) then these can score according to the difference that they make (generally none, +1 or +2; in theory it could be |

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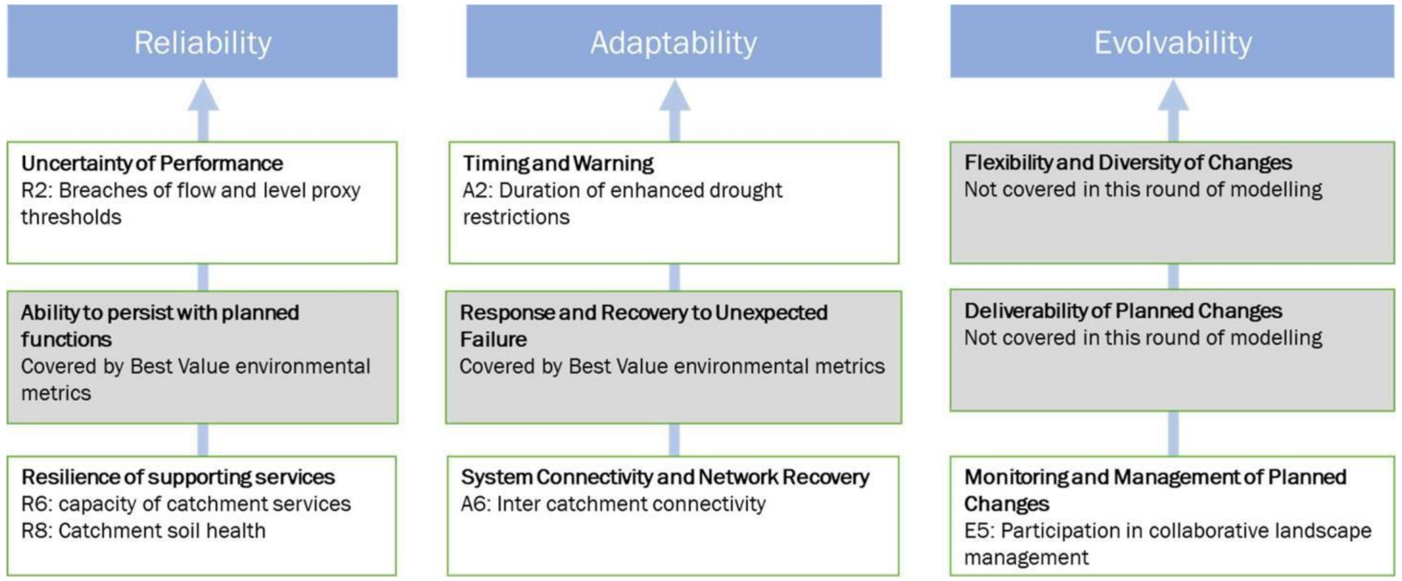
| | | hours or contamination entering the network are highly unlikely (e.g. bankside storage with intake protection). | negative but in practice it is very unlikely that options will be shortlisted that have a strong detrimental impact on water quality). |
| R7: Risk of failure of supporting services due to exceptional events | Subjective Scales | Evaluation of the nature of the services and supply chain that support the treatment and distribution network associated with the option to determine if they are particularly resilient or vulnerable to exceptional events, such as:<br>• cascading/long duration regional power outage events<br>• long duration communications loss - cyber attack/solar flare/ space weather/ telecoms failure<br>• Supply chain loss - materials shortages e.g. chlorine, fuel, strikes, commodity price change<br>• Human resource loss – Epidemic/ pandemic, civil unrest, skills crisis, national strike<br>• Rapid behavioral change – e.g. recent COVID conditions. | 5 point scale relative to the current 'typical' exposure and vulnerability of available supply options (1 = notably at risk, 2=higher than typical risk, 3=typical, 4=lower than typical risk, 5 = notably less at risk). Consider key vulnerable points, passive storage and availability of routine re-start capability. See Appendix B for further information.<br>Demand management measures may be vulnerable to this metric, depending on their nature (e.g. measures vulnerable to behaviour change due to societal changes such as pandemics). |
| A1: Expected time to failure | Modelled data Option and Portfolio level | *Only calculated for full portfolios during the second stage. Uses the baseline system simulator run to set the initial time between full and 'failed' resource state, by WRZ. Impacts expressed as a percentage change from this.* | Metric calculated as mean time from resource state = 100% to resource state failure under critical events. Percentage change from this calculated across the same events. Each WRZ is then given a score of 1-5 according to the range of outputs of % change (impacts on WRZ timing). A score of 3 means no significant change. Needs a granularity check – each band must represent at least a 5% change or else the difference is not considered to be significant. (N.B. although the effect of a scheme at the WRZ level may be small, this is accounted for when the scaling factor is applied in the summation calculation – see Appendix A) |
| A2: Duration of enhanced drought restrictions | Modelled data Option and Portfolio level | *Long term statistically expected duration (days/annum) with Drought Orders/Permits and NEUBs in place. This is only modelled at the system level when portfolios have been generated.* | System simulator (Pywr) output. Scored band 1-5 in the same way as the expected time to failure above (including the significance check, where each band must represent at least a 5% change). In this case the impact is only likely to be apparent once portfolios have been constructed – see Appendix A for scaling and calculation. |
| A3: Operational complexity and flexibility | Subjective Scales | A measure of the net impact that an option has on the complexity of operation of the abstraction, treatment and distribution infrastructure, which affect the ability of public water supplies to be reconfigured to cope with unexpected consequences of shock events. | 5 point scale relative to the current 'typical' situation (notably complex, complex, typical, less complex, notably less complex). Base on aspects such as reliance on multiple institutions, connectivity and the ability to move water around the network, experience of operation and other factor - See Appendix B for further information.<br>Demand management will tend to score neutrally (i.e. a 3). |
| A4 Inter-WRZ connectivity | Capacity | A measure of the capacity of new inter-Water Resource Zone (WRZ) connections that are made as part of the portfolio. | Absolute capacity of the transfer only. Identified at the portfolio level |
| A5: PWS system connectivity | Modelled data Option and Portfolio level | *Population effectively provided with an alternative water supply where a notable 'single point of failure' risk was previously in place. In this case the 'SPOF' can relate to network or treatment constraint, and can apply where there is more than one feed to a given area, but where the loss of either asset would result infailure.* | The option is scored according to the distribution input benefitting – i.e. where a baseline 'hotspot' is addressed. Scoring will therefore normally either neutral or positive, so the range is normally 0 to +2 (see Appendix 1 for application), although could be negative (-1 or -2) in some circumstances (e.g. where a transfer from one company to another creates a vulnerability). |
| A7: Customer engagement with demand restrictions | Subjective Scales | This metric reflects the benefits of mutual social obligation – a social contract – between customers and the company. Where customers perceive companies to be acting on the basis of mutual social obligation – doing the right thing – in controlling leakage, enforcing demand management and restoring the environment, then they will have a positive sense of mutual social obligation to do the right thing themselves. This metric reflects the | This is an additive benefit associated with different demand management strategies, so scores 0, +1 or +2 . depending on how well they engage customers, for example through media and influencing campaigns. There are some aspects of demand management that may have a lesser benefit, such as water efficient labelling with minimum standards (customers may feel that they have already 'done their bit) and rising block tariffs, which |

| | | | |
|---|---|---|---|
| | | contagion effect of action in one part of the system to another via the perception and association of issues in the perspective of the customer.<br><br>It is anticipated that such engagement can enhance the receptiveness of customers to calls for restraint, Temporary Use Bans and Non-Essential Use Bans during drought events, which help to manage the shocks associated with drought conditions. | monetise the social contract and will tend to mean that customers are less responsible to what they may see as a service failure. |
| E1: Modularity and scalability | Subjective Scales | Ability of proposed interventions to be implemented on a modular or scalable basis (i.e. can they be planned and constructed on a staged basis that can be expanded at a later date to address the under-achievement of benefits or mitigate the risk of investment 'white elephants'). | 5 point score based on the overall flexibility. A score of 1 represents an initiative that can only realistically be a single sizescale with no flexibility (e.g. reservoir or certain approaches to national water labelling). A score of 5 represents a scheme that can be implemented on a fully staged, modular and extendable basis. See Appendix B for further information |
| E2: Intervention lead times | Modelled data Option and Portfolio level | *Lead time to plan and then implement option.* | Total planning and construction/implementation time for the option/intervention. All options are evaluated and separated into 5 equal sized bands (DO weighted) to provide a 1-5 score. |
| E3: Reliance on external organisations | Subjective Scales | Evaluates the risk that the intervention could be halted by external challenge, or relies on other institutions to implement and maintain policies to support the intervention. It should be noted that this generally refers to third parties (e.g. not partners in a joint development or bilateral trades) and represents risks above and beyond 'normal' planning processes. | 5 point scale ranging from no risk (5) through to significant likely challenge but under well understood statutory planning arrangements (3) through to schemes that rely on new forms of co-operation between multiple, potentially conflicting institutions (1). See Appendix B for further information |
| E4: Flexibility of planning pathways | Modelled at Portfolio/System Level Only | Assessed at the end of Stage 2 only, once adaptive pathways have been identified. Represents the ease and availability of pathway changes available under the adaptive plan. The assumption here is that the fewer the number of decision points that are required and the less the economic difference between the branches of the plan, the easier it will be to manage adaptations (i.e. large, frequent changes in pathways are detrimental). | Can only be assessed once the adaptive planning alternative strategies are known. Evaluated based on the difference in NPV between the different pathways and the frequency/lead in time between pathway decision points. |

*Table 3 Environmental metric descriptions*

[A summary of the metrics that support the Environment system is shown in advance of the table, followed by the metric description and assessment colour coding]

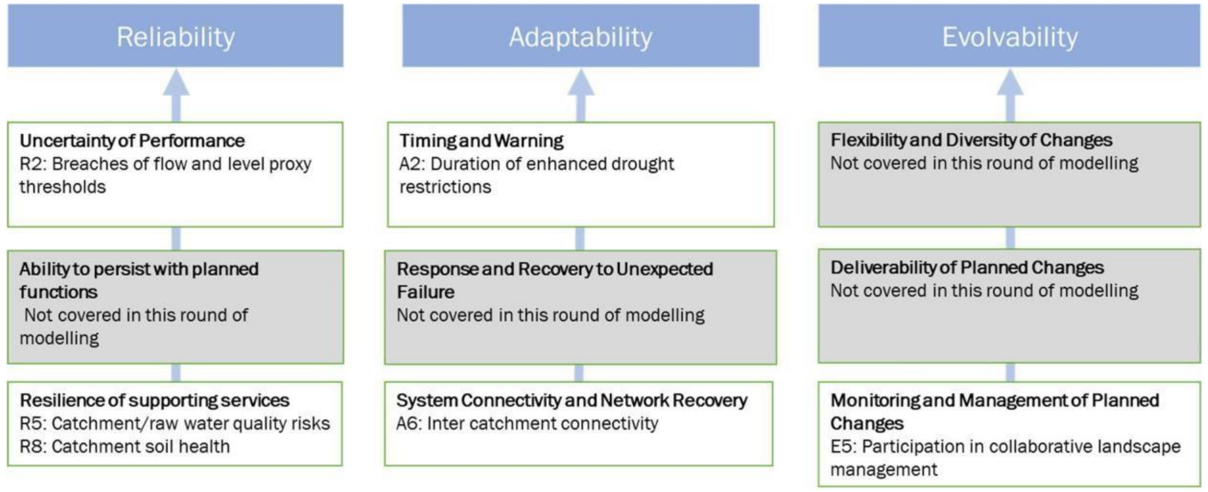



| Metric | Scoring | Description | Scoring Approach |
|---|---|---|---|
| R2: Breaches of proxy flow and level thresholds | Scored at the Portfolio/System Level Only | Thresholds are identified and set for modelled water courses based on an assessment of representative Hands off Flow conditions for that water course. Measured as the percentage of time, on average, that flows fall below the proxy threshold. Assessed in system simulator for stage 2 only. | Change in ratio – as a percentage between the baseline condition and the portfolio. Each assessment point is scored -2 to +2 depending on the range of outputs, scaled according to the Q95 Ml/d flow at the assessment point. |
| R6. Capacity of Catchment Services | Subjective Scales | Capacity of catchment services are derived from the catchment workstream. Outturn scores will be graded 0 to +2, depending on the impact that the scheme has on the catchment. See Appendix B3 for further guidance. | The benefit provided scores on a 0 to +2 scale according to the number of points improvement in the benefitting catchment. These are scaled according to the length of water course benefitting, with the total length of rivers failing 'good' WFD status used as the denominator. |
| R8. Soil Health | Subjective Scales | Improved soil health across the South East will enhance resilience of the water system in the following ways:<br>1. It will reduce spikes in poor water quality by retaining nutrients and sediment on the land in heavy rainfall. This benefit will principally be achieved through the use of cover crops.<br>2. It will improve retention of soil moisture in the soil profile which will benefit resilience in the agricultural sector.<br>3. By increasing infiltration and storage in the soil profile there will be some benefit to the resilience of rivers and aquifers dependent on seepage for baseflow and recharge.<br>4. Soil health has benefits at the bottom of the food chain of the environmental system, thereby increasing overall resilience of the environmental system. | As above, the option score is based on the improvement seen in the catchment, based on a 0, 1, or 2 point improvement. An increase of 1 represents an improvement to soil health of the type that would be achieved through continuous cover – the cover retains sediment and nutrients in the soil during rainfall events. An increase of 2 represents a more significant improvement to soil health such as enhancing organic content and soil structure. For example, regenerative agriculture would score +2<br>Scaling is based on the area affected and area of soils in poor health across the region.<br>See Appendix B3 for more details on scoring and scaling approach. |

| | | | |
|---|---|---|---|
| A2: Duration of enhanced drought restrictions | Modelled data<br>Option and Portfolio level | Long term statistically expected duration (days/annum) with Drought Orders/Permits and NEUBs in place. This is only modelled at the system level when portfolios have been generated. | System simulator (Pywr) output. Scored -2 to +2 depending on the amount of change from the baseline, where each band must represent at least a 5% change). In this case the impact is only likely to be apparent once portfolios have been constructed – see Appendix A for scaling and calculation. |
| A6: Inter catchment connectivity | Scored at the Portfolio/System Level Only | Capacity of new transfers between catchments | Total transfer capacity between meteorologically distinct catchments, in Ml/d. It is important to demonstrate that there is evidence that the catchments have responded differently from each other during historic droughts (only some differences are required – e.g. the response to 1976 may be similar, but there is evidence that catchments responded differently during 1921). Score based on total capacity. |
| E5: Participation in collaborative landscape management | Subjective Scales | Additive benefit that reflects options that improve the understanding and management of water environments and/or engagement of public and stakeholders with catchment needs. | Most schemes score zero (no benefit) by default. Single domain medium scale catchment interventions score a +1, large scale multi-benefit schemes score a +2. |

*Table 4 Non-PWS metric descriptions*

[A summary of the metrics that support the Non-PWS system is shown in advance of the table, followed by the metric description and assessment colour coding]




| Metric | Scoring | Description | Scoring Approach |
|---|---|---|---|
| R2: Breaches of proxy flow and level thresholds | Scored at the Portfolio/System Level Only | Thresholds are identified and set for modelled water courses based on an assessment of representative Hands off Flow conditions for that water course. Measured as the percentage of time, on average, that flows fall below the proxy threshold. Assessed in system simulator for stage 2 only. | Change in ratio – as a percentage between the baseline condition and the portfolio. Each assessment point is scored -2 to +2 depending on the range of outputs, scaled according to the Q95 Ml/d flow at the assessment point. |
| R5: Catchment & raw water quality risks | Modelled data Option and Portfolio level | Risk represented by transient water quality events occurring in the catchment beyond those that are adequately covered by outage (e.g. high colour/turbidity/metaldehyde affecting multiple sources during runoff events, algal blooms causing widespread treatment problems). Represents the net impact that the option has on the risk to service – if this causes benefit or detriment to the existing risk for abstractors during shock events then this should be included in the scoring assessment. This can be mitigated by option components, but only where these represent 'failsafe' elements that mean outages>24 hours or contamination entering the network are highly unlikely (e.g. bankside storage with intake protection). | 5 point scale based primarily on DWSP catchment risk assessment without control measures (1= notable increase in risk, 3 = 'typical', 5 = notable decrease in risk). Although this is a quantified metric based on catchment risk assessment scores, the standard DWSP approach allows flexibility between companies, so guidance is required - see Appendix B2.<br><br>Where an option changes the raw water quality risk within a catchment (e.g. catchment management scheme) then these can score according to the difference that they make (up to +2, or as low as -2, although it is very unlikely in practice that options will be shortlisted that have a strong detrimental impact on water quality). |
| R8: Soil health | Subjective Scales | *If there are potential benefits against this metric, these should be scored according to the environment system guidance – see Table 3.* | See Table 3. |
| A2: Duration of enhanced drought restrictions | Modelled data Option and Portfolio level | *Long term statistically expected duration (days/annum) with Drought Orders/Permits and NEUBs in place. This is only modelled at the system level when portfolios have been generated.* | System simulator (Pywr) output. Scored -2 to +2 depending on the amount of change from the baseline, where each band must represent at least a 5% change). In this case the impact is only likely to be apparent once portfolios have been constructed – see Appendix A for scaling and calculation. In this case the impact is only likely to be apparent once portfolios have been constructed – see Appendix A for scaling and calculation. |
| A6: Inter catchment connectivity | Scored at the Portfolio/System Level Only | Capacity of new transfers between catchments | Total transfer capacity between meteorologically distinct catchments, in Ml/d. It is important to demonstrate that there is evidence that the catchments have responded differently from each other during historic droughts (only some differences are required – e.g. the response to 1976 may be similar, but there is evidence that catchments responded differently during 1921). Score based on total capacity. |

| | | | |
|---|---|---|---|
| E5: Participation in collaborative landscape management | Subjective Scales | Additive benefit that reflects options that improve the understanding and management of water environments and/or engagement of public and stakeholders with catchment needs. | Most schemes score zero (no benefit) by default. Single domain medium scale catchment interventions score a +1, large scale multi-benefit schemes score a +2. |

# Amalgamating the Metric Scores

## Public Water Supply and Environment Systems

Resilience scores are generated in most cases against metrics for individual options, but for some metrics scores are derived only at the portfolio level either in the Investment model or subsequently through the Regional System Simulator. The metric level scoring provides the granularity of understanding that is required for the planning teams. However, to support Best Value Planning, investment modelling and consultation it is important that a single score can be generated for each of the three resilience attributes at portfolio level.

To do this, metric scores are scaled and summed to the attribute level based on the appropriate scaling factor. **Appendix A** provides details of the calculations used to generate the overall attribute scores. **At this stage there is no weighting given to any of the individual metrics, they all scale and contribute the same amount to the attribute level score.** A summary of the approach used to generate the overall portfolio scores is provided in Figure 6 below.

The scaling factors have been designed so that all metrics associated with options that generate a supply/demand balance benefit, are additive and in proportion with each other, without having to apply arbitrary 'weightings'. Each option or portfolio impact for each metric is scaled according to the supply/demand benefit or population affected, so each metric is effectively given the same weighting in the additive calculation. As a simple conceptual rule, the resilience benefit of all options or system changes is equal to:

$$\frac{\text{Resilience score} \times \text{size of benefit provided (DO, demand reduction etc)}}{size\ of\ the\ regional\ deficit\ in\ relation\ to\ that\ aspect\ (total\ baseline\ SDB\ deficit\ etc)}$$

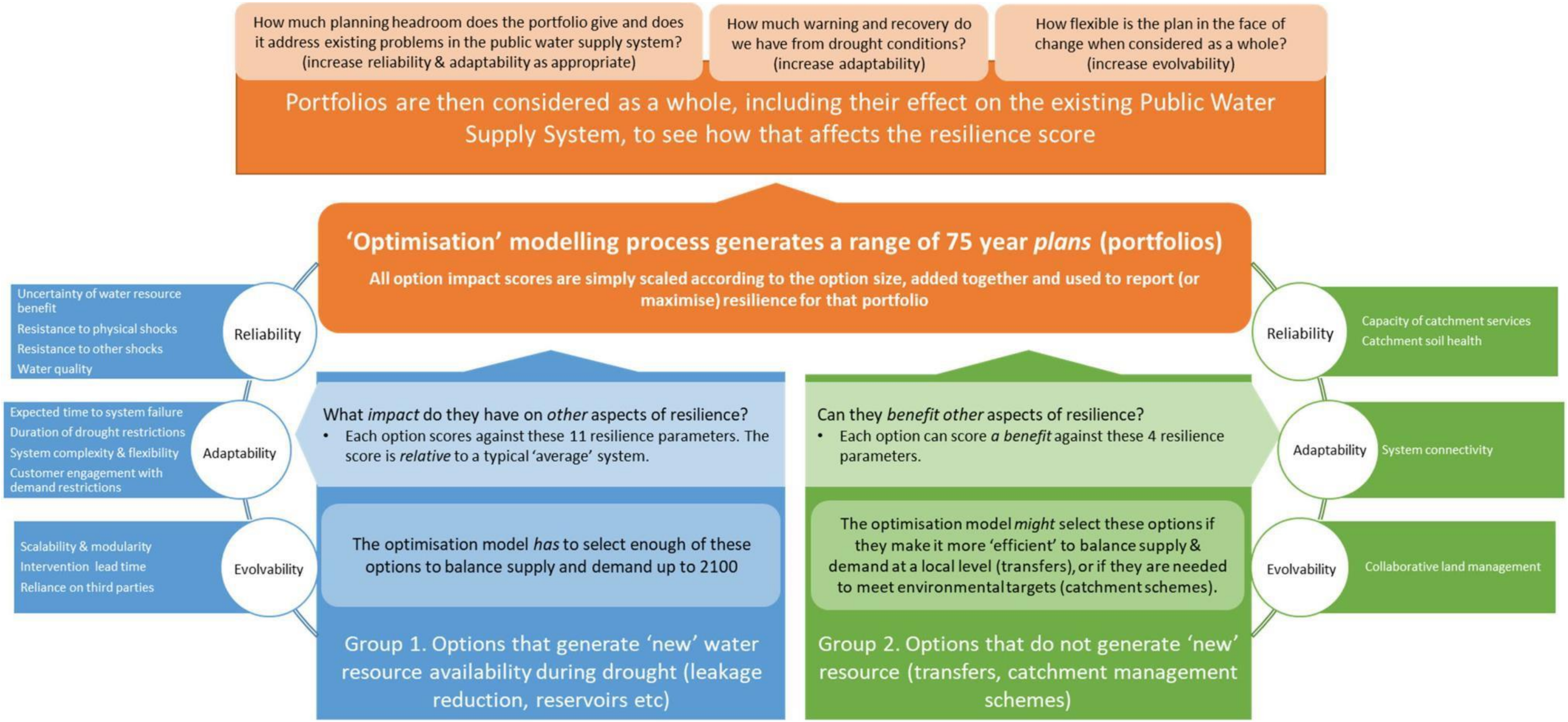
For SDB schemes, transfers and operational resilience schemes the 'deficit' (denominator in the above calculation) is equal to the mean SDB deficit over the planning horizon. For catchment schemes the denominator is the total length of water bodies in failing condition, or the total area of degraded catchment soils, as appropriate.

Because the approach is additive, each option will tend to have a small 'impact value', but on a relative basis (i.e. when the size of the option benefit is taken into account) this translates back to the 1-5 scoring. This means that, for each of the three attributes, a 'perfectly' resilient portfolio generated from the EBSD model for the South East would generate an overall score approaching '5' for a given metric, whilst the worst performing portfolio would score a '1'. An average portfolio would score a 3 for each metric. Transfers, catchment management and resilience schemes can then increase overall scores by up to 2 points each for the relevant metrics. Once the portfolios have been generated then there is an additional metric that is generated for each attribute based on the portfolio – this could increase the score by up to 1 point. All of the portfolios that are generated will then be scored on a comparative basis from 1 – 100 based on the range between the lowest scoring portfolio and the highest scoring portfolio.

## Non-Public Water Supply System

These metrics scores are generated after portfolios have been generated from the economic modelling based on the PWS system evaluation. As there are relatively few metrics and the attribute scores do not need to be included in the EBSD optimiser, each metric output is described on a stand-alone basis to help understand where the benefits and impacts are felt across these two systems.

*Figure 6 Summary of the Impact Generation for Options and Scoring Process for Portfolios*




*Note – there are 11 metrics that are scored for the PWS system at the individual option level, as indicated.*

# Appendices –Scoring Guidance and Tables.

# Appendix A: Details of the Aggregations of PWS Metrics to the Attribute Level in the EBSD Modelling

The mathematical approach to scoring, scaling and aggregating metrics for each of the three resilience attributes within the PWS system is provided in the table below. 'EBSD' refers to the economic optimisation model – initial scoring is either carried out at the input option level, or once a portfolio has been generated, or (in some cases) both, as the score is updated at the portfolio level once they have been generated. The 'Impact Value' of individual options, or whole portfolios, is the key to the scoring system. Essentially this is calculated based on the metric score × benefit scale (supply/demand benefit or population) ÷ need denominator (size of baseline deficit across the whole region or regional population).

| Metric | Basic Option Evaluation Process | Method Used for Scoring the Metric | How Option Score is Scaled and Entered into the Investment Model ('Impact Value') | EBSD Calculated Benefit | post EBSD Calculation of Portfolio Benefit |
|---|---|---|---|---|---|
| **Reliability** Attribute – Sum of 'R' Metric Impact Values | | | | | |
| R1: Uncertainty of option supply/demand benefit | Estimate % difference between $10^{th}$ percentile and mean of option benefit (%) | Score 1-5 for each option based on the relative uncertainty for each of the option types | Value = (score*Ml/d benefit)/average baseline deficit Ml/d[3] | Sum of option impact values | |
| R3: Risk of failure of planned service due to other physical hazards | Score 1-5 (each option) | | Value = (score*Ml/d affected)/average baseline deficit Ml/d | | N/A: total score = output from EBSD model For metrics R3, R5 and R7 where water resource schemes can improve resilience 'hotspots' in the existing system, scores will be reviewed post EBSD modelling to identify any additional benefits that portfolios provide in addressing hotspots. |
| R5: Catchment/raw water quality risks (incl. climate change) | Score 1-5 for the option itself. Where options improve existing catchment quality then this is added or subtracted from the score (e.g. if the option improves the catchment score from a 3 to a 4 then +1 is added based on the total Ml/d supply fed by that catchment) | | Value = ((baseline score + impact on catchment)*Ml/d of option) /average baseline deficit Ml/d). Needs to reflect area already included in score | | |
| R7: Risk of failure of planned service due to exceptional shocks | Score 1-5 (each option) | | Value = (score*M/d affected)/average baseline deficit Ml/d | | |
| R6: Capacity of catchment services | Score 0, +1 or +2 based in level of improvement | | Value = (score * water body length improved)/total water body length below WFD good status | | N/A: options scored as EBSD inputs – benefits already represent improvements to baseline 'hotspot' issues. |

[3] Average baseline deficit equals the deficit for that scenario as an average up to 2050 across *the whole of the WRSE region.* In this case demand = DI plus Target Headroom

| Metric | Basic Option Evaluation Process | Method Used for Scoring the Metric | How Option Score is Scaled and Entered into the Investment Model ('Impact Value') | EBSD Calculated Benefit | post EBSD Calculation of Portfolio Benefit |
|---|---|---|---|---|---|
| R8: Improvements to soil health | Score 0, +1 or +2 based on level of improvement | | Value = (score * catchment area improved)/total area of poor soils in region | | |
| R4: Availability of additional headroom | Not relevant at the individual option level. Calculate based on available headroom beyond Target Headroom. | | | | Amend portfolio level score = ((total WAFU capacity over 25 years/total demand over 25 years) -1) *10[4] |

| Metric | Basic Option Evaluation Process | Method Used for Scoring the Metric | How Option Score is Scaled and Entered into the Investment Model ('Impact Value') | EBSD Calculated Benefit | post EBSD Calculation of Portfolio Benefit |
|---|---|---|---|---|---|
| **Adaptability** Attribute – Sum of 'A' Metric Impact Values | | | | | |
| A1: Expected time to failure (PWS) | Change in mean time taken from 100% to failed resource state | Score 1-5 based on range of % impacts on WRZs affected | Value = (score * WRZ population)/total WRSE population | Sum of option Impact Values | Re-calculate in Pywr using the portfolio setup |
| A2: Duration of enhanced drought restrictions. | Change in mean duration | Score 1-5 based on rangeof % impacts on company areas affected | Value = (score * WRZ population)/total WRSE population | | |
| A3. Operational complexity and Flexibility[5] | Score 1-5 (each option) | | Value = (score*Ml/d affected)/average baseline deficit | | N/A: total score = output from EBSD model. For metrics A3 and A5 where water resource schemes can improve resilience 'hotspots' in the existing system, scores will be reviewed post EBSD modelling to identify any additional benefits that portfolios provide in addressing hotspots. |
| A7: Customer engagement with demand restrictions | Score +0 to + 2 for activities that enhance customer relations and hence customer engagement with demand management strategy | | Value = (score *Ml/d benefit from TUBs & NEUBs in that WRZ)/average baseline deficit | | |
| A4: Inter WRZ connectivity | No scoring required. | | Value = Ml/d of transfer/average baseline deficit. * 2[6] | | |
| A5: PWS system connectivity | Score +1 if option is addressing a 'notable' hotspot (category 2 in the baseline evaluation), score +2 if option is addressing a 'very notable' hotspot (category 1 in the baseline evaluation). | | Value = Score * DI benefitting/average baseline deficit | | Add to overall score once the portfolio can be compared with resilience baseline 'hotspots' |

[4] This has been calculated so that a surplus headroom of 10% generates a portfolio level score of +1, which is the same impact at the portfolio level that would occur if all the supply and demand options in a portfolio increased by 1 point in one of the reliability categories.

[5] For metrics R3, R5, R7, A3 and A5 there may be resilience only options that add to the overall score. These provide an added benefit of +1 or +2, depending on the severity of the 'hotspot' that they address, multiplied by the scale of the issue that is addressed (i.e. the Ml/d of existing supplies at risk from the 'hotspot'). These are added once initial portfolios have been generated.

[6] The connectivity benefits are doubled because this is reflective of the change from current (no additional connection) to ideal (connected) conditions – this is equivalent to a 2 point movement in the other metrics.

| Metric | Basic Option Evaluation Process | Method Used for Scoring the Metric | How Option Score is Scaled and Entered into the Investment Model ('Impact Value') | EBSD Calculated Benefit | post EBSD Calculation of Portfolio Benefit |
|---|---|---|---|---|---|
| | In the rare cases where an option causes a SPOF then it is attributed either -1 or -2. | | | | |
| **Evolvability** Attribute – Sum of Option 'E' Impact Values | | | | | |
| E1: Scalability and modularity of proposed changes | Score 1-5 | | Value = (score*M/d affected)/average baseline deficit | Sum of option Impact Values | N/A: total score = output from EBSD model |
| E2: Intervention lead times | Intervention lead time | Identify the ranges for all shortlisted options. Score 1-5 for each option based on an even allocation of options into each band | Value = (score*M/d affected)/average baseline deficit | | |
| E3: Reliance on external bodies to deliver changes | Score 1-5 | | Value = (score*M/d affected)/average baseline deficit | | |
| E5: Collaborative landscape management | Score 0, +1, +2 | | Score* area covered / RSE area | | |
| E4: Flexibility of planning pathways | Not relevant at the individual option level | | | | Adaptive Plan level uplift applied: Plan with lowest difference in NPV between highest and lowest scenarios and lowest number of decision points adds 20%, plan at other end loses 20% |

# Appendix B: Detailed Scoring Guidance Notes

## Metric R3 – Risk of failure of planned service due to other physical hazards.

This metric is most similar in concept to *outage*, but it is evaluated for new sources or demand management measures. It is intended to reflect both the risk that the interventions' contribution to the supply/demand balance may not be available during key drought periods, and the risk that the intervention could fail to the extent that it results in a large scale[7] interruption to supply as a result of the combination of resource stress (drought/freeze thaw etc) and the option failure. This risk could materialise as a result of numerous physical hazards, as outlined previously. These are most likely to be:

- flooding,
- extreme weather - excessive cold, ice, snow, or heat,
- fire/explosion
- terrorism/vandalism
- geotechnical instability

There are two areas of potential overlap with other metrics, and scoring between them should be interpreted as follows:

1) All catchment water quality risks are considered separately under that metric (R5) and should not be included here. Where outage is referred to in the text below then that should exclude risks associated with catchment water quality. For effluent re-use schemes, the failure of the scheme to provide the required water into the relevant abstraction or recipient as a result of the failure of the process should be included under this metric.

2) This metric takes account of the reliability benefit provided by storage and other 'passive' operational measures that are designed to prevent service failure following outage events, but does not consider operational workarounds or the ability to change operations to maintain service. Similarly, although planned, standard measures for recovery following failures such as standby generators or on-site flood mitigation measures should be taken into account, issues such as accessibility or the ease of repairs are not included. Such factors are covered by the 'operational complexity and flexibility' metric A3 (which falls within the *adaptability* aspect of resilience, and refers to institutional arrangements, system makeup and other factors that affect the ability of supplies networks to be reconfigured during shock events). Typically, that means *outage* type risks fall within this -metric – see Appendix B guidance on the operational complexity and flexibility metric.

It should be noted that wider business and organisation risks are not considered within this evaluation at this stage – it is intended that it should concentrate on the infrastructure involved and the immediate operational

[7] Large scale in this case will mean whole towns or demand centres, typically more than 10,000 properties with interruptions lasting for more than 24 hours.

issues associated with keeping the asset running (e.g. access, consumable materials essential to operation, power etc). Organisational risks may be reviewed during latter stages of the Plan.

Options and interventions will typically be assessed according to the top 2-3 hazard types, only falling into a category of '1' if they are highly vulnerable to a single hazard, or notably vulnerable to 2 or more hazards. In some cases there may be specific concerns where an asset is vulnerable to multiple smaller likelihood hazards. In that case an asset could score a 1, but this would have to represent an abnormal situation. More typically such an asset would score a 2. Assets where there is some exposure to multiple less likely hazards is a typical situation for a water company, so such assets should score a 3.

Further guidance on scoring is provided below.

**Metric R3 Scoring Guidance Notes**

| Score | Description | Notes and Application |
|---|---|---|
| 1 | **Notably vulnerable.** The location or nature of the scheme means that it is towards the upper end of risk. For PWS assets this means they are at a similar level of risk to those existing assets within the top 20% of outage scores, or they rely on systems that are notably vulnerable to a particular hazard type. Options that rely on multiple, exposed, in-sequence assets to function (e.g. multiple booster pumping stations) should be placed in this category. | Where risks have been deliberately and reliably designed out (e.g. fluvial floodplain protection) then options should not be placed in this category. This category should generally be used for sites where there is a clear, notable risk and should apply to around 10% to 20% of the options. |
| 2 | **Vulnerable.** This includes option types that are known to suffer from higher than 'typical' outage risks, options that have critical assets that do not have redundancy backup, or options and strategies where there is significant uncertainty around the level of risk that they face. Options that incorporate exposed critical assets where there are concerns over repair times could be placed in this category. | Overall, no more than 40% of options should fall into this category or notably vulnerable as above. Uncertainty in the option design is likely to be a key factor over the selection of this category. The precautionary principle should be applied where there are long transfer/supply routes or constraints on land availability that mean the option could have to be placed in a more vulnerable location. |
| 3 | **Typical asset.** Options that are typical ofexisting water company water resource schemes in terms of vulnerability and exposure will fall into this category. | Options and assets will be typical of existing water company arrangements in terms of duty/standby, number and exposure of sequential critical assets etc. Options where there are some uncertainties over location and nature can fall into this category, provided the uncertainties do not mean that critical assets could be vulnerable or exposed. |
| 4 | **Less vulnerable.** These options/strategies will tend to be relatively well defined and their nature or level of redundancy means that they are less vulnerable than a typical resource option. | Schemes need to be reasonably well defined, or relate to asset types that are inherently low vulnerability in low exposure locations, to be included in this category.<br>*Demand management strategies will tend to fall into this category by default, although some may be vulnerable to weather related events.* |

| | | |
|---|---|---|
| 5 | **Notably less vulnerable.** These options/strategies will be well defined and there are no notable vulnerabilities in the design, location or makeup to the scheme/strategy. | Schemes require a good degree of certainty about placement, lack of critical asset points etc to be in this category. Simpler schemes that supply raw water to existing, well established treatment and distribution systems that are known to be low risk could be a typical example.<br>*Simpler, distributed demand management strategies that are unlikely to be significantly disrupted by shock events could be placed into this category*. |

## Metric R5 – Catchment & raw water quality risks.

This assessment relates to the risk of disruption to supplies as a result of water quality events during times where there is resource stress (drought, freeze/thaw etc). The approach to scoring is based on the use of catchment risk assessments under the DWI Regulation 27 reporting. When carrying out the evaluation on a supply side intervention or catchment resilience scheme the company should:

1) Identify the most similar equivalent[8] catchment covered by an appropriate Regulation 27 assessment (i.e. a catchment associated with an existing supply asset).

2) For an intervention that does not affect this catchment risk, select the *pre control* risk score for the catchment and assign that to the intervention (unless the scheme incorporates catchment improvements – see below). This can be modified if there are passive/failsafe controls in place that do not risk an outage of the service (e.g. bankside storage with intake protection).

3) Options are scored in the table based on their relative ranking (e.g. schemes in the lowest 20% by DWSP CRA score fall into the top score category of 5). Ideally this assessment would not be relative within each company and/or use an absolute scale, but there is no requirement for conformity of completion to this level within the DWSP guidance and companies will score catchments and hazards differently. Review and normalisation of scoring will be carried out by WRSE once scores have been submitted.

The use of scoring prior to control is deliberate, as schemes that require large amounts of mitigation will tend to be inherently more vulnerable to failure and shutdown, and hence tend to be less *reliable* than others, unless the protection can be considered to be passive and failsafe, where there is very little risk of long term service interruption.

For an intervention (e.g. catchment management) that affects the catchment risk for existing or other planned new sources, use available information (e.g. existing catchment management initiative reporting) to evaluate the impact of the scheme and determine by how much the risk score changes (based on the guidance under point 3). If it improves the scoring by one category, then the scheme scores a +1. If it improves by 2 categories then the scheme scores a +2 and so on. Where a scheme involves both catchment improvements *and* provides yield then

[8] In this case 'nearest' refers to the nature of the catchment, not physical proximity. For example, a smaller urbanised catchment could be

the risk score should be taken based on the catchment risk after the improvements are taken into account. Similarly, if schemes such as indirect effluent re-use generate a deterioration to other resources then the risk level should be taken based on the abstraction point *with* the effluent re-use in place.

Options that rely on effluent re-use will only perform badly on this metric if the failure of the process represents a risk to downstream abstractions – e.g. if the scheme does not incorporate a passive failure type mechanism that means transfers halt by default when there is a problem. Failure of the effluent as an available resource is covered by 'risk of service failure due to other hazards,' as defined under R3 & R7.

**Assessors should be pragmatic when identifying suitable equivalent catchments – the exact risks around the individual options may not be well known, so it may, for example, be more appropriate to apply generic catchment level CRAs (if they are available) rather than individual source CRAs.**

As noted below, demand management options score a '3' by default, as the benefit they provide is spread across the supply base so the relative risk will not change.

| Score | Description | Notes and Application |
|---|---|---|
| 1 | **Notably vulnerable.** Equivalent to schemes scoring in the worst 20% of catchments. | Desalination schemes where there is a high variability in water quality other than the typical tidal cycle will fall into this category. Schemes where there are large unknowns and potential concerns over raw water quality should be placed into this category. |
| 2 | **Vulnerable.** Equivalent to schemes scoring in the 20% to 40% category. | Desalination schemes with a large, but predictable variability in turbidity etc fall into this category. Schemes where there are large unknowns/no reasonable DWSP equivalent but where there are no exceptional concerns should be placed in this category. |
| 3 | **Typical asset.** Equivalent to schemes scoring in the 40% to 60% category. *Demand management strategies score a 3 by default (they replace the need for water on a generalised basis)*. | Schemes where there are come uncertainties, but it is very unlikely that risks would be notably high should be placed in this category. |
| 4 | **Less vulnerable**. Equivalent to schemes scoring in the 60% to 80% category. | Need to be reasonably confident that the catchment with the DWSP score is a good representation of the catchment served by the scheme. Schemes that improve catchment risks by a single point score here. |
| 5 | **Notably less vulnerable.** Equivalent to schemes scoring in the 80% to 100% category. | Need to be very confident that the catchment with the DWSP score is a good representation of the catchment served by the scheme. Schemes that significantly improve catchment risk (i.e. by 2 or more points) score here. |

For non-PWS options, scoring is as for PWS above, although for interventions that serve only non-PWS or environmental systems, then these will need to be based on an 'equivalent setting' type approach – i.e. identify how the setting of the option compares to catchments with existing water company risk assessments and use the appropriate score.

## Metric R6 – Capacity of Catchment Services.

The purpose of this metric is to capture the change in the ability of a water body that is affected (positively or negatively) by an intervention to carry out its ecological services during 'shock' events (primarily drought). Each option is assessed based on the impacts (positive or negative) it has on the morphological, and biological conditions of the water body, in relation to its ability to cope with and recover from shock events (drought, large pollution incidents etc)

| Component | Description | Factors to consider when assessing |
|---|---|---|
| Morphological state | Condition and function of the channel and riparian habitat, including introduction of structures/ barriers, which could affect the ability of the environment to recover from shock events | Does the option move the catchment towards or away from natural state? What is the scale of the options? |
| Biological state | Diatoms: Does the option impact the diversity and adaptability of diatom communities? Is the option likely to impact environmental factors known to affect diatom communities such as salinity, temperature, pH, water velocity, depth and available substrate?<br><br>Macrophytes: Does the option impact on the habitat availability and ability of macrophytes to recover from shocks? Does the option lead to increase in nitrates or phosphates and affect dissolved oxygen levels? Does the option target multiple or single river fragments?<br><br>Fish: Does the option directly impact on the ability of fish populations to recover from shocks? | Local vs. catchment wide impacts: Local and catchment wide impacts. Benthic diatoms adhere to substrata and are indicative of a local catchment, whereas planktonic diatoms are mobilised down a water course and are likely to be impacted by local and catchment wide impacts.<br><br>Does the option reduce or increase network fragmentation? Resilience of ecosystems increases with the size of river fragments of adjacent stream reaches that are in a good ecological state, due to a larger probability of providing refugia to self-sustaining populations, which can act as sources for recolonization elsewhere in a catchment. |

The table below outlines the scoring methodology and provides examples for information.

| Score | Description | Example |
|---|---|---|
| 0 | No/negligible effect | Offline storage reservoir taking during winter only (high HoF). |
| +1 | Positive impact | For options that have a beneficial, though marginal benefit to morphological and biological state of rivers, or only address one of these issues. |
| +2 | Notably positive impact | For schemes that actively enhance the biological and morphological state of rivers. |

## Metric R7 – Risk of failure of planned service due to exceptional events.

This metric covers those shocks that tend to be either societal in nature, or affect the supply chain or supporting services. These typically include:

- cascading/long duration regional power outage events
- long duration communications loss - cyber attack/solar flare/ space weather/ telecoms failure
- Supply chain loss - materials shortages e.g. chlorine, fuel, strikes, commodity price change
- Human resource loss – Epidemic/ pandemic, civil unrest, skills crisis, national strike
- Rapid behavioural change – e.g. recent COVID conditions.

The level of risk and scoring therefore tends to concentrate on the availability of redundancy and storage in the system, and the risks presented by complex supply chains or specialist, limited human resources skills sets. Demand management measures may tend to score less well than they do under measure R3.

**Metric R7 Scoring Guidance Notes**.

| Score | Description | Notes and Application |
|---|---|---|
| 1 | **Notably vulnerable.** The nature of the option means that it is towards the upper end of risk. Schemes/options in this category will tend to be notably vulnerable to more than one type of event – i.e. the nature of power supplies, availability of chemicals, dependence on remote control for remote assets etc have the potential to combine to cause significant problems. For networks it is likely that demand/weather shocks will be the largest risk and this category would apply to a scheme that is reliant on existing infrastructure that is known to be stretched during such events. | Very complex schemes that score poorly under metric A3 are more likely to fall into this category, and there may be synergy between the two metrics. *Demand management strategies are unlikely to fall into this category, except where they are known to be vulnerable to unexpected societal changes, such as those caused by the COVID-19 pandemic.* |
| 2 | **Vulnerable.** As above, but where there is only one notable risk, or where there are uncertainties over network capacity/redundancy. | Overall, no more than 40% of options should fall into this category or notably vulnerable as above. Uncertainty in the option design is likely to be a key factor over the selection of this category. |

| | | |
|---|---|---|
| | | *Higher risk demand management strategies that contain some vulnerability to societal change, or vulnerabilities or significant unknowns in relation to data or network loss, or where they rely on supply chain or delivery arrangements that are vulnerable to medium term disruptions (pandemic/civil unrest/economic shock etc) could be placed in this category*. |
| 3 | **Typical asset.** Options that are typical ofexisting water company water resource schemes in terms of vulnerability and exposure will fall into this category. Demand management strategies will only fall into this category if they rely on the more complex elements of existing customer interactions, or they are a 'mixed bag' with some medium term vulnerability in their ability to deliver during events such as pandemics/civil unrest/economic shock. | Options and assets will be typical of existing water company arrangements in terms of duty/standby, number and exposure of sequential critical assets etc. Options where there are some uncertainties over location and nature can fall into this category, provided the uncertainties do not mean that critical assets could be vulnerable or exposed. *High tech demand management strategies where there is relatively little experience of mass operation will tend to be placed in this category* |
| 4 | **Less vulnerable.** These options/strategies will tend to be relatively well defined and their nature or level of redundancy means that they are less vulnerable than a typical resource option. Demand management strategies that are not particularly vulnerable to data issues, cyber attack, or where events such as pandemics/civil unrest/economic shock will only have a short term, transient impact on delivery and implementation should be placed in this category. | Schemes need to be reasonably well defined, or relate to asset types that are inherently low vulnerability in low exposure locations, to be included in this category. *Demand management strategies that rely on well proven technologies, but where there is potential uncertainty about their effectiveness in the face of societal events will tend to be placed in this category.* |
| 5 | **Notably less vulnerable.** These options/strategies will be well defined and there are no notable vulnerabilities in the scheme/strategy. | Schemes require a good degree of certainty about placement, lack of critical asset points etc to be in this category. Simpler schemes that supply raw water to existing, well established treatment and distribution systems that are known to be low risk could be a typical example. Simpler demand management strategies that are unlikely to be significantly disrupted by societal shock events could be placed into this category. |

## Metric R8 – Catchment Soil Health.

Improved soil health across the South East will enhance resilience of the water system in the following ways:

1. It will reduce spikes in poor water quality by retaining nutrients and sediment on the land in heavy rainfall. This benefit will principally be achieved through the use of cover crops.
2. It will improve retention of soil moisture in the soil profile which will benefit resilience in the agricultural sector.

3. By increasing infiltration and storage in the soil profile there will be some benefit to the resilience of rivers and aquifers dependent on seepage for baseflow and recharge.
4. Soil health has benefits at the bottom of the food chain of the environmental system, thereby increasing overall resilience of the environmental system.

There are additional benefits to the WRSE system such as carbon sequestration and regulation of flows that mitigate flood risks.

| Score | Description | Example |
|---|---|---|
| 0 | No change to soil | Demand management |
| +1 | Improvement to soil cover | Reverse auction for cover cropping |
| +2 | Improved organic content and structure in addition to measures in addition to cover cropping | Regenerative agriculture |

The metric works by allocating a score of zero to options that have no positive or negative impact on soil health. One step improvement is allocated to options that cover the ground, protecting it against intense rainfall and heat. A second step improvement to a score of +2 is allocated to options that enhance soil structure, organic matter and infiltration in additional ways over and above the use of cover crops.

Step 5 will reflect the priorities of regenerative agriculture which is a set of activities designed to transition soil husbandry from a predominantly fertiliser based production model to a model that relies on the inherent organic activity of healthy soils. The regenerative agricultural show Groundswell[9] identify 5 principles of regenerative agriculture as follows:

1. Diversity of crops.
1. Armour soil surface – protect from heat and rains.
2. Minimise soil disturbance.
3. Maintain living roots.
5. Integrating livestock into the system.

For the design of a metric the key point is to identify an activity or collection of activities that are distinct and create a clear step change in soil health. Armouring of the soil is the first of these. There are two alternative strategies for the second step which would either be the increase in organic matter in the soil or the adoption of minimal soil disturbance (no-till). Given that the principal function of this metric relates to the resilience of the water system, then we propose the metric relates to the adoption of minimum disturbance – no till farming.

We note that the planting of cover crops is relevant to land that would otherwise not be covered over winter. For this reason the likelihood of exposed ground is included in assessing the baseline (based on the prevalence of crops that are associated with bare ground (spring planted; potatoes etc).

[9] See Groundswell Agriculture Show & Conference - Mission Statement Groundswell. Affinity Water are the headline sponsor of Groundswell.

## Metric A3 – Operational Complexity and Flexibility

This metric is intended to focus on how the intervention affects the ability of the PWS to adapt, reconfigure and recover when shock events mean that normal modes of operation are disrupted. This essentially looks at how the option interacts with other factors such as network operation and network quality risks, and how much reliance there is on multiple organisations and/or specialist supply chains if the intervention has to be re-started or taken out of expected operational ranges.

| Score | Description | Notes and Application |
|---|---|---|
| 1 | **Notably complex.** These interventions will tend to be both inflexible due to operational constraints on use (e.g. desalination water not suitable for transfer outside the intended area) *and* they either rely on multiple institutions to run, require specialist supply schemes/complex procedures to re-start after a failure event or are difficult to access to effect repairs. | This score is applied to supply side schemeswhere there is obvious inflexibility and complexities in the management/operation of the resource. *Not generally used for demand management*. |
| 2 | **Complex.** These interventions will tend to be both inflexible due to operational constraints on use (e.g. desalination water not suitable for transfer outside the intended area) *or* they either rely on multiple institutions to run or require specialist supply schemes/complex procedures to re-start after a failure event. | This score is used for schemes with single complex issues, or a number of lesser operational risks (e.g. difficulties in transfer combined with blending constraints). *Demand management can score within this category, but only in exceptional circumstances (e.g. it could result in significant amounts of 'locked in' supply capability as a result of demand reductions causing existing sources to become under-utilised, but where this is not certain enough to include as a change in Deployable Output).* |
| 3 | **Typical asset.** These interventions are 'typical' of a surface water type source in terms of complexity and management. Control curves, group licences, environmental procedures, transfers may be involved, but any co-operation needs across multiple institutions is unlikely to result in failure of the source to adapt or re-start. Typical transfers where there is some availability of workaround and storage fall into this category. | Use for schemes that represent typical PWS operation (clear, unambiguous asset management and operation agreements), some flexibility in the area and nature of supply etc), where any constraints (e.g. blending need) are straightforward and unlikely to significantly constrain scheme operation. *Demand management strategies will tend to score a 3 by default (they replace the need for water on a generalised basis), unless there is a clear risk that they will result in significant 'locked in' capacity for water company existing sources.* |
| 4 | **Less complex**. Interventions that involve typical, routine operational arrangements where group and annual licences are straightforward to manage, the site can be manually operated if required and there is reasonable connectivity/storage with the existing network | As for 3) above, but schemes need to be free from complex multi-institutional agreements, and have limited constraints on operation and use of the water in a flexible way. |

| | | |
|---|---|---|
| 5 | **Notably less complex.** Intervention is simple to manage, with limited interdependencies and an ability to deploy across multiple areas | To fall into this category the scheme must have no obvious operational constraints, be free from complex multi-institutional arrangements, and the scheme should be notable in its ability to support various parts of the network without difficulty or operational constraint. |

## Metric A7 – Customer Engagement with Demand Restrictions

| Score | Description | Example |
|---|---|---|
| 0 | No noticeable change for customers | Status quo – only applicable to demand management strategies that rely significantly on tariff management (which monetises the social contract) *and* passive approaches, primarily minimum standards associated with water labelling, which are likely to have minimal, or event slightly negative, impact on customers' awareness of water resource issues. |
| +1 | Demand management strategies improve engagement with and understanding of the need to manage resources | Applies to demand management strategies where there is some reliance on tariffs or passive methods, or where methods are less likely to promote the 'social contract'. |
| +2 | Demand management strategies significantly improve customer understanding of their role in drought management and they respond very positively to such measures. | Demand management that incorporate a strong element of behavioural change and awareness, and where they do not monetise or promote passive engagement in the 'social contract'. |

The rationale for this metric is that customer action on demand management is essential to maintaining supply demand balance during drought. Where companies have the confidence of customers in drought management and leakage control then customers will be more responsive to calls for constraint or temporary usage bans – a representation of a 'social contract' between water companies and their customers in the management of drought. Conversely where companies have lost the confidence of customers, then they will be less inclined to respond to calls for restraint during drought.

Additional benefits of this metric are that it promotes demand management strategies that support Ofwat's social contract agenda. The metric operationalises the idea of the social contract by reflecting the fact that the supply demand balance is achieved by both parties playing their part during drought and this voluntary collaboration is enhanced by visibly reciprocal behaviours – the customers will be more or less inclined to play their part according to the commitment they see to this agenda in the actions of the company. The social contract is not just at an individual level: customers act, to some degree collectively. Therefore, if a company is seen to be active on leakage and seen to take action to enforce demand management then individuals will be less inclined to flout drought measures if their neighbours are compliant. If a customer's neighbours do not comply with drought management and the company does not manage leakage well, then response to demand restrictions during drought is likely to be lower.

This metric is designed to enhance adaptive behaviour in the system in response to drought stress and is therefore categorised as an adaptive system characteristic.

## Metric E1 – Modularity and Scalability

This metric is relatively straightforward, and reflects the ability of a given option to be delivered in a staged way that limits investment risk and provides opportunity to either scale back or extend development if the intervention is proving to more/less viable following further investigation and initial development. Scalability and modularity may also help address uncertainty in the need (supply/demand balance) as a modular plant can be implemented in phases depending upon the needs that arise in future, reducing the risk of stranded assets.

| Score | Description | Notes and Application |
|---|---|---|
| 1 | **Notably inflexible.** Option is fixed and binary without any real opportunity to scale back or extend development once the scheme has started. | Some reservoirs, where there is no real choice or flexibility around the source water availability, fall into this category. *Similarly, demand management strategies that present an either/or approach where the benefits are not well known until key policies are in place and large-scale implementation has started (e.g. Water Efficient Labelling) could fall into this category.* |
| 2 | **Fairly inflexible.** Option is fairly fixed and can only be changed in relatively minor ways once development has started. | As above, but there is some flexibility -e.g. reservoirs where there is flexibility around water sources, 'binary' demand management initiatives that can be effectively trialled before full scale implementation etc. |
| 3 | **Typical scheme.** The scheme will become well defined prior to full implementation, but can be scaled and adjusted as the detailed design is being developed. | 'Typical' resource schemes where assets can be re-sized or adjusted once constraints are fully understood, and there is some opportunity for modular development of certain components (e.g. treatment streams). Demand management initiatives where changes can be made as the rollout progresses, but the scale and scope of the initiative is reasonably fixed, fall into this category. |
| 4 | **Fairly flexible.** Some modular development is possible and/or the intervention is scalable in response to external factors. | Schemes where there are relatively few 'hard constraints' so development can be pursued in a relatively modular way, and there may be some scope to extend or scale back the size of the scheme as required. Many demand management initiatives will tend to fall into this category as they may have expectations on their maximum size, but ultimately can be scaled back as required if they are not providing to be effective. |
| 5 | **Notably flexible.** Scheme is fundamentally modular and there is significant opportunity for scaling as required. | Probably limited to options such as desalination where development can be fully modular, or demand management initiatives where there is full flexibility in scale and the ability to adapt the initiative as better information becomes available |

## Metric E3 – Reliance on External Organisations to deliver changes.

This metric is intended to reflect the risk that a scheme cannot practically be delivered because of dependencies on multiple institutions to implement, or uncertain approvals and delivery mechanisms that rely on third parties. Bilateral agreements and simple water trading are not intended to be highlighted by the metric.

| Score | Description | Notes and Potential Data Sources |
|---|---|---|
| 1 | **High risk.** The scheme has known, significant challenges and relies on third party organisations to approve or deliver the scheme using processes that are not yet well established. | Complex schemes that required support and consent of multiple actors and institutions where there are significant uncertainties over delivery mechanisms and future working arrangements. *Demand management schemes that require major policy or regulatory changes that have not yet been committed to.* |
| 2 | **Increased risk.** The scheme has known challenges and is relying on some third party organisations to approve or deliver the scheme. The processes involved are reasonably well defined, but non-statutory or have little precedent. | Complex schemes that require the support or consent of institutions other than the planning authorities, with associated risks to scope. *Demand management schemes that require minor external policy support or legislation, which has not yet been committed to, or where there is a need to develop technologies externally that are not yet available.* |
| 3 | **Typical scheme.** Although the intervention or scheme faces challenges to approval or implementation, this is through well known processes with mature institutional arrangements. | Schemes that could involve bilateral trade, but do not rely on multiple institutions and will follow standard planning application routes (DCO or conventional) where there is likely to be some opposition. *Typical demand management schemes that only require existing policy support and follow known and well-practiced regulatory processes.* |
| 4 | **Lower risk.** The scheme is not only reliant on well known processes with mature institutional arrangements, but the likelihood of challenge and major delay is low due to a lack of opposition or widespread support. | Typical supply schemes where expected objection risks are low. *Typical demand management schemes where there is broad support and customers and customer representatives are likely to be supportive*. |
| 5 | **Negligible risk.** The scheme is highly unlikely to experience substantive challenge or delay. | Smaller supply schemes that are carried out within permitted development rights, or where there is clear planning support and no known opposition. '*Flagship' demand management schemes with strong policy and/or customer support where delivery mechanisms are similar to existing, well tested approaches.* |

## Metric E5 – Participation in Collaborative Landscape Management.

| Score | Description | Example |
|---|---|---|
| 0 | No noticeable change for catchment stakeholders | Pipeline |
| +1 | Single domain medium scale catchment interventions. | Catchment partnership |
| +2 | Large scale multi-benefit landscape restoration with multiple revenue schemes. | LENs style, blended finance |

The rationale for this metric is that collaborative approaches to environmental management are essential to create transformative systemic change in the resilience of environmental systems. The environmental system supports the public and non-public water supply systems that are the focus WRSE. The metric will come under the category of evolvability because of the long term need to change the way that the four systems respond to the on-going changes affecting the environment.

The metric will work apply a score of 0 for options that do not involve collaborative land management. A one step increase to a score of 1 would be achieved by a collaborative intervention that is of medium scale and with impacts that are predominantly environmental; and predominantly third sector driven with engagement from some private sector actors in the agricultural sector. A two-step enhancement would be achieved by a major intervention that has multiple objectives and has a range of sectors engaged from the private sector collaboration as well as third sector. A score of 2 is achieved where the private sector is able to increase scale by capitalising risk.

The emphasis of this metric is not simply a matter of increasing environmental benefit – that effect is covered up in the environmental metrics. The purpose of this metric is to reflect the enhanced resilience of collaborations that a plural in purpose and multi-sectors in membership.

Examples of major, multi-benefit initiatives, that would score 2 in this metric include:

- Cumbria LENs http://www.3keel.com/wp-content/uploads/2018/01/healthy-ecosystems-cumbria-lens.pdf
- The Greater Manchester Natural Capital Investment Fund. https://naturegreatermanchester.co.uk/project/greater-manchester-natural-capital-investment-plan/
- Hampshire Avon LENs Creating a landscape network in Hampshire – 3Keel

The Hampshire Avon collaboration is driven by the local Catchment Based Approach (CaBA) group and addresses numerous multi-sector private sector actors. Provided that funding is derived from these actors at scale, then this partnership would score 5.

# Appendix C. Mapping to other Resilience Frameworks

Although it is not required to generate the metric scores and evaluations, the reason why each metric has been included is provided in the table below. This helps provide background understanding of the metrics. This also shows how the 4 'R's described in the Cabinet Office description of resilience are covered by the framework. In summary:

- **Reliability in the 4Rs** is covered by the metrics contained within reliability in this framework. Key metrics describe different facets of the Cabinet Office definition.

- **Resistance in the 4Rs** is also covered by the metrics con within reliability in this framework. Key metrics describe different facets of the Cabinet Office definition.

- **Redundancy in the 4Rs** is split between reliability and adaptability in this framework. 'Passive' forms of redundancy (e.g. storage, spare production capacity) are covered by reliability, whilst 'active' forms of redundancy (e.g. network and treatment capacity that can be re-purposed during shock events) are covered in adaptability.

- **Response/recovery in the 4Rs** is covered by the metrics contained within adaptability. The only exception is where planned/passive operational processes (e.g. standby generation) are routinely used to maintain the running of a system when it is exposed to expected and planned for shocks.

As noted within the 'Naturally Resilient' report[10], it is important that resilience is viewed in relation to longer term stressors, as well as transient stresses and system shocks caused by acute hazards. The framework presented here is focused on modelled investment requirements, so it ensures that both transient shocks and stresses, and longer term/chronic stresses are addressed by splitting the metrics according to:

- Reliability and adaptability, which reflect portfolio resilience to transient shocks and stresses
- Evolvability, which reflects the portfolios ability to respond to unplanned, longer term or chronic stresses.

[10] Wildlife and Countryside Link Report, draft at the time of writing

**Table C.1: Mapping of Reliability and Adaptability Metrics to the 4Rs and Hazard Type Coverage**

The key measure of 'resistance' to drought hazard, as described under the 4Rs, relates to the 1 in 500 year failure metric that underpins the supply/demand balance. The linkages that the resilience metrics have to the 4'Rs of resilience attributes (as detailed by the Cabinet Office – Resistance, Redundancy, reliability and Response/Recovery) and the main hazards that link the attributes described by the metric

**Public Water Supply System**

| Metric | Mapping to '4Rs' | Main hazard types linked to the attribute |
|---|---|---|
| R1: Uncertainty of option supply/demand benefit | Maps to '**reliability**' under the 4R classifications. | Drought, possibly societal where there are significant licencing uncertainties. |
| R3: Risk of failure of planned service due to other hazards | Maps to **'resistance'** and '**reliability'** under 4R classification, but covers physical hazards other than meteorological shock or exceptional demand events | Physical and adversarial hazards. Only considers hazards that can cause long term failure due to loss of asset function. Events such as forest or heath fires that could prevent access for repairs are particularly significant. |
| R4: Availability of additional headroom. | Maps to **'redundancy'** under 4R. | General system headroom to help allow operations to continue due to shocks caused by all hazards described under other metrics. |
| R5: Catchment/raw water quality risks (incl. climate change) | Maps to '**reliability'** of service under 4R. | Raw water quality hazards that lead to sustained loss of supply, particularly during drought or demand shock events[11]. |
| R7: Risk of failure of planned service due to exceptional shocks | Maps to **'resistance'** and '**reliability'** under 4R classification, but covers societal/supply chain hazards other than meteorological shock or exceptional demand events | Societal and supply chain hazards. Only considers shock events that could cause disruption resulting in outages and failures > 24 hours. |
| A1: Expected time to failure (PWS) | Maps to '**response'** under 4R – the greater the warning time the more likely it is that drought response measures can be made to be effective. | Drought |

[11] Demand shocks relate to peak demands outside of dry weather expectations, and can occur as a result of a number of circumstances – recent examples include freeze/thaw in 2017, high demand as a result of COVID-19 lockdown in some areas and localised issues during the 2018 prolonged heatwave.

| | | |
|---|---|---|
| A2: Duration of enhanced drought restrictions. | Maps to ‘**redundancy’** and **‘recovery’** under the 4Rs. Recovery is included because the impacts and hence recovery measures will tend to increase the longer that the exceptional period lasts for. | Mainly relates to human factors and the risk that these materialise during the drought event (e.g. demand shocks, supply chain failure due to civil or economic issues). |
| A3. Operational complexity and flexibility. | Generally maps to **‘response/recovery’** areas of the 4Rs. Core element to enable non-routine operational responses and workarounds during shock events. | All hazards other than drought, as described under other metrics. |
| A5: PWS system connectivity | Covers both ‘**redundancy’** and ‘**response/recovery’** potential. Removing risks to critical points and SPOFs is key to enabling work arounds during shock events. | All hazards other than drought, as described under other metrics. |
| A7: Good customer relations support engagement with demand management | Maps to both ‘**redundancy’** and ‘**response/recovery’** under the 4Rs. Customer ‘buy in’ to calls for restraint and usage bans affects both the likelihood of more severe emergency measures, and reduces the risk of demand spikes that could interact with other hazards during drought events. | Drought/human factors |

| Title | Method Statement: Investment Programme Development and Assessment |
|---|---|
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# Table of Contents

# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

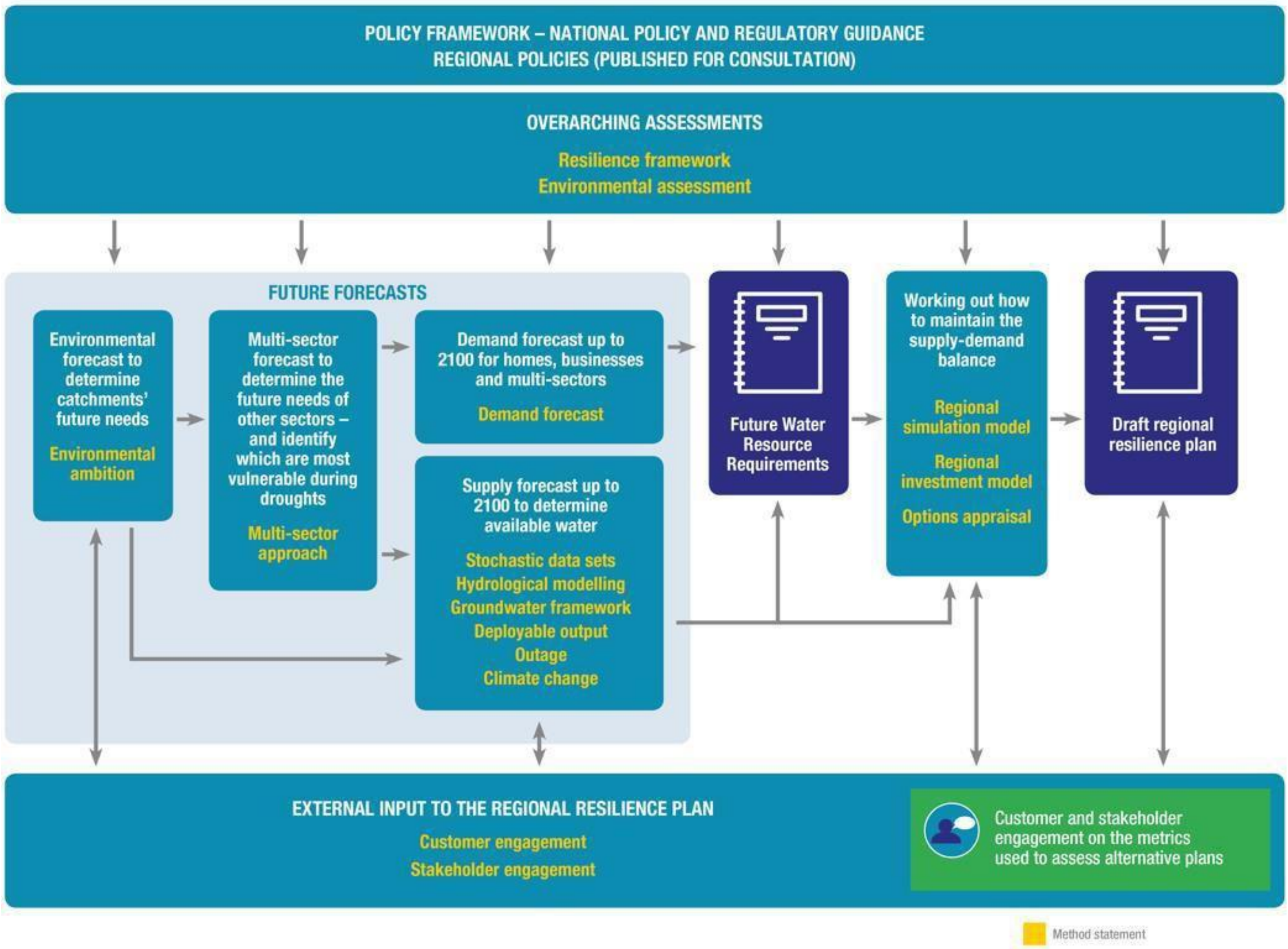
We have prepared method statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We are consulting on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this investment programme development and assessment method statement will contribute to the preparation process for the regional resilience plan.

The scale and complexity of water resources planning for the South East of England requires advanced decision-making methods to ensure that a robust solution is reached. This method statement details the process and tools for developing a best value, adaptive regional plan as described by the WRSE resilience framework, with special focus on the regional investment model and its supporting infrastructure and models. A separate method statement details the Regional Simulation Model and its role in the decision-making.

Integrated risk modelling is used to explore and define problems to be solved for regional water planning to support public water supply, non-public water supply, the environment, and social amenity while allowing explicit exploration of different uncertainties or risks. Real options and adaptive planning methods are combined in the WRSE investment model which seeks good value solutions to the integrated risk problems to 2100, for a variety of different values including cost, resilience, environmental impact and customer preference.

**Figure ES1: Overview of the method statements and their role in the development of the WRSE regional resilience plan**




A visualisation tool supports understanding and comparison of the alternative investment programmes produced by the investment model, to allow shortlisting for specialised assessment and stress-testing, before a preferred solution is selected.

A data landing platform underpins all data flows across this process to support robust governance, quality assurance and reporting.

# 1 Introduction and timeline

1.1 By 2050, the South East of England is forecast to experience a shortfall in water resources needed to ensure a resilient water supply for the public, other users and the environment of between 1000[1] and 1750[2] $Mld^{-1}$.

1.2 The scale of the problem and controversial nature of some of the potential solutions means that an advanced decision-making method is advocated by the planning guidance. WRSE is developing both regional simulation and aggregated optimisation models to develop and test investment programmes and enable selection of a best value adaptive plan for the region.

1.3 The investment modelling method, together with the process for dealing with associated data flows, problem and risk definition, and solution appraisal, is detailed in this document.

1.4 The overall timeline and milestones for the decision-making process to support the regional planning is shown in Table 1.

**Table 1: Milestones**

| Date of Delivery | Activity |
|---|---|
| July 2020 | Method statements produced |
| Oct 2020 | Policies and preferences agreed |
| Winter 2020/21 | Initial resilience planning for the South East region |
| Spring 2021 | Update Future Water Resource Requirements for South East England |
| Spring 2021 | Confirm the policies and preferences that we will embed in our regional plan |
| Summer 2021 | Reconciliation of draft regional plans to ensure alignment across England |
| January 2022 | Publish WRSE draft Regional Plan for informal consultation |

[1] March 2020, Future water resource requirements for South East England, WRSE.
[2] March 2020, *National Framework*, Environment Agency

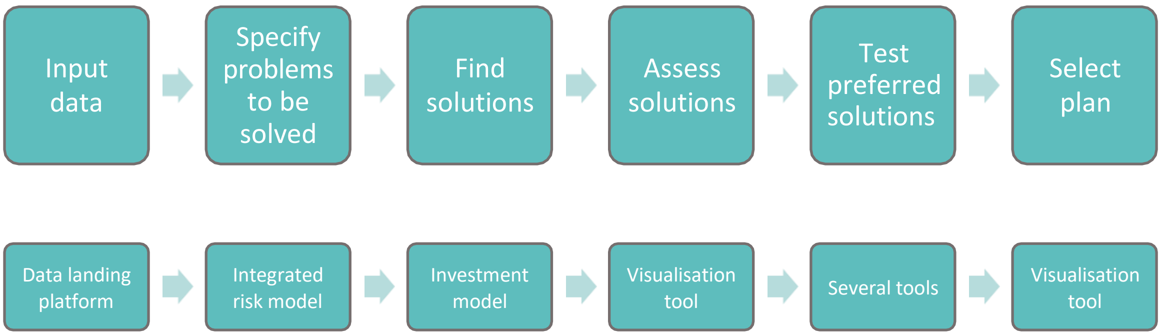
| | |
|---|---|
| May 2022 | Present the main issues raised in the consultation and how they will be addressed |
| August 2022 | Publish our final draft Regional Plan |
| August 2022 | WRSE water companies will submit their draft Water Resource Management Plans 2024 ahead of public consultation |
| March 2023 | Water companies publish their revised draft Water Resources Management Plans |
| September 2023 | WRSE will publish its final multi-sector, regional resilience plan |

# 2 Process overview

2.1 The process for generating and testing the regional plan[3] can be summarised in the six main stages shown in 0 together with the tools necessary to assist the undertaking of each step; these stages are an amalgamation of the full 17-step process for *development of a plan* described in the WRSE Resilience Framework, to allow the mapping of each stage to the tool developed to support it.

2.2 The full 17-step process is broken down in Sections 3, 4 and 5 of this document, which details the methods and tools under development to work through this process, although detailed description of the methods for testing the preferred good-value solutions in terms of system resilience, environmental impact and customer impact are described in the separate method statements referenced in Section 6.

**Figure 1: Steps to generate and test a regional plan**




2.3 The first tool, the data landing platform (DLP, Section 2.34), will handle all data sharing and transformation between all steps in the process, and facilitate data quality control.

2.4 The integrated risk model (IRM, Section 3) is used to specify the supply-demand balances (SDBs) and SDB trees to be solved for each investment model run.

2.5 The investment model (IVM, Section 4) is used to search for the optimal combination of options across time to satisfy the problems defined by the IRM, subject to whichever decision parameters, constraints and objective functions are specified for that optimisation.

2.6 The visualisation tool (VTL, Section 5) is used to graph, map and tabulate the outputs from the IRM and IVM to assist with output quality control, decision-making, and selection of good value investment programmes by company and industry experts.

[3] June 2020, *Securing resilient water resources for South East England – consultation on our resilience framework*, WRSE.

2.7 Methods for testing a shortlist of good investment programmes are outlined in Section 6. Shortlisted solutions are sent via the DLP to the other workstreams for advanced testing, while the IVM is used with additional parameters such as option restrictions, alternative scenarios or changing constraints, to stress or sensitivity test those good value investment programmes that have been identified as preferred.

2.8 A final selection is made using the VTL, including the additional data from the stress, sensitivity, and additional testing, and the preferred adaptive regional resilience plan then exported via the DLP to a headroom assessment tool and the WRP tables, to support consultation and reporting (Section 7).

# Input data

2.9 The methods for producing the input data required are detailed in the method statements for the workstreams which produce them. All data input to the DLP is signed-off by the input workstream and the version, authorisation and author automatically captured as part of the upload. This section lists the data required and expected provenance.

## Planning scenarios and planning horizon.

2.10 The Water Resource Planning Guideline (WRPG) states that a Water Resource Management Plan (WRMP) must consider the worst-case dry year combination of supply and demand forecasts for each zone, together with the uncertainties incorporated in target headroom. Drought resilience must also be included, and the revision of the WRPG to be published this August is in line to advocate resilience to 1:500 drought by 2040.

2.11 To enable investment modelling for dry year and drought across WRSE, baseline supply and demand forecasts and uncertainty profiles are imported for each of five deterministic planning scenarios:

1. Normal year annual average (NYAA)
2. Dry year annual average (DYAA)
3. Dry year critical period (DYCP)
4. 1:200 drought (1:200)
5. 1:500 drought (1:500)

2.12 Deterministic DOs are also provided for supply options for each of the planning scenarios, and demand reduction profiles for each of the demand reduction strategies.

2.13 Where possible drought interventions are not included in supply or demand baselines; media campaign impacts, temporary use bans, non-essential use bans, and drought permits or orders are all included as options that have a deployable output (DO) or demand reduction available during the dry year or drought planning scenarios.

2.14 As explained in the Initial Resource Position for WRSE, the planning horizon for WRMP24 will be April 2025/26 to April 2099/2100.

## Baseline supply forecasts

2.15 Baseline supply forecasts for the IRM and IVM define water available for use (WAFU) from each WRZ's own sources, plus or minus any external or commercial transfers to/ from the WRSE water companies, and inset appointments. These WAFU forecasts are generated by the Regional Simulation Model, based on regional weather and climate datasets, hydrological modelling, groundwater modelling and dynamic demand algorithms and methods.

2.16 Existing inter-zonal transfer pipelines and existing inter-zonal bulk transfer agreements within the region are included as options, to enable existing transfer agreement inclusion as either fixed volumes representing inter-company agreements, or options for optimisation of conjunctive use of regional WAFU, as desired for different IVM runs.

2.17 Drought intervention DO reduction or enhancement is not included in the baselines, but as options available for dry or drought year planning scenarios.

## Baseline demand forecasts

2.18 Baseline demand forecasts for the IRM and IVM are generated by the demand modellers for each company, based on the regional population and properties forecasts generated by Edge Analytics (Population and Property Forecasts – Methodology and Outcomes). The modellers provide deterministic distribution input (DI) forecasts with DI per WRZ per year, for each planning scenario.

2.19 As there are several relevant population and properties forecasts, the demand forecasters are devising a method to select forecasts that are most applicable for regional adaptive planning, as detailed in the Demand Forecast method statement. It is feasible to include alternative demand forecasts either:

- as fixed baselines, for separate optimisations of a range of supply demand balances where the range covers supply uncertainties only; or
- as demand forecast uncertainty profiles in the integrated risk model, sampled to generate a range of supply demand balances for a single optimization

2.20 Testing and evaluation of the IRM and IVM with full data will enable determination of the preferred method, or combination, going forward.

2.21 Drought intervention DI reduction should not be included in the baselines, but as options available for dry or drought planning scenarios.

## Situations and policies

2.22 Deterministic baseline forecasts require the forecaster to select a 'most likely' or 'best fit' forecast from among those feasible. Situations (i.e. circumstances beyond reasonable control of the water companies or regulators such as population growth, climate change etc.) and policies (either internal or governmental/

regulatory) are key factors that influence both system forecasts, and the uncertainty distributions around these influences are all captured as part of the supply and demand forecasting workstreams, to be input to the IRM via the DLP.

2.23 The guidance states that situation and policy uncertainties affecting public water supply forecasting should be sampled to provide a deterministic target headroom forecast to be included in problem development and ensure that water resources management planning can meet the risk that the future deviates from the most likely forecasts. The integrated risk model includes all the uncertainties used to create a target headroom buffer, but samples and solves for them separately and in combination to allow greater understanding of the relative impacts of key situations or policies on investment planning.

2.24 Situation and policy uncertainty profiles input to the IRM will include more than these key challenges to public water supply. Additional uncertainty profiles will also be input relating to environmental protection, non-public water supply, and wider South East systems, as defined in the WRSE Resilience Framework, so as to ensure that the problems to be solved are comprehensive enough to provide solutions resilient for all four systems.

## Investment options

2.25 The Options Appraisal team provide all regional supply, demand and transfer options not included in the baselines, whether existing, under construction, or new. Options may be stand-alone or made upof:

- Option elements (resource, conveyance)
- Option phases (modular increases in resource DO)
- Option stages (planning, development, construction and operation)

2.26 For example, existing transfers are input with two elements:

- DO of the bulk transfer agreement under different planning scenarios (resource element)
- capacity of the transfer pipeline (conveyance element)

This enables the investment model to both run simulations of the system with the bulk transfer agreements fixed, or to run with optimisation of existing transfer pipeline utilisation.

2.27 Drought interventions are included as options to enable better understanding of the impact of temporary use bans, non-essential use bans, drought permits and drought orders, and better evaluate the investment cost of resilience to different levels of service.

2.28 Supply options due for completion before the 2025 start of the planning horizon will be included in the baseline forecasts. Options for which planning, development or construction is due to start before 2025 will be provided with a new completion date, remaining costs, and a revised DO estimate; the water company providing each of these options under development decides whether the decision to build is fixed or whether completion is still optional.

2.29 Demand reduction strategies per WRZ are developed in company from combinations of available demand options to meet different demand reduction targets. Three per zone are envisaged. Recirculation of WAFU through effluent discharge is a consequence of demand levels upstream and therefore, for each demand strategy in upstream zones, the associated effect on downstream WAFU is calculated by the simulation model for input via the DLP.

2.30 New supply options and transfers can include elements, phases and stages as listed above; the combination of the components by the investment model defines when or if an option is commissioned, the maximum DO available, and the combined operational expenditure, which the optimiser uses in comparison with the opex of all other options to minimise utilisation opex while satisfying demand across all four planning scenarios.

2.31 Whether new treatment is required in a zone depends on:

- baseline demand growth
- amount of demand reduction that frees up existing treatment capacity
- amount of DO reduction that frees up existing treatment capacity (e.g. sustainability reductions)

It is therefore feasible to pre-calculate the zonal treatment expansion required for each of the three demand reduction programmes per zone, for each situation. These treatment options and costs can be combined with the demand programme costs, for consideration of the two together in investment optimisation.

2.32 The multisector group and the Environmental group will also provide potential options which will be considered in the investment model, see Multi-sector Approach and Environmental Ambition method statements.

2.33 A full description of options development, appraisal, and option component mapping for modelling is included in the Options Appraisal method statement.

# Data flow and quality control

2.34 Regional planning input data outlined in section 2.1 are being delivered by several workstreams listed above. The majority of these workstreams are being undertaken by different contractors, and each may include local data storage and visualisation elements to streamline and audit data. To control the data sharing, data management and quality assurance across the regional planning process a centralised Data Landing Platform (DLP) is being created.

- Stage 1 of DLP delivery enables all data storage, transfer and transformation to and from the integrated risk model, investment model and visualization tool.
- Stage 2 will extend the DLP to enable reporting the final problem, options and selection in the Water Resource Planning (WRP) tables for each zone in the region.

## Data landing platform

2.35 The project data flows in Figure 2 outline the DLP stage 1 specification as the blue connections between workstreams, the codes for which are in Table 2. The key for the additional codes is in Appendix 1. Figure 3 shows the flow of information through the DLP.

**Table 2: Integrated Risk and Investment Model Input Data**

| IRM/ IVM Input Data | Provided by | ID[4] |
|---|---|---|
| Baseline supply forecasts | Simulation model | M |
| Baseline demand forecasts | Demand forecasting models via simulation model | H→M |
| Forecast uncertainties | Simulation & demand forecasting models | F&J |
| Existing transfers | Options appraisal | N |
| New supply options and transfers | Options appraisal | N |
| Demand reduction strategies | Demand strategies via Options appraisal | C→N |

[4] Data IDs relate to the Data Landing Platform flow chart,

Figure 2: Data flows through data landing platform

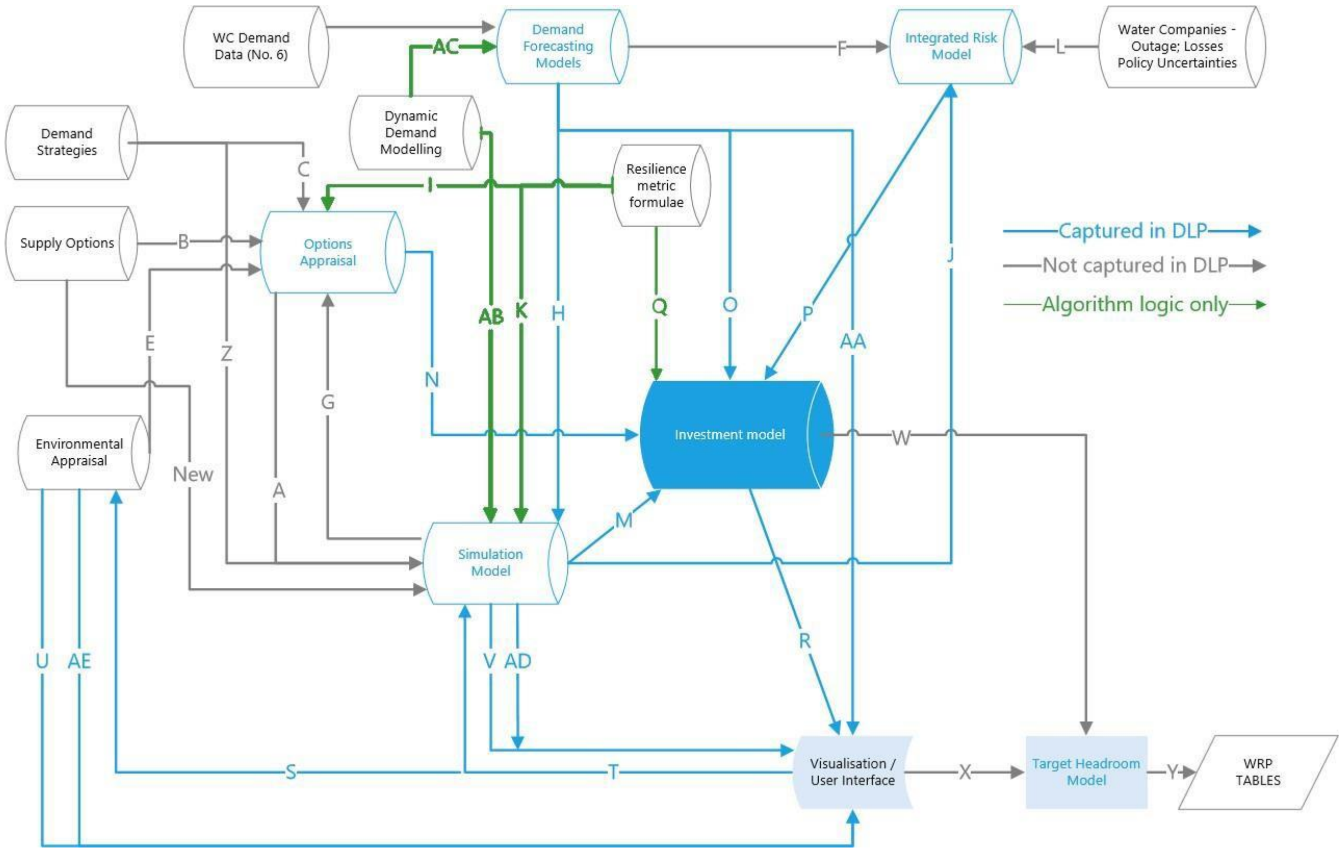
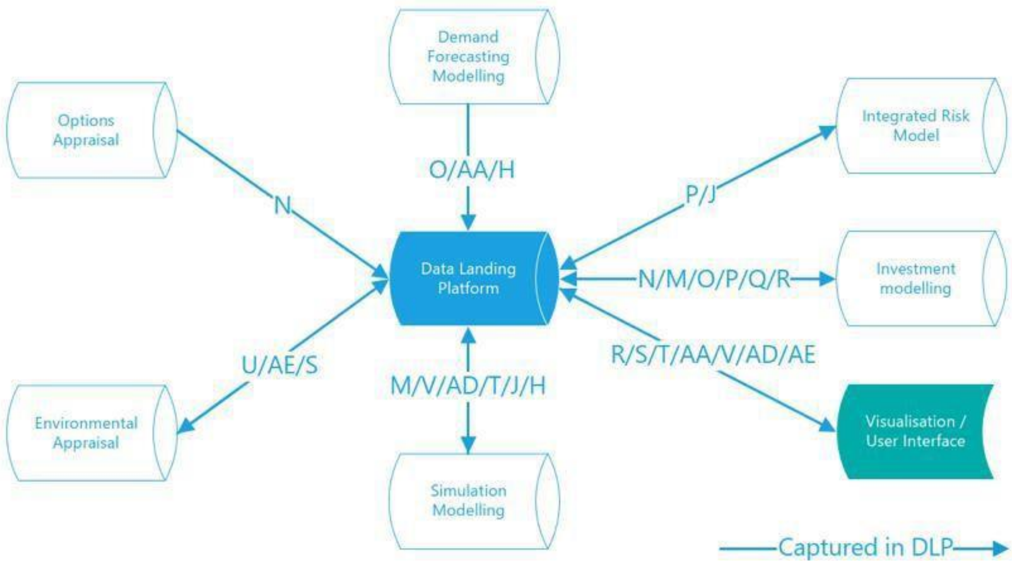



Figure 3: Flow of information through DLP



## Data assurance

2.36 The DLP will support the quality assurance process, through either visual or automated verification or likely both. Metadata will be set up to ensure governance of inputs in terms of version control and input personnel, and to track any transformations carried out in the DLP.

2.37 The QA logic will be defined by WRSE and will include identifying gaps in data, outliers, values outside of set tolerances, and incorrect value types, using a combination of manual and automated verification to balance out the pros and cons of each (Table 3).

2.38 **Manual quality assurance**. Dashboards are developed with the defined logic, with WRSE visually reviewing the data for any anomalies.

2.39 **Automated verification and checking of datasets.** All defined logic will be automated and applied on data upload, with alerts sent to users if anomalies are detected.

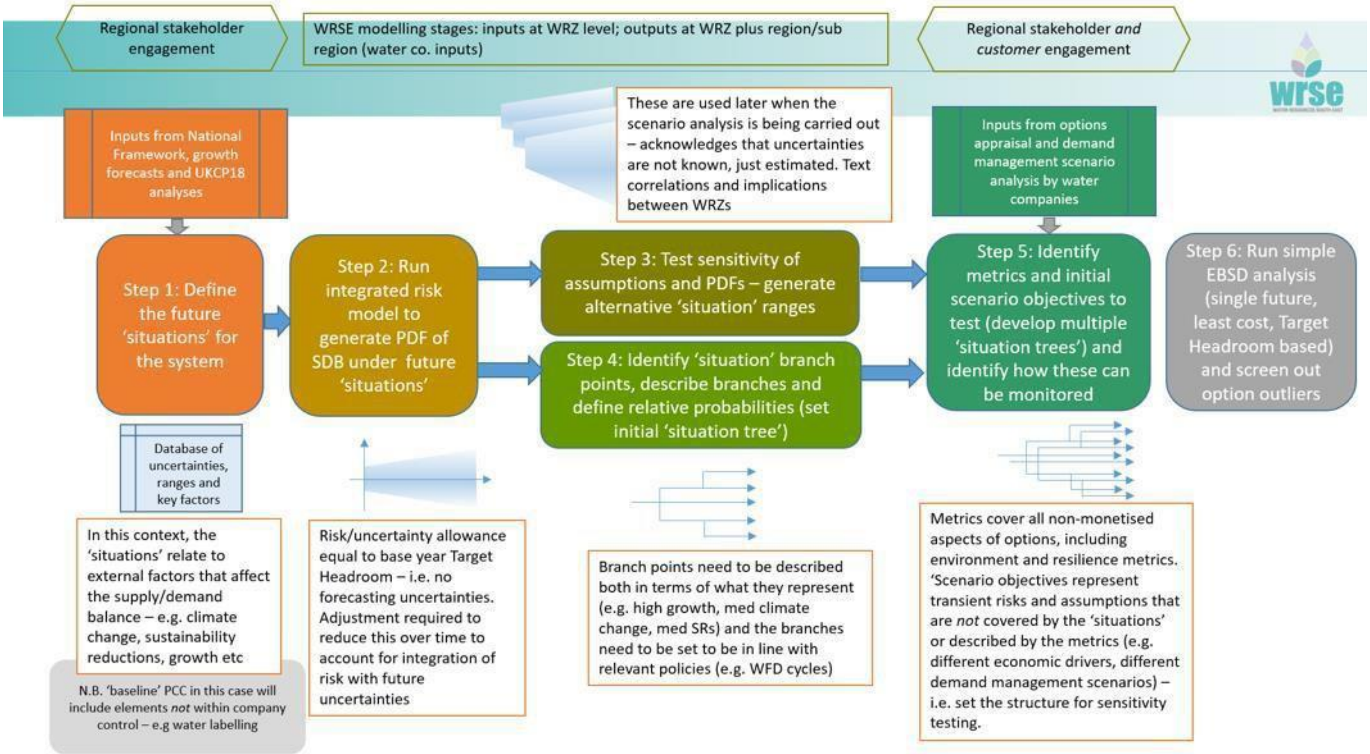
**Table 3: Manual and automated QA comparison**

| QA method | Pros | Cons |
|---|---|---|
| Manual | Can pick up anomalies that are difficult to automate<br>Can deliver contextual experience | Labour cost<br>Time intensive<br>Sometimes difficult to spot anomalies |
| Automated | Supports automated process and consistence<br>Can reduce human error | Development cost<br>Development time<br>Can be relied on too heavily |

# 3 Integrated risk modelling

3.1 The Integrated risk model derives the water resource planning problems to be investigated by the investment model; step 2 to step 5 of the *development of plan* process described in the Resilience Framework (Figure 4). Input data feeds into Step 1 and Step 5.

**Figure 4: Integrated Risk Modelling as part of development of a plan**




3.2 Before running the IRM to generate a PDF of situation uncertainties, the five supply and demand forecasts input via the DLP are first combined into four: NYAA, DYAA, DYCP and drought (EMDO[5]). The draft revised guidance states that 1:500 resilience should be attained in the 2030s; as such the EMDO baselines will represent 1:200 DO and DI until 2030, and 1:500 DO and DI from 2040, but the exact date of change from one level to the other may be varied in different SDB scenarios for optimisation in the investment model, or sensitivity testing of preferred regional plans.

3.3 For the multisector we will use equivalent of the NYAA, DYAA, DYCP but there might not be significant differences in their values. We will work with the multisector stakeholder group to understand their typical seasonal demand pattern use.

[5] Emergency drought order return period

3.4 The situation and policy uncertainties are sampled sufficient times to create a probability density function (pdf) around the four baseline forecasts for each drought scenario (date by which 1:500 resilience should be available), to represent the uncertainty range of potential supply-demand balances (SBDs) across the planning horizon (Step 2).

3.5 Probability percentiles of the SDB pdfs can be selected for single-pathway runs (solved for in Step 6), or combined to create a branched adaptive future for optimisation (Figure 5), known asa SDB tree (Step4).

**Figure 5: Example supply-demand balance tree of one planning scenario**

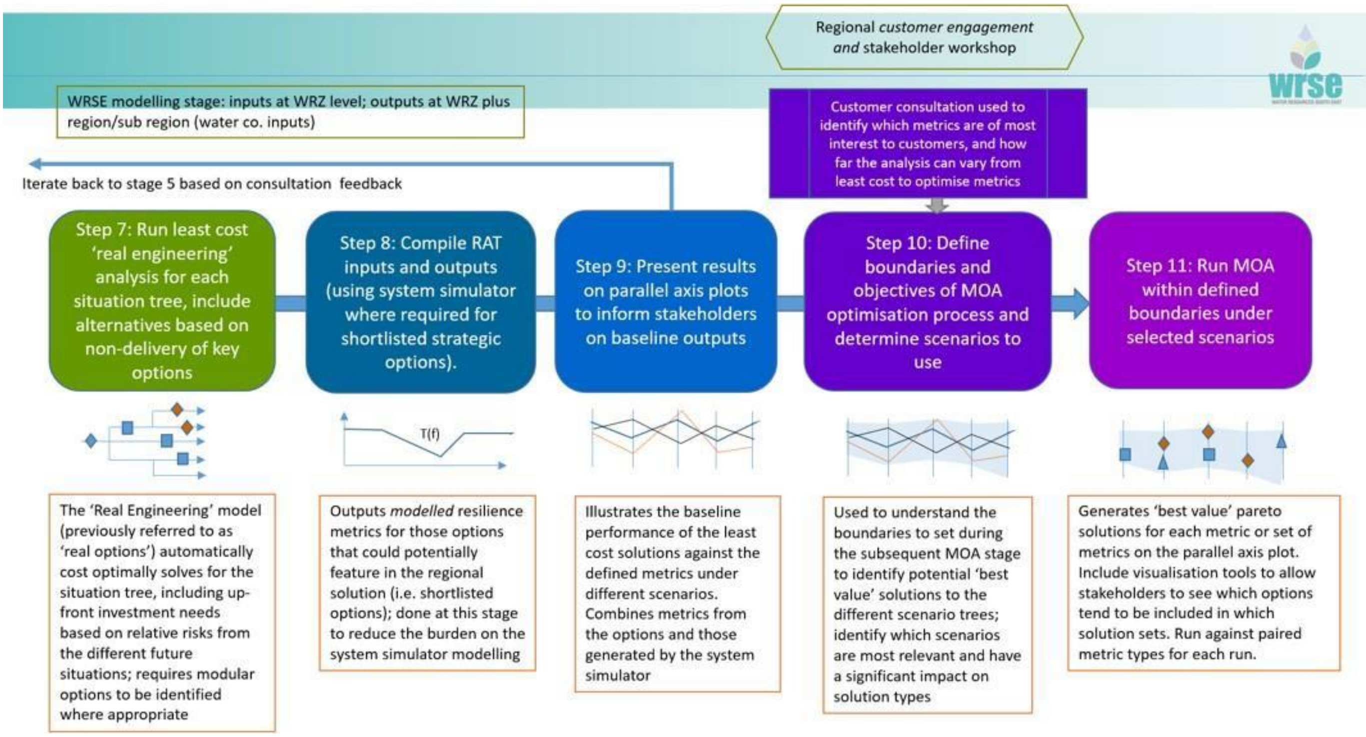

3.6 Alternative scenarios may be generated where a key situation or policy is used to perturb the baselines, and the remaining uncertainties combined in the pdf to generate SDBs and SDB trees (Step 5). Optimisation SDBs based on specific uncertainties will allow better understanding of the significance of individual drivers.

3.7 Assessment, assurance and sign-off of SDBs and SDB trees will be carried out using the visualisation tool (Section 5) before they are passed to the investment model for optimisation (Section4).

# 4 Investment modelling

4.1 The investment model is used for option screening, clarification and refinement (Step 6), and optimisation to find the most adaptive programme of options for each SDB tree both for least cost (Step 7), and for a variety of alternative values of interest (Step 10 and Step 11)(Figure 6). Steps 8 and 9 utilise the visualisation tool described in the next section to assess outputs throughout the process.

**Figure 6: Investment Modelling as part of development of a plan**




4.2 The primary function of the investment model is to identify programmes of water resource and demand reduction investment which satisfy the SDBs or SDB trees for the four planning scenarios for each WRZ in the region across the planning horizon, while minimising cost (Step 7), an alternative objective function, or a combination of functions (Step 11).

4.3 Metrics for coarse programme appraisal are calculated for all programmes developed (Section 5), and optimisation can also be carried out to minimise or maximise the majority of the metrics (Section 5) and so seek to develop investment programmes which are better in terms of resilience, environmental impact or social value as defined by the stakeholders or practitioners (Step 10).

## Conjunctive optimisation of planning scenarios

4.4 For a single SDB, the IVM seeks an optimal investment programme to ensure that the SDBs for each of the four planning scenarios is satisfied for each year in the planning horizon, in each zone, while minimising or maximising a single objective function, or multiple objective functions.

4.5 The IVM both ensures enough capacity is available in each year and prioritises utilisation of the assets selected to meet the objective function. For example, when minimising cost, new assets are selected by minimising fixed costs while prioritising utilisation of selected assets in ascending order of variable costs; the utilisation priority order will change as new assets with lower variable opex are commissioned throughout the planning horizon.

4.6 Proportionality weightings related to the likelihood of occurrence are applied to the planning scenarios to allow combination of utilisation from the different planning scenarios for objective function optimisation. Default values are in Table 4, although these can be adjusted per WRZ by the user.

**Table 4: Weightings for planning scenario utilisation**

| Scenario | Calculation | Weighting |
|---|---|---|
| NYAA | 40/52 | 0.7692 |
| DYAA | 8/52 | 0.1538 |
| DYCP | 1-(40/52+8/52+(15/200+60/500)/75) | 0.0743 |
| EMDO | (15/200+60/500)/75 | 0.0026 |

4.7 For an SDB tree, the IVM expands the optimisation to find the best solution that could meet the SDBs in all branches across the horizon.

4.8 These initial least-cost optimisations are used to assess the search space (number of options available) and refine those which are utilised, both identifying zones or areas where additional options, alternative option yields, or additional or alternative transfers would be beneficial, and identifying options which are never selected in any scenario (Step 6).

4.9 Step 6 also includes a conjunctive use analysis of the region, where existing formal bulk transfer agreements between WRSE zones are waived and the model optimises the transfer of water based on capacity of existing and potential transfer pipelines only, to identify the least cost sharing of resources and identify the minimum required resource development.

4.10 All assessments for Step 6 must be carried out for different risk scenarios, where the distribution on demand both in normal and dry year, and the impact of drought, is varied both spatially and temporally across the region, to assess for the full range of growth and weather scenarios.

## Single or multi-objective optimisation

4.11 The IVM is designed to optimise against a single objective function, or a combination of two objective functions with boundaries to the primary objective function limiting the search range for the secondary, for example:

- maximise environmental net gain within a 20% cost increase from the least cost programme, or
- minimise cost within a greater than 20% increase in environmental net gain from the least cost programme.

4.12 The IVM can be set to run single or batch optimisations of SDBs or SDB trees and export the resulting programmes of investment to the visualisation tool for appraisal (Section 5).

4.13 Following the initial assessment of available options and regional conjunctive use in Step 6, the Investment model is run to develop least-cost programmes of investment that are robust across the SDB trees for each risk scenario developed within the IRM (Step 7). Alternative programmes of investment can be developed using the draft multi-objective analysis metrics (Step 11), to facilitate communication with and assessment by stakeholders (Step 10) following assessment and selection of reasonable alternative programmes to quality control solutions using the visualisation tool (Step 8 and Step 9).

## Coarse metrics for programme appraisal

4.14 The cost, environment, resilience and customer metrics to be calculated in the investment model (Table 5) for each optimised programme will be fully defined through stakeholder engagement (Step 10), but placeholders have been designed in the investment model to allow for development, testing and refinement.

4.15 The investment programme metrics have been taken from a variety of sources: previous WRMPs, the resilience framework, environmental assessment framework, and discussion with customer engagement workstream leads. Both the calculation methods and the metric inclusion or combination will be subject to review as communication, utilisation and assessment progresses during plan development and engagement (Steps 7 to 11).

Table 5: Coarse programme metrics

| Type of Function | Code | Name |
|---|---|---|
| Cost | COST | Least cost discounting |
| Cost/ Social | IGEQ | Intergenerational equity discounting |
| Environment | ENV+ | Environmental benefit |
| Environment | ENV- | Environmental cost |
| Environment | BING | Biodiversity net gain |
| Environment | NATC | Natural capital |
| Resilience | COVA | Connectivity availability |
| Resilience | COVU | Connectivity use |
| Resilience | COTA | Contingency availability |
| Resilience | DELV | Benefit deliverability |
| Resilience | MITA | Mitigation availability |
| Resilience | MODA | Modularity availability |
| Resilience | DIVR | Diversity |
| Resilience | SURU | Surplus use |
| Social | CUPR | Customer preference for option type |

# Objective functions for programme development

4.16 The primary objective function of the model is least cost.

## Least Cost Optimisation

4.17 Minimise the sum for all selected options for all zones, using the STPR6 for discounting, of:

- NPV Capex (annuitized)
- NPV Fixed Opex
- NPV Variable Opex (frequency weighted average of NYAA, DYAA, DYCP & EMDO)
- NPV Embedded carbon
- NPV Fixed Operational Carbon
- NPV Variable Operational Carbon

Subject to:

1. Supply must meet or exceed demand plus risk in each WRZ in each year of the planning period under all planning scenarios
2. The utilisation of each option in each year is strictly non-negative and does not exceed the maximum yield of that option

## Alternative objective functions

4.18 Alternative objective functions are adaptations of the system metrics in Section 4.14. The value of each function is calculated for any solution programme; optimisation to find a solution focussed on one or more of the objective functions will be a user choice.

4.19 The objective functions available for investment modelling come from three sources: cost functions as defined and previously derived by the water companies; environmental assessment to enable coarse environmental evaluation and optimisation of investment programmes; and resilience assessment by metrics in the resilience framework screened as suitable for investment modelling:

### Intergenerational Equity (IGEQ)

4.20 Minimise the sum of the same six cost categories as for least cost optimisation, for all selected options for all zones for all planning scenarios, using the IEDR for discounting.

4.21 As the standard STPR assumes that weighting the cost of investment toward future generations is preferable, an alternative, intergenerational equity discount rate, IEDR, has been defined[7] to allow more equitable sharing of the costs of long-term investments across generations.

### Environmental benefit (ENV+)

4.22 Maximise, for all operation years, for all WRZs, the sum of the ENV+ scores for all new options

[6] HM Treasury Green Book *Social Time Preference Rate*.
[7] Appendix B: Intergenerational equity discount rate.

### Environmental disbenefit (ENV-)

4.23 Maximise, for all construction and operation years, for all WRZs, the sum of the inverted ENV- scores for all new options

### Biodiversity net gain (BING)

4.24 Maximise, for all years, for all WRZs, the biodiversity net gain values for all new options

### Natural Capital (NATC)

4.25 Maximise, for all years, for all WRZs, the natural capital values for all new options

### Connectivity availability (COVA)

4.26 Maximise, for all years, for all WRZs, for all planning scenarios, the capacity of inter-zonal transfers within the region

### Connectivity use (COVU)

4.27 Maximise, for all years, for all WRZs, for all planning scenarios, the utilisation of inter-zonal transfers within the region

### Contingency availability (COTA)

4.28 Maximise, for all years, for all WRZs, for all planning scenarios, the capacity of rapid deployment emergency capex schemes available

### Benefit deliverability (DELV)

4.29 Maximise, for all years, for all WRZs, for all planning scenarios, the probability that actual yield sampled through uncertainties equals nominal yield

### Mitigation availability (MITA)

4.30 Maximise, for all years, for all WRZs, for the drought scenario, the volume of DO in unused drought permits and orders

### Modularity availability (MODA)

4.31 Maximise, for each branch point, for all WRZs, for all planning scenarios, the volumeof remaining option phases for which the first phase has been commissioned

### Diversity (DIVE)

4.32 Minimise, for all years, for all WRZs, for all planning scenarios, the standard deviation of the volume selected of each option type from the mean for all ten option types

### Surplus use (SURU)

4.33 Minimise, for all years in which a new option is commissioned, for all WRZs, for all planning scenarios, the surplus available elsewhere in the region

### Customer preference (CUPR)

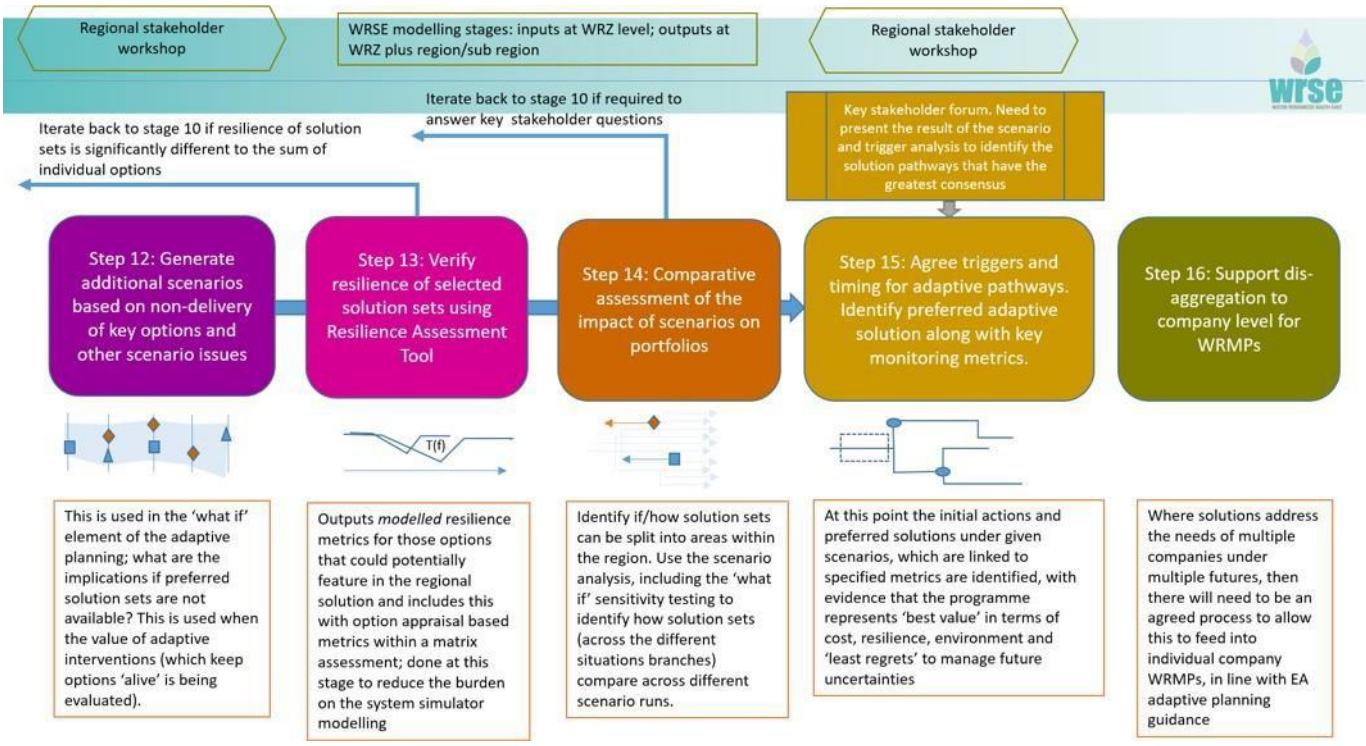
4.34 Maximise, for all years, for all WRZs, for all planning scenarios, the value based on customer preference for option types proportional to the volume supplied by each type.

4.35 Metric refinement or substitution will evolve with discussion, stakeholder engagement, visualisation and assessment, in line with consultation feedback on the resilience and environmental assessment frameworks, and refinement of the visualisation tools to enable analytic assessment using the additional metrics.

# 5 Programme visualisation and shortlisting

5.1 The visualisation tool is the primary decision support tool to allow quality assurance, appraisal, shortlisting, selection, communication and refinement of integrated risk SDB scenarios and trees and investment programme outputs and metrics throughout Steps 4 and 5, 8 and 9, and 13 to 15 of the development of a plan (Figure 7). As such the visualisation tool will be refined with all these audiences in mind, while considering the complexity of problem and option combinations that may be output from the IRM and IVM.

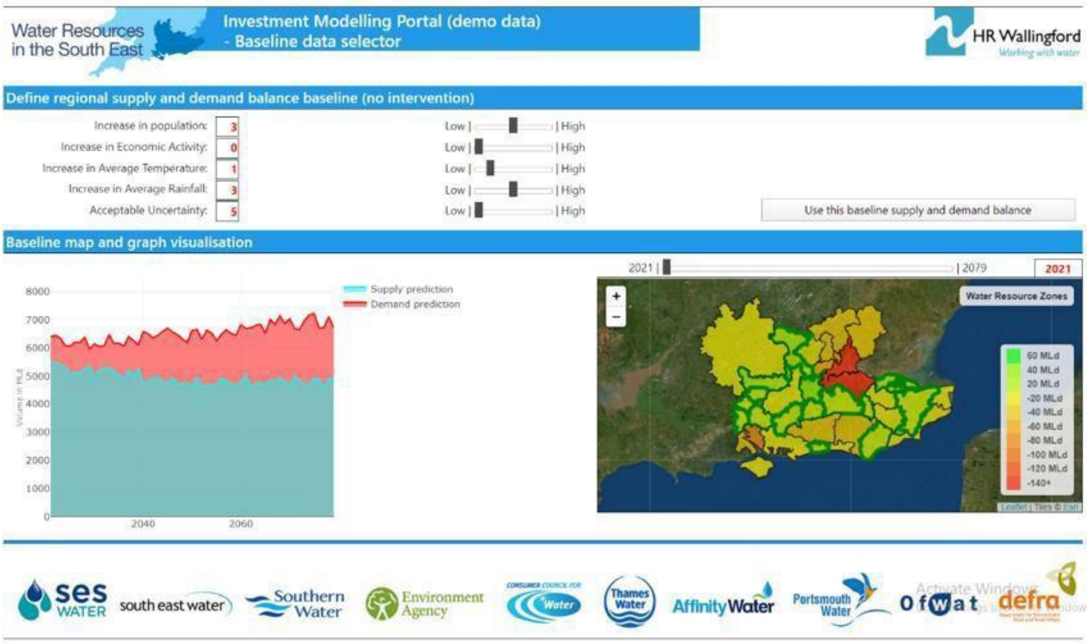
**Figure 7: Visualisation to support the development of the plan**



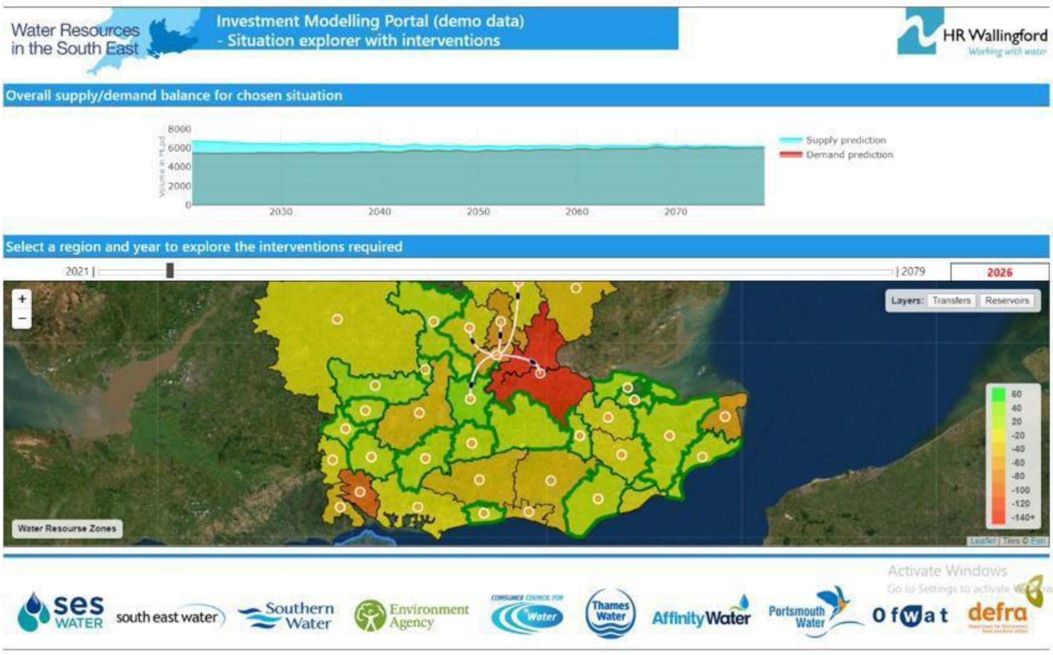

## Problem visualisation: baseline forecasts & existing transfers

5.2 The VTL enables viewing of SDB scenarios on a map and chart, and exploration of the supply and demand balance change through time. This will be used to show how existing transfers are utilised through time to meet the demands in the receiving water resource zone (see Figures 8 and 9).

### Figure 8: Visualisation of baseline forecasts




### Figure 9: Visualisation of transfers



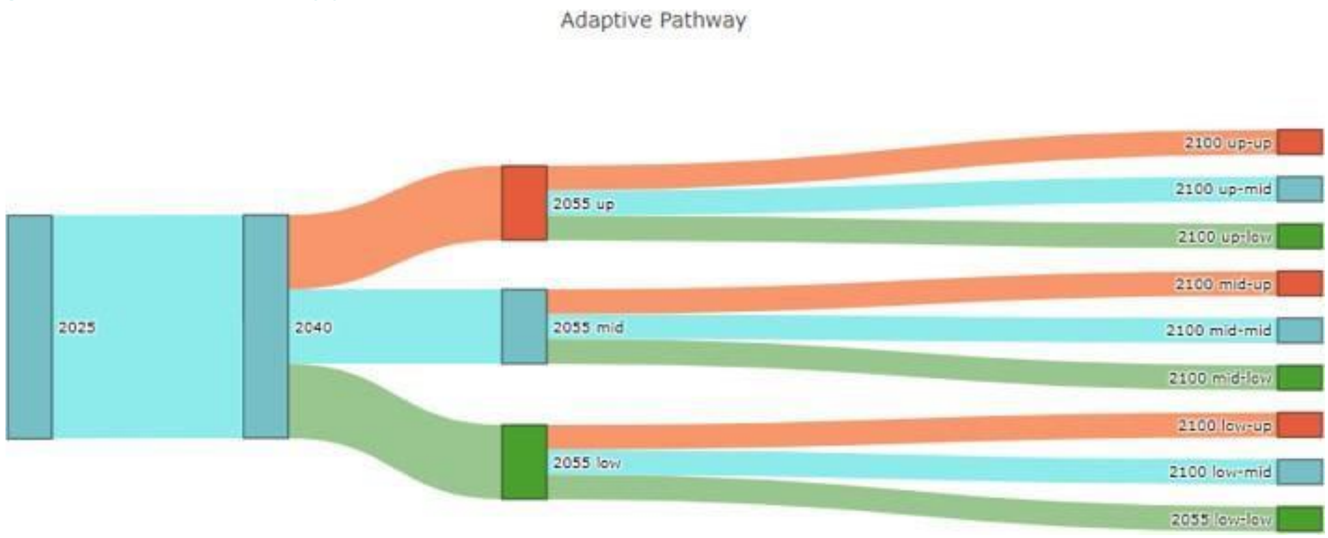
5.3 The purpose of these tools and various map layers is to gain a better understanding of where the requirements for water are being driven from and how the existing infrastructure can cope, or not, with these requirements. It is intended that the same set of tools are used to view the final preferred plan and its alternative plans.

# Problem visualisation: SDB trees

5.4 The amount of water required through the planning period will change according to some key externals influences such as climate change, population growth, policies and the requirements of the environment in the future. We will use animated Sankey plots (see Figure 10) to visualise the SDB trees through time, for both problem and solution understanding.

5.5 For each of the branches we will provide examples of some of the factors that could drive the supply demand balances to those anticipated levels. This will provide regulators, stakeholders and customers with a better understanding of the characterisation of these branches. However, in many cases the anticipated supply demand deficits could be achieved by several different combinations of external factors. This is also the case at the more extreme areas of the supply demand balances, albeit that the potential number of combination factors that achieve similar supply demand balances would be limited.

Figure 10: Animated Sankey plots to visualise the SDB trees

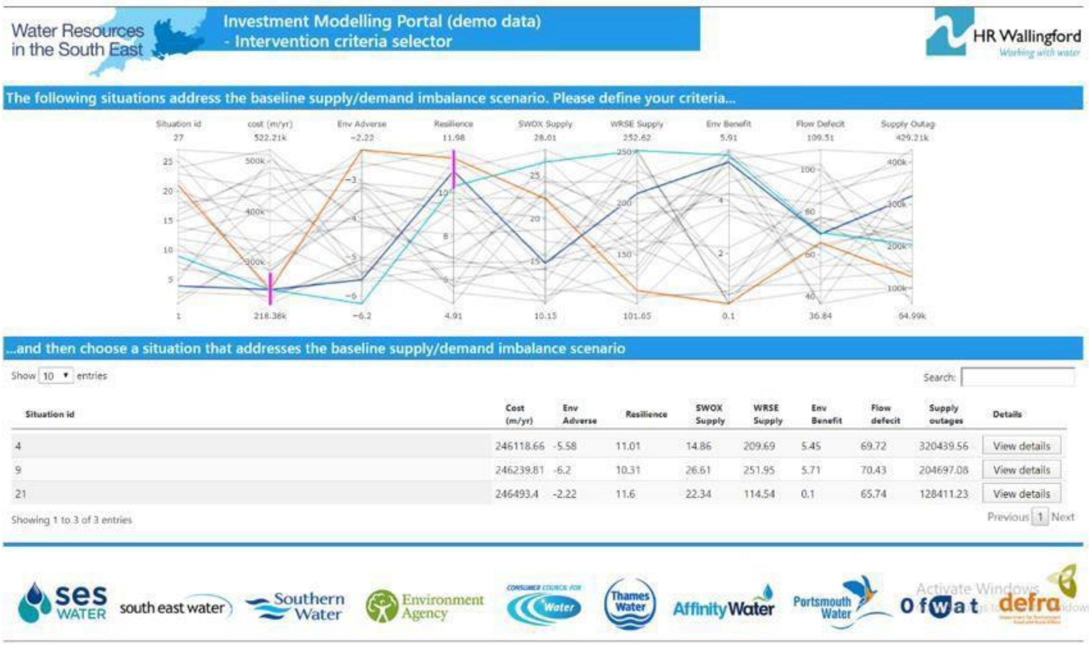



# Programme appraisal: metrics

5.6 A core requirement of a decision support tool for programme appraisal is the ability to review and filter alternative investment programmes using a parallel axis plot. Each parallel axis will represent a key metric that has been identified as being important to the overall programme assessment. By plotting the performance of each metric for each individual programme we can understand which programmes perform better than others, but more importantly which programme are unacceptable. These forms of plots and visualisations are key to the development and understanding of the overall investment programmes and our discussion with customers and stakeholders to gain opinion on the various investment portfolios. An example parallel axis plot is shown in Figure 11.

5.7 The selection of the metrics used for programme appraisal will be the resilience and environmental assessment metrics and any other metrics agreed through the stakeholder and customer engagement.

**Figure 11: Programme metrics on a parallel axis plot**




# Programme appraisal: options

5.8 In addition to the parallel axis plots we will also show which options are selected in a geographical context, see Figure 12 below. This will allow stakeholders, customers and regulators to review which schemes have been selected in the various water resource zones across the region and whether these options are company specific, catchment specific or multisector.

5.9 In addition to obtaining option information from the maps we will also show the overall volumetric or benefits information as well, as shown in the example in Figure 13. These overall tools and graphical displays will be able to provide programme information to regulators, stakeholders and customers. We are still developing these interfaces; we are trying to develop some other less technical summary of the schemes to help people navigate through the possible portfolio of options.

**Figure 12: Mapping of programme options**

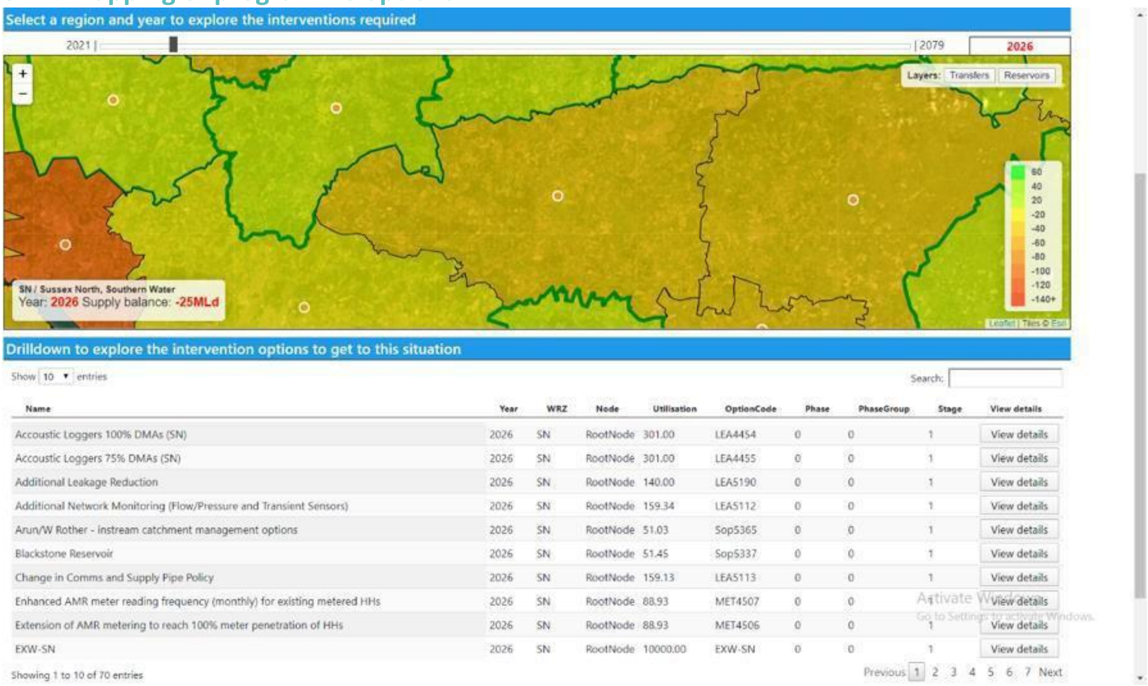
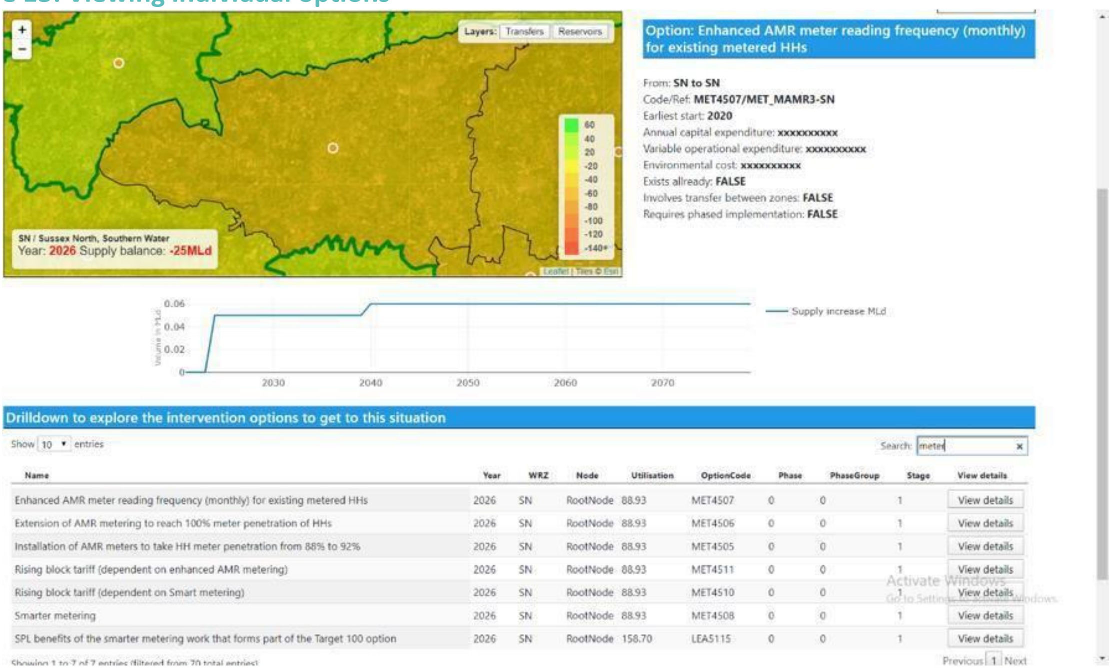



**Figure 13: Viewing individual options**



## Programme shortlisting

5.10 All the components of the visualisation tool as set out above will aid programme appraisal for shortlisting of good value plans for more detailed assessment and appraisal (Steps 8 and 9).

5.11 Further development of the VTL is being scoped to support appraisal of regional plans for this more detailed understanding of resilience, environment, customer and stakeholder views, and better allow each group to understand the trade-offs between the different challenges.

# 6 Best value programme appraisal

6.1 Shortlisted good value investment programmes will be passed back via the DLP to:

- the simulation model for resilience assessment
- the environmental assessment teams
- the customer engagement team
- the integrated risk/ investment model for sensitivity analysis and stress testing

6.2 The results of the specialised assessments for each programme will be fed back into the visualisation tool for further comparative appraisal, and selection of a preferred adaptive regional plan, including seeking views from the various WRSE groups (advisory, environment, multi-sector), stakeholders, customers and regulators.

## Resilience assessment

6.3 The resilience assessment of a regional plan is detailed in the WRSE Resilience Framework; the regional simulation model should be able to evaluate the effect of different stresses and hazards on a proposed investment programme in terms of impact on both the public water supply and non-public water supply, and also provide further information for the environmental assessment team directly related to water catchments.

## Environmental assessment

6.4 Environmental assessment of options can give some understanding of the effect of combining them into a potential investment programme, but the type of regional-level environmental assessment proposed[8] will provide much greater understanding of their combined impact.

## Customer assessment

6.5 Discussions with the customer engagement team have led to the proposal that customer focus groups could be trained and given access to the visualisation tool in order for the WRSE group to gain greater understanding of customer preference, and customers to better understand and demonstrate the trade-offs between resilience, environment, amenity and cost that they would prefer to make to support long-term water resources planning.

[8] March 2020, *Strategic Environmental Assessment (SEA) of the WRSE Regional Plan and environmental appraisal input to the WRMP24*, WRSE.

6.6 For this type of engagement, a form of bill impact calculation would be required to be integrated in the investment model and shown in the visualisation tool.

6.7 The scope for this method of customer engagement is under review; the initial proposal was for a separate tool to be used for engagement pre-investment modelling to feed customer preference data to the IVM.

## Investment parameters sensitivity assessment

6.8 While the simulation model will evaluate the robustness of a potential investment programme to the majority of climate and weather challenges, further challenges such as uncertainties around option cost and DO, asset failure, alternative demand forecasts and failure to gain planning permission for key assets will be assessed in the investment model together with regional conjunctive use assessments, to better understand the adaptability and robustness of each shortlisted programme.

# 7 Selection of preferred plan, outputs and reconciliation

7.1 The additional data from the assessments in Section 6 will support appraisal of the shortlisted good value programmes and selection of a preferred resilient regional adaptive plan with the help of the visualisation tool (Figure 7, Steps 13-15).

7.2 The preferred plan will then be exported to the WRSE water companies to support their statutory WRMP submissions and consultations and communicated to the other water regions for national reconciliation.

## Target headroom

7.3 The preferred resilience plan will be assessed for available headroom per zone per year in relation to the risk allowance around the baseline supply and demand forecasts from the robust adaptive plan selected, and compared with target headroom calculated using the method in the guidance in order to ensure compliance and populate the WRP tables.

## WRP tables

7.4 An expansion of the DLP is proposed (Stage 2) to enable automated population of the WRP tables. The scope of this will follow the build of Stage 1 of the DLP.

7.5 It has not yet been determined how the WRP tables could best capture adaptive plans, or drought baseline forecasts – there may potentially be several additional tables addended to the core planning scenario tables.

## Reconciliation of regional plans

7.6 A process for reconciliation of regional plans has been developed and will be implemented as necessary throughout the planning stages to ensure agreement on inter-regional transfers. The process of the reconciliation with the other regions is key to ensure that the various transfers align both in terms of volumes and dates.

# 8 The draft preferred plan

8.1 The selection of the preferred plan will have to accord with WRMP guidance and the UKWIR best value planning method. Currently both documents are in draft format and therefore we recognise that this method statement is still subject to change.

8.2 However, following the process that is outlined above we intend to derive a range of plans that can meet the key criteria that have been selected and discuss these with WRSE groups, stakeholders and customers. We hope that through this collaborative approach we will be able to understand what the consensus would be on the preferred plan and the reasons why it is preferred.

8.3 This preferred plan would be put forward to the WRSE board for their review and sign off. Following this governance review any changes would be relayed back to the groups and stakeholders. If there are no changes then this preferred plan and the alternatives would be put forward for consultation in January 2022.

8.4 We would then respond to the consultation submissions and adjust the plan accordingly, if required. The revised draft regional plan would then be used to inform: the WRMP's of the water companies, the multi-sector plans, national reconciliation of regional plans, and the catchment-based solutions to be delivered through the appropriate parties.

# 9 Next steps

9.1 We are consulting on this method statement from 1st August 2020 to 30th October 2020. Details of how you can make comments can be found here consultation website

9.2 We will take into account the comments we receive during this consultation process, in updating the Method Statement. Alongside this, the Environment Agency will shortly be publishing its Water Resource Planning Guidelines (WRPG) on the preparation of regional resilience plans. We may need to update parts of our method statements in response to the WRPG. We have included a checklist in Appendix 2 of this method statement which we will use to check that our proposed methods are in line with guidance where applicable.

9.3 If any other relevant guidance notes or policies are issued then we will review the relevant method statement(s) and see if they need to be updated.

9.4 When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

# Appendix 1: Codes for Data Landing Platform

| Chart ID | Data OUTPUT | Data INPUT | Required for | Stage | Data fields required | OUTPUT Data format (.csv/.json) | INPUT Data format (.csv/.json) | Data volume and size (MB/GB) | Access requirements (e.g for API/SharePoint upload) | Security/ confidentiality | QA Process & Meta Data | Data Transformations |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| A | Options Appraisal | Simulation model | Calculate option DOs for different droughts used in adaptive futures | 3 | List of ~20 screened options | .xlsx or .csv | .xlsx or .csv | < 10MB | Simulation team download from published data tables on PowerBI | n/a | Tables to have meta dat tags of check/approval | n/a<br>Simulation team to confirm format required to Options Appraisal team |
| B | Supply Options | Options Appraisal | To screen options for investment planning | 3 | Up to 700 options that pass into optionals appraisal, will have different benefits for each water company. | .xlsx | .xlsx | < 10MB | SharePoint upload - dedicated folders for each company to upload | Cost data held in Options Appraisal DB restricted to each WC and 'Admin' | Templates to include - Author/Check/Approval<br>Meta data from SharePoint taken revision, date and 'uploaded by' | Yes - from Excel to .csv format for import into Azure DB |
| C | Demand Strategies | Options Appraisal | To consolidate options for investment planning | 3 | Up to 700 options that pass into optionals appraisal, will have different benefits and demands for each water company. | .xlsx | .xlsx | < 10MB | SharePoint upload - dedicated folders for each company to upload | Cost data held in Options Appraisal DB restricted to each WC and 'Admin' | Templates to include QA information<br>Meta data from SP also taken fro Revision and 'uploaded' by | Yes - from Excel to .csv format for import into Azure DB |
| D | Demand Strategies | Simulation model | TBC - not essential | 3 | List of ~20 screened options | .xlsx | .xlsx or .csv | < 10MB | Supply WCs email excel to SM team | n/a | TBC - not essential | TBC - not essential |
| E | Environmental Appraisal | Options Appraisal | Options screening on environmental impact | 3 | 3no. metrics for; Environmental benefit, adverse effect metrics, biodiversity (score system -10 - 0 - 10).<br>1 no. metric for natural capital fixed cost £/ML/yr or in 0-10 score<br>1 no. metric in land use tonnes of carbon (Tonne C02)<br>700 options, therefore 3500 data points | .csv | .csv | < 10MB | or SharePoint | Geospacial data with exact locations to be locally randomised or represented by zone | Meta data in data transfer to include QA information | Options team to confirm format/attributes required with Environmental team |
| F | Demand Forecasting Models | Integrated Risk Model | To consolidate all supply demand balances in risk profile | 3 | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential |
| G | Simulation Model | Options Appraisal | To screen options for investment planning | 3 | Updated numbers for DO. & freefall numbers | .csv | .csv. | < 10MB | SharePoint upload or API | n/a | TBC - not essential | Options to confirm format/attributes required to Simulation team |
| H | Demand Forecasting Models | Simulation model | Simulation using different demand scenarios used in adaptive futures; Reforecasting of demand options' savings under different droughts | 1 | Split into components of household consumption, population, industrial consumption etc. to give a total demand value.<br>7 DO profiles over 75 year period to mirror the simulation model profile. | .xlsx | .xlsx or .csv | < 10MB | Assume it can be uploaded to a specified SharePoint or similar location. | None | No defined QA yet. Each water company completes its own checking internally using a different process and inputs into a master demand forecast model spreadsheet, which is checked. | Simulation modelling team to confirm transformations required from WRMP table 3 outputs |
| I | Resilience Metric Formulae | Options Appraisal | To assess resilience metrics of options | 3 | 24 sub metrics with scores e.g. yield, deliverability, modularity. Second Workshop - 16 metrics per option, 3 pt or 5 pt scale. | .xlsx | .xlsx | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential |
| J | Simulation Model | Integrated Risk Model | To consolidate all supply demand balances in risk profile | 1 | Receives uncertainty profiles from the demand and simulation models. | .csv | .csv | < 10MB | Assume it can be uploaded to a specified location. | None | Metdata: date, timestamp, version of the model, include check / approve data, resource zone identifier. | n/a |
| K | Resilience Metric Formulae | Simulation model | To assess resilience of options DOs incl environmental impact;<br>To assess resilience of preferred adaptive plan | 3 | resilience metrics | .csv | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential |
| L | Water companies (Outage etc.) | Integrated Risk Model | Including in integrated risk modelling SDBs | 3 | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential | TBC - not essential |
| M | Simulation Model | Investment model | Enable investment optimisation under adaptive futures | 1 | Central baseline DOs, and with climate scenarios, and drought.<br>37 resource zones, 5-7 DO scenarios, over 75 year period.<br>For each zone it will output a single number - MLD of water available at each zone. | .csv | .csv | < 10MB | Assume it can be uploaded to a specified SharePoint or similar location. | None | Metdata: date, timestamp, version of the model, include check / approve data, resource zone identifier. | n/a |
| N | Options Appraisal | Investment model | Enable investment optimisation under adaptive futures | 1 | 3 metrics from resilience metric.<br>Costs, Carbon costs, yields.<br>Options will be grouped with interdependencies & exclusivities. | .xlsx or .csv | .csv | < 10MB | Accessed through an API | Cost data access:<br>1. WRSE - all data;<br>2. PMB - single WC only. | Meta data in data transfer to include QA information | n/a<br>Investment team to confirm to confirm transformations required from Options Appraisal team |
| O | Demand Forecasting Models | Investment model | Enable investment optimisation under adaptive futures | 1 | Split into components of household consumption, population, industrial consumption etc. to give a total demand value.<br>7 DO profiles over 75 year period to mirror the simulation model profile. | .xlsx | .csv | < 10MB | Accessed through an API | None | No defined QA yet. Each water company completes its own checking internally using a different process and inputs into a master demand forecast model spreadsheet, which is checked. | Investment modelling team to confirm transformations required from WRMP table 3 outputs |

# Appendix 2 Checklist of consistency with the Environment Agency WRMP24 Checklist

The Environment Agency published its WRPG on XXXXXX 2020, including the WRMP24 Checklist. The following table identifies the relevant parts of the checklist relating to this Method Statement, and provides WRSE's assessment of its consistency with the requirements in the Checklist.

| No. | Action or approach | Method Statement ref: | WRSE assessment of consistency |
|---|---|---|---|
| | | | |
| | | | |
| | | | |
| | | | |
| | | | |

# Method Statement: Groundwater Framework

## Revised version

## August 2021

| Title | Method Statement: Groundwater Framework |
|---|---|
| **Last updated** | August 2021 |
| **Version** | Post-consultation version |
| **History of changes made to this version** | Updated following consultation comments and revised Water Resources Planning Guidance. |
| **Summary of areas where substantive changes have been made as a result of consultation feedback** | No substantive changes. |
| **Summary of areas where substantive changes have been made as a result of the revised Water Resource Planning Guidelines** | No substantive changes. |
| **Author** | Simon Cook |
| **Approved by** | Meyrick Gough |
| **WRSE Director approval** | Meyrick Gough |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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

# Executive summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

We have prepared Method Statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

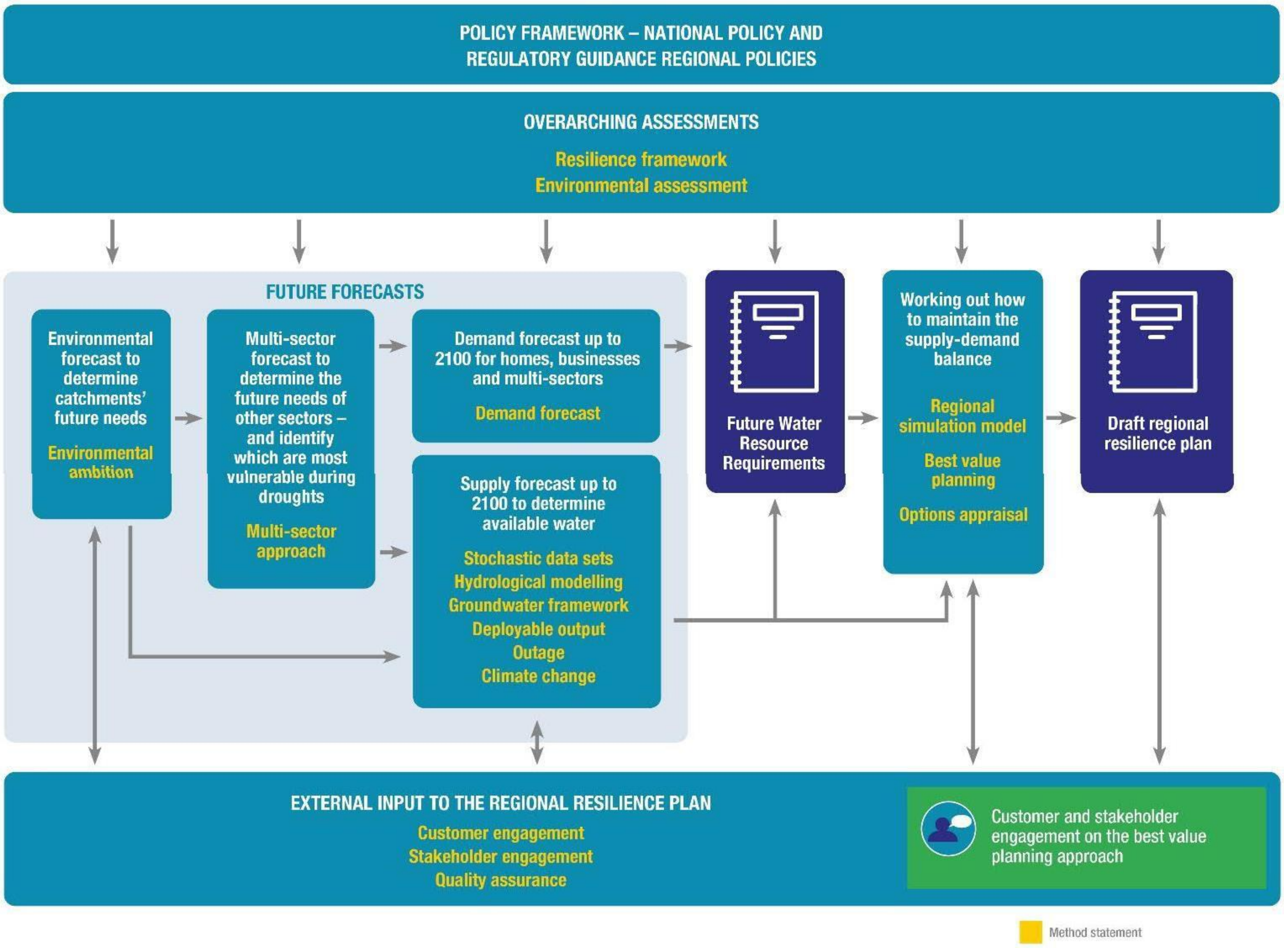
Figure ES1 illustrates how this groundwater framework Method Statement will contribute to the preparation process for the regional resilience plan.

Groundwater comprises around 70% of the water used for public supply in South East England. To date, for WRSE companies the assessment of groundwater deployable output (DO) has largely been achieved outside of system simulator models following the guidance set out by UKWIR, 2017. The computational demands of these standard methods, particularly where regional groundwater models are used to determine flows or groundwater level responses, has so far limited the extent to which groundwater can be represented within system simulators.

There are multiple benefits to developing a more sophisticated representation of groundwater. The groundwater framework we have developed proposes a standard assessment approach to be applied across all water companies and water resource zones. Application of the framework assigned a weighted score across different source characteristics and suggests the DO modelling approach and system simulator representation that should be employed.

Generally, the higher scoring a source is under the framework the more suitable and the more benefit would be gained from dynamic representation within the Regional Simulation Model.

Figure ES1: Overview of the Method Statements and their role in the development of the WRSE regional resilience plan



# 1. Introduction

1.1 Groundwater makes up around 70% of the water used for public supply in South East England. The assessment of DO for groundwater tends to be more complex than for run of river sources as it must consider aquifer properties, variation in groundwater levels, antecedent operation, interference effects and asset and licence constraints.

1.2 To date for WRSE companies the assessment of groundwater deployable output has largely been achieved outside of system simulator models following the guidance set out by UKWIR[1]. The computational demands of these standard methods, particularly where regional groundwater models are used to determine river and groundwater flows or groundwater level responses, has so far limited the extent to which groundwater can be represented within system simulators. The simplest and most common approach has been to develop groundwater DOs outside of the system simulator model, and represent them within the simulator either by a fixed value or represented by a simple time series derived from coherent climate data used to derive surface water flows.

1.3 There are multiple benefits to developing a more sophisticated representation of groundwater within the WRSE Regional Simulation Model, these include, but are not limited to:

- Where antecedent operation and utilisation of a groundwater source may affect future yield and hence drought DO through preserving or depleting groundwater storage, abstraction could be optimised to preserve that storage for supply
- Optimising abstraction where groundwater has conjunctive use with surface water, for example through aggregate licence volumes, hands off flows or works treatment capacity.
- Differences in the timing of drought responses between surface water and groundwater dominated resource zones would allow optimisation of transfers and use of supplies
- Groundwater – surface water interactions are important at environmentally sensitive sites and by incorporating groundwater in a more dynamic way resource use could be optimised to reduce environmental impact.
- Better inclusion of groundwater sources will aid consideration of resilience benefits and more realistic assessment of option utilisation and stress testing.

1.4 Development of more dynamic representation of groundwater is challenging within the timescales available for this first Regional Resilience Plan. We have set out a framework for prioritisation within this “groundwater framework”. The framework has been designed to focus development of dynamic groundwater approaches within the Regional Simulation Model for those aquifer blocks or sources where such representation will provide the most benefit in aiding decision making. When using “dynamic” in this

[1] UKWIR, 2014, Handbook of source yield methodologies, Report Ref. No. 14/WR/27/7, UK Water Industry Research Limited, London

sense we are considering groundwater sources where the yield and/or DO and any associated impacts are determined by the Regional Simulation Model rather than as an external boundary condition.

1.5 The framework proposes a standard assessment approach to be applied across all water companies and water resource zones. Application of the framework assigned a weighted score across different source characteristics and suggests the DO modelling approach and regional simulation representation that should be employed. Generally, the higher scoring a source, the more suitable and the more benefit would be gained from dynamic representation within the Regional Simulation Model.

1.6 ~The groundwater framework is therefore closely linked to several other Method Statements:

- **Method Statement 1320 WRSE Deployable Output** which describes the calculation of system level deployable outputs within the Regional Simulation Model
- **Method Statement 1331 WRSE Regional Simulation Model** which covers the development and operation of the regional system simulation model. It is within this model where groundwater deployable outputs will be included as recommended by the framework - either modelled dynamically, or represented by external boundary conditions.

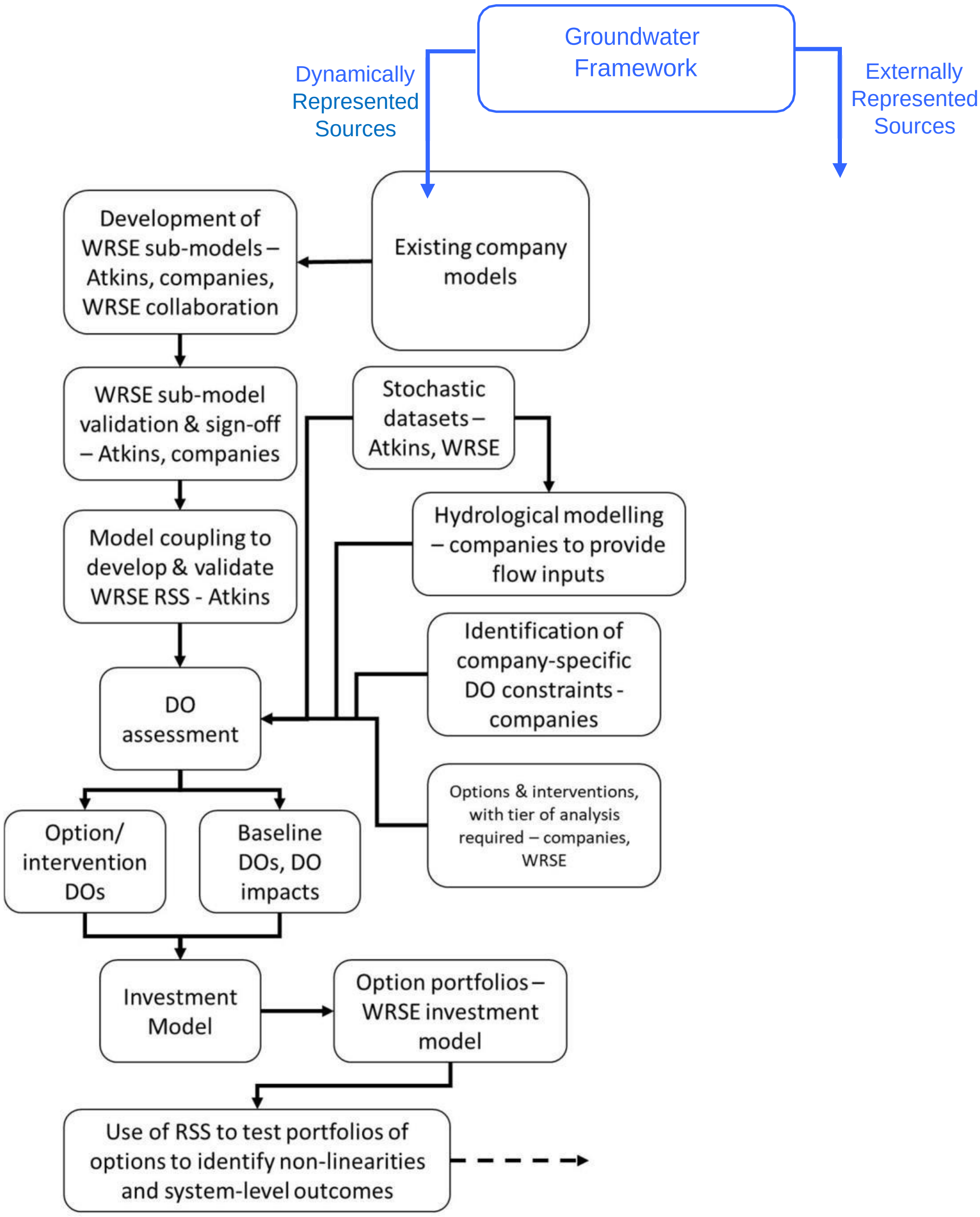
1.7 The groundwater framework does not specify in detail the method for DO assessment for each individual groundwater source, although the approach does provide a high level recommendation. A detailed description of the groundwater DO assessment method, where it occurs outside the Regional Simulation Model, will be provided by each company and summarised in the technical reporting by WRSE for the regional supply forecast. Where system DOs are calculated by the Regional Simulation Model this is covered by Method Statements 1320 and 1331. Figure 1 illustrates how the Groundwater Framework relates to the wider WRSE modelling process.

1.8 A key principal of the framework is that the application is standardised across all companies and water resource zones. It should include an auditable governance trail and be robust to scrutiny and challenge such that it may be used as supporting evidence within a public inquiry.

1.9 However, it should be recognised that the framework is semi quantitative and assessment must consider both uncertainties in numerical data and in hydrogeological understanding.

1.10 This is our first attempt at considering the region's groundwater resources in a more sophisticated manner within the WRSE Regional Simulation Model. The WRSE groundwater framework will be subject to ongoing refinement/development through multiple planning periods as system simulators and groundwater models continue to become more sophisticated in step with advances in computational speed.

Figure 1: Relationship of the Groundwater Framework to the wider WRSE modelling process



# 2. Development of the framework

2.1 The groundwater framework was developed in the first half of 2020 over a series of workshops including both face to face meetings and teleconferences. It included participants from:

- WRSE
- Groundwater resource specialists and water resource planners from WRSE member water companies
- Water resource specialist consultants working on behalf of WRSE and water companies.

2.2 We reviewed each water company's approach to assessing groundwater DOs across their resource zones and the extent to which groundwater resources were presently included in company system simulation models.

2.3 We considered that there were in general three main approaches to developing groundwater deployable output:

- Indicator borehole approaches using recharge or climate data to curve shift drought curves at sources to estimate DO during drought
- Lumped parameter models which directly estimate groundwater levels from recharge and rainfall inputs
- Distributed regional groundwater models which are used to either simulate groundwater levels at indicator boreholes or at groundwater sources themselves
- We also recognised a hybrid approach developed for the Water Resources East (WRE) which was based on lumped parameter models developed from regional groundwater models.

2.4 Within these approaches there are sources that have fixed characteristics, for example those sources which are not drought sensitive and which are constrained by infrastructure or simple licence conditions (e.g. daily/annual). These sources would therefore not benefit from dynamic representation. The groundwater framework should therefore be capable of screening these sources from further assessment.

2.5 We also considered the key characteristics which should be used to prioritise groundwater sources for dynamic inclusion within the Regional Simulation Model. These included:

- The DO constraints with higher weighting applied to those sources where DO varied by drought severity or with complex licence conditions (e.g. seasonal licences, surface water flow constraints)
- Potential groundwater and surface water conjunctive use benefits, including environmental benefits where sources may have adverse environmental impacts
- Sensitivity to antecedent conditions and operation for sources where groundwater storage may have an impact on groundwater DO

- Proportionality of any benefit, focusing on where useful DO gains or transfers might be achieved through better representation. This also recognised that even small volumes of available unutilised DO may have still have an overall regional resilience benefit
- Stated levels of service
- The level of uncertainty associated with current DO assessment to understand whether it is better to spend more time in investigating approaches to limit this uncertainty in source DO (e.g. by models) rather than to build into the simulator.

2.6 We tested several approaches in development and refinement of the groundwater framework to ensure we appropriately characterising the aquifer blocks and their sources. Ensuring consistency in approach and moderation across the different water companies was also a key theme of the development. A pilot exercise was iteratively refined by the steering group through feedback, discussion, and trial applications. The key enhancements achieved through this process were:

- Improved wording and more automated scoring criteria for some questions to allow clearer and more consistent interpretation
- Simpler and more standardised approaches for characterising the key hydrogeological characteristics of a source and aquifer water body
- Improving consistency of how existing company DOs could be included, recognising that each company has different baseline planning DOs and understanding of how DO varies across droughts of different severity. Adjusting the scoring and banding around DO variation at varying levels of drought sensitivity
- Adjustments to proportionality scoring to remove consideration of adjacent water resource zones
- Adjustments to overall ranking system to better screen out simple groundwater sources that would not benefit from dynamic inclusion in the Regional Simulation Model
- Adjustments to the weighting of conjunctive use benefits and sensitivity to antecedent conditions so scoring highly on either would increase the prioritisation of the source
- Addition of an automated suggestion for the most appropriate representation of each source within the Regional Simulation Model was added.

2.7 Following these adjustments, the water companies undertook a further review of their characterisation and a final review of score weighting and modelling method from four possible choices:

- Development of lumped parameter model of the source or group of sources which would be included in the Regional Simulation Model
- Dynamic representation by other means for example computational algorithms within the Regional Simulation Model where DO is not necessarily estimated by a physically based model such as a lumped parameter approach
- Representation of DO by a coherent time series developed externally to the Regional Simulation Model derived using the standard UKWIR method for groundwater DO
- Simple representation of a fixed DO or repeating annual profile (to account for peak, average and minimum conditions.

2.8 Each Water company reviewed and adjusted the suggested method based on their understanding of the source, existing model approaches and what could be practically achieved in the time available for the regional resilience plan.

2.9 Although the DO of all groundwater sources will be represented in the Regional Simulation Model in some way, only those where availability will depend on a parameter calculated by the simulator should need to be modelled in a dynamic fashion. An example of where this may apply is where there is a strong interaction with surface water or other abstractions. All others can be calculated outside of the model and provided as an input; to save on computational time.

2.10 Private groundwater abstractions, such as for industry or agriculture will not be represented within the Regional Simulation Model directly but, where appropriate may be included within company models, for example if regional groundwater models are used. Multi-sector drought risks to private groundwater abstraction will be considered under a separate methodology.

# 3. The final groundwater framework

3.1 The following section sets out the arrangement and application of the groundwater framework we have developed. The key sections of the framework are outlined along with the scoring criteria.

3.2 The groundwater assessment consists of three phases:

a. Phase A: Background information. This includes the source name, type of source (e.g. single borehole, well and adit etc), the WFD Groundwater body from which it abstracts and if it is a confined or unconfined source. This information is not considered in prioritisation but provides some context when considering the modelling methodology and potential grouping of some sources.

b. Phase B: Prioritisation criteria. This considers the prioritisation of sources for dynamic modelling based on their importance and potential value of their representation within the simulator. Four key criteria are considered in the scoring:

   1. DO constraints
   2. Conjunctive use benefits
   3. Sensitivity to antecedent conditions
   4. Proportionality/threshold benefit

c. Phase C: Methodology. A review of current and available modelling methods, the suitability of the sources as well as the outcome of the assessment and the overall prioritisation. This balance the feasibility of implementation with the overall aim and method identified.

3.3 Phases B and C are the most critical in determining the prioritisation of a groundwater source and are described in more detail below.

a. Phase B Criterion 1 – DO constraints. This considers the potential change in DO with increasing drought severity. It also considers the sensitivity of the source to climate change and the nature of the constraints on DO. A source can be assigned a score of 1 to 5 (Table 1). A score is automatically assigned based on the gradient of the change in DO at different drought severity. If the DO under different drought return periods is not known, sensitivity of DO to climate change is used as a proxy. Assessment of DO from previous WRMPs should be used to complete this assessment. Highest scores are assigned to those sources which have large DO gradients and which are not asset or simple licence constrained.

b. Phase B Criterion 2 - Conjunctive benefits. This considers the conjunctive use benefits either with other downstream or downgradient sources or to the environment. It considers the extent to which groundwater source impacts on surface water and the designation of that affected surface water under the Water Framework Directive (Table 2). Sites score highly if there are downstream impacts on surface water or conjunctive use with surface water abstractions.

c. Phase B Criterion 3 - Sensitivity to antecedent conditions. This mostly considers the role of groundwater storage in providing a benefit to yields at a site. It is concerned with whether operation of a source may have a later impact on groundwater yield. For example, this may be where operation of a source at high rates during peak periods may reduce the yield of the source during minimum or average periods owing to depletion of groundwater levels or storage. The greater the sensitivity the higher the score assigned (Table 3).

d. Phase B Criterion 4 - Proportionality of benefit. This criterion is included in the framework and is automatically calculated by considering the DO of the site a proportion of the deficit in neighbouring resource zones expressed as a percentage. The intention was to represent the possible strategic importance of a site to resolve deficits. Whilst a score is assigned (Table 4) it was agreed that this criterion should not be used to determine if a source should be considered for dynamic modelling as it only provides an understanding of source size not of its other hydrogeological or environmental characteristics.

Table 1: Scoring for Criteria 1: DO constraints

| **Maximum gradient of DO drop off (%) >>**<br>**Or climate change assessment if multiple DO's not available to generate gradient Maximum constraint** | **-0.5%**<br>**Not Sensitive** | **-2%**<br>**Low sensitivity** | **-5%**<br>**Medium Sensitivity** | **-10000%**<br>**High sensitivity** |
|---|---|---|---|---|
| Asset / Static | 1 | 1 | 1 | 1 |
| Other | 2 | 3 | 4 | 5 |

Table 2: Scoring for Criteria 2: Conjunctive benefits

| **Question** | **Responses** | **Score>>** |
|---|---|---|
| Potential DO benefit? | Yes | 1 |
| | Uncertain | 1 |
| | No | 0 |
| Is there a water resource WINEP driver? | Yes | 1 |
| | No | 0 |
| WFD GW body quantitative status | Poor | 1 |
| | Not assessed | 0 |
| | Good | 0 |
| WFD SW body status | Band 1 | 1 |
| | Band 2 | 1 |
| | Band 3 | 1 |
| | Not assessed | 0 |
| | Compliant or surplus | 0 |

| | | |
|---|---|---|
| Associated SW source | Yes | 1 |
| | No | 0 |

Table 3: Scoring for Criteria 3: Sensitivity: to antecedent conditions

| Question | Responses | Score>> |
|---|---|---|
| Vulnerability to antecedent conditions | Low | 1 |
| | Medium | 3 |
| | High | 5 |

Table 4: Scoring for Criteria 4: Proportionality/threshold of benefit

| | | DO as % of neighbouring WRZ deficit | | | |
|---|---|---|---|---|---|
| | 0% | <5% | <20% | <50% | >50% |
| DO as % of WRZ deficit | <5% | 1 | 1 | 1 | 1 |
| | <20% | 2 | 2 | 2 | 2 |
| | <50% | 3 | 3 | 3 | 3 |
| | >50% | 4 | 4 | 4 | 4 |

3.4 Following conclusion of the assessment a final ranking score is automatically calculated. Based on the final scores for Criteria 1, 2 and 3. If these scores exceeded a defined threshold for each criterion (Table 5) the site was prioritised for possible dynamic modelling by assigning a final ranking score of 5. If the site did not exceed the criteria it was assigned a score of 0 and it is not considered to be a priority for dynamic modelling within the Regional Simulation Model as existing simplified approaches are appropriate.

Table 5: Overall ranking/thresholds for criteria determining prioritisation

| | Criteria 1: DO constraint | Criteria 2: Conjunctive benefit - system | Criteria 3: Sensitivity to antecedent conditions | Criteria 4: Proportionality / threshold of benefit |
|---|---|---|---|---|
| Threshold value | 3 | 4 | 5 | Not used |

3.5 The final stage of the framework is to automatically suggest a DO modelling approach within the Regional Simulation Model for each source. This is based on the prioritisation criteria previously calculated.

a. If a source is screened out from dynamic assessment only an external profile of DO is required.
b. If a source is sensitive to antecedent operation (Criteria 3 score = 5) a lumped parameter model is most appropriate.
c. If there are conjunctive use considerations (Criteria 2 Score >=4) then dynamic assessment within the

Regional Simulation Model would be most appropriate

d. Similarly, If DO constraints are variable due to drought or climate change sensitivity (Criteria 1 score >=3) and there are other considerations such as conjunctive use or antecedent sensitivity a dynamic approach is also recommended.

e. If a site only has variable DO then it may still be possible and more computationally efficient to generate a coherent time series of DO using conventional methods outside of the Regional Simulation Model.

3.6 At each stage of the framework assessment, including the suggested modelling approach, the suggested modelling methodology is intended to represent the ideal approach based on the outcome of the assessment and methods available. However, we recognised that this may not be practical to achieve in the required timescales or with the data available. The user can override the automated scoring, however, if this is done a justifying comment supporting the change must be provided and to provide a record of the manual adjustment to the framework outcome to ensure governance. The framework and modelling approaches are intended to be reviewed and updated for subsequent rounds of modelling which would allow for more advanced approaches to be developed in the future.

# 4. Worked examples and results

4.1 This section contains two worked examples that illustrate how the framework has been applied to determine the appropriate modelling approach for two different groundwater sources.

4.2 In addition to the worked examples the results of applying the groundwater framework to each companies' groundwater sources are presented in an accompanying spreadsheet to this Method Statement. This shows the scoring applied to each source, the recommended modelling approach and, where different, the final modelling approach.

## Worked example 1.

4.3 This source comprises a multiple borehole chalk groundwater source located close to a small river which is impacted by the abstraction.

4.4 The source is licence constrained, even during drought and its DO is therefore static. The Criteria 1 DO Constraint Score is therefore 1.

4.5 For Criteria 2 Conjunctive Benefits assessment, there are no conjunctive use benefits for downstream abstraction for this source (score 0) and there is no associated surface water source (score 0). Because of the abstraction impacts on nearby surface waters there is a current Water Resource WINEP driver for the source (score 1), the groundwater body quantitative status is good (score 0) and the associated surface water body is Band 2 EFI non-compliant (score 1). This gives a total score for Criteria 2 Conjunctive Use Priority of 2.

4.6 Because output from the source is abstraction license constrained its yield is not vulnerable to antecedent conditions and it scores 1 (low risk) for Criteria 3.

4.7 The source is a strategic source within its Water Resource Zone, comprising 40% of the total WRZ deficit and 60% of the neighbouring WRZ deficit and hence scores 3 for the Criteria 4, the Proportionality/Threshold of benefit

4.8 Overall, the source scores 1 for Criteria 1, 2 for Criteria 2, 1 for Criteria 3 and 3 for Criteria 4. This total score does not exceed any of the thresholds for determining priority for dynamic simulation within the Regional Simulation Model. The suggested modelling method within the Regional Simulation Model is as an externally generated profile of deployable output with the values determined by standard groundwater deployable output assessment methods.

4.9 Table 6 summarises the scores for the first example source

Table 6: Scoring for worked example 1

| Assessment | Justification | Score |
|---|---|---|
| Criteria 1 | Asset / Static / Licence Constrained<br>Maximum gradient of DO drop off >-0.5 | 1 |
| Criteria 2 | No Potential DO Benefit<br>Water Resource WINEP driver<br>Good WFD Groundwater Body Status<br>Band 2 Non-compliant Surface Water Body Status<br>No associated Surface Water Source | 0<br>1<br>0<br>1<br>0 |
| Criteria 3 | Low Vulnerability to antecedent conditions | 1 |
| Criteria 4 | DO 44% of WRZ Deficit<br>DO >60% of neighbouring WRZ Deficit | 3 |
| Total | Criteria 1 (Threshold for prioritisation = 3)<br>Criteria 2 (Threshold for prioritisation = 4)<br>Criteria 3 (Threshold for prioritisation = 5)<br>Criteria 4 | 1<br>2<br>1<br>3 |
| Recommended Modelling Approach – externally generated DO profile | | |

# Worked example 2

4.10 This source comprises a large strategic well field developed in the chalk aquifer and located adjacent to a river which is impacted by the abstraction.

4.11 Yield from the source is variable and linked to available flow in the adjacent river above a hands off flow condition within its abstraction licence. It scores 5 for the Criteria 1 DO Constraint.

4.12 For Criteria 2 Conjunctive Benefits assessment, there are conjunctive use benefits for downstream abstraction for this source (score 1) and there is also an associated surface water source (score 1). Because of the abstraction impacts on nearby surface waters there is a current water resource Water Industry National Environment Programme (WINEP) driver for the source (score 1), the groundwater body quantitative status is poor (score 1) and the associated surface water body is Band 3 EFI non-compliant (score 1). This gives a total score for Criteria 2 Conjunctive Use Priority of 5.

4.13 The primary control on the source yield is flow in the adjacent river and it is only mildly sensitive to antecedent pumping so scores 1 for Criteria 3.

4.14 The source is a strategic source within its Water Resource Zone, comprising 150% of the total WRZ deficit and >200% of the neighbouring WRZ deficit and hence scores 4 for the Criteria 4, the Proportionality/Threshold of benefit

4.15 Overall, the source scores 5 for Criteria 1, 5 for Criteria 2, 1 for Criteria 3 and 4 for Criteria 4. This total score exceeds two of the three thresholds (for Criteria 1 and 2) for determining priority for dynamic simulation within the Regional Simulation Model. The suggested modelling method is therefore to dynamically represent this source within the Regional Simulation Model.

4.16 Table 7 summarises the scores for the second example source.

Table 7: Scoring for worked example 2

| Assessment | Justification | Score |
|---|---|---|
| Criteria 1 | DO is transient and linked to HoF Condition<br>Maximum gradient of DO drop off 17% | 5 |
| Criteria 2 | Potential DO Benefit to downstream sources<br>Water Resource WINEP driver<br>Poor WFD Groundwater Body Status<br>Band32 Non-compliant Surface Water Body Status<br>Associated Surface Water Source | 1<br>1<br>1<br>1<br>1 |
| Criteria 3 | Low Vulnerability to antecedent conditions | 1 |
| Criteria 4 | DO 150% of WRZ Deficit<br>DO >200% of neighbouring WRZ Deficit | 4 |
| Total | Criteria 1 (Threshold for prioritisation = 3)<br>Criteria 2 (Threshold for prioritisation = 4)<br>Criteria 3 (Threshold for prioritisation = 5)<br>Criteria 4 | 5<br>5<br>1<br>3 |
| Recommended Modelling Approach – dynamic simulation within Regional Simulation Model | | |

# 5. Next steps

5.1 We consulted on this Method Statement from 31st July 2020 to 31st October 2020. This Method Statement has now been updated to take into account the comments we receive during this consultation process and has been published on our website.

5.2 We may need to update parts of our Method Statements in response to regulatory reviews, stakeholder comments or improvements identified during the implementation phase of the methodology.

5.3 If any other relevant guidance notes or policies are issued, then we will review the relevant Method Statement(s) and see if they need to be updated.

# Method Statement: Calculation of deployable output

November 2022

| Title | Method Statement: Calculation of deployable output |
|---|---|
| **Last updated** | November 2022 |
| **Version** | Draft regional plan version |
| **History of changes made to this version** | 21/06/2020 – First Draft Written<br>10/07/2020 – Amendments made after technical working group review<br>26/07/2020 – Amendments made after PMB and QA Review<br>August 2021 – Amendments after consultation feedback<br>November 2022 – Draft regional plan version |
| **Summary of substantive changes made, and reasons for these** | Removed some sections of text which are not related to 'methods'.<br>Removal of text relating to the inclusion of dynamic demand within the regional simulation model.<br>Amendment to detail associated with some methods where these were changed when implemented.<br>Inclusion of statement over caveats. |
| **Author** | Peter Blair |
| **Approved by** | Meyrick Gough |
| **WRSE Director Approval** | Meyrick Gough |

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A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

# Executive Summary

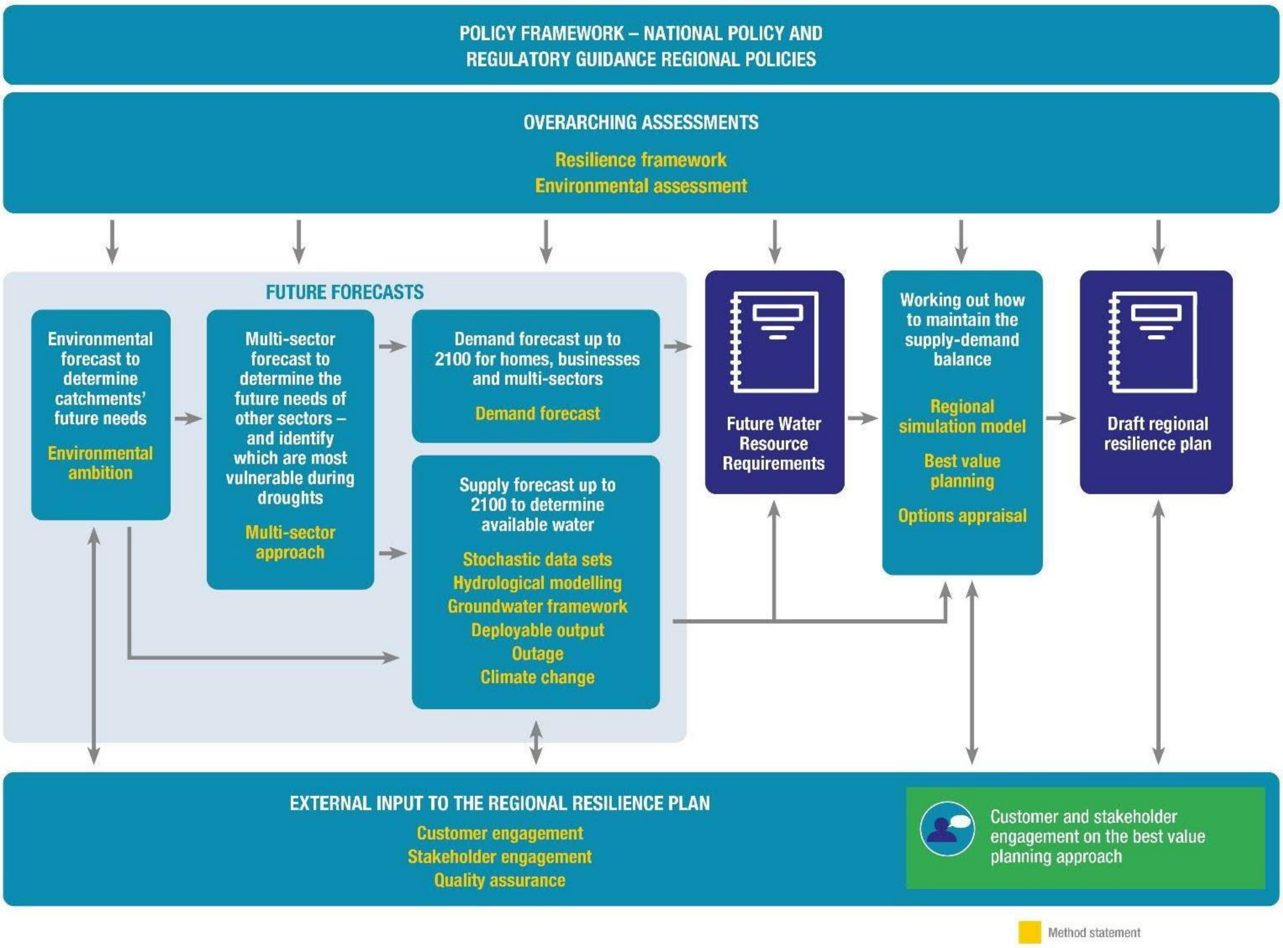
Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2075.

We have prepared Method Statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this deployable output Method Statement will contribute to the preparation process for the regional resilience plan.

Deployable output is a key building block of the supply-demand balance and is the metric used to determine the supply capability of a water resources supply system in the UK. Consideration of water resources on a regional scale and the development of a regional water resources model for the South East have implications for the calculation of deployable output, and so this Method Statement outlines how deployable output will be calculated as part of the WRSE regional plan.

Figure ES1: Overview of the Method Statements and their role in the development of the WRSE regional resilience plan



# 1 Introduction

1.1 This Method Statement outlines the methodology that will be followed when using the 'Regional System Simulator' (**Method Statement 1331 WRSE Regional System Simulator**) to calculate Deployable Output (DO).

1.2 DO is a key metric in water resources planning, used as a measure of the supply capability of a water supply system, and a component of the supply-demand balance. DO is also used to quantify the impact that climate change is forecast to have and assess the benefits that different interventions may have on supply capability.

1.3 By way of clarification, this Method Statement does not cover a WRSE-consistent approach to the calculation of source deployable output (SDO) values. SDOs are values which state the supply capability of individual sources, while 'system' DO considers the supply capability of a water supply system, potentially involving many different sources and different source types. This Method Statement is focussed on this 'system' DO assessment, and where 'DO' is used in isolation, this is what is meant. If source deployable output is referred to, the abbreviation SDO is used.

1.4 DO is defined as the supply capability for a water resources system under specified conditions, as constrained by: hydrological yield; licensed quantities; the environment (via licence constraints); abstraction assets; raw water assets; transfer and/or output assets; treatment capability; water quality; and levels of service, as defined by the Water Resources Planning Guideline.

1.5 Recent changes have been made to the required standard of resilience for which water companies must plan. For WRMP24, companies must define their DO as a supply capability which is resilient to drought of an approximate return period of once in five hundred years, where return period is determined based on 'system response' (as opposed to being based on rainfall/other drought metrics). This is otherwise stated as there being a 0.2% annual probability of 'failure' of a water supply system. In this context, 'failure' means the expected imposition of emergency drought orders (exceptionally severe demand restrictions). Droughts which cause a '1 in 500-year' system response are likely to be different for different water resource zones (WRZs).

1.6 The development of the Regional System Simulator (RSS) allows WRSE water companies to use methods considered advanced in this guidance, such as 'behavioural modelling' (see Environment Agency Water Resource Plan Supplementary Guidance on 1 in 500-year drought). The development of the RSS also provides a consistent basis for methods to be applied on.

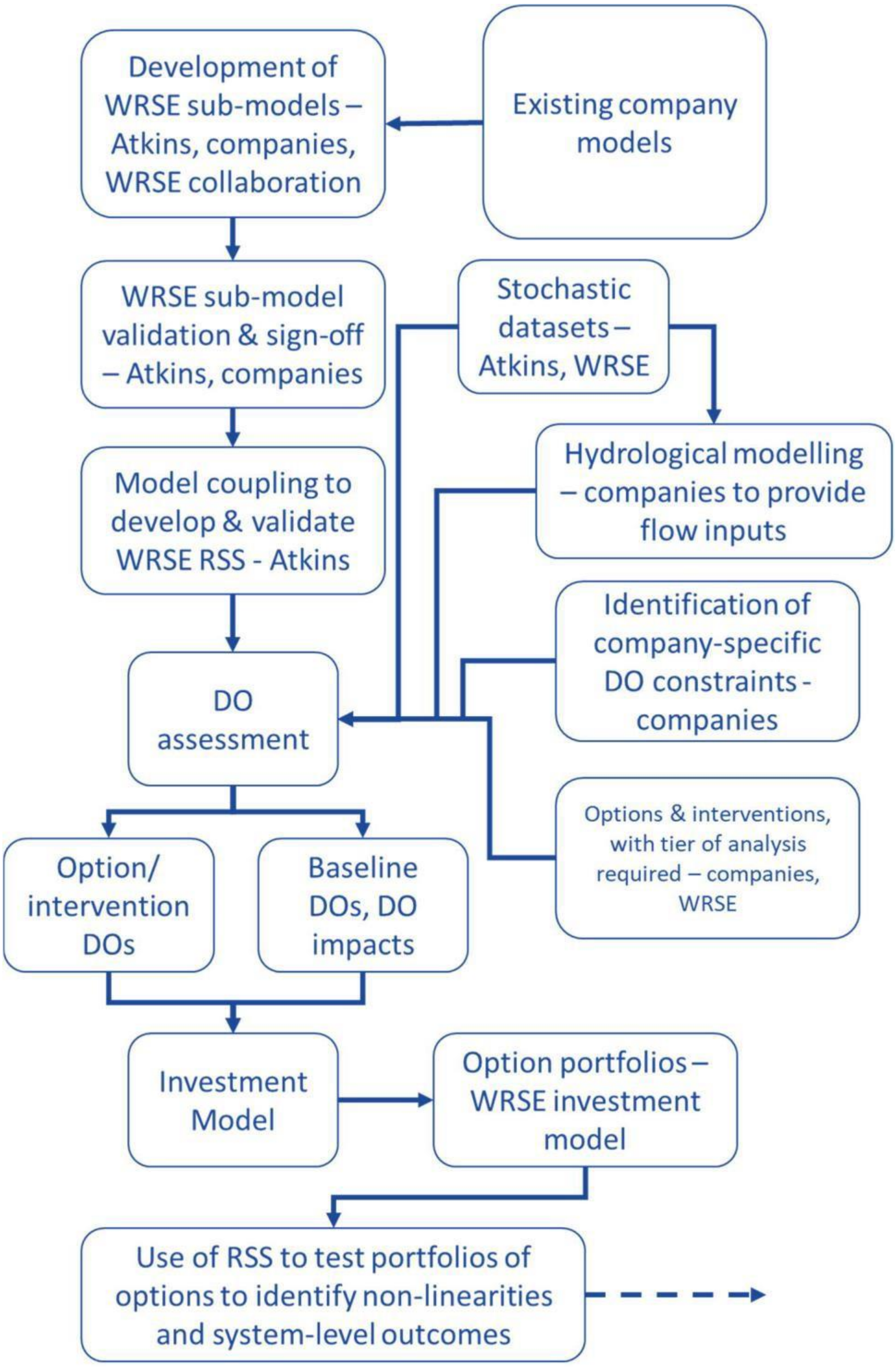
1.7 While this document aims to define a deployable output methodology to be applied across the WRSE region, it is recognised that the RSS may provide a more accurate representation of some WRSE sub-systems than others. As such, individual companies must decide whether the WRSE RSS and this method of determining DO are suitable for determining DO for each of their WRZs. If companies feel that the model and/or method are not suitable for determining DO in one/some of their WRZs, they may apply their own methods. If companies do not accept the WRSE method/model, it will be incumbent on them to provide values which are required for the integrated risk model and investment model, and which are as far as possible consistent with WRSE methods. This is an acceptable fallback position, because the RSS will be used in two phases: an initial phase in which DO is the focus, and a second phase in which the RSS will test outcomes that portfolios of options result in. This second phase of modelling will provide valuable information and would be impossible to do using a company-specific model.

1.8 Figure 1 is a flow chart showing an RSS-centric view of WRSE modelling that is being undertaken.

1.9 This document contains the following sub-sections:

a) Inputs to the regional system simulator (RSS) model specifically relevant to the calculation of DO
b) Characteristics of a successful method for the calculation of DO
c) Methodology for calculation of baseline DO
d) Application of methodology to the calculation of DO benefit for options and interventions

Figure 1: A view of the WRSE modelling process, centred around the regional system simulator



# 2 Methods and approach

## Input data

2.1 A significant amount of data will be included within the RSS model. The RSS Method Statement (**Method Statement 1331 WRSE Regional System Simulator**) gives a comprehensive account of the data which will feed the RSS, with a summary of some items which are of particular significance for DO calculation provided here.

2.2 Weather data is one key input to the RSS, specifically rainfall and potential evapotranspiration (PET). This rainfall & PET data comprises four hundred 48-year sequences, a total of 19,200 years of stochastically generated data (400 x 48 years). This has been designed to be representative of the latter half of the 20th Century, but which represents different versions of what could have happened, given the underlying climatic drivers that occurred during this baseline period. A separate Method Statement covers the generation of this data (stochastic datasets Method Statements). To account for more of the hydrological variability in assessing the system's response to a range of droughts, it would be preferable to use all this data to determine DO. Where it is not possible to use all this data, some selection of replicates/events will be carried out. In this context, a 'replicate' is one of the four hundred 48-year sequences, and an 'event' is a time series from within a replicate (shorter than 48 years).

2.3 Hydrological data in the form of river flows are important inputs for DO runs. This hydrological data is being developed as part of a separate workstream, and the methodologies used to develop this can be found in **Method Statement 1330 WRSE Hydrological Modelling**. This hydrological data will be generated for all rivers across the South East region for all four hundred 48-year replicates and will also be generated for all required climate change scenarios.

2.4 Groundwater yields are being considered in more detail for the regional plan than they have in the South East for previous WRMPs. The groundwater framework (**Method Statement 1322 WRSE Groundwater Framework**) has identified three categories of representation within the regional simulator: profile; time series; and dynamic. Profile representation involves a repeating yearly profile of groundwater yield. Time series representation involves the development of a time series of groundwater yields which is coherent with stochastically generated climatic inputs. Dynamic representation involves the inclusion of lumped parameter groundwater models and/or triggers to represent flow constraints or drought permits and will involve the calculation of groundwater yields and their availability within the RSS.

## Characteristics of a successful method for the calculation of DO

2.5 The methodology presented in the following section is based on the characteristics of a successful methodology as discussed here.

2.6 The methodology must produce outputs which are consistent with the requirements of water resource planning tables. This means that the methodology must adhere to Environment Agency guidelines for values to be produced. In many cases within the RSS, groundwater will be aggregated to beyond source level, but source-level information is required in the EA tables. Completion of tables requiring source-level information may require some back-calculation of results and/or further analysis.

2.7 Outputs from the calculation of DO and DO benefit of interventions must also be compatible with requirements of the investment model and integrated risk model (**Method Statement 1318 WRSE Best Value Planning**).

2.8 The method should be clear and understandable not only for those working within water resources planning, but also for stakeholders. The WRSE regional plan will be extensively consulted on and the more easily readers can understand methods, the more meaningfully they will be able to engage.

2.9 Water resource plans benefit from consistency between forecasts. Outputs are more likely to be consistent if methodologies are consistent. As such, methods should be consistent with previous company approaches, where this is sensible. Differences are to be expected, since some company methods will change to bring regional consistency, but where differences exist, it should be possible to explain why.

2.10 The more well-aligned individual company plans are with the regional plan, the better. As such, it should ideally be possible for companies to extract information for their WRMPs directly from the WRSE regional plan. The WRSE DO methodology will, therefore, produce outputs that companies can use to form the basis of their WRMPs. A key implication of this is that analysis will be carried out on a water resource zone (WRZ) level, or results from analysis will need to be disaggregated from sub-region to WRZ level, as consistent with current company approaches. As stated above, however, some back-calculation may be required to obtain source-level information for water resources planning tables.

2.11 Regarding assumptions during DO runs, this WRZ-level focus is kept in mind. There are many cases where WRZs/sub-regions interact, for instance those where there are upstream/downstream interactions (i.e. abstractions and discharges in one WRZ/sub-region impact flows in another zone). DO runs will be conducted for each WRZ/sub-region individually, and assumptions across the region should be such that boundary conditions for determining a WRZ/sub-region's DO should be consistent with 'baseline' conditions at the beginning of the planning period.

2.12 Bulk supplies and transfers should generally not be included in baseline deployable output. Instead DO benefit and disbenefit for recipient and donor zones respectively should be calculated for bulk supplies and transfers, whether these are existing transfers or options. However, in some cases bulk supplies and transfers have very important system response implications (for example releasing 'locked-in' DO). In situations where there is sound reasoning for doing so, companies may include inter-zonal/inter-company transfer(s) in baseline deployable output. In such cases, however, it must be made explicitly clear that this is being done, explain why this is necessary, and both zones/companies involved must adopt the same approach. In addition, the impact of these transfers should be accounted for after DO modelling (i.e. within the baseline supply-demand balance) such that DO values used as investment modelling inputs include only DO which 'belongs' to a given zone, such that the investment model can optimise intra-regional transfers.

2.13 From the perspective of performing modelling as efficiently as possible, there are two particularly important criteria. Firstly, DO runs should be as parallelisable as possible, as this allows different levels of demand to be applied at the same time, and different replicates to be run simultaneously, reducing overall runtimes for DO runs. Secondly, processes should be automatable, and it should be possible to run a given 'DO' run from start to finish with no manual intervention.

2.14 As mentioned above, while it is hoped that the WRSE RSS will be universally applicable across all companies' WRZs, it may be that some WRZ/sub-region sub-models produce results which differ materially from expectations, and companies will require further investigations to be carried out to understand the differences in expectation versus outputs, before committing to the outputs. In these instances, it will not be mandatory for companies to adopt baseline DO and/or option DO values calculated via this method until the uncertainty is resolved. An important implication of this is that this method should be sufficiently flexible that companies/WRZs can be excluded from analysis and not render the whole method invalid.

## Methodology for calculation of baseline DO

2.15 Based on the characteristics of a good method identified in the previous section, the DO calculation methodology is outlined in this section.

2.16 The baseline DO methodology does not attempt to calculate a 'regional DO'. Instead, DO will be calculated for each WRZ (or sub-region) individually, with coherent datasets, methods, and assumptions across the region.

2.17 The RSS will be used to generate a 'simulated' system DO for all WRZs where it is applied.

2.18 Baseline DO runs will be based on running all four hundred 48-year replicates through the RSS and observing system outcomes.

2.19 WRZ-level DO will be based on applying different levels of demand to a WRZ and observing system response, particularly modelled 'Levels of Service' (LoS) and overall system-level ability to meet demand. There is a WRSE-wide policy workstream regarding the alignment of LoS; it is not yet known, however, whether LoS will be aligned across the region. If LoS are aligned, WRSE will make clear LoS to be applied; if LoS are not aligned, companies must document LoS to be considered as DO constraints.

2.20 For a given WRZ, the number of events which cause the modelled imposition of emergency drought orders at each level of demand will be counted. The return period of emergency restrictions will be determined from this figure.

2.21 Where the modelled imposition of emergency drought restrictions is the governing constraint on DO, the baseline DO will be defined as the highest level of demand which causes a modelled imposition of emergency drought orders not more than once every X years (where X is the 'DO return period' sought), in order to provide the range of DOs required by the WRSE investment model. DOs with return periods of 2 years, 100 years, 200 years, and 500 years will be found in order to provide required inputs for the WRSE investment model.

2.22 Emergency storage in raw surface water storage reservoirs is an allowance that companies make to ensure that water will still be available even if drought more severe than that which is planned for occurs. Emergency drought restrictions are often defined based on the point at which companies enter their emergency storage allowance. It is recognised that different companies within WRSE make different assumptions around dead storage and emergency storage requirements due to the nature of different reservoirs and reservoir systems and the way that they operate. As such, WRSE will not align assumptions regarding emergency storage requirements. Companies must clearly define how and why their emergency storage volumes have been calculated.

2.23 Individual companies will state the conditions under which emergency demand restrictions would be applied. Generally this will be associated with either a 'demand centre failure' (i.e. in the model a demand centre requires a certain amount of water to be supplied to it, but sources of supply cannot supply enough to meet this requirement), or a failure associated with a 'Level 4' LoS trigger (generally reservoir storage going below a control curve). The mode of any 'failure' should be recorded by the RSS, to help with the identification of DYCP/DYAA/MDO events.

2.24 As per the requirements of the Water Resources Planning Guideline, baseline DO figures are calculated without the benefit of demand saving measures (media campaigns, TUBs and NEUBs). The DO benefit of these measures can be found using the simulation model and by following the same approach, such that they can be included as options. The same is true of supply-side drought permits.

2.25 DO will be determined for each WRZ/sub-region individually (i.e. DO runs will not involve placing 'DO-consistent' levels of demand on all WRZs in the region simultaneously).

2.26 Where DO is being found for one WRZ/sub-region, all other WRZs in the RSS will have WRMP19 Year 5 Final Plan Dry Year Demand as the demand placed on them where this makes sense, considering the wider water resource system. Where this would double count the DO of a given resource, a 'DO' level of demand will be applied in some WRZs.

2.27 The RSS is a model which is formed of WRZ/sub-system/company sub-models. The DO calculation for a zone will use the minimum model complexity required to adequately capture boundary conditions.

2.28 Baseline deployable output is calculated using simulation model outputs where different levels of demand are applied. Failures are counted at each level of demand in order that the return period of emergency restrictions at each level of demand can be determined. This gives points of demand against return period of emergency restriction; these values are interpolated to give DO values for different return periods.

2.29 For the calculation of peak/critical period DO, companies will provide their 'critical period' (e.g. July, or July and August), and failures only during that period will be considered in DO calculation.

2.30 It has been necessary to adapt this method (retaining the broad principles) for application in some areas, notably Affinity Water's Central Region (where inter-zonal transfers play a very significant role) and the 'River Medway System' (where an Act of Parliament governs the distribution of resource between Southern Water and South East Water associated with shared reservoirs). For details of specific methodological caveats/adaptations, please see the report written by Atkins describing the Regional Simulation Model development, and the calculation of deployable output.

## Application of methodology to the calculation of DO benefit for options and interventions

2.31 Options and interventions here include those things traditionally thought of as water resources 'options' (e.g. new sources of water, transfers, reservoirs, etc.), as well as sustainability reductions, the use of drought permits and orders (both supply-side and demand-side), and changes to failure criteria.

2.32 It is recognised that the DO calculation methodology is computationally intensive. Using this methodology (i.e. running 19,200 years' worth of data) to assess the impact of climate change and to determine the DO benefit that all possible options and interventions bring is infeasible due to the sheer computational burden involved.

2.33 As such, a tiered approach to the calculation of DO benefit for options and interventions will be taken.

2.34 **Tier 1:** Where intervention benefit is deemed to be highly dependent on climate and/or triggers and/or there are significant conjunctive-use implications associated with an intervention, it is proposed that the same DO calculation methodology will be used as for the baseline DO benefit (i.e. use of all four hundred 48-year replicates and determination of DO based on the frequency of imposition of emergency drought restrictions). The DO benefit shall be calculated as the DO with the intervention in place, minus the baseline DO. It may be that the number of schemes that can be analysed using 'tier 1' analysis is limited, due to the computationally intensive nature of this approach. Examples of 'Tier 1' options in the WRSE region include the Severn-Thames Transfer and SESRO.

2.35 **Tier 2:** Where intervention benefit is deemed to be slightly dependent on climate and/or triggers and/or there are potentially minor conjunctive-use implications associated with an intervention, a 'drought library' approach will be taken. In this approach, results from the 'baseline DO' assessment will be used to highlight and select a number of droughts of approximate magnitudes (based on baseline system response) ranging from 1 in 500 to 1 in 50 years (selection being more heavily weighted towards more severe drought). A wide range of pre-intervention magnitudes is included due to the recognition that interventions can change the relative severity of different droughts. In this approach, the 'yield' of the baseline system will be calculated for each drought in the 'library' (yield being defined as the demand just below which emergency restrictions would be required for a specific drought event); the yield would then be recalculated for each drought in the library with the intervention in place. The yield benefit for each drought in the library would, therefore, be found. If it is found that there is significant variability in the yields found under different droughts, a 'check' will be undertaken using the full sequence and the estimated DO to ensure that the system response at the new DO is as expected. If this check is failed, Tier 1 analysis may need to be undertaken (note, this is a potential feedback loop). Otherwise, the DO benefit of the option should be found using the interpolation of DO benefit values for droughts of different return periods, taking the DO benefit to be that predicted for a return period of 500 years. A range of drought magnitudes may be required to provide the relevant information into the "states of the world" analysed in the investment model (e.g. 1:200, 1:500). It should be noted that, at the time of writing, no options have had their DO modelled using a 'Tier 2' approach; options have either been assessed using a 'Tier 1' or 'Tier 3' approach, or have had DOs modelled using companies' own water resource models.

2.36 **Tier 3:** Where intervention benefit is not expected to be dependent on climate inputs and/or triggers and/or where there is little/no conjunctive-use impact, DO benefit of an intervention will not be calculated via modelling in the RSS. Preferred options are still likely to be built into the RSS for future 'resilience testing' model runs of the preferred plan (i.e. the output from investment modelling).

2.37 The investment model is based on an additive assumption regarding DO benefits of different options. As such, DO benefits will be calculated for different interventions independently.

2.38 For joint options and transfers, the same 'minimum complexity required' approach to determining sub-models used in determining DO benefit/disbenefit will be taken, but with consideration given to the intervention being investigated.

2.39 For transfers, it may be the case that the DO benefit/disbenefit is not zero-sum under different rule configurations, due to differing vulnerabilities of different WRZs.

2.40 For transfers and joint options, the RSS will not seek to maximise the DO-benefit brought by a given option by dynamically allocating water to participating companies/WRZs (options and transfers being a supply-demand issue, not a supply capability issue). Instead, rules regarding transfers and joint options must be pre-specified, though these rules could be based on the relative drought severity affecting different areas if it is possible to implement this in the model and if it would be possible to write the rules into a contractual agreement. This reflects the necessity of water resource modelling to represent what would happen during a drought situation. As mentioned above, final assessment in the RSS will be full conjunctive "simulation" of the region to address any integration/non-linear issues.

2.41 It is recognised that large-scale interventions may require the re-optimisation of operational rules and control curves. This has not been carried out at the time of writing but will be carried out as part of further investigation of options.

## Decision points & documentation

2.42 As described throughout this Method Statement, there are several decision points when producing models and calculating deployable outputs. Examples of decisions to be made are: determining which uses a given sub-model is suitable for; determining whether to use the RSS or company models/ assessments for calculating baseline DO; which tier of assessment to be applied for a given option.

2.43 For key decisions, keeping appropriate documentation is valuable for later justifying outcomes and decisions further down the modelling chain. In this section, key decision points are identified. Decision makers, those collating decisions across the region, and required documentation are described for identified decisions. There are of course many small decisions made during the course of building a water resources model and it is infeasible that all decisions would be recorded, although all decisions should be justifiable if questioned. This section only focusses on high-level decisions.

2.44 Identification of key assumptions to underly DO assessments which will not be aligned across WRSE - Water companies should document and justify key assumptions which will underly their DO; WRSE will collate assumptions from companies. Assumptions considered 'key' will vary between companies and WRZs and so companies should identify those assumptions that they see as key for given WRZs. Examples of key assumptions include Levels of Service, emergency/dead storage assumptions, control curves, the point at which Level 4 restrictions would be implemented, and inclusion/exclusion of the benefits of demand restrictions from baseline DO.

2.45 Identification of suitability of model for different purposes - As part of the model build process, Atkins is undertaking a model validation process in collaboration with water company leads. Company model leads will 'sign off' models for use in different circumstances based on the validation evidence presented to them.

2.46 Choice between application of WRSE Deployable Output Methodology and WRSE Regional Simulation Model for determining baseline DO, or application of company models & methods - Companies will need to document and justify a decision that does not apply the WRSE DO methodology and/or WRSE Regional Simulation model.

2.47 Inclusion of bulk supplies/transfers in baseline deployable output - If any inter-zonal or inter-company transfers are to be included in baseline deployable output, this should be justified and documented by the relevant company. If it is an inter-company transfer, the company should inform the other company involved to ensure a consistent approach. WRSE should be informed of all cases where transfers are to be included in baseline DO.

2.48 Choice regarding tier of analysis required for different options - Companies will be required to advise Atkins on how options should be included within the system simulation model.

## Confidence grades

2.49 It is recognised that a methodology will be required for assigning confidence grades to deployable output. However, this has not yet been determined.

# 3 Summary

3.1 This Method Statement has outlined how deployable output will be calculated as part of the WRSE regional planning process.

3.2 The input data used in the deployable output assessment has been described, particularly noting those datasets which are significantly different to those used in WRMP19.

3.3 The characteristics of a successful methodology have been described, in order that the methodology that follows may be assessed by the reader against these criteria.

3.4 The deployable output methodology was then detailed.

3.5 The different circumstances under which the deployable output methodology will be applied were then detailed, including cases where adaptations of this method may be required.

# 4 Next steps

4.1 We consulted on this Method Statement from 1st August 2020 to 30th October 2020. This Method Statement has now been updated to take into account the comments we receive during this consultation process and has been published on our website.

4.2 We may need to update parts of our Method Statements in response to regulatory reviews, stakeholder comments or improvements identified during the implementation phase of the methodology.

4.3 If any other relevant guidance notes or policies are issued, then we will review the relevant Method Statement(s) and see if they need to be updated.

# Method Statement: Climate Change – Supply Side Methods

## Updated version

## August 2021

| Title | Method Statement: Climate Change – Supply Side Methods |
|---|---|
| **Last updated** | August 2021 |
| **Version** | Post-consultation version |
| **History of Changes made to this version** | July 2020 – First Draft Written<br>July 2020 – Changes made to reflect comments from technical experts<br>August 2021 – Changes made after consultation feedback and WRPG revisions |
| ***Summary of areas where substantive changes have been made as a result of consultation feedback*** | • Where option CC DO impact is calculated, pre-CC return periods used should be assessed with options in place<br>• Clarifications on methodological points<br>• Acknowledgement of limitations of approach |
| ***Summary of areas where substantive changes have been made as a result of revised Water Resource Planning Guidelines*** | None |
| ***Summary of other substantive changes made, and reasons for these*** | • Deletion of caveats – WRSE companies all ended up following the same climate change assessment method, and so caveats around use of different methods unnecessary |
| **Author** | Peter Blair |
| **Approved by** | Meyrick Gough |
| **WRSE Director Approval** | Meyrick Gough |

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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

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Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

We have prepared method statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

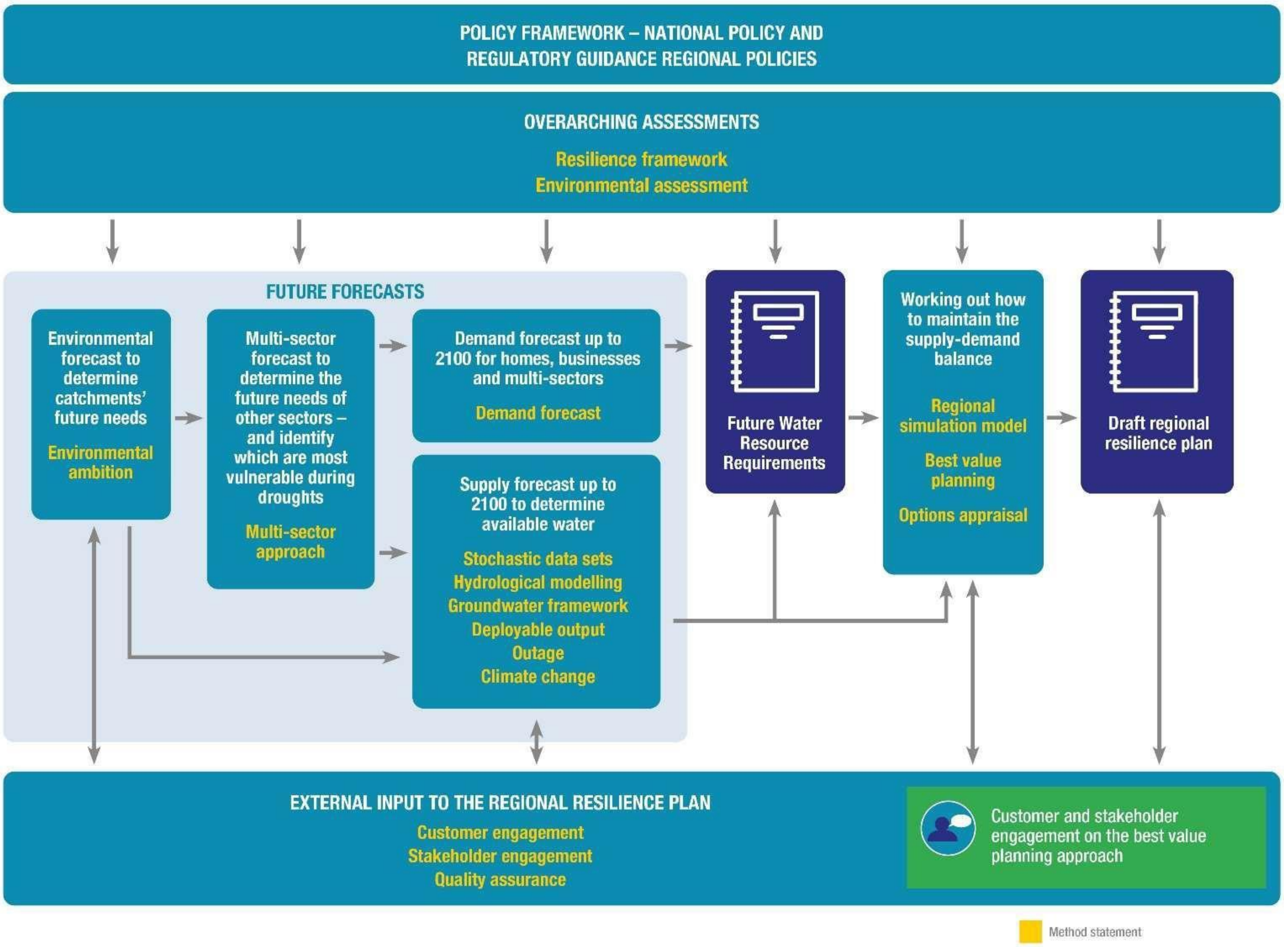
Figure ES1 illustrates how this method statement on supply-side climate change impacts will contribute to the preparation process for the regional resilience plan.

Water companies must ensure that their strategies are suitable for meeting future stresses and so must take account of the impacts that climate change will have on their supply systems. Current methods involve the calculation of 'deployable output impact' of climate change.

Since the production of WRMP19, there have been new datasets (UKCP18) produced which have potentially significant impacts for the methods used in determining the impact of climate change. Core messages from UKCP18 are very similar to UKCP09, with hotter, drier summers and warmer, wetter winters becoming more likely in a climate change impacted future, but the specific datasets available and importance of spatial coherence in regional planning bring new challenges in applying climate change projections in water resources planning.

This method statement describes how climate change impacts will be calculated as part of the WRSE regional plan.

**Figure ES1: Overview of the method statements and their role in the development of the WRSE regional resilience plan**



# 1 Introduction

1.1 Water companies must ensure that their Water Resource Management Plans (WRMPs) include an appropriate allowance for the impact that climate change will have on their supply capability over the period for which they are planning, in order that appropriate investment is made.

1.2 All companies in the UK have conducted analyses determining the impact of climate change on their supplies as part of WRMP19. These analyses involved a great deal of work and represent the most comprehensive supply-side climate change assessment that the UK water industry has undertaken to date. However, since these analyses have been conducted, the underlying data that was used has been updated, with the 'UKCP09' climate change projections being replaced with 'UKCP18' projections. Data from UKCP18 provides the most up to date climate change projections available for the UK, using the best climate models from the UK and around the world, and provides several datasets which can be used by the water industry to determine the range of outcomes that climate change may result in. UKCP18 is not, however, a completely 'like-for-like' replacement for UKCP09 and there are several important differences.

1.3 The Environment Agency (EA) has released new draft guidance associated with assessment of supply-side climate change impacts to incorporate guidance on using UKCP18 projections and on how to account for climate change impacts when also considering '1 in 500-year' drought.

1.4 This document will not provide a detailed description of the differences between the UKCP09 and UKCP18 datasets or EA guidance. There is a comparison of the different UKCP18 products and bias correction methods in a report by Atkins (2020a).

1.5 In WRMP19, WRSE companies used methods which are broadly aligned with one another and which follow EA guidance. There are, however, differences in some areas between company assessments which could have consequences when planning on a regional basis. This combined with the changes necessitated by new datasets and guidance have led WRSE to seek an aligned approach to climate change assessment across the region.

1.6 There are significant disparities between the forecast impact that climate change will have for companies' Water Resource Zones (WRZs) across the WRSE region, with central impacts of between 0 Ml/d and around 200 Ml/d.

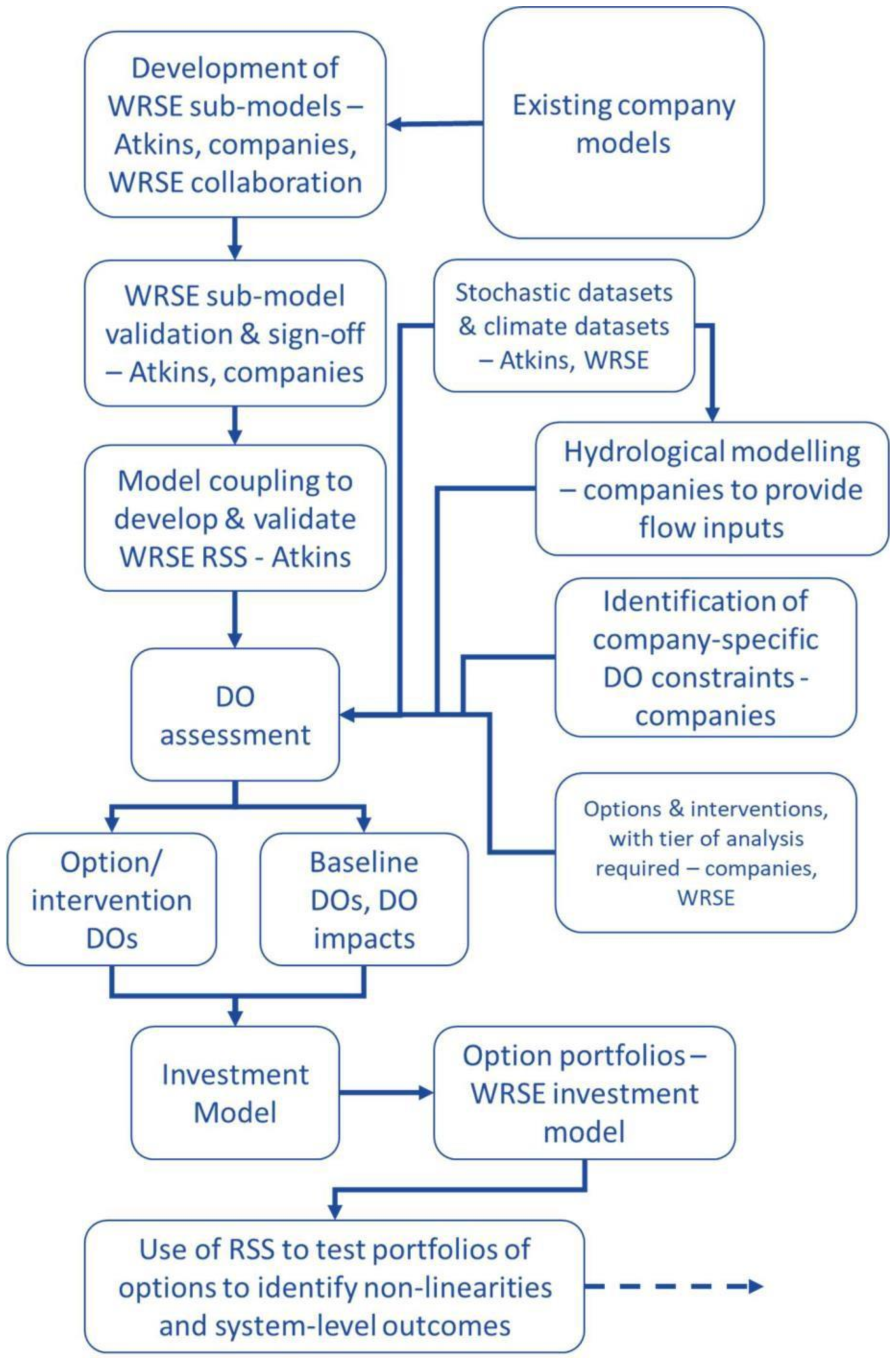
1.7 The methods used to determine the supply-side impact of climate change centre around the calculation of Deployable Output (DO) impact of climate change, i.e. the change in DO from the 'Baseline DO' for a given climate change scenario. This involves the use of 'perturbation factors' (monthly change factors for rainfall, potential evapotranspiration (PET), temperature, and sometimes flows associated with a given climate change scenario) which are applied to baseline records (these baseline records can be historical series, or stochastically generated weather sequences). Perturbed records are used to feed hydrological and hydrogeological models, which can in turn be used in water resources models to determine WRZ/system-level DO.

1.8 The methods outlined here are to be implemented using the WRSE Regional System Simulator (RSS), a water resources model (**Method Statement 1331 WRSE Regional Simulation Model**). While this climate change method statement aims to define a methodology to be applied across the WRSE region, it is recognised that the RSS may provide more acceptable results for some WRSE WRZs/sub-systems than others. As such, individual companies must decide whether the WRSE RSS and this method of determining climate change DO impact are suitable for determining climate change DO impact for each of their WRZs.

1.9 If companies consider that the WRSE model and/or method are not suitable for determining climate change DO impact in one or more of their WRZs, they may apply their own methods. If companies use an alternative to the WRSE method/model, they will need to provide climate change DO impacts, which are required for the integrated risk model and investment model, and which are, as far as possible, consistent with WRSE methods. If companies apply their own approaches, they should apply them to the same climate change data as is used in WRSE assessments and should ideally investigate the same scenarios that WRSE is investigating, in order to bring consistency. This is an acceptable approach, because the RSS will be used in two phases: an initial phase in which DO assessment is the focus, and a second phase in which the RSS will test the responses of portfolios of WRSE-wide options to different possible future states, including possible climate futures. This second phase of modelling will provide valuable information and requires use of the WRSE RSS rather than company-specific models.

1.10 Figure 1 is a flow chart showing an RSS-centric view of WRSE modelling that is being undertaken.

**Figure 1: A view of the WRSE modelling process, centred around the regional system simulator**



# 2 Methods and approach

## UKCP18 Data

2.1 This section gives a brief overview of the UKCP18 products relevant to determining the impact of climate change on DO.

2.2 UKCP09 data was available for different emissions scenarios. These scenarios were classified based on the greenhouse gas emissions associated with different socio-economic scenarios and were classified as low, medium and high. These three scenarios were taken from a larger range of Intergovernmental Panel on Climate Change (IPCC) scenarios, for example the medium emissions scenario is otherwise known as SRESA1B. UKCP18 does not adopt the same approach. Instead, the projections are based on a value of radiative forcing ($W/m^2$) reflecting the increase in radiation that greenhouse gases bring, with the value defining a scenario being the radiative forcing in 2100 and a plausible pathway to this point. The scenarios available in UKCP18 are RCP2.6, RCP4.5, RCP6.0, RCP8.5, with higher values indicating more extreme climate change scenarios, as well as the 'medium' (SRESA1B) scenario consistent with UKCP09 which provides a point of comparison with UKCP09 projections (this scenario uses the same emissions inputs, and so differences in outputs are attributable to differences between models used for UKCP09 and UKCP18). However, not all products are available for all emissions scenarios.

2.3 It is worth noting that some water companies have previously found that it is not a given that increasing emissions lead to bigger DO impacts; some systems are vulnerable to multi-season drought and so the impact of more extreme 'wetter winters and drier summers' is not to continually reduce supply capability. In some cases, further summer drying has less and less effect, while increased winter rainfall can lead to more favourable conditions before summer drawdowns; this is also linked to the level of demand placed on storage within a water resources system.

2.4 **Probabilistic projections** are useful for showing the range of uncertainty present in climate projections, there being many samples available which capture the range of uncertainties associated with climate model outputs.

2.5 There are 3000 samples of climate change factors available for each climate change scenario in the UKCP18 probabilistic data, for every future time slice, which can be defined as a 20-year block or for an individual future year.

2.6 Data from probabilistic projections are available at 25km grid squares, but projections between these grid squares are not temporally or spatially coherent (i.e. there are not probabilistic time series available and, for example, probabilistic projection no.1 for two adjacent grid squares will not give results which are coherent with one another). There are, however, ways of using the probabilistic data and adding spatial coherence, for example assuming observed or modelled correlations between regions, but these methods have not been tested as part of the EA/HR Wallingford project (which informed EA guidance) or the WRSE/Atkins regional data tools projects. There are also spatially averaged projections available which are coherent over larger areas, for instance river basins and countries. The 'England and Wales' region is the smallest scale at which probabilistic projections are available for the whole WRSE region. The England and Wales region is clearly significantly larger than the WRSE region and contains areas where the impacts of climate change could be significantly different to the South East.

2.7 Probabilistic data is available at a monthly timestep from 1960-2100 (UKCP09 data was only available for 30-year time slices).

2.8 Probabilistic projections are available for RCP2.6, RCP4.5, RCP6.0, RCP8.5, and also SRESA1B (the UKCP09 medium emissions scenario), and so there are projections available at a wide range of emissions scenarios. As projections are available for SRESA1B, a direct comparison between UKCP09 and UKCP18 is possible, but no other UKCP18 products can be compared directly with UKCP09.

2.9 The UKCP18 **global projections** are time series from 1900-2100. These provide worldwide climate projections. These projections are spatially and temporally coherent, which enables a coherent consideration of climate change impact over the WRSE region, and more widely.

2.10 There are 28 time series available. 13 of these use the CMIP5 ensemble, while 15 use the latest Met Office Hadley model. The Hadley model produces notably hotter climate projections than the CMIP5 ensemble, although most Hadley model members are within the range of probabilistic data, and so the Met Office have deemed them to be plausible.

2.11 Global projections are available at a $60km^2$ resolution.

2.12 Currently global projections are only available for RCP8.5 (the highest emissions scenario). There is an ongoing project, being delivered by the Met Office, to deliver global projections for the RCP2.6 scenario which should deliver results during 2020, but is likely to be delivered too late to be incorporated into the first iteration of the WRSE regional plan.

2.13 **Regional projections** take the UKCP18 global projections as boundary conditions and downscale using a regional climate model. The results from these projections are of a higher resolution than the global projections, and are spatially and temporally coherent.

2.14 The regional projections are available for 12 of the 15 global projections from the Met Office Hadley model. These regional projections are available at a resolution of $12km^2$ but only for the RCP8.5 (the highest emissions scenario). As stated earlier, however, more severe emissions scenarios do not necessarily imply more severe DO impacts in all cases.

2.15 The regional projections have been thoroughly reviewed (Atkins (2020a); Regional Water Resources Planning: Climate Data Tools), and a derived product has been developed, specifically bias corrected regional climate model time series and change factors.

2.16 There are two other products available from UKCP18: the **high-resolution projections** downscale results from the regional projections using a convective permitting model (meaning that summer storms are well represented) to give sub-daily projections available at up to $2.2km^2$ resolution (only available throughthe user interface at 5km$^2$ resolution); the **derived projections** take results from the global projections and derive results for RCP2.6 and also ‘2 degrees of warming’ and ‘4 degrees of warming’ scenarios.

2.17 Atkins (2020a) carried out a full SWOT (strengths, weaknesses, opportunities, threats) analysis of UKCP products and concluded that spatial coherence is an essential feature for regional water resources planning. Therefore, there is a preference for using regional and global projections for WRSE.

2.18 Key points to mention regarding UKCP18 data are: core messages from UKCP18 are very similar to UKCP09, with hotter, drier summers and warmer, wetter winters becoming more likely in a climate change impacted future (as such previous climate change impact assessments using UKCP09 are still valid as a useful guide); not all products are available at all emissions scenarios (spatially coherent projections are currently only available for RCP8.5, the highest emissions scenario); the newer Hadley model shows some significantly different results to the older CMIP5 ensemble for some key hydrological variables, and some results (for some areas/months, but including autumn precipitation in the South East) from the Hadley model sit outside the range of uncertainty suggested by the probabilistic projections. It is not currently known, however, whether these impacts will be coherent across the region, or more localised. It is not currently known whether this newer model is ‘more correct’ than the older models or not, although some papers have investigated this. The Met Office have published results from all models, and so without specific guidance WRSE will consider all models to be equally valid. It also cannot be known whether the same differences would exist were the model run using a lower emissions scenario, because these newer models have only been used under RCP8.5 (although this picture will become more clear when the global projections are released at RCP2.6).

2.19 WRSE have commissioned Atkins to produce several climate datasets for use in regional planning (Atkins 2020a 2020b). The outputs from this work package include: bias corrected outputs (and non-bias-corrected outputs) from the 12 regional projections, including time series of temperature and precipitation and bias corrected change factors for 2061-80 for UKCP river basins and more than 200 water supply basins across England and Wales; non bias corrected outputs from the 28 global projections (change factors for England & Wales); probabilistic data for the England & Wales area for RCP8.5 and A1B to provide a broader context and compare the different modelling products. The bias corrected RCM data have been rolled out in Water Resources North (WRN), Water Resources East (WRE) and West Country Water Resources Group (WcWRG). Therefore, the RCMs provide coherent datasets for application to any regional transfers between these regions.

2.20 Global model outputs can be downloaded from the UKCP interface for river basins and admin areas, without the need for accessing full datasets.

2.21 Climate modelling is of course ever evolving and new climate models are being built and used to develop new data. For example, a series of high-resolution European and global models are becoming available as part of CMIP6.

2.22 It is relatively quick to generate change factors for spatial extents given climate model outputs, and tools are available which can readily perform this task.

## Environment Agency guidance: key points

2.23 This section gives a brief overview of new EA guidance regarding the assessment of climate change DO impacts. The Environment Agency has produced draft guidance on climate change, 1:500-year drought and stochastic datasets; all of these documents shape the approaches that WRSE will take. Water companies have been consulted on these supplementary guidance documents, and the documents will be publicly available from August 2020. It is also important to note that the 1:500-year drought supplementary guidance contains content on assessment of climate change impacts. It is important that the implications of these three pieces of supplementary guidance are considered as a whole, rather than individually.

2.24 EA guidance states that companies should continue to use a perturbation-based approach (supplementary guidance note on 1:500-year drought), whereby 'baseline' records are perturbed by change factors generated from climate projections. This is due to a change in the resilience standard for which companies must plan, whereby baseline DO should be calculated such that modelled emergency restrictions are not enforced more frequently than once every 500 years. The EA do not feel that a '1 in 500-year' severity climate change impacted drought can currently reasonably be determined directly from available UKCP18 data, and so have recommended continuing to adopt a perturbation approach. The potential downside in using a perturbation-based approach is that it does not allow for consideration of changes to the length of drought events that may occur due to climate change. This factor is of particular relevance to companies/regions vulnerable to short, very intense drought.

2.25 A new vulnerability assessment should be carried out by companies; this is slightly different to previous vulnerability assessments; in that it specifically considers investment planned due to climate change impacts. This assessment has been included due to the recognition that a great deal of work has been carried out using UKCP09 data. Where climate change does not drive significant investment, fully reassessing the impact of climate change using UKCP18 data is not proportionate (due to many of the core messages being the same as UKCP09) and so the EA have detailed 3 tiers of analysis which companies can follow.

2.26 **Tier 1:** where there is low vulnerability of a WRZ to climate change and low investment driven by climate change, and where there are no significant differences between UKCP09 and UKCP18 probabilistic projections, companies may reuse WRMP19 results for WRMP24 climate change assessments. When classifying a WRZ as 'tier 1', care should be taken that regional factors are considered. For example, if a zone is not impacted by climate change in isolation, but is likely to be a significant donor zone to other more vulnerable zones, tier 1 analysis would not be suitable.

2.27 **Tier 2:** where there is low/medium vulnerability of a zone to climate change, or some investment driven by climate change, or if there is a significant difference between UKCP09 and UKCP18 probabilistic projections, existing evidence must be enhanced with appropriate UKCP18 datasets. The method of assessment for this enhancement will vary dependent on evidence, investment and vulnerability, and could be anything from comparison of climatology to full system modelling.

2.28 **Tier 3**: if there is high vulnerability of a zone to climate change, a new climate change assessment must be carried out using UKCP18 projections, accounting for the full range of uncertainty within UKCP18. This is because it is recognised that no single product available from UKCP18 can adequately represent both spatial coherence and the range of uncertainty present in the projections as a whole. For tier 3, a number of UKCP18 products should be analysed using rainfall-runoff/groundwater/recharge modelling, and where possible be taken forward to water resources system modelling. It may not, however, be necessary to take a large number of scenarios though the whole modelling chain.

2.29 No changes are suggested regarding the methods used to determine the climate change impact associated with a given set of perturbation factors (i.e. use of rainfall-runoff/ groundwater/ recharge/ water supply models), other than that it must be demonstrated that selected drought events still reflect a 1 in 500-year level of risk once climate change perturbations have been applied (recognising that the impact of climate change can alter the relative severity of drought events in a record). This method and more generally approaches about how to combine the requirement for resilience to ‘1 in 500-year’ drought in combination with planning for climate change brings a significant amount of uncertainty, and it will be interesting to compare a ‘perturbed 1:500’ drought against the most severe droughts in the transient UKCP18 time series. It is envisaged that initial results from climate change impact modelling will be able to inform methods for combining climate change and stochastics.

2.30 Reflecting on climate data in conjunction with stochastic data, bearing in mind the data that the stochastic data was trained on and the methods used in the generation of this data, can bring some interesting thoughts. For example, climate change signals for the South East of England present in the regional climate model outputs, particularly much reduced precipitation during the autumn period, may imply that certain ‘types’ of events are becoming more likely, but this won’t necessarily be reflected in outcomes using a perturbation factor approach.

2.31 There is currently no guidance on how evidence from different sources and different emissions scenarios should be combined to determine a central impact of climate change or uncertainty in climate change impacts (i.e. there is no statement on whether more/less weight should be placed on different emissions scenarios). It is important to note that use of the Medium emissions scenario from UKCP09 was never explicitly mentioned in guidance, but use of the medium emissions scenario became an accepted norm for determining the central impact of climate change. It may well be that a norm is arrived upon for UKCP18 projections.

2.32 No changes are suggested regarding guidance on scaling of climate change impacts. Linear scaling from the baseline period to a period in the far future is recommended, but non-linear scaling may be used if this can be justified.

2.33 Supply-side options should be investigated to determine the impact of climate change on their deployable output benefit, using methods consistent with those used to assess the baseline climate change assessments for zones relevant.

2.34 For all tiers of analysis, regular communication and consultation with the EA is recommended. WRSE will consult regularly with the EA on climate change methodology.

# Tiers of analysis

2.35 Companies will determine the tier of analysis to be applied for each of their WRZs. WRSE will not mandate the use of 'tier 3' assessment in all zones. As of April 2021, however, all companies have followed a 'Tier 3' approach, using consistent methods, models, and datasets. If companies use their own simulation models in this assessment, they should justify this.

2.36 WRSE companies may undertake additional analysis as they wish and may incorporate this into their supply forecasts.

# Calculating DO impact for a climate change scenario

2.37 As with the deployable output methodology (**Method Statement 1320 WRSE Deployable Output**), the impact of climate change on DO will be calculated on a WRZ/sub-region level with coherent datasets and suitable boundary conditions used across the WRSE region. The implication here is that there will not be a 'regional DO' value calculated, nor a 'regional DO impact of climate change'.

2.38 Any scenario for which DO impact will be calculated will follow largely the same assessment process for each WRZ/sub-region. The starting point for this assessment is a single set of monthly perturbation factors (for rainfall, PET and temperature) to be applied to a baseline record.

2.39 Replicates which contain significant droughts (based on analysis of rainfall alongside preliminary results from hydrological and hydrogeological models) will be selected, and so the selection will not be representative of the whole stochastic sequence and so it is important to highlight that the DO impact of climate change method will be focussed on calculating the 'water resources yield' impact of climate change on a range of drought events (an 'English and Welsh'-type method). This differs from the 'Scottish DO method' used to calculate the baseline DO, which is based on analysis of the long time series available in the whole stochastic sequence. It is also important to stress that selected replicates will be treated as individual replicates, rather than being considered as a long time series. For spatially coherent climate change runs, a regionally coherent set of replicates will be chosen. These replicates will be chosen such that a range of drought return periods are contained within them, with checks done to ensure that droughts with baseline magnitudes of between 1 in 100-year and 1 in 500-year are chosen for all WRZs; some analysis has already been done to conduct this selection the basis of rainfall, but this will be supplemented with results from baseline DO runs.

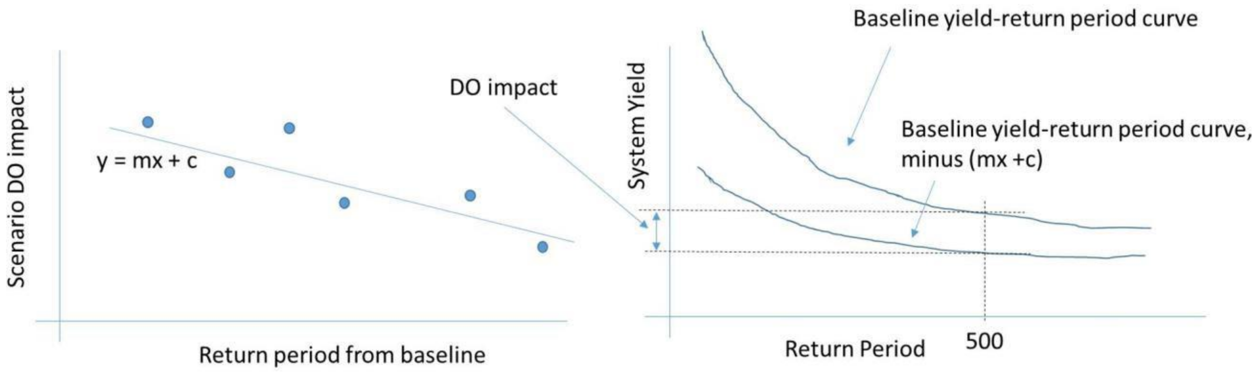
2.40 Companies will take change factors for rainfall & PET, for the 2070s (2061-2080 – the RCM outputs only extend to 2080) and apply these to input time series for rainfall-runoff, groundwater and recharge models. These results will be used as inputs to the regional simulator (the regional simulator requires flows & groundwater yields as inputs).

2.41 WRSE will then run the RSS. As with the DO methodology, when the DO impact of climate change is being found for one WRZ/sub-region, demand in all other WRZs/sub-regions will be held constant.

2.42 For each replicate selected, the baseline water resources yield will already be known. Yield here is a surrogate for DO and is the highest demand which can be placed on the system before the model suggests that emergency drought restrictions would be needed. This is similar to DO, but only accounts for the 'Level 4' (emergency drought restriction) trigger. It is assumed that this trigger will be the main constraint on DO for all zones. If this is not the case for a given zone/sub-region, this method will need to be adapted.

2.43 The water resources yield will then be found for climate change impacted input series for each selected replicate. This will allow for the calculation of the water resources yield impact of climate change for each selected replicate. When the water resources yield has been found for each selected replicate for a given scenario, the DO impact of the scenario will be calculated. Figure 2 shows this process graphically.

**Figure 2: Calculation of DO impact of a climate change scenario**




2.44 Baseline return period will be plotted against the water resources yield impact found for each replicate. If it is reasonable to do so (based on an $R^2$ threshold), a line will be fitted to this (in the example, a straight line is used; in practice a regression between the logarithm of the return period and DO impact has been used). The DO impact will be found as the change in system yield that this line of best fit implies at a return period of each of 100, 200, and 500 years. A check will also be undertaken to ensure that the '1 in 500-year' event with climate change factors is still reasonably representative of a '1 in 500-year' event accounting for climate change. If the climate change impacted yield of an event with a baseline return period of less than 500 years is lower than the yield value calculated using the method above, the DO impact for the scenario will be amended and will be calculated as the baseline '1 in 500-year' DO, minus the lowest yield of any drought with a baseline return period of less than 500 years. It is recognised that significant reordering of droughts may be a consequence of perturbing the stochastic record; however, we don't necessarily know how best to handle this as yet and will further refine methods when we begin to get results.

2.45 Where applicable, there may be other steps involved before/after these core steps. For example, where it is important, the impact of saline intrusion under climate change will be included, using groundwater modelling and climate projections consistent with warming inputs associated with the regional climate model projections used in the rest of this method.

2.46 If the impact of climate change on the DO of an option is being found, the 'Return period from baseline' should be the return period of each replicate with the option in place.

2.47 The use of a perturbation factor based approach, with consistent data being used in both hydrological and hydrogeological models, means that the overall impact of climate change on WRZ DO will be assessed, rather than the impact of surface water and groundwater source DOs separately.

2.48 There are limitations associated with the approach WRSE is taking. One such limitation is that the return period of drought events after climate change cannot be assessed (i.e. is the impact of climate change to make a previously extreme event relatively less severe, or vice versa?).

## Use of different UKCP18 products

2.49 Figure 3 summarises WRSE's proposed use of different UKCP18 products.

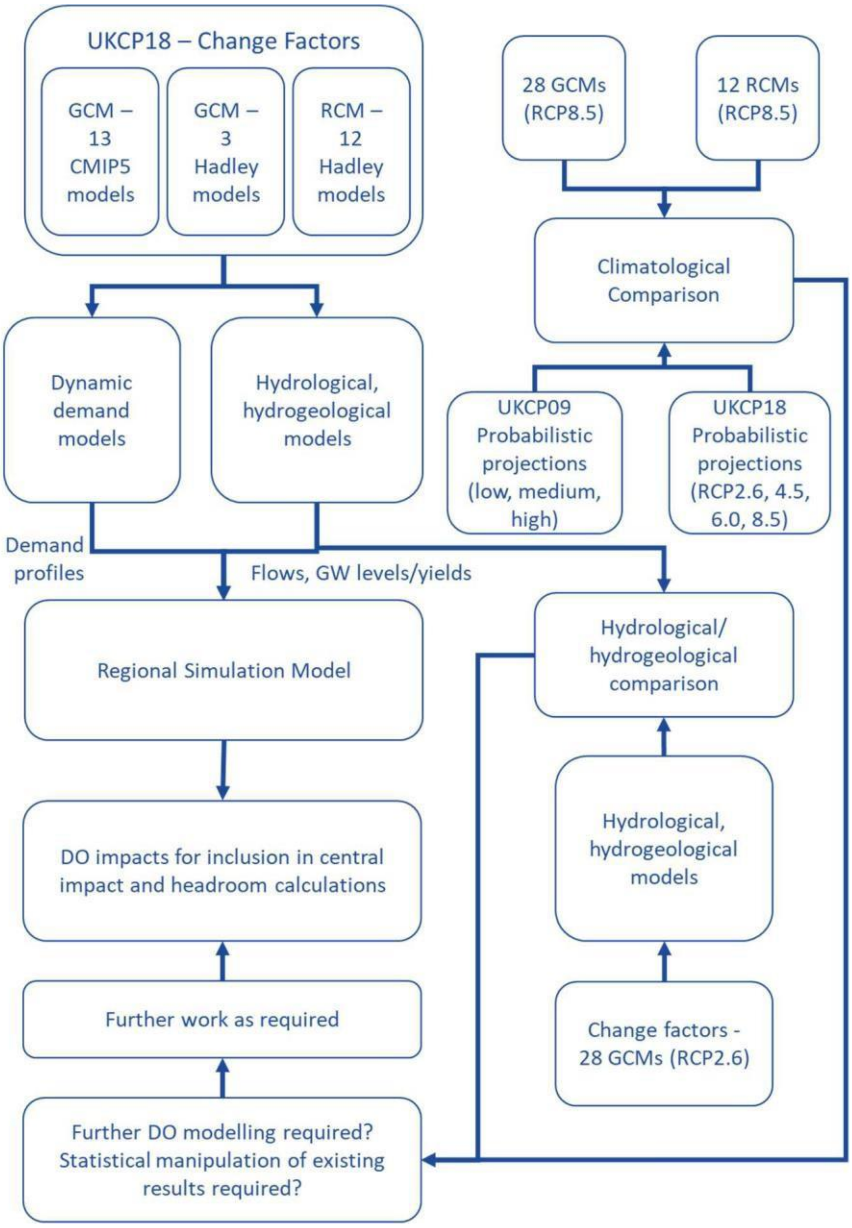
2.50 Conducting a full DO analysis for a single climate change scenario involves a significant amount of work and a large computational burden. As such, WRSE is looking to limit the number of climate change scenarios taken through the modelling chain required in determining the DO impact of climate change while still considering the full range of uncertainty present in UKCP18 data.

2.51 WRSE will carry out water resources system modelling to determine a DO impact for 28 climate change scenarios. These will be the 12 regional projections, the 3 global projections from the Hadley Model which were not run through the regional climate model, and the 13 global projections from the CMIP5 ensemble.

2.52 It will be assumed that the 28 projections are all equally likely, when considering the central impact of climate change on DO, and when determining the uncertainty of climate change impacts.

2.53 Work carried out by WRSE companies has so far suggested that the uncertainty in the range of projections contained within a single UKCP product may be greater than the difference between products (specifically, HR Wallingford carried out a rapid assessment of UKCP18 implications for Thames Water and returned this finding). It can also be seen that the probabilistic data for RCP8.5 covers a wide range of uncertainty, including the range of uncertainty present in other products for most variables; the RCMs and GCMs together appear to cover a similar range of projections as the probabilistic data in many respects, although some key hydrological outputs in the South East from the RCMs appear to be outside the range of the probabilistic projections. It may be that DO impacts from these 28 climate change scenarios are sufficient to capture the range of uncertainty present in the UKCP18 products (perhaps subject to some statistical manipulation based on other results), given that this will involve use of RCP8.5 in the far future, and given that initial analysis of this dataset shows a range of results.

**Figure 3: WRSE's proposed use of different UKCP18 products**




2.54 WRSE will gather existing evidence from assessments that have been carried out investigating the relative impacts of different UKCP09 and UKCP18 datasets to inform what further work isrequired.

2.55 WRSE will complement this with a comparative assessment of the climatology of UKCP09 and UKCP18 probabilistic projections, as well as a comparative assessment of the climatology of the probabilistic, global and regional projections produced for UKCP18.

2.56 When the global projections under the RCP2.6 scenario are available, WRSE will conduct hydrological and hydrogeological modelling for 5-10 zones across the region, with the most climate vulnerable zones chosen, while also ensuring good spatial coverage across the region. This modelling will be compared with results from RCP8.5. One of the main aims of this comparison will be to inform a view as to whether the effects seen in regional climate models (e.g. lower autumn precipitation in the South East) are seen in other emissions scenarios, or if that is something which is only seen under the highest emissions scenario.

2.57 WRSE is currently not proposing to do DO modelling using UKCP18 probabilistic projections, although DO scenarios using specific 'marker' scenarios (e.g. median) may be undertaken to ensure coherence with other results. If the results from any of the above climatological/hydrological studies imply that use of the 28 RCP8.5 spatially coherent projections does not cover the range of uncertainty associated with UKCP18 products, further DO runs may be undertaken.

2.58 It should be noted that the use of different UKCP18 datasets is subject to change, dependent on interaction with the Environment Agency. This is also dependent on outcomes from conversations between the inter-regional coordination group and the Environment Agency.

## Scaling of climate change impacts

2.59 There will not be a consistent approach to scaling the impact of climate change across WRSE WRZs. This reflects the fact that the impacts of climate change will not necessarily occur at the same rate across the region.

2.60 The standard linear scaling approach suggested by the EA will be used unless a company suggests that this is not suitable for a given zone.

2.61 Companies may, however, choose their own scaling approaches, as appropriate for each zone.

2.62 The baseline used will be 1981-2000 in order that all products used can use the same baseline. This is also fairly representative of the baseline used for generation of stochastic sequences (1950-1997).

# 3 Summary

3.1 This method statement has outlined how climate change impacts will be calculated as part of the WRSE regional planning process.

3.2 Data available from UKCP18 climate projections has been described, including the different products available and their potential applicability in WRSE's regional planning.

3.3 Key points from draft guidance written by the Environment Agency have been identified and their implications explored.

3.4 The approach to determining the tiers of analysis required for different WRZs have been explained.

3.5 The method for calculating the DO impact of a single climate change scenario has been detailed.

3.6 Methods for incorporating different UKCP18 products have been explored and WRSE's proposed application of different UKCP18 products has been outlined. It should be noted that this is subject to change and is dependent on outcomes from interactions between the inter-regional coordination group and the Environment Agency.

3.7 Methods for scaling climate change impacts on DO have been detailed.

# 4 Next Steps

4.1 An initial version of this document was consulted upon between 1st August 2020 to 30th October 2020 and comments received during this time have been incorporated in this version.

4.2 We have also reviewed this document against the final WRPG and supplementary guidance notes issued by the regulators.

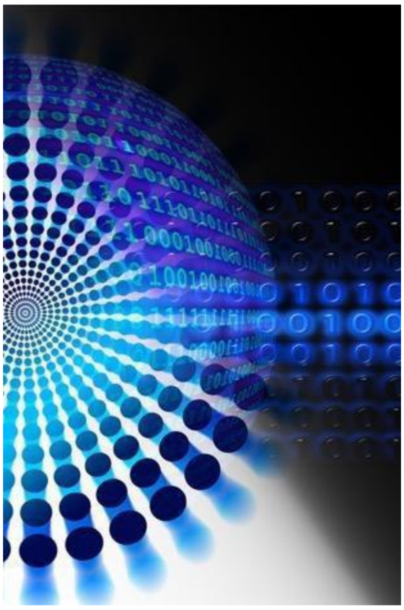
4.3 If any other further relevant guidance notes or policies are issued then we will review this Method Statement to see if it needs to be updated.

4.4 When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

# 5 References

Atkins (2020a); Regional Water Resources Planning: Climate Data Tools

Atkins (2020b); Regional Climate Data Sets: WRSE Baseline Stochastic Roll Out (available on request)



# Method Statement: Stochastic Climate Datasets

**Consultation version**

**July 2020**

| Title | Method Statement: Stochastic Climate Datasets |
|---|---|
| **Last updated** | July 2020 |
| **Version** | Consultation version 2020 |
| **History of Changes made to this version** | June 2020 – First Draft Written<br>July 2020 – Changes made after technical working group comments, Programme Management Board comments, and Quality Assurance review comments |
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# Table of Contents

# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

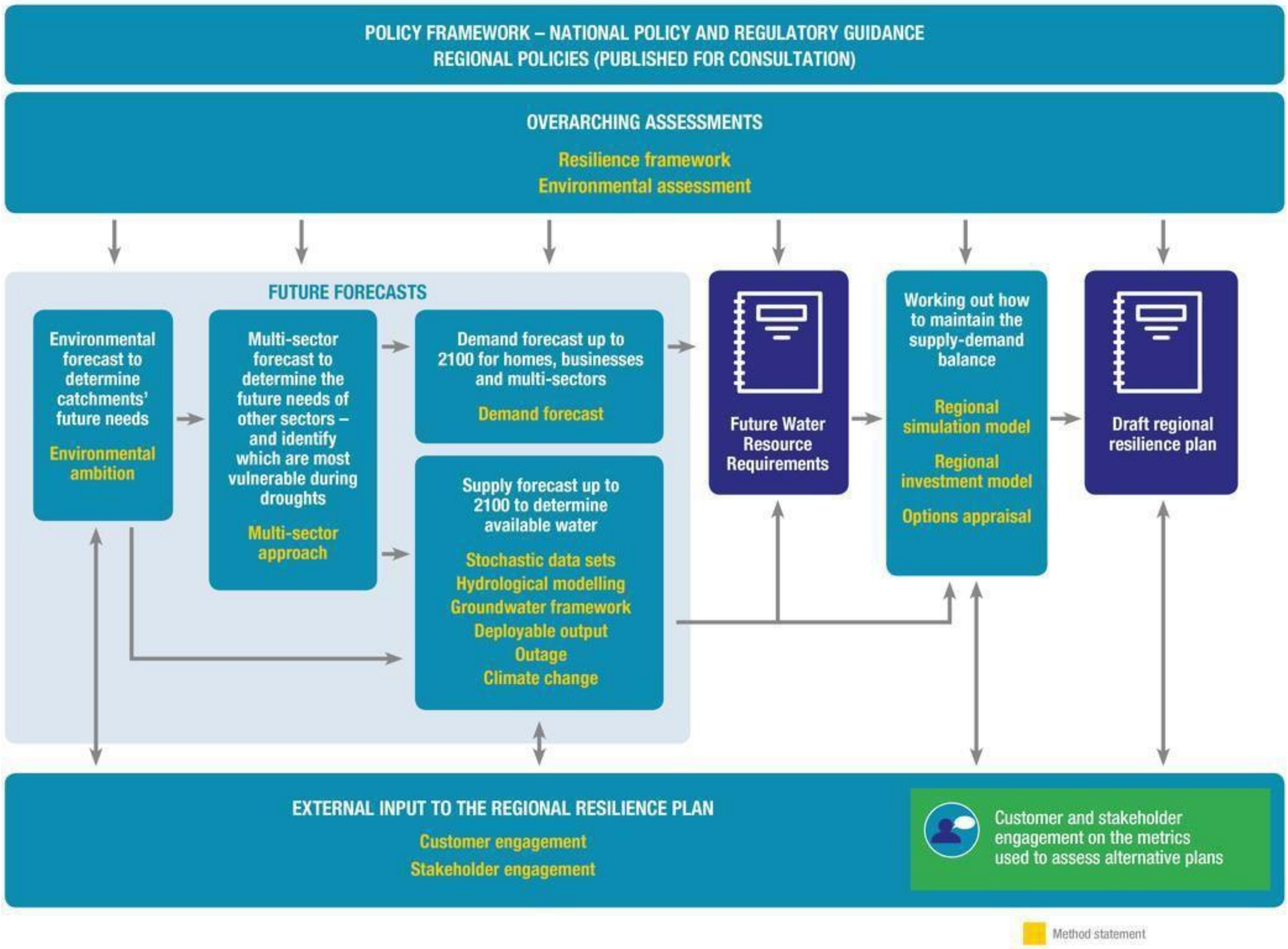
We have prepared method statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We are consulting on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this stochastic datasets method statement will contribute to the preparation process for the regional resilience plan.

Water companies are required to consider droughts beyond those in the historical record, in order that companies can demonstrate that their plans will bring resilience to more severe and/or different droughts to those which have occurred previously. The method that has been applied in the water industry in the UK is the generation of 'stochastic datasets', time series of rainfall and potential evapotranspiration which are wholly/partially statistically generated and which allow companies to explore droughts beyond the historical record.

This method statement gives an overview of the stochastic datasets that have been generated for WRSE and how they will be applied in WRSE's regional plan.

Figure ES1: Figure 1 Overview of the method statements and their role in the development of the WRSE regional resilience plan



# 1 Introduction

1.1 The use of 'stochastic' climate datasets is growing within water resources planning, driven by a need to consider the impact of droughts that have not happened in the past. Historically, water resources planning has been carried out based on assessing supply capability considering droughts that have happened in the past. This use of the historical record gives climate datasets that water companies, regulators, and stakeholders can be confident in (being based on weather that has happened) but does not allow for thorough exploration of impacts of droughts which could happen in thefuture.

1.2 The need for water companies to consider droughts beyond those in the historical record has increased in recent years due to the introduction of requirements from the Environment Agency that water companies show how companies would make their water supply systems resilient to '1 in 200 year' drought as part of WRMP19, and a new requirement for regional planning and WRMP24 that companies' water supply systems are resilient to '1 in 500 year' drought by 2039 at the latest. Reliable historical records for rainfall and potential evapotranspiration (PET), which are two of the most important inputs to hydrological models, are generally no more than around 100 years long, and so for companies to confidently assess their supply capability under '1 in 500 year' drought requires a significant amount of statistical analysis of climatic drivers and historical records.

1.3 The variables most needed to feed hydrological and water resources models are rainfall, PET, and temperature, and so these are the variables contained in stochastic datasets that have been produced.

1.4 Climate datasets were produced for many companies/regions for WRMP19 assessments. The methods and data underlying the generation of stochastic datasets have been improved in recent years, and so new datasets have been generated in a project commissioned by the Regional Coordination Group and delivered by Atkins (WRSE Regional Climate Data Tools)

1.5 The use of the term 'stochastic' regarding climate datasets references the nature of rainfall and the way that these datasets are derived. Rainfall cannot be predicted based solely on climatological indicators and rainfall volumes are instead climate-driven, but partially random (i.e. it would not have been possible at the beginning of 1976 to determine how much rain would have fallen that year, or when). The climate datasets are derived using relationships between output variables needed (temperature, rainfall) and climate indicators (e.g. North Atlantic Oscillation (NAO), Sea Surface Temperature (SST)), alongwith 'random chance' to generate datasets which are statistically consistent with the historical baseline, but which represent different versions of what 'could' have happened.

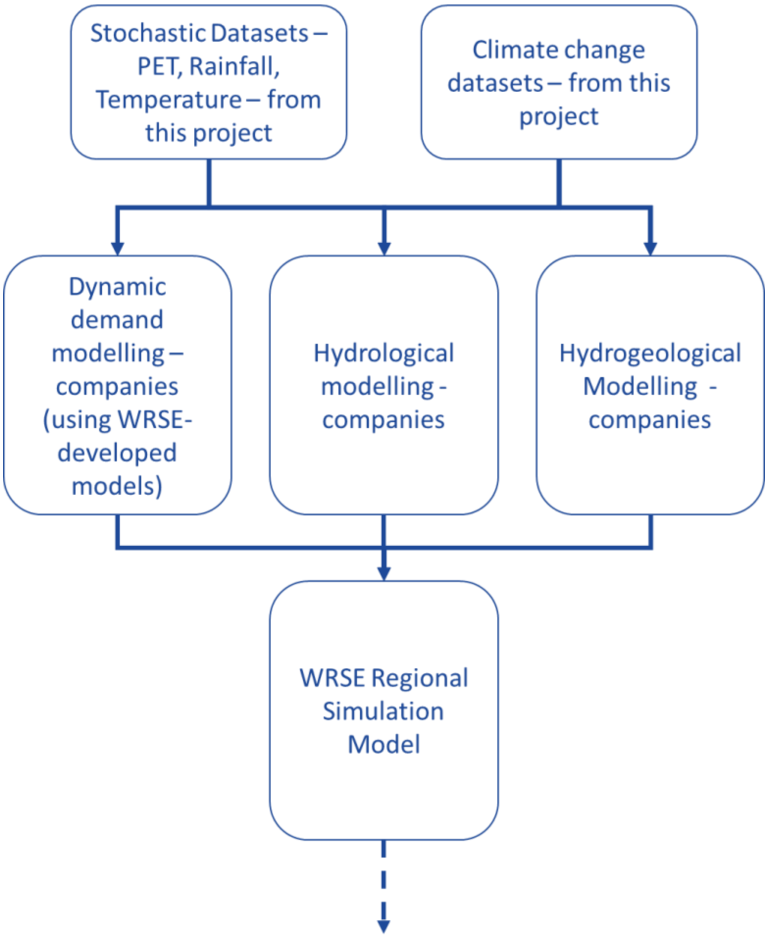
1.6 Figure 1 is a flow chart summarising the use of stochastic and climate datasets in WRSE. This figure shows how the climatic datasets drive the hydrological, hydrogeological and dynamic demand modelling to ensure there are spatially coherent responses to the input climatic data.

1.7 This method statement contains the following sub-sections:

a) Generation of stochastic climate datasets

b) Application of datasets
c) Selection of subsets

**Figure 1: Flow chart centred on use of stochastic datasets for WRSE**



# 2 Methods and approach

## Generation of Stochastic Climate Datasets

2.1 The generation of stochastic climate datasets involves a significant amount of complex analysis involving climate science and statistics. This method statement does not give an in-depth description of the methods used to generate these datasets but does outline key differences between those datasets generated for WRMP19 and those generated for this round of planning, as well as highlighting key characteristics of these datasets. For a detailed description of the methods used, please see the technical report on the production of these datasets (Atkins, 2020). In essence the work that Atkins have undertaken allows the key climatic indicator time sequences between 1950 to 1997 to be resampled to produce varying temporal and spatial climatic patterns across the South East region. Each resampled year forms a replicate.

2.2 Four hundred replicates of a 48-year baseline have been produced, meaning that the climate datasets represent a total of 19,200 years. The dataset should not, however, be seen as a continuous sequence of 19,200 years and represents 400 different versions of what a baseline period (1950-1997) could have resulted in, given underlying climate drivers.

2.3 Time series of rainfall, PET and temperature have been generated for locations across the WRSE region. These can be used as required as inputs for various models, by reformatting inputs to be gridded or amalgamated to catchments.

2.4 A key change from data generated for WRMP19 is that these stochastic datasets are based on a greater range of climate drivers and little bias correction. Data generated for WRMP19 only included NAO and SST as climate drivers, but several more climate drivers have been used in this recent project. The inclusion of a greater range of climate drivers has resulted in a better model fit and a smaller need to bias correct outputs. Where bias correction has been used, improved methods have been applied to reduce the production of implausible droughts.

2.5 The use of a greater range of climate drivers has also driven a change to the baseline period used on which to fit the models. For WRMP19, 1920-1997 was used as a baseline, but this has been changed to 1950-1997 due to better quality data for more climate drivers being available only from 1950.

2.6 HadUK data (Met Office; Hollis, D.; McCarthy, M.; Kendon, M.; Legg, T.; Simpson, I. (2018): HadUK-Grid gridded and regional average climate observations for the UK. Centre for Environmental Data Analysis) has been used to derive these datasets, as opposed to the catchment average time series used for WRMP19. This HadUK data is a more flexible and consistent product, suitable for this application.

2.7 As with any dataset generated based on existing datasets using statistical methods, the stochastic weather sequences are only as good as the datasets on which they are trained. As stated above, the stochastic dataset is formed of 400 48-year sequences and is trained on the 1950-1997 baseline period. There is a risk that extreme, extended droughts may not necessarily be well reflected in the dataset, although quantifying this risk is extremely difficult. Companies may complement the stochastic dataset with drought artificial weather series to represent prolonged drought events (which the stochastic generator will not have been trained on).

2.8 The new EA-PET dataset has not been used in the generation of these climate datasets, due to the dataset not being available at the time needed for generation of the stochastic data.

2.9 The datasets that have been generated exclude leap years (i.e. all 48 years within each replicate are 365 days long). Where models require representation of the 29th Feb, a 'zero rainfall' day should be inserted, and PET should be copied from the day before. The biasing effect that this introduces will be negligible.

2.10 Stochastic sequences have been generated consistent with a baseline of 1950-1997. Water company historical baselines may have previously included data up to 2019, although their previous (WRMP19) stochastic data is unlikely to have been generated on a baseline ending more recently than 2000. Climate change impact on DO will be assessed using a baseline of 1981-2000 and so the baseline period of 1950-1997 is consistent with the climate change assessment.

# Application of stochastic climate datasets

2.11 The datasets that have been produced will see wider use than has previously been the case. The data will be applied in deployable output assessment, assessment of the impact of climate change, assessment of the benefit that different supply-side options will have, and examining the outcomes that portfolios of options result in. The data will also be used in considering the impact of weather and climate change on demand, and how this interacts with the supply system.

2.12 Many of the applications that these stochastic datasets will be used for involve use of rainfall and PET data in hydrological and/or hydrogeological models. Companies may be required to conduct translation and/or bias correction to align data that has been produced with existing rainfall-runoff and groundwater models. This is to deal with spatial issues (some models may require gridded data, others require point/catchment average time series) as well as bias impacts (models may have been calibrated using different datasets and application without bias correction may result in bias of model outputs).

## Deployable output (DO) assessment

2.13 Stochastic datasets will be used in the assessment of baseline deployable output. Please see the WRSE Deployable Output method statement for full details of how deployable output will be calculated using the regional system simulator. Stochastic climate data will be used in hydrological and hydrogeological models to generate flows (WRSE Hydrological Modelling method statement) and groundwater yields, which are key inputs to the regional system simulator.

2.14 As per the groundwater framework (WRSE Groundwater Framework method statement), many groundwater sources will have outputs which are either modelled dynamically within the regional simulator, or are modelled outside the simulator but which have yields which are coherent with climate sequences determining yields which are different during different drought events. In these cases, this will be the first time that WRSE companies will have considered groundwater yields in this way, and this will give a better assessment of system-level conjunctive use. It will highlight the types of drought to which company systems are most vulnerable. Baseline deployable output will, where possible, be calculated using the whole stochastic record and will be assessed as the supply capability of systems under '1 in 500 year' drought conditions, as determined by system response.

## Assessment of impact of climate change

2.15 Stochastic datasets will be used extensively in the assessment of climate change impacts on deployable output. Please see the WRSE climate change - supply side methods method statement for full details of the supply-side assessment of the impacts of climate change. Environment Agency guidance recognises that the impact of climate change can change the relative severity of different droughts. As such, water companies cannot simply apply climate change factors to 'DO-defining' droughts (those identified as having a severity of 1 in 500 years) to assess the impact of climate change on DO. It would, however, be infeasible to use the whole stochastic sequence to assess the supply-side impacts of climate change, given that this would involve running 19,200 years-worth of data through groundwater models, hydrological models and the regional simulator for each climate change scenario and that there will be many tens of climate change scenarios investigated. As such, a range of droughts that exist within the stochastic sequences will be used to assess the impact of climate change on deployable output (WRSE post-baseline DO drought selection method statement).

## Assessment of supply-side option benefits

2.16 As well as the baseline deployable output, stochastic datasets will be used in the assessment of the DO benefit that different options and interventions bring. The benefit that some options bring is more dependent on climate variables than others, for example the benefits associated with reservoirs are more impacted by climate and hydrology than desalination plants. As such, a tiered approach to the detail associated with DO benefit assessment will be used. Those options where climate significantly impacts option benefit will have their benefits assessed using the whole stochastic climate record. Those options where climate slightly impacts option benefit will have their benefits assessed using selected droughts from the stochastic record. Those options which are not impacted by climate will not be modelled in the regional simulator.

## Examining outcomes associated with option portfolios

2.17 After the investment model has been run and potential future portfolios of options and interventions have been developed, these portfolios of options will be run in the regional simulator to analyse whether the system outcomes associated with portfolios align with the benefits that are anticipated. This will involve use of the stochastic climate datasets.

### Dynamic demand

2.18 In water resources planning, demand variation within years has been considered based on static profiles (i.e. profiles which are the same for all modelled years). For this round of planning WRSE have developed models which are able to give profiles of demand in each WRZ dependent on climate inputs including temperature and rainfall (WRSE demand forecast method statement). This means that dynamic variations in supply and demand are considered in a fully coherent manner within the regional simulator. This will give a better idea of how supply and demand interact during drought events, for instance how long, hot periods may imply that demand remains higher for longer than may be suggested by static profiles.

## Selection of Drought Events

2.19 Some of the applications above imply the selection of subsets of the whole climate dataset for specific applications. Environment Agency guidance requires that 'system response' is considered where possible, recognising that rainfall deficit alone cannot reliably be used to determine system-level outcomes, and so droughts will not be selected for these purposes based on analysis of climate data. Instead other metrics, such as baseline supply-system yields, will be used to select series to be used in these analyses (WRSE post-baseline DO drought selection method statement).

2.20 Some inputs, most notably groundwater yields where time series inputs are needed for the regional system simulator, will also require the selection of time series from the larger climate dataset. This is because it is infeasible to run detailed groundwater models using many thousands of years of input data due to runtimes. As above, the Environment Agency would like 'system response' to be considered where possible and so climate data alone will not be used to select drought events for this purpose. Initially it was thought that climate data would be used to select 'regionally coherent' droughts to be run through groundwater models (i.e. assessing system stress at a regional level and selecting events based on regional stresses, or assessing system stress at a local level and choosing events which stress different parts of the region). However, 4 of the 6 WRSE companies will be running only 'fast' groundwater models (less detailed models, where runtimes are not prohibitive) to produce time series inputs, with only Thames Water and Southern Water using more detailed models which could not practically be run using all climate input sequences. Both Thames Water and Southern Water are using 'fast' groundwater and surface water models to select time series that will be run through more detailed models, rather than relying on climate inputs for selection. Southern Water have a greater capacity for running more data through models, and so 10 of the 48-year replicates will be selected based on system response of indicators associated with the Thames catchment, which Thames Water will run through detailed models; Southern Water will run these same 10 replicates through their models (for coherence of analysis) along with other replicates selected based on system response variables for the Southern Water region.

# Decision Points & Documentation

2.21 While there have been many decisions made in producing stochastic datasets for WRSE, there are relatively few decisions which WRSE and/or water companies must make specifically regarding these datasets. The datasets represent an improvement on those which are available and so it is expected that companies will apply them throughout their assessments. The technical report (Atkins, 2020) which describes in detail the production of the datasets contains significant detail on the methods used and how these methods were chosen. No feedback loops exist in the generation and application of stochastic datasets.

2.22 There are decisions that companies should make regarding how stochastic datasets are applied in hydrological/hydrogeological modelling, but these decisions are detailed in the WRSE hydrological modelling method statement.

2.23 Should companies wish to consider drought events/time series not contained within the stochastic record, they should document their decision to do so. Justification and explanation should be captured by companies regarding the drought events that they are exploring and the rationale behind doing so.

# Confidence Grades

2.24 It is recognised that a methodology will be required for assigning confidence grades. However, this has not yet been determined.

# 3 Summary

3.1 This method statement has briefly outlined the stochastic datasets that have been produced for WRSE, which will be applied in WRSE's regional planning.

3.2 The methods underlying these datasets are complex, and so those seeking to explore the technical detail of these methods should read the technical report detailing their production (WRSE Regional Climate Data Tools).

3.3 The applications which stochastic datasets will be used for have been outlined. These include assessment of deployable output, assessment of climate change impacts, assessment of supply-side option benefits, exploring outcomes associated with different option portfolios, and assessing the variation of demand with weather and climate.

# 4 Next steps

4.1 We are consulting on this method statement from 1st August 2020 to 30th October 2020. Details of how you can make comments can be found here consultation website).

4.2 We will take into account the comments we receive during this consultation process, in updating the Method Statement. Alongside this, the Environment Agency will shortly be publishing its Water Resource Planning Guidelines (WRPG) on the preparation of regional resilience plans. We may need to update parts of our method statements in response to the WRPG. We have included a checklist in Appendix 1 of this method statement which we will use to check that our proposed methods are in line with guidance where applicable.

4.3 If any other relevant guidance notes or policies are issued then we will review the relevant method statement(s) and see if they need to be updated.

4.4 When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

# Appendix 1 Checklist of consistency with the Environment Agency WRMP24 Checklist

The Environment Agency published its WRPG on XXXXXX 2020, including the WRMP24 Checklist. The following table identifies the relevant parts of the checklist relating to this Method Statement, and provides WRSE's assessment of its consistency with the requirements in the Checklist.

| No. | Action or approach | Method Statement ref: | WRSE assessment of consistency |
|---|---|---|---|
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Member of the SNC-Lavalin Group

# Regional Climate Data Tools

## Final Report

Sutton and East Surrey Water on behalf of WRSE

1st July 2020

5194482-2

# Notice

This document and its contents have been prepared and are intended solely as information for Sutton and East Surrey Water on behalf of WRSE and use by the four other regional water resources planning groups, Water Resources East, Water Resources North, West Country Water Resources Group and Water Resources West.

W.S. Atkins International Limited assumes no responsibility to any other party in respect of or arising out of or in connection with this document and/or its contents.

This document has 166 pages including the cover.

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## Client signoff

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|---|---|
| Client | Sutton and East Surrey Water on behalf of WRSE |
| Project | Regional Climate Data Tools |
| Job number | 5194482 |
| Client signature/date | |

# Contents

## Tables



## Figures

# Executive Summary

This is the final report of the Regional Climate Data project, which has developed new climate data sets to support regional water resources planning in England and Wales.

The two main data sets are:

- Stochastic daily time series of precipitation and potential evapotranspiration for more than 200 locations in England and Wales, based on Met Office HadUK observation data for precipitation and several Potential Evapotranspiration (PET) data sets, required for water resources modelling
- Bias corrected future climate change factors and daily time series based on UK Climate Projections 2018 Regional Climate Models under Representative Concentration Pathway (RCP8.5) and HadUK precipitation and temperature at the catchment scale

The first data set provides a set of 400 time series for each location for the assessment of climatological drought risk across England and Wales for a baseline climate without climate change. The same stochastic model is now applied to five regions of England and Wales and is an improved model compared to previous assessments for WRMP19[1]. Within each region these data are spatially and temporally coherent, providing plausible scenarios of a wide range of possible drought conditions. These data provide inputs to hydrological, groundwater and water resources systems models for the assessment of baseline deployable outputs and risks of very low rainfall over durations from 3 months to several years. Example outputs from the drought library are shown in Figure ES1.

A project development phase tested the performance of a new stochastic model, which was driven by a wider range of climate drivers including the North Atlantic Oscillation (NAO), Sea Surface Temperatures, Atlantic Multidecadal Oscillation, East Atlantic, East Atlantic West Russia and Scandinavia Indices. It also developed improved post-processing and sampling tools with the overall impact of improving the model fit to low rainfall by 25%[1]. Overall, the post-processing adjustments are minor, and the improved fit means that post-processing correction is not required for all sites. Case studies were used to test the workflow and compare the new stochastic model to older versions applied in WRMP19.

The second data set provides spatially coherent Regional Climate Model (RCM) change factors and accompanying daily time series to assess the impacts of climate change. These scenarios are based on Met Office UKCP18 Regional Climate Models under scenario Representative Concentration Pathway RCP8.5. The RCMs were bias corrected to match HadUK observations for more than 200 catchments in England and Wales. These data provide time series for modelling from 1981 to 2070, but it is anticipated that water companies will make use of the change factors and apply these to historical baseline and selected stochastic time series to assess future impacts.

A full Strengths Weaknesses Opportunities and Threats (SWOT) analysis on UKCP18 reviewed the available data sets for regional water resources modelling, with spatial coherence as a key criteria The RCMs provided the most suitable model outputs in this regard, despite other weaknesses. The bias-corrections applied were more advanced than the methods used for the previous Future Flows project, thereby creating a product that both fits the baseline climate and provides time series for future climate change at the catchment scale. However, it is clear the Met Office HadGEM global model and regional model are hotter than other models in the CMIP5 ensemble and the median projections from the UKCP probabilistic data, with predictably greater impacts on low flows.

*Conclusions*

This project was started before the development and publication of the Environment Agency Water Resources Planning Guidelines, which includes supplementary guidance on both stochastic data and climate change impacts assessment. Both data sets can be implemented in a way that is fully compliant with the guidelines and the interactions are summarised in Figure ES2.

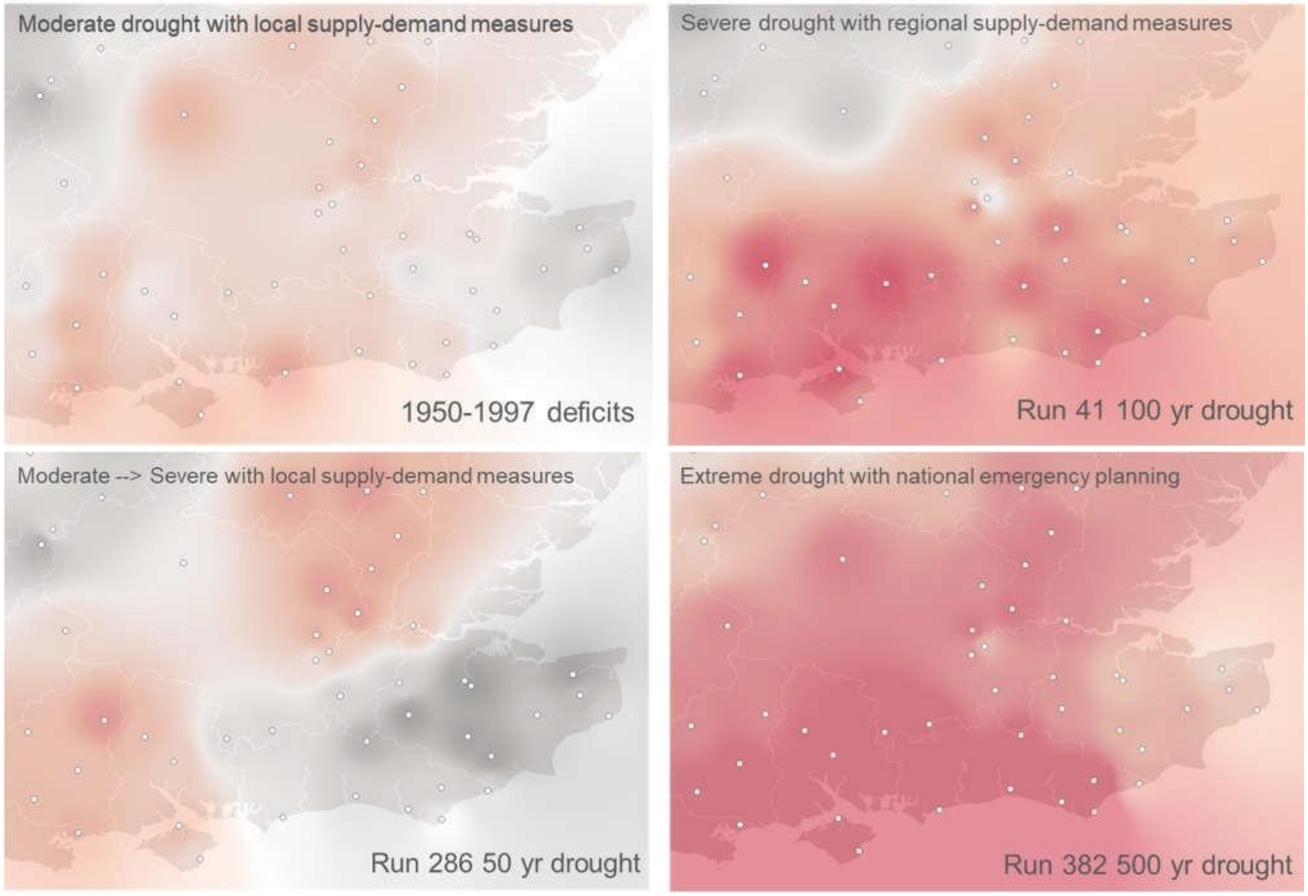
On stochastic analysis the Environment Agency favours a water resources systems assessment of drought, so that severe droughts (annual probabilities of 1%,0.5% and 0.2%) need to be defined in terms of system outputs. This means that the full 400 time series or a representative sub-sample need to be modelled.

On climate change the Environment Agency presents a comprehensive process-based approach, with updated modelling for zones at risk or where major investment is necessary. This modelling will include the application

[1] Based on the Mean Absolute Error of low rainfall in mm/month for three test regions and low rainfall metrics from 3 months to 36 months.

of the RCM factors provided by this project, but for the most detailed 'Tier 3' assessments, it is likely to require further scenarios to capture a larger range of climate change scenarios and stochastic analysis[2].

**Figure ES1 – Baseline minimum rainfall and selected drought scenarios based on low rainfall in the south west of WRSE region**

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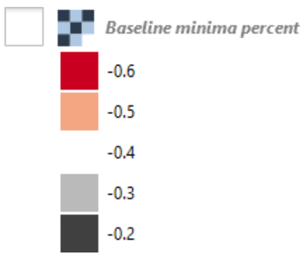
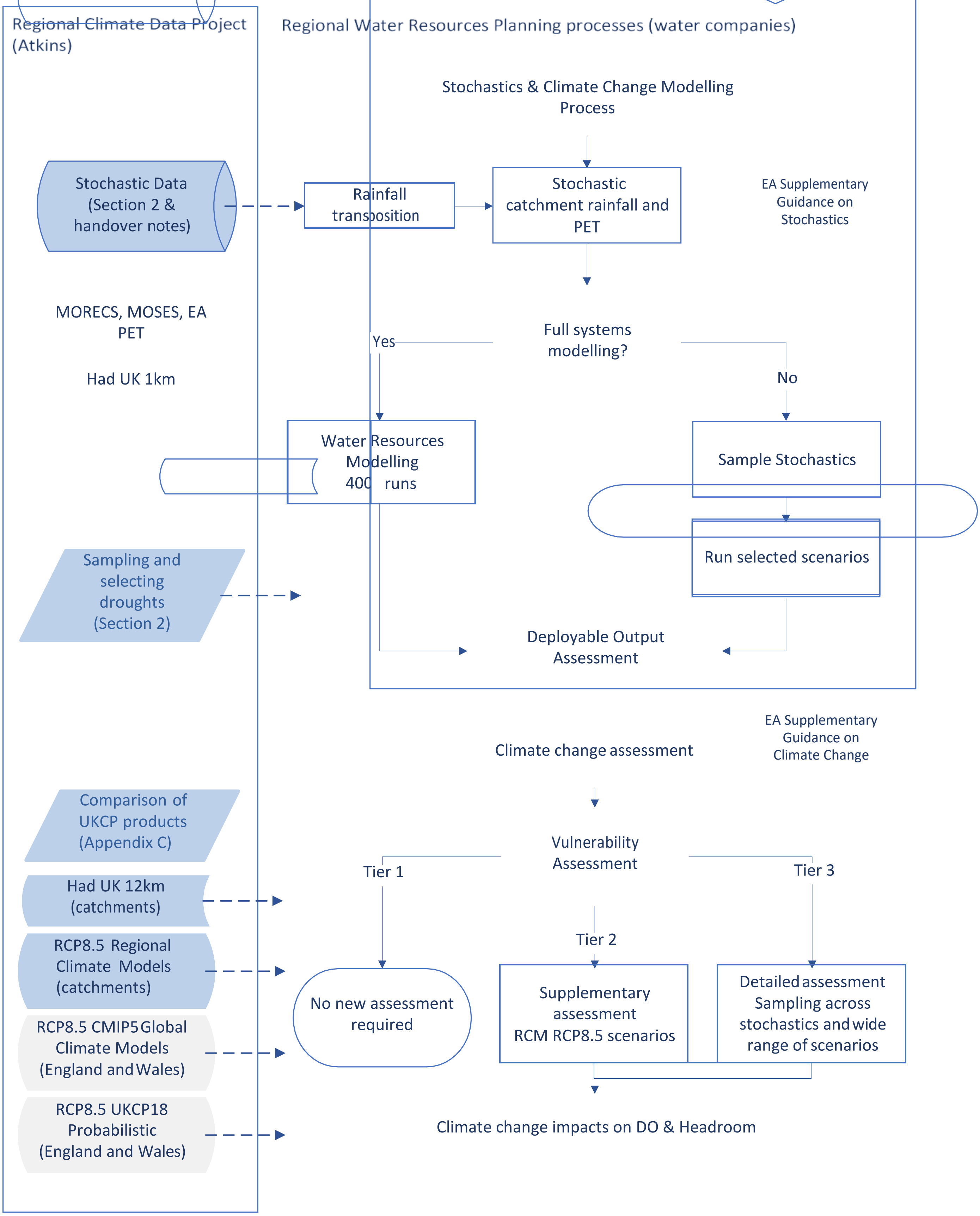



Scenarios selected based on ordering the "worst droughts" in 400 stochastic runs

The estimated annual probabilities are for low rainfall for hydrological years in the south west WRSE region, centred on Hampshire

[2] For this reason, we provide CMIP5 global model factors and UKCP18 probabilistic data for England and Wales.

**Figure ES2 - Regional Climate Data Project data and its relevance for Regional Water Resources Planning**



# 1. Introduction

Water companies in England and Wales have a statutory duty to deliver water resources management plans (WRMPs), which include assessment of baseline water availability and the impacts of climate change of future water supply and demand. The National Framework for Water Resources sets out how regional planning groups should work together to assess strategic regional options for water supply and demand management schemes[3]. The draft Environment Agency Water Resources Planning Guideline provides a framework for the development of plans, including supplementary guidance on climate change, the use of stochastic data and assessment drought risks.

This project developed new climate data sets to support regional water resources planning in England and Wales. The two main data sets are:

- Stochastic daily time series of precipitation and potential evapotranspiration for more than 200 locations in England and Wales
    - These data were based on an improved stochastic model using HadUK precipitation at sites with good quality data from the 1950s to the present
    - For the assessment of baseline water resources drought without climate change
- Bias corrected future climate change factors and daily time series based on HadUK precipitation and temperature and the UK Climate Projections 2018
    - For the assessment of future climate change impacts on supply and demand
    - Provides climate change factors for perturbation of the baseline stochastic data
    - Provides daily bias-corrected precipitation and temperature time series from 12 Regional Climate Models for the assessment of future trends

All data provided are spatially coherent across England and Wales and can be used for the analysis of regional and national drought. This report is the final project report and is structured as follows:

- Section 1 provides background information on data used for the project and its application to regional water resources planning
- Section 2 describes the development of the baseline stochastic data, focusing on changes in the way the model was implemented (between WRMP2019 and this project, which informs WRMP24) and how to make use of the results
- Section 3 summarises the bias corrected Regional Climate Models and other climate change products provided by the project
- Section 4 provides conclusions and recommendations for further development of these tools
- A set of appendices provides more detailed information to support Sections 1-4. Appendix C is the main part of climate change report, which was provided prior to our workshop in March 2020.

## 1.1 Baseline data sets

The stochastic modelling was based on HadUK 1km daily data for specific locations, which were selected because those grid cells contained high quality observations from 1950 to the present. HadUK12 km daily precipitation and temperature data sets were used for the bias correction of climate models and were also averaged for selected river basins to provide a baseline data set for the 1981-2000 period[4].

Compatible Potential Evapotranspiration (PET) data sets were provided based on data provided by the water companies, typically Met Office Rainfall and Evaporation Calculation Systems (MORECS) data[5] or other proprietary water company data sets. The Environment Agency's new 1km PET data (released July 2020) was incorporated into some regional data sets but was delivered too late for the Water Resources South East (WRSE) programme. Appendix A provides more information about the data sets used in the project.

[3] https://www.gov.uk/government/publications/meeting-our-future-water-needs-a-national-framework-for-water-resources

[4] Hollis, D, McCarthy, MP, Kendon, M, Legg, T, Simpson, I. 2019: HadUK‐Grid—A new UK dataset of gridded climate observations. Geosci Data J. 2019; 6: 151– 159. https://doi.org/10.1002/gdj3.78

[5] Hough, M. N. and Jones, R. J. A.: The United Kingdom Meteorological Office rainfall and evaporation calculation system: MORECS version 2.0-an overview, Hydrol. Earth Syst. Sci., 1, 227-239, doi:10.5194/hess-1-227-1997, 1997

## 1.2 Stochastic data sets

This project implements the stochastic multisite rainfall generators, originally developed by Serinaldi and Kilsby (2012) and developed further by Atkins on a series of projects to support Water Resources Management Plans in 2019 to provide daily rainfall and PET time series. The original model enabled the simulation of low and high rainfall scenarios more extreme than those observed as well as the reproduction of the distribution of the annual accumulated rainfall, and of the relationship between the rainfall and circulation indices such as North Atlantic Oscillation (NAO) and Sea Surface Temperature (SST) (Serinaldi and Kilsby, 2012). The model was developed under 3 projects during WRMP19 and has been developed further to include a larger number of climate indices and improved post-processing to provide drought sequences for all regions of England and Wales.

In this project's development stage, stochastics data were created for three regions (WRSE, United Utilities and Water Resource East) and in the delivery stage the final model was run for all five regions (West Country Water Resources Group, Water Resources North, Water Resources West, WRSE, WRE) and a total of 195 rainfall locations. This report uses the development data sets for selected hydrological case studies and the WRSE final delivery data set to show final results for the South East of England. The final delivery data sets for other regions form part of separate delivery contracts and are not described in detail in this report.

One of the innovations in the new data sets was to drive the stochastic model using a larger number of climate drivers, in addition to the North Atlantic Oscillation (NAO) index and Sea Surface Temperatures (SSTs). As these 'driver' data sets were only available from 1950 the new modelling provides a baseline from 1950-1997 (48 years). The data stop in 1997 to be consistent with data sets used for WRMP19 and to avoid including significant climate change in the baseline data. Environment Agency supplementary Water Resources Planning Guidelines stipulate that the baseline should stop by 2000, so as not to double count climate change in the stochastic data and future climate change scenarios.

The stochastic data delivered to water companies provides 400 model runs of replicates of the 1950-1997 climate. The data include 'wetter' and 'drier' time series that cover a wider range of possible conditions, including longer dry periods similar to those that occurred outside of the model calibration period, for example, at the end of the 19th century. Section 2 focuses on improvements to the stochastic methods developed as part of this project; further background research is included in Appendix B.1.

## 1.3 Selection of droughts

Regional groups will use the data sets in different ways, and many will run the full set of 400 time series through their hydrological and systems models to characterise water resources drought risk. Some companies may select time series or drought events based on rainfall or other hydrological characteristics, including severe droughts that are outside of the recent historical period (1950-1997).

To support rainfall drought analysis and selection of scenarios, we provide summary data for 16 rainfall metrics that were widely used in previous studies. These provide rainfall averages and minima for durations from 6 months to 36 months with different end dates to align with hydrological or calendar years. Example outputs for WRSE are shown in Section 2 and further information is provided in Appendix B.2.

## 1.4 Climate change scenarios

The climate change scenarios were derived from the UK Climate Projections 2018 (UKCP18), which provide a range of modelling products with the most emphasis on Representative Concentration Pathway 8.5 (RCP8.5), which is a higher emissions scenario. This scenario indicates warming of 1.4 to 4.1 °C in the 2070s above the 1981-2000 baseline for England and Wales[6] (therefore 2 to 5 °C above pre-industrial average temperatures). The main climate change products produced were:

(i) bias-corrected time series for 12 Regional Climate Models; and,

(ii) monthly change factors at the catchment scale for RCP8.5 and the 2070s (2061-2080).

It is anticipated that most users will apply the change factors to stochastic data in order to model a stochastic baseline and then add climate change.

In order to give a broader context, we also provide UKCP probabilistic data for several scenarios and CMIP5 Global Climate Models (GCMs) for England and Wales. The approach to climate change modelling was agreed at the first project workshop in March 2020. Further information on application of the climate scenarios is

[6] Based on 10th and 90th percentile of the UKCP probabilistic data for 2060-2079

provided in Section 3 and a full report on the pros and cons of different climate model data sets is included in Appendix C.

## 1.5 Regional Groups

There are five regional groups, which include water companies, Environment Agency, National Resources Wales and other representatives (including Natural England, energy and agriculture sectors). The water company representation in each regional group is summarised below:

- Water Resources North (WReN) – Northumbrian Water, Hartlepool (Anglian) Water, Yorkshire Water
- Water Resources West (WRW) – Severn Trent Water, United Utilities, South Staffordshire Water, Dŵr Cymru (Welsh Water)
- Water Resources East (WRE) – Anglian Water, Essex and Suffolk Water, Cambridge Water, Severn Trent Water, Affinity Water
- Water Resources South East (WRSE) – Affinity Water, Portsmouth Water, South East Water, Southern Water, SES Water, Thames Water[7]
- West Country Water Resources (WCWRG) – Bristol Water, Wessex Water, South West Water

Data sets are being provided for each group. The approach for combining these data sets is discussed in Section 4 and in the appendices.

## 1.6 Development of case studies

Each regional group proposed a case study as shown in Table 1-. These are "within" region studies that make use of regional stochastic data sets and catchment scale bias corrected Regional Climate Models as well as other standard UKCP18 products. Five case studies were completed; the WReN is ongoing.

**Table 1-1 - Selected case studies**

| Region | Case study | Technical focus | Modelling resources |
|---|---|---|---|
| Water Resources in the South East (WRSE) | Western Rother | Stochastics & climate change | Catchmod model<br>(Calibration period 1994-2009) |
| Water Resources East (WRE) | River Ouse | Stochastics<br>Hydrological impacts | Stanford Watershed Model with analysis completed by Water Resources East |
| Water Resources West (WRW) | River Dee | Stochastics<br>Hydrological impacts | Catchmod model of the Celyn sub-basin only |
| West Country Water Resources Group (WCWRG) | Wimbleball surface water and Ashton recharge | Climate change<br>Hydrological impacts | Application of water company models for Wimbleball Reservoir inflow and Ashton recharge model |
| Water Resources North (WReN) | Langsett Group of catchments | Climate change<br>Hydrological impacts | Catchmod model |

The WReN Model provided was a HYSIM model, which is being changed to Catchmod as HYSIM is not an appropriate model for batch processing with 1000s of scenarios.

[7] The report was produced under contract from Seswater on behalf of the WRSE group. The same modelling approach was provided to other regions and the only differences were related to the choice of PET data used.

# 2. Stochastic data sets

## 2.1 Introduction

The key features of the new stochastic model and the specific data set are summarised in Table 2-1.

**Table 2-1 - The differences between the WRMP19 stochastic data sets and the new Regional Planning stochastic data sets, using the example of the WRSE data set**

| Model component | WRMP 19 data sets | Regional Climate Data Project[8] | Rationale |
|---|---|---|---|
| Baseline precipitation data | Water company provided catchment average daily time series or time series from selected rainfall stations | 195 HadUK 1km grid cells located over 'high quality' meteorological stations<br>The same data source was used for all regions | Preference to use a single operational product for rainfall<br>Focus on "grid cells" with quality data rather than interpolated data<br>Flexibility to translate points to basins or demand areas as required |
| Number of precipitation series | 40-65 sites per region<br>Each region has a bespoke model | 195 in total<br>50-80 sites per region (includes overlapping sites) | Each site is a 1km grid cell from the HadUK data set<br>Improved coverage of key basins |
| Number of PET data sets | 20-65 locations per region<br>(river basin, MORECs or MOSES data) | Up to 200 basin daily PET data sets per region<br>(River basin, MORECs, MOSES and new EA PET data). | Focused on use of PET data sets used in current hydrological and groundwater models |
| Climate drivers used | NAO, SST<br>(and EAI for WRE) | NAO, SST, Kaplan SST, COBE SST, AMO, EAI< EA, EAWR, SCA and interactions between indicators<br>(See Appendix B) | Marginally better fit and explanation of low rainfall in regions with weaker NAO influence (e.g. South East).<br>Same model in all regions to support national scale work. |
| Model fitted to | 1920-1997 | 1950-1997 | High quality climate driver data available from 1950 only |
| Model validated against | 1920-1997 | 1920-1997<br>1902-1949 (independent checks) | Demonstrates that contemporary stochastic model can fit early 20th century droughts |
| Number of replicate time series | 200 | 400 (sub-sampled from 1000) | An increase in the number of replicates improves the fit to dry years |
| Length of replicate time series (and total years) | 88<br>(17,600 years) | 48<br>(19,200 years) | Broadly equivalent number of years |
| Bias correction | Simple scaling of driest 10% to match observed data | Less bias correction using a more sophisticated approach | Responds to previous peer review criticisms<br>Avoids implausible droughts |
| Implementation of results | Drought library, selected events | Point to catchment transposition required. | Flexibility in application to different catchment models<br>Meets EA supplementary guidance requirements |

[8] The new stochastic model reduces Mean Absolute Errors of fitting extreme droughts by 25% across WRSE, WRE and UU regions and provides a large coherent rainfall and PET data set for regional water resources planning. It also reduces the need for bias correction.

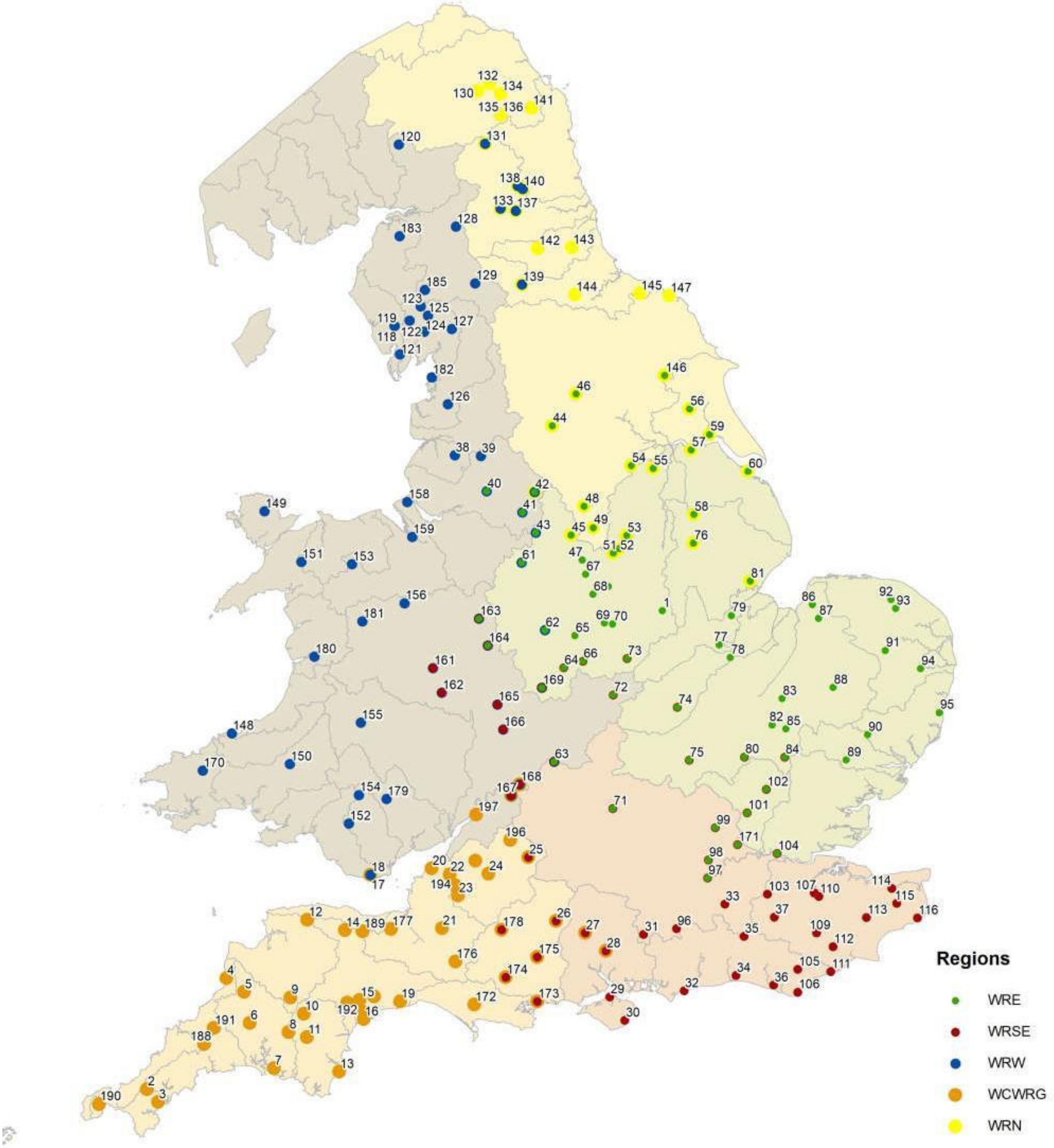



**Figure 2-1 – Location of standard hydrometric areas and selected rainfall locations across England and Wales (illustrating overlapping sites that have modelled in more than one region)**

## 2.2 Selection of rainfall locations

Rainfall locations (1km cells) were selected according to the following criteria:

- Sites with good quality data from 1950 to the present, to match the availability of the improved 'climate drivers' data set (Section 2.3), based on Met Office and CEH GEAR rainfall meta-data[9]
- An improved spatial coverage in England and Wales, particularly in locations with important regional water supplies
- Water company preferences to add further sites to provides improved spatial coverage and sites at higher elevations

A total of 195 sites were selected and assigned to one or more regional groups. The assignment to groups ensured that there was good overlap between regions so that the data could be brought together for national assessments as required. Stochastic time series were generated for selected locations rather than for river basins for several reasons.

- The original methodology was designed for point data, and this scale highlights the high variability of rainfall which is lower when averaging over large catchment areas
- It provides some flexibility to transpose these data to different spatial areas, whether these are catchments or water distribution zones for demand modelling
- Two out of three previous assessments used point locations, so this approach provides a clearer audit trail from the WRMP19 work to the present study
- Hydrological modelling strategies were developed in parallel to this study, so the full set of catchment boundaries were not available for all regions at the start of this study

## 2.2.1. Comparison of HadUK data and CEH GEAR data

In the previous WRMP19 stochastic weather generators used CEH GEAR rainfall data but this has now been replaced with Met Office HadUK gridded rainfall. We undertook a comparison of these data as inputs for the stochastic weather generator and the results were presented to the Technical Steering Group at the project workshop in March which confirmed the decision to use HadUK data (Figure 2-2). The two data sets are very similar but individual days may be different due to the different quality assurance procedures applied to each data set. Going forward the HadUK data is the operational data set that will be used by water companies in England and Wales, which is endorsed by the Environment Agency

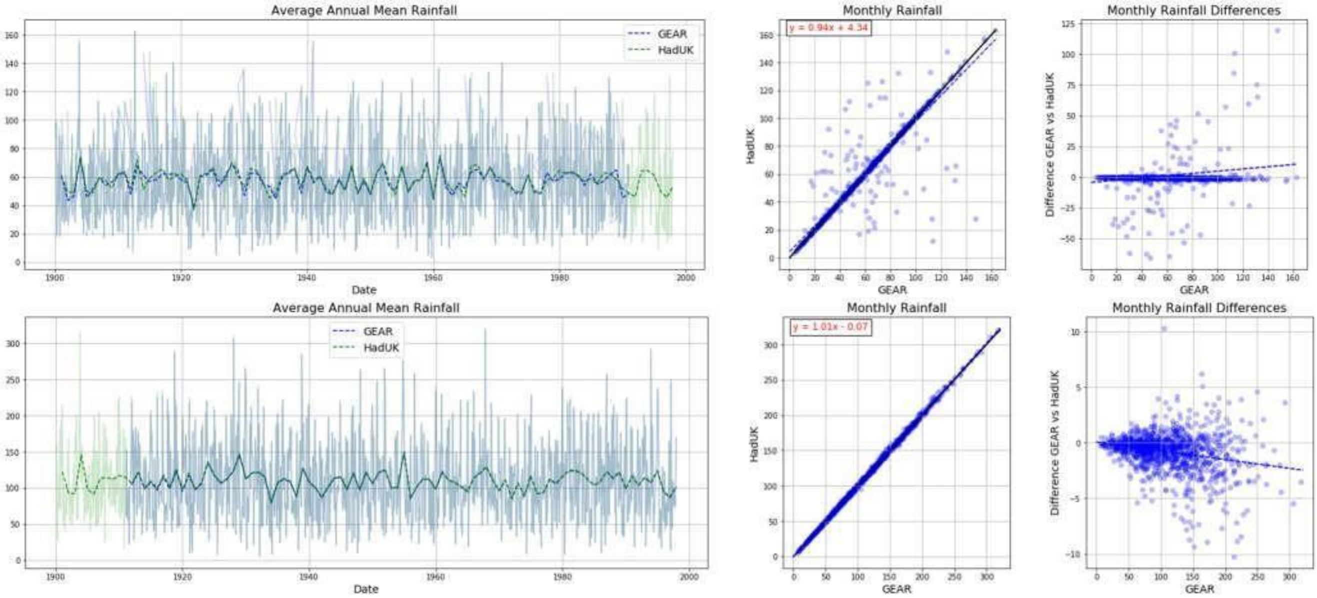



**Figure 2-2 - Comparison of GEAR and HadUK observed monthly rainfall data. Averaged across the WRE region (top) and United Utilities (bottom).**

[9] The rainfall "sites" were selected by processing CEH GEAR rainfall metadata and comparing this information with HadUK metadata to identify locations with meteorological stations and good quality rainfall records between 1950 and the present (i.e. a low percentage of missing data and long periods of continuous time series)

### 2.2.2 Transposing from site locations to river basins

In many cases, the selected rainfall locations will be those used for hydrological modelling. As these data are drawn from the HadUK 1km data set, they will also be broadly consistent with HadUK12km catchment average precipitation used for the climate change modelling (Section 3).

Hydrologists utilise a range of methods for transposing from points to basins. In previous studies stochastic data sites have been linked to sites used for catchment modelling using a 1:1 scaling relationship (WRE for WRMP19) or based on multiple linear regression (UU for WRMP19).

In developing the case studies we have used Thiessen polygons and a scaling factor to convert stochastic series to catchment series for "target" river catchments, as follows:

$$= \frac{}{} \left( 1. \quad + \; 2. \quad + \quad . \; \right)$$

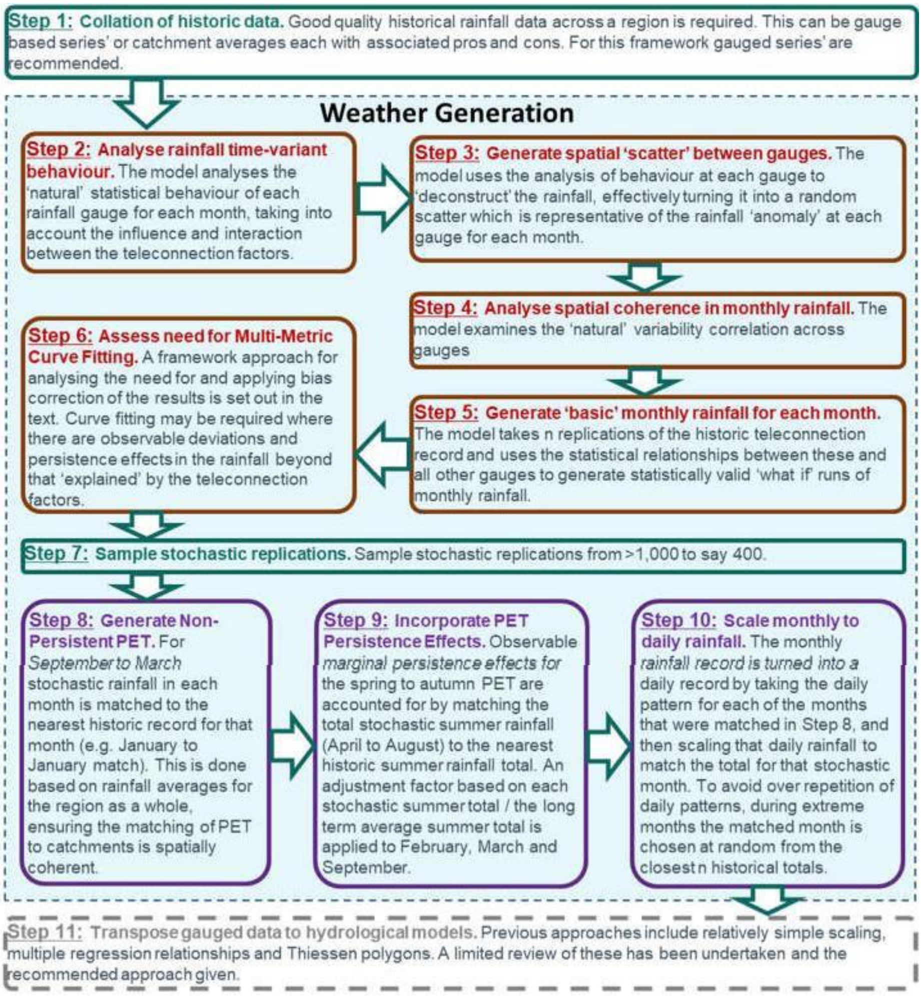
Where R is the rainfall on any day for "target" catchments or stochastic sites 1 to *n*, AAR is the Average Annual Rainfall for the target basin (*AARt*) or weighted average of stochastics (*AARs*), *w*1…*n* are Thiessen weights. Therefore, catchment rainfall is estimated based on the weighted average from stochastic sites and scaled by Average Annual Rainfall (AAR). This approach may need refining in areas of complex relief or variable seasonality and in such cases monthly weights may be required

## 2.3 Further development of stochastic methods

The stochastic weather generator outlined in this framework uses the observed relationships between climate data and regional climatic drivers to produce replicates of the historical climate. The model works by analysing and modelling the underlying rainfall behaviour in relation to climatic drivers as well as 'random chance'.

The basic concept behind this approach is that the historic record provides only one set of actual weather conditions (i.e. the one that did occur) out of the possible range of conditions that might have occurred given the climatic drivers. The implicit assumption behind this approach is that the historical record included in the model is reasonably 'typical' in terms of its overall statistical behaviour.

Figure 2-3 outlines the key steps involved in generating stochastic precipitation and PET data, outlined in further detail in the following sections.




Notes: "Gauge based series" refers to point observations or grid cells, which include one or more meteorological stations. We use the HadUK 1km data as the basis for this work. In Step 5 the models are fit to a large number of sites, which is distinctly different to generators focused on single sites or a small number of sites. For more details see Appendix B.

**Figure 2-3 - Overview of stochastic weather generator**

### 2.3.1 Summary of updates for this framework

The approach applied for this framework is similar in its core to the stochastic weather generators previously applied as part of WRMP19 for several water companies and regional groups. However, some key testing and improvements have been carried out at various stages of the modelling process to improve the results as much as possible. These are summarised below and compared in more detail to the previous approach in the following sections:

- **Inclusion of additional teleconnection factors**[10], the model previously used NAO and SST as the climatic drivers (WRE also included an East Atlantic Index). For this framework we have analysed the inclusion of several additional factors.
- **Inclusion of seasonal and interaction terms between the factors to explain rainfall.** Previous iterations of the model considered month, SST and NAO as independent 'main effects' parameters. For this work we have allowed the inclusion of interactions between these, notably to allow for monthly variations but also to enable interactions between the teleconnections.
- **Multi-metric curve fitting approach.** This was a post-processing step to improve the final model fit; it was arguably a contentious component of the previous approach. As part of this framework we have retained the ability to bias correct but amended the method to limit the adjustment and ground the approach in probabilistic methods.

[10] A teleconnection is a causal connection or correlation between meteorological or other environmental phenomena which occur a long distance apart.

- **Adjustment to the daily resampling approach.** The previously applied approach matched each stochastic rainfall month to the closest historical month. This can lead to over-representation of a daily pattern during extreme events where the stochastic total gets repeatedly matched to the lowest historical total and therefore the same daily pattern is selected. To account for this, a small amendment has been incorporated to match to one of a random selection of the ‘n’ closest historical months. This reduces the chance that one daily pattern is seen repeatedly.

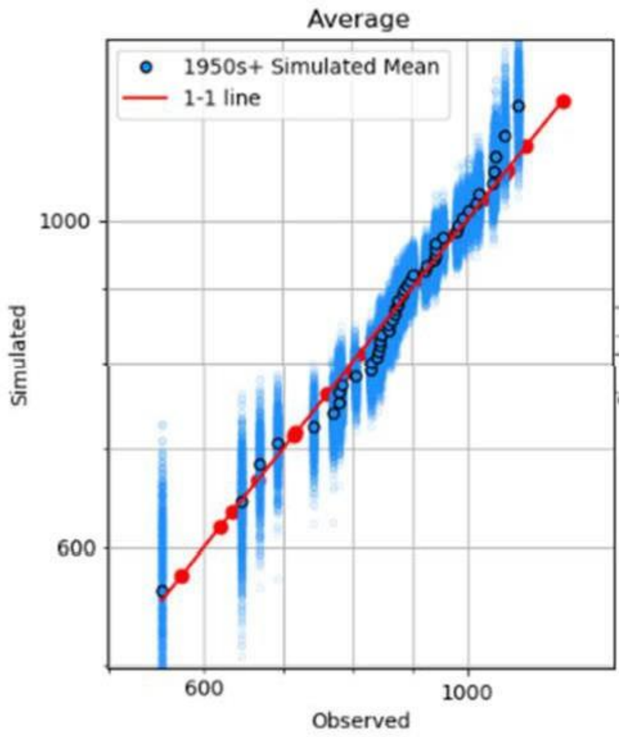
### 2.3.2 Validation of outputs

At each stage of the weather generation process the outputs are validated using a range of visualisations and rainfall total metrics. The standard rainfall metrics include:

- Longer than annual total rainfall:
  - 18 months ending September
  - 24 months ending September and December
  - 30 months ending September
  - 36 months ending September and December
- Annual total rainfall:
  - 12 months ending September and December
- Winter – Summer total rainfall:
  - December – August
  - January – August
- Summer total rainfall:
  - April – September
  - April – August
  - June – August
  - July – September
- Autumn total rainfall:
  - August – October
  - September – November
- Winter total rainfall:
  - October – March
  - November - February

Checking these rainfall metrics ensures the time coherence of the generated data is retained through the process. To ensure the spatial coherence of the outputs, the data are examined at varying spatial scales including regional average, sub-regional average and site data. For each rainfall metric and spatial scale, ranked rainfall ‘Q-Q type’ plots[11] and cumulative percentile plots are produced as shown in Figure 2-4 and Figure 2-4.

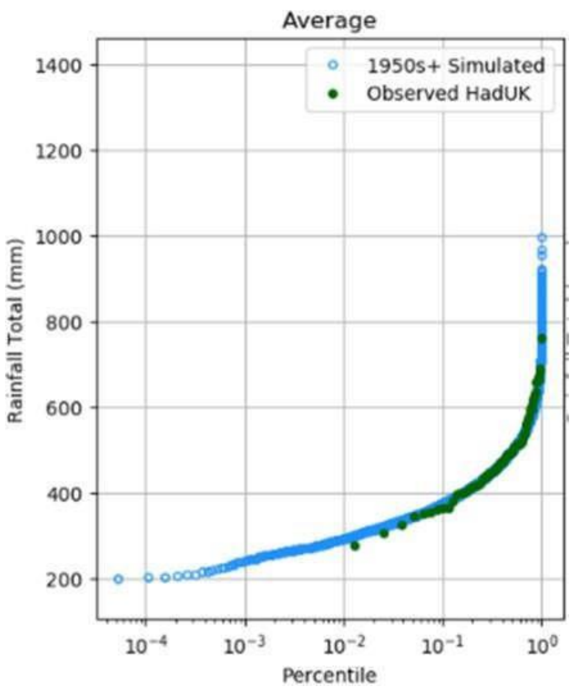
[11] Strictly speaking Q-Q plots would show the probabilities of the data but we show the ranked precipitation values for easier interpretation




*These curves show the Q-Q plots of the observed versus simulated total rainfall (mm) (i.e. ranked years from driest to wettest for each simulation compared with the historic record). The black circles represent the mean of the simulation and the individual simulations form the blue 'scatter'. The red line represents the 1-1 mapping between the simulated and observed values – i.e. if the black circles plot on the red line, then the average of the simulations is the same as the historic ranked value (i.e. the historic value falls close to the 'expected' ranked value based on the stochastic).*

*For additional context, the bold red dots on the 1-1 line indicate observed values that have not contributed to the simulated data (i.e. occurred before 1950).*

**Figure 2-4 - Example 'Q-Q' ranked rainfall plot**




*These curves show the cumulative percentile plots of the stochastic and observed rainfall. The blue dots show all the simulated data sorted from driest to wettest. The green dots show the sorted observed data from driest to wettest.*

*The observed data may contain more points than used to generate the stochastics. For example, in the plot the observed record includes data prior to 1950.*

**Figure 2-5 - Example percentile plot 2.4 Weather Generation Methodology**

### 2.3.3 Monthly rainfall generator

The core monthly rainfall generator is implemented in R and is an adaptation of the principles originally proposed by Serinaldi and Kilsby (2012) and later applied for several water companies and regional groups as part of WRMP19.

The R module initially uses the GAMLSS package in R[12] to fit generalised linear models (GLMs) to de-seasonalised rainfall probability distributions for each calendar month at each rainfall site. Each GLM contains two components, describing the mean and standard deviation for each rainfall site based on the month, explanatory factors and observed 'natural variability'.

## Previous Approach

The previously applied stochastic weather generator approaches used Month, Sea Surface Temperature (SST) and North Atlantic Oscillation (NAO) as explanatory factors for the mean and standard deviation. In other words:

$$\mu \ = f \ \ (Mo \ \ h) + f \ \ \ (SST) + f \ \ \ (N \, O) + E$$
$$= f \ \ \ (Mo \ \ h) + f \ \ \ (SST) + f \ \ \ (N \ \ O)$$

Where:

- $\mu =$ the mean of the rainfall for site a
- $=$ the variance (standard deviation squared) for site a
- $f(Mo \ h) =$ the function of the month, which is a categorical factor so acts as a separate month intercept at each site
- $f(SST) =$ function of the observed sea surface temperature anomaly
- $f(N \, O) =$ function of the North Atlantic Oscillation index anomaly
- $E =$ the amount of 'error' (random variability) at site a

## Updated Approach

We have incorporated several updates to the R module as part of this framework. These include:

- Consideration of the interaction between the explanatory variables in the equation describing mean rainfall at each site;
- Inclusion of additional explanatory factors;
- The inclusion of a cubic spline time dependent term.

Interaction terms between the explanatory variables allow the model to identify more complex patterns and relationships between the climatic drivers. At a simple level, the interaction between Month and SST (signified with a colon as, $f\,(Mo\ h{:}\ SST)$) allows the model to identify a varying degree of influence between sea surface temperature and rainfall across the year.

In general, when fitting a model, a balance is sought between including the factors and relationships that provide the best explanation of the observed data and constructing a model with the fewest unnecessary terms (termed *the Principle of Parsimony*). However, in this case where the model is fitted to multiple rainfall series individually it was felt more importance should be given to maintaining the consistency of the model formula between sites and in fact between each of the regional groups. Therefore, when analysing the inclusion of additional terms, we have erred on the side of retaining any factors or interactions even if only found to have a significant impact on rainfall at a limited number of locations.

Additional teleconnection factors analysed for this framework include:

- Alternative sources of SST anomaly, notably Kaplan SST V2 and COBE-SST2 in addition to the HadSST2 previously used;
- Atlantic Multi-decadal Oscillation (AMO);
- East Atlantic Index (EAI), previously used by the Met Office in the WRE stochastic weather generation;
- East Atlantic (EA);
- East Atlantic West Russia (EAWR);
- Scandinavia (SCA).

Detailed comparison of the source of these factors and relationship with rainfall across the country were carried out prior to inclusion in the weather generator. Further detail is given in Appendix B.

Prior to 1950 the availability and quality of teleconnection data is significantly reduced, and most of the additional factors listed above are not available before this time. Therefore, further analysis was carried out to compare the model fit and outputs as a result of generating data using the full 20th Century historical record but

[12] 'Generalised Additive Models for Location, Scale and Shape', https://www.gamlss.com/

with a more limited teleconnection dataset compared to a fuller set of teleconnection explanatory factors with data from 1950s onwards. The details of this comparison are summarised in Appendix B. The analysis concluded that while the 1950s model does not include some of the key droughts in the 20th Century, in most cases this model performed as good as, or marginally better, when viewed against the observed data in the 20th Century[13].

Finally, a time dependent cubic spline term has been included in the mean rainfall formula. This is a pragmatic approach that recognises that the model is not capable of fully capturing all the physical processes influencing weather. Therefore, the cubic spline term identifies and accounts for the remaining *structured change* in the residuals after fitting to the teleconnection variables.

Following these updates, the final GAMLSS model for each rainfall series is defined by:

$$\begin{aligned} \mu = {} & f(Mo\ h) + f(N\ O) + f(SST) + f(\ MO) + f(E\ ) + f(E\ W\ ) + f(S\ ) + f(Mo\ h{:}\ N\ O) \\ & + f(Mo\ h{:}\ SST) + f(Mo\ h{:}\ MO) + f(Mo\ h{:}\ E\ ) + f(Mo\ h{:}\ E\ W\ ) + f(Mo\ h{:}\ S\ ) \\ & + f(N\ O{:}\ SST) + f(N\ O{:}\ MO) + f(N\ O{:}\ E\ ) + f(N\ O{:}\ E\ W\ ) + f(N\ O{:}\ S\ ) \\ & + f(SST{:}\ MO) + f(SST{:}\ E\ ) + f(SST{:}\ E\ W\ ) + f(SST{:}\ S\ ) + f(\ MO{:}\ E\ ) \\ & + f(\ MO{:}\ E\ W\ ) + f(\ MO{:}\ S\ ) + f(E\ {:}\ E\ W\ ) + c\ (\ ime, df = 5) + E \end{aligned}$$

$$= f(Mo\ h) + f(N\ O) + f(SST) + f(\ MO) + f(E\ ) + f(E\ W\ ) + f(S\ )$$

Where:

- $\mu =$ the mean of the rainfall for site a
- $=$ the variance (standard deviation squared) for site a
- $f(fac\ or) =$ the function of the main effects for each  factor
- $f(fac\ or1{:}\ fac\ or2) =$ the function of the interaction between factor 1 and factor 2
- $c\ (\ ime, df = 5) =$ the cubic spline time dependent term to account for residual structure change in the data
- $E =$ the amount of ‘error’ (random variability) at site a

### 2.3.4 Curve fitting

In the previous weather generator, a multi-metric curve fitting approach was applied to the monthly stochastic rainfall outputs. This identified observed anomalies with a deviation of the statistical behaviour of the historic climate from the predictions of the model. The rationale behind applying such a correction is that the observed deviations represent all the other potential climatic influences not represented in the model. This can, in part, be backed up by research suggesting the influence of blocking behaviours not closely linked to NAO or SST that impacts regions of the country, most notably in the South and East.

A curve-fitting adjustment essentially moves the stochastic predictions so that the observed record falls closer to the ‘expected’ distribution of generated data. However, the implicit assumption of such an approach is that the anomalies demonstrated by the more severe droughts (i.e. greater than a 1 in 20-year return period) are ‘typical’ for the climate in that region. Statistically speaking there is no reason why the events that occurred in the 20th Century should be statistically ‘typical’ and it could be argued that without sufficient evidence there is no basis for bias correction.

This highlights the trade-off between a fully theoretical model and a model that needs to be used for practical application. While it could be argued that there is limited evidence to justify correcting the outputs, from a very practical sense it is important that the generated outputs adequately represent and extend the range of droughts observed in the historical record for water resources modelling and testing purposes.

Additionally, while the model had been updated to include more teleconnection factors it is still primarily a pragmatic approach using the best tools and data available at this time. It is recognised that other influences will also be affecting weather across the country, and therefore, making small post-process adjustments to improve the model fit is a practical approach. It is worthwhile noting that the adjustments made are very small compared to the bias in climate modelling that underpins UKCP18 (Appendix C).

In line with this assessment, we have retained the bias correction step with some key improvements to the method. The new approach makes use of our previous understanding and experience from applying the method during WRMP19 while aiming to reduce the amount of adjustment needed/applied and to provide a

[13] A key element of the approach is to validate the generated data against observed rainfall from the full 20th Century record rather than just 1950 onwards.

stronger framework around which to select adjustments. The following two sub-sections compare the multi-metric curve fitting approach previously applied and the updated approach developed as part of this framework.

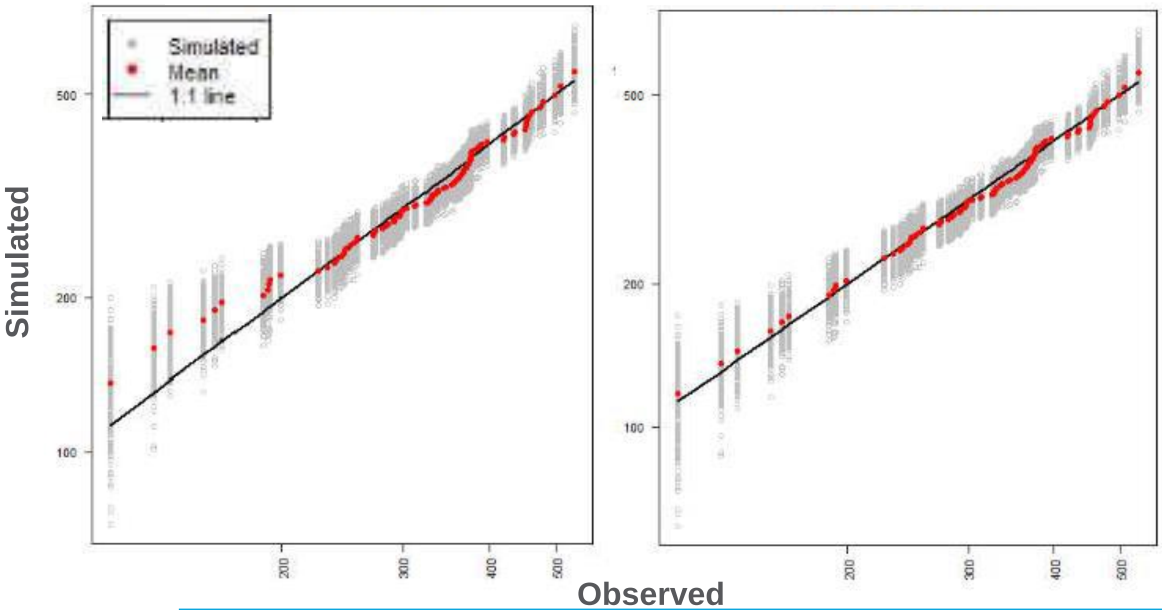
### Previous approach

The previous multi-metric curve fitting approach identified persistent deviations between the stochastic and historic data using a series of rainfall total metrics. This approach relied on an element of ‘skill’ in its application so that each adjustment was carried out in the right order to prevent interference with the spatial and temporal coherence of the model.

The approach was primarily a manual process which involved analysing outputs at multiple metrics and scales after each adjustment. However, following extensive application and testing, two key guidelines around implementing this approach were identified:

- Carrying out adjustments based on a sub-regional average rather than each individual rainfall site helped to maintain spatial coherence across the region;
- Adjusting longer term metric totals before moving on to the shorter duration events reduces the likelihood of causing unacceptable deviation across other metrics.

Figure 2-6 illustrates the previous application of the curve fitting process for one metric across one sub-regional average.




*The figure on the left shows the raw output from the monthly rainfall generator with the adjusted output on the right. The adjustment takes the bottom 15% of ranked data (in this case the lowest 13 points) and calculates the difference between the mean stochastic total (i.e. the red dot) and the historical value (i.e. the black line) to move the stochastic data 90% of the way towards the historical value.*

**Figure 2-6 - Example of multi-metric curve fitting adjustment**

## Updated approach

As part of this project a number of improvements have been made to the previous multi-metric curve fitting approach. The updated approach aims to:

- Minimise the amount of adjustment applied;
- Apply a structured probabilistic statement to define any adjustment carried out;
- Provide a framework for suggesting the metrics against which to adjust (as far as this is possible).

In the updated probabilistic curve fitting approach at least 1,000 replications are initially generated from the monthly generator. This means that when viewed in terms of the Q-Q plots there are enough simulated points at each ranked observed total (i.e. each vertical spread of data) to treat the stochastic simulations as a distribution and construct a probability statement around the chance that the observed value falls within the X% prediction interval specified by the stochastic data.

In this way an observed value is considered to deviate from the predicted stochastic data if it falls outside the X% prediction interval, i.e. the stochastic data suggests there is a less than (100-X)% chance of this being observed naturally. If this is the case, then the adjustment module calculates the adjustment needed to apply to the stochastic data so that the observed value falls just within the defined prediction interval.

Figure 2-7 illustrates the application of this approach for one metric using a 50% prediction interval (i.e. observed values outside the prediction interval occur with less than 50% chance).

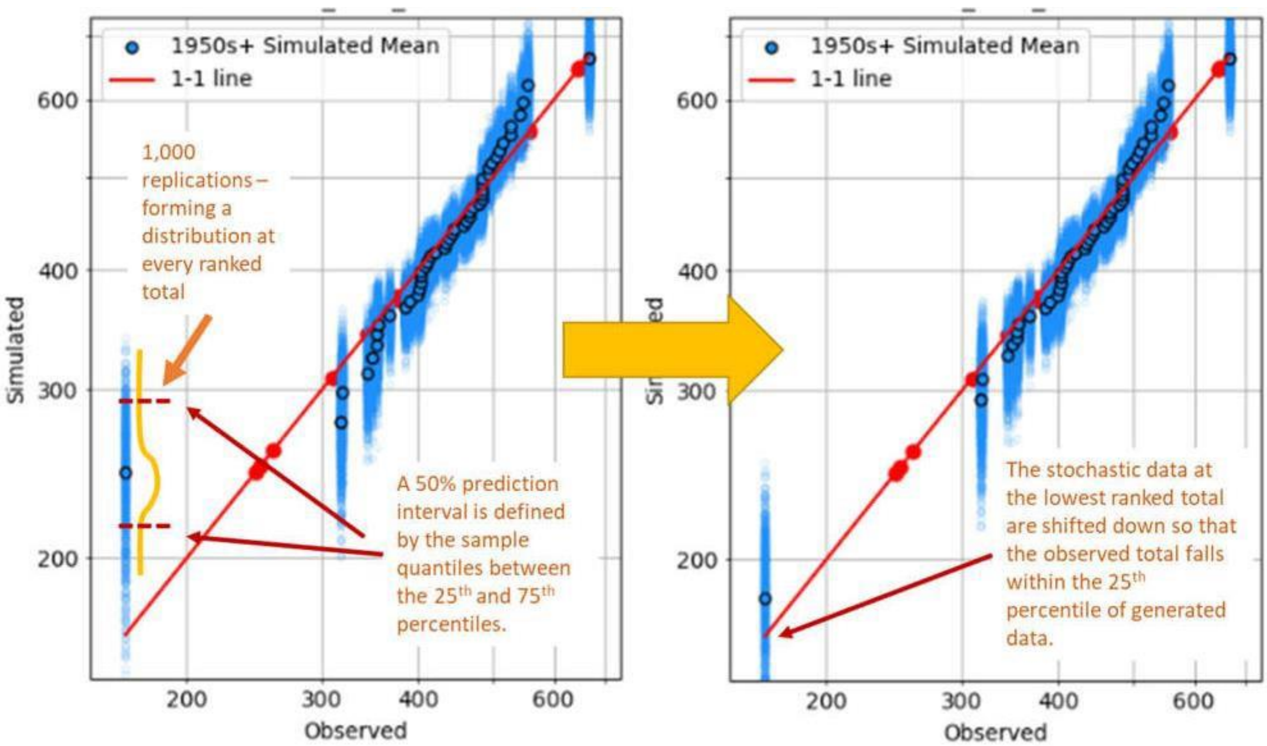



**Figure 2-7 - Example of probabilistic curve fitting approach**

Following initial testing, a 50% interval was felt to represent the fairest balance between minimising unnecessary adjustment while still achieving a noticeable improvement.

The key improvements to the previous approach are:

- Adjustments are applied on a ranked point by point basis rather than across the bottom X% of data;
- The stochastic simulations are adjusted so that the observed value meets the prediction interval rather than approaching the mean.

## Framework for selecting adjustments

As part of this project we have developed a set of guidelines for, when necessary, selecting and applying the curve-fitting. These make use of several factors including our understanding and experience from applying the previous multi-metric curve fitting, greater automation in the coded modules and crucially the proposed approach considers the simulated data within the context of the longer historical record[14].

The process defined below can be implemented with varying degrees of automation and control however it is important to note that even at the most automated a certain level of 'skill' and regional knowledge is still required to present appropriate periods and metrics. To remove all levels of automation the model could be run by completely specifying the metrics to adjust.

Step 1: Define a series of 'periods' to test

Periods define the broad durations within which to examine specific rainfall metric totals. Using our previous experience these are recommended to start with longer term durations and reduce in length.

Step 2: Define specific metrics within each period

Each defined period may contain more than one specific rainfall total metric against which to analyse any deviation. For example, a typical series of periods and metrics might include:

- **Longer than annual periods**, containing the 24-month rainfall total ending September and 18-month rainfall total ending September;
- **Annual periods**, containing 12 months rainfall total ending September (the hydrological year) and 12 months ending December (calendar year);
- **Winter – Summer periods**, containing 9 months rainfall total ending August and 8 month ending August
- **Summer periods,** containing rainfall total metrics covering April – August, March – September etc.
- **Winter periods,** containing rainfall total metrics covering November – February, October – March.

Step 3: Run automated bias correction process to identify metrics displaying significant deviation

Starting with the first period, each of the metrics defined within this period are analysed and, at most, one metric selected for curve fitting based on analysis of persistent deviation across all the sub-regions between the simulated and observed data for each of the metrics. If none of the defined metrics within a period are considered to display significant deviation, then this period is skipped, and no bias corrections carried out. The module identifies significant deviation between the simulated and observed data by comparing the equivalent percentile totals for each dataset and for each metric. This allows the simulated data at each metric to be considered within the context of the longer observed record (i.e. pre 1950).

Step 4: Apply probabilistic curve fitting

Probabilistic curve fitting is applied across the selected metric within the period to bring observed values within the 50% prediction interval of the simulated data.

Step 5: Analyse any remaining deviation in the results against the next defined 'period' and metrics

Repeat the process for shorter duration drought periods.

### Worked example

After generating the raw stochastic monthly rainfall data for a region, we produce the Q-Q and percentile plots of the data across the range of rainfall total metrics.

Step 1 above, sets out how to define the series of 'periods' to analyse for deviation. We will take these as:

- Longer than annual
- Annual
- Winter – Summer
- Summer
- Winter

In order to define which metrics to place within each period (Step 2 above), we look at the output plots and select metrics where there appears to be significant deviation. For example, within the 'longer than annual' period we look at the 36, 30, 24 and 18-month rainfall totals ending September and December. Little deviation is observed at the 36 and 30-month durations (see Figure 2-8) and so we do not include these within the period. Similarly, while some deviation can be seen in the 24 months ending December metric this deviation in

[14] This is particularly relevant now that the model is generated using observed data from 1950 onwards rather than earlier in the 20th Century.

part covers the range of events in the historic record prior to 1950 and would be counterproductive to correct against (see Figure 2-9).

The 24-month ending September and 18 month ending September metrics potentially show some deviation and so are included within this period.

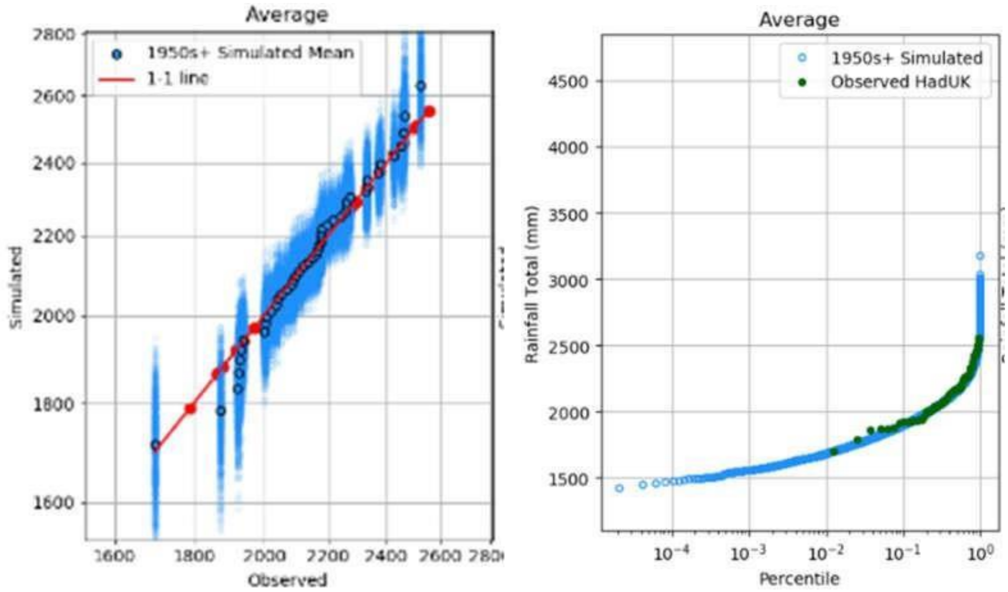



**Figure 2-8 - Simulated vs observed data across 30 months ending September for Q-Q plot (left) and percentile plot (right). The bold red dots on the Q-Q plot show where observed data points prior to 1950.**

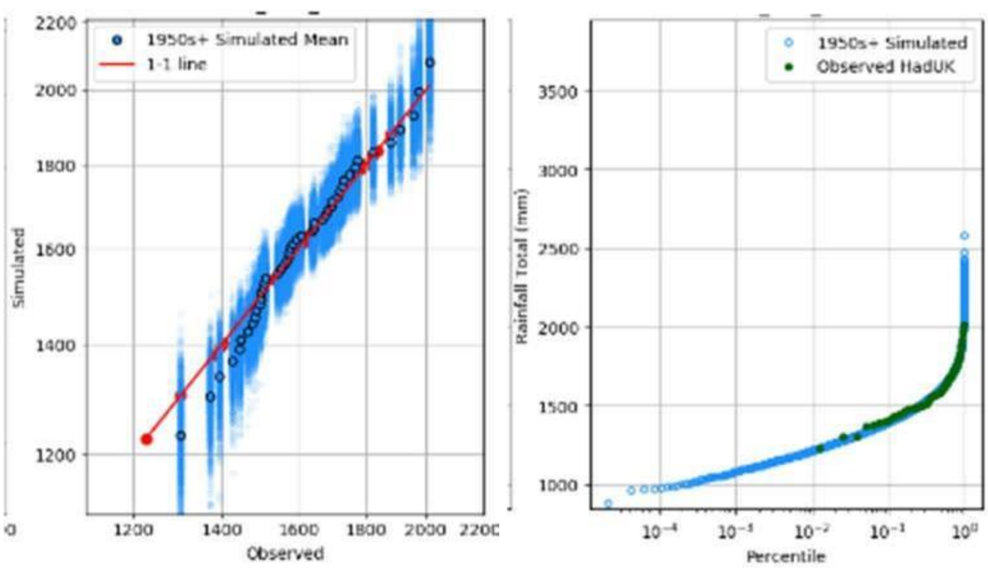



**Figure 2-9 - Simulated vs observed data across 24 months ending December for Q-Q plot (left) and percentile plot (right). While the lowest ranked simulated data deviate from the observed the range covered by the simulated data can be taken to account for the lowest observed point in the record which is prior to 1950 (i.e. the bold red point). This can be seen in the percentile plot on the right where the stochastic and observed appear to show a good fit.**

This process is continued across each of the periods to define the metrics to consider. It may be that only one potential metric within a period shows any deviation and, in this case, just one metric would be included. Or, alternatively, the period could be removed entirely from the bias correction process if no metrics are considered to show deviation.

Once steps 1 and 2 are completed the automated bias correction process can be run to numerically calculate the extent of any deviation at each of the lower percentiles and apply adjustments to selected metrics. This provides two levels of check against the need for curve-fitting. For instance, in the example above, although the 24 months ending September and 18 months ending September are included within the 'longer than annual' period the automated curve-fitting module does not find significant deviation against the percentiles for these metrics and so this period is not adjusted.

### 2.3.5 Sampling

The probabilistic curve fitting approach outlined above requires at least 1,000 replications to be generated in order to produce adequate distributions at each ranked level. This is equivalent to approximately 48,000 stochastic years and although it would be possible to generate daily sequences for this full series this would significantly increase the memory and processing time required for the resampling stage. Additionally, many regional groups and companies will already be looking to sample from the stochastic datasets to reduce the burden on their water resources models.

A sampling sub-module has therefore been developed to randomly sample replications from the 1,000 samples to 400[15] which is equivalent to just under 20,000 years and is approximately equal to the length of datasets that most companies and regional groups have worked with for previous stochastic datasets. As each replication is equally as likely to have occurred as another a simple random sample is enough to ensure that the final stochastic dataset is representative of the original sample. Moreover, this can be checked by comparing the output plots before and after sampling to ensure that the sampling has not biased the results at any metric as shown in Figure 2-10.

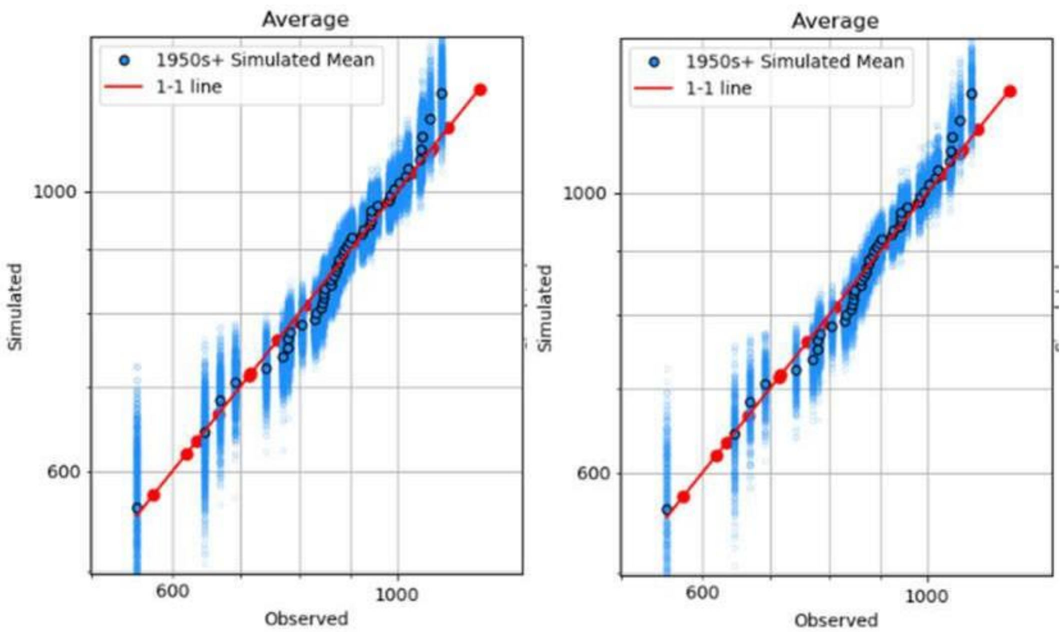



**Figure 2-10 - Example Q-Q plots before sampling (left, 1000 runs) and after sampling (right, 400 runs). This confirms that the sampling process has not biased the stochastic distributions.**

### 2.3.6 Generate daily sequences

The method to produce stochastic PET and daily rainfall sequences essentially follows the same approach as undertaken for the previous stochastic weather generator with a minor update in Figure 2-11, which describes the resampling approach. PET and daily rainfall sequences are generated from the observed record on a 'nearest neighbour' basis. This means that the regional average rainfall for each stochastic month is compared against the observed record for that month and matched to the closest historic month. PET is taken as absolute from the matched month while the daily rainfall sequences are scaled to total the stochastic month total (in effect, a multiplier to wet days rather than changing the number of wet days per month).

As shown in the flow chart a couple of additions have been made to this process. Firstly, summer PET is matched based on the 'nearest neighbour' summer rainfall total (April – August) rather than on a month by month basis. This was implemented because previous versions of the stochastic weather generator summer

[15] 400 replications are the default although this can be easily amended as preferred.

persistence effects around PET were not being adequately simulated when matched on a month by month basis.

Secondly, following feedback from the regional groups, it was identified that the previous matching process could often lead to repetitions of just one or two daily rainfalls, and subsequently repeated flow sequences in extreme events. This is because extreme stochastic months that are lower than the lowest observed month were always matched to the same month. To minimise the impact of this, a small update has been included to the process so that stochastic values that fall in the bottom 20th percentile of observed values are matched randomly to one of the closest four observed months rather than the absolute closest. We have analysed the impact of this update as part of one of the case studies examples.

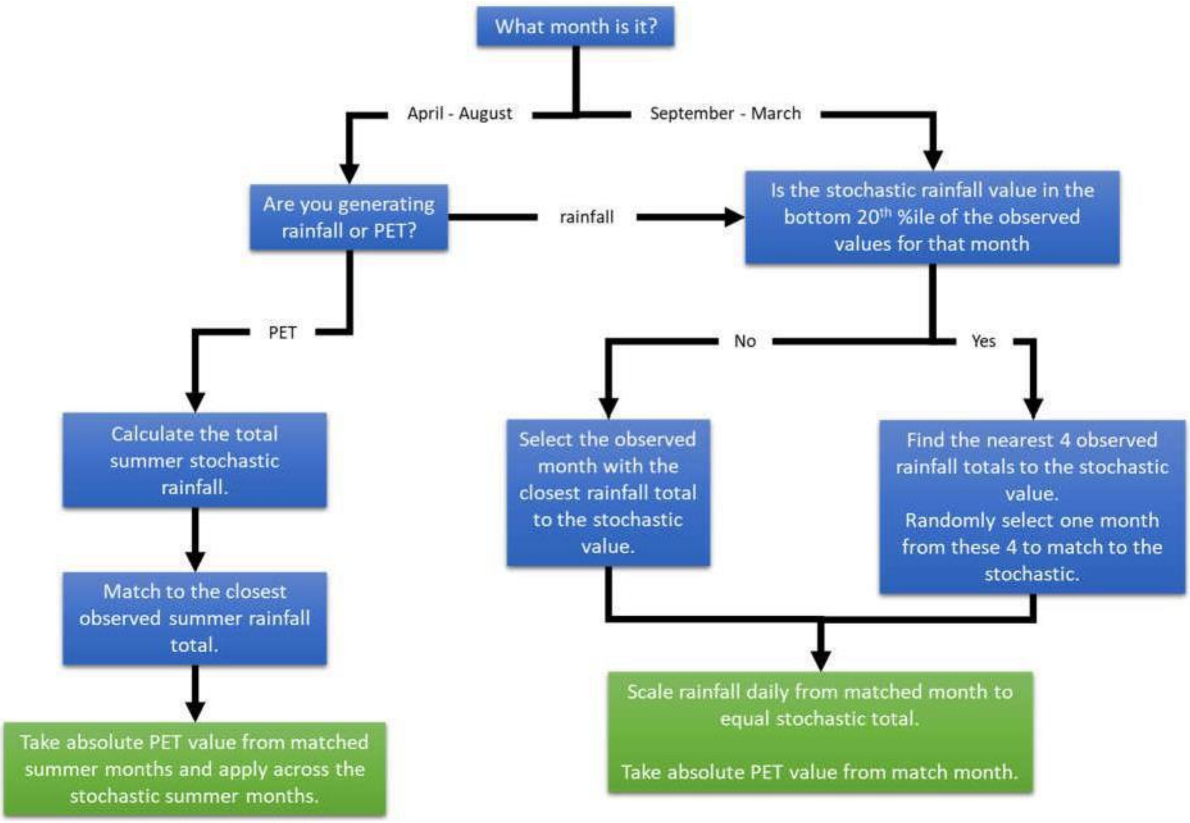



**Figure 2-11 - Stochastic PET and daily rainfall resampling**

## 2.4 Results from final delivery dataset for WRSE region

This section provides further information on results and how they can be used for water resources planning[16].

### 2.4.1 Analysis of regional drought

In the WRSE dataset there were 57 sites including the Severn Trent locations (43 sites of direct relevance to the South East),

For many water resources planning applications all 400 time series will be run through water resources models but for other applications a sub-set of stochastic runs may be selected. To aid this selection summary tables for all metrics were provided as well as an Excel template to illustrate analysis for calendar year droughts (Appendix B).

[16] The stochastic results for 57 sites across WRSE were provided as text files and supported by a handover note and a large number of ranked rainfall and percentile plots. Uploaded 15th May 2020.

### Choice of metrics

The standard drought metrics are summarised below. These data were provided by site and by metric for the stochastics and for HadUK observed data for the 1950-1997 period and earlier 1902-1949 period to provide an independent check of the stochastic model fits.

**Table 2-2 - Standard drought metrics (✓ - rainfall metrics provided)**

| Climate metrics | | Hydrological metrics |
|---|---|---|
| Seasonal metrics | Annual and multi-year metrics | All timescales |
| Winter | Jan – Dec ✓ | Q min |
| 4 month Nov – Feb✓ | *Oct – Sept (hydrological year)✓ | Q min 7 day |
| Oct – March (winter half year)✓ | | Q mean (Oct-March) |
| Summer | Multi-year metrics | Q mean (June, July, Aug) |
| June – Aug✓ | 2 year calendar✓ | Q mean (April-Sept) |
| April – Aug✓ | 3 year calendar✓ | Q5 |
| July – Sept✓ | 2 year hydrological✓ | Q95 |
| April – Sept (summer half year)✓ | 3 year hydrological✓ | Q50 |
| Winter to summer | 18 months April – Sept ✓ | |
| Jan – Aug✓ | | |
| Autumn | 30 months April – Sept ✓ | |
| Sept - Oct✓ | | |

### Low rainfall in sub-regions

The Drought Vulnerability Framework (DVF) is a form of sensitivity analysis that presents the rainfall deficits for a catchment or region over a range of durations and overlays the impacts in terms of low river flows or other water availability indicators. Figure 2-11 plots the results of the stochastic analysis in a similar way to facilitate comparisons with previous DVF work. This figure summarises rainfall deficits for 3 months to 36 months for five sub-regions in the South East of England.

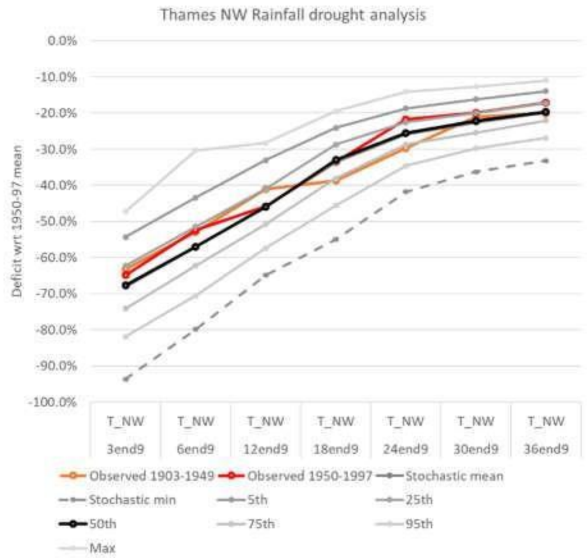
The black line plots the median of the stochastic data and the grey lines indicate the 5$^{th}$ to 95$^{th}$ percentile range of the stochastic data and the maximum deficit (dotted). The observed data 1950-1997 that were used for calibration are shown in red and an independent data set of the same length 1902-1947 provides a check and useful comparison. This earlier period includes more extreme droughts in the southern region over short and longer durations.

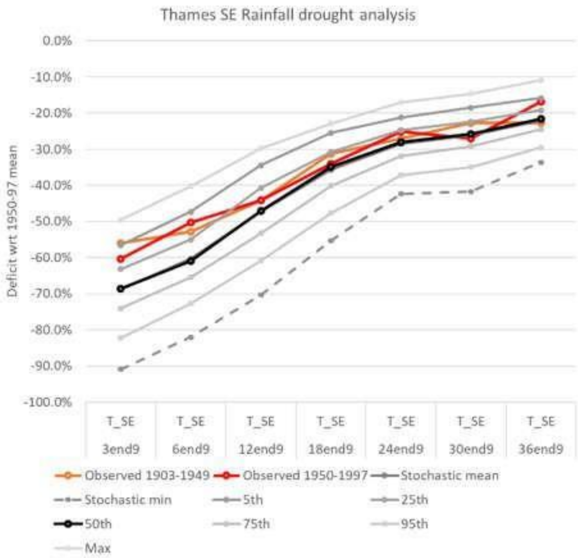
The observed data generally sit between the 25$^{th}$ and 75$^{th}$ percentiles of the stochastic data. Overall the stochastic model is providing a good fit, which improves for longer duration drought.

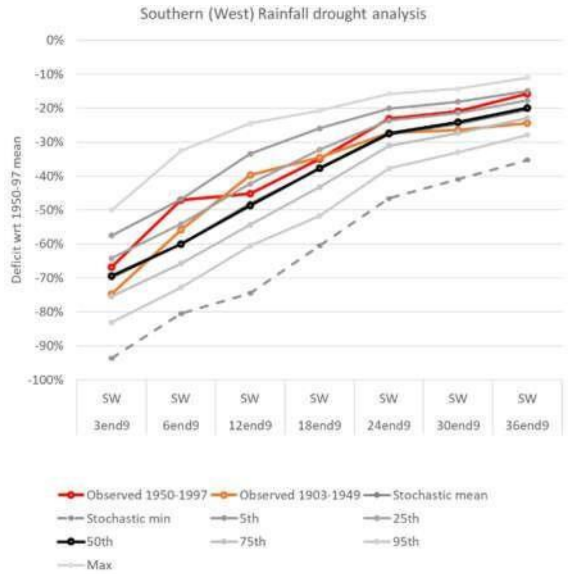
### Correlation between regions

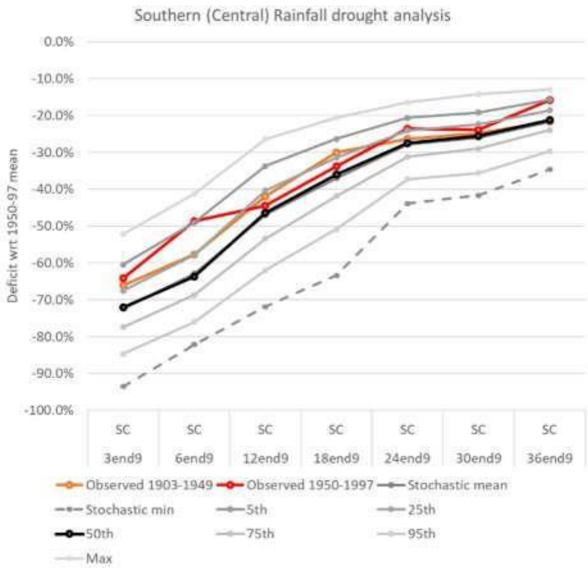
Figure 2-12 illustrates the correlation in low rainfall between sub-regions. While there is a positive correlation between sub-regions, it declines with distance. The black lines indicate the minimum sub-regional rainfalls for hydrological years. The plots highlight the much wider spread of the stochastic minima and the possibility of drier or wetter periods in both regions and the somewhat lower chance of drier periods in one region and wetter periods in the second region, i.e. more local severe drought conditions.

Along with an assessment of drought severity, the correlation between regions is an important consideration if the data are sampled to create drought scenarios. For example, it may be useful to stress test the regional water resources system against both severe regional droughts and more local droughts with extremely low rainfall in the east or west of the region. Understanding correlations is essential for the assessment of national transfers.




**Notes:**

Each region is represented by up to 10 rainfall locations. This model used 57 sites including large areas of the River Severn, which are not summarised here. This analysis is for the worst drought in each run only.

The red line is observed data from 1950-1997 from HadUK 1km; the orange line is 1903-1947 and provides an independent check on the model fit. The black line shows the median of the stochastic data Grey lines are percentiles and min/max of 400 stochastic runs. Deficits are calculated against 1950-97 mean rainfall for each metric.

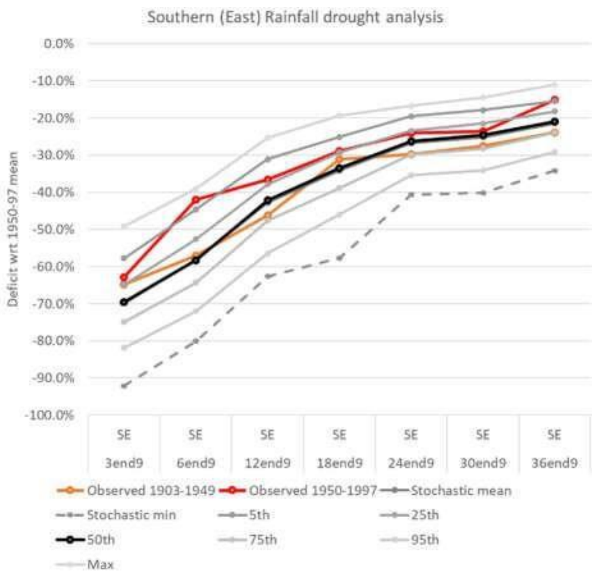
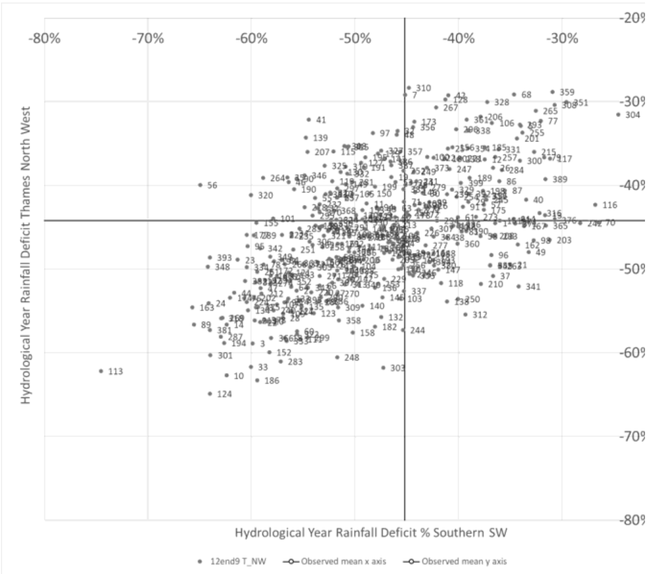
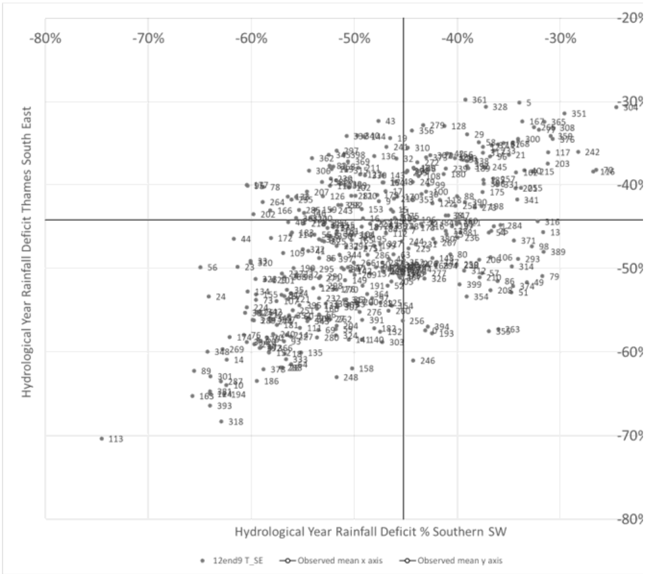


**Figure 2-12 - The WRSE Stochastic Rainfall Data Summary: Rainfall droughts of between 3 and 36 months duration**

Southern South West versus Thames NW

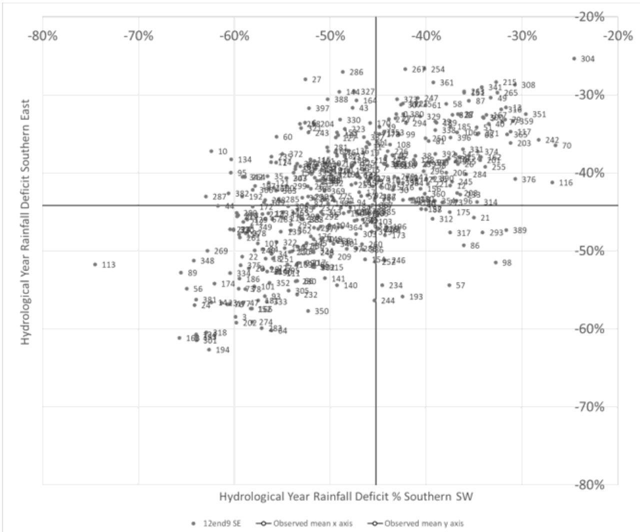



Southern South West versus Thames South East




West versus Central


West vs East




Correlation is strong between rainfall metrics of the same duration and neighbouring regions, but decays with distance

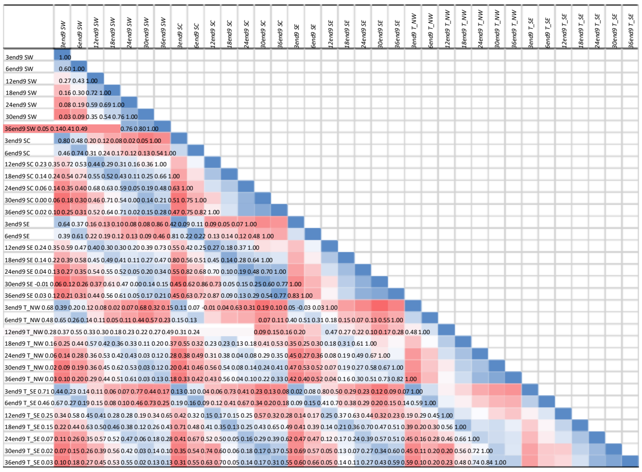


**Figure 2-13 Correlations of minima between WRSE bias- regions**

## 2.4.2 Analysis of single sites

The analysis of single sites provides a check on the model's performance and is useful to compare periods of low rainfall in the stochastics with the observed data, including an independent observed data set prior to 1950.

### Time series

A standard Excel sheet was provided to assist in the analysis of single sites. Time series plots (such as Figure 2-14) show the observed data (red) compared to the median (black) and the 5th to 95th percentiles (grey) of the stochastic data. Figure 2-14 shows how the stochastics follow the observed pattern fitting closely where North Atlantic Oscillation (NAO) index and other teleconnections explain the rainfall pattern but deviate in some years. Overall the observed 1950-1997 series fits well with the stochastics and always within the min and max range. However, it's clear that the stochastics include many years with lower rainfall than observed during the 1950-1997 period.

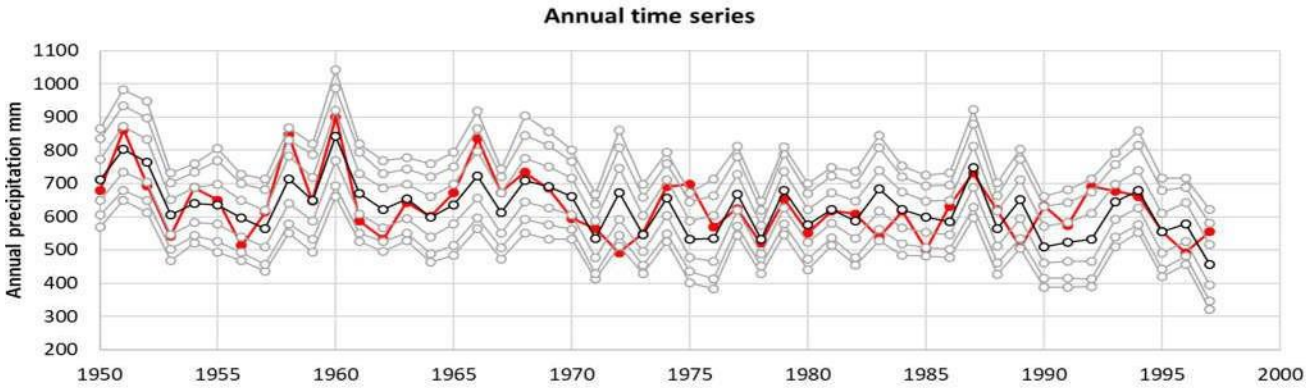



**Figure 2-14 Annual rainfall time series for Canterbury showing observed HadUK data (red) and 400 stochastic series as percentiles**

The series can be presented as a Drought Deficit by subtracting the mean and dividing by the standard deviation, then multiplying by minus one, so that droughts are positive in the range 1 to 3 as shown in Figure 2-15**.** Fairly normal conditions cover the range +1 to -1 and wetter conditions are less than -1.This particular series suggests a small increase in the magnitude of rainfall drought after 1970 but there were lower rainfall periods in the first half of the 21st century (see extreme value analysis in next section).

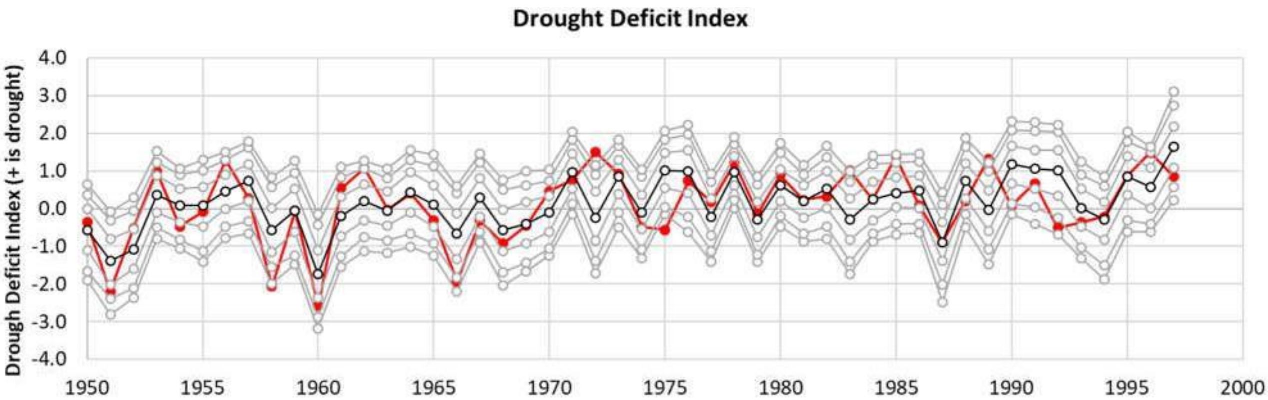



**Figure 2-15 Annual Drought Deficit time series for Canterbury showing observed HadUK data (red) and 400 stochastic series as percentiles**

## 2.4.3. Extreme Value Analysis

As part of the framework development we have undertaken a study looking at extreme value analysis of low rainfalls (see Figure 2-16). **This indicated that a Weibull distribution provides the best fit and most practical distribution for periods of low rainfall.** There are still many different ways that EVA can be approached using the stochastic data; this section presents two simple approaches that can be implemented in Excel without the need for specialist statistical software.

## Case study: WRSE (Western Rother, Hardham)

We used the Western Rother catchment, at Hardham to consider the impact of different approaches to Extreme Value Analysis (EVA) for calculating the return period (RT) of droughts. We explored the use of Weibull and other distributions instead of ranking, use of outputs as replicates rather than a single long time series and the use of more complex Bayesian methods.

We analysed the EVA method for calculating Return Periods (RP) from a Peaks Over Threshold (POT) or Summer Average rainfall deficit index (RDI) series. The EVA methods explored were:

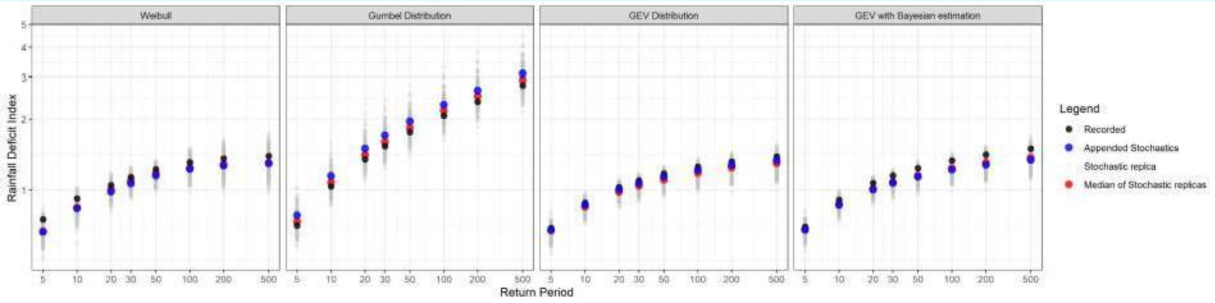
- Weibull method
- Fitting a Gumbell distribution
- Fitting a Generalized Extreme Value (GEV) distribution
- Fitting a GEV distribution with Bayesian estimation with prior assumptions taken from a similar Met Office analysis for Water Resources East

As shown in the plots below, the POT approach produces anomalous results (when compared to the baseline) for the appended stochastics data treatment, when the data are treated as one long time series. In the POT series stochastic case, lower return periods are notably over-estimated compared to the baseline and POT parallel stochastic case. This is to be expected, as the effect of appending stochastic timeseries shifts the frequency distribution such that frequent events (such as 1 in 5 year) become more frequent compared to low frequency events (such as 1 in 500 year).

While the appended stochastics generally over predict the RP compared to baseline, the series stochastics centre around the baseline more closely, with the median of these being the closest to the baseline RPs.

We found that the GEV method provides the most conservative estimation of RP, however, fitting can be problematic simply due to the finer-scale variability in stochastic frequency distributions. To avoid over complication, the Weibull approach is recommended as it is easy to understand, calculate and is the most robust (i.e. plotting positions are easily calculated and its less sensitive to assumptions around distribution fitting).

**EVA comparison for Summer Average extreme event definition:**




**EVA comparison for POT extreme event definition:**

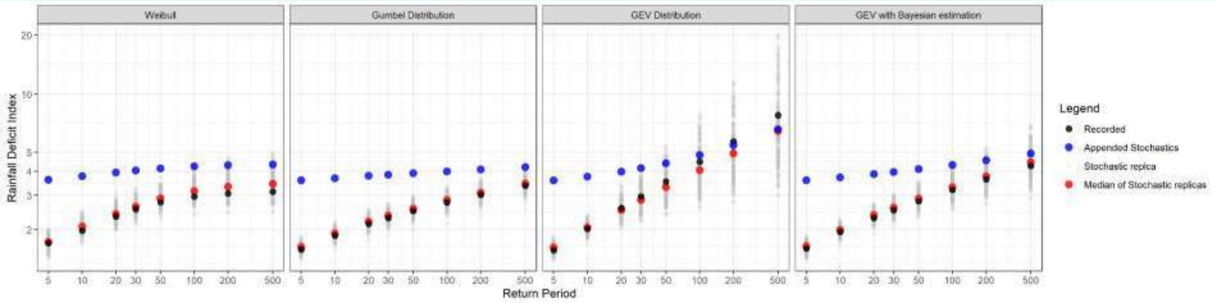



**Figure 2-16 - Exploration of Extreme Value Analysis Methods using WRSE, Western Rother case study location**

## EVA of full stochastic time series

A key aspect of the stochastics is how to interpret the probability of periods of low rainfall, in particular whether to treat the stochastics as 400 runs or ‘replicates’ of 48 years or as a larger data set equivalent to 19,200 years. While the former approach is most appropriate because the model is driven by specific climate drivers for that period, at some stage the data need to be ranked and sorted to support the selection of particular runs or replicates. This is particularly the case where it is not possible to run 400 models (e.g. detailed groundwater modelling or rapid assessment in a low vulnerability zone).

The simplest estimate of average frequency is the rank order divided by the sample size and annual minima are typically plotted using rank divided by n + 1, which is the Weibull plotting position. In spreadsheets that accompany the results files, indicators of the rank and frequency of the minimum rainfall in each run are summarised so that the user can estimate drought magnitude and frequency across the full data set.

In addition to using a simple frequency estimate, a Weibull distribution can be fitted to the observed or any stochastic data using Maximum Likelihood Estimation; in this case the Excel Data Solver tool was used to optimise the fit of the parameters ‘alpha’ and ‘beta’ for the 1950-1997 and 1902-1949 periods. For simplicity, the parameters for 400 stochastic series can be estimated assuming a constant relationship between the mean and beta derived in the spreadsheet. Low rainfalls for any return period can then be estimated from:

$$Q = \beta\left(-\ln\left(1 - \frac{1}{R}\right)\right)^{\frac{1}{\alpha}}$$

Q – Quantile (mm)
R – Return Period in Years
$\beta$ – Beta parameter of Weibull distribution
$\alpha$ – Alpha parameter of Weibull distribution

Developing a satisfactory fit for an extreme value distribution is complex, particularly for events that last more than one year. In the project team’s experience, the simple approach of ranking the stochastic data and estimating the annual probability and return period produces plausible results for low rainfall that tend to decline to an asymptote, whereas a standard EVA on a short record of 48 years can produce rather unrealistic results and be very sensitive to the choice of fitting method and the influence of outliers.

An important aspect of the analysis is that the same approach is applied to all data, so the relative magnitude is calculated in the same way. We also found that a lognormal distribution can provide an adequate fit beyond 1 in 20 years but can’t be fitted easily to the full data set. More advanced statistical software, such as In-Extremes in R could be used for a more detailed assessment as shown in the above case study.

In

Figure 2-17, the rainfall droughts are shown following these approaches, including plotting the most extreme stochastic droughts as a range of values around a 1 in 48 year drought, as ranked and plotted according to the full data set of 19200 years. This highlights the large uncertainties around the estimation of 1 in 100, 200 and 500-year droughts and the sensitivity of the time period selected (for example 1902-1949 plots vary differently to 1950-1997). It also shows that the stochastic data minima from 400 series cover a range of probabilities (according to the fitted Weibull distributions) from annual probabilities of 10% to less than 0.01% providing a large library of drought events with different time series.

## A Rapid Assessment Method for analysis of rainfall droughts based on “worst droughts” in each stochastic run

By introducing some simplifying assumptions, an understanding of drought magnitude and risk can be established through analysis of the “worst droughts” in each stochastic run, reducing the analysis load 50-fold.

The Rapid Assessment Method is based on the minimum rainfall for specific metrics in each stochastic run. If it is assumed that these minima span a range from say 1 in 25 years to 1 in 19200 years, with the same difference in annual probability between each run minima they can be converted from Type A to Type B without analysing all years, just focusing on the minimum of each 48 year period.

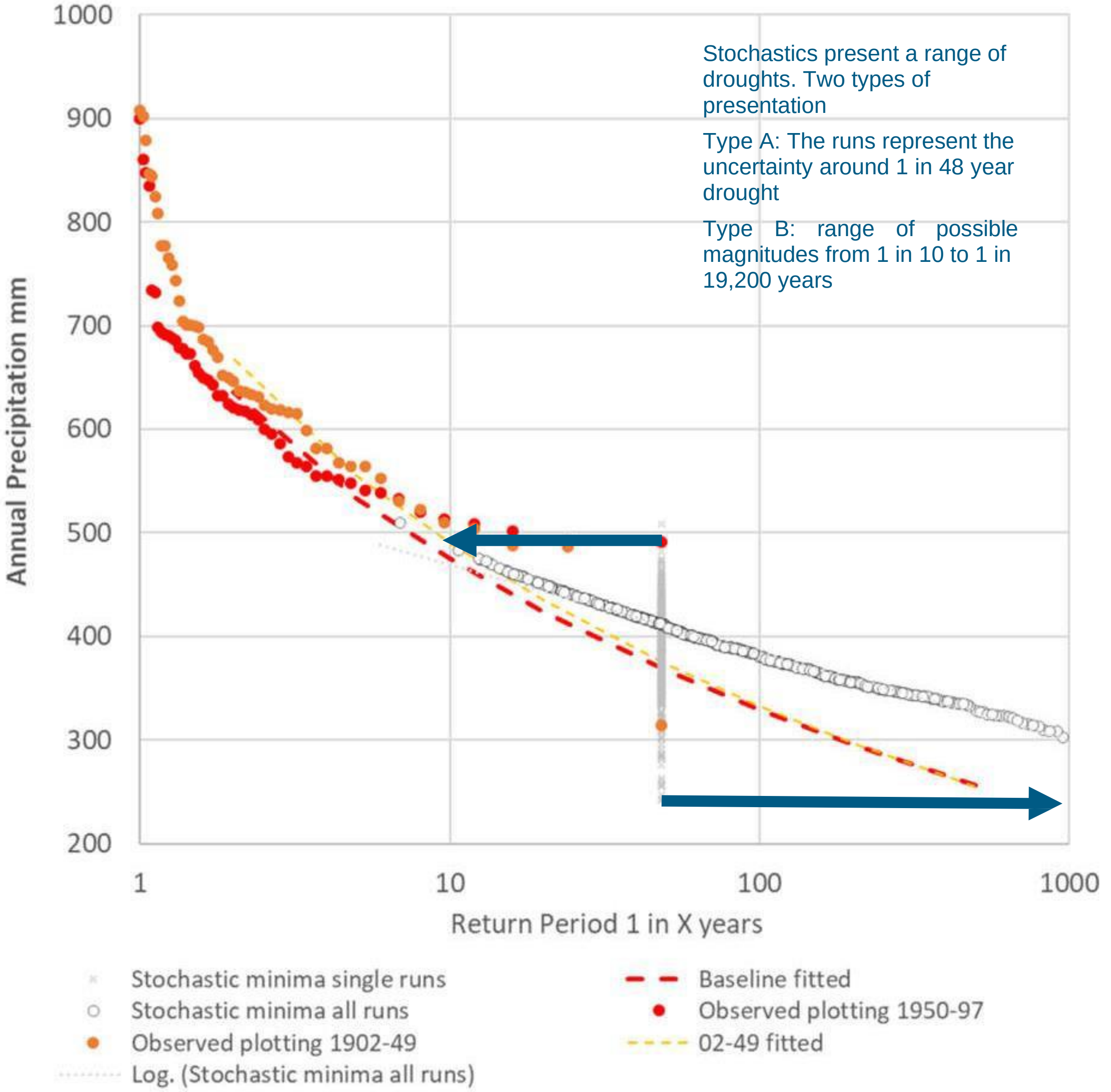
If RP bar is the estimated return period, R is the rank of run minima from 400 runs and ‘c’ is the difference in annual probability between each data point.

$$P = \frac{1}{\left(\frac{1}{19200}\right) + c.( \quad - 1)}$$

The coefficient c is calculated by assuming the return period of the wettest stochastic run minimum rainfall. If we assume it is 1 in 25 years[17]:

$$c = \frac{\frac{1}{25} - \frac{1}{19200}}{400}$$

This gives the following relationship between rank of run minima and approximate return period and implies a range of ranks that are suitable for assessment of 500 year and other droughts (see Figure 2-18 and Figure 2-19). The median or 200th rank stochastic run minima will be interpreted as a 1:50-year event in this case. With these assumptions the 1:500-year drought will sit close to the 5th percentile of the Drought Vulnerability Framework (DVF) plots.




[17] The starting return period could be 1 in 10, or estimated more precisely, but 25 years assumption provides a neat solution and useful heuristic as the 200th rank run will equal a 50 year event.

**Figure 2-17 - Extreme value analysis of low annual rainfall for Canterbury showing the observed data used for training the model (red), an independent observed data set (orange), Weibull distributions (dashed), stochastic data plotted for individual runs (grey crosses) and the rank 1 droughts from the full stochastic data set (grey circles), grey dashed line for lognormal fit to the full stochastic rank 1 series**

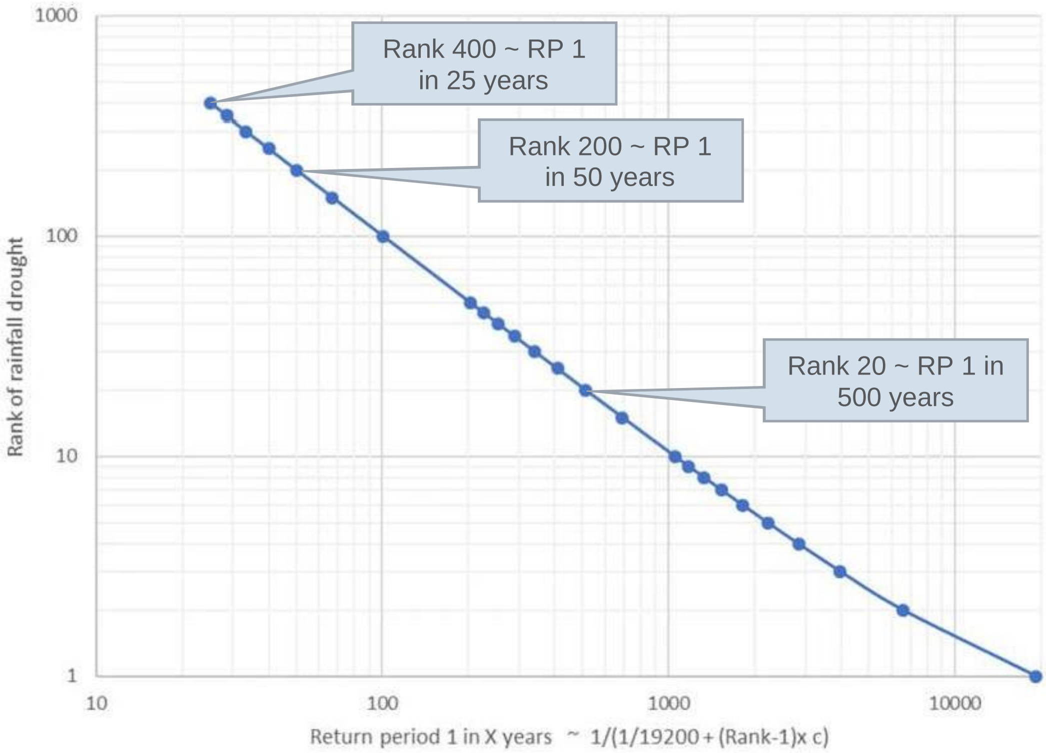
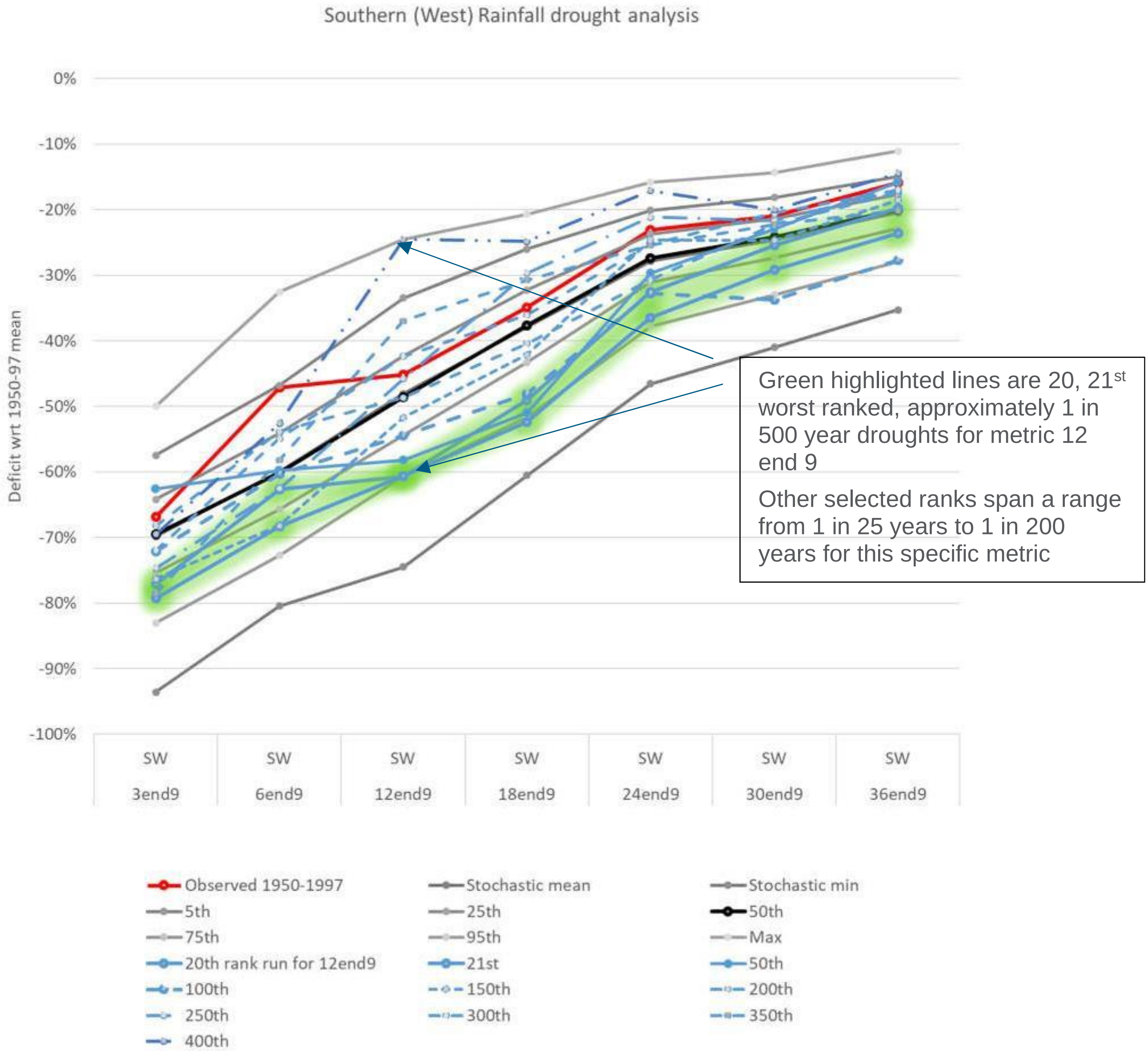



**Figure 2-18** Estimated relationship between rank of run minima and average frequency of events over a longer time period

This approach can be used to select droughts using the most important rainfall metric, in cases where a smaller sample of stochastic data are required. Figure 2-18 provides an example of the west of southern England (centred on Hampshire) with a range of stochastic time series selected based on the probability of low rainfall in hydrological years ending September.




Notes: Grey lines are percentiles of 400 stochastic runs and the blue lines are ranks according to the hydrological year rainfall minima.

**Figure 2-19 - Example for Hampshire (Metric – Hydrological Year rainfall 12 end 9)**

If all 400 stochastic time series are input into hydrological models, a similar analysis is useful to understand the severity of rainfall droughts and how these may impact on river flows and groundwater availability.

## 2.4.4. Case studies of stochastic data applied to hydrological modelling

Several case studies were completed to test the workflow of hydrological modelling and different aspects of the development of the stochastics tools. The case studies are summarised in Appendix D.

The changes from the WRMP19 rainfall generator to the new rainfall generator was tested on 5 case studies. Figure 2-20 shows some results from the Ouse case study completed by WRE, summarising the impacts on median, 70th percentile and 95th percentile flow. The new stochastics were calibrated on 1950-97 and therefore the resulting flows are expected to be centred on the historic flows for this period, whereas the previous model used a longer time period for calibration from around 1918-1990. In this case study the new stochastic data produced a wider range of possible flow conditions despite being fitted on a shorter period. It indicated marginally lower Q95 flows than the 1950-1997 period and the distribution sits between the different historical periods. This shows that the model provides a good coverage of a range of historical conditions as well as the possibility of wetter and much drier conditions than have been observed in the 1918-2015 period.

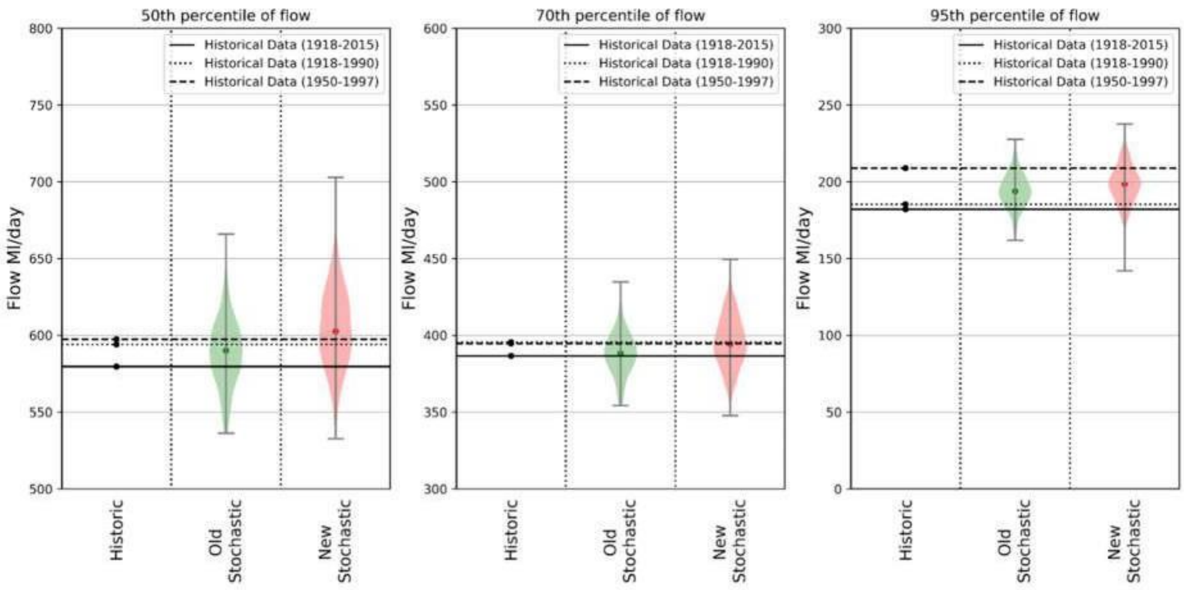



**Figure 2-20 - Flow statistics for stochastic series compared against historical data (provided by the WRE team)**

Similar results were found for Hardham with the median results from the new stochastic model providing a good fit to Q5 and Q95 flows, with a marginally higher flow at Q50 (Appendix D)

# 3. Climate change data sets

This section evaluates the strengths and weaknesses of UKCP18 and other climate data sets for regional water resources planning. The climate change outputs of this study were presented in March 2020 and this section provide a summary of the outputs with the remainder of the project's interim report included in Appendix C.

The Water UK Long Term Water Resources Planning Framework[18] (LTWRP) provided the first national assessment that included the use of stochastic rainfall generators and future climate scenarios to assess future drought risk. Many water companies made use of stochastic models in WRMP19 as well as the UK Climate Projections 2009 (UKCP09).

This project was undertaken in advance of the Environment Agency Water Resources Management Planning guidelines for drought and climate change risk assessment. However, it adopted some basic principles that should apply, based on the LTWRP and the water resources and climate risk assessment literature:

- Planning for the longer term
  - National and regional water resources infrastructures are significant long-term investments that should consider drought risks under the current climate as well as climate and socio-economic scenarios to the end of the century.
- Adaptive decision making
  - National and regional drought scenarios should consider a wide range of plausible drought conditions, including droughts of different magnitude, severity, duration and spatial extent.
  - Future climate scenarios should cover a range of possible future conditions to support decision making; planning for a single or narrow range of scenarios increases the chance of maladaptation (building too much, too soon or too little too late.

[18] https://www.water.org.uk/publication/water-resources-long-term-planning/

- Understanding risks and resilience
  - Future climate scenarios should include low probability but high consequence models to demonstrate their climate resilience and ability to maintain supplies during severe national/regional future drought scenarios.
- Line of sight between regional and company plans
  - Regional plans should inform company Water Resources Management Plans (WRMPs) and therefore provide higher level/broader scale drought/climate scenarios that can be investigated in more detail or at least be consistent with those used for WRMPs.

The project considered UKCP18 Global Climate Model (GCM), UKCP18 probabilistic, UKCP18 Regional Climate Model (RCM) and MaRIUS climate model data in terms of their technical quality, usability and above principles. Regional planning has specific requirements, such as the development of plausible regional and national drought scenarios that can be used to test proposed regional transfers and other significant national and regional supply/demand measures. In the context of climate change, these scenarios need to be 'spatially coherent' or in other words provide a credible representation of the spatial patterns of drought both in the past and under future climate change scenarios.

The advantages, disadvantages and potential use of each data set is summarised in Table 3-1 and Appendix B provides a detailed Strengths-Weaknesses-Opportunities-Threats (SWOT) assessment of each data source following a review of the data sets, particularly testing the RCM outputs against observed data sets.

The work undertaken in this project has shown that:

- The UKCP probabilistic projections headline findings are similar to UKCP09. The range of possible outcomes in UKCP18 RCP8.5 probabilistic data cover almost all of the other scenarios and A1B Medium Emissions scenario can be used for direct comparison with the UKCP09 Medium Emissions.
- The UKCP GCMs include both Met Office Hadley Centre (MOHC) and a filtered set of CMIP5 models for RCP8.5. The former models are hotter than CMIP5, which has implications for water resources planning; this issue has knock-on impacts to the RCMs that are driven only by the MOHC models.
- The UKCP RCM raw data provide a poor fit to monthly precipitation at the UKCP river basin scale and require correction for biases at the daily, monthly and annual time scales.

Different bias correction methods were reviewed and tested. An implementation of the Quantile Mapping method Equidistant CDF (EDCDF) mapping was the most promising approach because it can correct daily, monthly and seasonal bias in precipitation (Li, Sheffield and Wood, 2011). We have shown that this corrects for the bias in the observed period and illustrated the impact of this method at the regional scale.

**Table 3-1 - Climate change data sets for regional planning (RAG credibility score)**

| Data set | Advantages | Disadvantages | Potential use for regional planning |
|---|---|---|---|
| UKCP18 Probabilistic Projections | Flexible User Interface (UI) and ease of use.<br>Covers a large range of futures outcomes based on RCPs and the A1B(Medium) emissions scenario.<br>Scenarios available for the end of 21st century and at many spatial scales. | 3000 scenarios per time/period and RCP so sub-sampling is needed for most users.<br>Lack of spatial coherence between catchments. | Supply forecasts or scenarios ~ climate change perturbation using RCP8.5 at the UKCP regional river basin or national scales.<br>(A1B can be used to provide an audit trail to previous assessments based on UCKP09 Medium Emissions)<br>Headroom assessment. |
| UKCP18 Regional Climate Models (raw data) | Flexible UI and ease of use.<br>Spatially coherent change factors. | Only available for RCP8.5.<br>Poor fit to observed precipitation in the baseline period (1981-2000).<br>High rates of warming compared to CMIP5 models with implications for PET (particularly if derived using temperature based formulae). | None (poor fit to observed precipitation limits their credibility). |
| UKCP18 RCM (bias-corrected) | Bias correction deals with poor daily, seasonal and annual fit for precipitation.<br>Provides transient time series as required by | Bias correction model introduces specific assumptions/caveats.<br>Potential loss of spatial coherence.<br>Only available for RCP8.5. | Stress testing of regional water resources plans. |

| Data set | Advantages | Disadvantages | Potential use for regional planning |
|---|---|---|---|
| | some decision-making methods. *To be made available for regional planning basins as part of this project.* | High rates of warming compared to CMIP5 models with implications for PET. | Relying on RCMs alone will not cover a sufficient range of possible outcomes. |
| UKCP18 GCM | Flexible UI and ease of use. Includes a filtered set of CMIP5 models. Will include information on weather types (yet to be released). | Coarser data set with lower confidence in precipitation modelling. Only available for RCP8.5. | Supply forecasts or scenarios ~ climate change perturbation using simplified scenarios (England and Wales or regional scale) Weather generator ~ use of weather types could improve the weather generator |
| MARIUS data set | Includes 100 time series representing the near term and longer term. Includes bias corrected precipitation, using a simple method. Includes two versions of PET for hydrological modelling. | Difficult to use data set (e.g. rotated grid and awkward file structure). Too warm and dry in the summer season. Only available for RCP8.5. | Unclear at this stage, expensive time investment required to roll out and known biases. |

## 3.1 Project outputs

The outputs provided by the project are as follows:

- Twelve sets of RCM bias-corrected precipitation and PET climate change factors[19] for scenario RCP8.5 and the 2070s period for every river basin required for regional planning
- RCM Bias-corrected precipitation and temperature time series for scenario RCP8.5 and the 2070s for each basin
- UKCP18 probabilistic data for RCP8.5 and A1B and 'raw' Global Climate Model data for RCP8.5 for England and Wales to provide a broader context for the RCM based data above.

An example of the bias corrected average temperature data for the Anglian Region are shown in Figure 3-1.

Changes in future seasonal rainfall and average annual temperature for England and Wales are shown in Figure 3-2. The Met Office global models are shown as red squares and the RCMs as red diamonds; the CMIP5 models are shown as blue squares; the probabilistic data for RCP8.5; the same data are shown for scenario A1B, which is equivalent to the previous Medium emissions scenario.

It is anticipated that users will apply RCM RCP8.5 change factors to the stochastic data to assess the potential impacts of climate change. As outline in the draft WRMP guidance this will be a supplementary assessment, which will be combined with other evidence for a "Tier 2" assessment. For the most detailed "Tier 3" assessment, users may wish to add further scenarios to sample a broader range of possible climate change futures, which could be based on the Global CMIP5 models or a sub-sample of the UKCP18 probabilistic data.

Several case studies were completed on the impacts of stochastic data and climate change scenarios on river flows. These studies confirmed that the RCM data for RCP8.5 is significantly different to the other data sets and, as expected, produces larger reductions in river flow (Section 3.2; Appendix D).

[19] Change factors were based on the Oudin temperature based PET formula

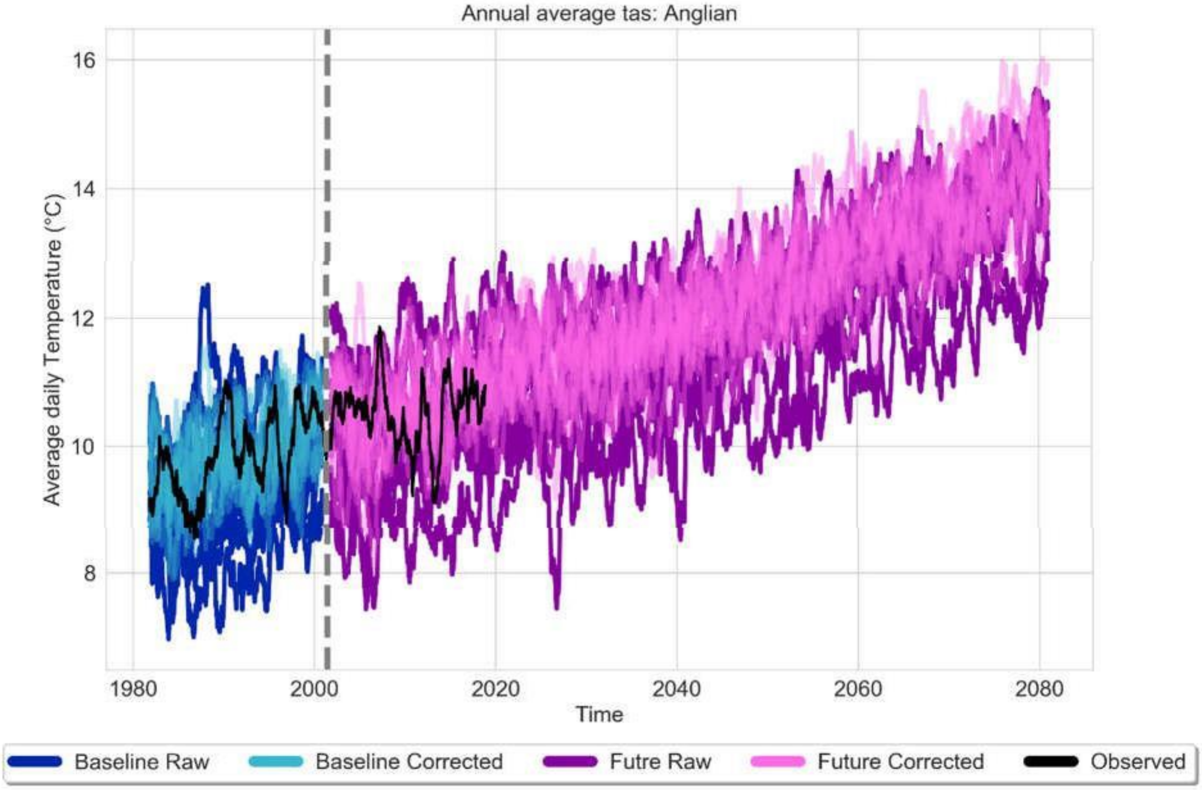



**Figure 3-1 – Example of bias-corrected temperature time series**

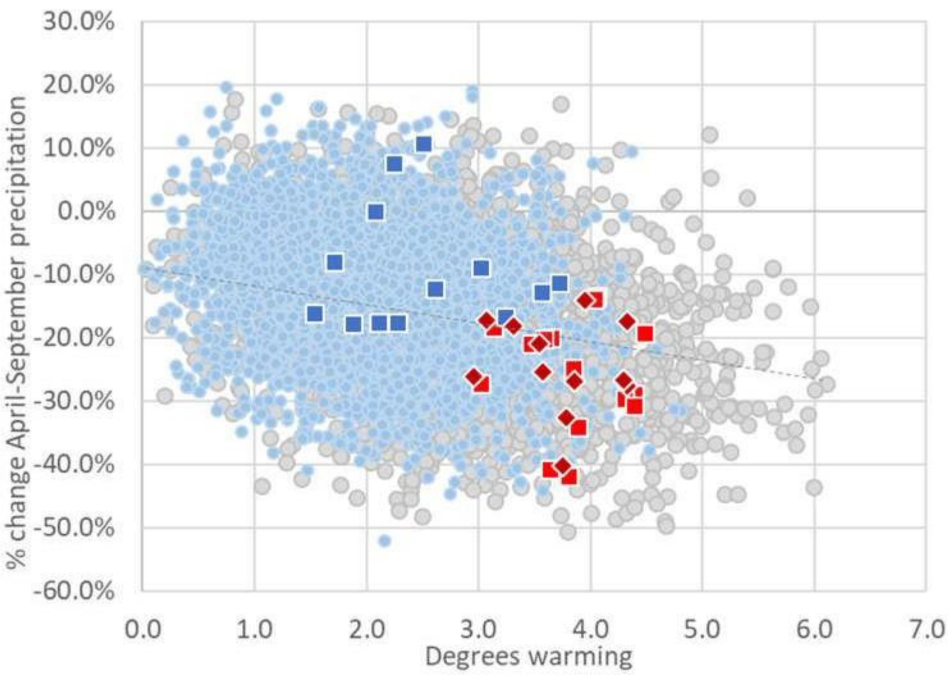



**Figure 3-2 - Comparison of different climate model data for England and Wales in the 2070s (UKCP probabilistic A1B blue circles; RCP8.5 grey circles; CMIP5 blue squares; HadGEM red squares and RCM red diamonds)**

## 3.2 Case studies of the impacts of climate change scenarios on low river flows

Several case studies have been undertaken to assess the impacts of climate change on flows, based perturbation of the full stochastic data set with different climate change factors for the 2070s. In the case of Hardham on the Western Rother the stochastic data produce a much wider range of flows than observed, ca. +10%/-5% on Q5 high flows. +/- 10% on median flows and +10%/-12% on Q95 low flows.

The impacts of climate change under RCP8.5 by the 2070s is greater with median impacts of around -10%, -22% and -12% for UKCP18 probabilistic, RCM and CMIP5 GCMs (Figure 3-3). Similar results were found for Wimbleball case study, with median changes to Q95 of around -35%, -50% and -30% for the same scenarios (Figure 3.4).

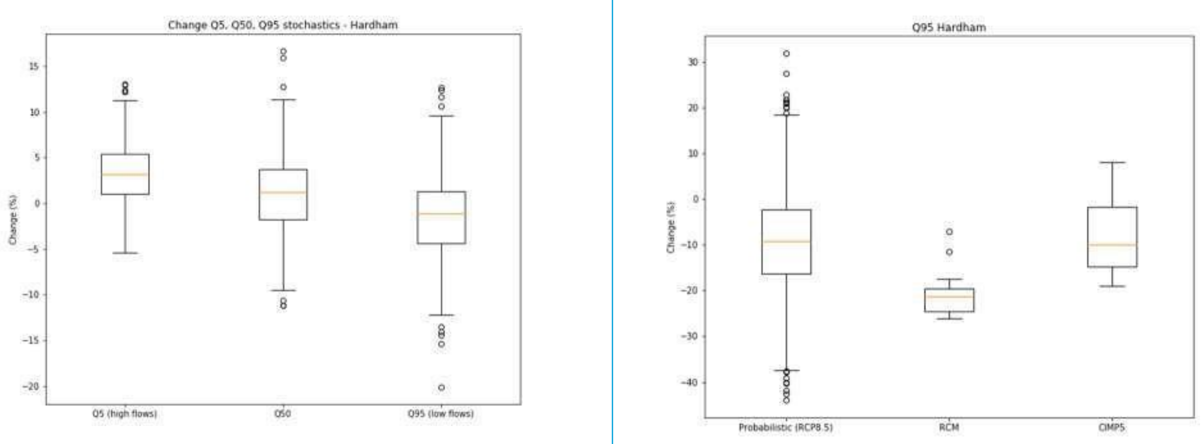



**Figure 3-3 – A) Percentage differences between flows at Hardham calculated using observed HadUK 1961-1997 and those calculated using stochastic weather data (Q5: extreme high flows, Q50: median flows, Q95: extreme low flows). B) Percentage differences between baseline Q95 and Q95 in the 2070s based on UKCP18 RCP8.5 probabilistic data (3000 scenarios), bias corrected RCMs (12 scenarios) and CMIP5 global models (13 scenarios).**

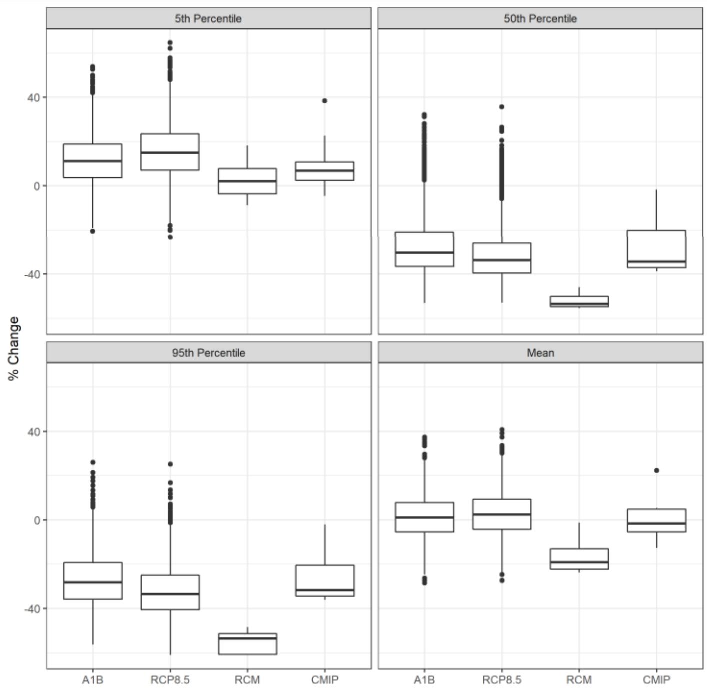



**Figure 3-4 – Impacts of climate change in the 2070s on Wimbleball flows under A1B and RCP8.5 scenarios (A1B and RCP8.5 probabilistic based on 3000 runs, RCM, 12 runs and CMIP5, 13 runs)**

# 4. Conclusions and recommendations

The project has provided two new national data sets to support regional water resources planning:

- Stochastic time series of precipitation and potential evapotranspiration for more than 200 locations in England and Wales, based on Met Office HadUK observation data for precipitation and several Potential Evapotranspiration (PET) data sets, required for water resources modelling
- Bias corrected future climate change factors and time series based on UK Climate Projections 2018 Regional Climate Models under Representative Concentration Pathway (RCP8.5) and HadUK precipitation and temperature at the catchment scale

The first data set provides a set of 400 time series for each location for the assessment of climatological drought risk across England and Wales for a baseline climate without climate change. The overall impact of improving the model fit to low rainfall by 25%[20]. Our analysis shows that model provides a wide range of drought conditions for drought risk assessment and testing of water resources systems models.

The second data set provides spatially coherent Regional Climate Model (RCM) change factors and accompanying time series to assess the impacts of climate change. These scenarios are based on bias-corrected UKCP18 Regional Climate Models under scenario Representative Concentration Pathway RCP8.5. Our analysis shows that this scenario has high rates of warming compared to other global models with a greater impact on river flows. Climate change assessments following EA WRMP guidelines may also use the England and Wales CMIP5 factors and other evidence to provide a comprehensive assessment of risks in water resources zones with a high vulnerability to climate change.

Both data sets can be used in a way that is fully compliant with the Environment Agency Water Resources Planning Guidelines and supplementary guidance on stochastics and climate change.

Based on this work we make the following recommendations:

- Update the stochastics assessment running at a national scale rather the regional scale and with the new EA PET data sets for all regions

[20] Based on the Mean Absolute Error of low rainfall in mm/month for three test regions and low rainfall metrics from 3 months to 36 months.

- Further development of post-processing tools to visualise, screen and select results
- Running stochastic models up to 2020 to explore the increased risk of low rainfall due to changes in climate drivers.
- Downscaling of the CMIP5 and new HadGEM RCP2.6 global climate models to the same 200 catchments to provide a spatially coherent climate change data sets, which provide future scenarios with less warming than UKCP RCM RCP8.5 models
- Application of the RCM bias-corrected time series to models from 1981-2080 to provide more information on the pace of hydrological change and potential onset of more extreme droughts due to climate change.
- Application of the bias corrected RCM data as stress-test to proposed water resources infrastructure but to combine these data with other assessments to consider a wider range of adaptation pathways.

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# Appendices

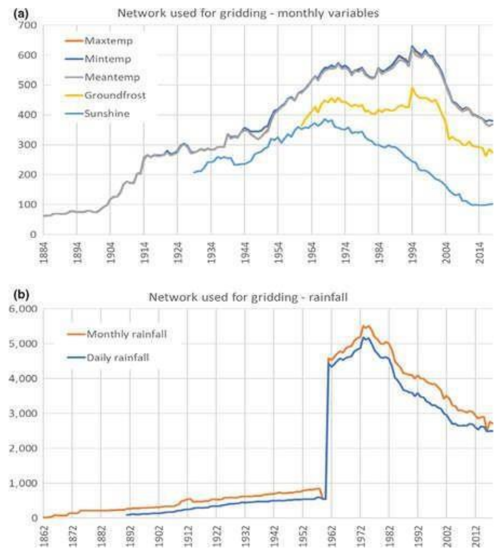
# Appendix A. Background data sets

## A.1. UK Observations Data

Meteorological and hydrological monitoring in England and Wales is undertaken by the Met Office, Environment Agency and Natural Resources Wales. The national meteorological network of synoptic stations, which measure a full range of weather variables[21], is supplemented by specialist networks and individual observer stations that collect precipitation and temperature data. These data are brought together in a number of national data sets curated by the Met Office[22], Centre for Ecology and Hydrology (CEH) and the Environment Agency and include gridded data products at resolution from 1km to 60km.

Water companies typically develop their own catchment data sets using local networks of station data collected by the Environment Agency and on their own sites. Increasingly, use is being made of national gridded data sets, such as CEH GEAR 1km precipitation data[23] (Tanguy et al., 2019) and the Met Office HadObs 1km precipitation data (Met Office, 2018a; Hollis et al;., 2019). This report has used the HadObs data sets to test the performance of the UKCP Regional Climate Models (Section 2.2.4). There are differences in these data sets depending on the level of checking and QA and the adopted interpolation methods, which rely on fewer observations further back in the historical record. Figure 2.1 highlights that large difference in the number of statins (Hollis et al., 2019). The strengths and weaknesses of these data sets are not discussed in this report but will be highlighted in the project's case study work and uncertainty analysis.

**Figure 5 -1 - Number of observations stations used for Met Office gridded climate observations data sets**




Source: Hollis et al., 2019 Geoscience Data Journal, Volume: 6, Issue: 2, Pages: 151-159, First published: 05 September 2019, DOI: (10.1002/gdj3.78)

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[21] https://www.metoffice.gov.uk/weather/guides/observations/uk-observations-network
[22] https://www.metoffice.gov.uk/research/climate/maps-and-data/about/archives

# Appendix B. Stochastic Modelling

## B.1. Introduction

This Appendix includes further detailed information on the stochastic data for WRSE region and background research and generator development completed as part of the project.

## B.2. Precipitation locations

| OBJECTID | Alt ID | Nearby Station Name | x | y | Quality | Comments |
|---|---|---|---|---|---|---|
| 25 | 411686 | Lyneham | 400600 | 178300 | good | Original selection |
| 26 | 336376 | Boscombe Down | 417200 | 140300 | good | Original selection |
| 27 | 329084 | Houghton Lodge | 434400 | 133200 | OK | Original selection |
| 28 | 325638 | Otterbourne | 446800 | 122500 | OK | Original selection |
| 29 | 334509 | Wight: Cowes W Wks | 449100 | 95200 | good | Original selection |
| 30 | 333785 | Wight: Shanklin Victoria Avenue | 458100 | 81200 | OK | Original selection |
| 31 | 280369 | Rotherfield Park | 469300 | 132400 | good | Original selection |
| 32 | 320345 | Bognor Regis | 493300 | 98800 | good | Original selection, Y grid location round up to miss sea |
| 33 | 285411 | Dorking, Pixham Lane S Wks | 517700 | 150500 | good | Original selection |
| 34 | 314073 | Mile Oak P Sta | 524300 | 107900 | good | Original selection |
| 35 | 311123 | Balcombe W Wks | 529000 | 131200 | OK | Original selection |
| 36 | 311001 | Poverty Bottom W Wks | 546700 | 102300 | good | Original selection |
| 37 | 293375 | Falconhurst | 547000 | 142600 | OK | Original selection |
| 63 | 453197 | Blockley, Greenway Resr | 416000 | 235100 | OK | Original selection |
| 64 | 97263 | Whitacre New W Wks | 421600 | 291100 | good | Original selection |
| 66 | 98543 | Hartshill S Wks | 433000 | 295100 | OK | Original selection |
| 71 | 256221 | Oxford | 450900 | 207200 | OK | Original selection |
| 72 | 448540 | Rugby, Braunston | 451200 | 274900 | OK | Original selection |
| 73 | 111947 | Wigston S Wks | 459300 | 296700 | good | Original selection |
| 74 | 161728 | Wellingborough, Swanspool | 489400 | 267500 | OK | Original selection |
| 75 | 172601 | Woburn | 496400 | 236000 | OK | Original selection |
| 80 | 182074 | Odsey | 529200 | 238000 | OK | Original selection |
| 84 | 181126 | Saffron Walden, Co High School | 553200 | 237800 | OK | Original selection |
| 96 | 281629 | Hindhead W Wks | 488900 | 135900 | OK | Original selection |
| 97 | 280037 | Shepperton Lock | 507300 | 165900 | good | Original selection |
| 98 | 247536 | Heathrow | 507700 | 176700 | good | Original selection |
| 99 | 277604 | Watford, Aldenham Road P Sta | 512000 | 195800 | good | Original selection |

| | | | | | | |
|---|---|---|---|---|---|---|
| 100 | 284152 | Hampton W Wks | 513100 | 169500 | good | Original selection |
| 101 | 244569 | Darnicle Hill P Sta | 530900 | 204800 | good | Original selection |
| 102 | 242787 | Moor Place | 542200 | 218800 | good | Original selection |
| 103 | 290116 | Betsoms Hill | 543000 | 156300 | OK | Original selection |
| 104 | 290007 | Cross Ness S Wks | 548700 | 180600 | good | Original selection |
| 105 | 309730 | Hailsham, Magham Down | 560900 | 111600 | OK | Original selection |
| 106 | 310007 | Eastbourne | 561100 | 98000 | good | Original selection |
| 107 | 297880 | East Malling | 570800 | 157100 | good | Original selection |
| 109 | 295604 | Goudhurst | 572200 | 133300 | OK | Original selection, also covers Bedgebury (X571900_Y134100) which closed in 1975 |
| 110 | 297347 | Barming W Wks | 573500 | 154900 | OK | Original selection |
| 111 | 309040 | Hastings, Newgate | 580700 | 110200 | OK | Original selection |
| 112 | 306947 | Great Dixter | 582000 | 125000 | good | Original selection |
| 113 | 301985 | Ashford, Hythe Road | 601800 | 142500 | OK | Original selection |
| 114 | 302770 | Canterbury S Wks | 616900 | 159700 | good | Original selection |
| 115 | 303401 | Barham P Sta | 619900 | 150900 | good | Original selection |
| 116 | 305050 | Dover W Wks | 632200 | 142100 | good | Original selection |
| 161 | 442927 | Church Stretton S Wks No 2 | 343900 | 290900 | good | Original selection, also covers Church Stretton gauge (X343800_Y291100) which closed in 1981 |
| 162 | 443216 | Oakly Park | 349100 | 276200 | good | Original selection |
| 163 | 432251 | Newport (Salop) | 371100 | 320300 | good | Original selection |
| 164 | 435528 | Hatton Grange | 376400 | 304300 | good | Original selection |
| 165 | 438993 | Lincombe Lock | 382100 | 269300 | good | Original selection |
| 166 | 440222 | Worcester, Fort Royal Hill | 385500 | 254300 | OK | Original selection |
| 167 | 459378 | Witcombe Resr | 390400 | 215100 | OK | Original selection |
| 168 | 458896 | Cheltenham, Sandford Mead | 395300 | 221600 | OK | Original selection |
| 169 | 96712 | Highters Heath Resr | 408600 | 279200 | OK | Original selection |
| 171 | 246695 | Hampstead, Kidderpore Resr | 525200 | 185900 | OK | Original selection |
| 173 | 346876 | BRANKSOME, BOURNE VALLEY GAS WKS | 406000 | 92500 | OK | Added by SDW |
| 174 | 344052 | BRYANSTON | 387200 | 106700 | OK | Added by SDW |
| 175 | 340765 | MARTIN DOWN NO 2 | 405900 | 118800 | OK | Added by SDW |
| 178 | Not in Met Office archive | South Kingston Deverill | 384740 | 135179 | OK | Suggested by CH |

## B.3. Analysis of teleconnections

### B.3.1. Representation of seasonal and inter-annual variability

The current weather generator uses explanatory teleconnection data to model monthly observed rainfall. For the previously applied projects North Atlantic Oscillation (NAO) and Sea Surface Temperature (SST) were used with the WRE generated data also considering the East Atlantic Index (EAI).

As part of this project we have reviewed available teleconnection series with reference to data availability and an initial analysis of precipitation / teleconnection correlation across the country. Based on this initial analysis, we have analysed model outputs against various changes to the model explanatory factors for the three case study areas with existing stochastic data.

We analysed:

- Inclusion of additional explanatory factors (e.g. teleconnection series);
- Inclusion of interaction terms between the factors within the "gamlss" model which were not previously considered;
- Impact of the length of input data (due to the scarcity of teleconnection data prior to 1950).

The 'success' of a model variation has been judged against two areas:

- The model statistics including significance of factors within the model and overall model fit statistics. This has specifically been used to identify the significance of interaction terms within the gamlss model.
- The ability of the outputs to represent the observed rainfall record. This is evidenced with the use of rainfall duration plots against seasonal as well as longer inter-annual trends.

### B.3.2. Teleconnection data

This section highlights the groups of teleconnections patterns analysed in the model.

North Atlantic Oscillation (NAO)

The NAO is one of the major modes of variability of the Northern Hemisphere atmosphere. Traditionally defined as the normalised pressure difference between a station on the Azores and one on Iceland, it combines parts of the East-Atlantic and West Atlantic patterns originally identified by Wallace and Gutzler (1981) for the winter season.

Strong positive phases in the NAO tend to be associated with above average temperatures and high winter precipitation across northern Europe and strong negative phases usually lead to drier conditions.

Two sources of NAO have been analysed:

- NAO (Jones): available between 1821 – 2019, series used in previous stochastic generation projects. From Climate Research Unit, University of East Anglia.
- NAO: available between 1950 – 2019. From the NOAA (National Oceanic and Atmospheric Administration)

Sea Surface Temperature (SST):

- Sea surface temperatures, particularly warmer temperatures due to the Gulf Stream, have a significant effect on the UK climate.
- The SST datasets are available as gridded data either in absolute values or anomaly form. The original Serinaldi and Kilsby (2012) study and previously applied stochastic projects used SST anomalies averaged across the gridded data corresponding to the three 5° x 5° boxes in the domain 50°N-55°N, 10°W-5°E. These gridded boxes were chosen to analyse the relationship between rainfall and a local climate index, as the grid boxes represent an area covering England, Wales and Ireland. For consistency this same gridded region was used for comparison between the other SST datasets.

Three sources of SST have been analysed:

- HadSST2: available between 1850 – 2011, series used in the previous stochastic generation projects. From UKMO Hadley Centre
- Kaplan SST V2: available between 1856 – 2019. From the NOAA
- COBE-SST2: available 1850 – 2018. Data provided by the *NOAA/OAR/ESRL PSD, Boulder, Colorado, USA, from their Web site at https://www.esrl.noaa.gov/psd/*

East Atlantic Index (EA)

- The East Atlantic Index is structurally similar to the NAO consisting of a north-south dipole of anomaly centres spanning the North Atlantic from east to west. The anomaly centres of the EA pattern are displaced south-eastward to the approximate nodal lines of the NAO and for this reason the EA is often interpreted as a southward shifted NAO pattern. However, it contains a strong subtropical link which makes it distinct from the NAO.
- Positive phase EA values are associated with above average surface temperature in Europe in all months as well as above average precipitation over norther Europe.

Two sources of EA have been analysed:

- EAI: available between 1850 – 2016, series used in the Water Resource East analysis. Data was calculated by the Met Office for the purposes of the project.
- EA: available between 1950 – 2019. From the NOAA
- East Atlantic / Western Russia (EA/WR)
- The EAWR is one of the three prominent teleconnection patterns that affect Eurasia throughout the year. It consists of four main anomaly centres. The positive phase EAWR is associated with below average precipitation across central Europe.

One series has been analysed:

- EAWR: available between 1950 – 2019. From the NOAA

**Scandinavia (SCA)**

The Scandinavia pattern consists of a primary circulation centre over Scandinavia, with weaker centres of opposite sign over western Europe and eastern Russia. The positive phase of the SCA is associated with below average temperatures across western Europe, above average precipitation across central and southern Europe and below average precipitation across Scandinavia.

One series has been analysed:

- SCA: available 1950 – 2019. From the NOAA.

Atlantic Multidecadal Oscillation Index (AMO)

The AMO is an ongoing series of long duration changes in the sea surface temperature of the North Atlantic Ocean, with cool and warm phases that may last for 20-40 years at a time and a difference of about 1°F between extremes. The AMO affects air temperatures and rainfall over the Northern Hemisphere. It is associated with changes in the frequency of droughts and if reflected in the frequency of severe Atlantic hurricanes.

One series has been analysed:

- AMO: available between 1856 – 2019. Calculated from the Kaplan SST V2 dataset. From ESRL

### B.3.3. Teleconnection correlations

This section summarises the initial exploratory analysis of precipitation and teleconnection correlations. Figure 5.2 shows that NAO is positive correlated with rainfall in the north and west of the country, particularly during the winter months. This supports existing understanding of the influence of NAO across the country (see Serinadli and Kilsby, 2012).

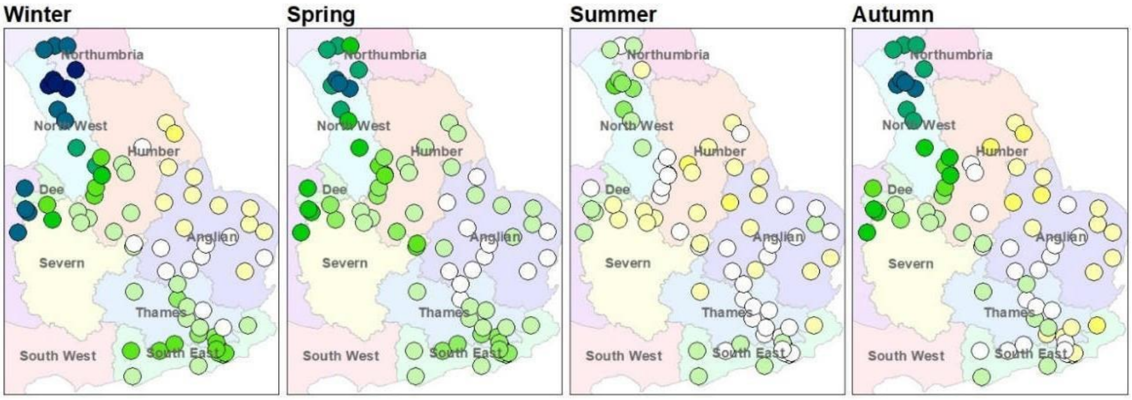



**Figure 5-2 – NAO (1950 onwards) vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

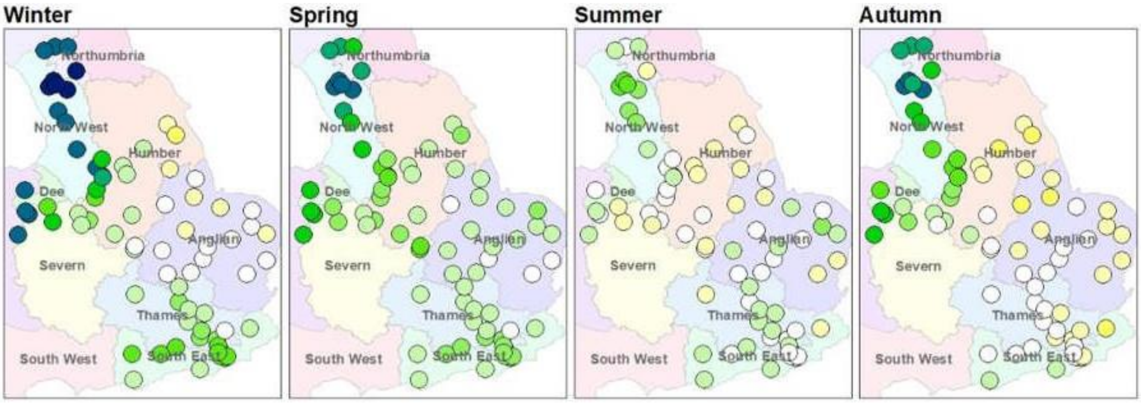



**Figure 5-3 – NAO Jones vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

Figure 5-4 shows a weaker relationship between SST and precipitation as compared to NAO however some patterns can still be observed suggesting higher SST anomalies associated with wetter winter conditions and drier summer conditions, particularly in the north west. This analysis also suggests that the HadSST series used in the previous weather generation may not be the best sea surface temperature indicator to use.

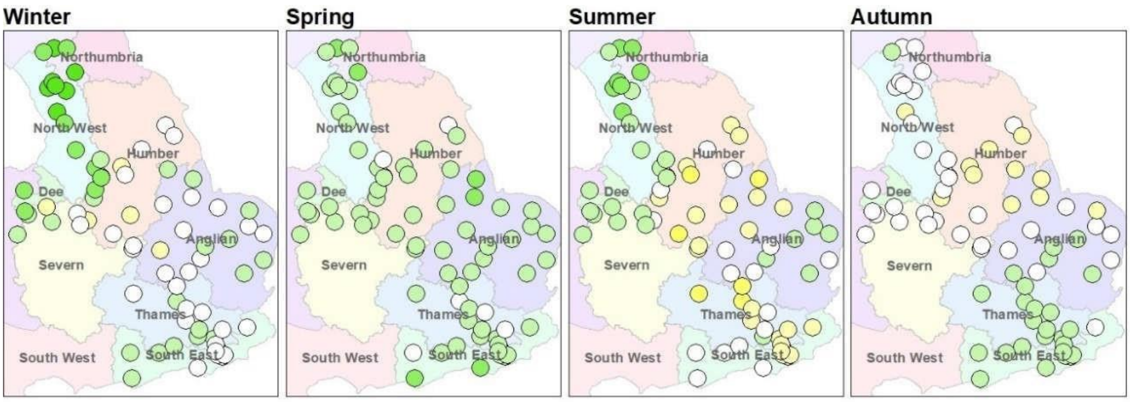



**Figure 5-4 – SST vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

The East Atlantic (EA) pattern shows a strong positive correlation of precipitation across all water resource regions and all seasons as shown in Figure XX.

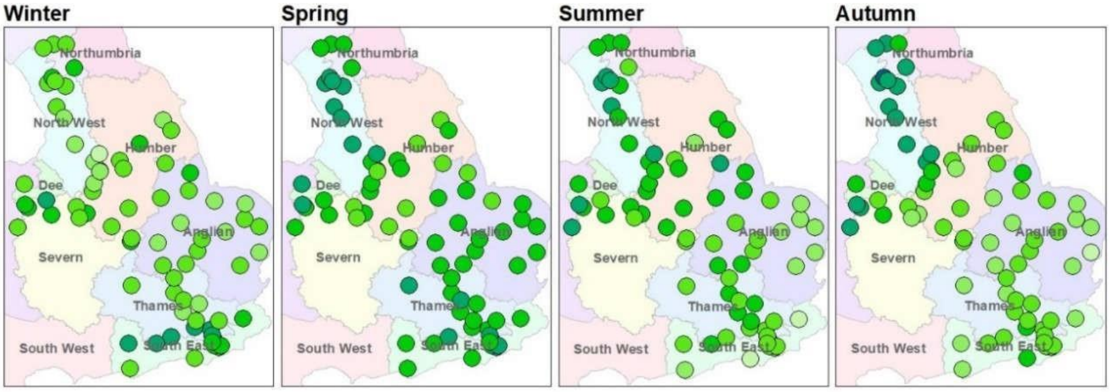



**Figure 5-5 – EA vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

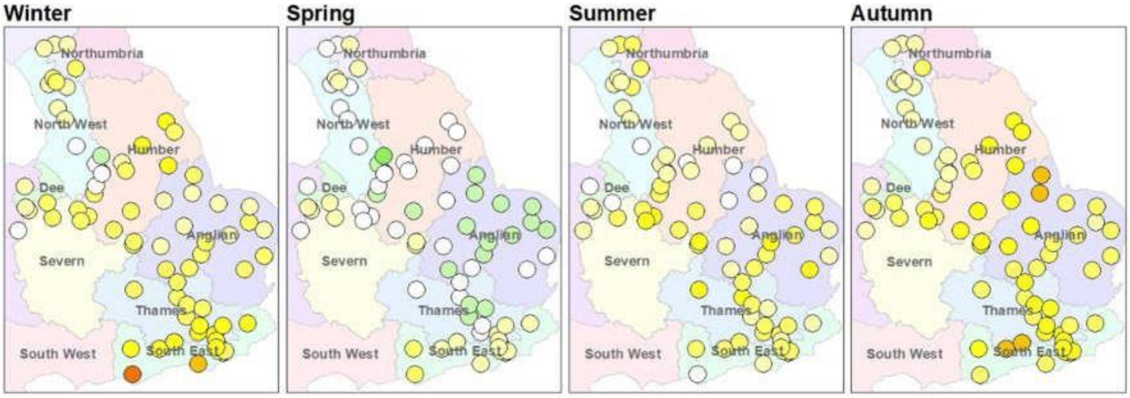



**Figure 5-6 – EA Index (calculated by Met Office for WRE) vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

The East Atlantic / West Russian (EAWR) pattern provides a strong negative indicator of precipitation in the summer and autumn months across all regions. The relationship is weakened in the south of the country (WRSE region) during winter and spring, with the inverse observed in the north west (WRW region) in winter and spring.

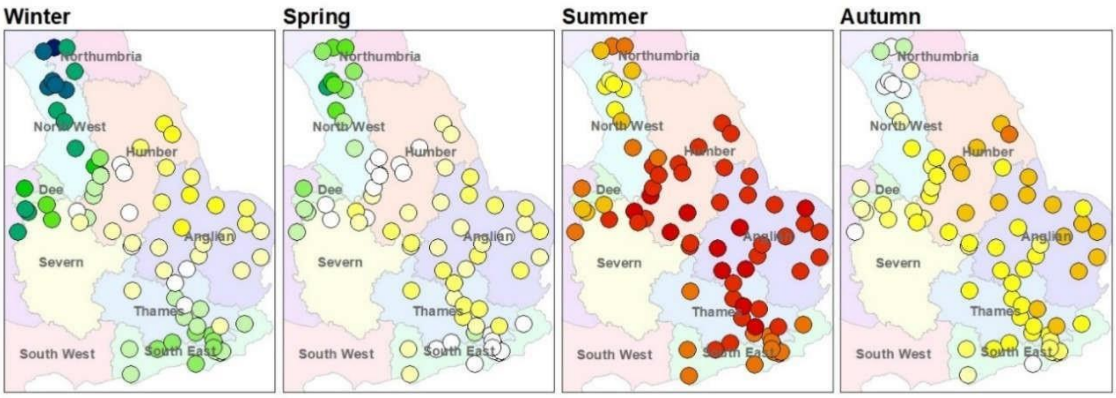



**Figure 5-7 – EA/WR vs precipitation correlations across the UK. Darker blue/green shades indicating stronger positive correlations and red strong negative correlations.**

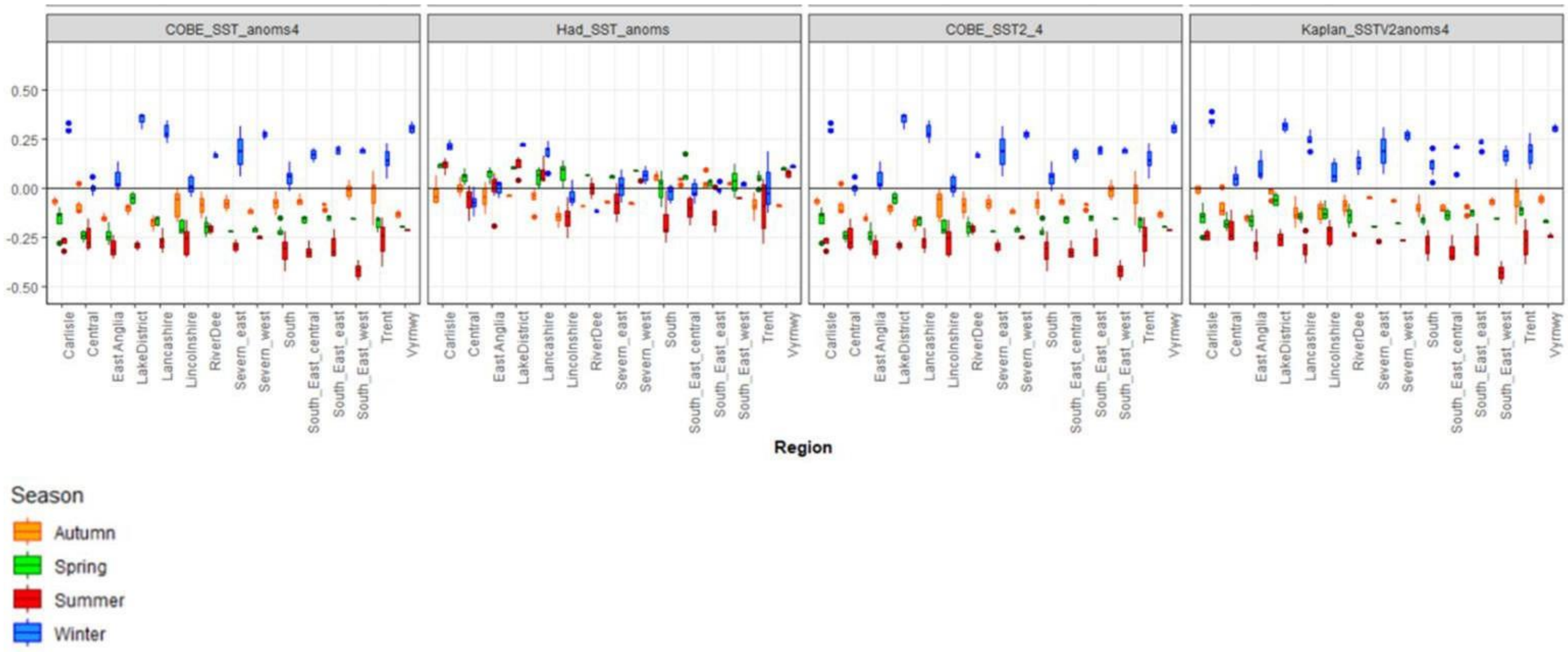



**Figure 5-8 – SST vs precipitation correlations across the UK for each season.**

The SCA pattern indicates increased precipitation totals in during winter and autumn in the south and east of the country as shown in Figure XX.

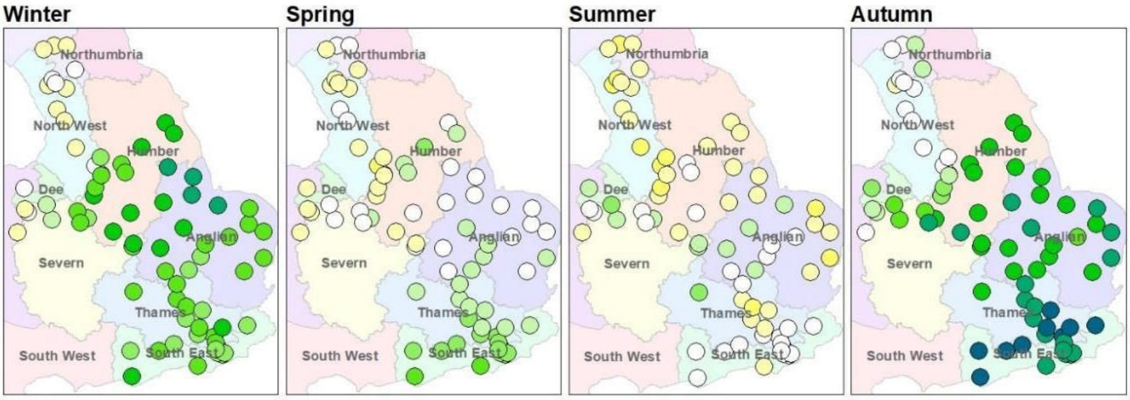



**Figure 5-9 – SCA vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

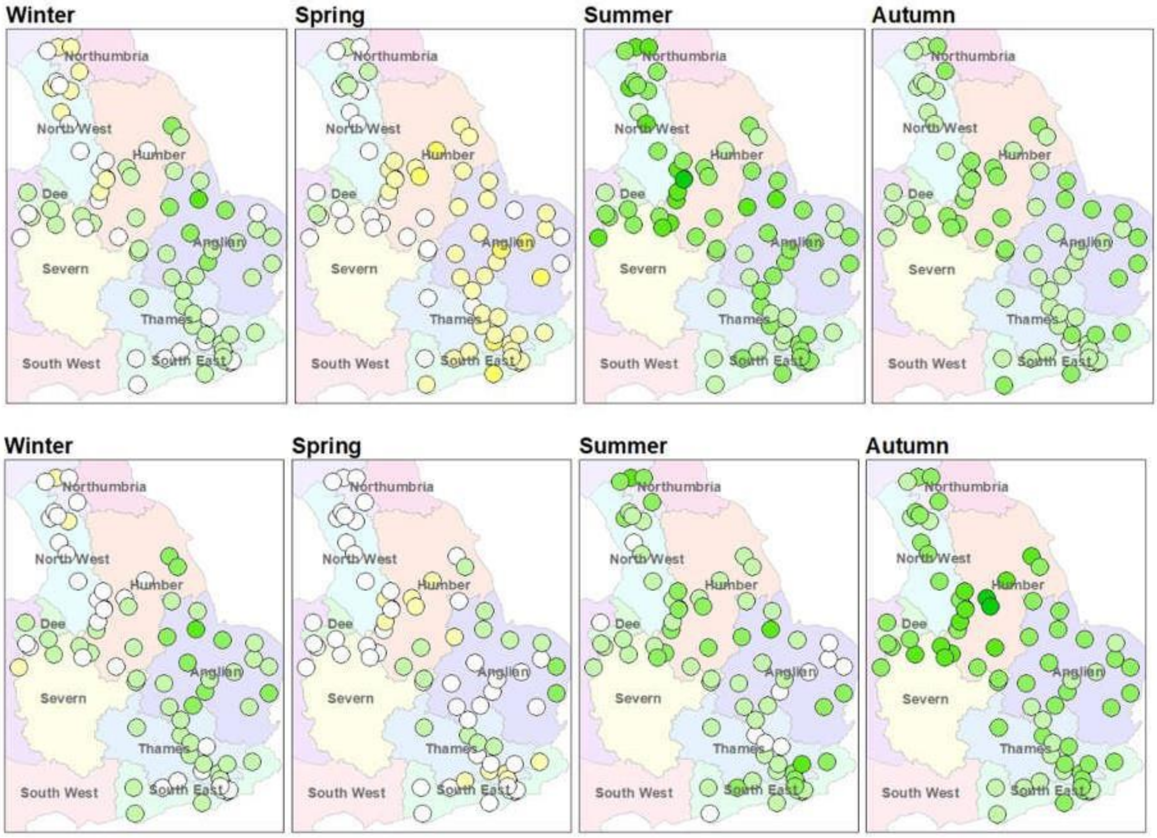



**Figure 5-10 – AMO smoothed (top) unsmoothed (bottom) vs precipitation correlations across the UK. Darker shades indicating stronger positive correlations.**

## B.4. Demonstrating the improved fit of the 1950s model over the 20th century model

### B.4.1. Models

All the models have been run with historical rainfall data from the HadUK 1km gridded dataset using observed data as outlined in the table below[24]. To maintain a sizeable quantity of stochastic data 400 replications of the 1950's models have been generated as opposed to 200 previously adopted for the stochastic work.

| Model | Region | Historical years | Teleconnections |
|---|---|---|---|
| 20th Century | WRSE | 1920 – 1997 | Main effects and interactions between:<br>• Month factor<br>• North Atlantic Oscillation<br>• Sea Surface Temperature<br>• Atlantic Multi-decadal Oscillation<br>• East Atlantic Index |
| | WRE | 1900 – 1997 | |
| | UUW | 1911 – 1997 | |
| 1950's | WRSE | 1950 – 1997 | Main effects and interactions between:<br>• Month factor<br>• North Atlantic Oscillation<br>• Sea Surface Temperature<br>• Atlantic Multidecadal Oscillation<br>• East Atlantic<br>• East Atlantic West Russia<br>• Scandinavia |
| | WRE | | |
| | UUW | | |

### B.4.2. Comparison of outputs

Several approaches have been used to compare the outputs of the models[25]:

- QQ plots of the range of stochastic replications against the observed rainfall values at multiple rainfall total metrics;
- Cumulative plots of each of the stochastic series' against observed rainfall at multiple rainfall total metrics;
- Comparison of the two models in terms of estimated rainfall return periods at multiple metrics after fitting GEV distributions to the generated stochastic data.

A detailed Atkins internal memo describes the changes and selected extremes statistic for all trial regions are summarised below.

For WRSE WRE and UU the Mean Absolute Errors of extremely low rainfall between 1:50 year and 1:500 year metrics have been reduced from -3.83 mm/month in the previous model to -2.9 mm/month in the new model (25% reduction in average errors).

For WRSE the Mean Absolute Errors have been reduced from -6.05 mm/month to -5.74 mm/month (5% reduction in average errors)

This shows a marginal improvement in the model fit even though the 1950s models were trained on a much shorter period of observed data.

The differences at individual sites can be larger and some bias correction is still required. In general, the stochastic model produces slightly higher rainfall/wetter conditions that observed.

[24] The 20th Century models have been run from the historical year used for the original generation of these datasets ranging between 1900 and 1920.

[25] Note: this comparison has been undertaken on the 'raw' outputs before any bias correction or adjustments have been applied.

### B.4.3. Summary of return period analysis to check model fits

This analysis was completed to compare the old model to the new model for sites used in the WRMP19 plans. Note that any EVA is highly sensitive to the methods chosen and in this case an automated method was use for comparison purposes only. These data should not be used for planning purposes that may require more detailed analysis.

| Metric | Region | RP | Obs | 20th Century model | 1950s model | Diff 20thC – 1950s (per month) | Diff Obs – 20thC (per month) | Diff Obs – 1950s (per month) |
|---|---|---|---|---|---|---|---|---|
| April - August | UUW | 50 | 261.8 | 276.5 | 267.9 | 1.7 | -2.9 | -1.2 |
| | UUW | 100 | 221.4 | 257.4 | 248.0 | 1.9 | -7.2 | -5.3 |
| | UUW | 200 | 180.1 | 240.8 | 230.6 | 2.0 | -12.1 | -10.1 |
| | UUW | 500 | 123.7 | 221.7 | 210.2 | 2.3 | -19.6 | -17.3 |
| | WRSE | 50 | 116.3 | 158.4 | 147.4 | 2.2 | -8.4 | -6.2 |
| | WRSE | 100 | 81.6 | 144.5 | 132.4 | 2.4 | -12.6 | -10.2 |
| | WRSE | 200 | 47.2 | 132.3 | 119.4 | 2.6 | -17.0 | -14.4 |
| | WRSE | 500 | 1.6 | 118.2 | 104.3 | 2.8 | -23.3 | -20.5 |
| | WRE | 50 | 144.0 | 159.1 | 153.2 | 1.2 | -3.0 | -1.8 |
| | WRE | 100 | 121.2 | 146.3 | 139.9 | 1.3 | -5.0 | -3.7 |
| | WRE | 200 | 99.1 | 135.2 | 128.3 | 1.4 | -7.2 | -5.8 |
| | WRE | 500 | 70.3 | 122.4 | 114.7 | 1.5 | -10.4 | -8.9 |
| April - September | UUW | 50 | 365.1 | 354.5 | 340.3 | 2.4 | 1.8 | 4.1 |
| | UUW | 100 | 337.8 | 331.0 | 314.1 | 2.8 | 1.1 | 4.0 |
| | UUW | 200 | 311.7 | 310.4 | 291.2 | 3.2 | 0.2 | 3.4 |
| | UUW | 500 | 278.4 | 286.7 | 264.5 | 3.7 | -1.4 | 2.3 |
| | WRSE | 50 | 195.5 | 207.0 | 190.3 | 2.8 | -1.9 | 0.9 |
| | WRSE | 100 | 176.8 | 191.1 | 171.0 | 3.4 | -2.4 | 1.0 |
| | WRSE | 200 | 160.5 | 177.3 | 154.1 | 3.9 | -2.8 | 1.1 |
| | WRSE | 500 | 141.4 | 161.3 | 134.5 | 4.5 | -3.3 | 1.2 |
| | WRE | 50 | 199.6 | 199.1 | 193.9 | 0.9 | 0.1 | 1.0 |
| | WRE | 100 | 186.9 | 184.4 | 177.4 | 1.2 | 0.4 | 1.6 |
| | WRE | 200 | 176.0 | 171.6 | 162.9 | 1.5 | 0.7 | 2.2 |
| | WRE | 500 | 163.6 | 156.8 | 145.9 | 1.8 | 1.1 | 3.0 |
| January - August | UUW | 50 | 573.1 | 540.3 | 543.1 | -0.3 | 4.1 | 3.7 |
| | UUW | 100 | 549.7 | 513.2 | 513.5 | 0.0 | 4.6 | 4.5 |
| | UUW | 200 | 529.5 | 489.6 | 486.2 | 0.4 | 5.0 | 5.4 |
| | UUW | 500 | 506.0 | 462.5 | 452.5 | 1.3 | 5.4 | 6.7 |
| | WRSE | 50 | 243.2 | 309.3 | 304.2 | 0.6 | -8.3 | -7.6 |
| | WRSE | 100 | 184.3 | 289.5 | 283.2 | 0.8 | -13.2 | -12.4 |
| | WRSE | 200 | 124.4 | 272.3 | 265.0 | 0.9 | -18.5 | -17.6 |

| Metric | Region | RP | Obs | 20th Century model | 1950s model | Diff 20thC – 1950s (per month) | Diff Obs – 20thC (per month) | Diff Obs – 1950s (per month) |
|---|---|---|---|---|---|---|---|---|
| | WRSE | 500 | 43.1 | 252.4 | 243.7 | 1.1 | -26.2 | -25.1 |
| | WRE | 50 | 265.3 | n/a | 285.3 | n/a | n/a | -2.5 |
| | WRE | 100 | 237.7 | n/a | 268.4 | n/a | n/a | -3.8 |
| | WRE | 200 | 212.2 | n/a | 253.4 | n/a | n/a | -5.2 |
| | WRE | 500 | 180.6 | n/a | 235.9 | n/a | n/a | -6.9 |
| October - September | UUW | 50 | 967.5 | 972.3 | n/a | n/a | -0.4 | n/a |
| | UUW | 100 | 924.9 | 931.0 | n/a | n/a | -0.5 | n/a |
| | UUW | 200 | 888.0 | 895.1 | n/a | n/a | -0.6 | n/a |
| | UUW | 500 | 845.3 | 854.1 | n/a | n/a | -0.7 | n/a |
| | WRSE | 50 | 501.7 | 551.8 | n/a | n/a | -4.2 | n/a |
| | WRSE | 100 | 459.8 | 516.6 | n/a | n/a | -4.7 | n/a |
| | WRSE | 200 | 423.6 | 485.5 | n/a | n/a | -5.2 | n/a |
| | WRSE | 500 | 381.6 | 448.9 | n/a | n/a | -5.6 | n/a |
| | WRE | 50 | 460.7 | 498.8 | 480.9 | 1.5 | -3.2 | -1.7 |
| | WRE | 100 | 426.0 | 474.0 | 455.4 | 1.5 | -4.0 | -2.5 |
| | WRE | 200 | 394.3 | 451.3 | 433.2 | 1.5 | -4.7 | -3.2 |
| | WRE | 500 | 355.6 | 423.6 | 407.2 | 1.4 | -5.7 | -4.3 |
| January - December | UUW | 50 | 988.2 | 969.8 | 962.8 | 0.6 | 1.5 | 2.1 |
| | UUW | 100 | 932.7 | 929.8 | 920.9 | 0.7 | 0.2 | 1.0 |
| | UUW | 200 | 878.2 | 894.9 | 884.5 | 0.9 | -1.4 | -0.5 |
| | UUW | 500 | 806.7 | 854.9 | 842.1 | 1.1 | -4.0 | -3.0 |
| | WRSE | 50 | 565.7 | 559.1 | n/a | n/a | 0.6 | n/a |
| | WRSE | 100 | 514.3 | 528.9 | n/a | n/a | -1.2 | n/a |
| | WRSE | 200 | 463.4 | 502.7 | n/a | n/a | -3.3 | n/a |
| | WRSE | 500 | 396.3 | 472.3 | n/a | n/a | -6.3 | n/a |
| | WRE | 50 | 516.2 | 496.2 | 490.3 | 0.5 | 1.7 | 2.2 |
| | WRE | 100 | 495.7 | 475.6 | 466.5 | 0.8 | 1.7 | 2.4 |
| | WRE | 200 | 476.8 | 458.0 | 445.9 | 1.0 | 1.6 | 2.6 |
| | WRE | 500 | 453.5 | 437.9 | 421.8 | 1.3 | 1.3 | 2.6 |
| October - March | UUW | 50 | 471.9 | 478.6 | 472.5 | 1.0 | -1.1 | -0.1 |
| | UUW | 100 | 432.1 | 448.8 | 442.4 | 1.1 | -2.8 | -1.7 |
| | UUW | 200 | 394.8 | 422.9 | 416.2 | 1.1 | -4.7 | -3.6 |
| | UUW | 500 | 348.1 | 393.2 | 385.9 | 1.2 | -7.5 | -6.3 |
| | WRSE | 50 | 260.1 | 273.9 | 280.8 | -1.1 | -2.3 | -3.4 |
| | WRSE | 100 | 237.7 | 254.5 | 262.3 | -1.3 | -2.8 | -4.1 |

| Metric | Region | RP | Obs | 20th Century model | 1950s model | Diff 20thC – 1950s (per month) | Diff Obs – 20thC (per month) | Diff Obs – 1950s (per month) |
|---|---|---|---|---|---|---|---|---|
| | WRSE | 200 | 218.2 | 237.6 | 246.3 | -1.5 | -3.2 | -4.7 |
| | WRSE | 500 | 195.5 | 218.1 | 227.7 | -1.6 | -3.8 | -5.4 |
| | WRE | 50 | 218.0 | 223.3 | 223.1 | 0.0 | -0.9 | -0.8 |
| | WRE | 100 | 205.1 | 208.4 | 208.7 | 0.0 | -0.5 | -0.6 |
| | WRE | 200 | 194.3 | 195.5 | 196.2 | -0.1 | -0.2 | -0.3 |
| | WRE | 500 | 182.1 | 180.6 | 181.7 | -0.2 | 0.3 | 0.1 |
| November - February | UUW | 50 | 268.6 | 285.9 | 274.2 | 2.9 | -4.3 | -1.4 |
| | UUW | 100 | 220.3 | 262.0 | 253.8 | 2.0 | -10.4 | -8.4 |
| | UUW | 200 | 171.4 | 241.4 | 237.1 | 1.1 | -17.5 | -16.4 |
| | UUW | 500 | 105.3 | 217.9 | 218.6 | -0.2 | -28.1 | -28.3 |
| | WRSE | 50 | 152.4 | 170.6 | 167.1 | 0.9 | -4.5 | -3.7 |
| | WRSE | 100 | 132.7 | 155.2 | 151.8 | 0.9 | -5.6 | -4.8 |
| | WRSE | 200 | 115.1 | 141.8 | 138.3 | 0.9 | -6.7 | -5.8 |
| | WRSE | 500 | 94.1 | 126.5 | 122.5 | 1.0 | -8.1 | -7.1 |
| | WRE | 50 | 132.4 | 142.1 | 142.6 | -0.1 | -2.4 | -2.6 |
| | WRE | 100 | 122.4 | 132.4 | 131.6 | 0.2 | -2.5 | -2.3 |
| | WRE | 200 | 114.0 | 124.2 | 121.6 | 0.7 | -2.6 | -1.9 |
| | WRE | 500 | 104.4 | 115.1 | 109.5 | 1.4 | -2.7 | -1.3 |
| 18 months to September | UUW | 50 | 1431.2 | 1449.8 | n/a | n/a | -1.0 | n/a |
| | UUW | 100 | 1356.5 | 1394.9 | n/a | n/a | -2.1 | n/a |
| | UUW | 200 | 1286.7 | 1347.0 | n/a | n/a | -3.3 | n/a |
| | UUW | 500 | 1199.7 | 1292.0 | n/a | n/a | -5.1 | n/a |
| | WRSE | 50 | 823.5 | 865.2 | 859.1 | 0.3 | -2.3 | -2.0 |
| | WRSE | 100 | 774.1 | 828.2 | 820.5 | 0.4 | -3.0 | -2.6 |
| | WRSE | 200 | 728.8 | 796.2 | 787.0 | 0.5 | -3.7 | -3.2 |
| | WRSE | 500 | 673.2 | 759.1 | 748.0 | 0.6 | -4.8 | -4.2 |
| | WRE | 50 | 744.5 | 769.8 | 760.2 | 0.5 | -1.4 | -0.9 |
| | WRE | 100 | 691.4 | 739.0 | 727.3 | 0.7 | -2.6 | -2.0 |
| | WRE | 200 | 638.0 | 712.3 | 698.7 | 0.8 | -4.1 | -3.4 |
| | WRE | 500 | 566.4 | 681.4 | 665.4 | 0.9 | -6.4 | -5.5 |
| 24 months to September | UUW | 50 | 2199.9 | 2100.2 | 2099.5 | 0.0 | 4.2 | 4.2 |
| | UUW | 100 | 2127.7 | 2026.9 | 2033.1 | -0.3 | 4.2 | 3.9 |
| | UUW | 200 | 2054.3 | 1962.0 | 1974.8 | -0.5 | 3.8 | 3.3 |
| | UUW | 500 | 1954.4 | 1886.7 | 1906.5 | -0.8 | 2.8 | 2.0 |
| | WRSE | 50 | 1270.3 | 1258.8 | 1263.6 | -0.2 | 0.5 | 0.3 |

| Metric | Region | RP | Obs | 20th Century model | 1950s model | Diff 20thC – 1950s (per month) | Diff Obs – 20thC (per month) | Diff Obs – 1950s (per month) |
|---|---|---|---|---|---|---|---|---|
| | WRSE | 100 | 1205.9 | 1212.3 | 1217.5 | -0.2 | -0.3 | -0.5 |
| | WRSE | 200 | 1142.2 | 1172.0 | 1177.4 | -0.2 | -1.2 | -1.5 |
| | WRSE | 500 | 1058.2 | 1125.3 | 1130.9 | -0.2 | -2.8 | -3.0 |
| | WRE | 50 | 1108.4 | n/a | 1087.5 | n/a | n/a | 0.9 |
| | WRE | 100 | 1071.3 | n/a | 1052.9 | n/a | n/a | 0.8 |
| | WRE | 200 | 1035.3 | n/a | 1022.5 | n/a | n/a | 0.5 |
| | WRE | 500 | 988.6 | n/a | 986.6 | n/a | n/a | 0.1 |

Note: This analysis takes a specific approach of automated fitting of extreme value distributions to the driest years only. It is not a traditional AMAX or POT style analysis.

## B.5. Data delivery

### B.5.1. Data checking and review

At each stage of the weather generation process the outputs are validated using a range of visualisations and at least 15 total rainfall metrics over different durations. In addition, Q-Q ranked rainfall plots and percentile plots are used to compare the stochastic data to the observed data for the calibration period and an independent data set (1902-1949) to demonstrate that the contemporary stochastic model can fit an historic period of low rainfall from the beginning of the 20th century.

A large amount of the checking process is done automatically but final checks are completed manually. This includes some Extreme Value Analysis (EVA), annual time series checks and independent checks against rainfall from 1902-1949. As well the rainfall generator Python code, additional checking tools in R and Excel are being made available to the WRSE modelling team. Some further details are provided in Appendix A.

When reviewing individual sites, it is important to consider that the data are calibrated to get good results across the whole region and retain coherence between sites. Any bias corrections made to improve the fits are completed on groups of sites called “bias regions” (Fig. 1) and are generally very small. Some individual sites may appear wetter or drier than observed for different metrics. The transposition of data to catchments provides an opportunity to align the stochastics with the baseline climatology of each river basin.

## B.6. Files provided

The **inputs folder** contains the baseline daily and monthly rainfall and PET data sets from which the 1950 to 1997 rainfall was used to train the stochastic weather generator.

In addition, the **teleconnection data** are provided and file containing **bias regions**, which are used in the bias correction process (see Appendix A).

The main outputs are in the **daily folder**, include all generated precipitation and PET series. A figures sub-folder provides a large amount of percentile plots for visual checking of results. The precipitation sites have an ID number that is linked to each location (see Appendix B).

Finally, additional outputs are provided at the monthly scale in the **monthly_rain** folder

The **config.yaml** file details the stochastic weather generator parameters.

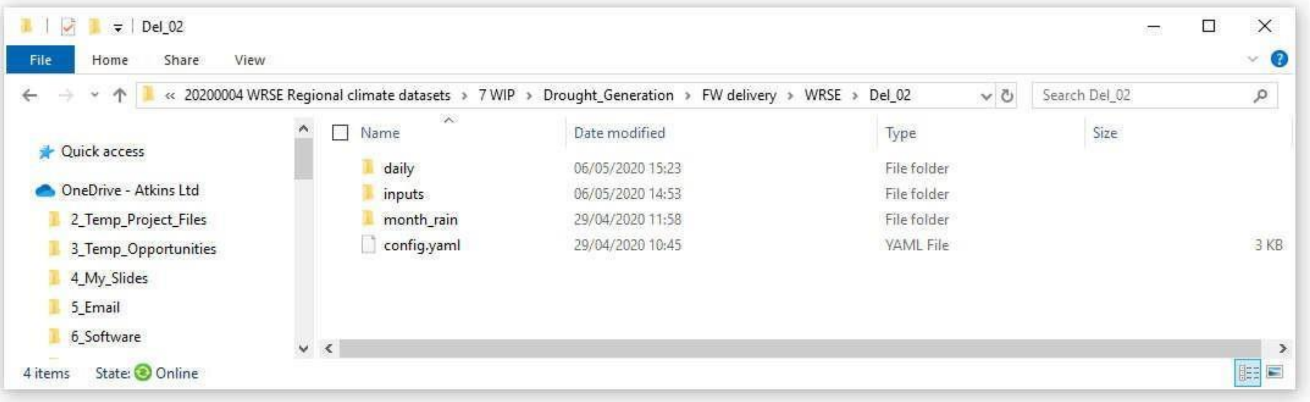



**Figure 2. Screenshot of files provided**

### B.6.1. License for data use

Atkins licenses use of these data to the Client free of charge and on a non-exclusive, worldwide basis to such extent as is necessary to enable WRSE to make reasonable use of the Deliverables and the Services in relation to the Project[26].

The stochastic data are based on Had UK 1km data, which should be cited as follows:

Met Office; Hollis, D.; McCarthy, M.; Kendon, M.; Legg, T.; Simpson, I. (2019): HadUK-Grid Gridded Climate Observations on a 1km grid over the UK, v1.0.1.0 (1862-2018). Centre for Environmental Data Analysis, 14 November 2019. doi:10.5285/d134335808894b2bb249e9f222e2eca8.

http://dx.doi.org/10.5285/d134335808894b2bb249e9f222e2eca8

## B.7. WRSE Drought Scorecards

The data were summarised in a series of scorecards, an example is shown below.

**Table 3 Characteristics of annual rainfall droughts from 400 stochastic series, sorted based on proportion of sites in extreme droughts (Flags indicate relative magnitude and bars indicate the proportion of 43 sites in categories based on frequency, >2000 years, 200-2000 years, < 200 years)**

[26] This includes providing access to the Environment Agency and other regional groups, which will fund their own climate data set development.

| | | Deficit (% of LTA) | | | | | Whole Region Drought Status | | |
|---|---|---|---|---|---|---|---|---|---|
| Order | Replicate | SW | SC | SE | Thames NW | Thames SE | Extreme | Severe | Moderate |
| 1 | 123 | 41% | 38% | 40% | 44% | 41% | 91% | 9% | 0% |
| 2 | 177 | 42% | 38% | 46% | 59% | 71% | 60% | 14% | 26% |
| 3 | 393 | 46% | 40% | 51% | 61% | 45% | 47% | 49% | 5% |
| 4 | 204 | 45% | 47% | 63% | 64% | 39% | 47% | 26% | 28% |
| 5 | 66 | 50% | 42% | 47% | 56% | 49% | 42% | 51% | 7% |
| 6 | 305 | 49% | 53% | 41% | 53% | 38% | 42% | 58% | 0% |
| 7 | 94 | 57% | 44% | 49% | 50% | 44% | 40% | 51% | 9% |
| 8 | 337 | 38% | 57% | 64% | 43% | 48% | 30% | 37% | 33% |
| 9 | 379 | 46% | 47% | 50% | 52% | 48% | 30% | 70% | 0% |
| 10 | 292 | 51% | 45% | 48% | 56% | 48% | 28% | 67% | 5% |
| 11 | 141 | 54% | 47% | 48% | 55% | 46% | 26% | 72% | 2% |
| 12 | 231 | 52% | 57% | 55% | 48% | 37% | 26% | 56% | 19% |
| 13 | 399 | 60% | 45% | 60% | 63% | 43% | 23% | 42% | 35% |
| 14 | 57 | 58% | 50% | 47% | 54% | 43% | 23% | 63% | 14% |
| 15 | 37 | 58% | 54% | 43% | 56% | 54% | 23% | 47% | 30% |
| 16 | 131 | 62% | 54% | 55% | 62% | 42% | 21% | 35% | 44% |
| 17 | 143 | 61% | 46% | 48% | 66% | 64% | 21% | 28% | 51% |
| 18 | 230 | 44% | 56% | 54% | 62% | 52% | 19% | 60% | 21% |
| 19 | 49 | 59% | 62% | 63% | 62% | 42% | 16% | 26% | 58% |
| 20 | 113 | 49% | 49% | 61% | 51% | 46% | 14% | 70% | 16% |
| 21 | 47 | 53% | 51% | 51% | 52% | 46% | 14% | 84% | 2% |
| 22 | 386 | 60% | 50% | 47% | 66% | 51% | 14% | 63% | 23% |
| 23 | 185 | 62% | 64% | 52% | 53% | 44% | 14% | 40% | 47% |
| 24 | 22 | 49% | 47% | 53% | 48% | 50% | 12% | 86% | 2% |
| 25 | 80 | 47% | 65% | 64% | 57% | 56% | 12% | 28% | 60% |
| 26 | 320 | 61% | 51% | 47% | 66% | 50% | 12% | 63% | 26% |
| 27 | 264 | 47% | 60% | 63% | 63% | 62% | 12% | 9% | 79% |
| 28 | 378 | 54% | 50% | 64% | 53% | 50% | 9% | 56% | 35% |
| 29 | 391 | 53% | 50% | 52% | 55% | 45% | 9% | 91% | 0% |
| 30 | 28 | 56% | 51% | 50% | 50% | 47% | 9% | 84% | 7% |
| 31 | 193 | 62% | 55% | 57% | 51% | 43% | 9% | 56% | 35% |
| 32 | 112 | 50% | 63% | 63% | 47% | 52% | 9% | 42% | 49% |
| 33 | 384 | 62% | 58% | 60% | 46% | 59% | 7% | 12% | 81% |
| 34 | 56 | 53% | 49% | 53% | 61% | 50% | 7% | 81% | 12% |
| 35 | 64 | 64% | 59% | 63% | 53% | 46% | 7% | 40% | 53% |
| 36 | 24 | 49% | 55% | 66% | 62% | 63% | 7% | 30% | 63% |
| 37 | 50 | 56% | 54% | 58% | 48% | 61% | 5% | 49% | 47% |
| 38 | 244 | 50% | 54% | 57% | 63% | 55% | 5% | 53% | 42% |
| 39 | 155 | 63% | 53% | 51% | 60% | 45% | 5% | 60% | 35% |
| 40 | 302 | 51% | 55% | 55% | 59% | 52% | 5% | 81% | 14% |
| 41 | 34 | 58% | 57% | 52% | 66% | 48% | 5% | 58% | 37% |
| 42 | 132 | 55% | 49% | 61% | 63% | 61% | 5% | 47% | 49% |
| 43 | 191 | 53% | 55% | 54% | 53% | 53% | 2% | 79% | 19% |
| 44 | 145 | 53% | 52% | 52% | 58% | 48% | 2% | 88% | 9% |
| 45 | 124 | 57% | 55% | 56% | 52% | 51% | 2% | 74% | 23% |
| 46 | 227 | 54% | 50% | 54% | 56% | 51% | 2% | 88% | 9% |
| 47 | 139 | 54% | 47% | 52% | 61% | 54% | 2% | 81% | 16% |
| 48 | 93 | 56% | 55% | 55% | 54% | 48% | 2% | 79% | 19% |
| 49 | 363 | 49% | 50% | 66% | 57% | 62% | 2% | 53% | 44% |
| 50 | 59 | 54% | 52% | 55% | 61% | 56% | 2% | 63% | 35% |

Run 141: Extreme drought in Thames SE and South Central/East

Run 131: Extreme drought in Thames SE and Severe across the region

Run 230: Extreme drought in Hampshire and Severe across the region

Run 124, 59: Severe across the region

## Files provided

The following files are provided:

Excel template for ranking and sorting stochastic data for all sites

CSV files for stochastic data summarised by site and by metric

# Appendix C. SWOT analysis of climate change products

This appendix includes a full review of UKCP data sets and example UKCP outputs for regions in England and Wales.

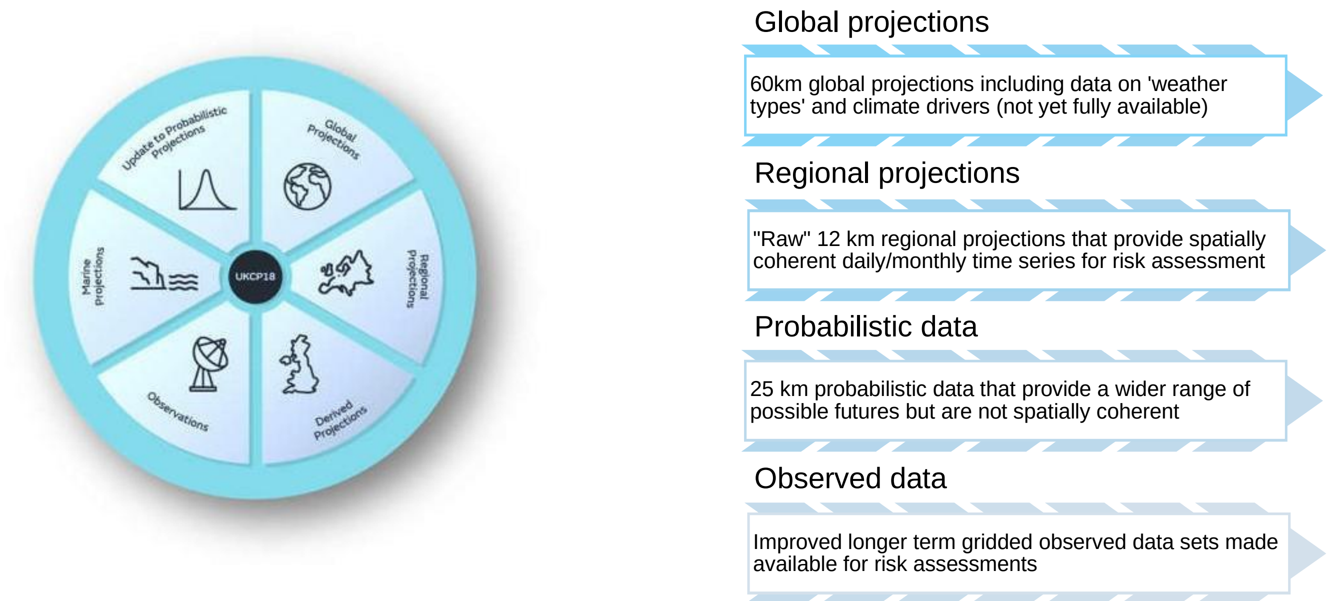
## C.1. UK Climate Projections 2018 (UKCP18)

In November 2018 the UK Met Office released a new set of climate change projections for the UK (UKCP18) which are based on the latest versions of the Met Office Hadley Centre climate models and provide an update to the previous set of projections. The new UKCP18 projections are broadly consistent with earlier projections (UKCP09) showing an increased chance of warmer, wetter winters and hotter, drier summers along with an increase in the frequency and intensity of extreme climatic events[27]. UKCP18 provides a larger range of data sets, tools and capabilities introducing further options and choices for risk assessments, including the application to regional water resources planning. The key data products are summarised in Figure 2.1; the Derived Projections and new UKCP Local data are of less relevance for regional water resources planning and are not considered in this report.

### C.1.1. Overview of UKCP data sets

Detailed background information on UKCP including guidance and caveats[28] are provided on the Met Office web pages. This section reviews some of the main data sets drawing our relevant points **for regional water resources planning.** The projections were published in late 2018, but some products are yet to be delivered including data sets of North Atlantic Oscillation (NAO) indices and weather types, which are of interest for the stochastic generation of droughts. The “UKCP Local” 2.2km are a higher resolution version of the RCMs, which have been promoted for assessment of heavy rainfall and other extremes. These are relevant for water resources planning at the more local scale but were out of scope for this study. There are no new H++ scenarios[29], which were used by some companies in the last round of plans (Wade et al., 2015).

**Figure 5-11 - An overview of Met Office UKCP Products and their relevance to water resources planning**




[27] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp-headline-findings-v2.pdf and https://www.metoffice.gov.uk/research/approach/collaboration/ukcp/
[28] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---caveats-and-limitations.pdf
[29] https://www.theccc.org.uk/publication/met-office-for-the-asc-developing-h-climate-change-scenarios/

## C.1.2. Global Climate Models

A new set of GCM experiments have been developed for UKCP which combines the latest Met Office modelling with models from other research centres that have passed some screening tests to be included in the UKCP product. The data set includes 'GC3.05-PPE' – a new 15-member simulation of the global system at 60km resolution and a further 13 Coupled Model Inter-comparison Project (CMIP5) models (CMIP5-13). The former models were used to drive the 12km RCM simulations for the UK and Europe.

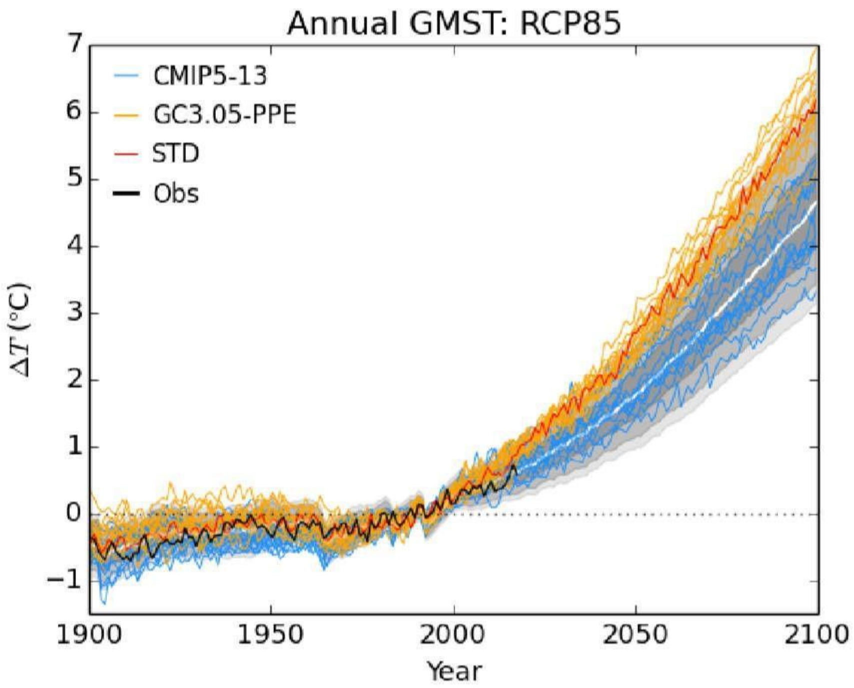
It is unlikely that global models would be downscaled for use in UK water resources planning because several other products have been made available by the Met Office (Figure 2.1). However, they are relevant because they provide a broader context for UKCP RCMs, highlight some weaknesses in the Hadley Centre model that carry through to the RCMs and include some data that could be applied in future water resources projects (e.g. a filtered set of CMIP5 models and UKCP Weather Types). The global data could be used to provide a simple set of change factors for England and Wales using downscaling and bias correction methods (Section 3.1), but most companies are expected to use the probabilistic data.

The Met Office UKCP Science Report provides detailed information on the evidence used for UKCP including the global models and how the Met Office models compare to the results from other modelling centres (Lowe *et al.,* 2018). The Met Office models sit at the "hot end" of the global ensemble (Figure 2.2) and as these models are used to drive the RCMs the high temperature uplifts will carry through to all RCM time series. The research literature has highlighted that the Met Office models are particularly hot and dry, offered some explanations behind this and suggested that these "hot and dry" models should be excluded from ensembles (e.g. Vogel, et al 2018). This has implications for the UK water industry because if plans are based *only on* these models, their validity could be challenged. This issue is discussed further in Section 4.

**Table 5-1 - SWOT of UKCP Global Climate Models**

| Strengths | Weaknesses |
|---|---|
| Provides an ensemble of baseline conditions (28 models), with a greater range than the observed data.<br>Includes a filtered set of the "best" 13 CMIP models as well as the Met Office Perturbed Physics Ensemble (PPE) models.<br>The CMIP5 models in the ensemble cover a reasonable range of the changes reported in UKCP probabilistic data.<br>Changes are spatially and temporally coherent across the UK.<br>Available for a wider set of variables (that are physically consistent) than are available from the probabilistic projections.<br>Will include Weather Types and other indicators that could be used for stochastic weather generation. | Relatively coarse resolution compared to other UKCP products.<br>Only available for RCP8.5, a scenario with relatively high rates of warming.<br>The Met Office PPE (15 models) is substantially warmer and drier than CMIP5 global projections, which is probably linked to the land-surface scheme used (Vogel et al., 2018).<br>Application of the CMIP5 models would require spatial downscaling as well as bias correction. |
| **Opportunities** | **Threats** |
| Provides a 28 member time series, which can be used to explore changes in climate over the next 80 years.<br>The Met office models could be used for stress testing extreme climate change at the margins of the global RCP8.5 ensemble. | Met Office PPE models simulate much higher rates of warming than the CMIP5 ensemble, which may undermine credibility of GCM and RCM outputs.<br>See Figure 5-12and further discussion in Section 4. |
| **Evidence** | **References** |
| The Met Office UKCP Land Projections: Science Report (Murphy *et al*., 2018) | Lowe *et al.* (2018)<br>Vogel *et al.* (2018) |

**Figure 5-12 - Historical and future changes in annual Global Mean Surface Temperature (GMST) from 1990-2100, relative to 1981-2000, from Strands 1 (probabilistic) and 2 (GCMs) of UKCP18, with future changes for the RCP8.5 emissions scenario**




Notes: STD ~ Standard Perturbed Physics Ensemble (PPE) Variant; the grey shaded areas are the equivalent probabilistic data, with white line indicating the median.

## C.1.3. Probabilistic data

The future probabilistic projections in UKCP18 are an update to those produced for UKCP09. The probabilities indicate how much the evidence from models and observations taken together support a particular future climate outcome. The projections are available for four different RCPs – 2.6, 4.5, 6.0 and 8.5 as well the scenario A1B, which was the Medium emissions scenario in UKCP09.

In the previous round of WRMPs most companies used the Medium emissions scenario for water resources planning but some also considered the UKCP09 High emissions scenario[30]. In UKCP18 there are 3000 possible climate outcomes for each RCP and future time period, whereas there were 10000 possible outcomes for each UKCP09 emissions scenario. Typically, a sub-sample of probabilistic data (e.g. 20 or 100 scenarios) are used for hydrological and water resources systems modelling (Thames Water, 2019).

The UKCP18 headline findings are similar to UKCP09 (Figure 2.3) but the move to RCPs means that the industry will need to consider different scenarios in order to understand the full range of possible climate outcomes. RCP6.0 is the closest to A1B (Medium emissions) but RCP8.5 is often used for risk assessment purposes. Some authors argue that the likelihood of RCP8.5 is reducing due to our efforts to reduce emissions[31] but observed carbon concentrations in the atmosphere continue to rise at a rate consistent with this scenario[32]. The range of possible outcomes in UKCP18 RCP8.5 probabilistic data cover almost all of the other scenarios.

The strengths and weaknesses of the available probabilistic data are summarised in Table 2-2.

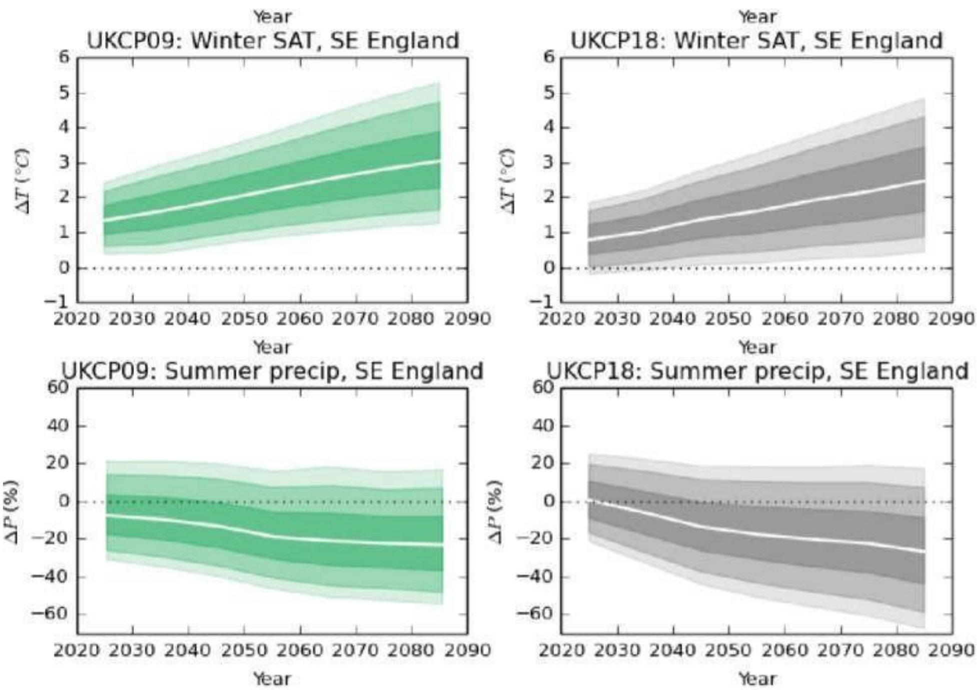
**Table 5-2 - SWOT of UKCP probabilistic data**

| Strengths | Weaknesses |
| --- | --- |

[30] Water Resources East and Anglian Water Services considered High Emissions and WRE also applied the UKCP09 Spatially Coherent Projections (SCPs), an 11-member ensemble, for regional planning rather than the probabilistic data.
[31] https://www.nature.com/magazine-assets/d41586-020-00177-3/d41586-020-00177-3.pdf
[32] https://www.esrl.noaa.gov/gmd/ccgg/trends/

| | |
|---|---|
| Data are available for all RCP scenarios and for different future time periods.<br>Provides a wider range of possible future changes in climate, including limiting warming to below 2°C and rising well above 4°C.<br>The most widely used data set in WRMP19, so companies are familiar with these data. | Lack of spatial coherence between climate change factors in different regions, so risks that national drought could be overestimated.<br>With 3000 scenarios for every RCP and time period, a sampling approach is needed to derive a practical set of future scenarios.<br>No daily averages provided, only available as monthly, seasonal or annual projections for future time periods. |
| Opportunities | Threats |
| Clear audit trails: Updates the widely used UKCP09 probabilistic data, which formed the basis of most companies Price Review 2019 (PR19) assessments.<br>The wider range of scenarios could be valuable for some specific risk assessments, which require a lower warming scenario, e.g. Task Force on Climate-related Financial Disclosures (TCFD) reporting.<br>The wide range of possible futures is useful to specific decision-making methods such as robust decision making (RDM). | Lack of spatial coherence could lead to overestimation of risk and underestimation in yields of regional schemes (only if multiple sets of local factors are used).<br>Application of different baseline periods between UKCP09 and UKCP18 – potential for errors and a communications challenge.<br>Headlines of wetter winters and drier summers may underplay the likelihood of dry winters and wet summers. |
| Evidence | References |
| UKCP Science Overview and Science Reports<br>Met Office (2018b)<br>Summary plots are provided for UKCP river basin areas in Appendix A. | Lowe et al (2018); Atkins for Severn Trent Water (2019); Atkins for South West Water (2019). |

**Figure 5-13 - Probabilistic projections from UKCP09 (left) compared with those of UKCP18 (right), for the A1B emissions scenario for the South-East England administrative region**




As part of a previous project, we assessed the impacts of UKCP18 probabilistic data using the same approaches to those used for UKCP09 projections for selected catchments in the Midlands and found that:

The overall impacts of climate change on river flows are very similar between UKCP18 and UKCP09 under a Medium emissions scenario and in the short term (2030s).

In the context of UKCP18 and improvements in underpinning climate science, UKCP09 appears to be too warm and marginally too dry; the extremely dry scenarios under UKCP18 A1B are less likely than in UKCP09 and were not selected when a "like for like" sampling methodology was adopted.

The UKCP18 RCP8.5 scenario has higher rates of warming than the UKCP09 Medium emissions scenario and is likely to have a greater impact on river flows and Deployable Outputs.

The choice of future emissions scenario (RCP4.5, RCP6.0, A1B or RCP8.5), the sampling method applied to UKCP18 probabilistic data and choice of time period (and any scaling method) were more important than the move to UKCP18 climate models *per se*.

The UKCP probabilistic data for all river basins, RCPs and SRE1AB have been downloaded and are summarised in Appendix A.

### C.1.4. UKCP Regional Climate Models (raw data)

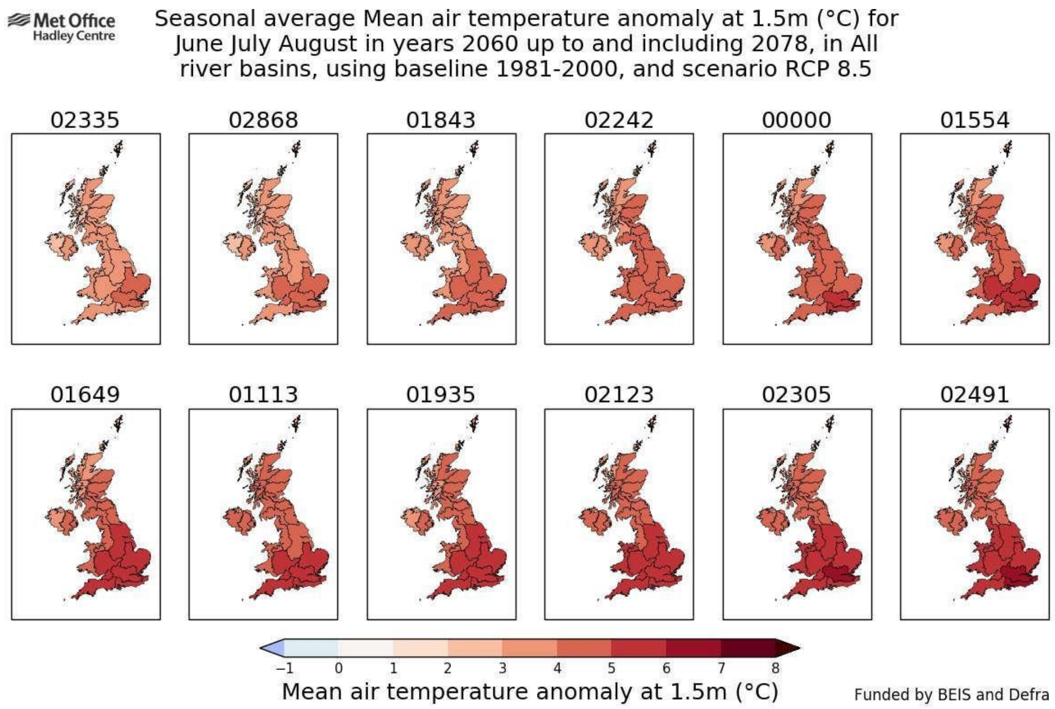
The UKCP18 Regional Climate Models are 12 projections for the RCP8.5 scenario at 12km grid scale. The headline findings are similar to the UKCP probabilistic data. The rates of warming are relatively high because the Met Office model projects greater rates of warming than most other CMIP5 global climate models. The RCMs cover a narrower range of possible outcomes than the UKCP18 probabilistic data.

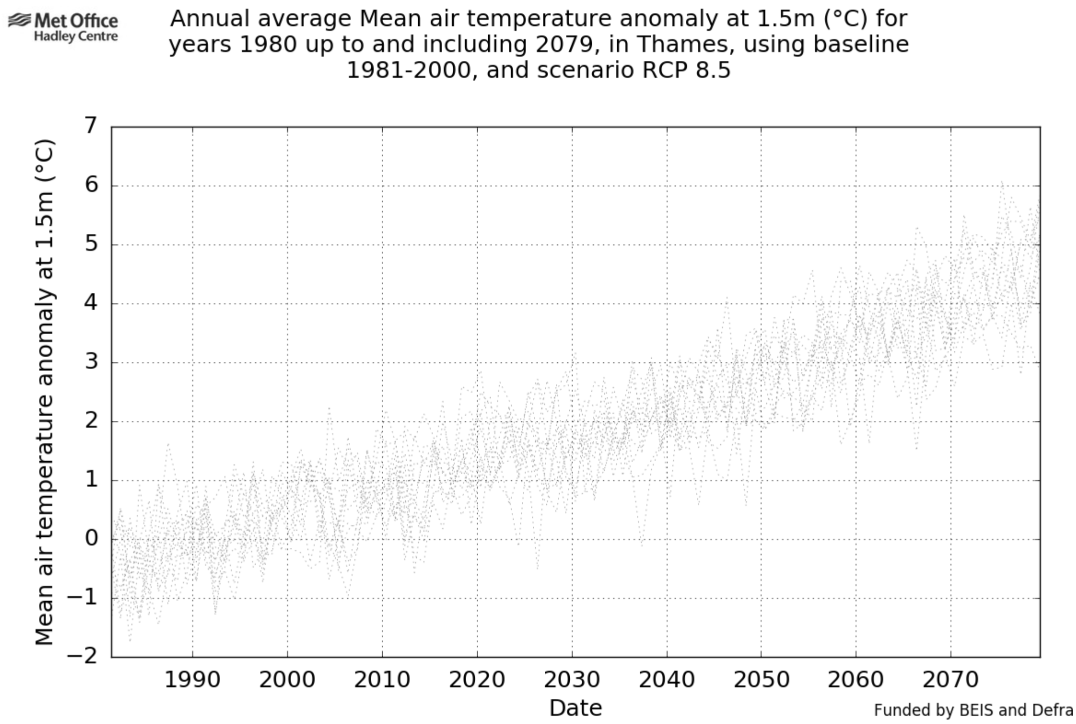
The most significant problem with the raw climate model data is the poor representation of precipitation at the grid and regional scales. For this reason, the data are bias corrected as outlined in Section 3. The strengths and weaknesses of the RCMs are summarised in Table 2-3. Comparisons of raw RCM data and HadObs observed data are shown in Appendix B.

**Table 5-3 - SWOT of UKCP Regional Climate Models**

| Strengths | Weaknesses |
|---|---|
| Provides an ensemble of baseline conditions, with a greater range than the observed data.<br>The 12km model is better at simulating heavy rainfall events in winter than the previous models.<br>Finer spatial resolution than the 60km global model, with better representation of regional patterns.<br>Changes are spatially and temporally coherent across the UK.<br>Available for a wider set of variables than is available from the probabilistic projections. | Only downscales the Met Office atmospheric model.<br>Systematic bias in the models means that they do not reproduce baseline rainfall very well.<br>Do not cover the full range of the CMIP5 global projections, reported in the research literature.<br>Indicates a smaller range of future changes than presented in the probabilistic scenarios.<br>Only available for RCP8.5, a scenario with relatively high rates of warming.<br>Projections only available from 1980 to 2080. Regional studies tend to consider impacts to 2100. |
| **Opportunities** | **Threats** |
| Provides a 12 member time series, which can be used to explore changes in climate over the next 60 years<br>The Met Office promote the use of RCMs over and above weather generator methods (because they rely on atmospheric physics rather than statistics), but they may be more appropriate for stress testing rather than planning (Section 4). | Systematic bias in the precipitation baseline may undermine model credibility.<br>Simulates much higher rates of warming than the CMIP5 ensemble, which may undermine credibility. |
| **Evidence** | **References** |
| Plots in Appendix B.<br>Met Office (2018c) | Lowe *et al.* (2018). |

**Figure 5-14 - Example outputs of the Regional Climate Model: Increases in summer temperatures with implications for PET and soil drying (numbers indicate RCM run)**




## C.1.5. UKCP Regional climate model data (bias-corrected data)

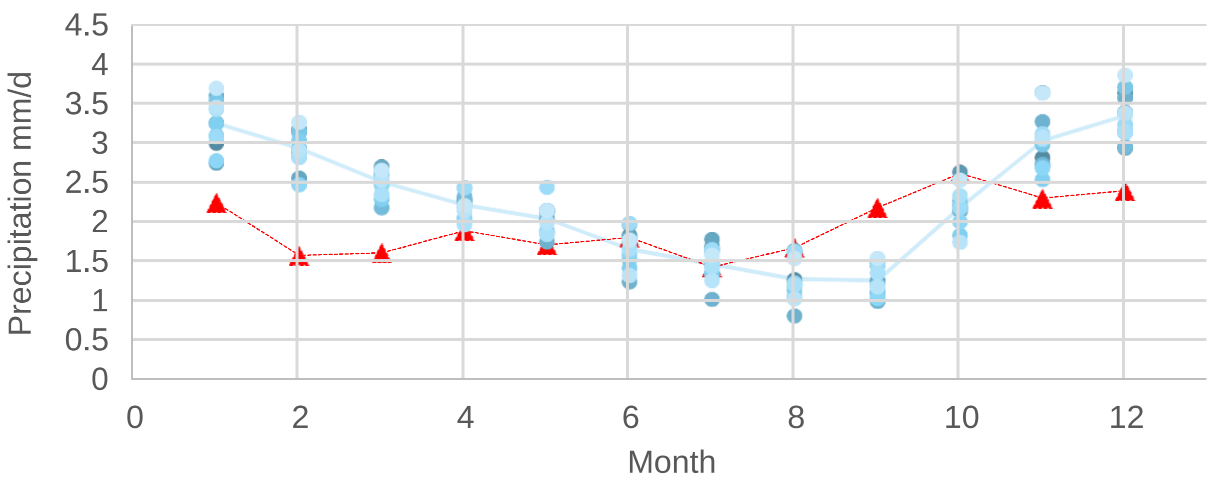
The UKCP18 Regional Climate Models bias corrected models are being developed by this project, based on published 'quantile mapping' bias correction methods (e.g. Li *et al*., 2010). The specific method developed is referred to as Equidistant CDF mapping (EDCDF) in the scientific literature and involves correcting daily, seasonal and annual bias using 31 day moving window on daily RCM data independently for each variable and ensemble member. This method was chosen following a review of the RCM raw data at the river basin scale, which indicated clear problems with data at multiple time-scales (Figure 2.5).

There are 12 projections for the RCP8.5 scenario at the 12km grid scale. The strengths and weaknesses of the bias-corrected RCMs are summarised in Table 2-4. Section 3 provides a full description of the bias correction methodology and the impacts of bias correction are illustrated in Appendix B.

**Table 5-4 - SWOT of UKCP bias corrected Regional Climate Models**

| Strengths | Weaknesses |
|---|---|
| The 12km model is better at simulating heavy rainfall events in winter than the previous models.<br>Finer spatial resolution than the 60km global model, with better representation of regional patterns.<br>Changes are spatially coherent across the UK.<br>Systematic bias in the models are removed using bias correction methods, which ensure more realistic seasonal and daily variations in rainfall. | Only downscales the Met Office atmospheric model.<br>Does not cover the full range of the CMIP5 global projections, reported in the research literature.<br>Indicates a smaller range of future changes than presented in the probabilistic scenarios.<br>Only available for RCP8.5, a scenario with relatively high rates of warming.<br>Bias correction may have an impact on correlation between variables and also auto-correlation of time series; model may be "overfitted" to the baseline; variance could reduce. |
| **Opportunities** | **Threats** |
| Provides a 12-member time series, which can be used to explore changes in climate over the next 60 years.<br>Baseline scenarios once corrected still provide a slightly wider range of conditions than the observed data. | Simulates much higher rates of warming than the CMIP5 ensemble, which may undermine credibility<br>Many different bias correction methods can be applied, which will produce different results. |
| **Evidence** | **References** |
| Plots in Appendix B. | Lowe *et al*. (2018); Fung (2018)[33]. |

**Figure 5-15 - An example of poor RCM model fit (blue) for catchment rainfall for the Thames Basin based on HadObs 1km data (red)**




# C.2. Other climate model data sets

## C.2.1. MaRIUS Regional climate model data (raw and bias-corrected data)

The NERC MaRIUS project[34] included climate change modelling using data generated by weather@home2 project (Guillod *et al*., 2017a and Guillod *et al*., 2017b), which consists of a global and an embedded regional climate model (known as HadAM3P and HadRM3P respectively).

The main climate data generated within MaRIUS comprise 100 time series for the recent past and five plausible near and far future periods at a resolution of 25km. These timeseries represent a range of plausible continuous sequences of weather events. The most interesting features of MaRIUS are its larger ensemble of time series

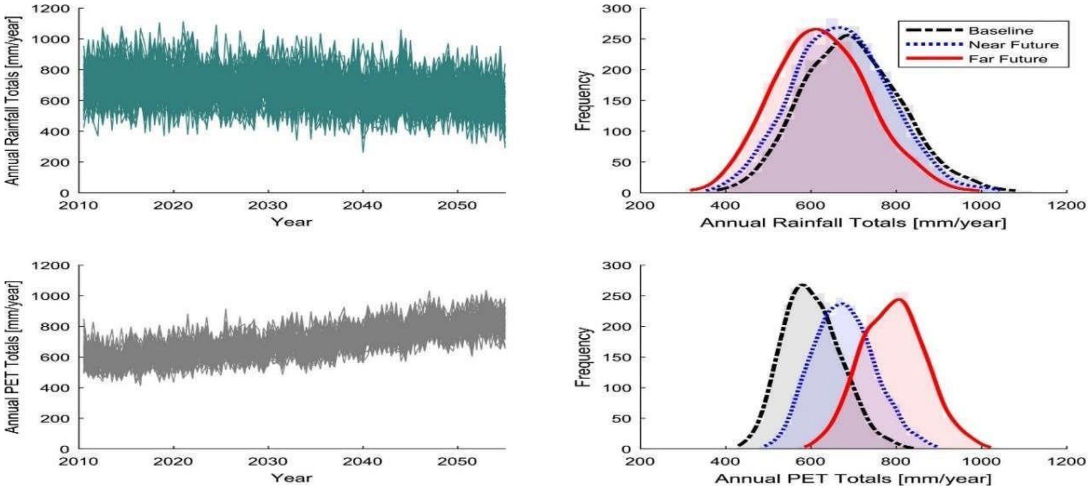
[33] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---how-to-bias-correct.pdf
[34] http://www.mariusdroughtproject.org/

compared to UKCP and its development of two potential evaporation data sets, which are not provided by the Met Office as part of UKCP. The main strengths and weaknesses of MaRIUS data are summarised in Table 2.5 and example outputs presented in Figure 2-6.

**Table 5-5 - SWOT of MARIUS Regional Climate Models**

| Strengths | Weaknesses |
|---|---|
| Provides an ensemble of baseline conditions (n=100), with a greater range than the observed data.<br>Finer 25km spatial resolution than the 60km global model, with better representation of regional patterns.<br>Changes are spatially coherent across the UK. | Systematic bias in the models underestimates rainfall and over-estimates temperature in summer. A simple bias-corrected data set only adjusts for the mean change in monthly precipitation.<br>Only available for RCP8.5, a scenario with relatively high rates of warming.<br>The models were run one year at a time and then stitched together; a weakness for long droughts. |
| **Opportunities** | **Threats** |
| Provides a 100 member time series, which can be used to explore changes in climate for two periods in the next 80 years.<br>Provides two PET data sets with different assumptions related to stomatal resistance. | Arguably replaced by UKCP18 RCMs, which may be regarded as a superior version of the Hadley Centre model. Both data sets appear to suffer from hot and dry bias in future compared to other CMIP5 models Data formats and structure are not easy to work with. |
| **Evidence** | **References** |
| Plots in Appendix B. | Guillod *et al*., 2017; Hall *et al*., 2019. |

**Figure 5-16 - Example outputs for the Thames basin (Hall et al., 2019)**




# C.3. Bias correction methods

Regional climate models can have systematic biases, which mean they have limited skill in reproducing important hydrological characteristics, such as the magnitude and frequency of very wet days and the length of dry periods. In addition, some models may be too warm/dry and/or too wet in specific months or seasons to accurately reproduce catchment water balances. For these reasons climate model outputs have typically been used to understand changes rather than absolute values of future rainfall and other climate variables.

Some water companies have an interest in using RCM data directly in their modelling, which requires the application of bias correction methods to correct the baseline period and future scenarios based on the assumption these biases carry through to the future modelling periods.

There are a range of possible applications and “use cases”:

***Use of monthly change factors:*** Bias correction is not absolutely necessary if water companies or regional groups want to apply change factors. UKCP probabilistic data or RCM data can be applied to observed data or stochastically generated baseline data. The use of change factors is very similar to linear scaling, which is the simplest form of bias correction of RCM time series data (Fung, 2018).

***Use of monthly RCM time series.*** Bias correction is advisable if users want to use monthly time series. There are a number of possible methods that could be used to implement bias correction at a monthly scale (e.g. Vidal and Wade, 2008). These data could be combined with observed or stochastically generated patterns of precipitation, temperature and PET. However, bias correction may have an impact on correlation between variables and also auto-correlation of time series.

***Use of daily RCM time series:*** Bias correction is essential if users want to use daily precipitation and other variables. There are a large range of possible methods for bias correction of daily data, which correct for specific issues, such as too many days of drizzle at a daily scale, through to correcting monthly statistics (Maraun, 2016). In general, basic methods change some aspects of the data, such as the change factors or long-term trends and should be used with caution and in the context of the objectives of the proposed study.

## C.4. Previous UK water industry approaches

The traditional 'delta change' approach to applying climate change factors (based on future modelled versus historic modelled data) is akin to the simplest form of bias correction (based on the differences between historic modelled and historic observed data) (Navarro-Racines et al., 2015). In effect, climate models are used to understand potential future changes in monthly average climate and the observed baseline climate is regarded as the best data set for quantifying natural variability, including daily extremes.

The UKWIR CL-04 project (2004) applied bias-correction methods to 6 GCMs to produce national climate scenarios that were used by the water industry (Vidal and Wade, 2008). The method fitted statistical distributions to monthly temperature (normal) and precipitation (gamma), corrected the raw climate model data to match the observed data for the baseline period and assumed that future biases were the same as those seen in the model baseline period.

## C.5. Future Flows

The Future Flows project took a different approach, most importantly precipitation was bias corrected using a gamma distribution at a daily scale rather than monthly scale and one transformation was applied to all the rainfall data, irrespective of the month or season (Prudhomme *et al*., 2012; Piani *et al*., 2010). Temperature was shifted using a linear transfer function for each month (Prudhomme *et al*., 2012). The main impact of this approach is removing the "drizzle" effect where climate models produce too many rain days with low intensities. The simple method has been shown to be effective in improving model skill at both wet extremes and for dry periods (Piani *et al*., 2010), however it would not be sufficient on its own to correct UKCP18 data due to the larger seasonal bias in modelled versus observed data.

## C.6. UKCP guidance note

The Met Office presented a short summary of bias correction methods in the format of a UKCP Guidance Note[35].

Key assumptions include:

The causes of the biases do not change in the future.

Sufficient observational data are available to characterize the reference climatology.

The physical consistency of the different climate variables remains valid.

The original biases are not large and if they are, such models should be disregarded from the assessment.

In addition, the note explains that "[t]he most common application of the methods presented use station data as reference and are not suitable in a multi-site context, as the temporal correlation between neighbouring stations does not enter the method". On the contrary, it could be argued that the spatial correlation problem is trivial compared to original poor fit of the modelled data, which already exhibit unrealistic spatial patterns compared to what is observed.

The UKCP note highlights four methods. However, these are broad groups with many variants within each methodology: linear scaling, variance scaling, quantile mapping, trend-preserving quantile-mapping. For

[35] https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---how-to-bias-correct.pdf

example, so called quantile mapping methods can be implemented on daily data or monthly data using fitted statistical distributions or empirical distributions (ranked data/percentiles).

## C.7. Summary of methods

The different groups of bias correction methods are summarised in Table 3.1 based on UKCP guidance and methods implemented by this project are discussed in Section 3.5. There is a very large literature base on bias correction methods, which are likely to be reviewed as part of the larger Met Office Strategic Priorities Fund (SPF) research project.

**Table 5-6 - Alternative bias correction methods including those tested on this project (grey shaded)**

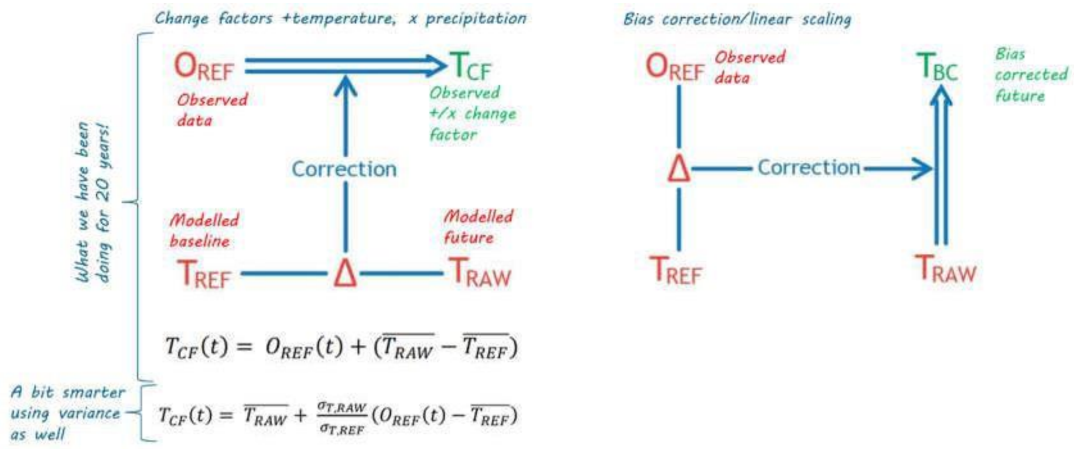
| Method | Summary | References | Code | Tested |
|---|---|---|---|---|
| Linear scaling | Simple method that only adjusts for mean bias. Akin to the simple delta change methods used in the water industry but can be applied at any time-step, not just monthly. | UKCP Note (Fung, 2018)<br>CCAFS website http://ccafs-climate.org/bias_correction/ | Simple to code | Yes<br>Useful comparator to other methods |
| Variance scaling | A popular method that adjusts mean and variance bias. | UKCP Note (Fung, 2018)<br>CCAFS website http://ccafs-climate.org/bias_correction/ | Simple to code | No |
| Quantile mapping | A method often used for precipitation as it preserves the distribution (of daily or monthly data) and can inform extreme values; a large family of methods with different variants. | UKCP Note (Fung, 2018)<br>CCAFS website http://ccafs-climate.org/bias_correction/<br>Lafon *et al.* (2013), Li, Sheffield and Wood (2010), Maraun (2016), | Yes (QMAP in R[36]).<br>Atkins Python code | Yes<br>Two variants - a basic form and more advanced form |
| CDF transform | Method implemented by the 'Climate Data Factory'. This method does not rely on the stationarity hypothesis: model and observational distributions can evolve and be different. The assumption is that the model and observational distributions can be inferred by a mathematical function (the "transform") which remains the same for past and future distributions. | Michelangeli *et al*. (2009).<br>Kallache *et al*. (2011) | R Code available[37] | No<br>But this is similar to the method of Li et al 2010, which has been implemented. |
| Scaled Distribution Mapping | A bias correction method that preserves raw climate model projected changes. | Switanek *et al* (2017) | Yes (python)[38] | No |

[36] https://cran.r-project.org/web/packages/qmap/qmap.pdf
[37] R Code available on rdocumention.com by M. Vrac
[38] https://pycat.readthedocs.io/en/latest/intro.html

## C.8. Principles of change factors and bias correction using linear scaling

The simplest form of bias correction is using linear scaling and this approach is similar to the traditional use of change factors, which has been an industry standard approach for more than 20 years (see Fung, 2018; Navarro-Racines, 2015 and Appendix D). Change factors consider the long-term average differences between a modelled future period and a modelled reference or control period (for 20-30 year periods) and then apply this correction to the observed data using the same reference period or, in the case of UK water resources, longer observed records. Temperatures changes are additive (+ degrees centigrade) and precipitation changes are multiplicative (expressed % change or factors, e.g. +20% or x 1.2). The corrections are normally applied on a monthly basis. Linear scaling is very similar but uses the differences between modelled and observed data for the reference period and then applies this correction to the future modelled time series (Figure 3-1).

**Figure 5-17 - Schematic representation of change factors and linear scaling**



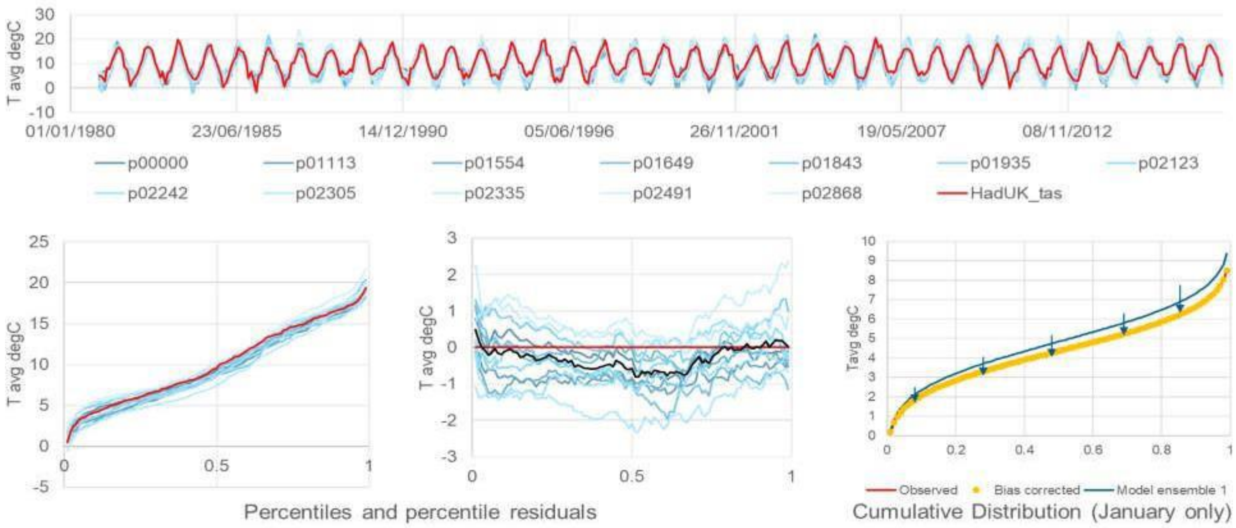

## C.9. Principles of bias correction using quantile mapping

Quantile mapping approaches seek to adjust modelled data considering the distribution of modelled versus observed data rather than using a single annual, seasonal or monthly linear scaling factor (see Fung, 2018; Navarro-Racines, 2015, Appendix D).

The results of a very simple example using monthly temperatures is summarised in Figure 3-2. The UKCP RCM monthly data are compared to the HadObs 12km data as a time series and as percentiles in Fig. 3-1 (a) to (c). Overall the RCMs appear to match the lowest and highest temperatures well but are too cool around the median values by 0.5 – 1°C (black line). Bias correction in this case would consider all months or individual months and compare the modelled to the observed distributions and map, then shift the modelled distribution for each model to the observed distribution.

Fig. 3-2 (d) shows one model ensemble member that is too warm for January and therefore the shift in this case would be downwards to make it match the observed distribution. For the correction of the baseline or future periods there are different ways these can implemented mathematically, e.g. using a look up table of change factors/differences or mapping the data using standard and the inverse of statistical distributions, typically the gamma distribution for precipitation. Further details on the implemented methods are included in Appendix D.

**Figure 5-18 - Average temperature biases in the Thames River basin in RCMs (a) monthly time series, (b) percentiles, (c) residuals of modelled minus observed and (d) correction of one model for January**




The results of the bias correction for the baseline period 1981-2000 are shown in Appendices B.4 and B.5. An example of the impacts of bias correction on monthly precipitation and seasonal precipitation and temperatures is shown in Figures 3.2 and 3.3 for the baseline period 1981-2000.

By design, linear scaling perfectly matches the observed data set at a monthly scale, although the daily pattern of precipitation is not corrected and the variance of the data is substantially reduced, which means the results are not appropriate for the assessment of extremes, including droughts.

Implementing QM on daily precipitation using the percentiles of the whole data set corrects for the annual errors in precipitation (in this case reducing the average precipitation effectively) and errors in the daily pattern but fails to correct for monthly and seasonal biases. This method was used for the Future Flows project but is not sufficient for UKCP18 due to the large seasonal bias in Southern England in UKCP18.

QM31 based on the Equidistant CDF method, corrects the data using the percentiles of 15 days prior and 15 days after each day. This method worked well at all time scales, correcting daily rainfall distributions, monthly averages and annual average precipitation. This method considers the differences in the modelled historic and observed historic and assumes that the differences can be carried forward and applied to future time periods. It therefore avoids some of the limitations of basic QM, e.g. related to extrapolation. The risk of this approach is over-fitting a model to a relatively short baseline period. It involves are very large number of parameters.

The impacts of bias correction on seasonal precipitation and temperature are shown best using scatterplots of the means and variances versus the HadObs data (Figure 3.3). In the case of Anglian, the modelled winter precipitation for the baseline period is far too high. QM on the daily data for the year does not correct this and variance in each data set is also too great. Linear scaling corrects the means but hugely reduces variance in winter and spring. Only the QM31 method corrects adequately for means and variance of both precipitation and temperatures.

The impacts of the QM31 bias correction method are shown in Figure 3-4, including the observed data and clearly showing its impact in the historic and future periods version the raw climate model data. In the case of Anglian river basin, precipitation is reduced, seasonal errors are corrected, and temperatures are increased. It is likely that bias correction will substantially increase the impacts of climate change on river flows in Southern England due to the increased temperatures/PET and an increased likelihood of low seasonal rainfall. The project case studies will test the impacts of using raw versus bias corrected data in hydrological models.

**Figure 5-19 - Impacts of linear scaling and Quantile Mapping on monthly precipitation in the Anglian river basin**

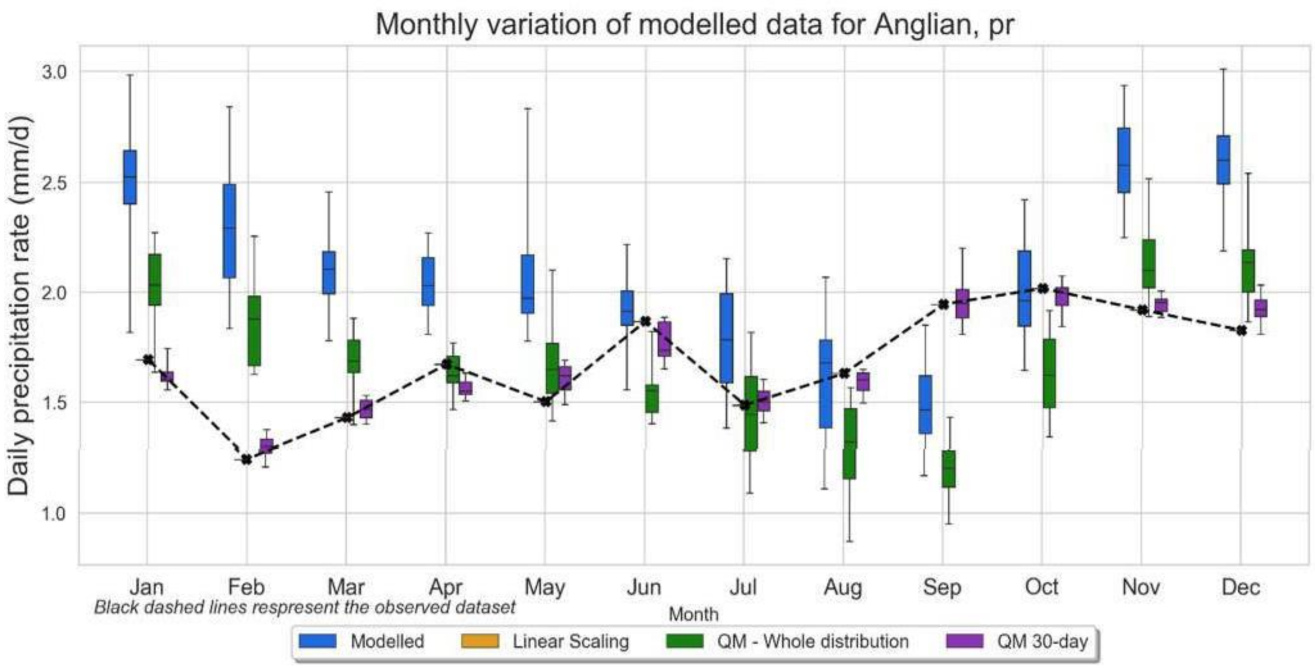



**Figure 5-20 - Impacts of linear scaling and Quantile Mapping on seasonal precipitation and temperatures in the Anglian river basin**

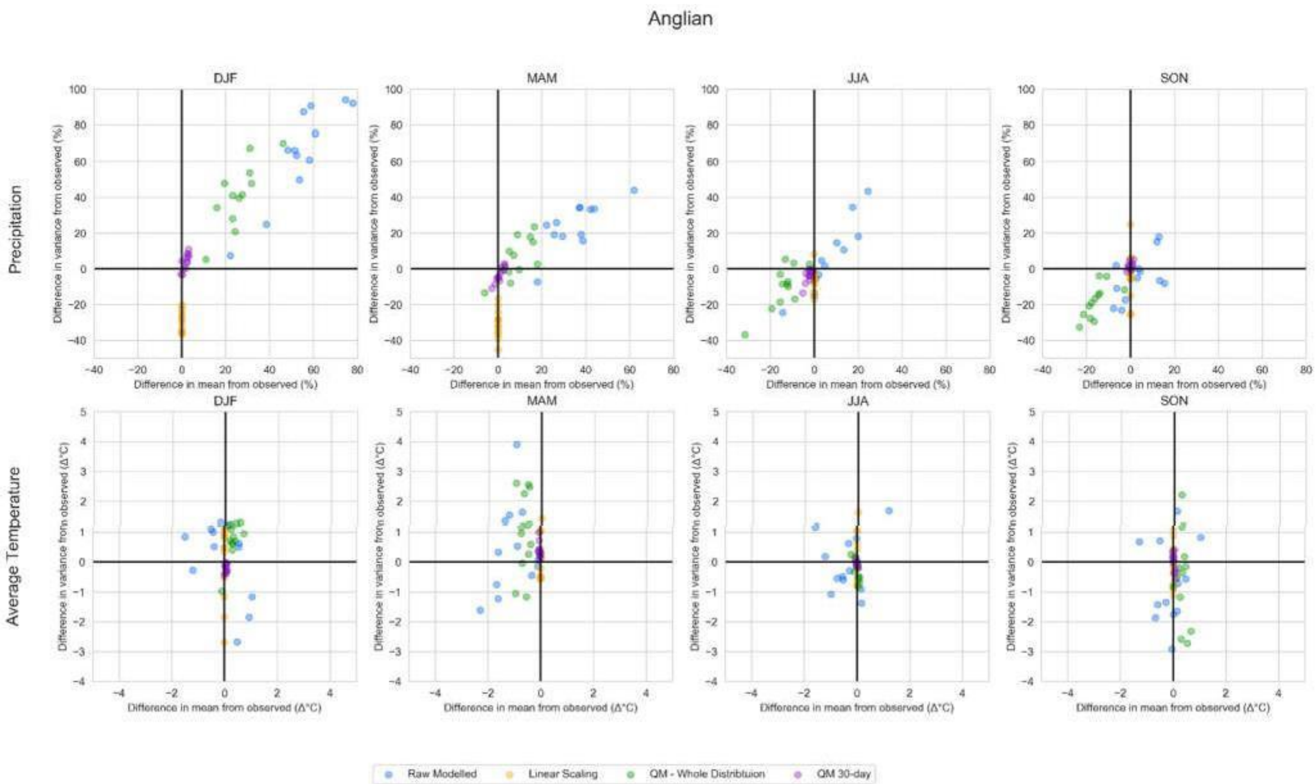
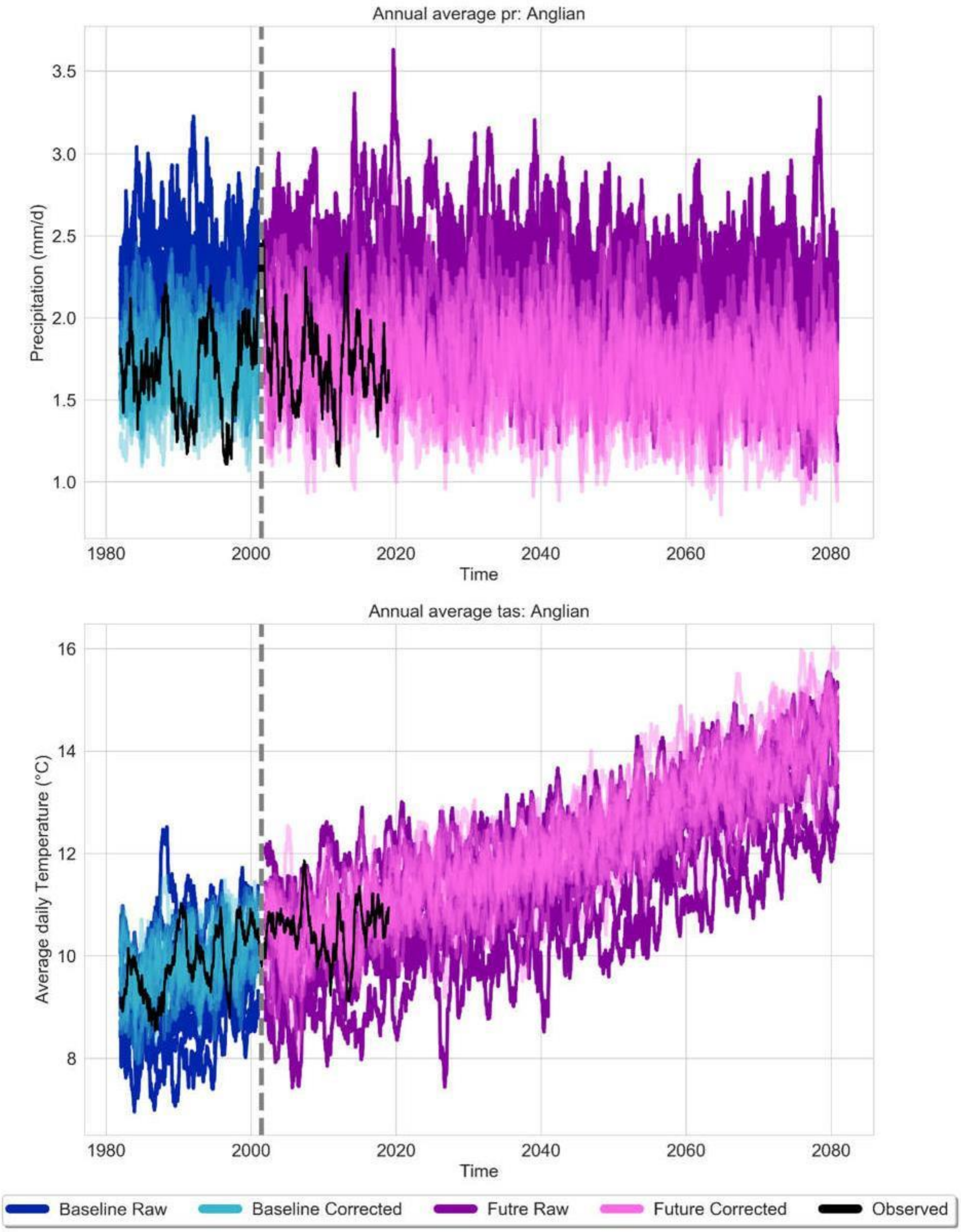



**Figure 5-21 - Impacts of EDCDF on baseline and future evolution of precipitation and temperature time series [to be updated]**




## C.10. Conclusion

There is an increasing number of climate data sets available for water resources planning; the UKCP18 climate projections have updated the UKCP09 probabilistic projections but also provide more complex choices of products including global models at 60km resolution and regional models at 12km resolution. In addition, the Met Office have now released new *'HadObs'* 1km and 12km observed data sets and there are alternative modelling products available from recent NERC research projects, such as the MaRIUS data sets.

The UKCP18 probabilistic data are very similar to the UKCP09 data but are presented as RCP scenarios rather than Low, Medium, High Special Report on Emissions Scenarios. A Medium A1B scenario is also available that can be used for direct comparison to UKCP09. The UKCP river basin or administrative area data could be used for regional water resources planning for some regions; however, caution is needed combining UKCP probabilistic data from adjacent regions because these data are not spatially coherent.

The Met Office RCMs provide a poor fit to river basins in England and Wales and require bias correction before model timeseries are used for impact assessment. The project has reviewed several bias correction methods and shown that the EDCDF mapping method provides a pragmatic approach to correcting the data for use in regional planning. Further case study work with water company data will demonstrate the use of these data for risk assessment.

The Met Office Global and Regional Climate Models are relatively hot and dry in future periods compared to models from many other climate modelling centres. Some studies have questioned the physical plausibility of the changes in extreme temperature and precipitation modelled and suggested that these models should be excluded from impacts studies. This needs to be considered further because it influences how and what the models could be used for in regional water resources plans. One possibility is that the RCMs should only be used for stress testing proposed schemes rather than water resources planning *per se*, which may continue making use of the probabilistic data to characterise future change in climate.

Further case study work is needed but the limitations and systematic errors in regional climate models indicate that there is still a clear requirement to plan using good quality historical data, supplemented by the application of stochastic methods to explore possible drought scenarios.

The key parts of the climate and hydrological impacts assessment process are summarised in Figure 4.1. including the weather generator and its interaction with climate change models for development of future scenarios.

An outline roadmap for the longer-term development of tools is shown in Table 4.1. Available tools are shaded in green, this project’s work in yellow and other future developments (under contract) in orange.

**Figure 5-22 - The overall drought risk assessment process combining weather generator outputs with climate change models**

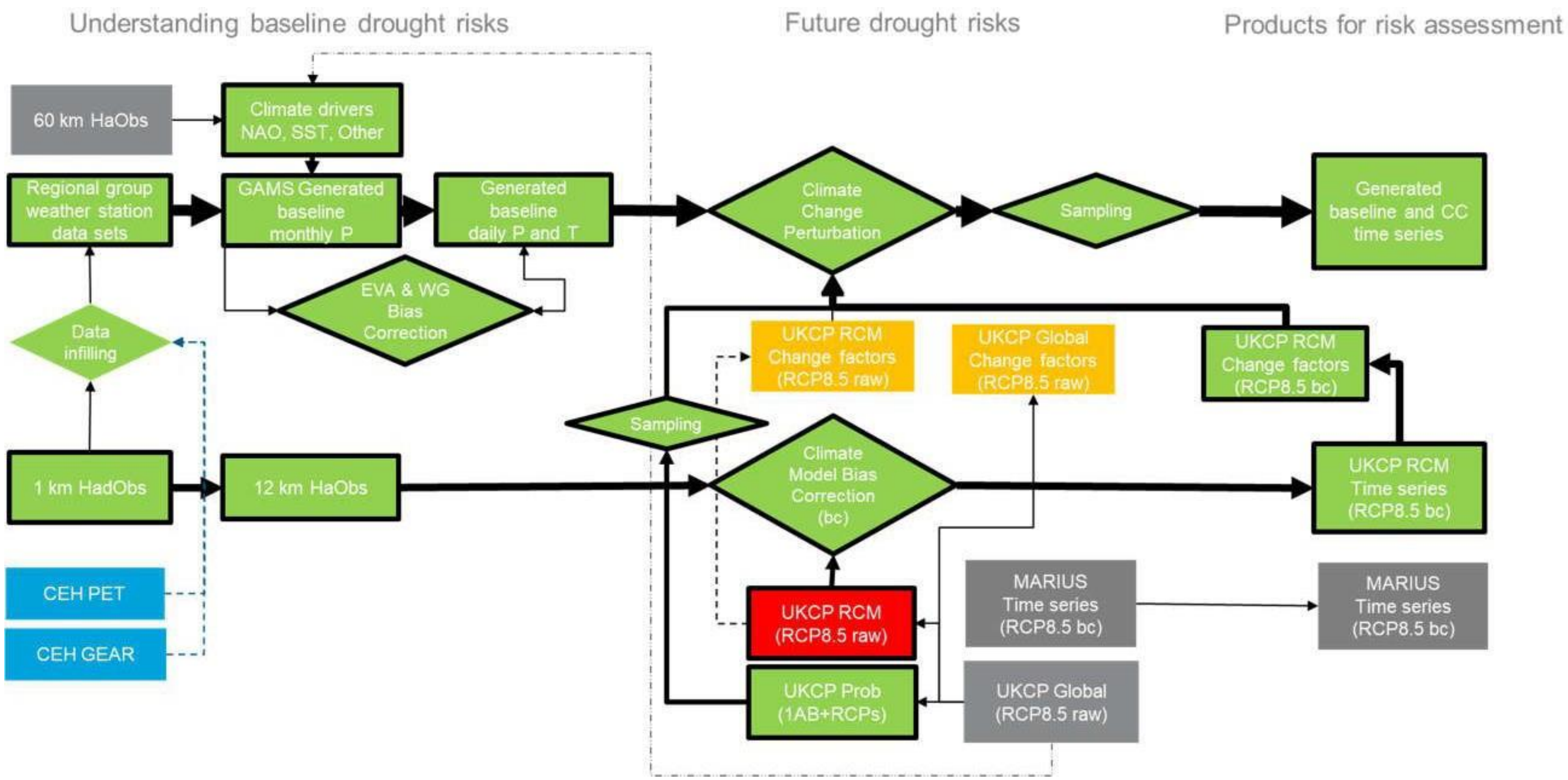


Table 5-7 - Outline road map for the development of climate data tools

| Tools for PR19 | Regional Plans 2020 | WRMP 24 | WRMP29 | Comments |
|---|---|---|---|---|
| Regional point rainfall data sets | Extended HadObs 1km 1873-2018; new regions | Longer hindcasts<br>Better EVA | UKCPNext | Better hindcasts and higher resolution data; new areas modelled |
| CEH GEAR & PET | EA PET 1km (due March 2020) | Recalibration of hydro and GW models | | Model recalibration will be needed if inputs are updated |
| Drought/rainfall generation<br>GAMS model with NAO/SST indicators | 'Drought Studio' better post processing; EA/SCA indicators; better guidance and implementation | 'Drought Studio 2'<br>Weather Types (UKCP due to release in April 20)<br>Met Office Drought Explorer | 'Drought Studio 3'<br>National drought libraries<br>Met Office DePreSys & 'UNSEEN' methods | Evolution towards non-stationary multi-variate daily Weather Generators or use of Numerical-Weather-Prediction reanalysis |
| UKCP09 Probabilistic data; smart sampling | UKCP18 Probabilistic (sampled at national scales) | UKCP18 spatial new "smart sampling" tools | UKCPNext | Sample over large areas. Lack of spatial coherence means that new sampling methods may be needed |
| n/a | UKCP18 Global Models (60km) | | UKCPNext | Possible use of GCM CMIP5 models as simple scenarios |
| UKCP09 SCPs | n/a | n/a | UKCPNext | Discontinued but were used in WRE in 2019. |
| Future Flows RCM data (bias-corrected) | 'Climate Studio'<br>UKCP18 RCMs<br>(bias corrected P/T with QM30) | Met Office SPF Project<br>UKCP18 RCMs (Oct 2020), river flows & recharge (March 2021) | UKCPNext HiRes RCMs<br>(bias correction) | Bias corrected precipitation only |
| n/a | MaRIUS (100 x bias corrected precipitation and PET) | n/a | Future research | Difficult to apply – to be tested further (x 100 time series @ 25km) |
| Flow generator (SAMS) | n/a | Will companies still use flow generation methods? | | Some zones may still lack hydrological models |

| | | | | |
|---|---|---|---|---|
| Extreme Value Analysis (Frequentist) | Extreme Value Analysis (Frequentist/Bayesian) | | EVA (Non-stationary and multivariate) | Move towards more sophisticated methods |

Notes: Drought Studio and Climate Studio are Atkins python and R codes for water resources risk assessment. The Met Office Drought Explorer and DePreSys work are under contract with Anglian Water services. The Met Office SPF project is being implemented by CEH.

# C.11. Sampling climate change projections

## C.11.1. Introduction

The UK Climate Projections 2018 (UKCP18) provide Global Climate Models (60km), Regional Climate Models (12km), a high-resolution RCM (2.2/5km) and probabilistic data (25km) for scenario RCP8.5. Probabilistic data are also provided for scenarios RCP2.6, RCP4.5, RCP6.0 and A1B Medium Emissions.

The strengths and weaknesses of each data set for regional water resources planning was presented in our first report.

## C.11.2. Choice of RCPs and the sampling problem

Most products are focused on RCP8.5 because this is a "business as usual" type scenario that demonstrates the impact of climate most clearly, over and above natural variability and model uncertainties. The UKCP probabilistic data for RCP8.5 present a wide range of outcomes and in the mid-century is not much warmer than RCP4.5, RCP6.0 and A1B. In fact, the probabilistic results for RCP8.5 encompass the range of possible outcomes from other scenarios.

The Met Office RCMs are driven by the Met Office RCM HadGEM3 and these models are at the *"warm and dry"* end of possible outcomes by the end of he century. In fact, they average 1 $^{o}$C warmer than the average of the probabilistic data in the 2070s compared to a 1981-2000 baseline. This makes RCMs very useful for risk assessment of low probability-high impact outcomes and for stress testing plans but less useful for considering adaptive planning that requires consideration of a wider range of outcomes. The Met Office GCMs include HadGEM3 models but also 13 CMIP5 models that have average warming of 2.5 $^{o}$C above 1981-2000 for the same future period, which is much closer to the average of the probabilistic data.

The UKCP probabilistic data has 3000 possible outcomes and most companies will find it impractical to model this number of scenarios. The main issue with this approach for regional planning is the that factors for England and Wales would need to be used to ensure spatial coherence in future climate change signals. In the last round of plans a sampling method was used to present subsets of 100 and 20 (10 + 10 dry) scenarios for risk assessments. The same could be done again but a more even and unweighted sampling strategy is now more appropriate.

### C.11.2.1. Proposed approach

It is proposed that Regional Plans make use of RCP8.5 RCMs for the regions/basins plus RCP8.5 CMIP5 change factors for England and Wales (or the regions) for climate change impacts assessment. They may wish to use all 25 scenarios (12 RCMs plus 13 GCM) or select a sub-set but these should indicate average warming of 2-3 $^{o}$C by the 2070s rather than 3 to 4.5 $^{o}$C in the HadGEM3 subset.

We are waiting for guidance on WRMPs but for these plans the RCMs could effectively replace the 10 "dry" scenarios used in the previous assessments and the CMIP GCMs would replace the 10 additional scenarios that companies used in PR19. This has the advantage that all companies would use the same scenarios rather than sample the probabilistic data in different ways.

## C.11.3. Methods

To test the impact of different methods, we used the RCMs (raw and bias corrected P and T factors), CMIP5 GCMs and full probabilistic data for case studies 1, 4 and 5.

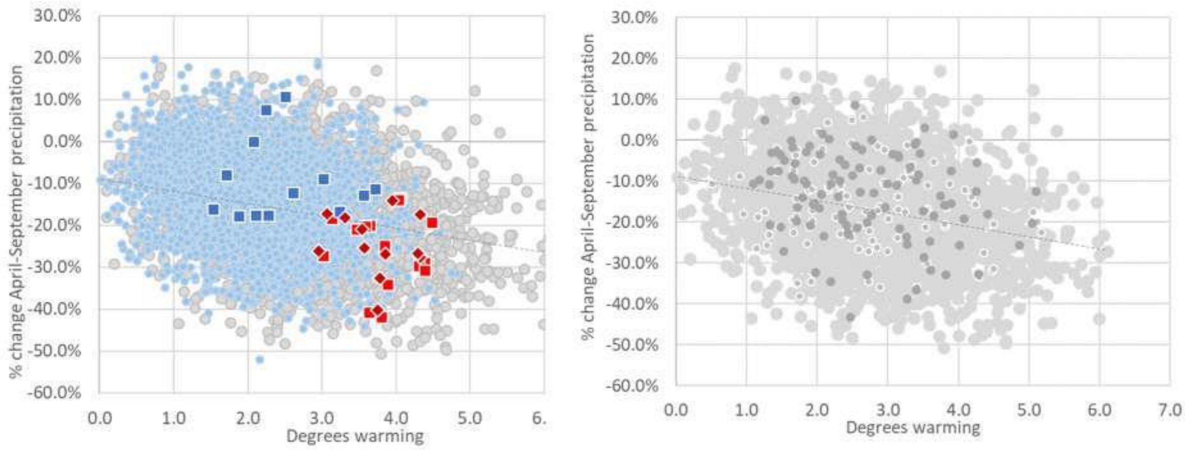
To illustrate key differences the England and Wales data from all UKCP source were downloaded for monthly average temperatures and precipitation. A key indicator for systems in the Midlands is April to September precipitation so this was plotted against average warming to compare data sets.

To explore the impacts of sub-sampling UKCP probabilistic data, e.g. selecting a representative sub-set of 100 outcomes of changes in monthly precipitation and temperature, a simulator was developed in @Risk. This fitted distributions to the 3000 UKCP samples for 24 change variables and modelled the correlations between these variables. The simulator can then be used to resample these distributions and produce coherent sub-samples of the full data set.

## C.11.4. Results

### C.11.4.1. England and Wales climate change scenarios for the 2070s

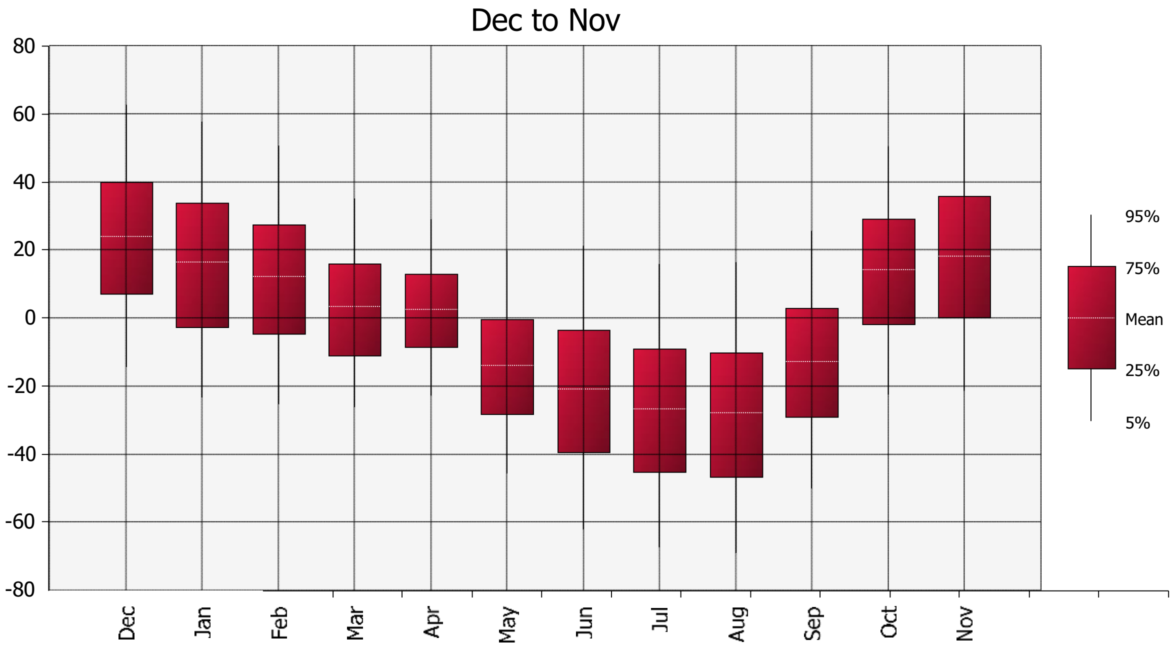
Changes in future seasonal rainfall and average annual temperature are shown in the figure below. The Met Office global models are shown as red squares and the RCMs as red diamonds; the CMIP5 models are shown as blue squares; the probabilistic data are light grey dots along with two simulated sub-samples of 100 scenarios. The blue dotted lines ate the 10th and 90th percentiles of the probabilistic data are show that three of the RCMs are very hot or dry and three CMIP scenarios show no change or increased seasonal precipitation.

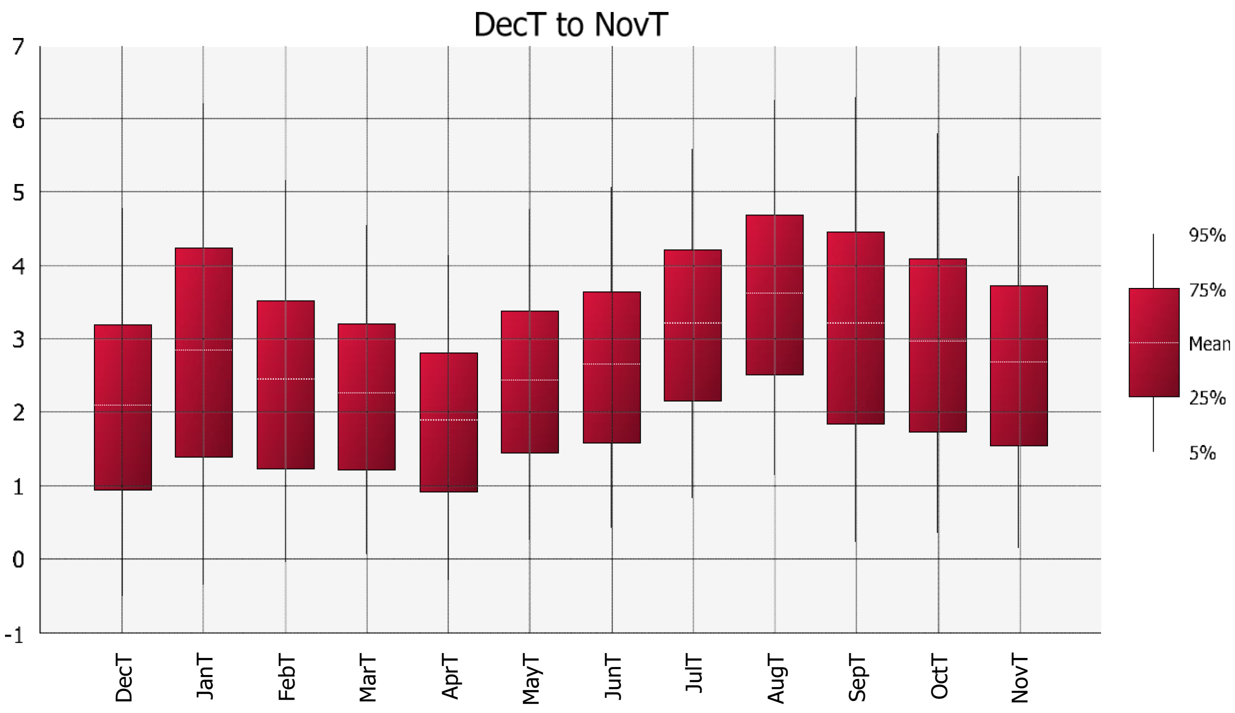



2060-2079

| Summary statistics | RCP 8.5 | | | | | A1B | | |
|---|---|---|---|---|---|---|---|---|
| Annual average temperature rise °C | Probabilistic 3000 | Random 100 | LHS 100 | RCM HadGEM3 n=12 | GCM CMIP5 n=13 | Probabilistic 3000 | Random 100 | LHS 100 |
| Median warming | 2.7 | 2.5 | 2.7 | 3.8 | 2.3 | 2.0 | 2.0 | 2.0 |
| 10th percentile | 1.4 | 1.5 | 1.4 | 3.1 | 1.7 | 1.0 | 1.0 | 1.0 |
| 90th percentile | 4.1 | 3.9 | 4.2 | 4.3 | 3.5 | 3.1 | 3.1 | 3.1 |
| April-Sept rainfall change | | | | | | | | |
| Median change | -17% | -12% | -17% | -26% | -12% | -13% | -13% | -13% |
| 10th percentile | -32% | -27% | -28% | -32% | -18% | -27% | -26% | -27% |
| 90th percentile | -2% | -1% | -2% | -17% | 6% | 0% | -1% | 0% |

Simulated UKCP change factors (n=100) precipitation % and degrees warming for 2060-2079


Dec to Nov
80
60
40
20
0
-20
-40
-60
-80
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
95%
75%
Mean
25%
5%


DecT to NovT
7
6
5
4
3
2
1
0
-1
DecT
JanT
FebT
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Mean
25%
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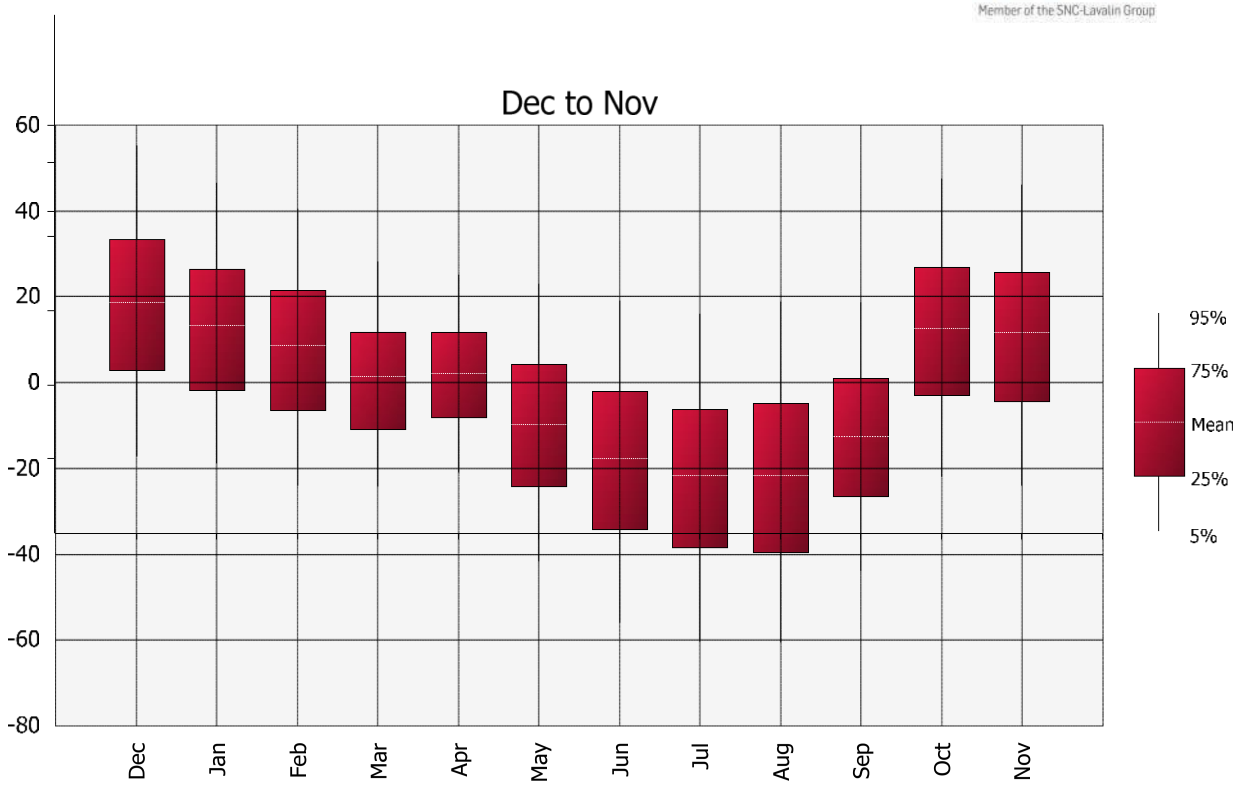

Dec to Nov
60
40
20
0
-20
-40
-60
-80
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May
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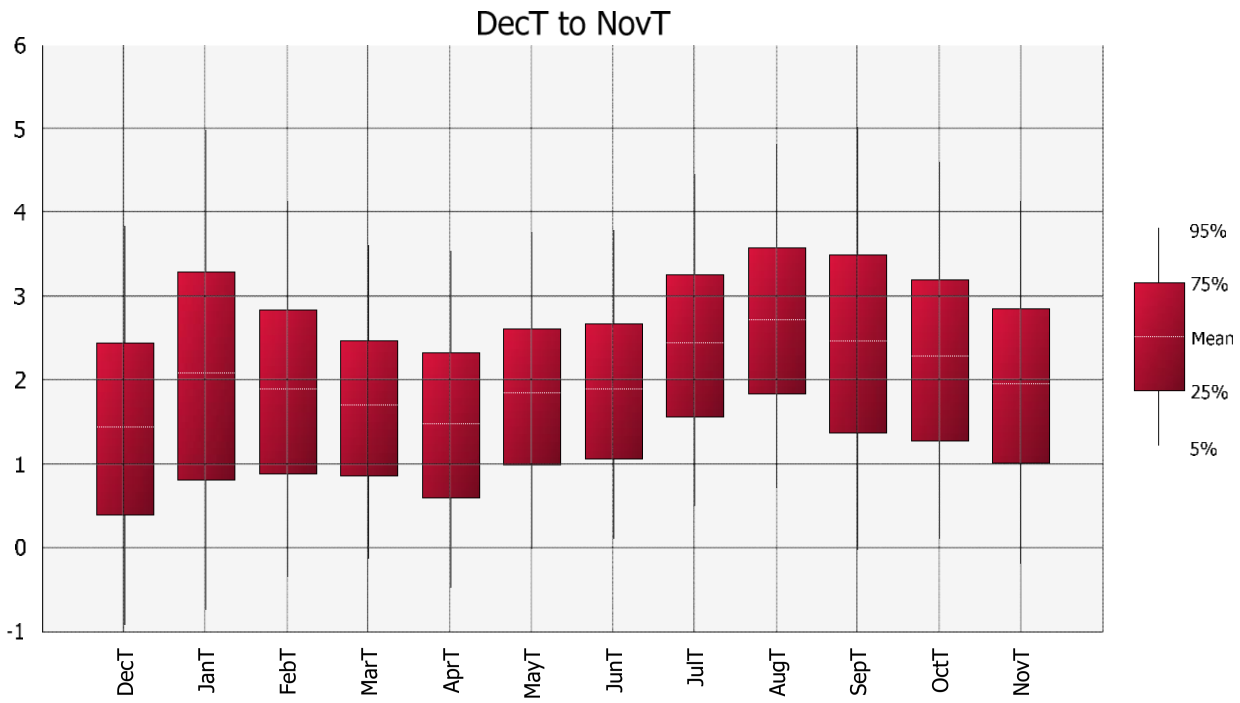
Nov
95%
75%
Mean
25%
5%

DecT to NovT
6
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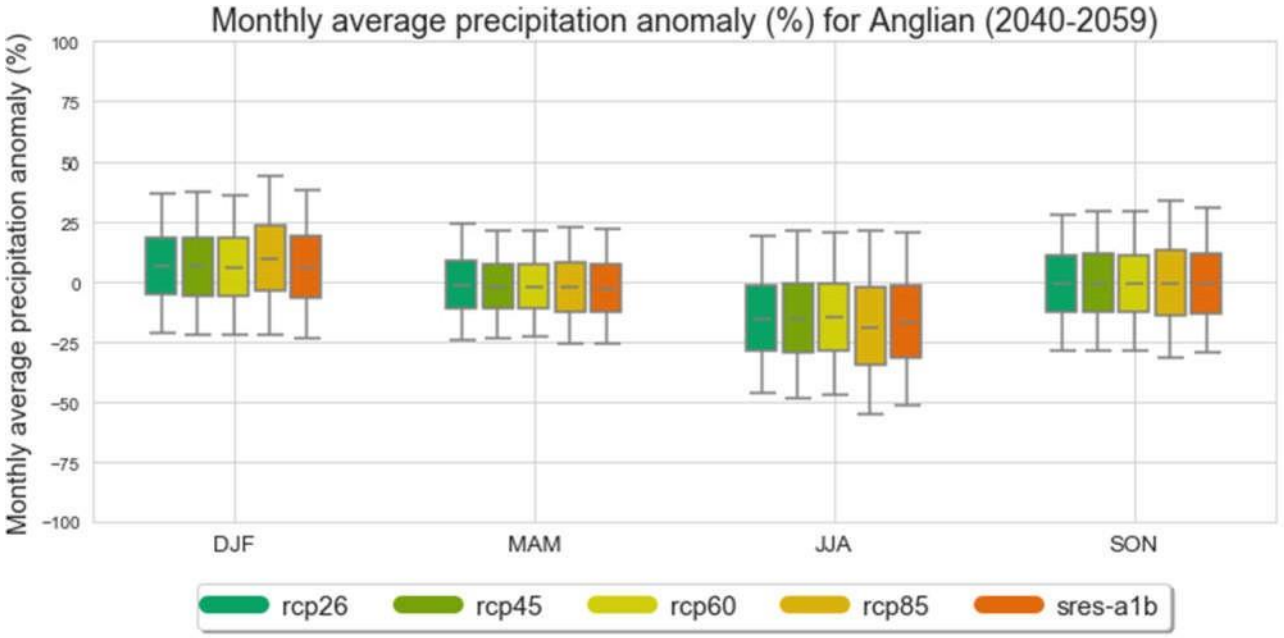
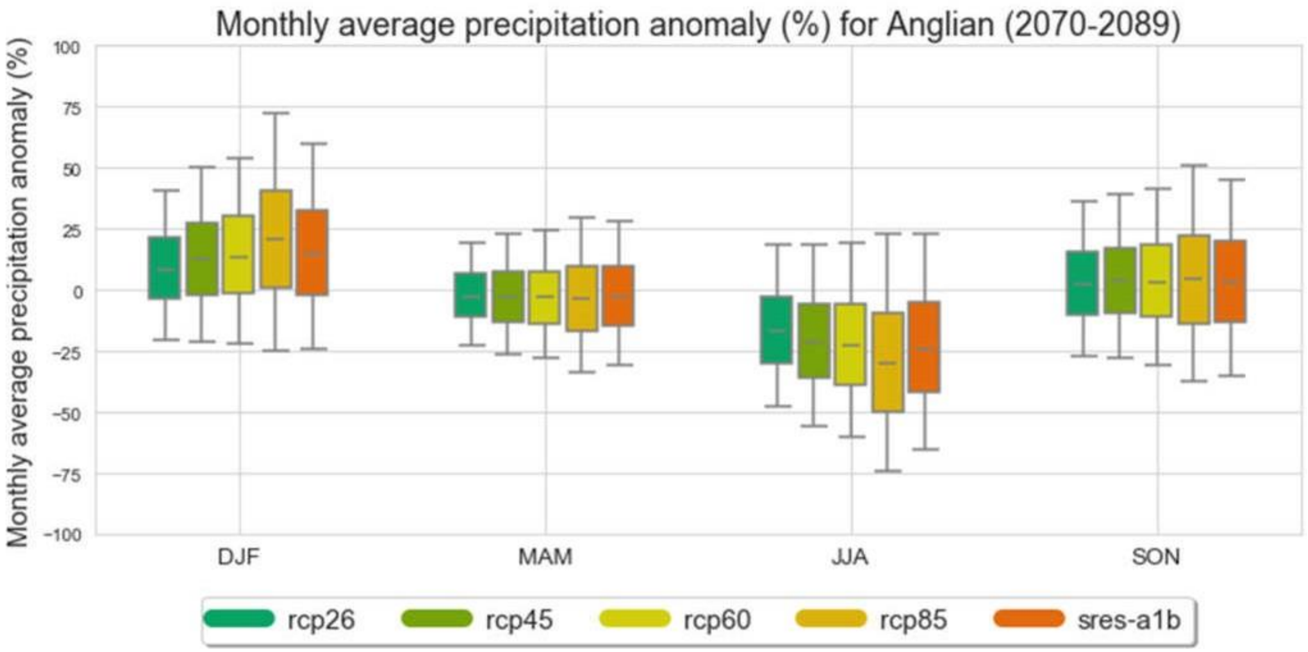
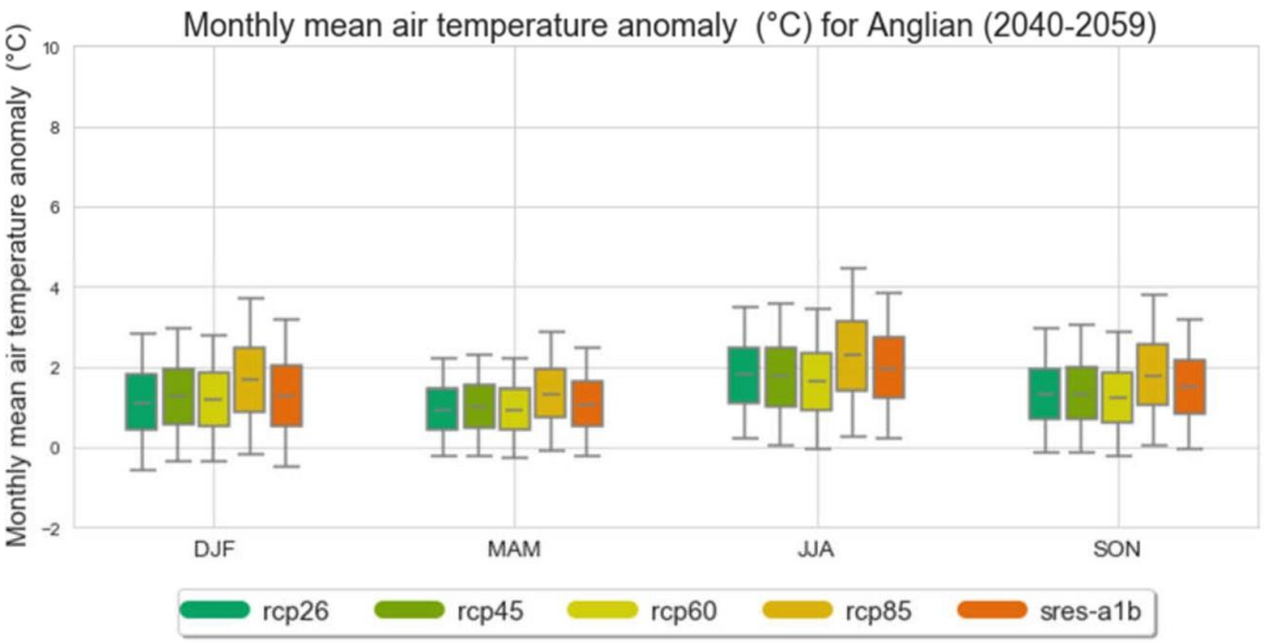
OctT
NovT
95%
75%
Mean
25%
5%

## C.12. UKCP Probabilistic data for river basins

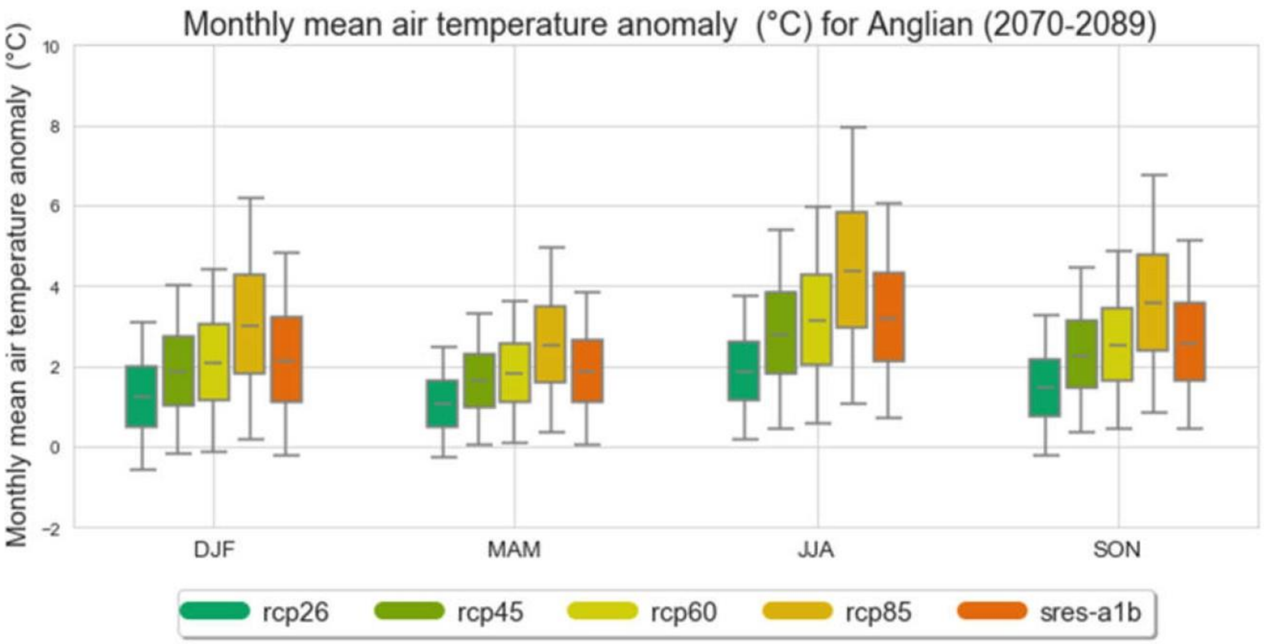
### C.12.1. Precipitation and temperature anomalies for all RCPs and river basins





Monthly mean air temperature anomaly (°C) for Anglian (2040-2059)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

Monthly mean air temperature anomaly (°C) for Anglian (2070-2089)
Monthly mean air temperature anomaly (°C)
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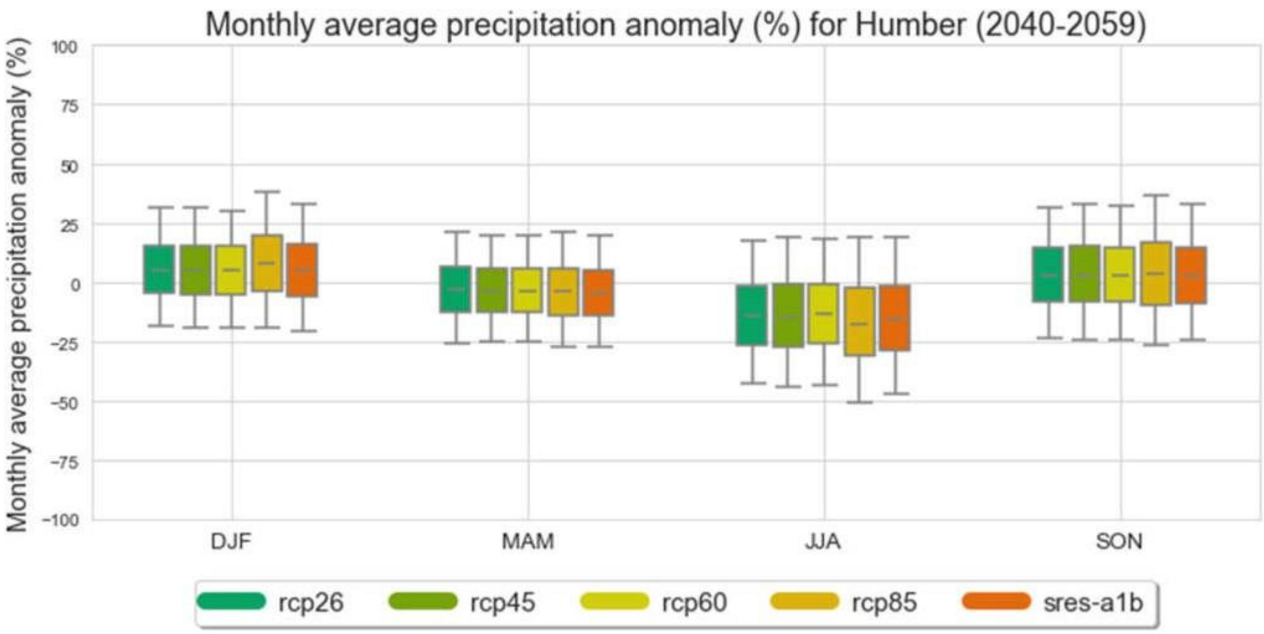
rcp85
sres-a1b


Monthly average precipitation anomaly (%) for Humber (2040-2059)
Monthly average precipitation anomaly (%)
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DJF
MAM
JJA
SON
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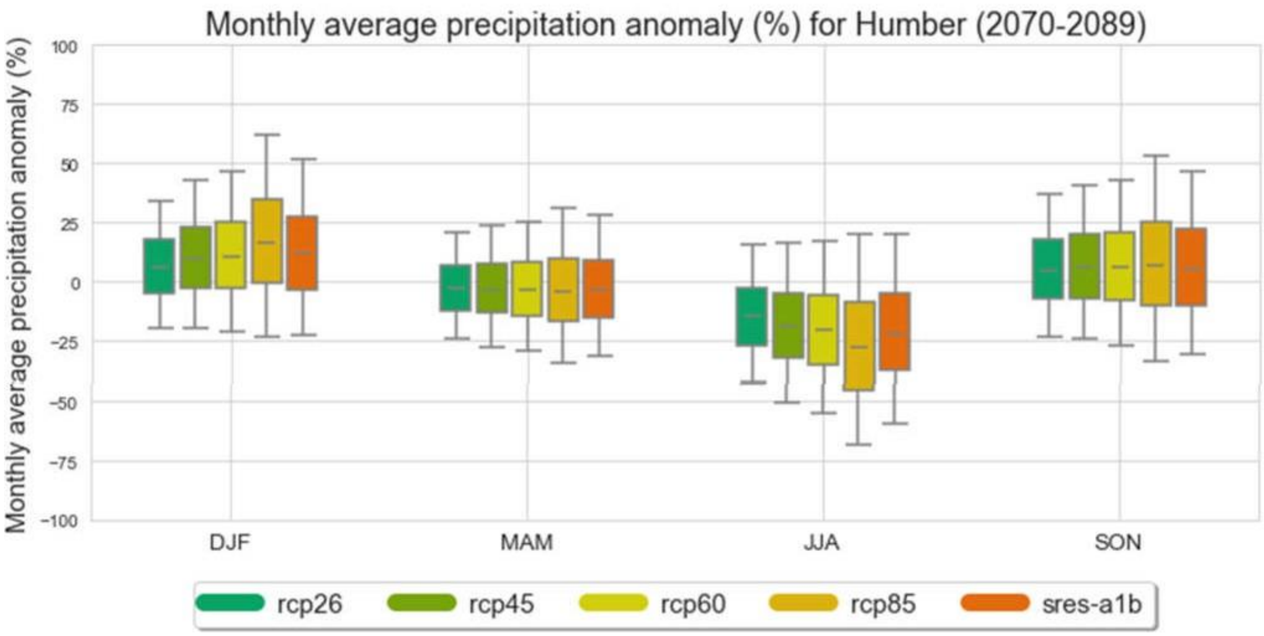
rcp60
rcp85
sres-a1b


Monthly average precipitation anomaly (%) for Humber (2070-2089)
Monthly average precipitation anomaly (%)
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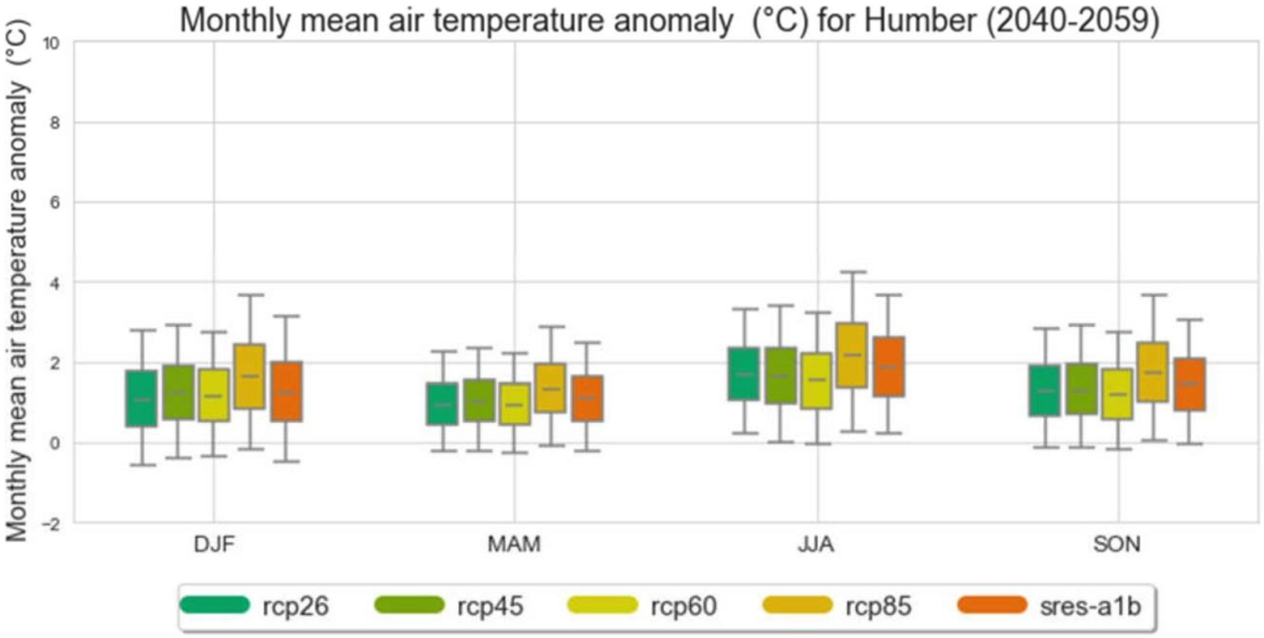
Monthly mean air temperature anomaly (°C) for Humber (2040-2059)
Monthly mean air temperature anomaly (°C)
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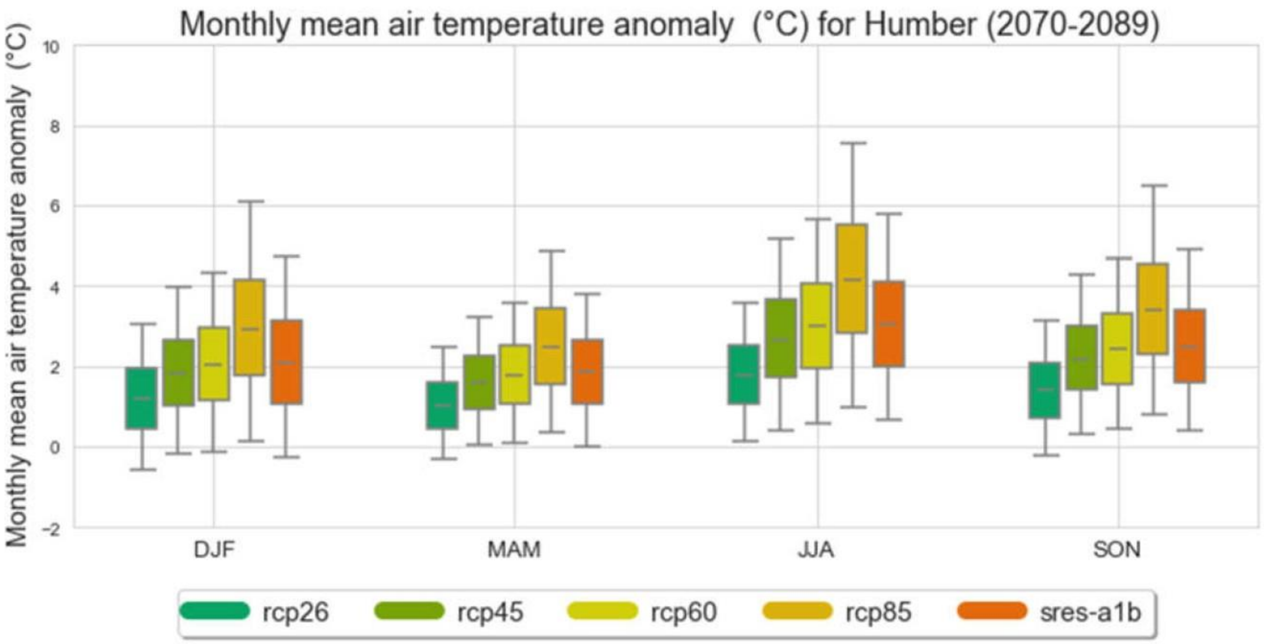
Monthly mean air temperature anomaly (°C) for Humber (2070-2089)
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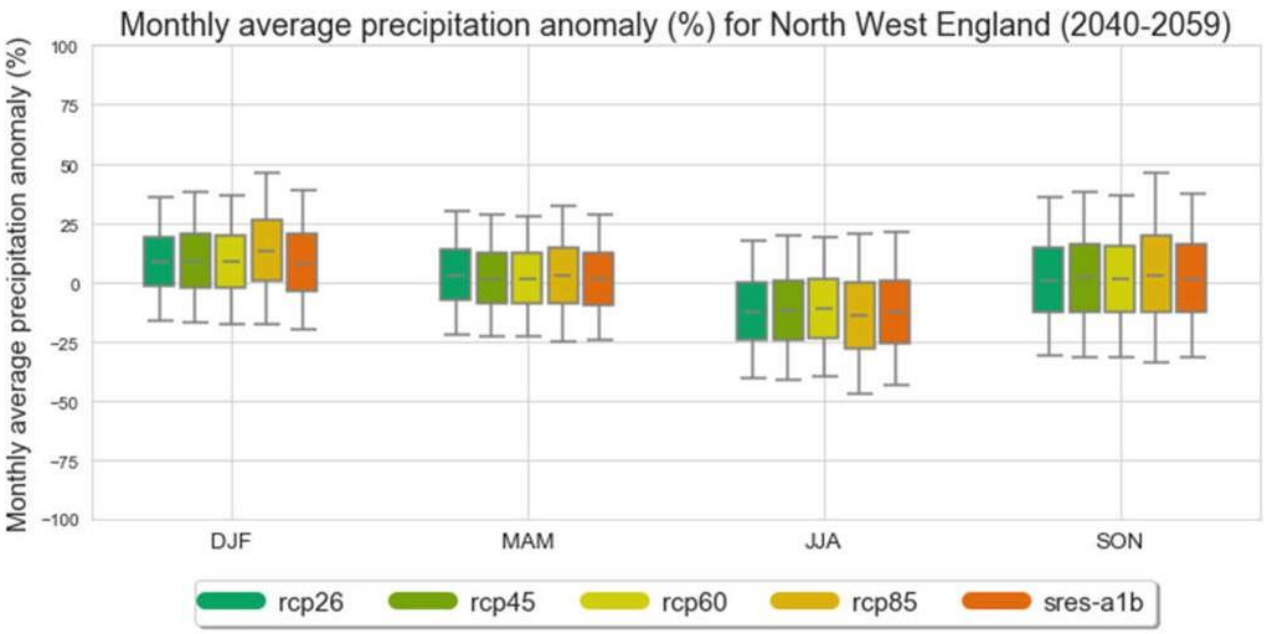
Monthly average precipitation anomaly (%) for North West England (2040-2059)
Monthly average precipitation anomaly (%)
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SON
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rcp45
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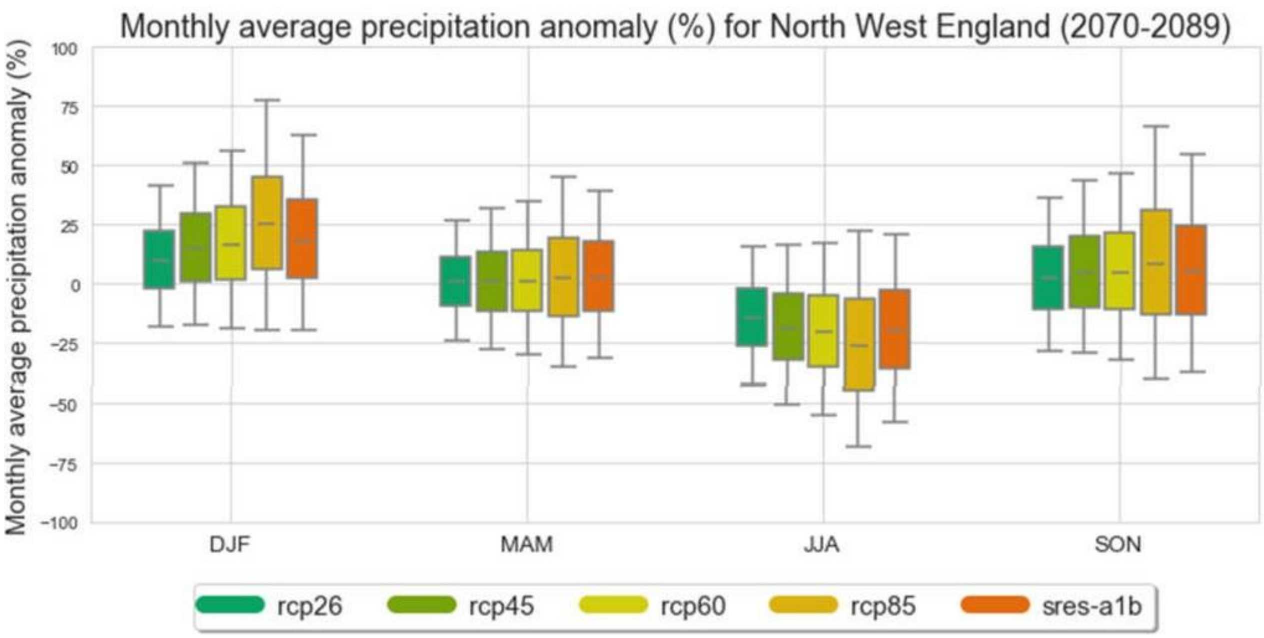
Monthly average precipitation anomaly (%) for North West England (2070-2089)
Monthly average precipitation anomaly (%)
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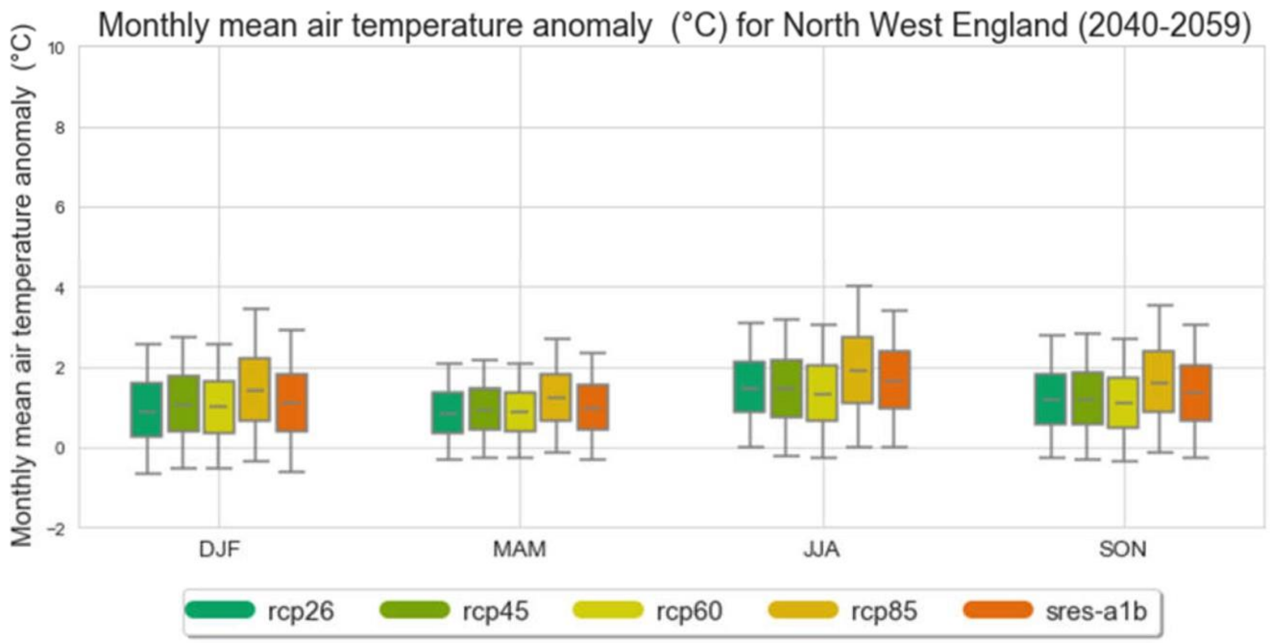
Monthly mean air temperature anomaly (°C) for North West England (2040-2059)
Monthly mean air temperature anomaly (°C)
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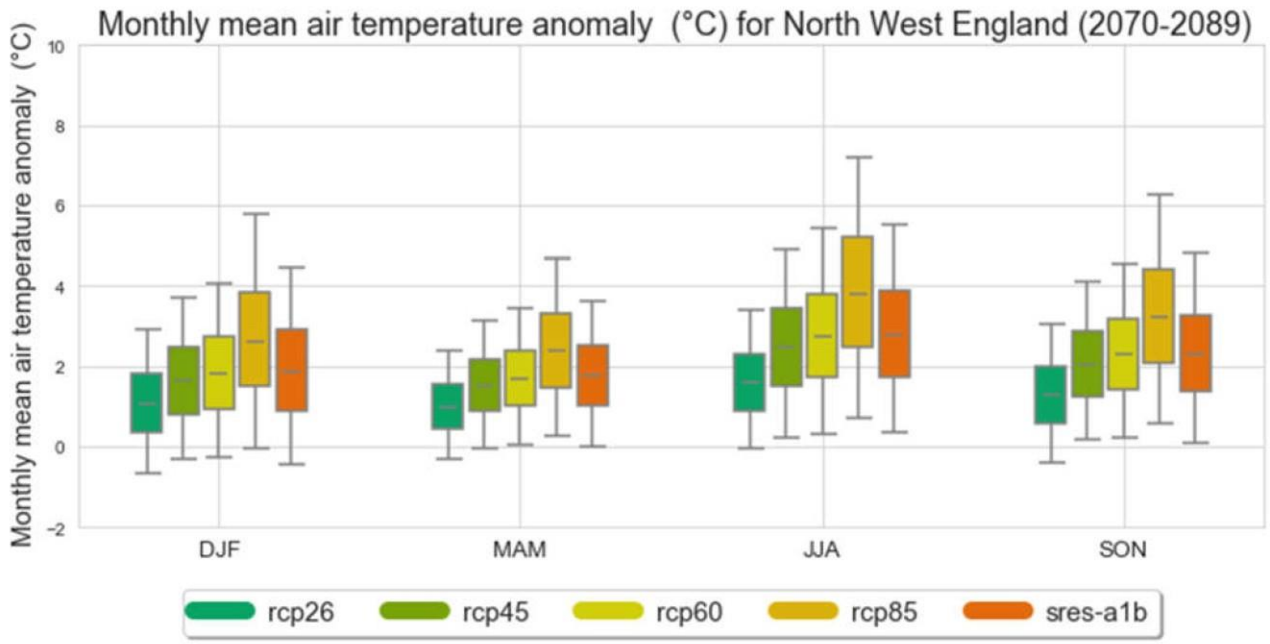
Monthly mean air temperature anomaly (°C) for North West England (2070-2089)
Monthly mean air temperature anomaly (°C)
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JJA
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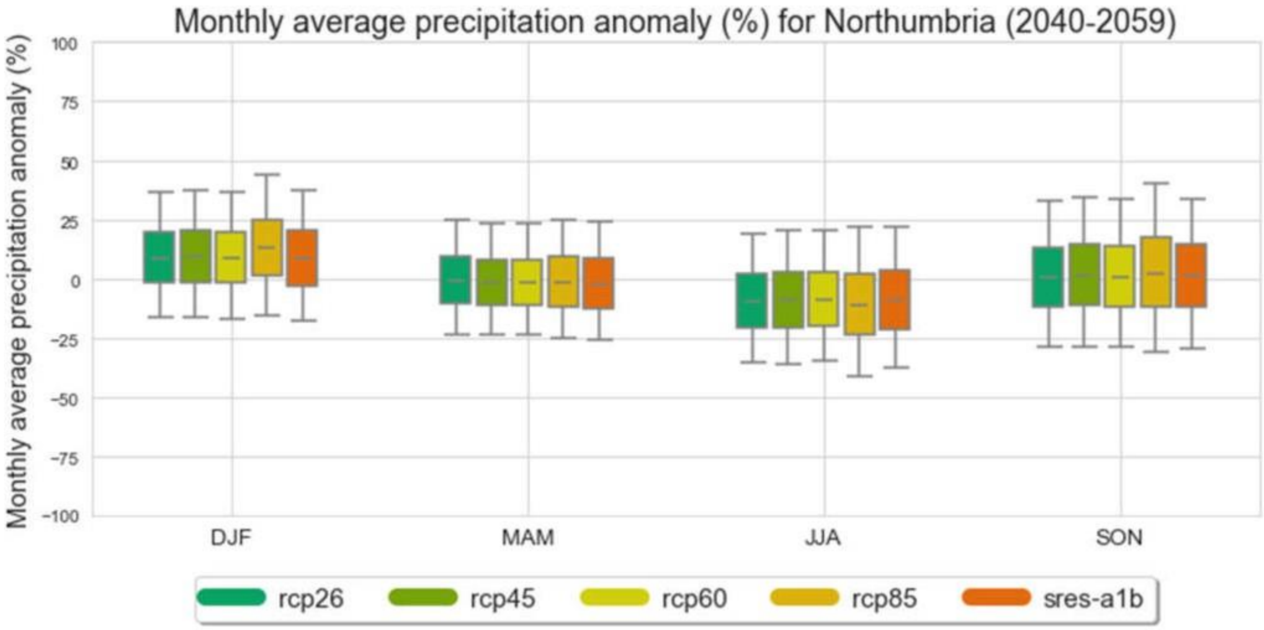
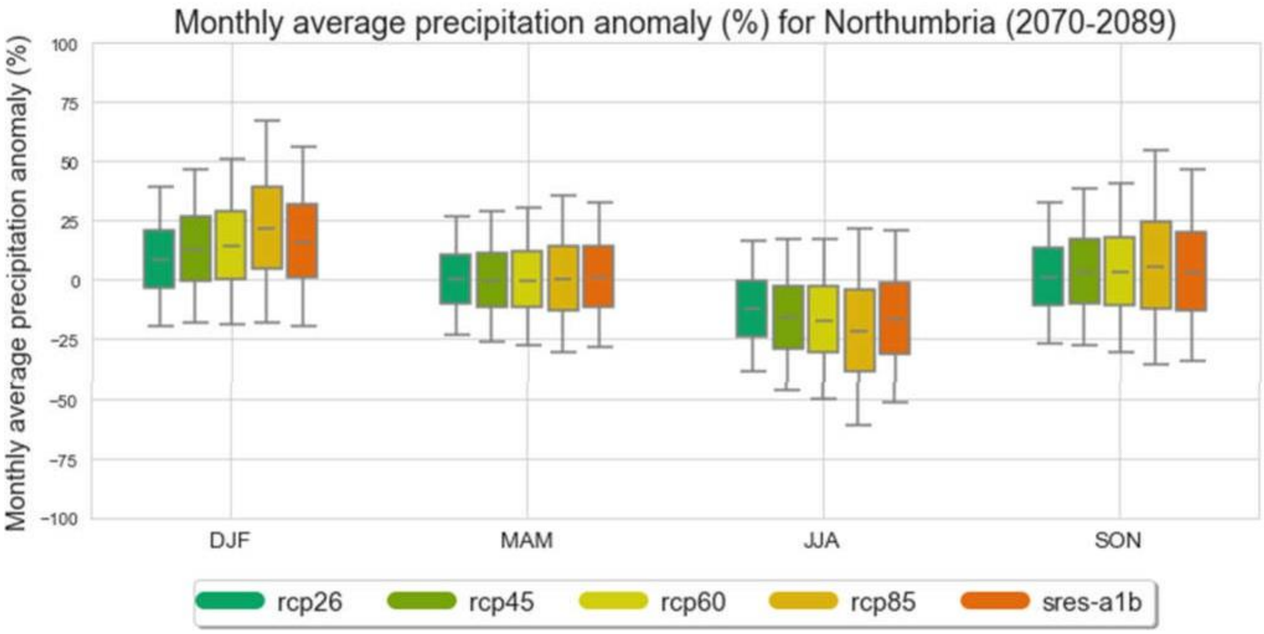
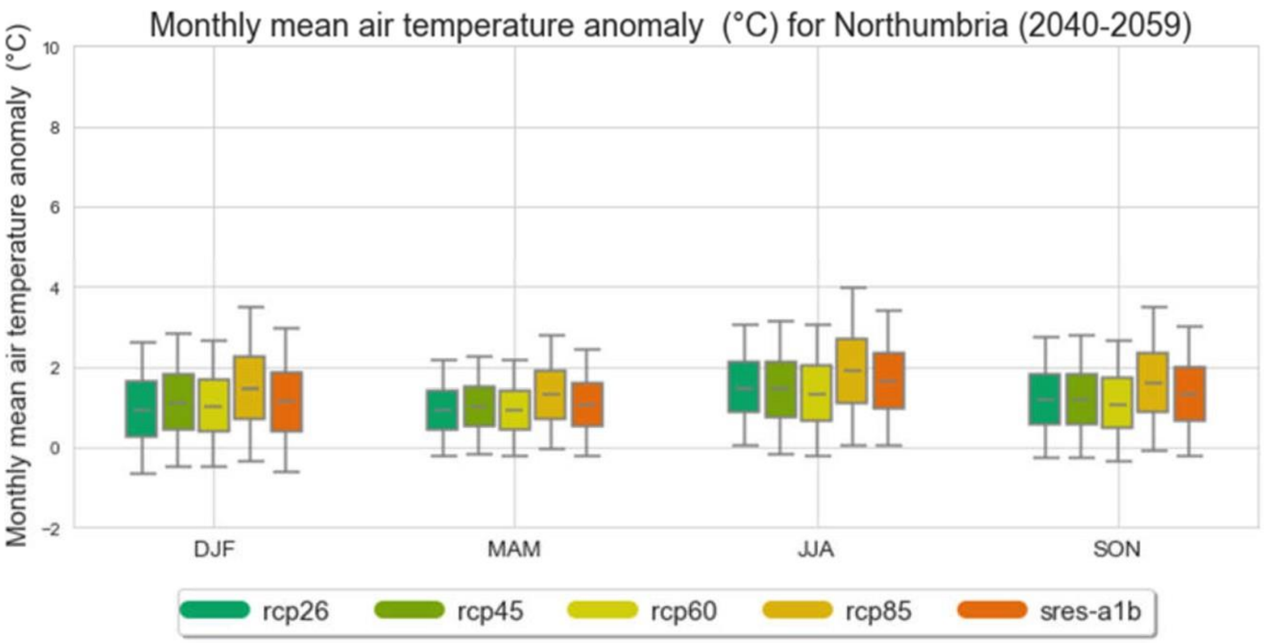
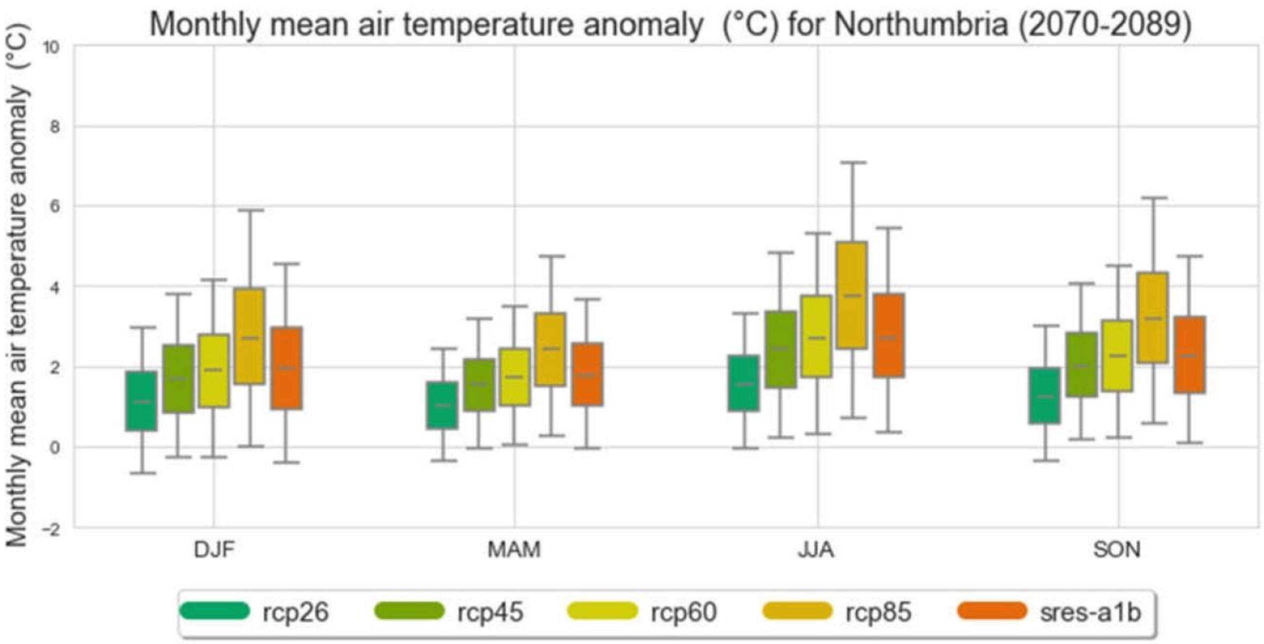
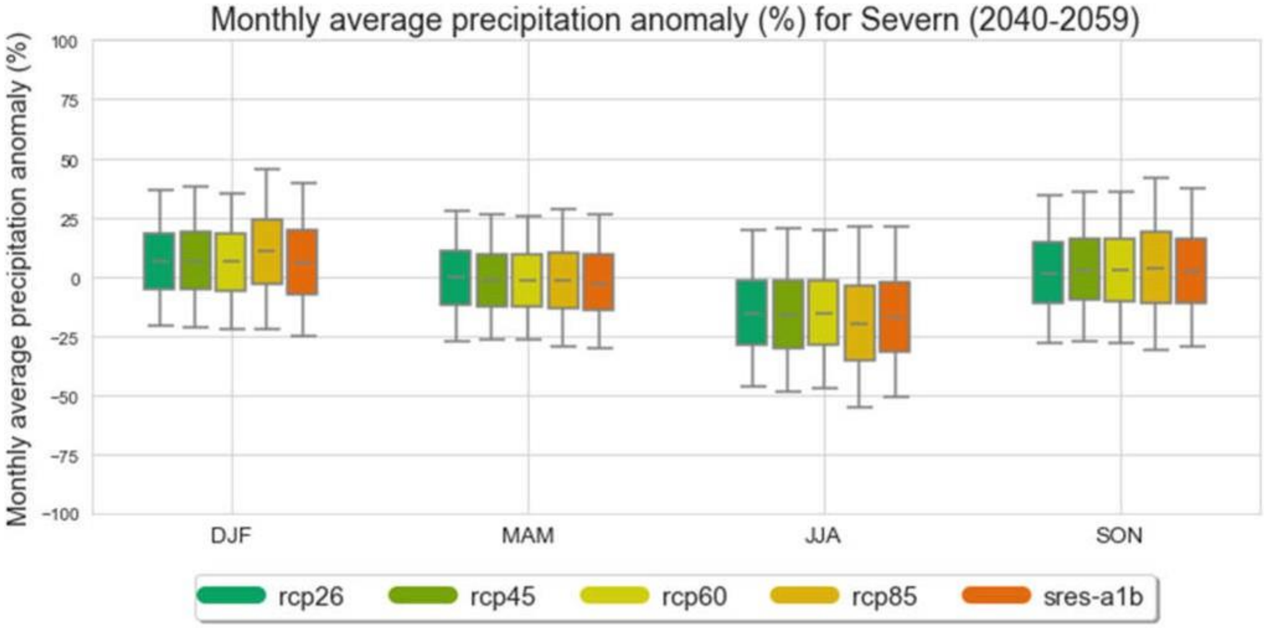
rcp45
rcp60
rcp85
sres-a1b

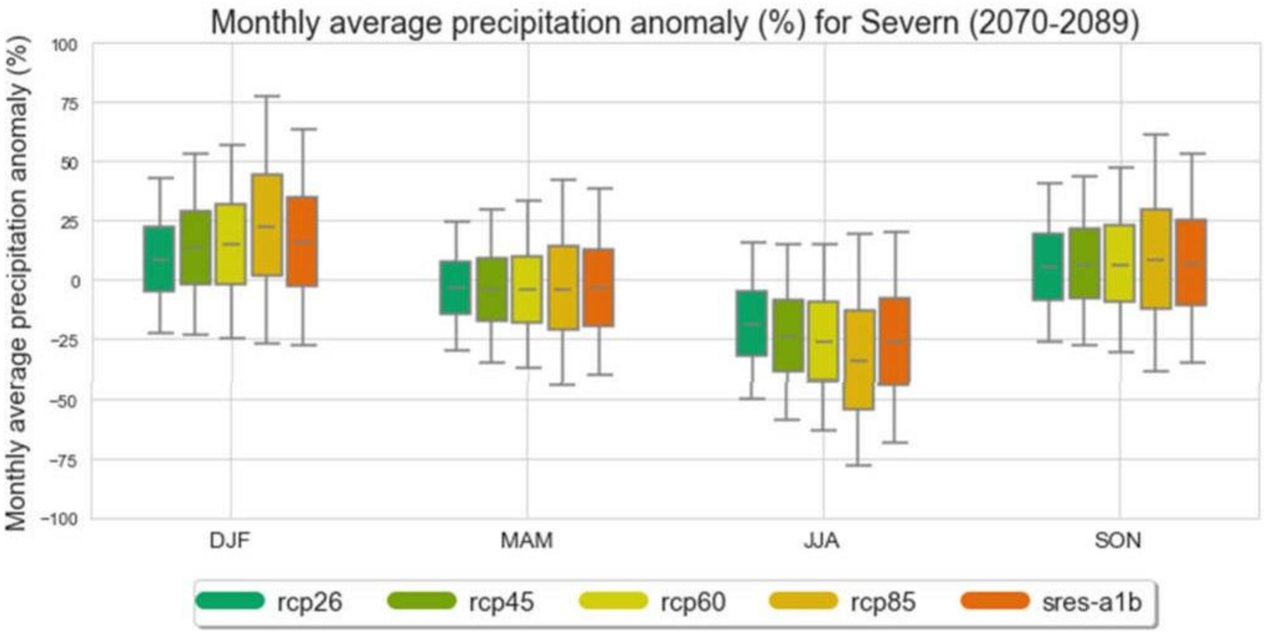

Monthly average precipitation anomaly (%) for Northumbria (2040-2059)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

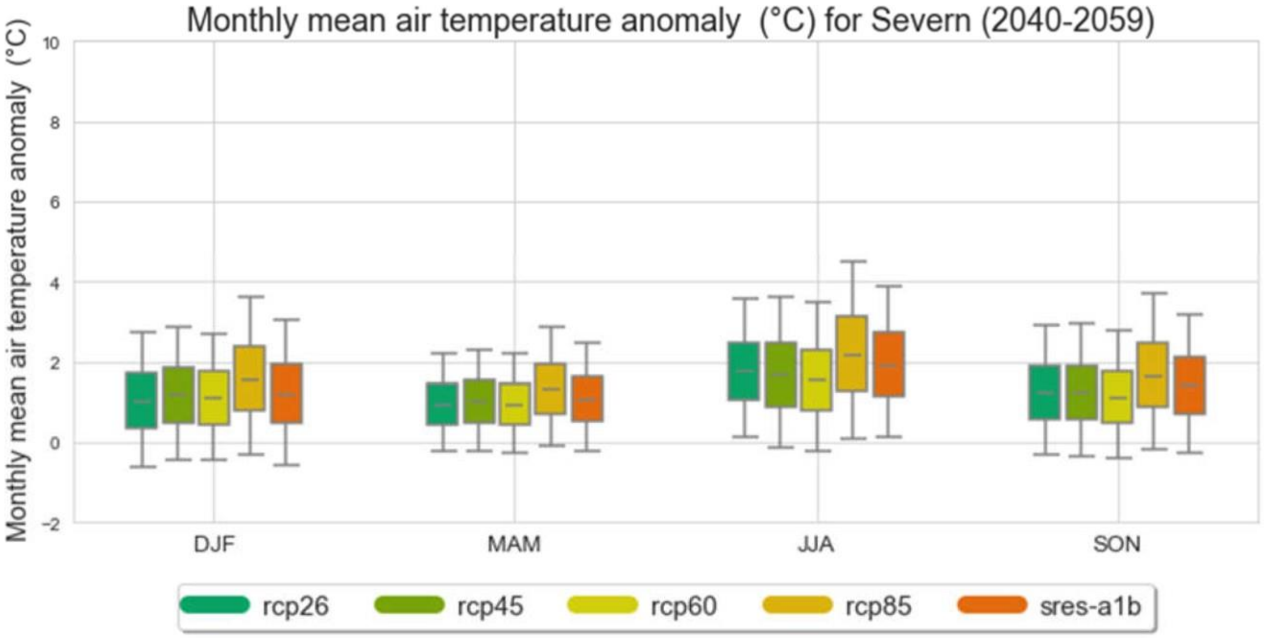

Monthly average precipitation anomaly (%) for Northumbria (2070-2089)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

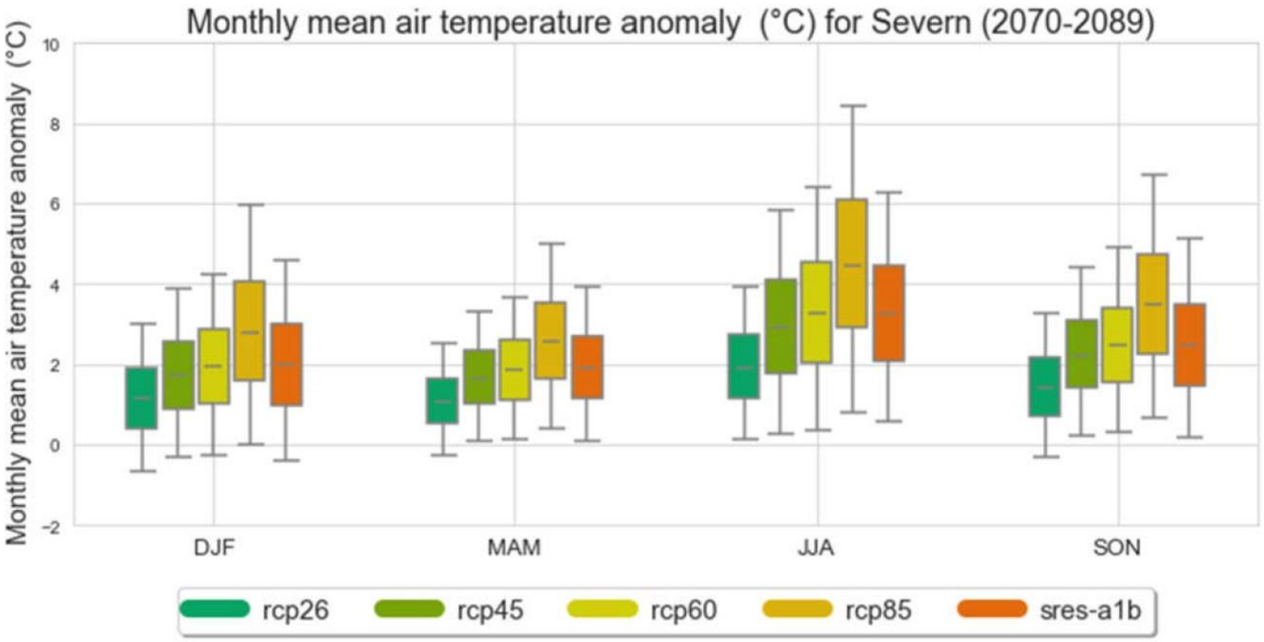

Monthly mean air temperature anomaly (°C) for Northumbria (2040-2059)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

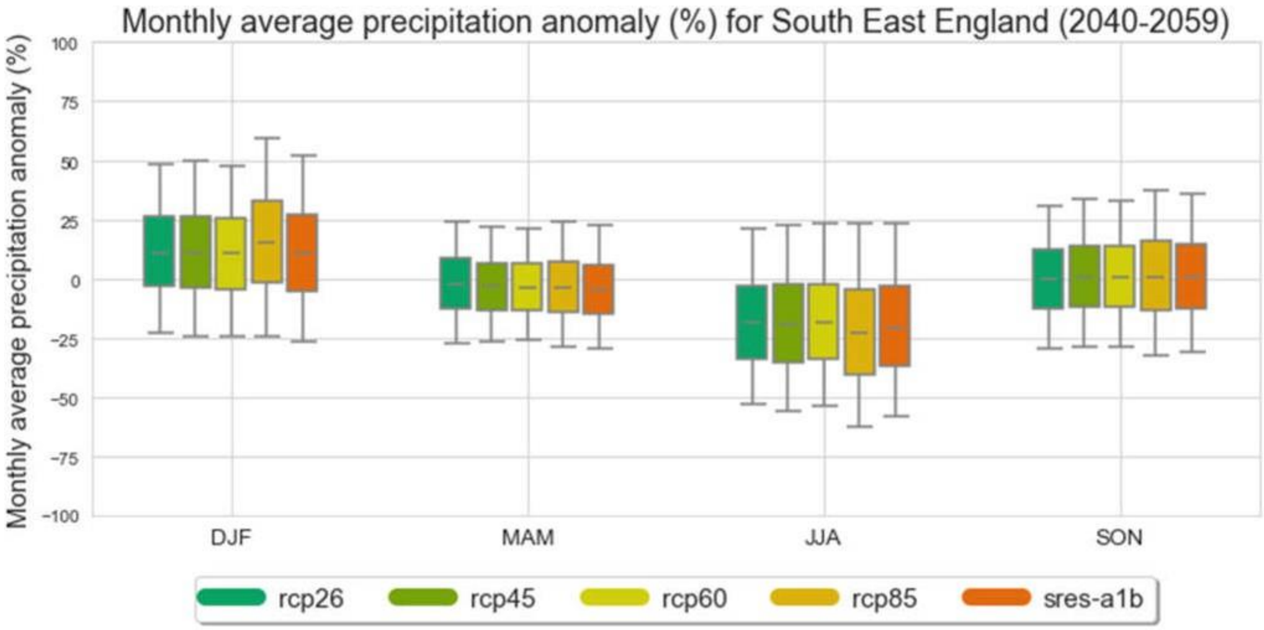

Monthly mean air temperature anomaly (°C) for Northumbria (2070-2089)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

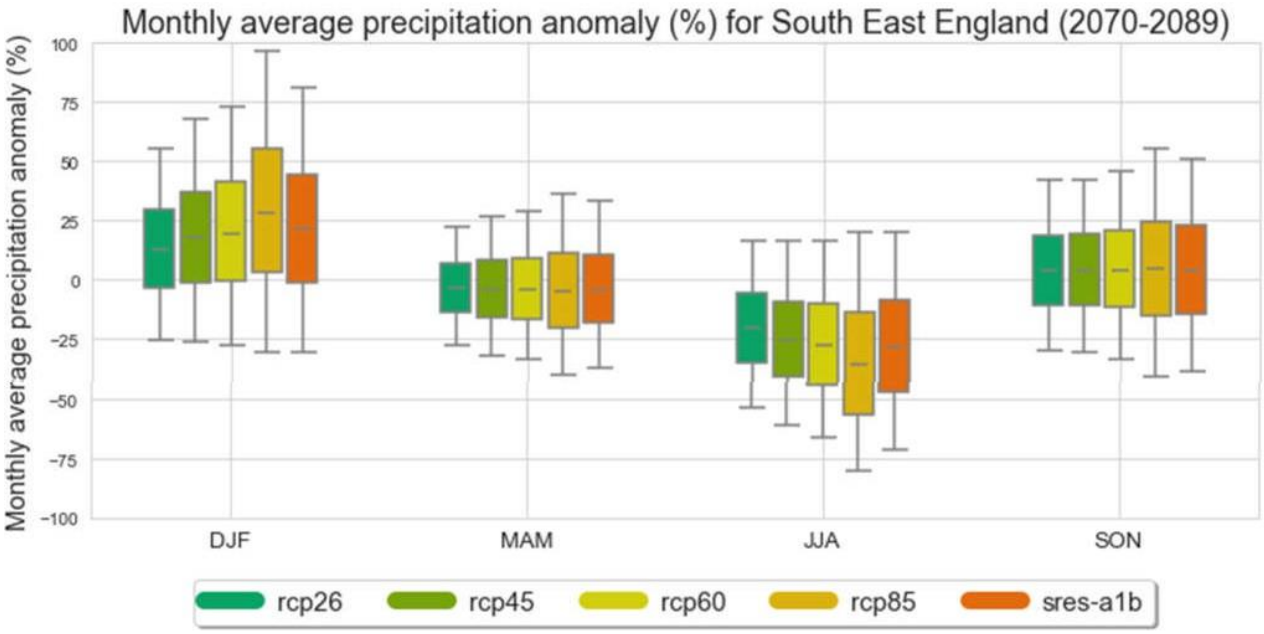

Monthly average precipitation anomaly (%) for Severn (2040-2059)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

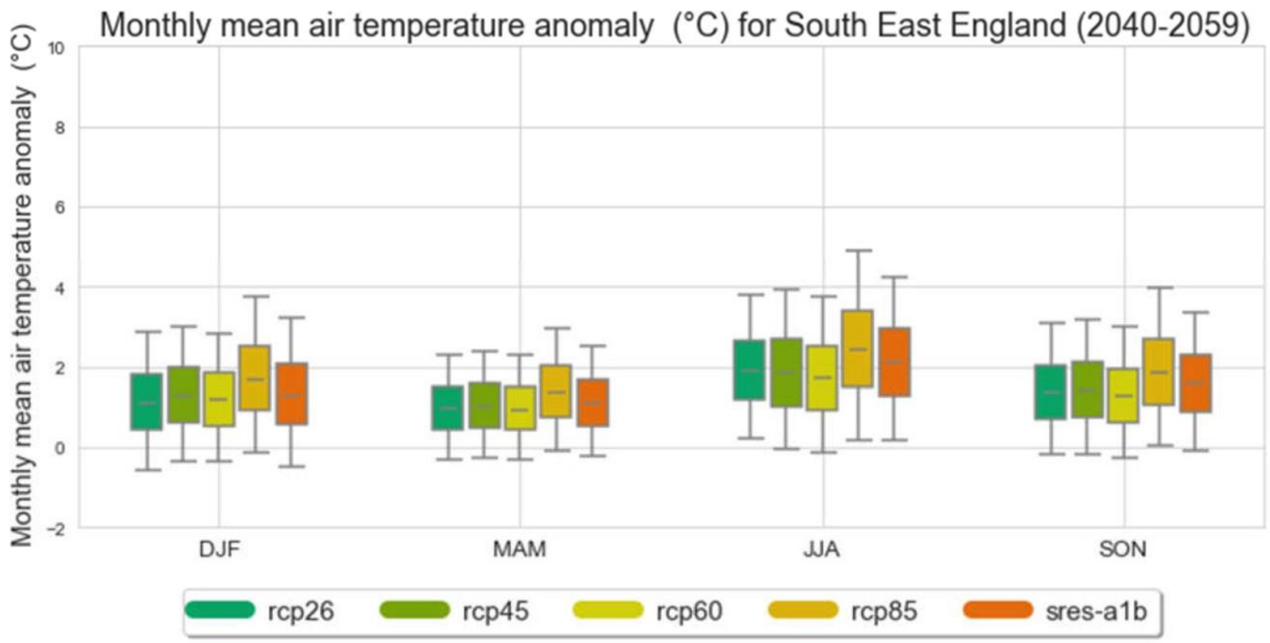

Monthly average precipitation anomaly (%) for Severn (2070-2089)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

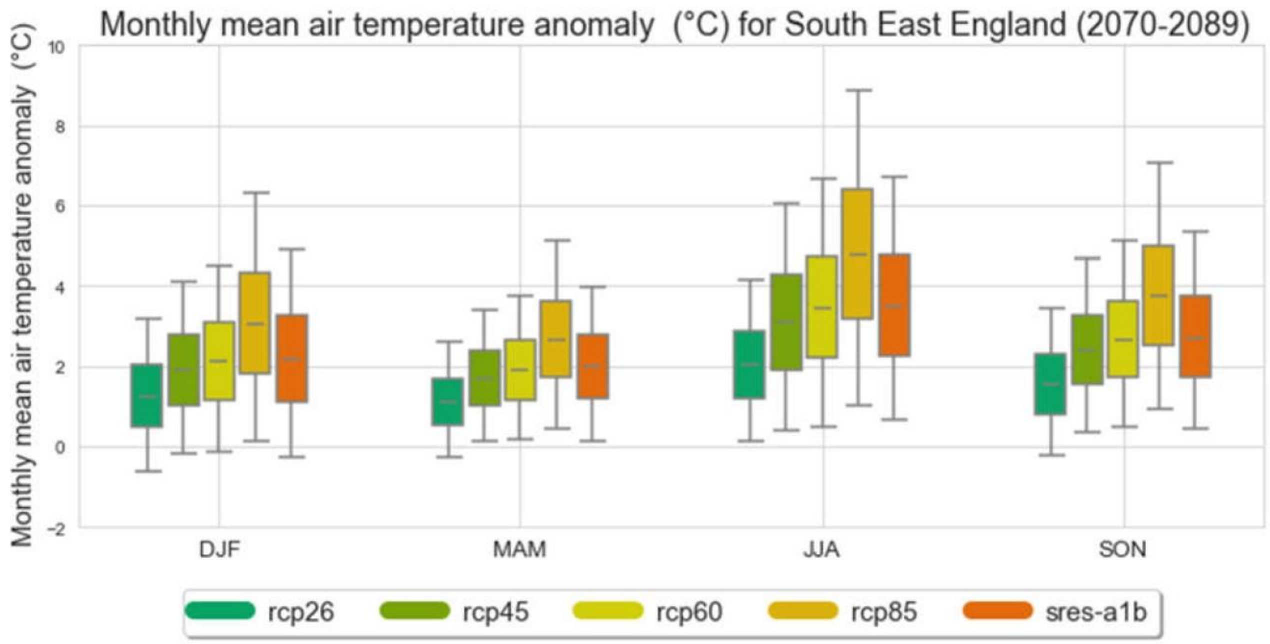

Monthly mean air temperature anomaly (°C) for Severn (2040-2059)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

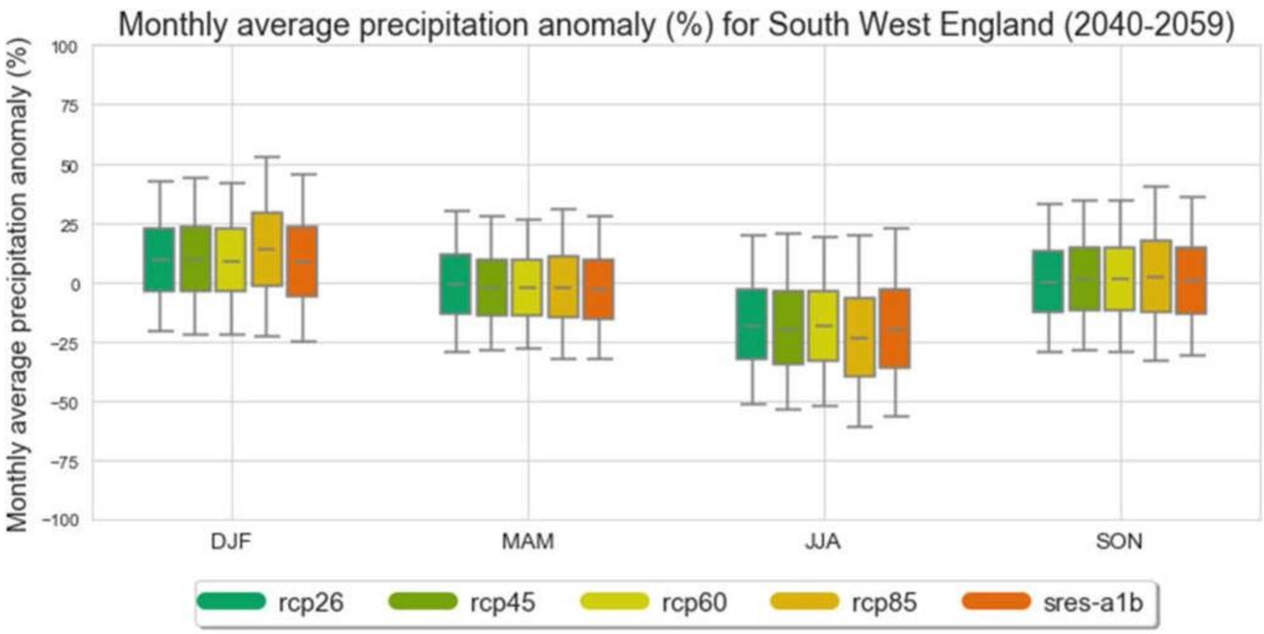

Monthly mean air temperature anomaly (°C) for Severn (2070-2089)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

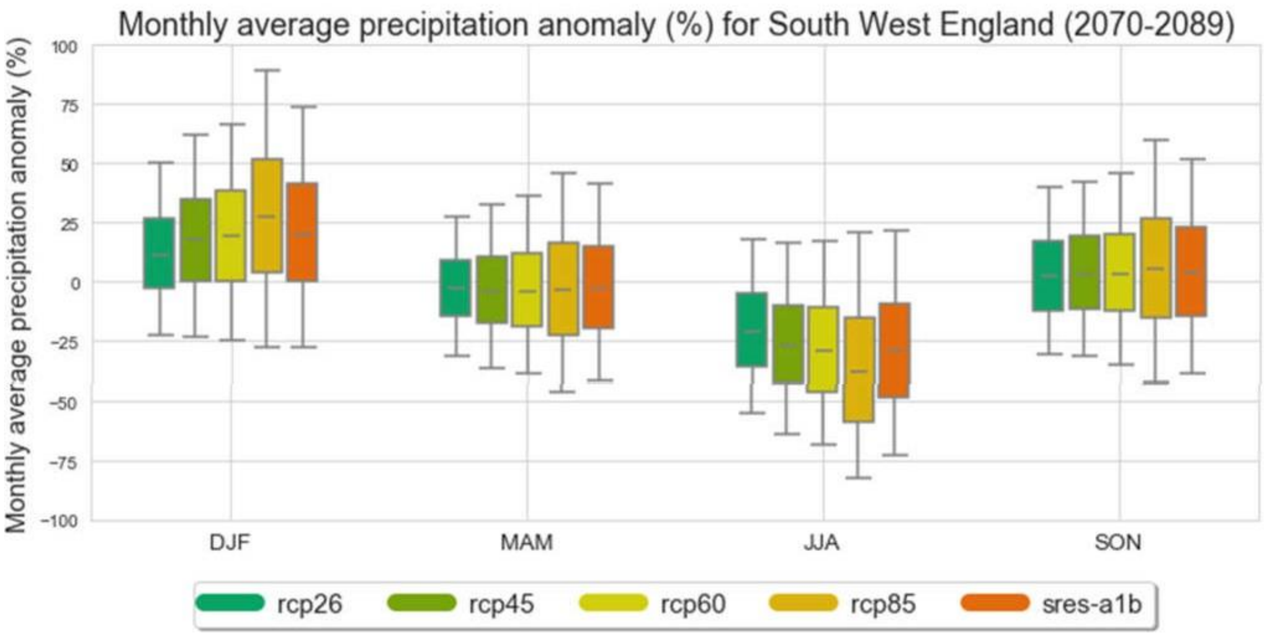

Monthly average precipitation anomaly (%) for South East England (2040-2059)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

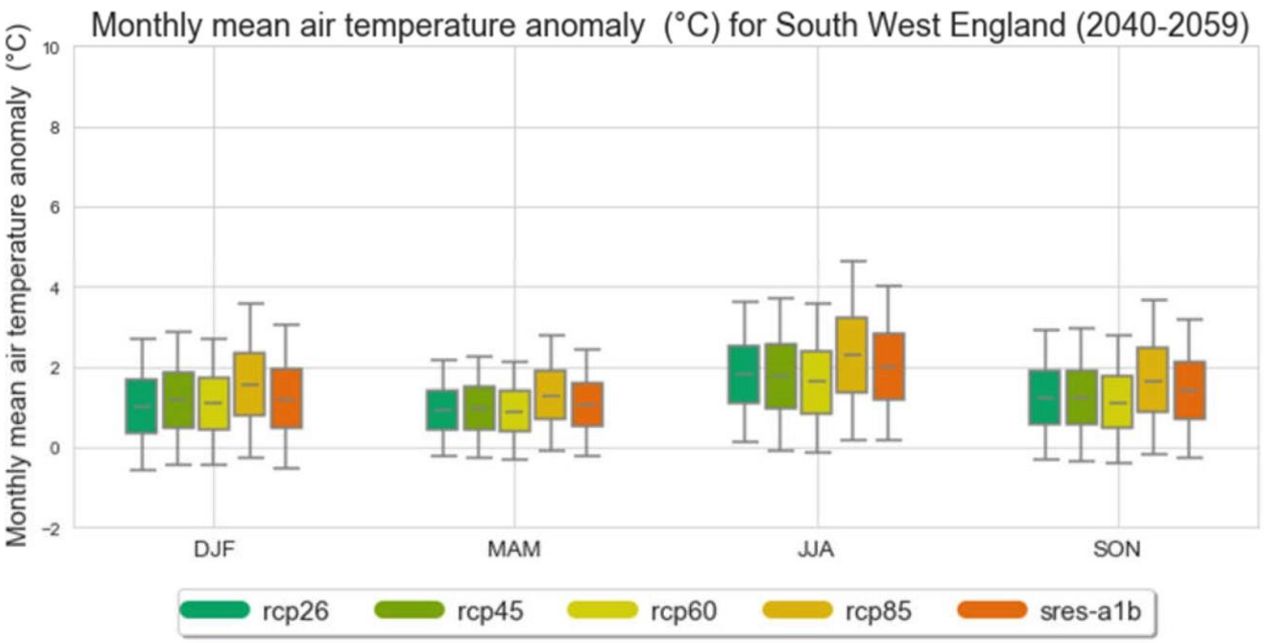

Monthly average precipitation anomaly (%) for South East England (2070-2089)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

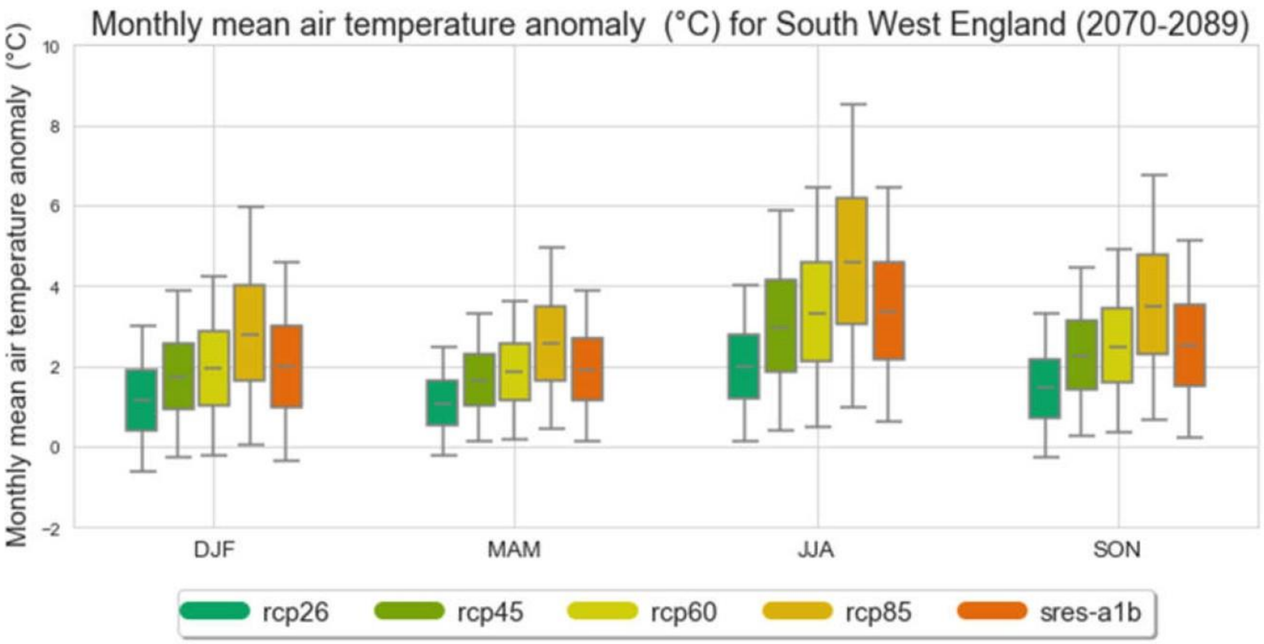

Monthly mean air temperature anomaly (°C) for South East England (2040-2059)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

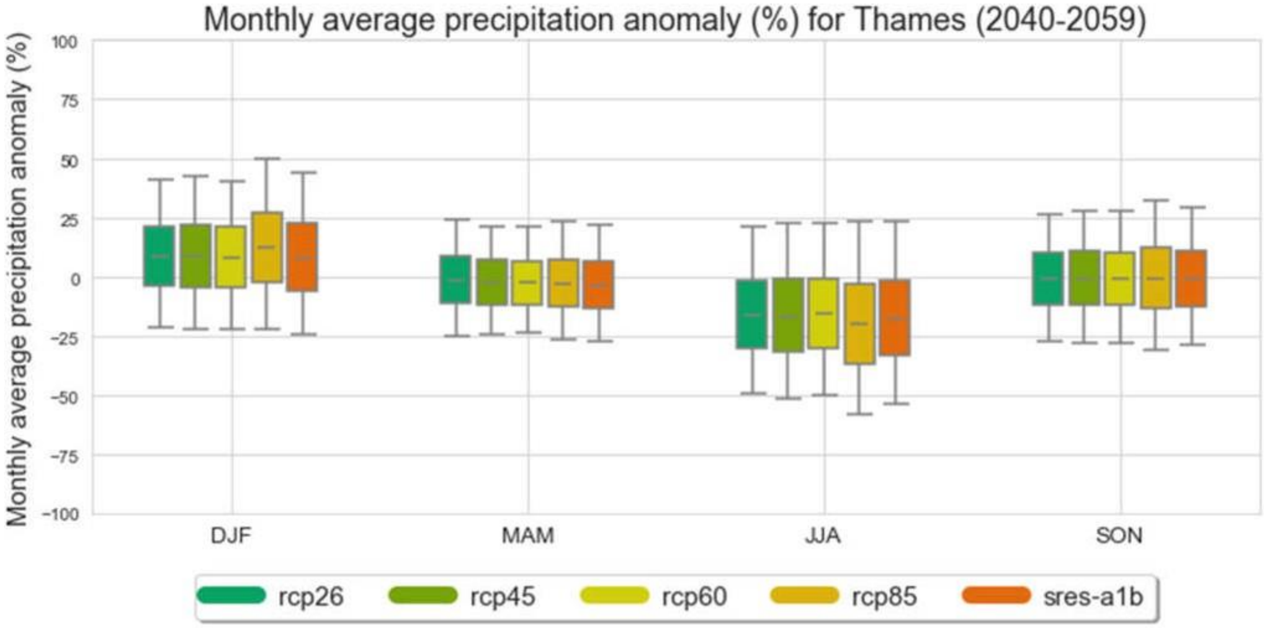

Monthly mean air temperature anomaly (°C) for South East England (2070-2089)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

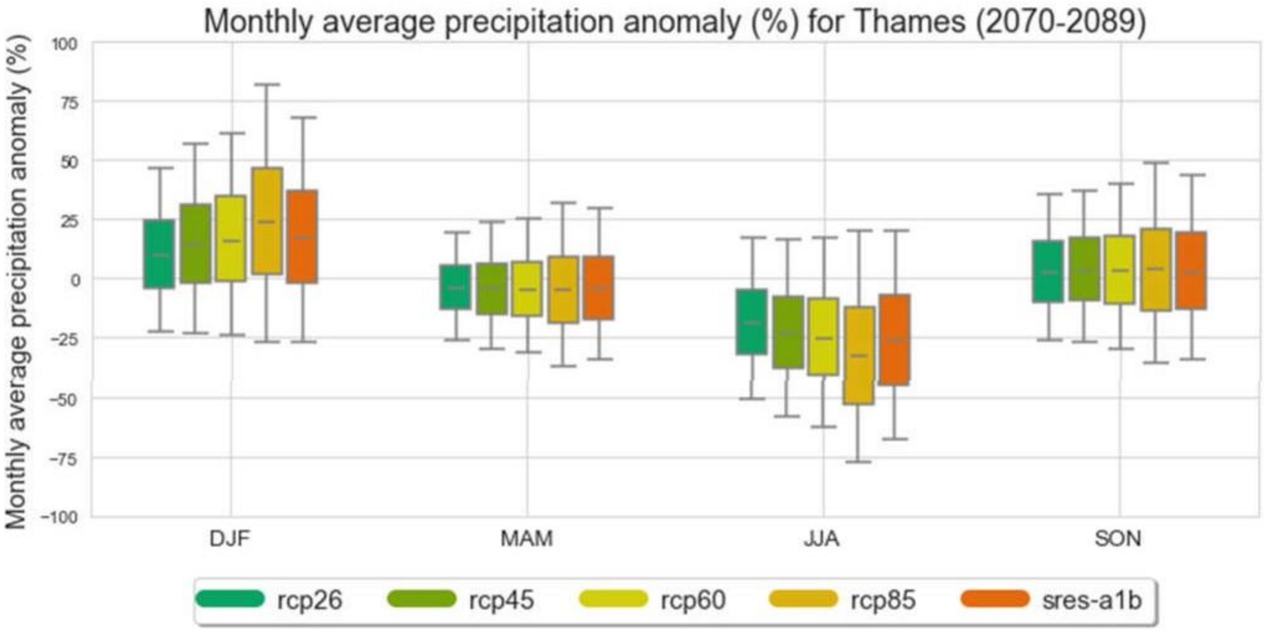

Monthly average precipitation anomaly (%) for South West England (2040-2059)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

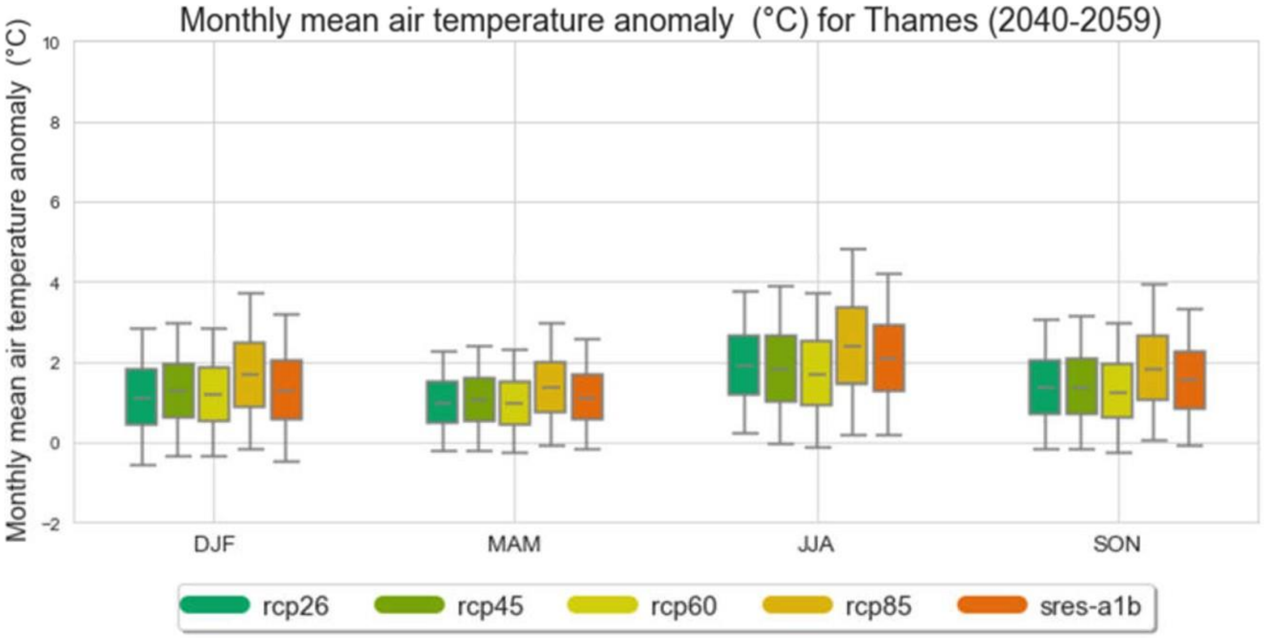

Monthly average precipitation anomaly (%) for South West England (2070-2089)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

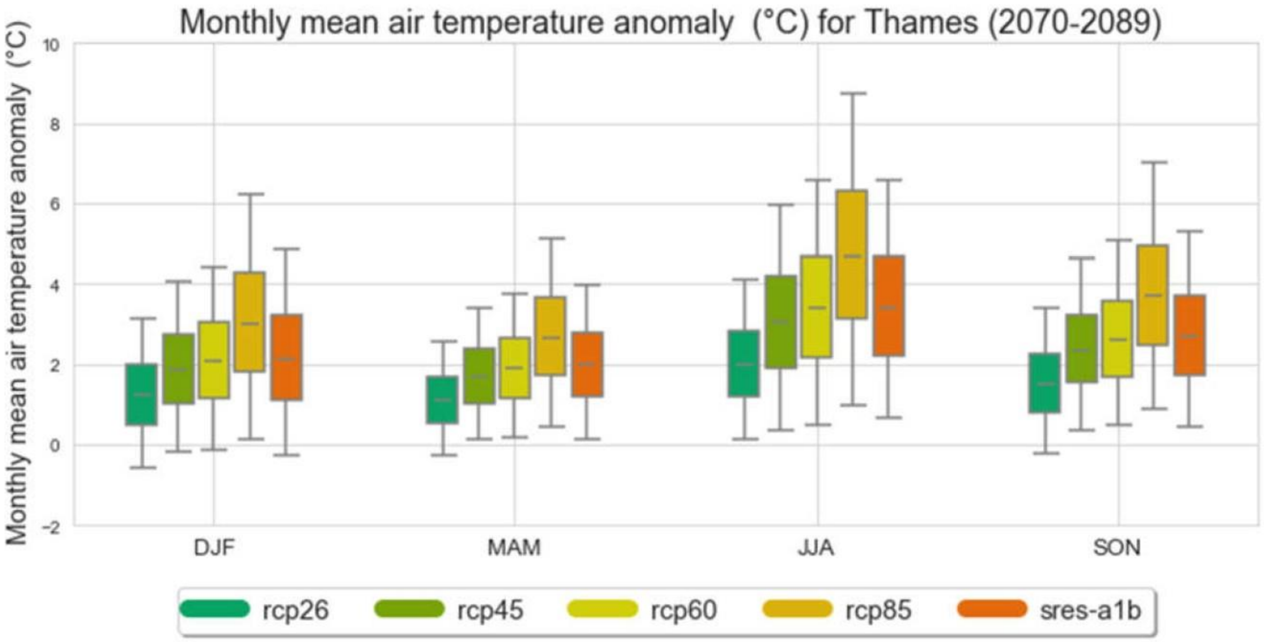

Monthly mean air temperature anomaly (°C) for South West England (2040-2059)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

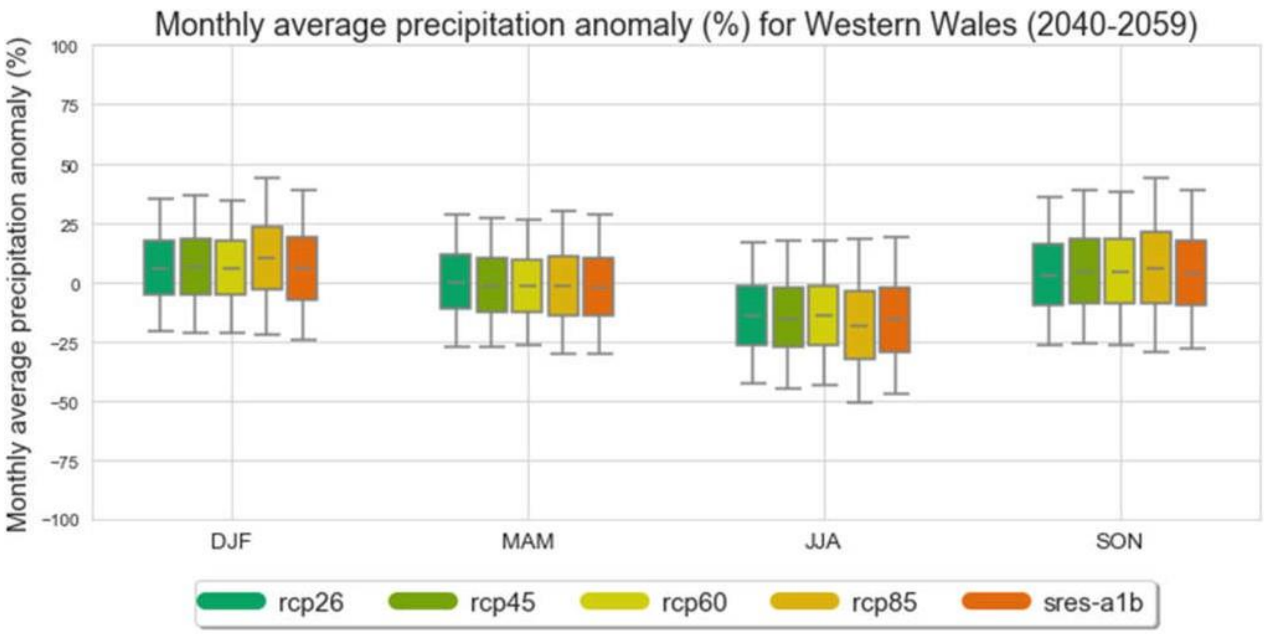

Monthly mean air temperature anomaly (°C) for South West England (2070-2089)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b


Monthly average precipitation anomaly (%) for Thames (2040-2059)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

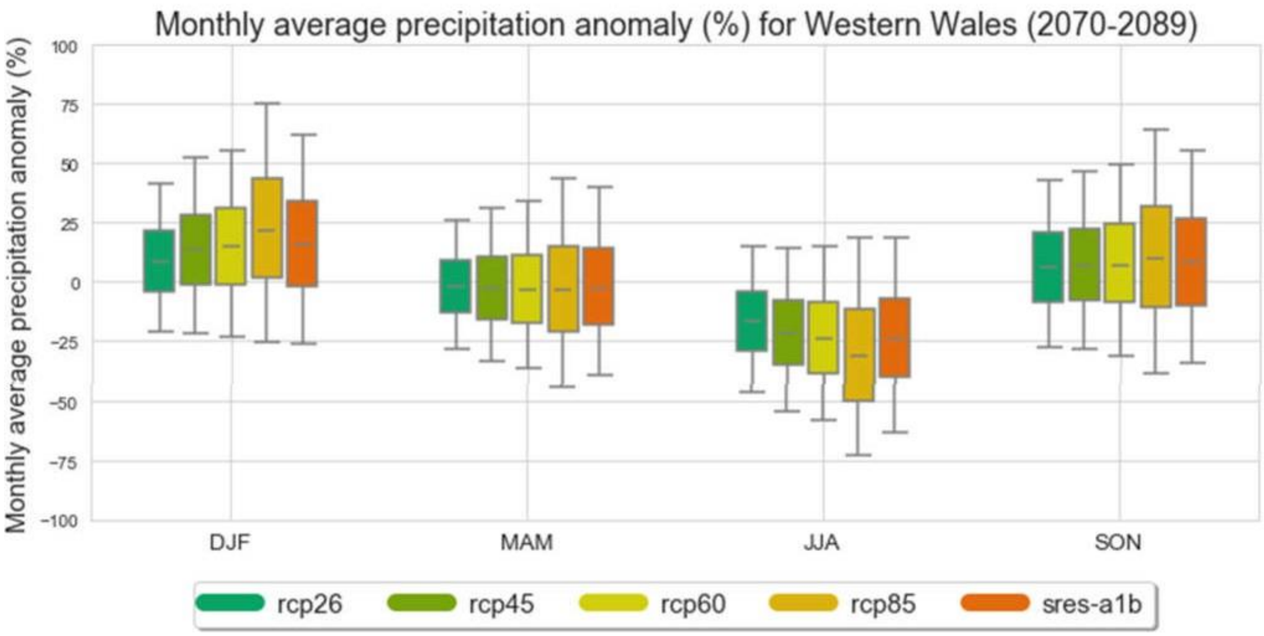

Monthly average precipitation anomaly (%) for Thames (2070-2089)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b


Monthly mean air temperature anomaly (°C) for Thames (2040-2059)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

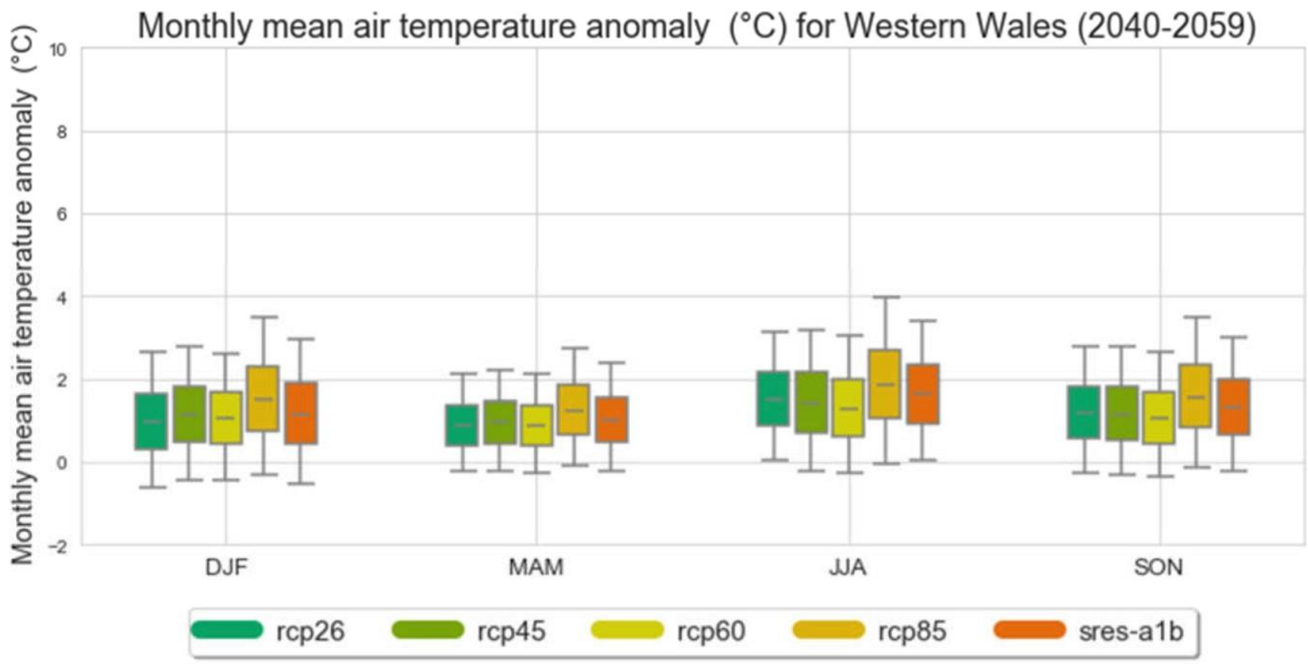

Monthly mean air temperature anomaly (°C) for Thames (2070-2089)
Monthly mean air temperature anomaly (°C)
10
8
6
4
2
0
-2
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

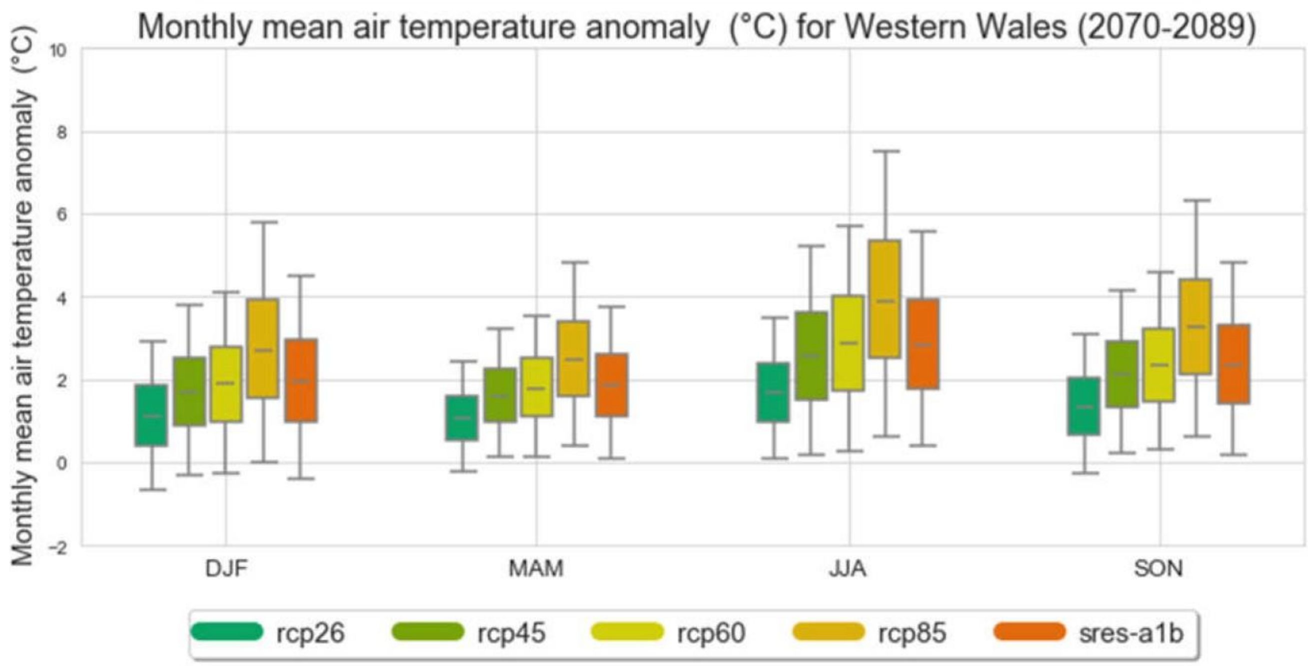


Monthly average precipitation anomaly (%) for Western Wales (2040-2059)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

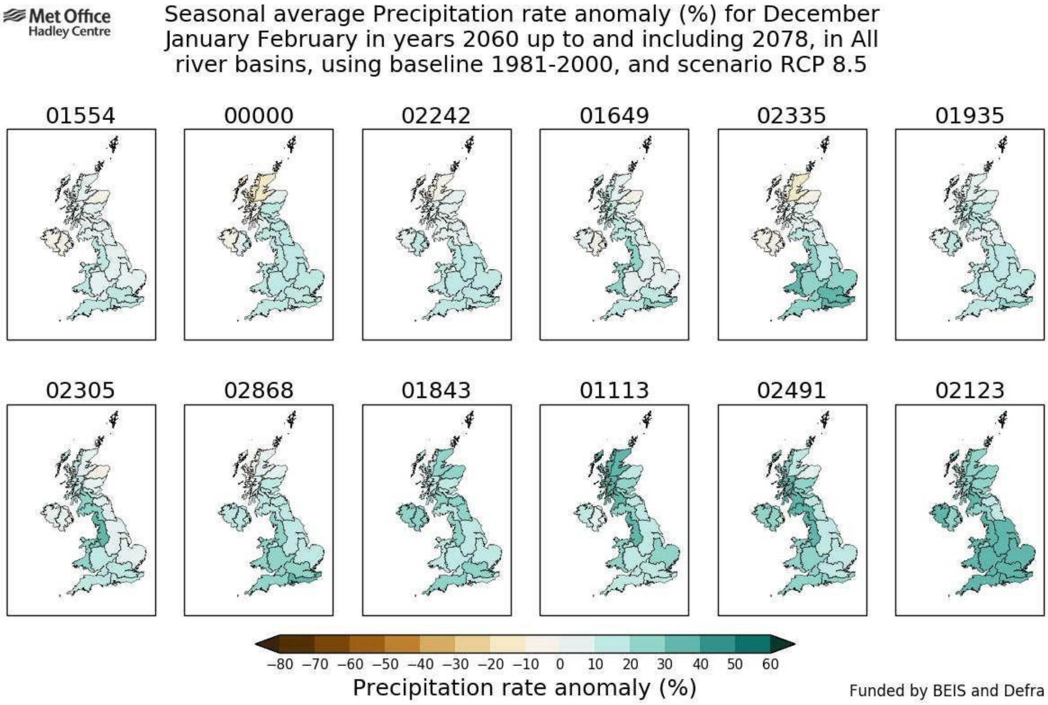
Monthly average precipitation anomaly (%) for Western Wales (2070-2089)
Monthly average precipitation anomaly (%)
100
75
50
25
0
-25
-50
-75
-100
DJF
MAM
JJA
SON
rcp26
rcp45
rcp60
rcp85
sres-a1b

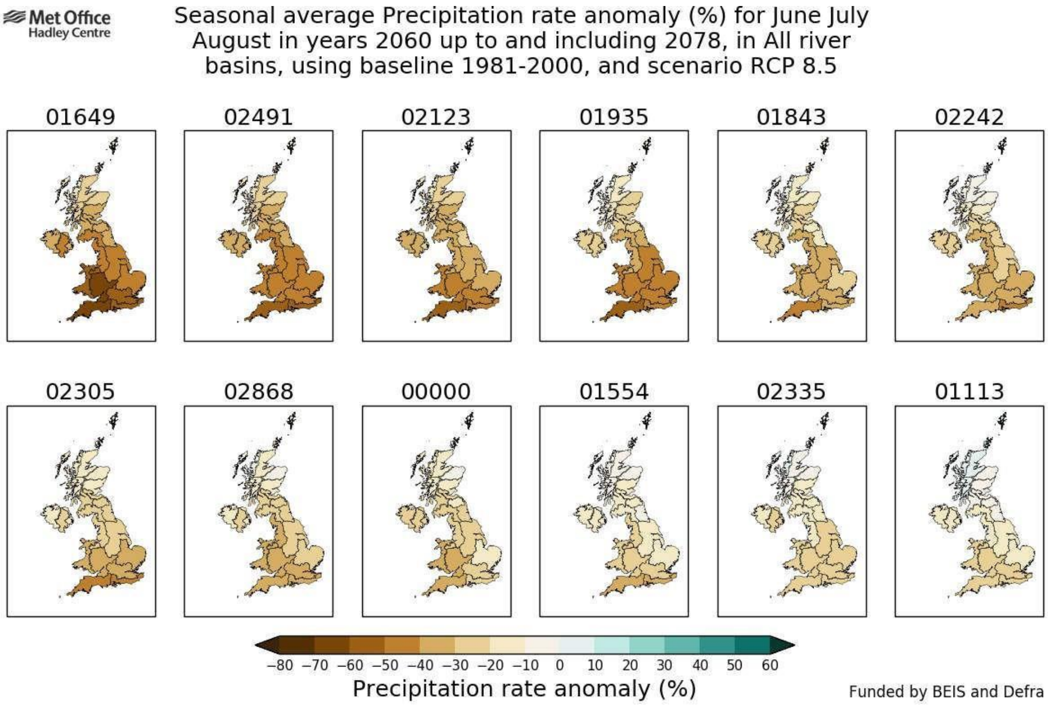


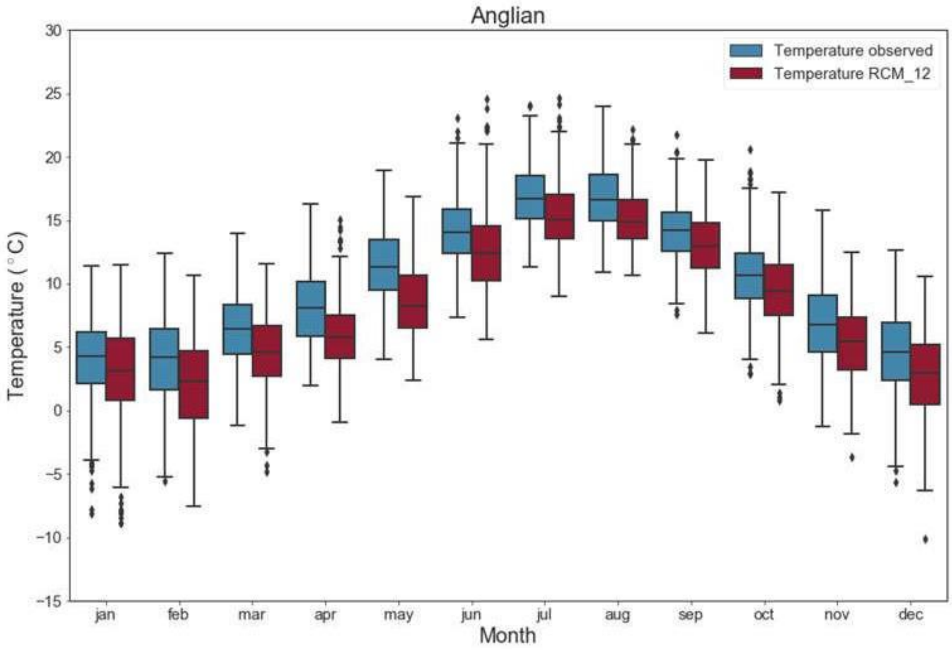

## C.12.2. UKCP Regional Climate Models

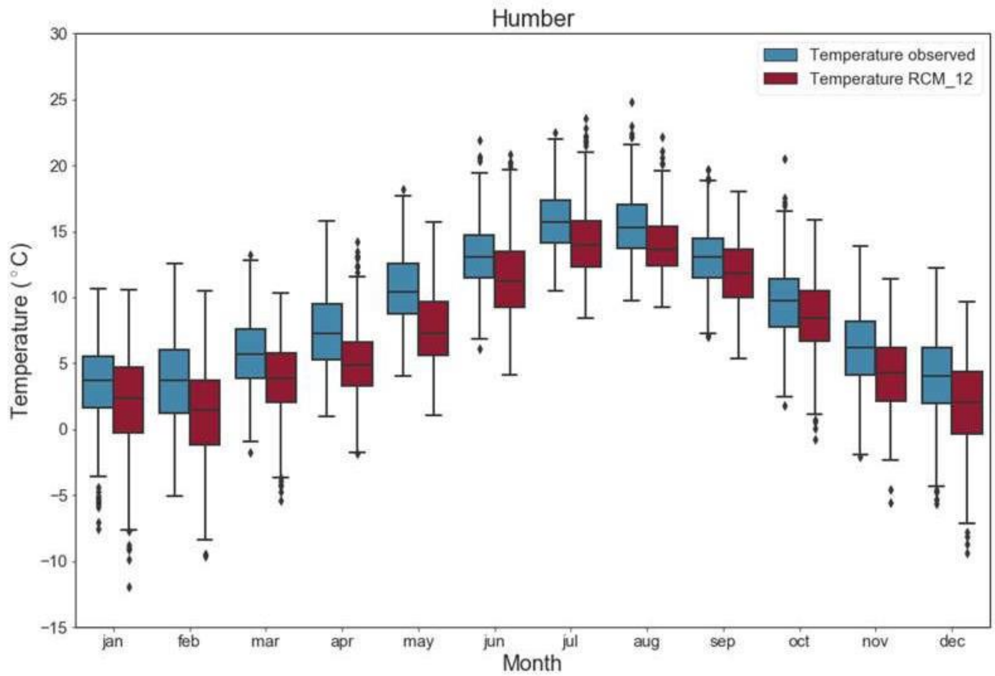
### C.12.2.1. Raw RCM data maps from the UKCP User Interface

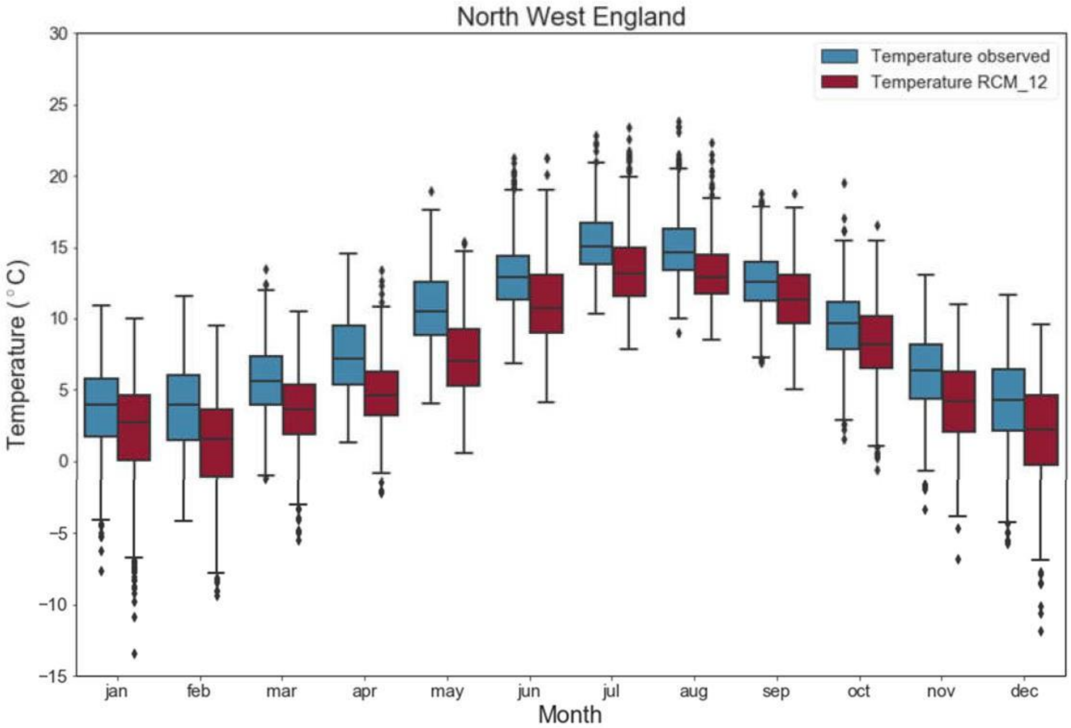

Met Office
Hadley Centre
Seasonal average Precipitation rate anomaly (%) for December January February in years 2060 up to and including 2078, in All river basins, using baseline 1981-2000, and scenario RCP 8.5
01554
00000
02242
01649
02335
01935
02305
02868
01843
01113
02491
02123
−80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60
Precipitation rate anomaly (%)
Funded by BEIS and Defra

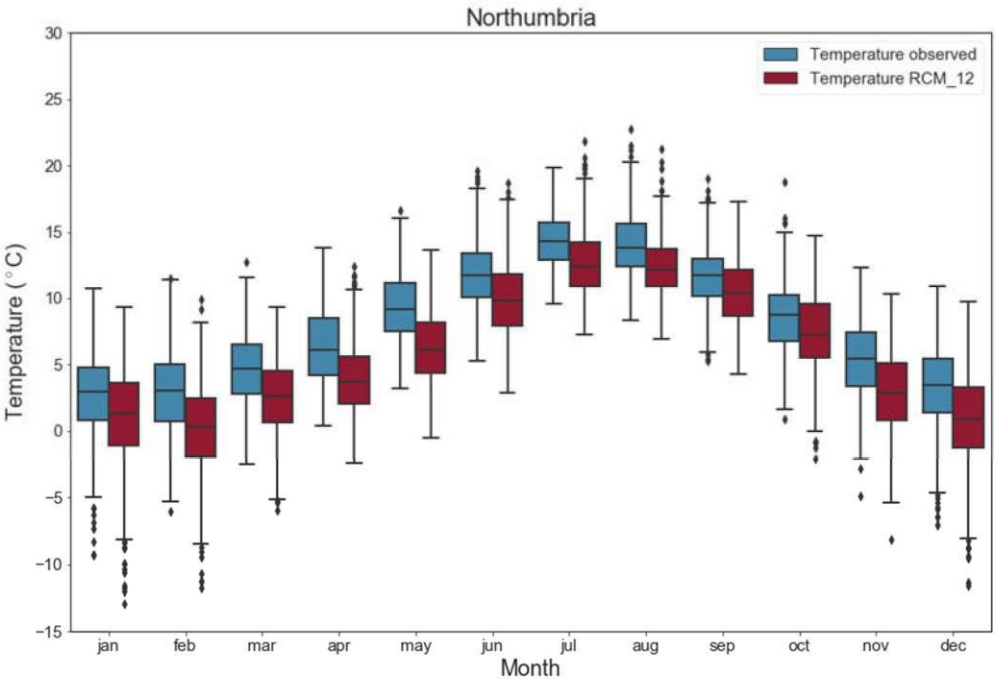

Met Office
Hadley Centre
Seasonal average Precipitation rate anomaly (%) for June July August in years 2060 up to and including 2078, in All river basins, using baseline 1981-2000, and scenario RCP 8.5
01649
02491
02123
01935
01843
02242
02305
02868
00000
01554
02335
01113
−80 −70 −60 −50 −40 −30 −20 −10 0 10 20 30 40 50 60
Precipitation rate anomaly (%)
Funded by BEIS and Defra

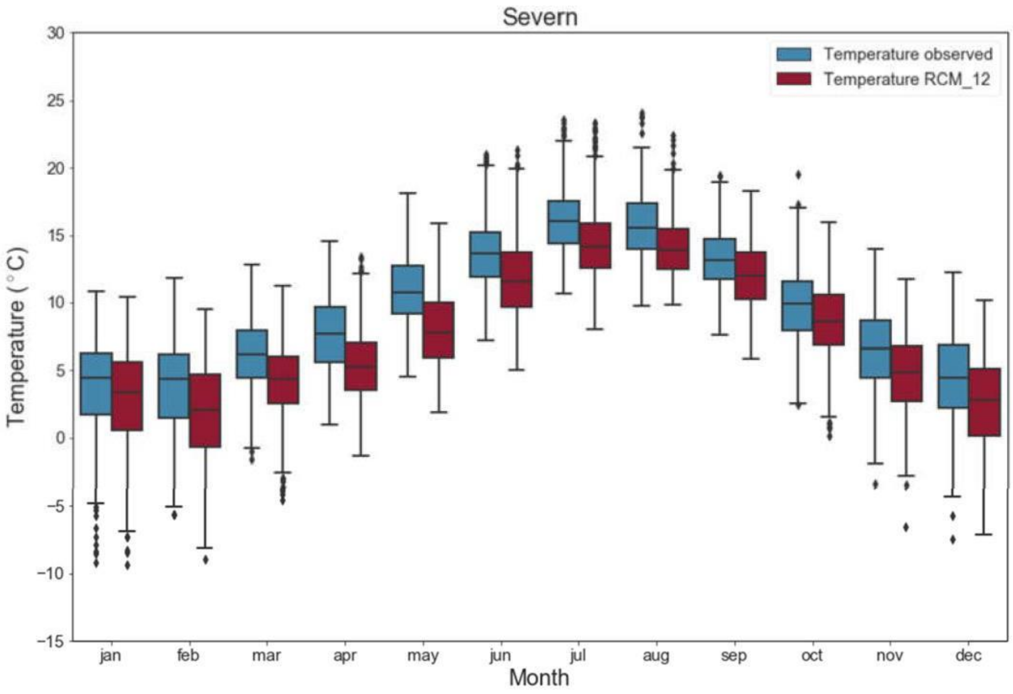
## C.12.3. Comparisons between modelled and observed data: Monthly boxplots of daily average temperature

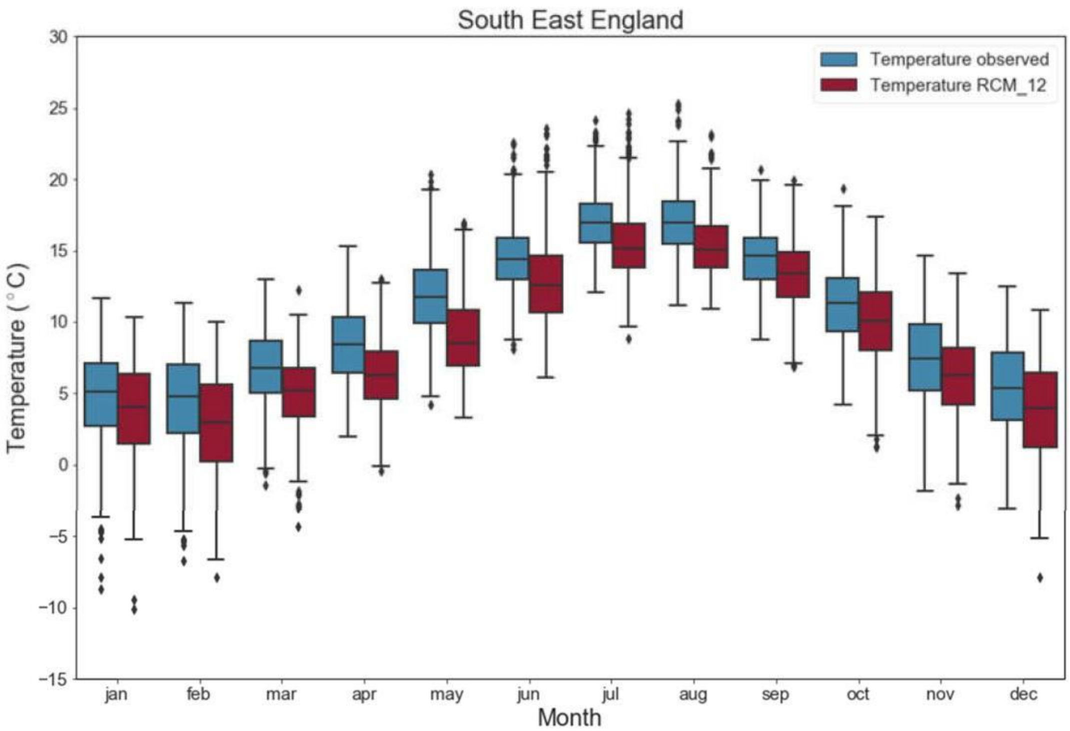


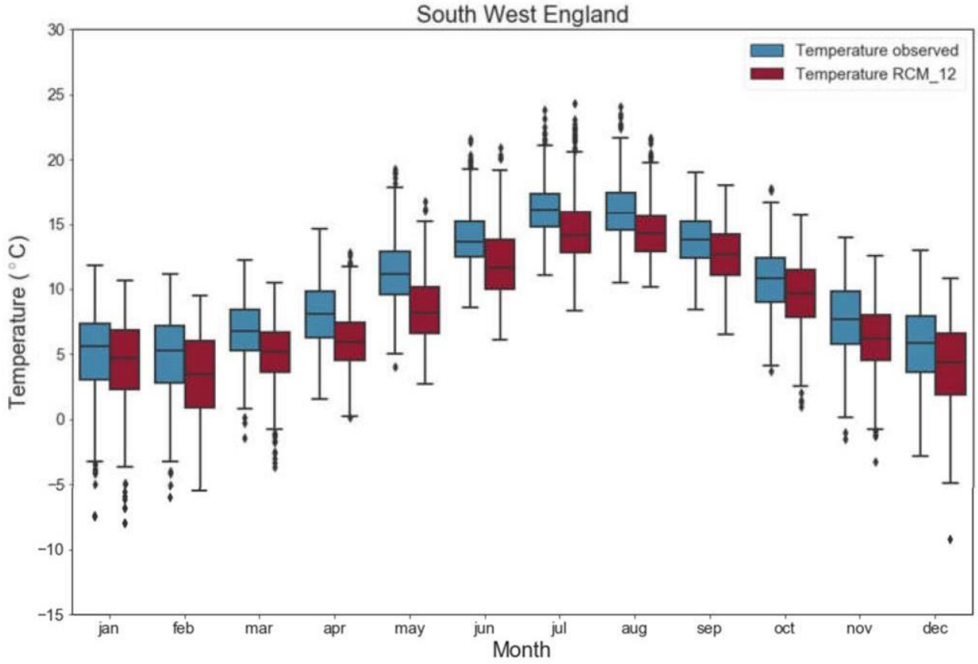



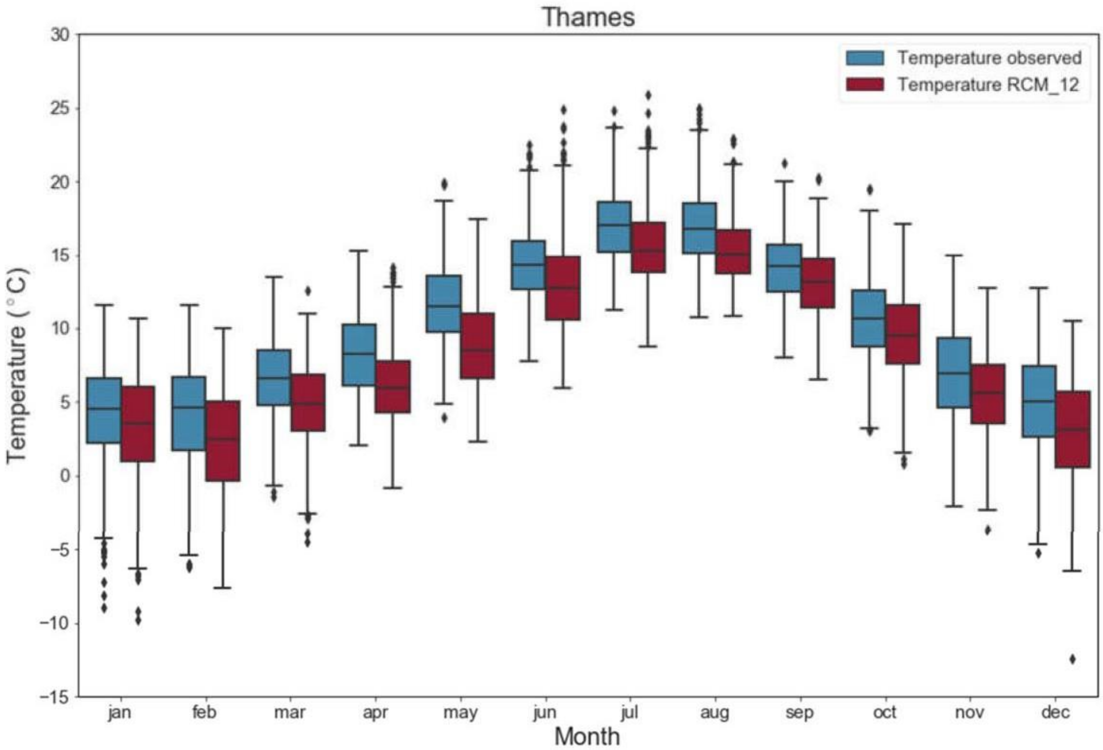

North West England
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
-5
−10
−15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month

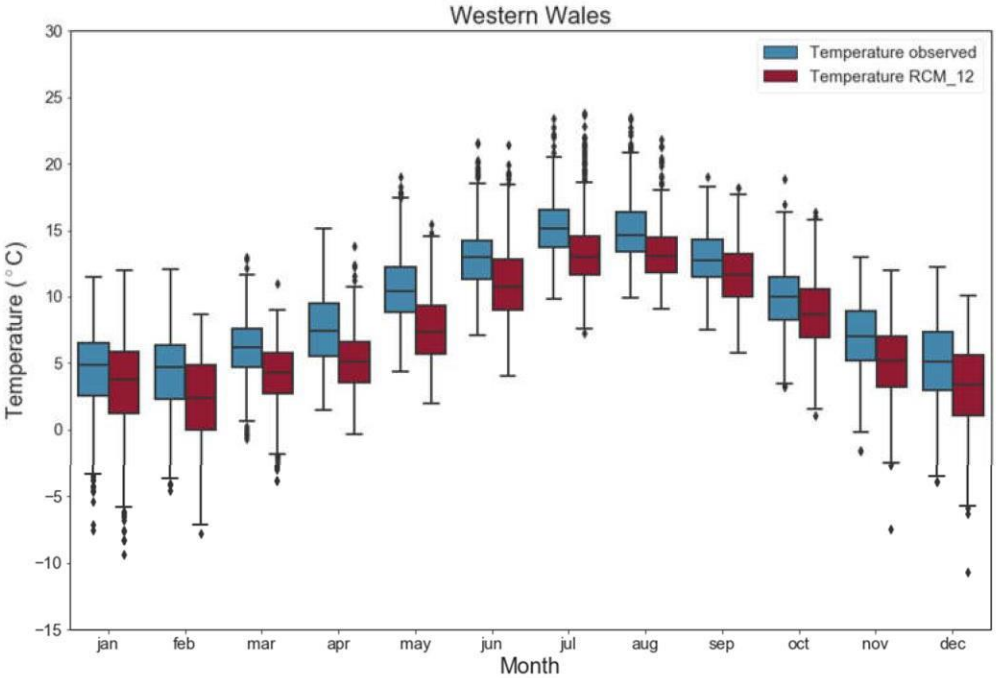

Northumbria
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
-5
−10
−15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month


Severn
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
-5
-10
-15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month

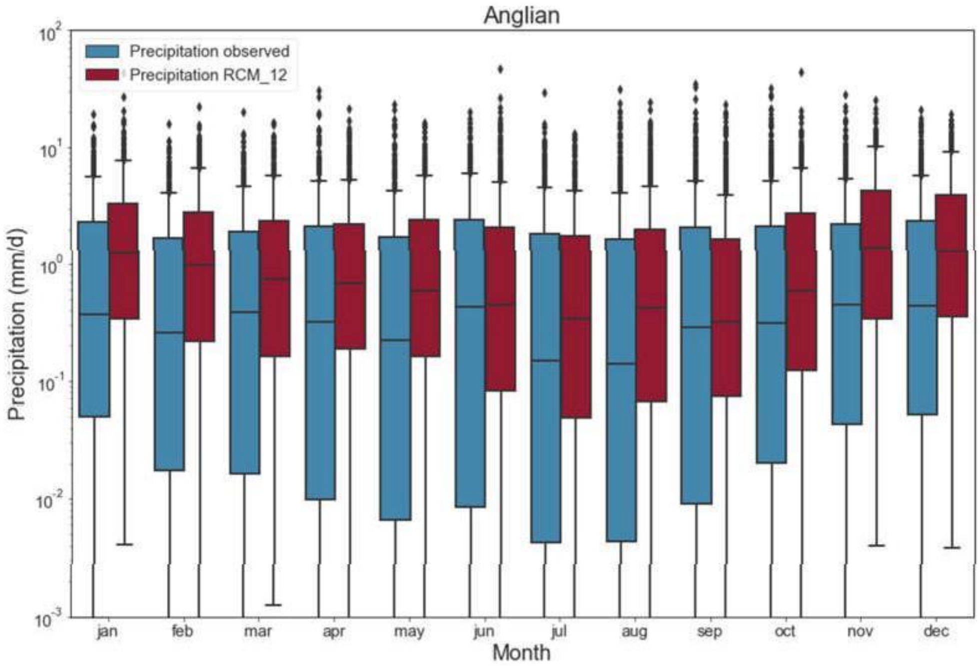

South East England
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
-5
-10
-15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month

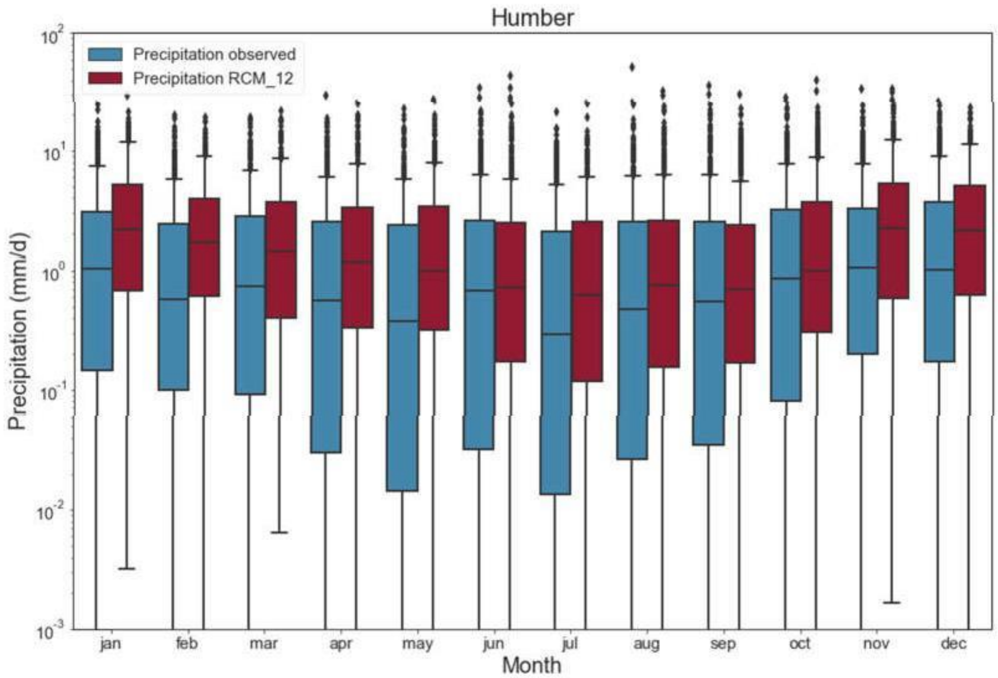

South West England
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
−5
−10
−15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month

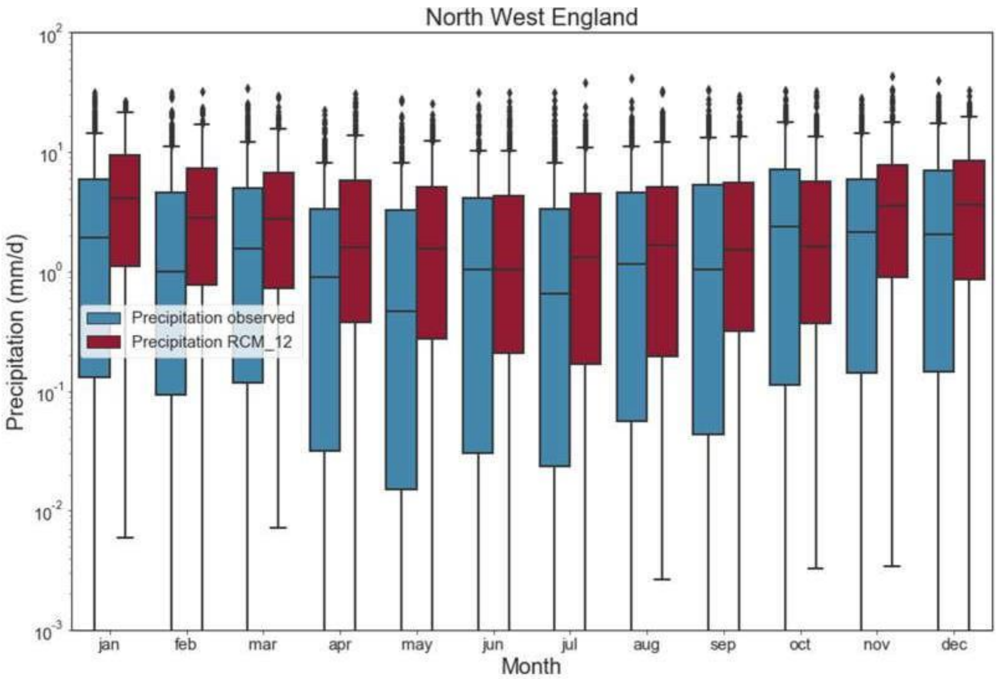

Thames
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
−5
−10
−15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month

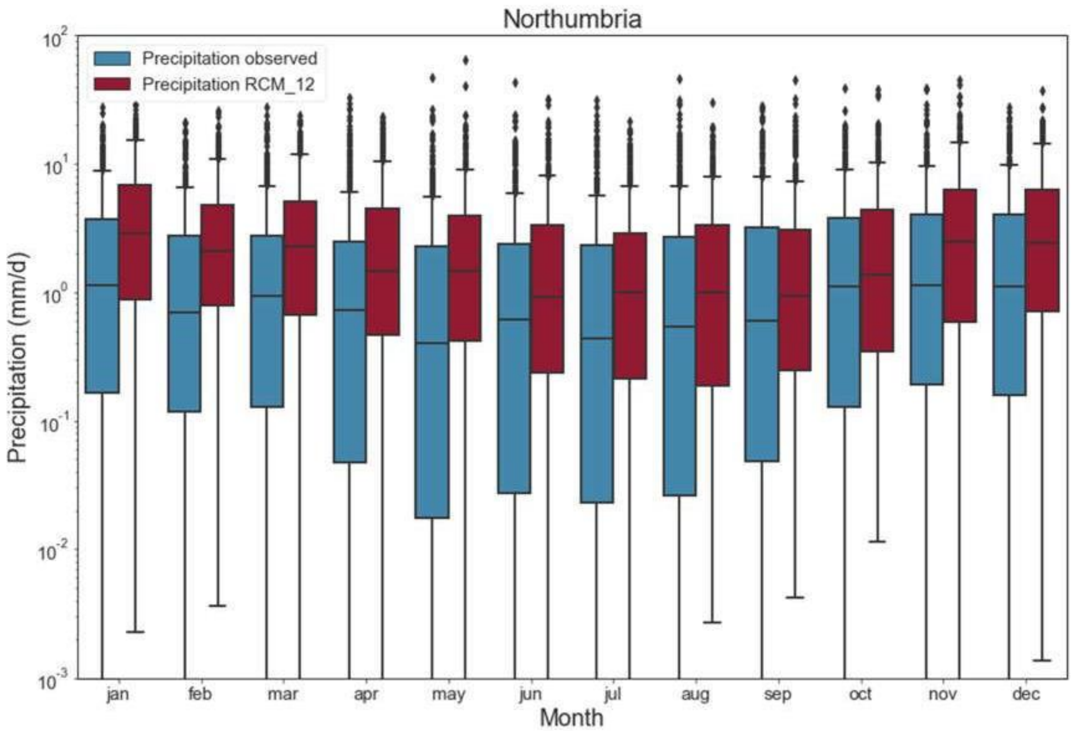

Western Wales
Temperature observed
Temperature RCM_12
Temperature (°C)
30
25
20
15
10
5
0
−5
−10
−15
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Month

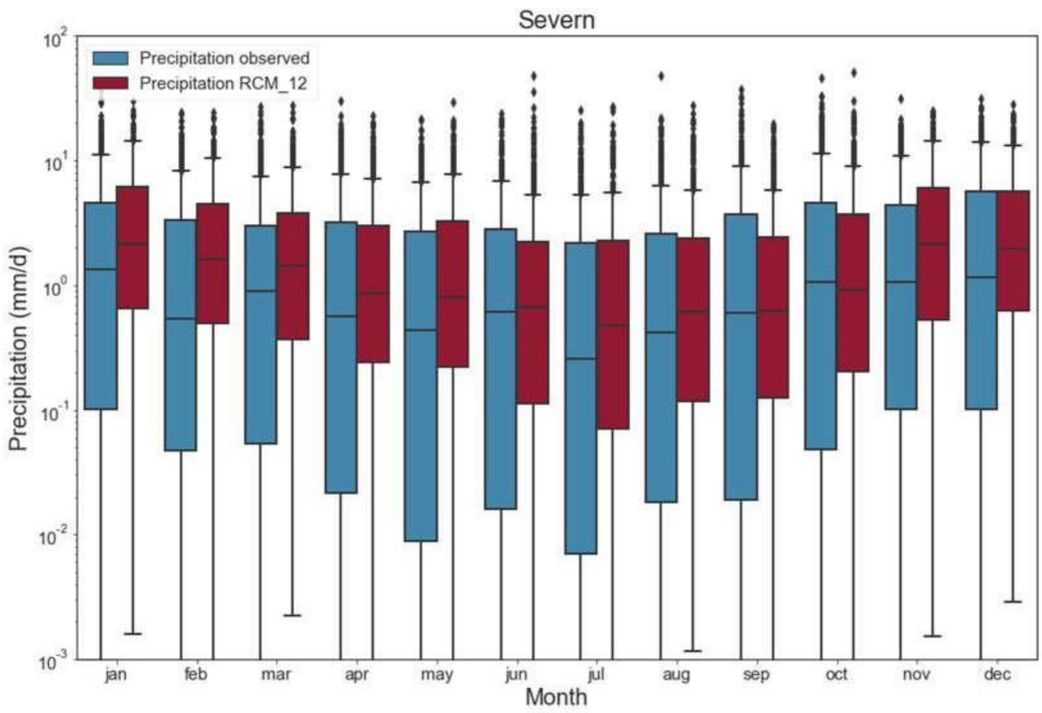
# C.13. Comparisons between modelled and observed data: Monthly boxplots of daily precipitation

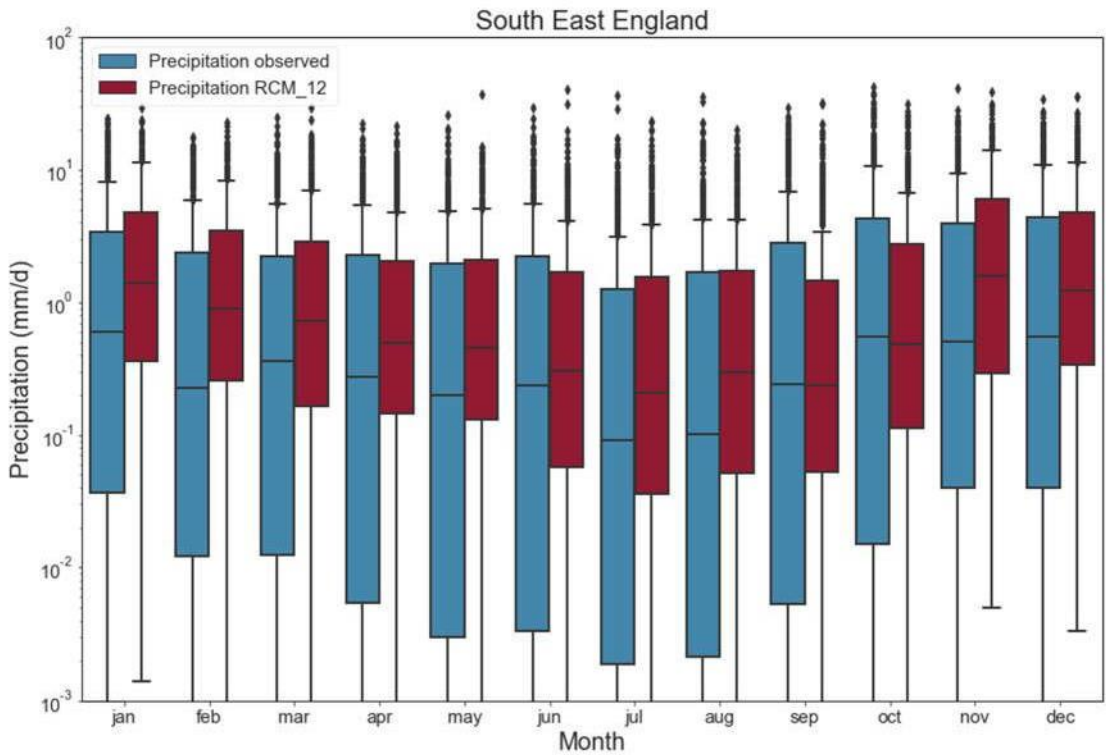


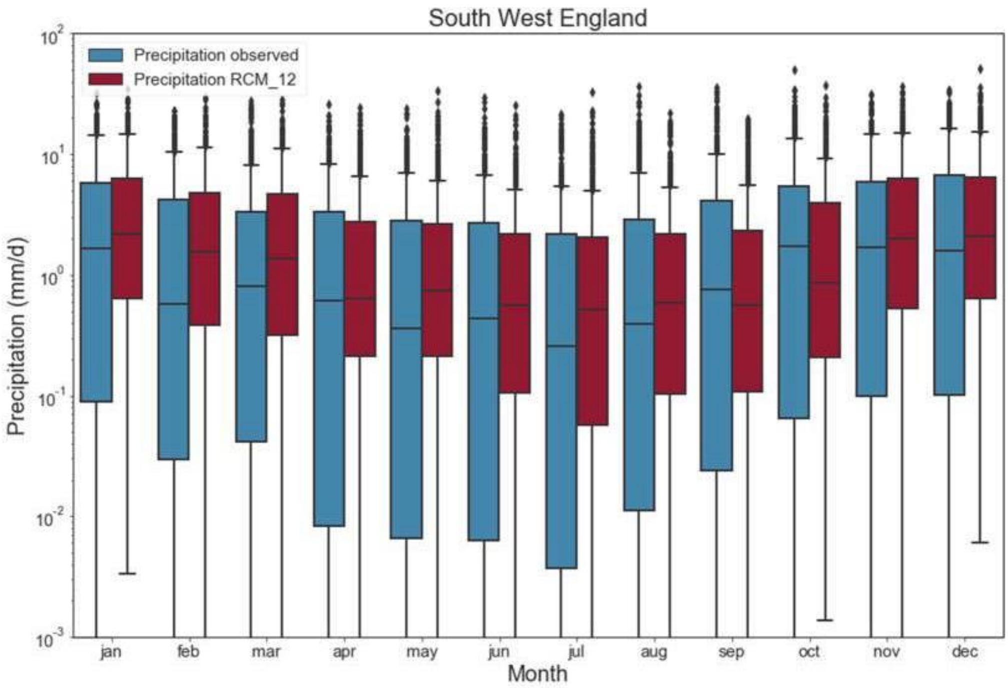



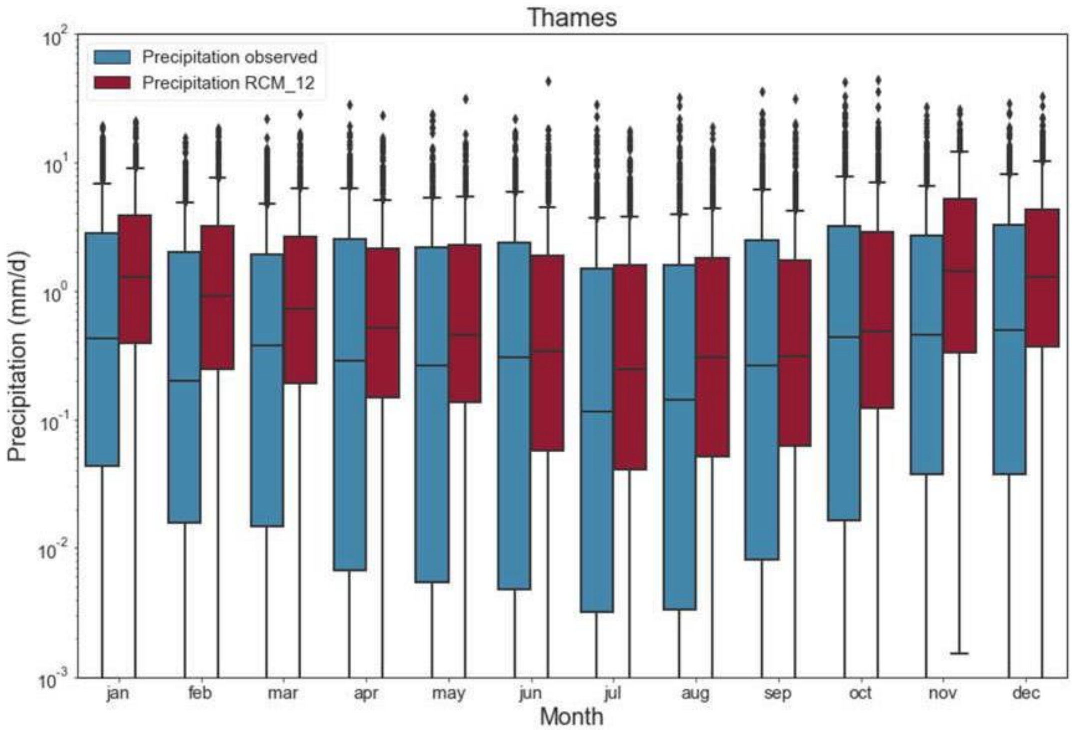

North West England
Precipitation observed
Precipitation RCM_12
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec

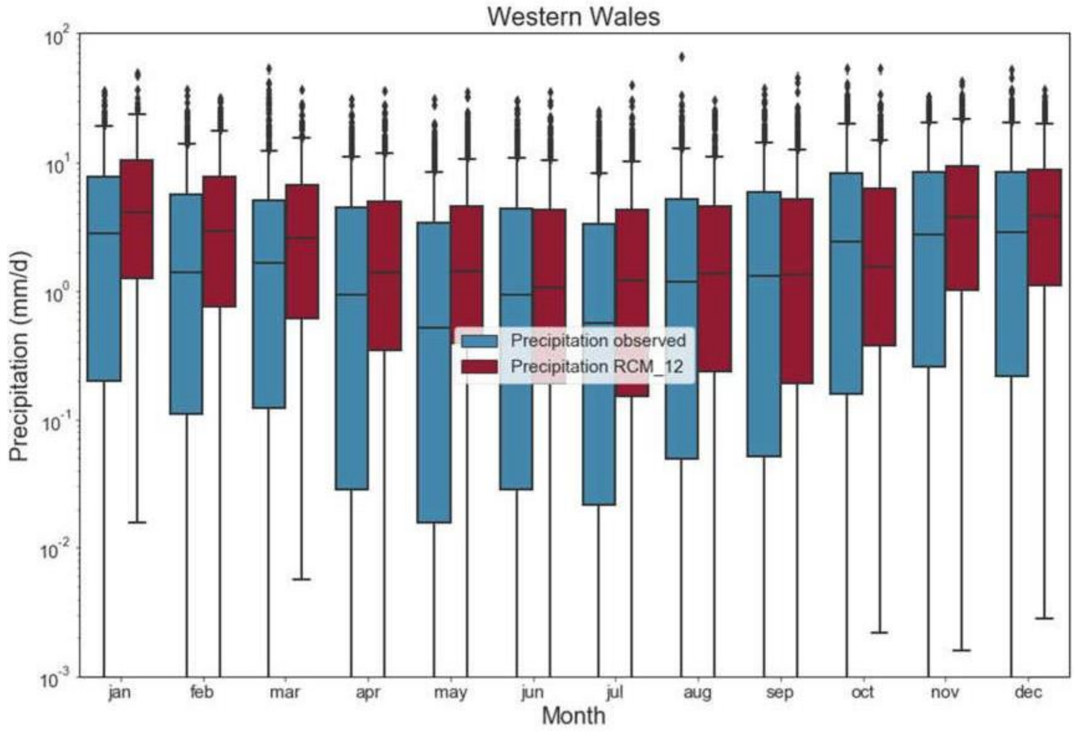

Northumbria
Precipitation observed
Precipitation RCM_12
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec


Severn
Precipitation observed
Precipitation RCM_12
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec

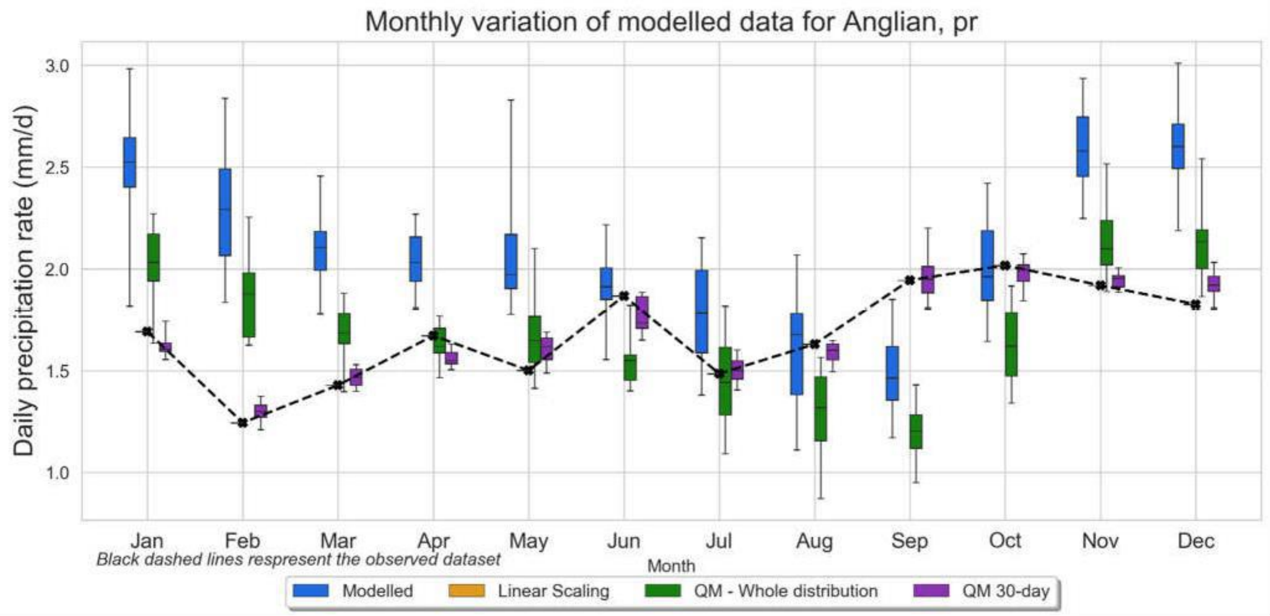

South East England
Precipitation observed
Precipitation RCM_12
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec

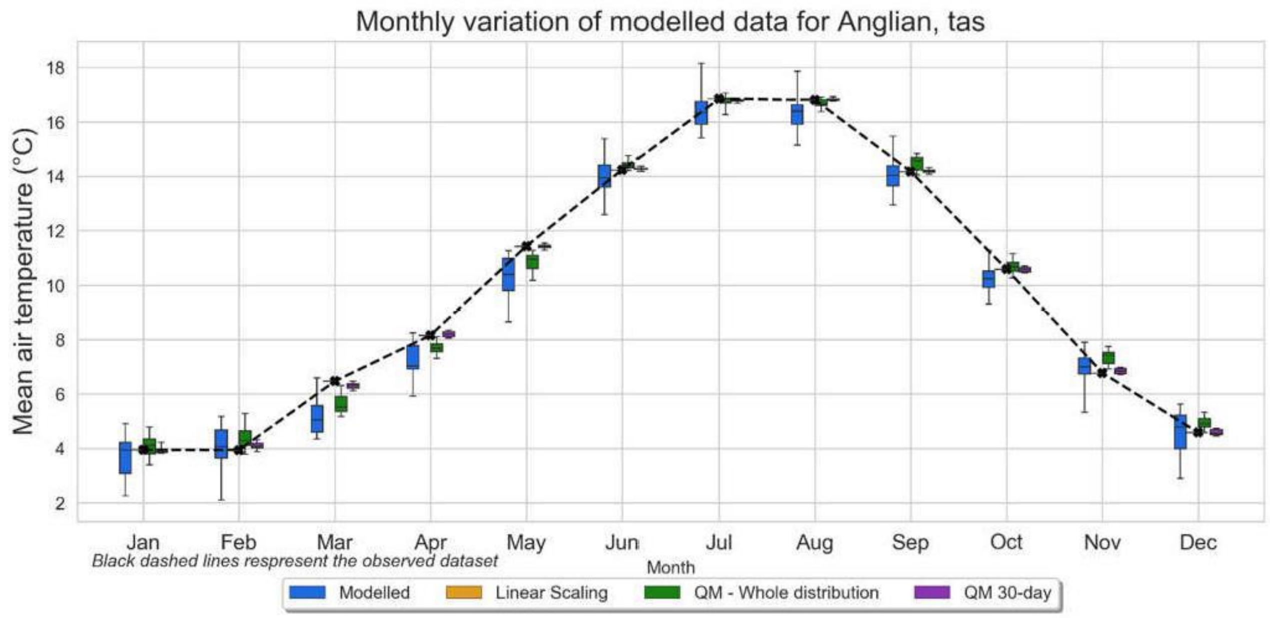

South West England
Precipitation observed
Precipitation RCM_12
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec

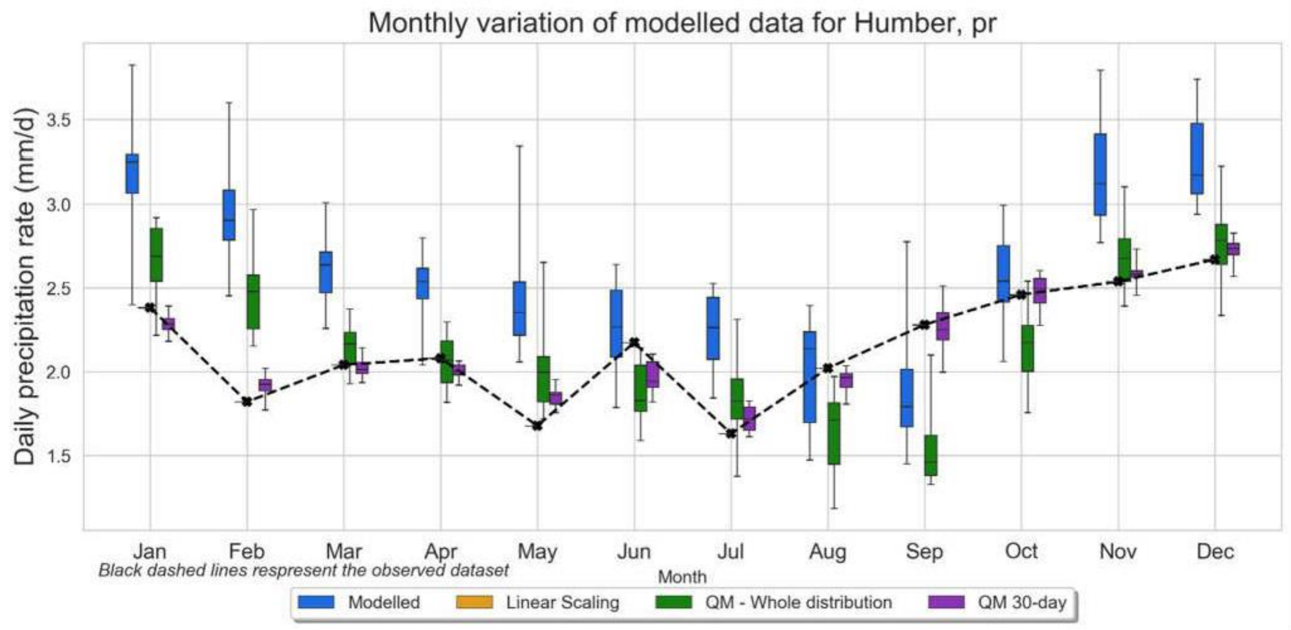

Thames
Precipitation observed
Precipitation RCM_12
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec

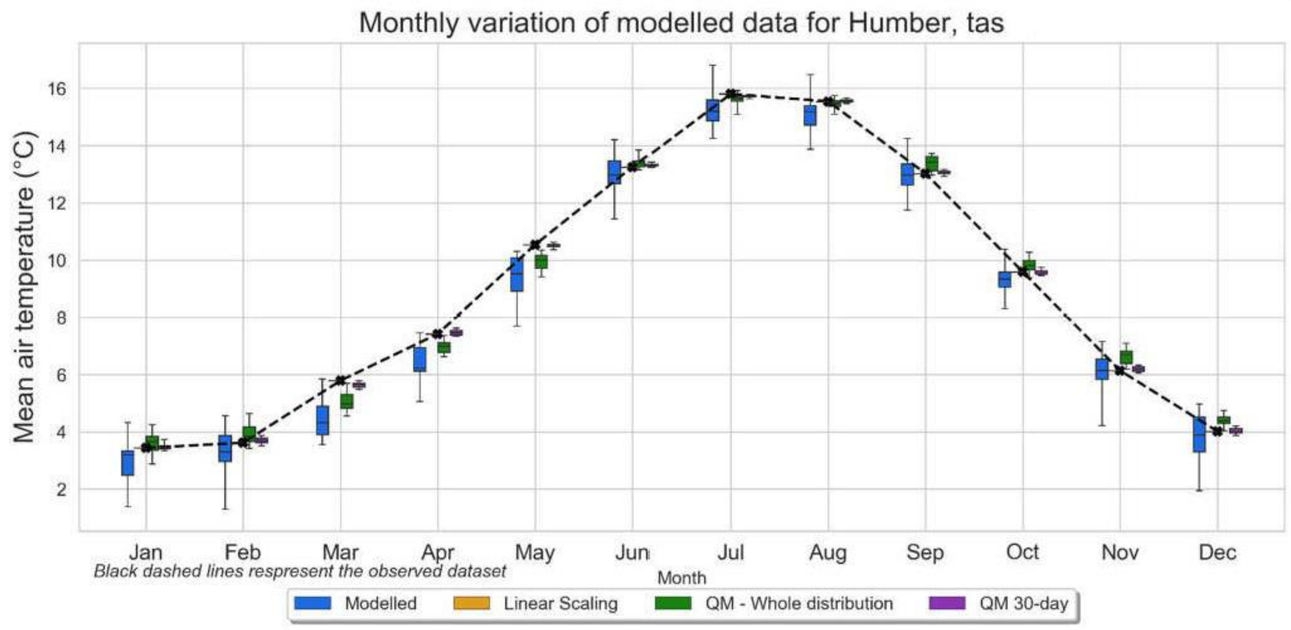

Western Wales
Precipitation (mm/d)
Month
jan
feb
mar
apr
may
jun
jul
aug
sep
oct
nov
dec
Precipitation observed
Precipitation RCM_12

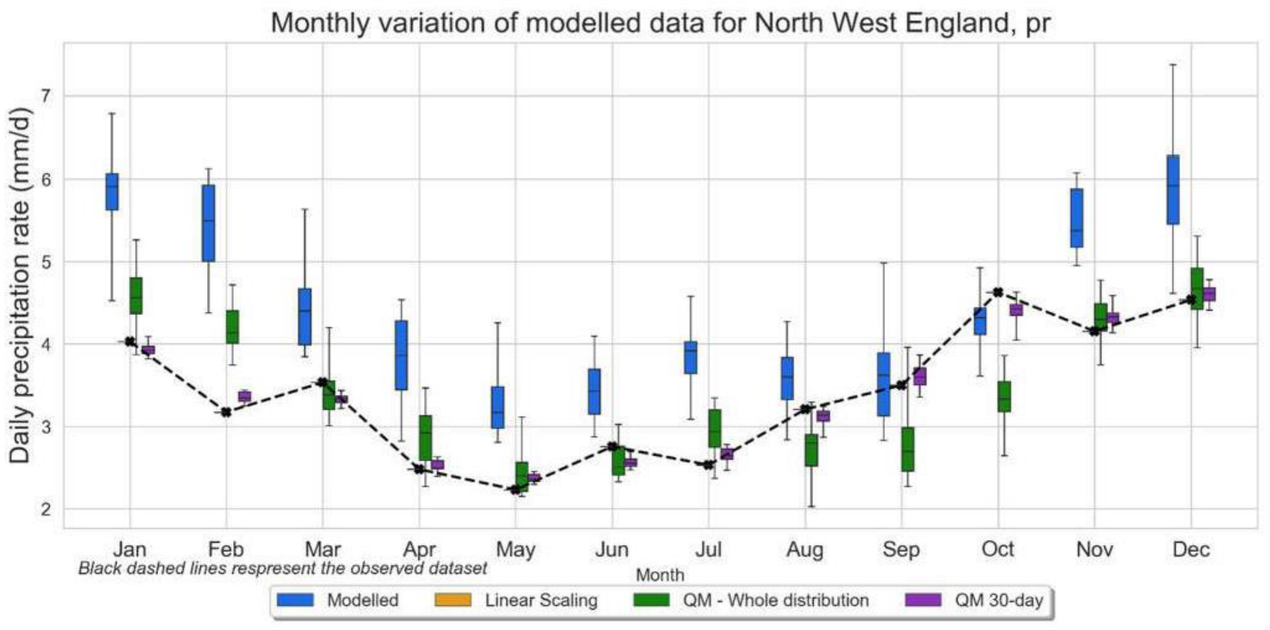
## C.13.1. Bias correction: Boxplots of monthly temperature and precipitation before and after bias correction

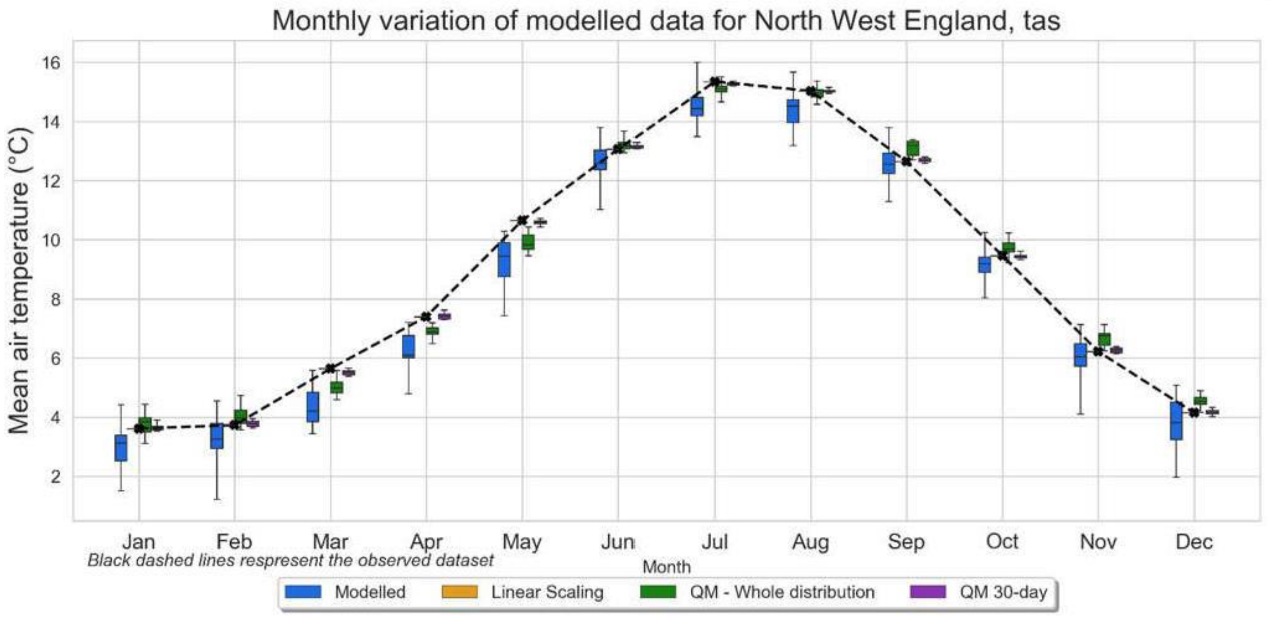


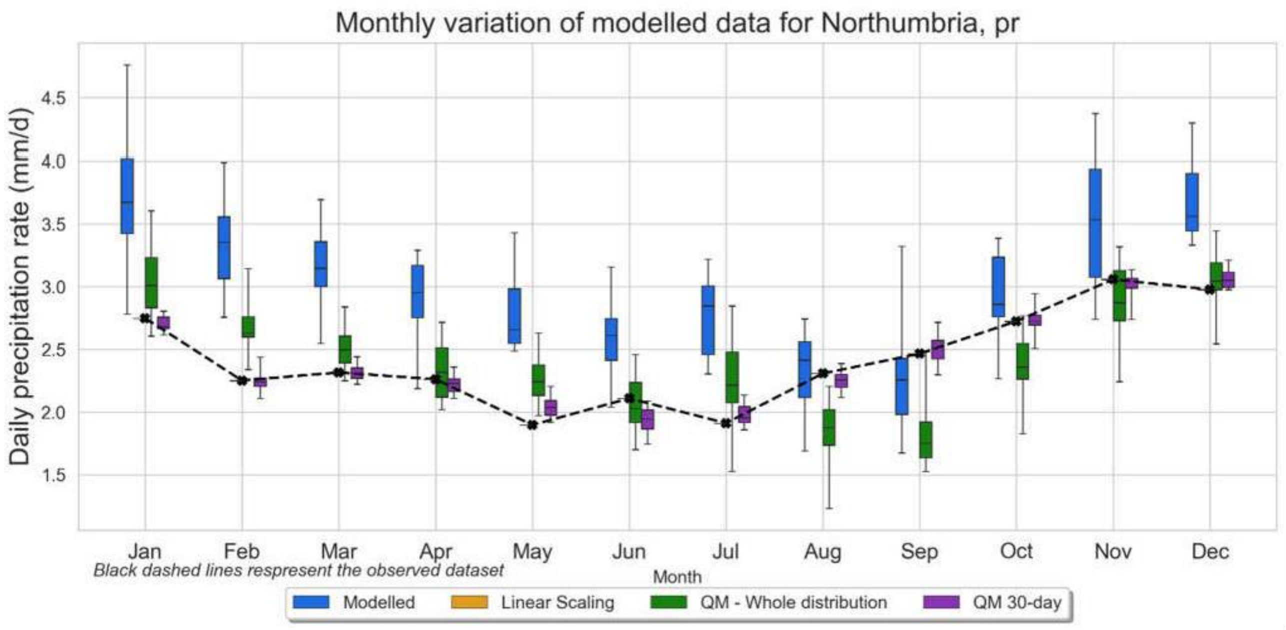



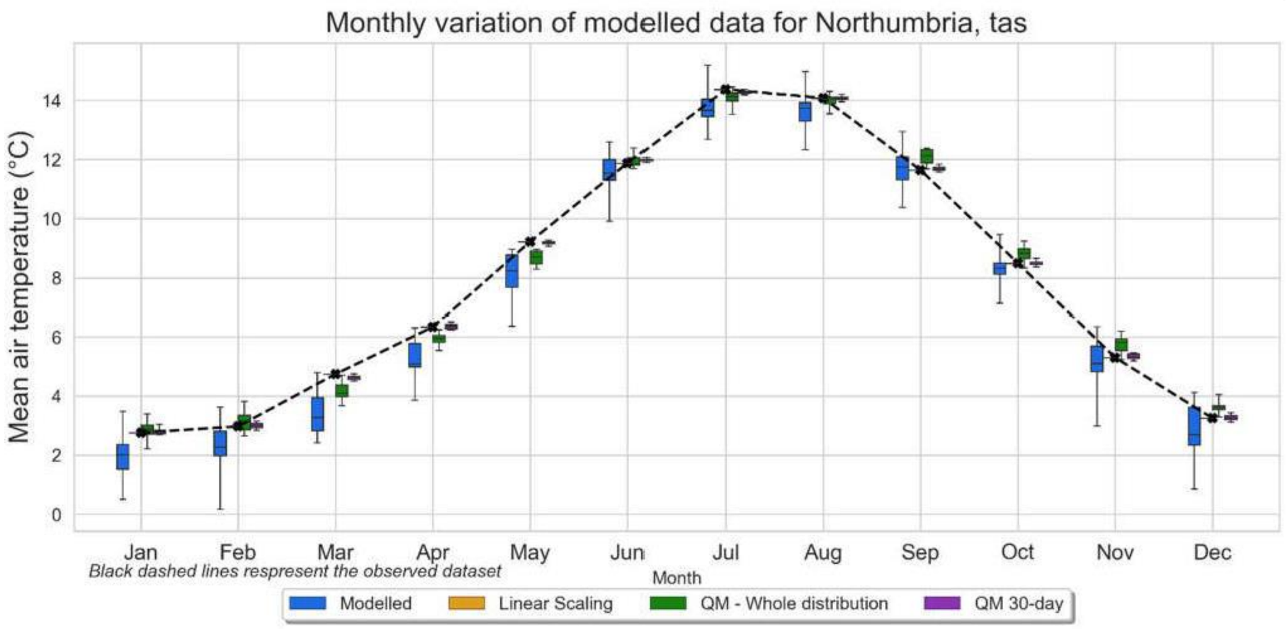

Monthly variation of modelled data for Humber, pr
Daily precipitation rate (mm/d)
3.5
3.0
2.5
2.0
1.5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

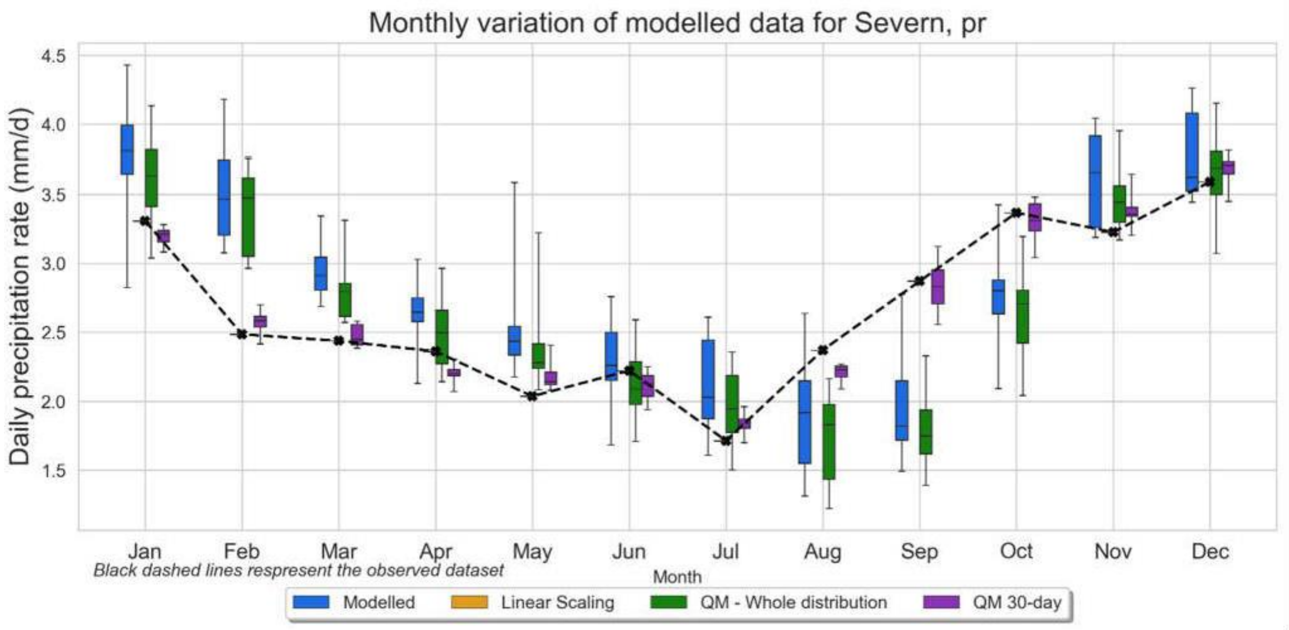

Monthly variation of modelled data for Humber, tas
Mean air temperature (°C)
16
14
12
10
8
6
4
2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day


Monthly variation of modelled data for North West England, pr
Daily precipitation rate (mm/d)
2
3
4
5
6
7
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Black dashed lines respresent the observed dataset
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

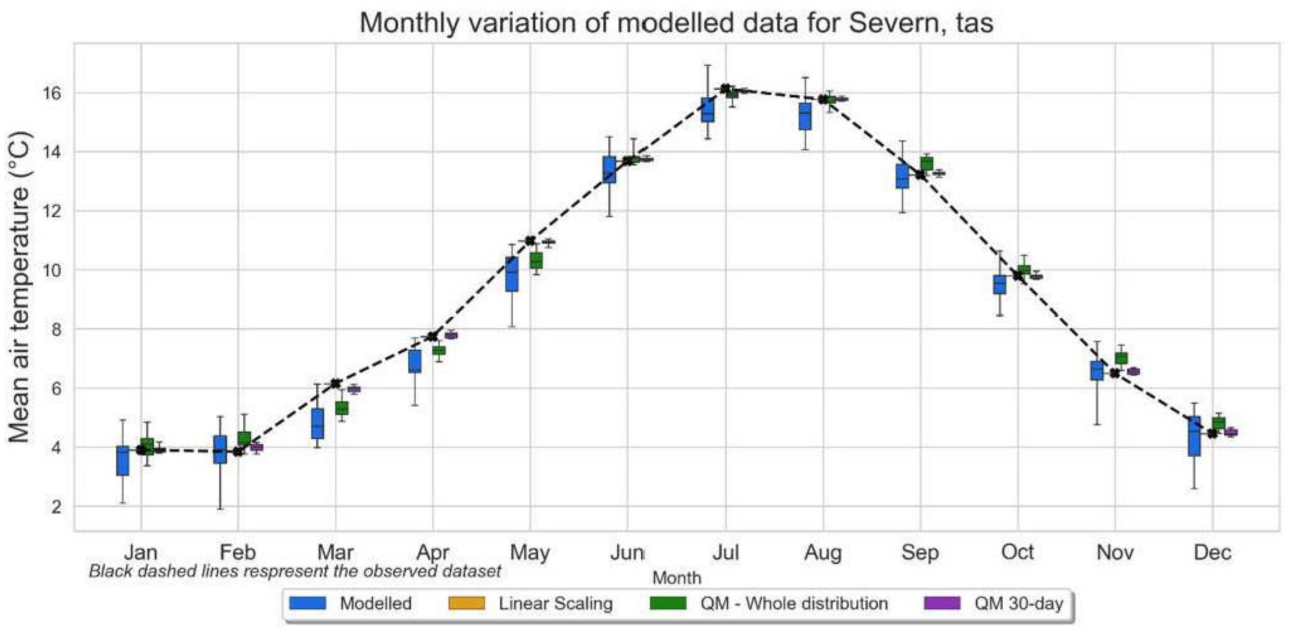

Monthly variation of modelled data for North West England, tas
Mean air temperature (°C)
2
4
6
8
10
12
14
16
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Month
Black dashed lines respresent the observed dataset
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day


Monthly variation of modelled data for Northumbria, pr
Daily precipitation rate (mm/d)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

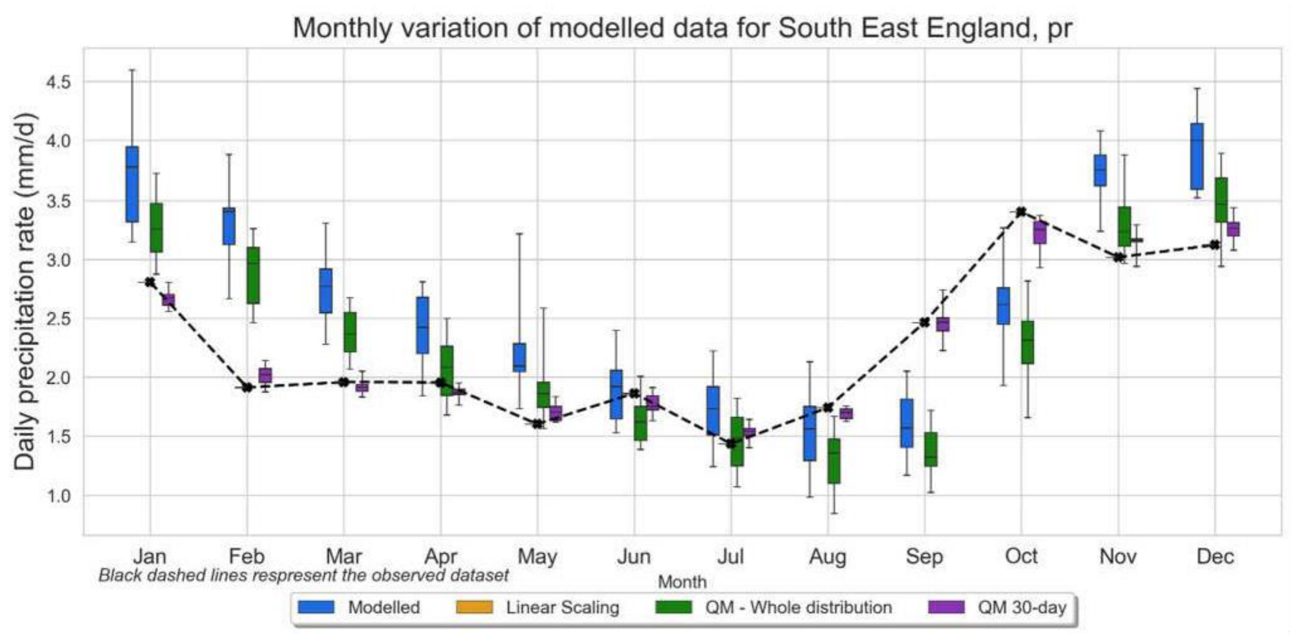

Monthly variation of modelled data for Northumbria, tas
Mean air temperature (°C)
14
12
10
8
6
4
2
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

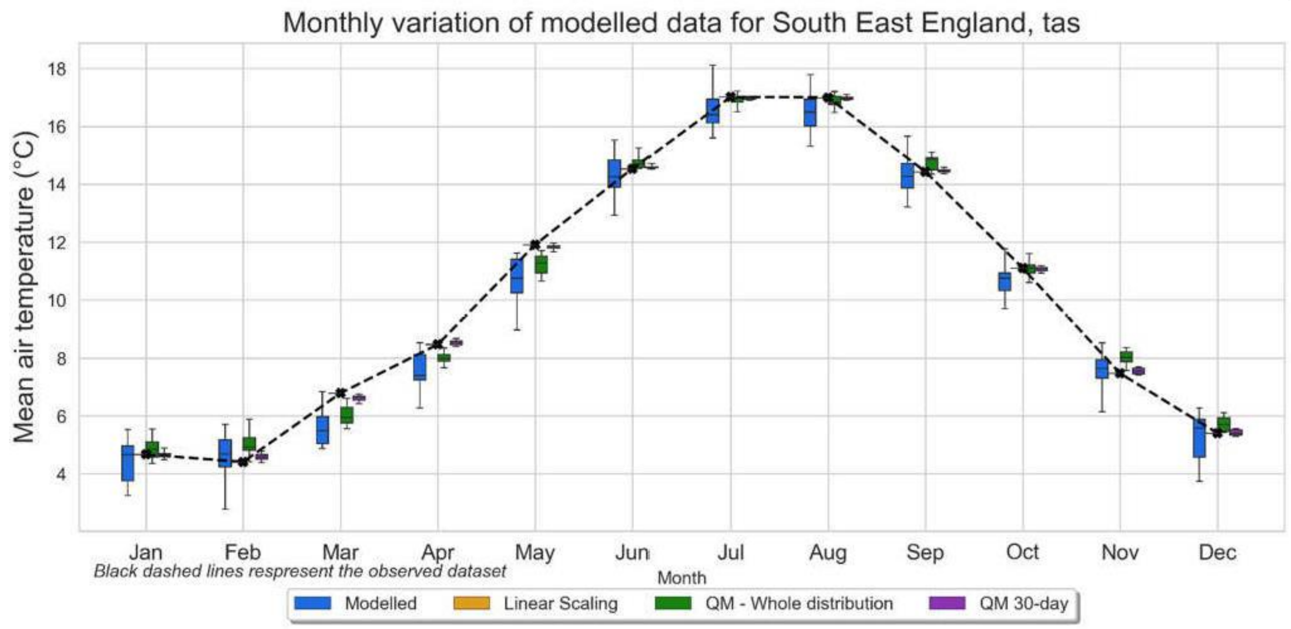


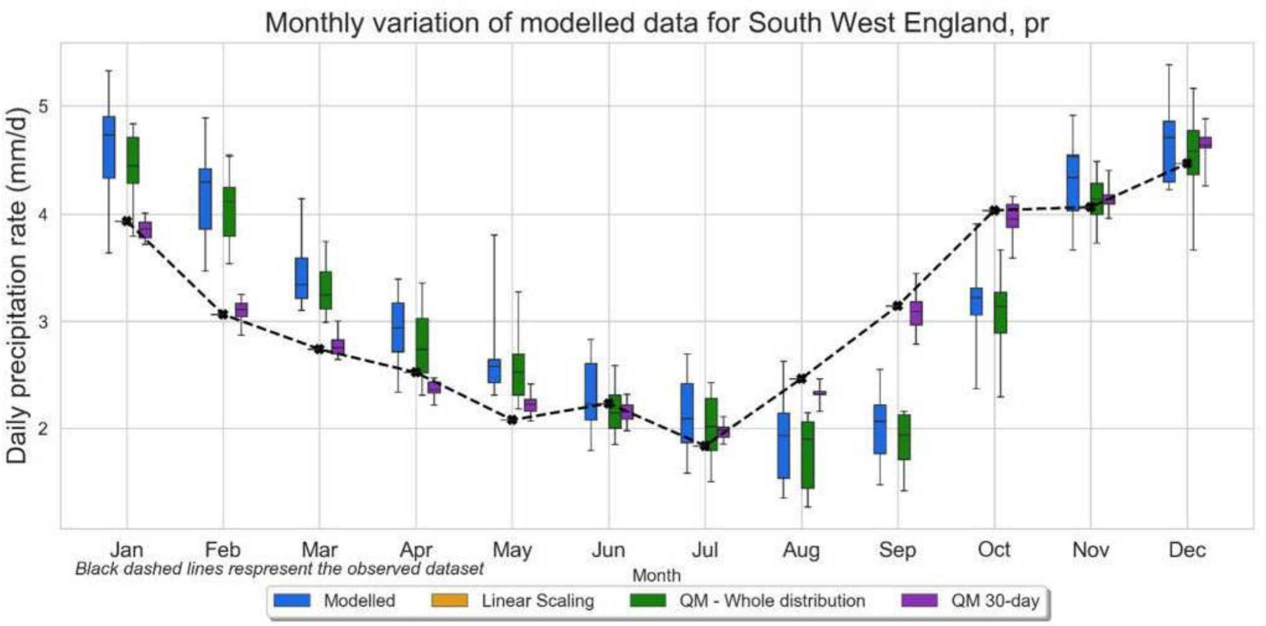
Monthly variation of modelled data for Severn, pr
Daily precipitation rate (mm/d)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

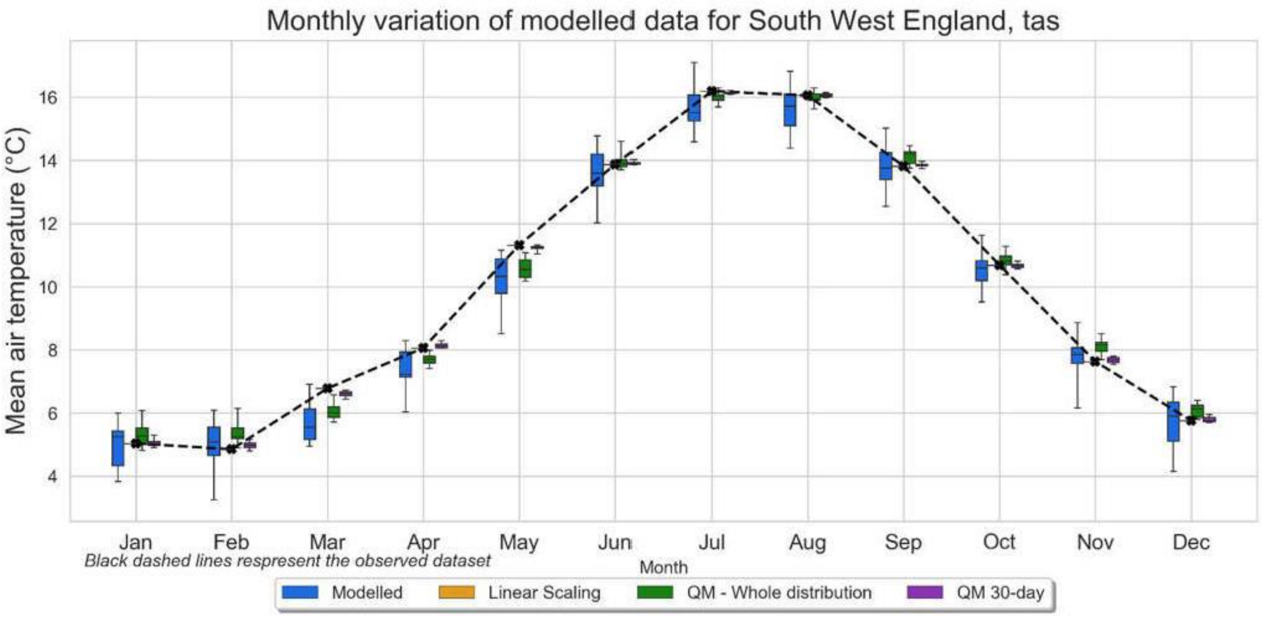



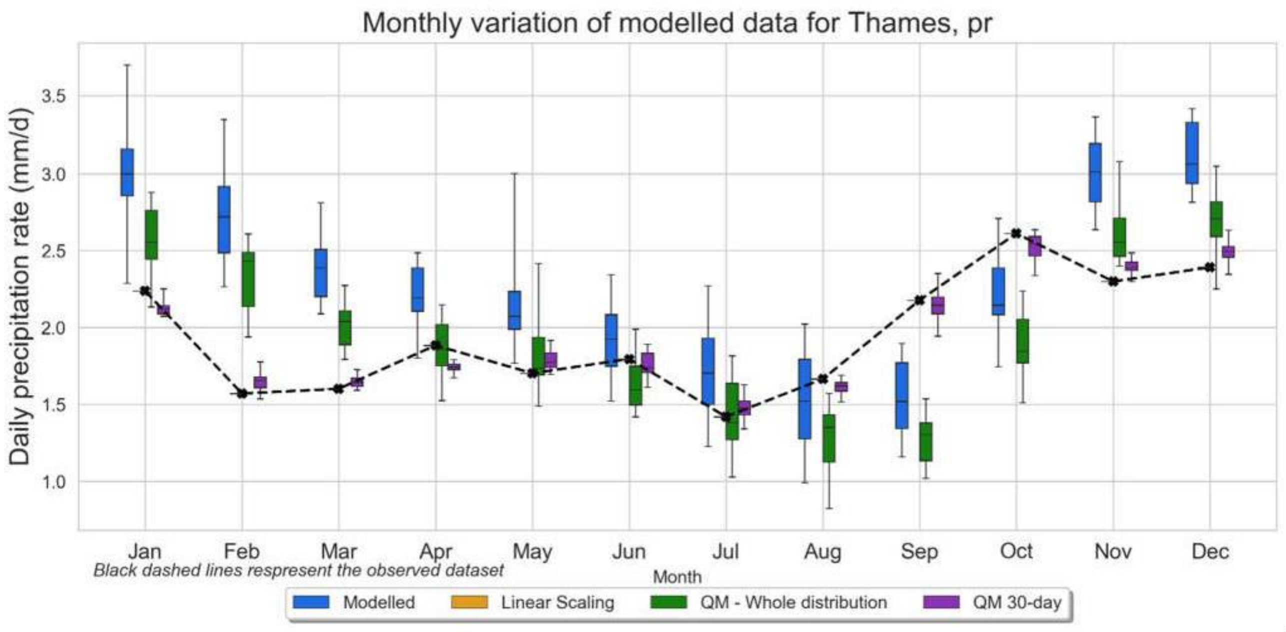
Monthly variation of modelled data for Severn, tas
Mean air temperature (°C)
16
14
12
10
8
6
4
2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

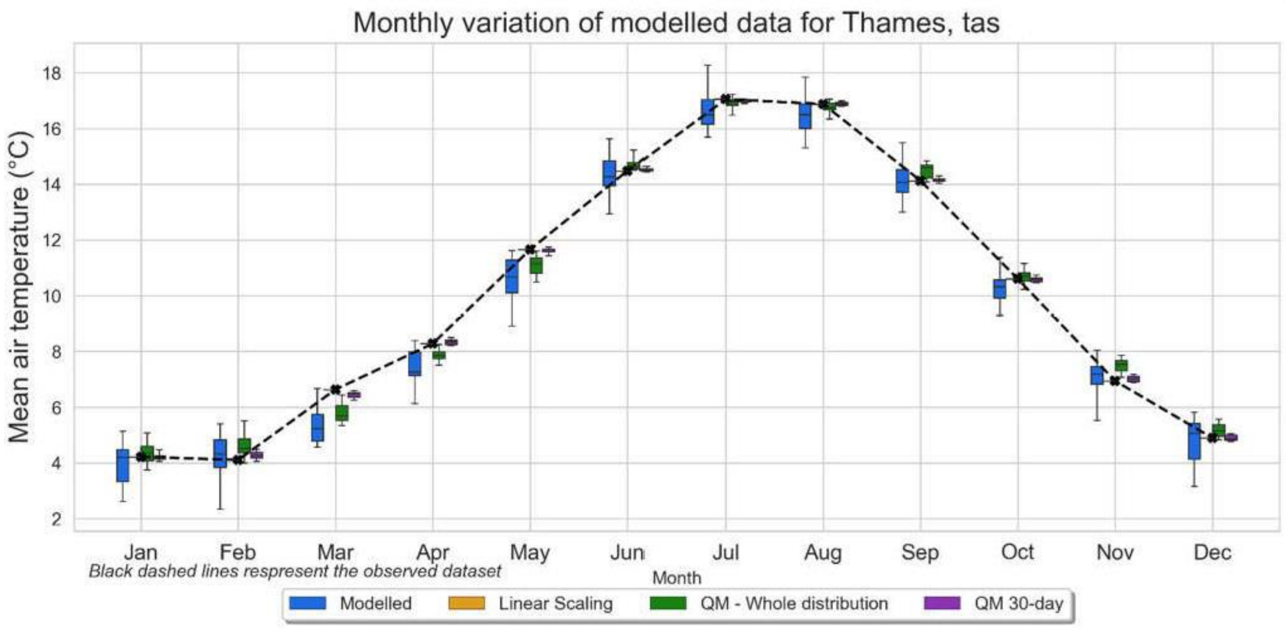

Monthly variation of modelled data for South East England, pr
Daily precipitation rate (mm/d)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

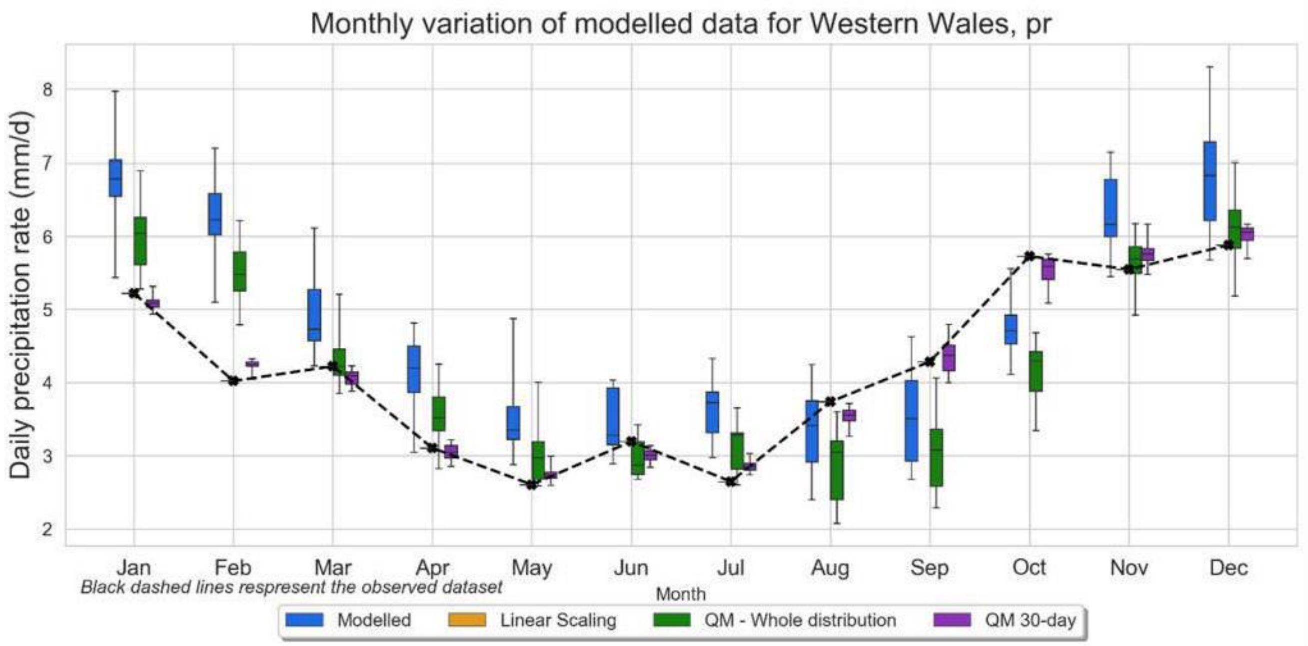

Monthly variation of modelled data for South East England, tas
Mean air temperature (°C)
18
16
14
12
10
8
6
4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

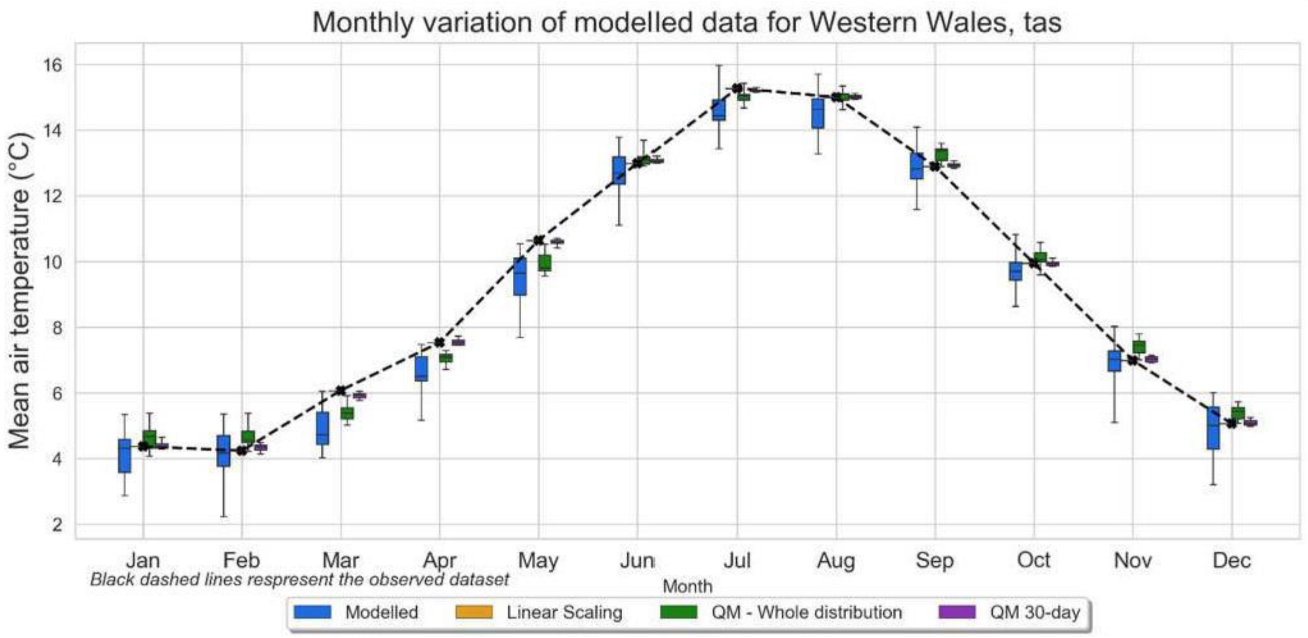

Monthly variation of modelled data for South West England, pr
Daily precipitation rate (mm/d)
5
4
3
2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day


Monthly variation of modelled data for South West England, tas
Mean air temperature (°C)
16
14
12
10
8
6
4
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

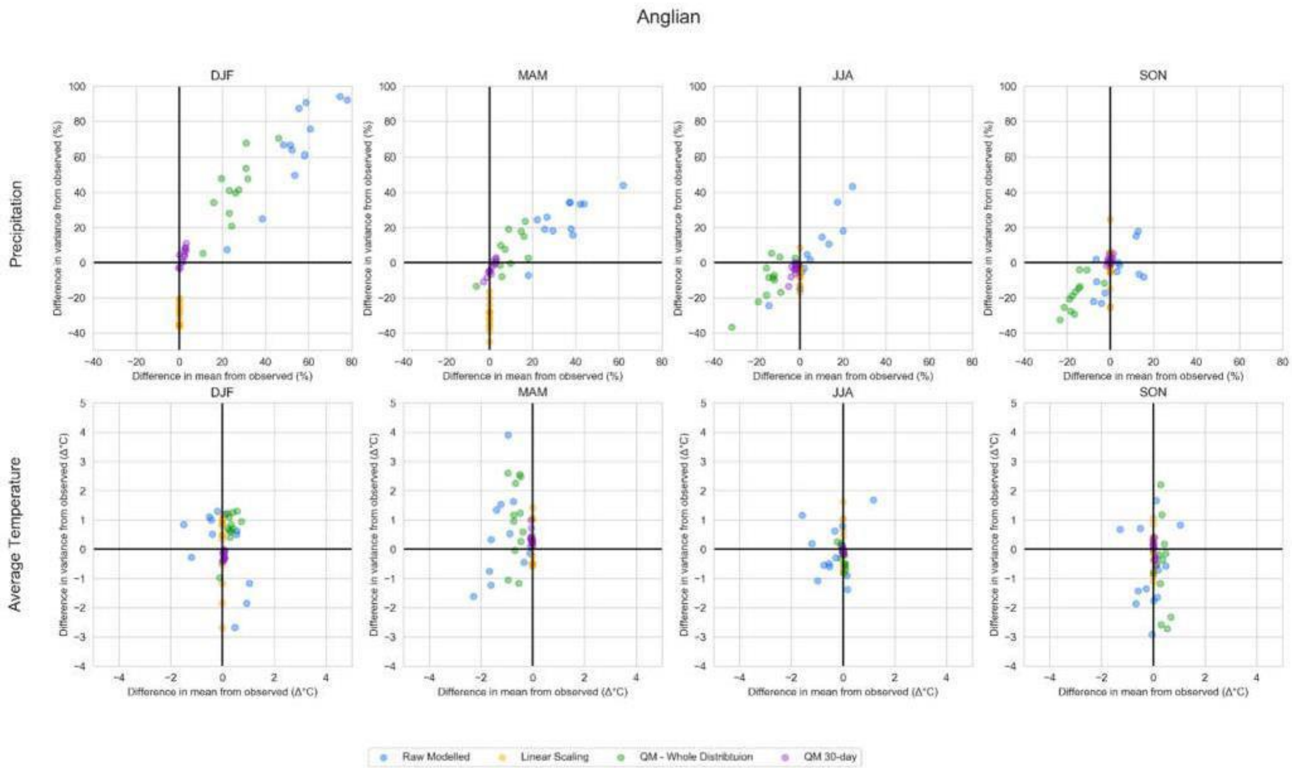

Monthly variation of modelled data for Thames, pr
Daily precipitation rate (mm/d)
3.5
3.0
2.5
2.0
1.5
1.0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day

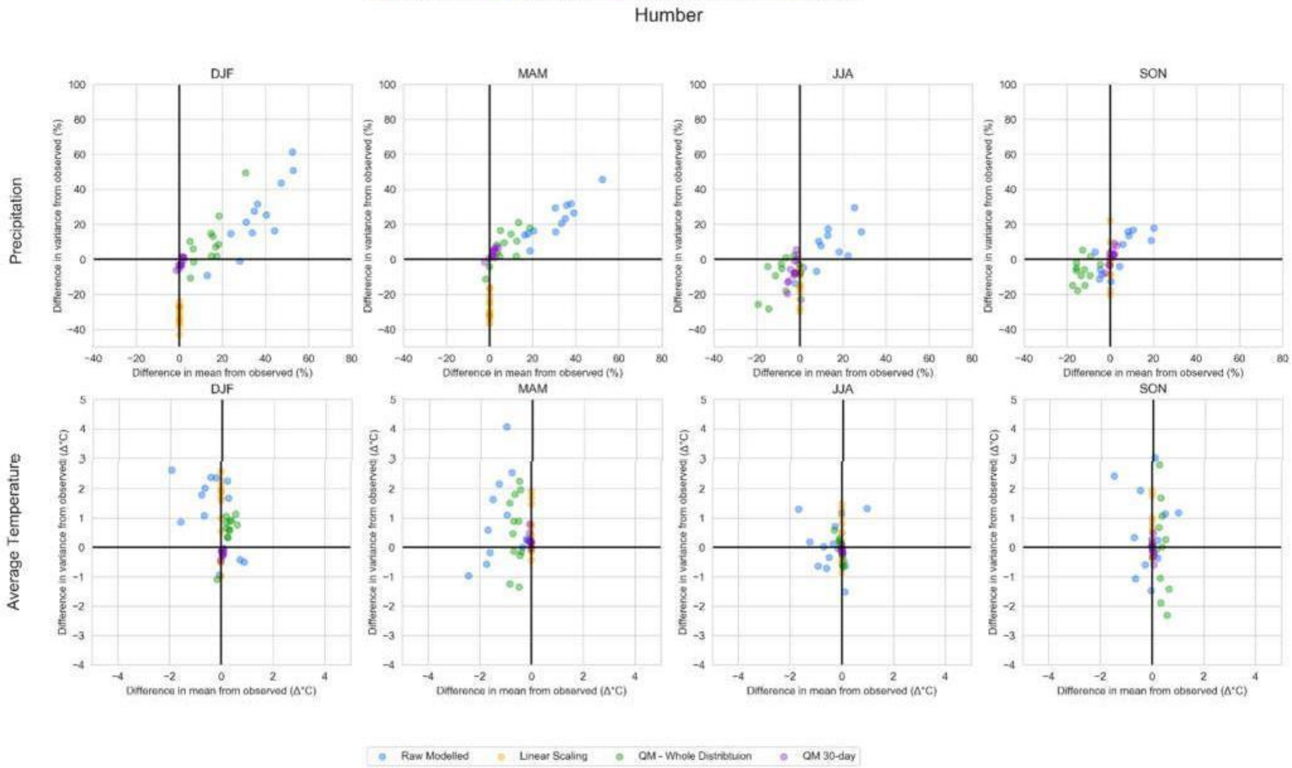

Monthly variation of modelled data for Thames, tas
Mean air temperature (°C)
18
16
14
12
10
8
6
4
2
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Black dashed lines respresent the observed dataset
Month
Modelled
Linear Scaling
QM - Whole distribution
QM 30-day



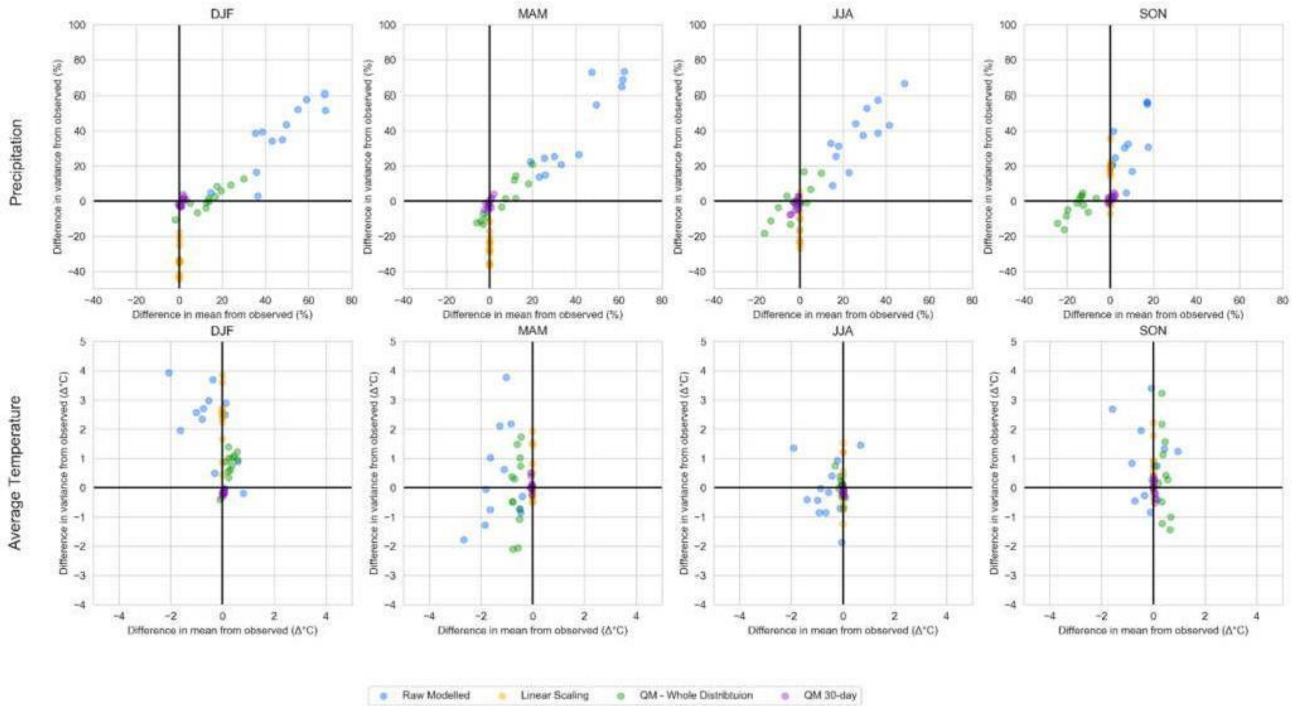




### C.13.2. Bias correction: Seasonal scatterplots of means and variances of temperature and precipitation before and after bias correction

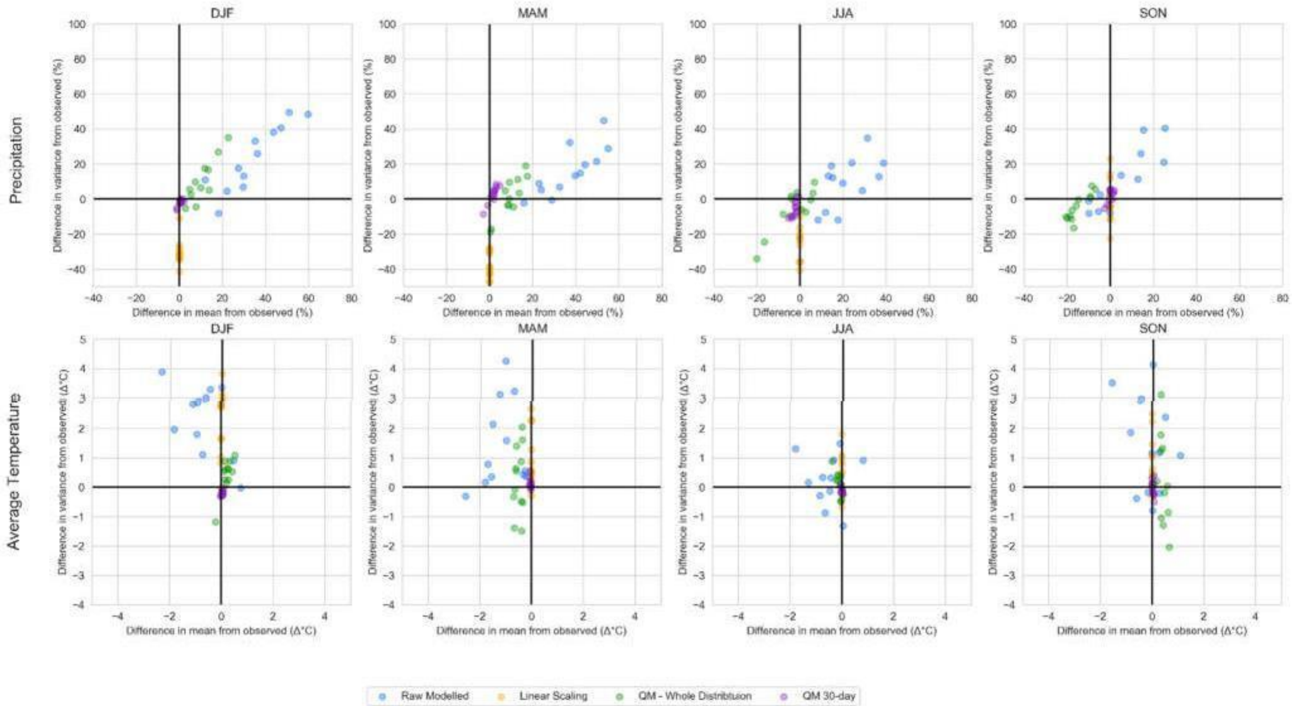

Anglian
DJF
MAM
JJA
SON
Precipitation
Average Temperature
Difference in variance from observed (%)
Difference in mean from observed (%)
Difference in variance from observed (Δ°C)
Difference in mean from observed (Δ°C)
Raw Modelled
Linear Scaling
QM - Whole Distribtuion
QM 30-day


Humber
DJF
MAM
JJA
SON
Precipitation
Average Temperature
Difference in variance from observed (%)
Difference in mean from observed (%)
Difference in variance from observed (Δ°C)
Difference in mean from observed (Δ°C)
Raw Modelled
Linear Scaling
QM - Whole Distribtuion
QM 30-day

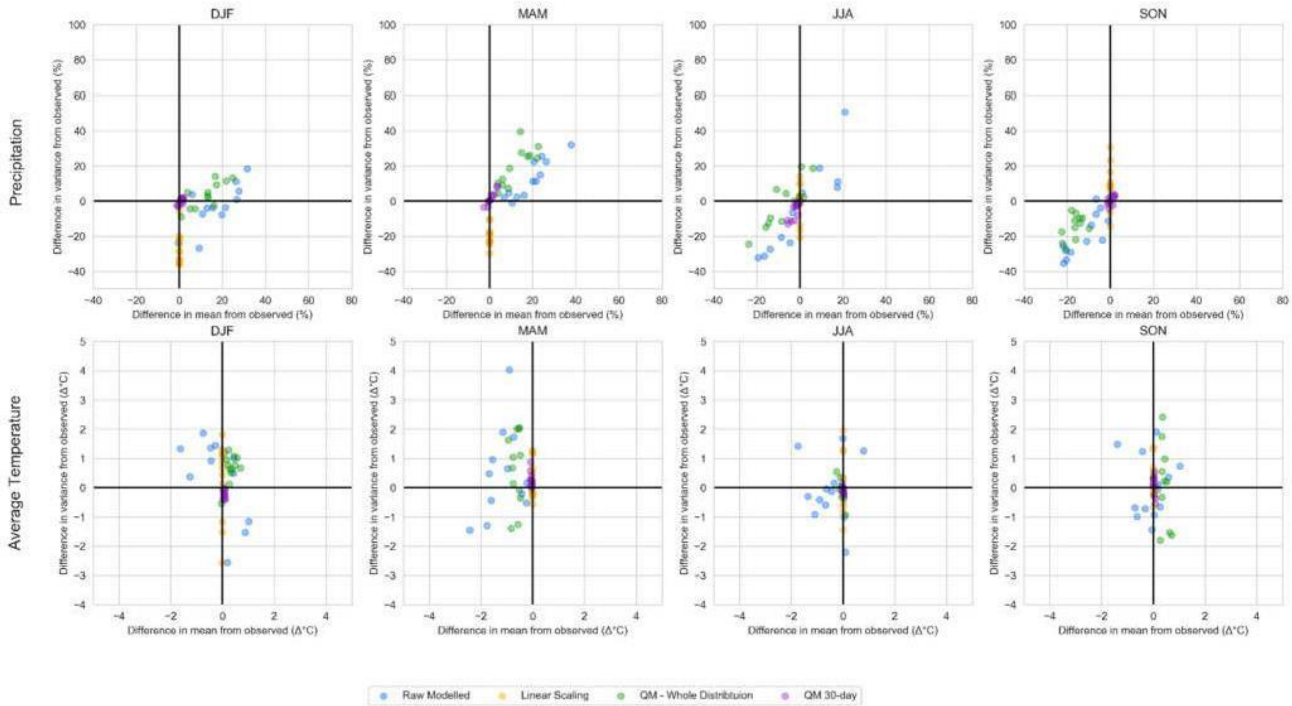
North West England



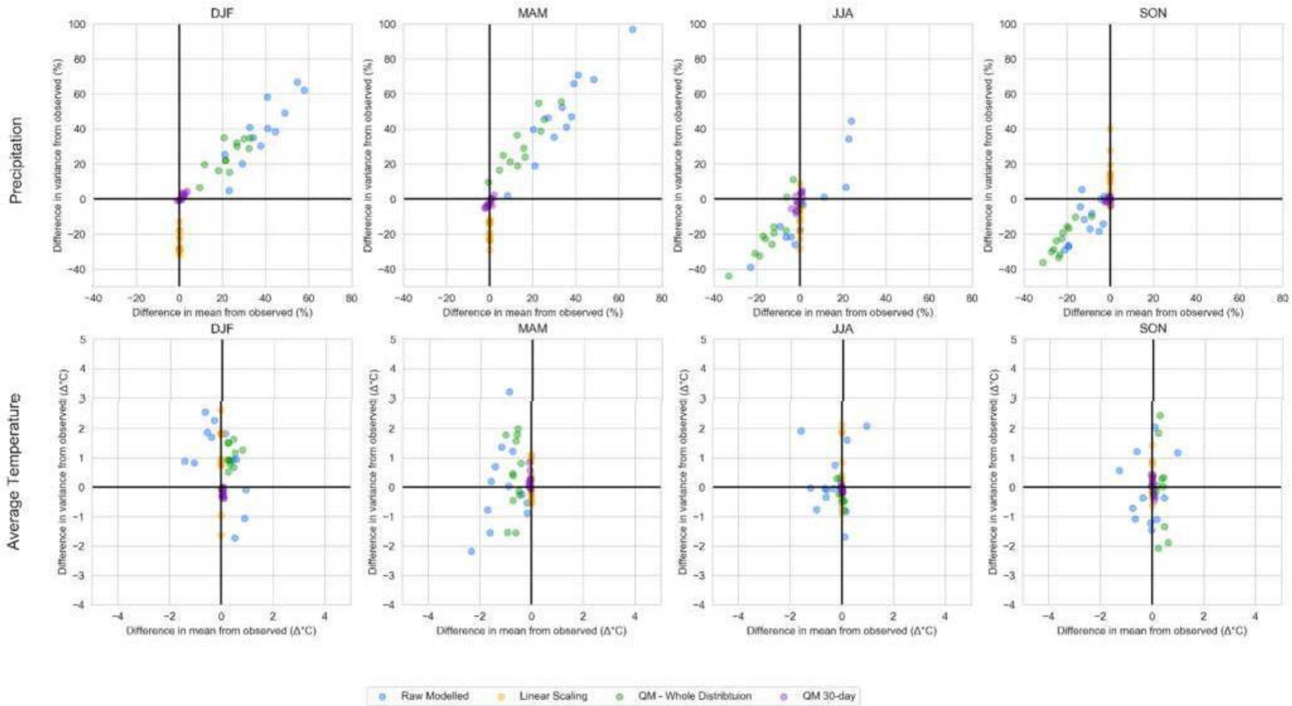

Northumbria

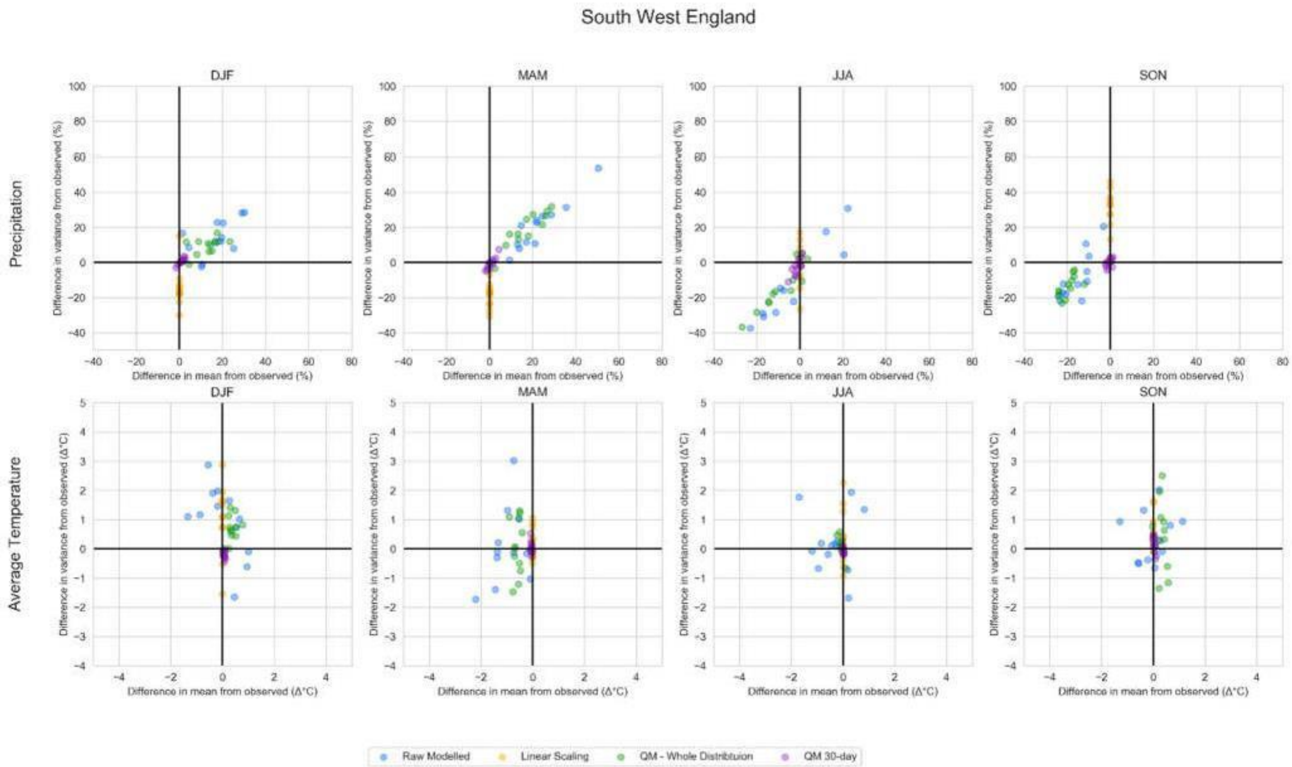


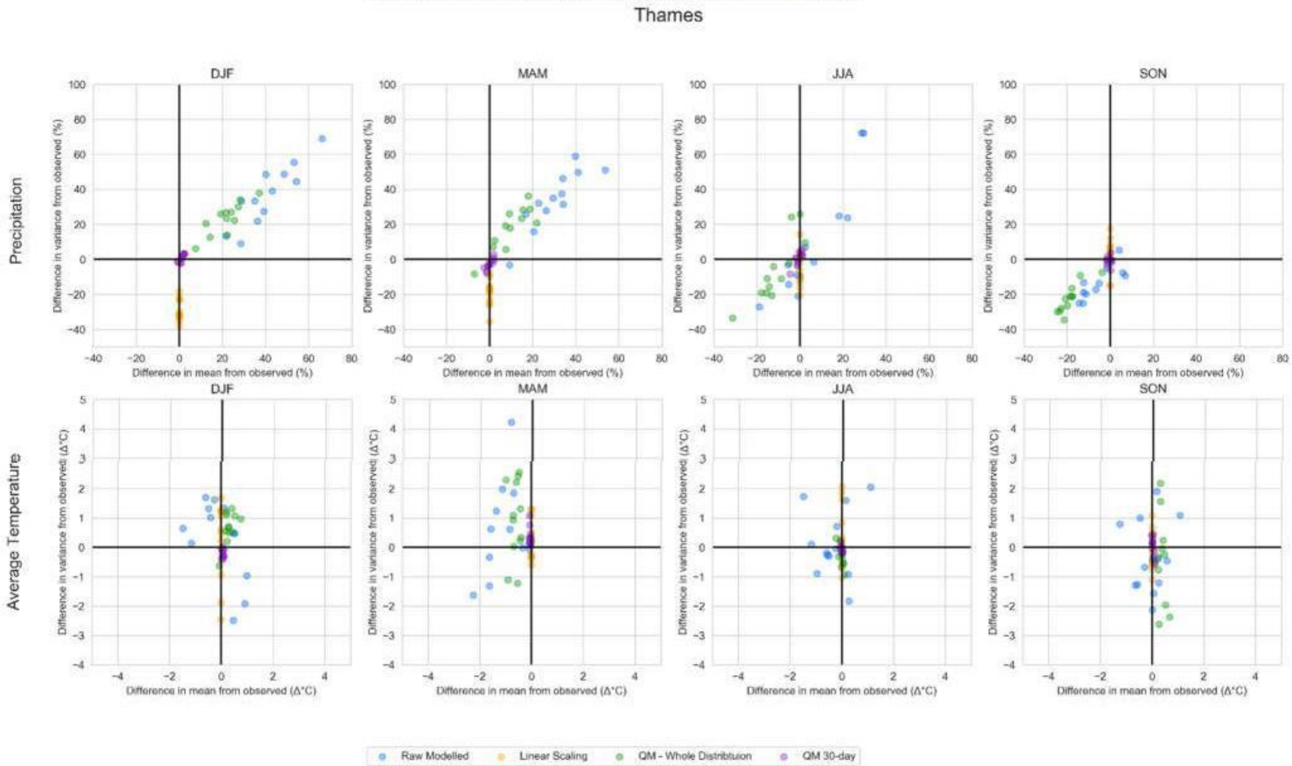
Severn

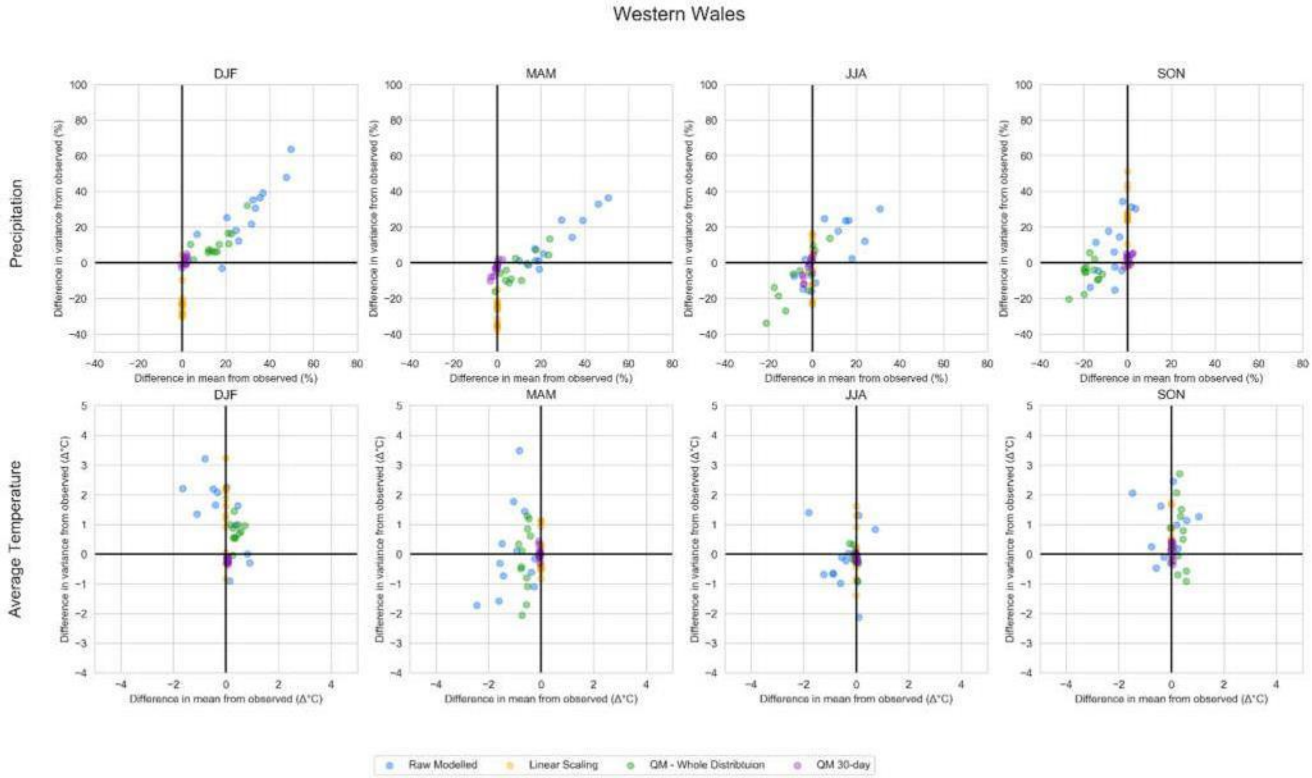



South East England

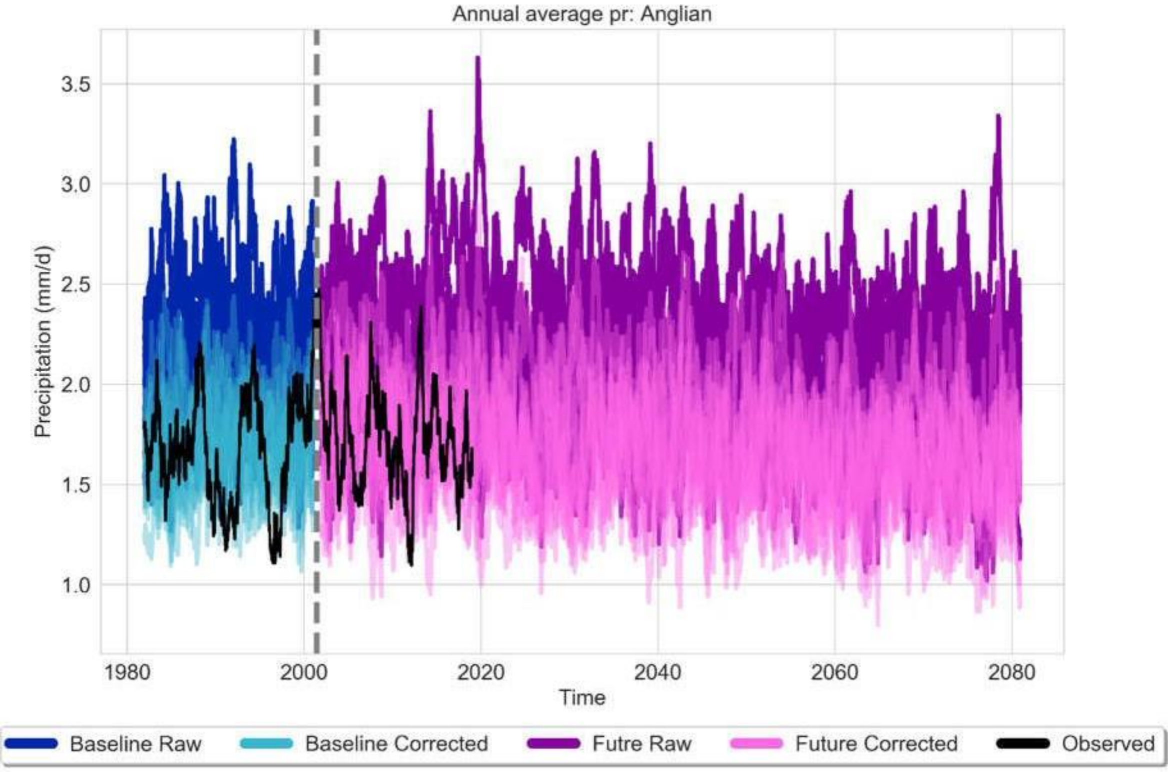


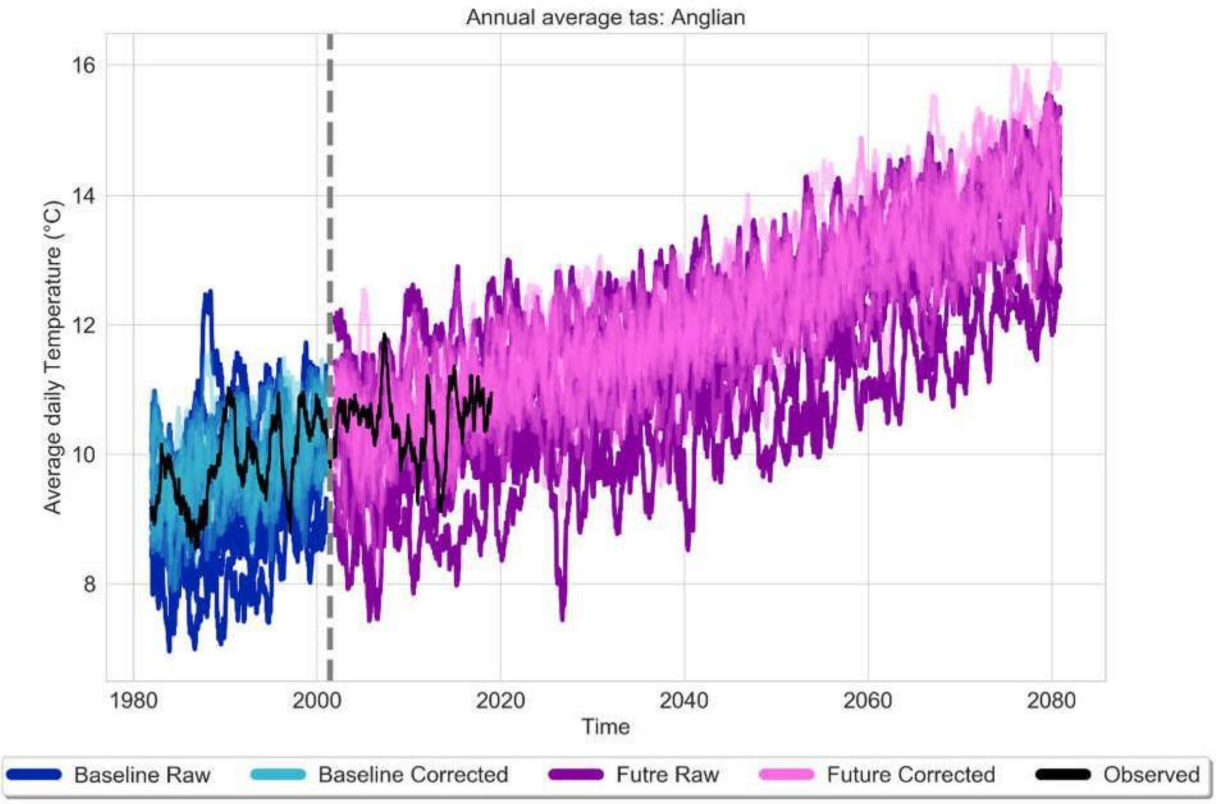

South West England
DJF
MAM
JJA
SON
Precipitation
Average Temperature
Difference in variance from observed (%)
Difference in mean from observed (%)
Difference in variance from observed (Δ°C)
Difference in mean from observed (Δ°C)
Raw Modelled
Linear Scaling
QM - Whole Distribtuion
QM 30-day

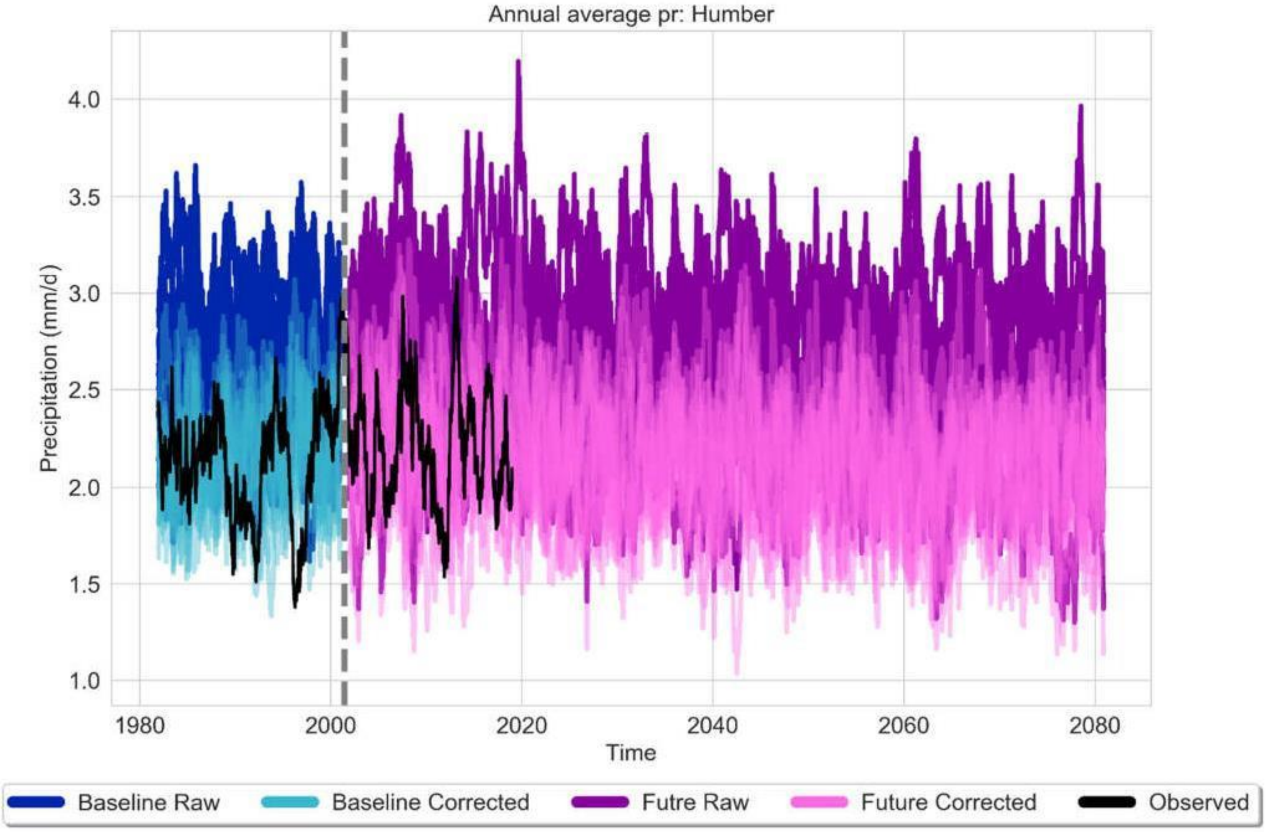

Thames
DJF
MAM
JJA
SON
Precipitation
Average Temperature
Difference in variance from observed (%)
Difference in mean from observed (%)
Difference in variance from observed (Δ°C)
Difference in mean from observed (Δ°C)
Raw Modelled
Linear Scaling
QM - Whole Distribtuion
QM 30-day

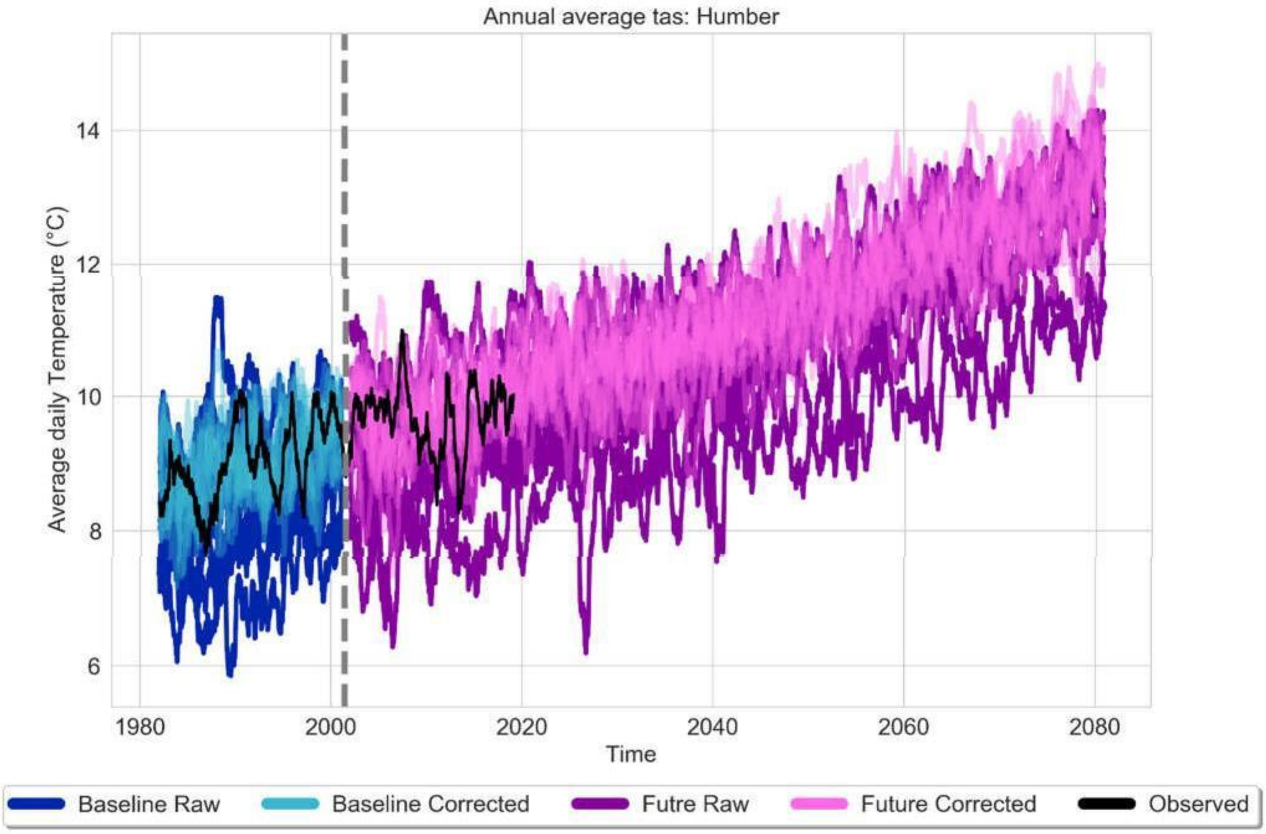


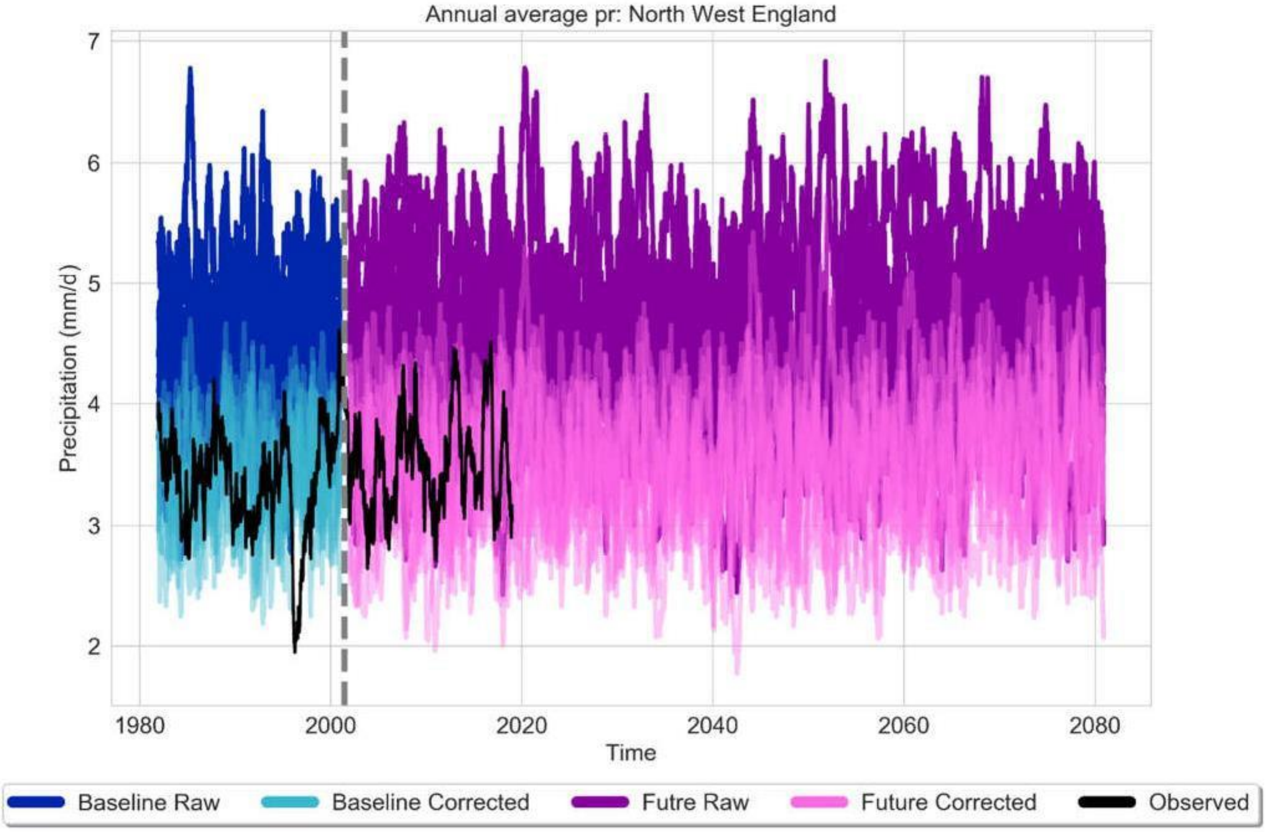

### C.13.3. Bias correction: Time series of average temperature and precipitation before and after bias correction

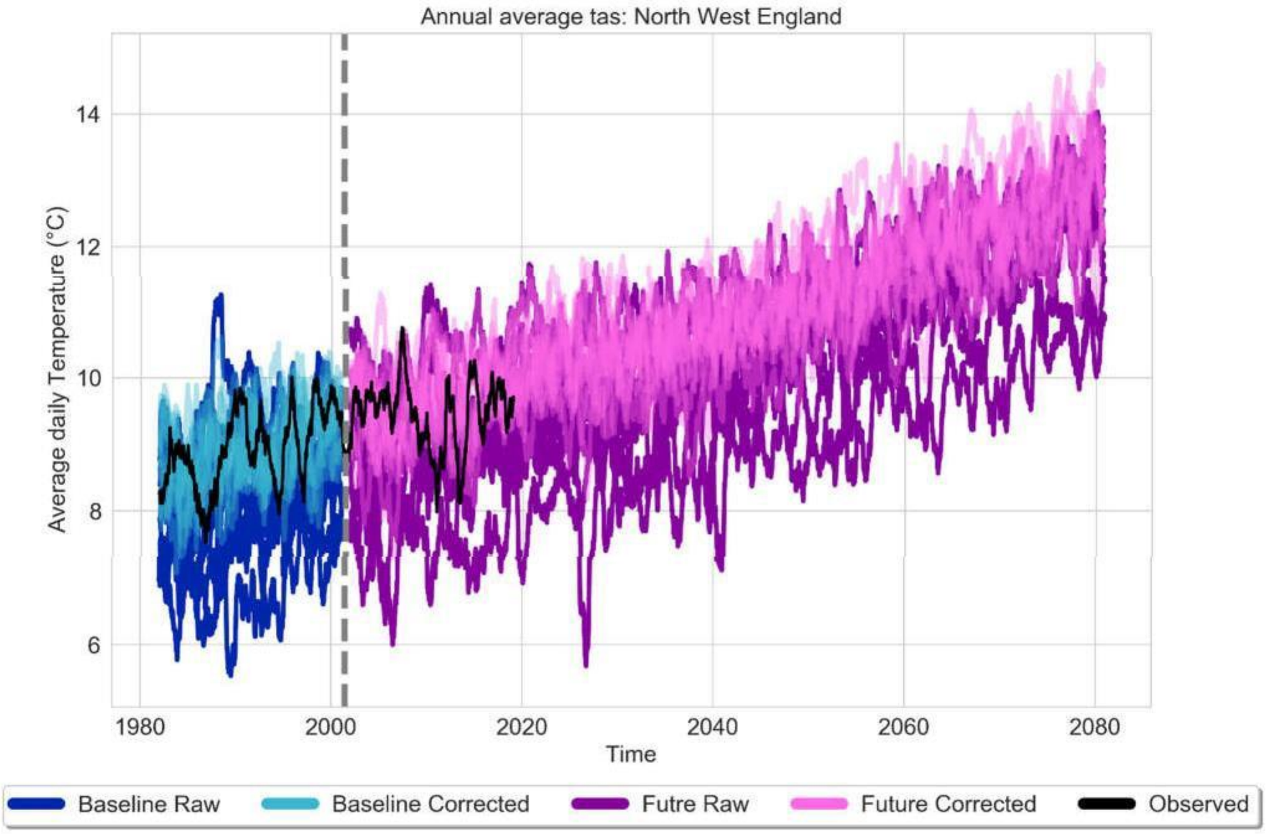

Annual average pr: Anglian
Precipitation (mm/d)
3.5
3.0
2.5
2.0
1.5
1.0
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

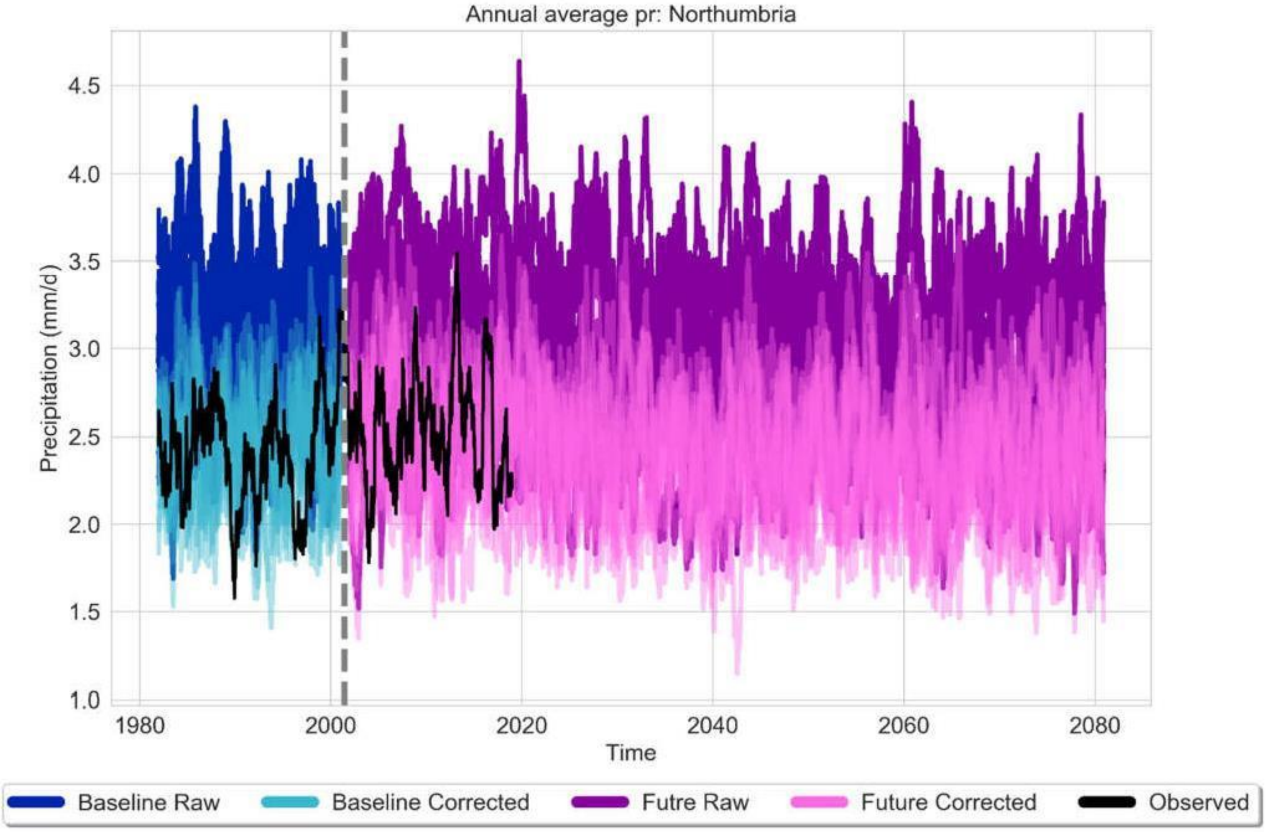

Annual average tas: Anglian
Average daily Temperature (°C)
16
14
12
10
8
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed


Annual average pr: Humber
Precipitation (mm/d)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

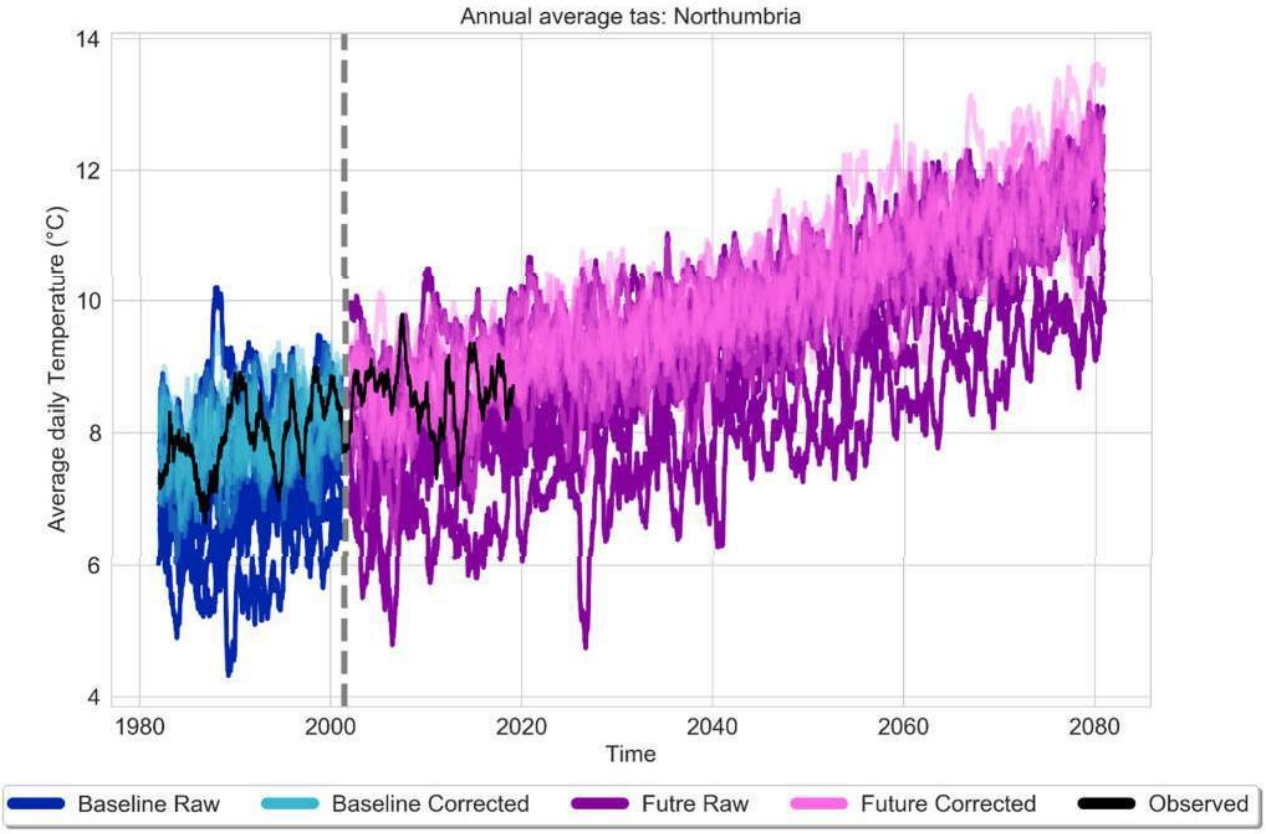

Annual average tas: Humber
Average daily Temperature (°C)
14
12
10
8
6
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed


Annual average pr: North West England
Precipitation (mm/d)
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

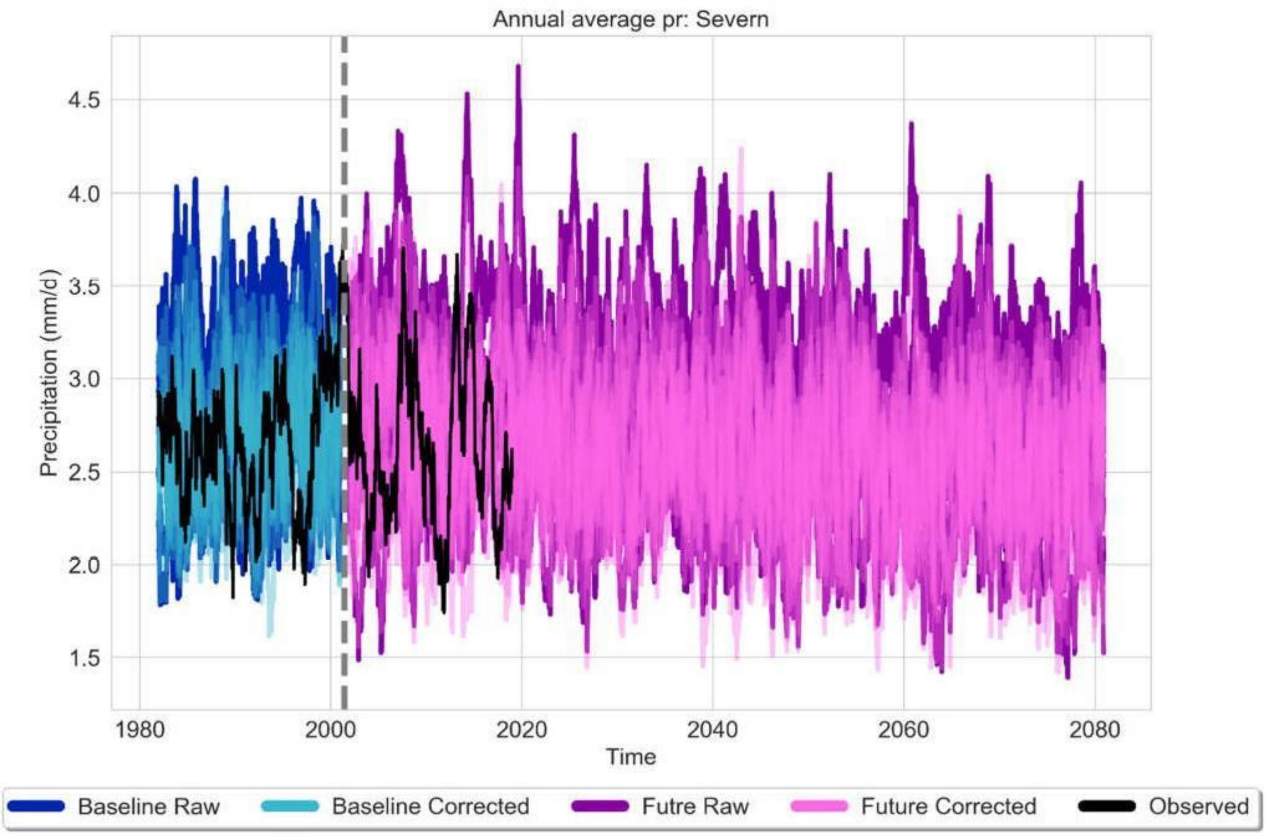

Annual average tas: North West England
Average daily Temperature (°C)
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

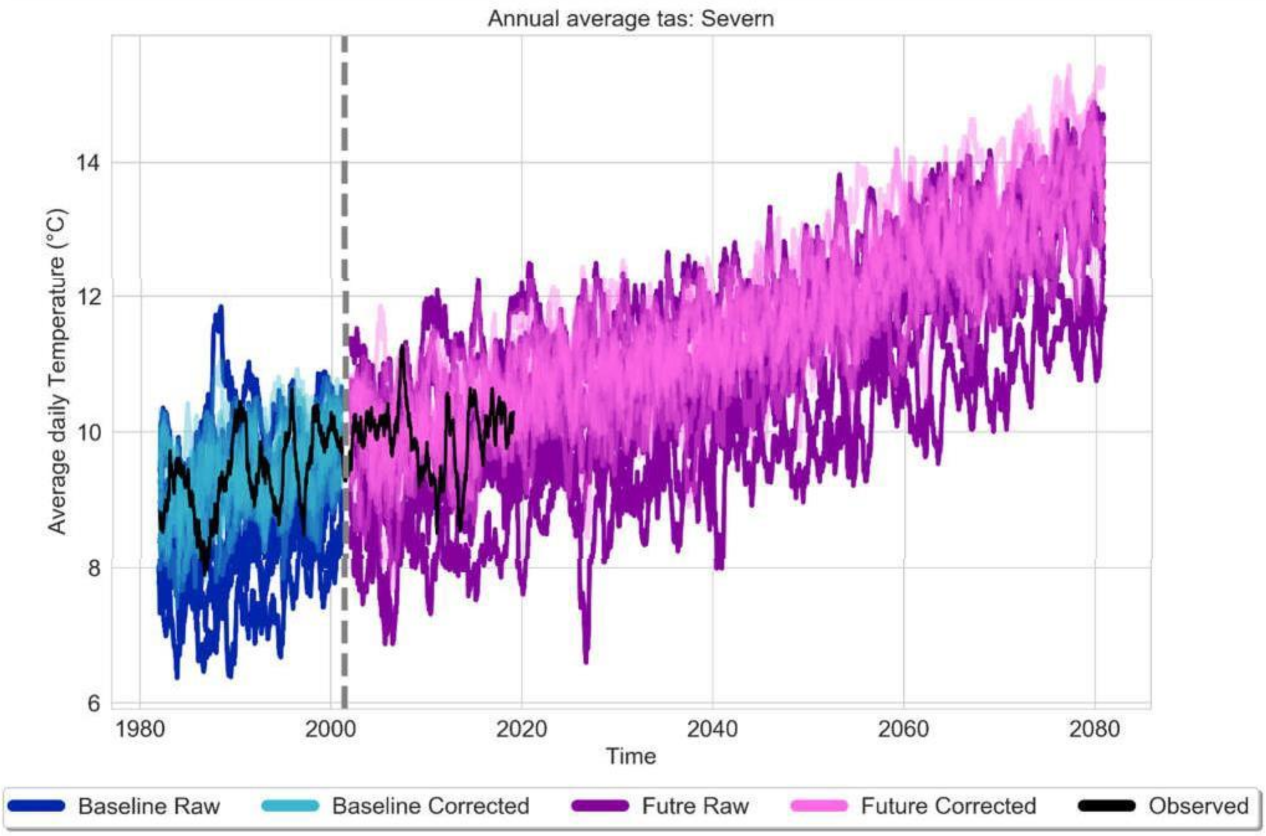


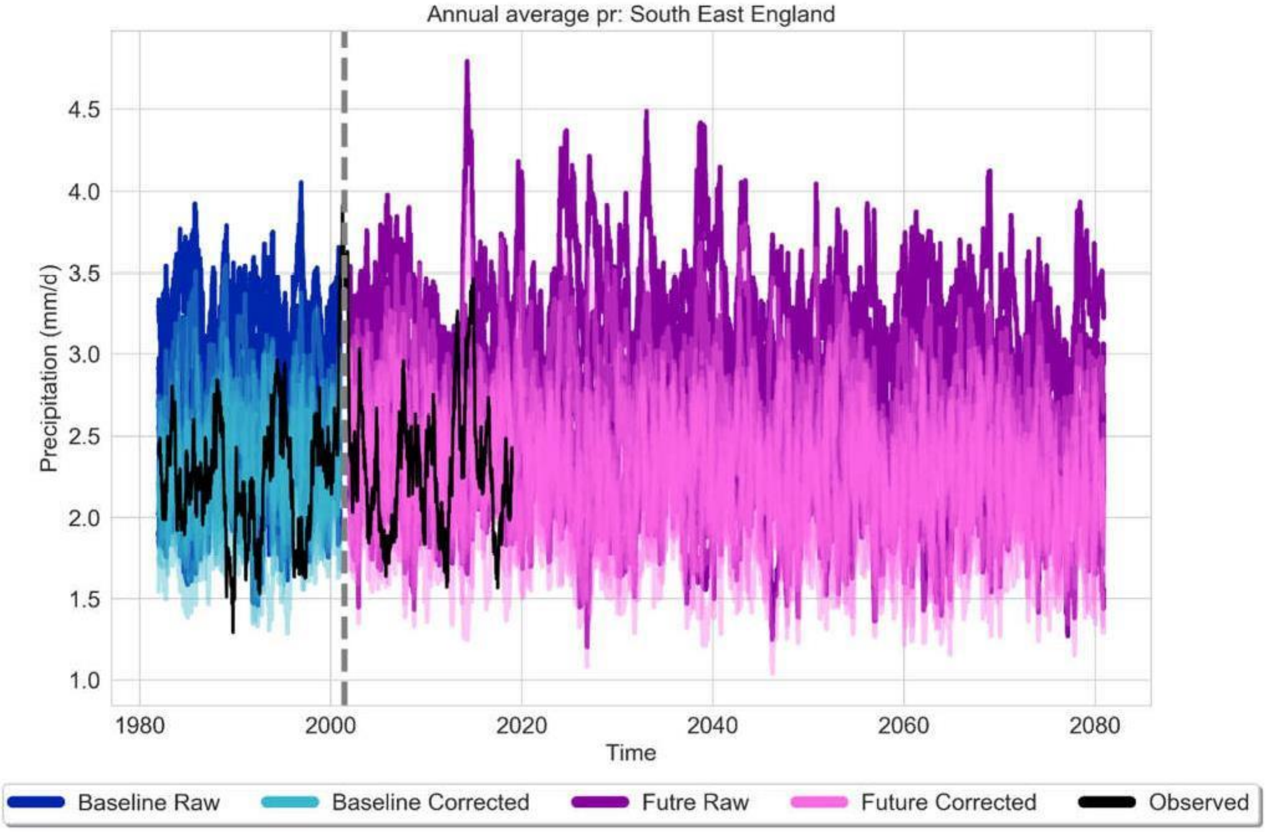
Annual average pr: Northumbria
Precipitation (mm/d)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

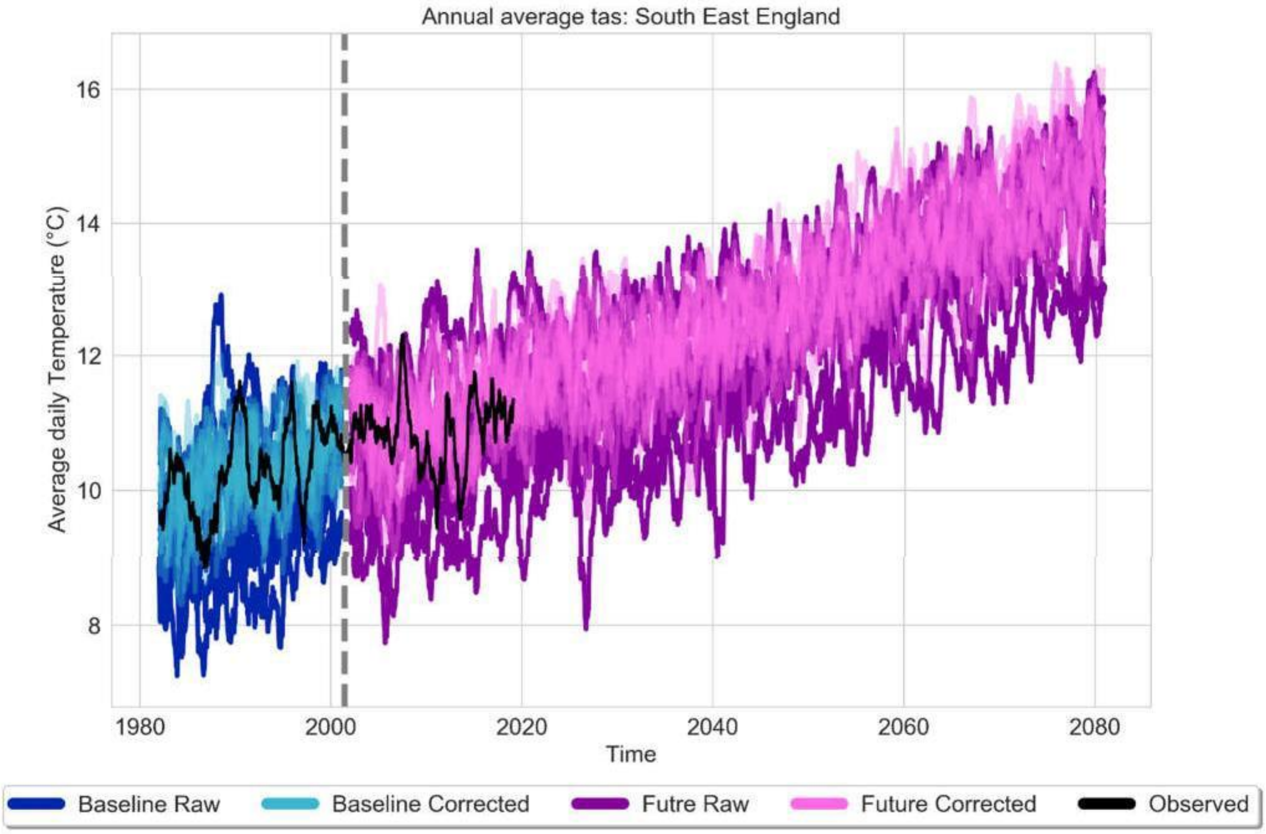



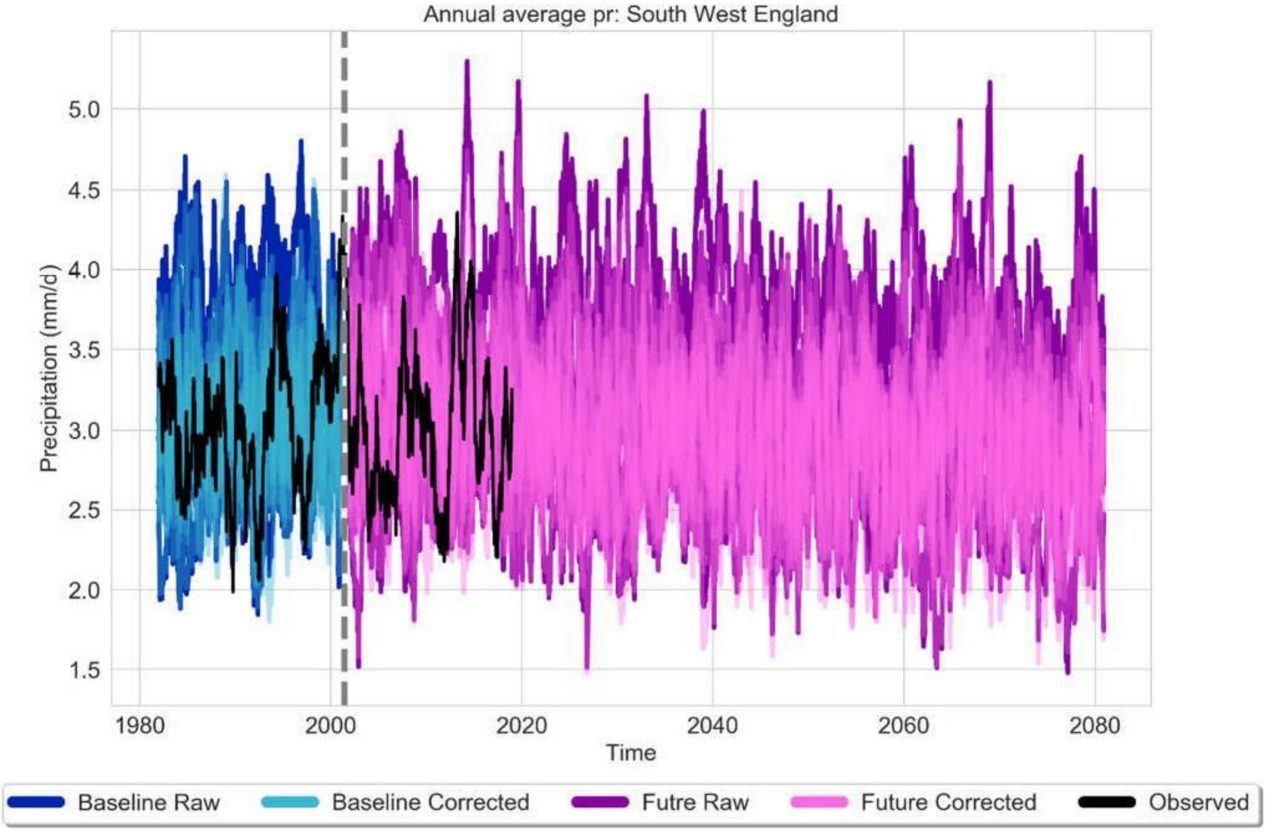
Annual average tas: Northumbria
Average daily Temperature (°C)
14
12
10
8
6
4
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed


Annual average pr: Severn
Precipitation (mm/d)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

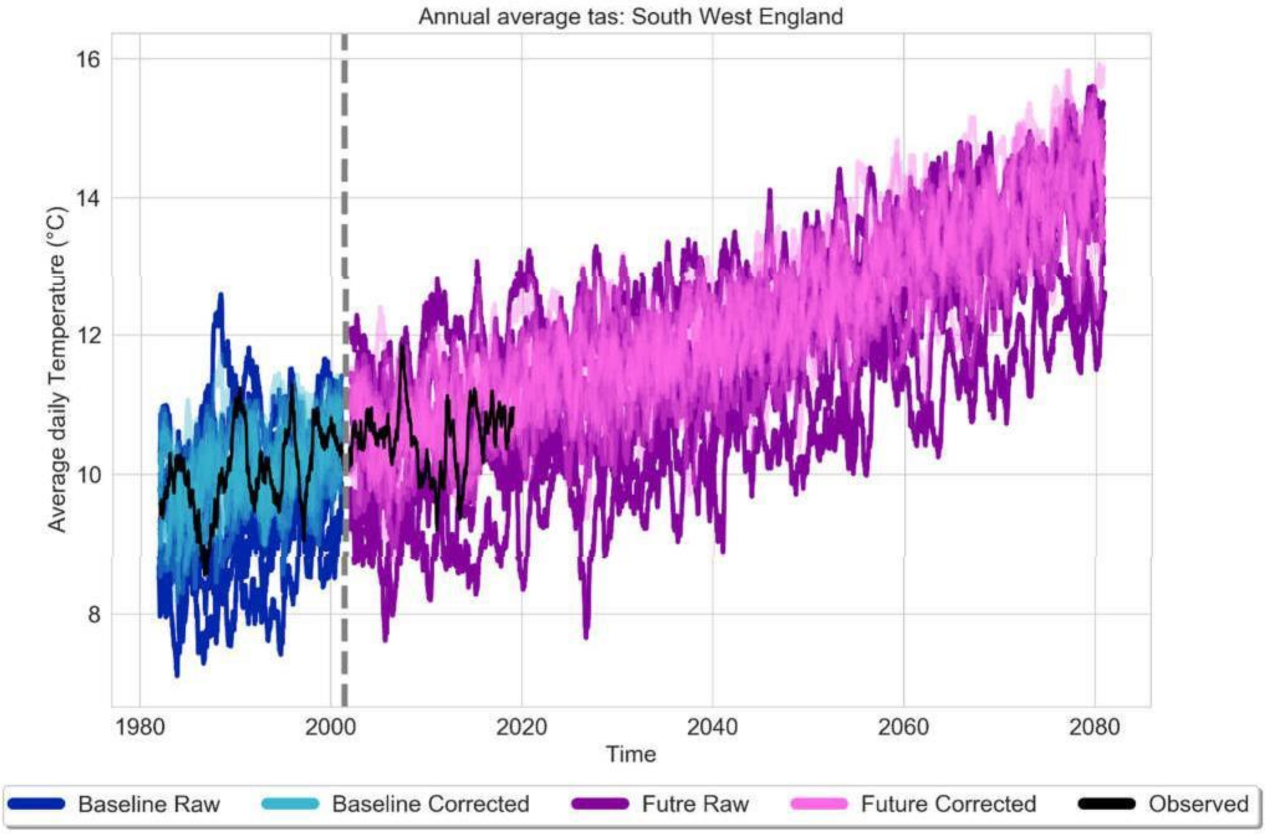

Annual average tas: Severn
Average daily Temperature (°C)
14
12
10
8
6
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed


Annual average pr: South East England
Precipitation (mm/d)
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

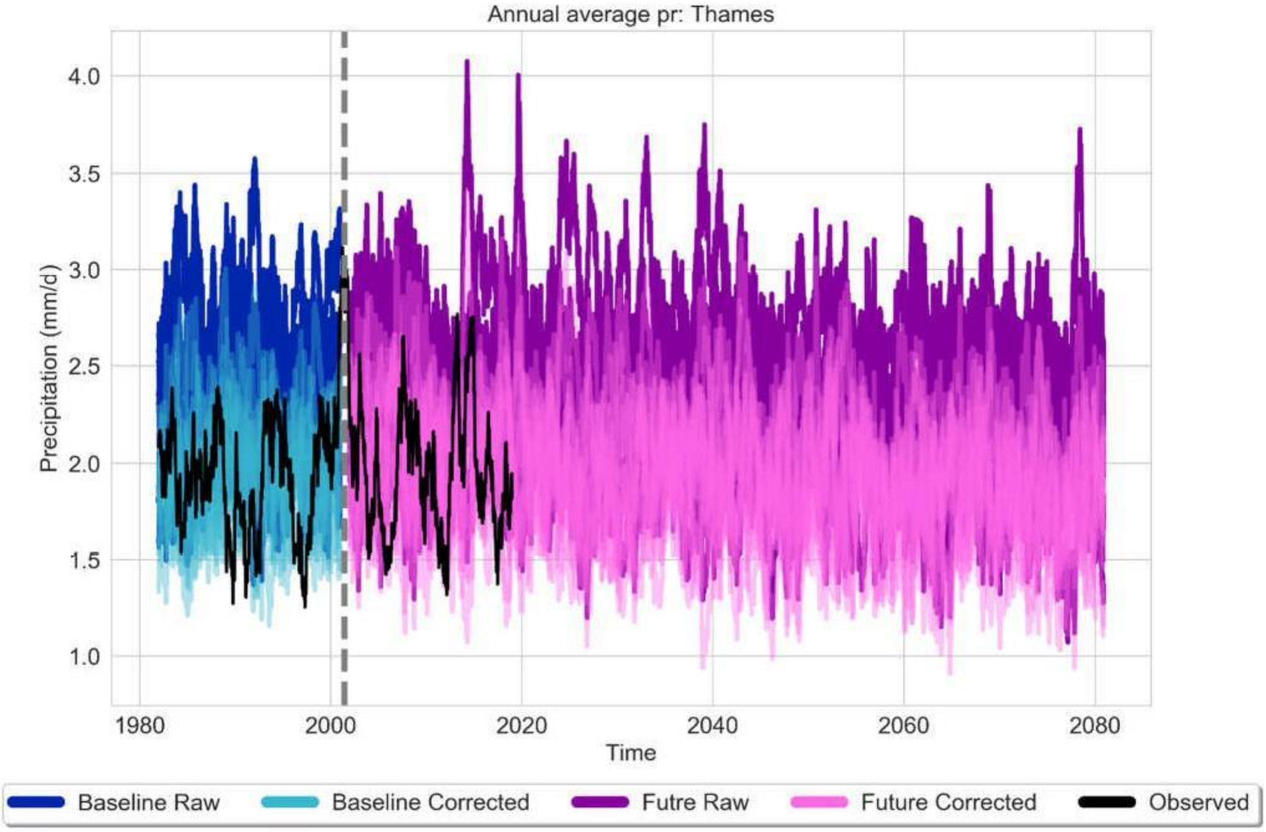

Annual average tas: South East England
Average daily Temperature (°C)
16
14
12
10
8
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

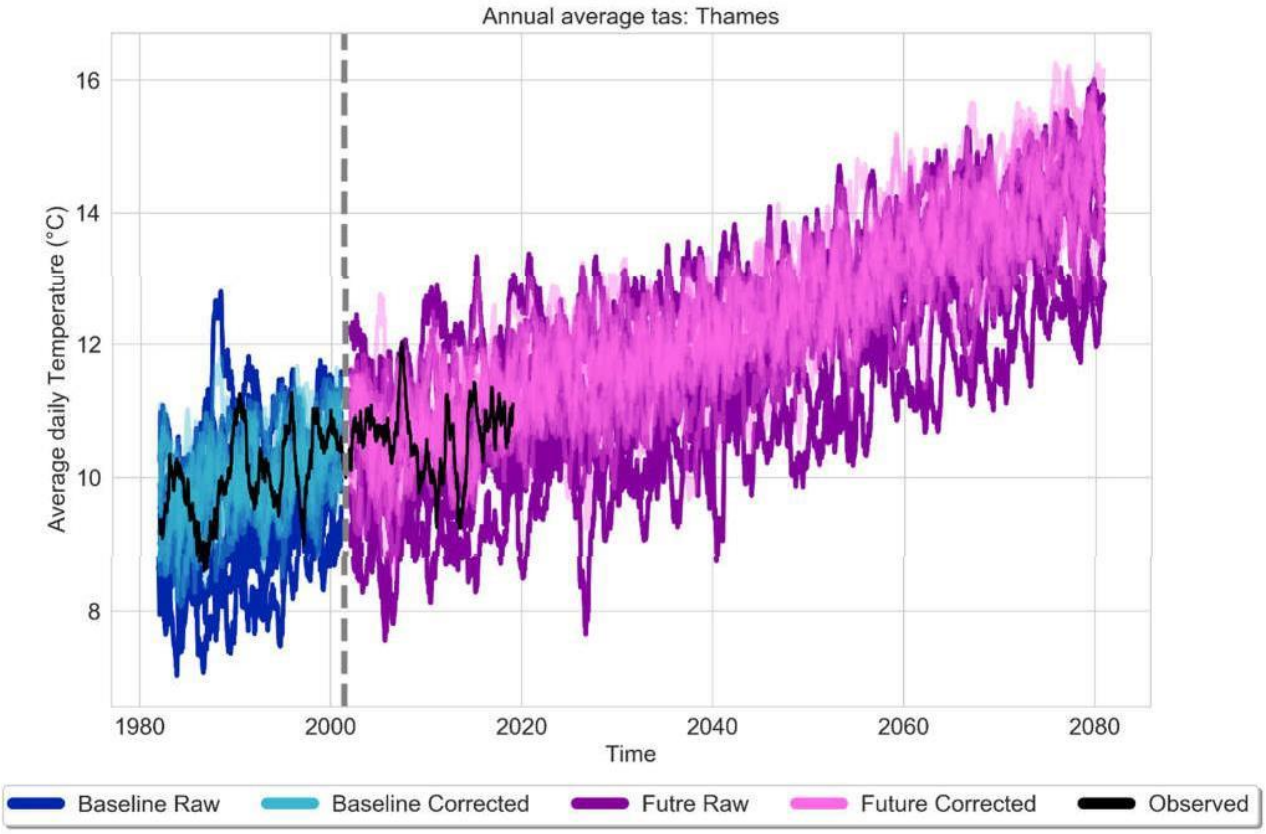


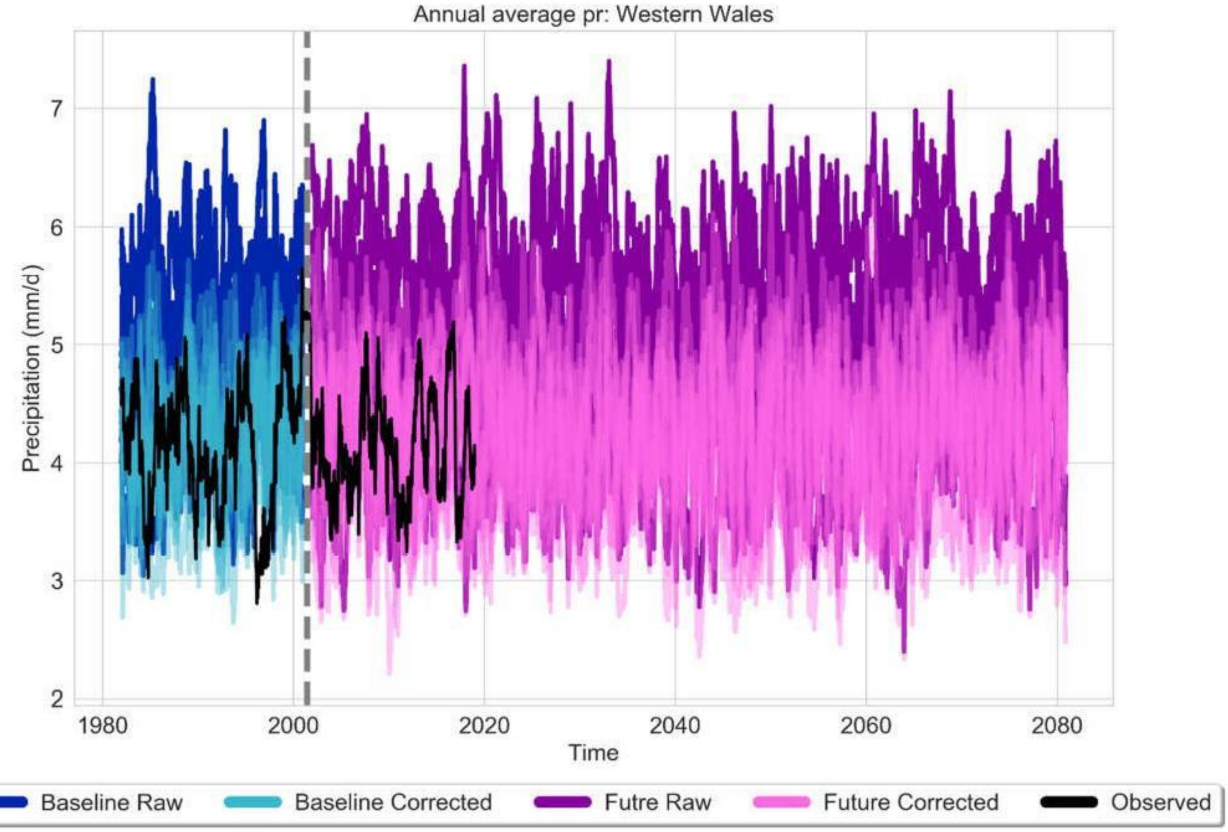
Annual average pr: South West England
Precipitation (mm/d)
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

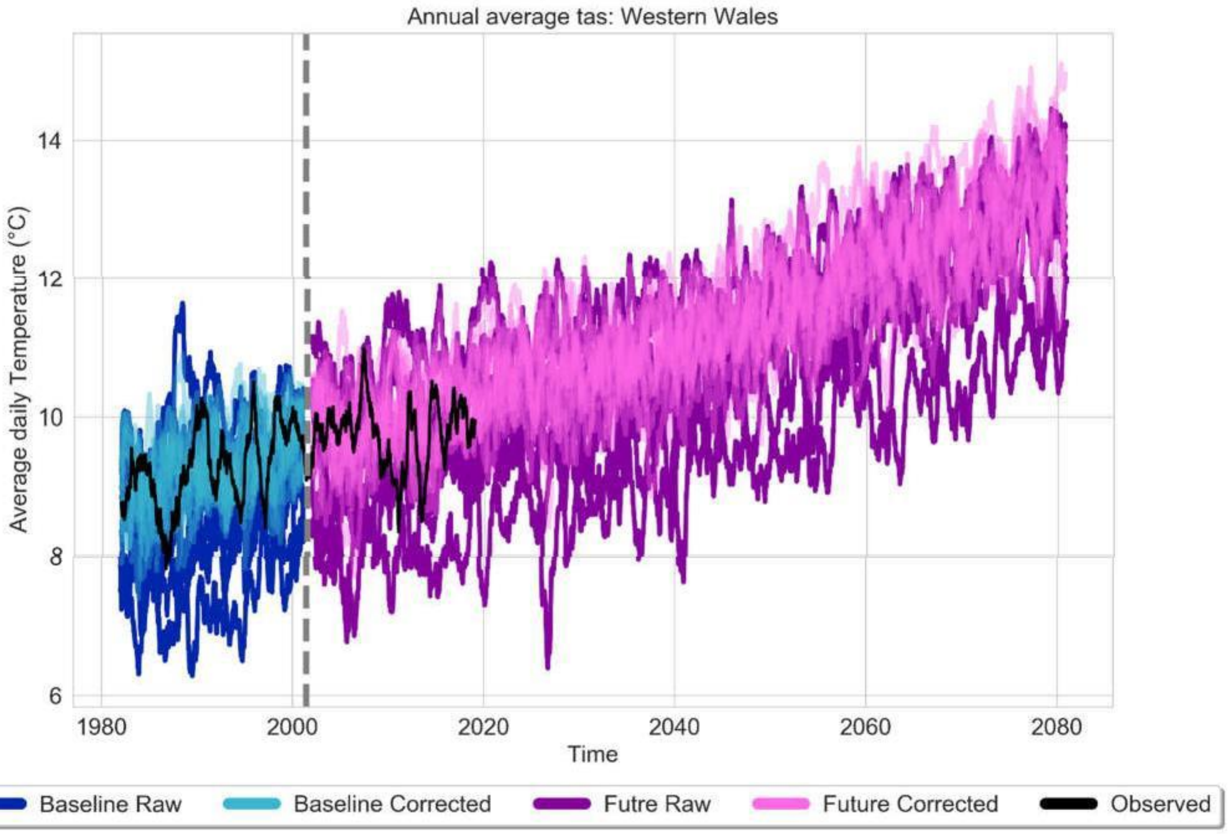



Annual average tas: South West England
Average daily Temperature (°C)
16
14
12
10
8
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed


Annual average pr: Thames
Precipitation (mm/d)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

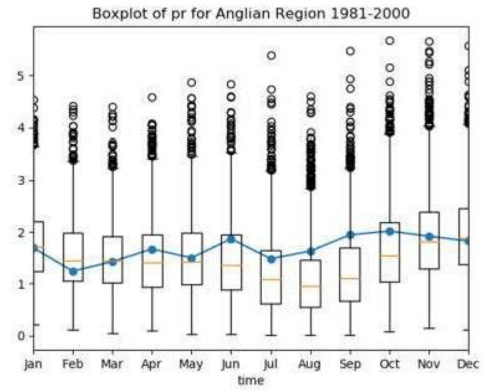

Annual average tas: Thames
Average daily Temperature (°C)
16
14
12
10
8
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

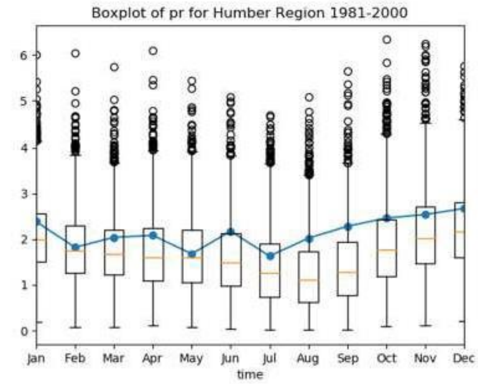

Annual average pr: Western Wales
Precipitation (mm/d)
7
6
5
4
3
2
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

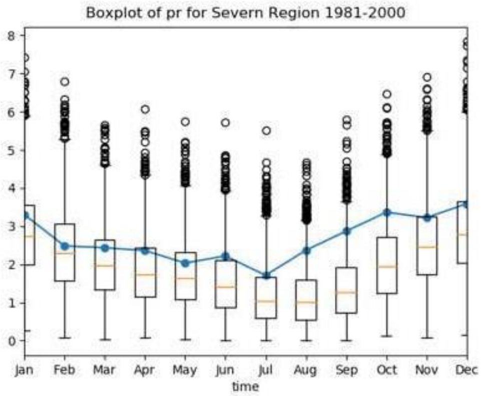

Annual average tas: Western Wales
Average daily Temperature (°C)
14
12
10
8
6
1980
2000
2020
2040
2060
2080
Time
Baseline Raw
Baseline Corrected
Futre Raw
Future Corrected
Observed

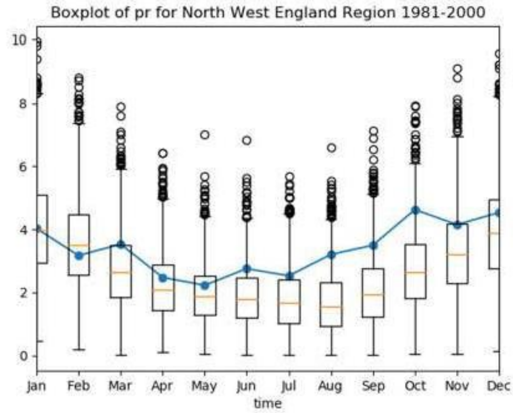
## C.14. MaRIUS data sets

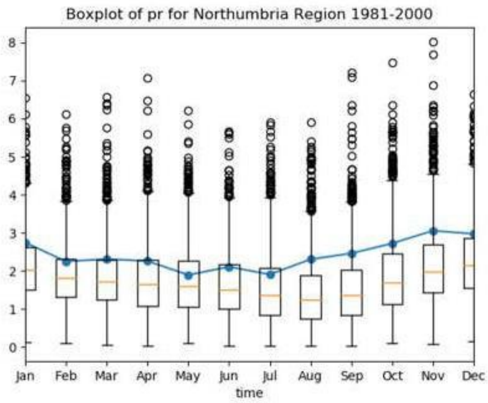
### C.14.1. Precipitation (raw)

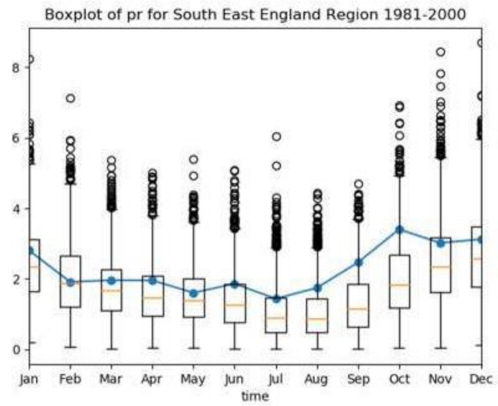


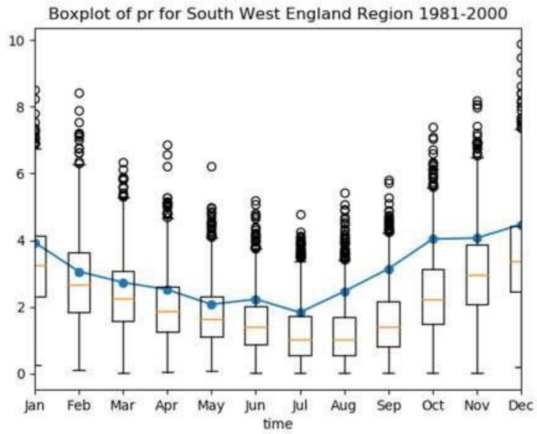



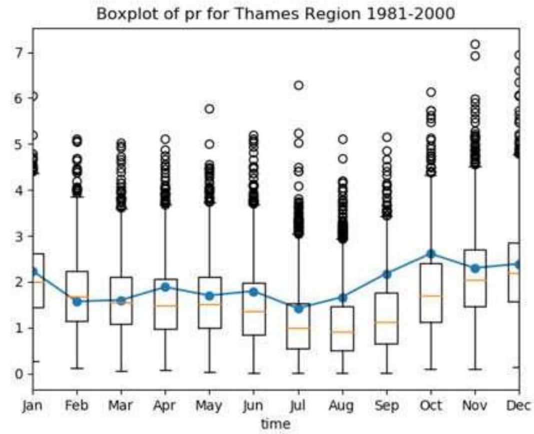



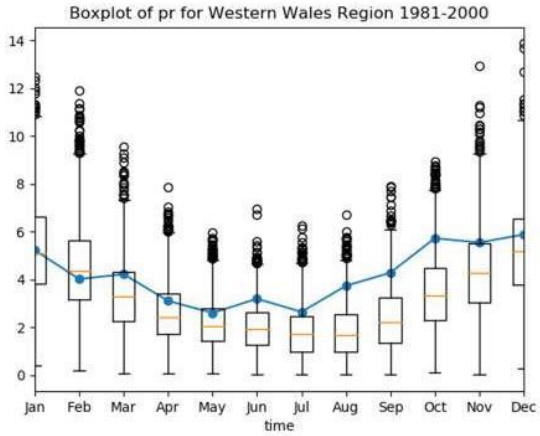



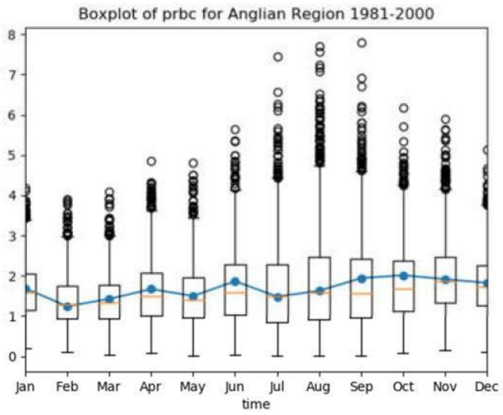

Boxplot of pr for South West England Region 1981-2000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

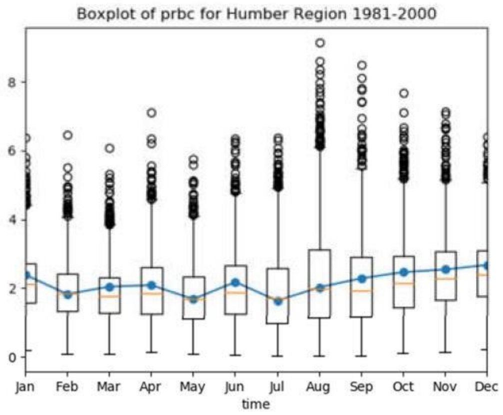

Boxplot of pr for Thames Region 1981-2000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

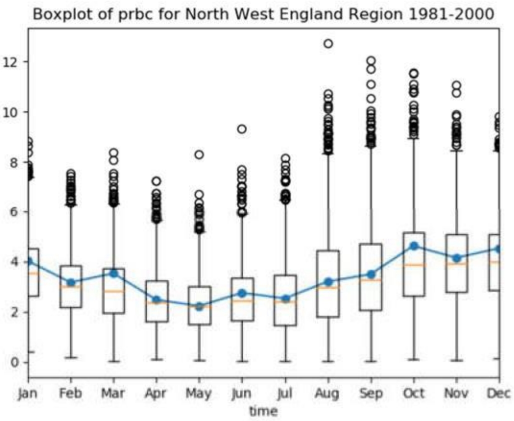

Boxplot of pr for Western Wales Region 1981-2000
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

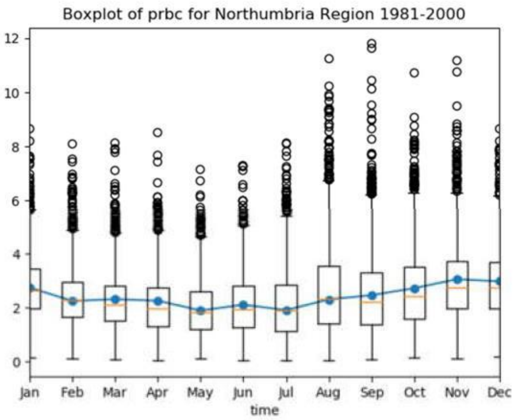
ATKINS
Member of the SNC-Lavalin Group

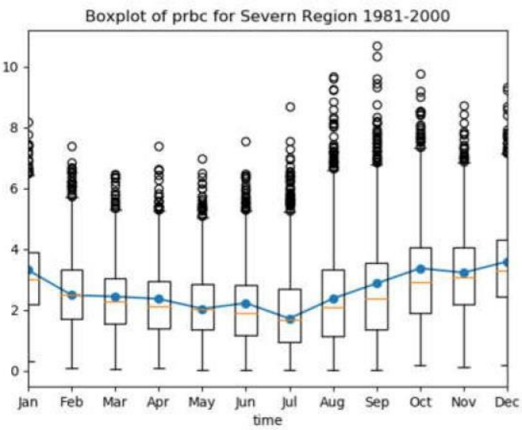
## C.14.2. Precipitation (bias-corrected)

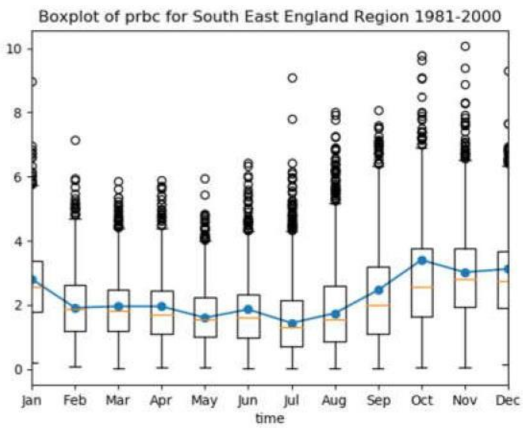


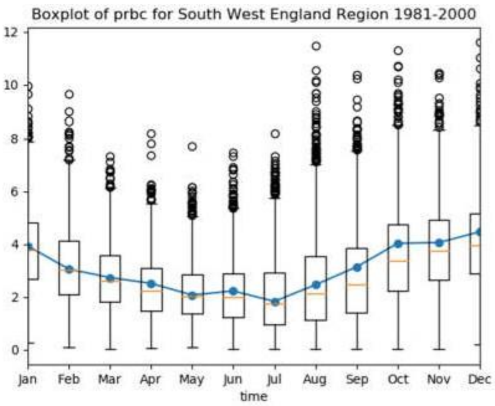



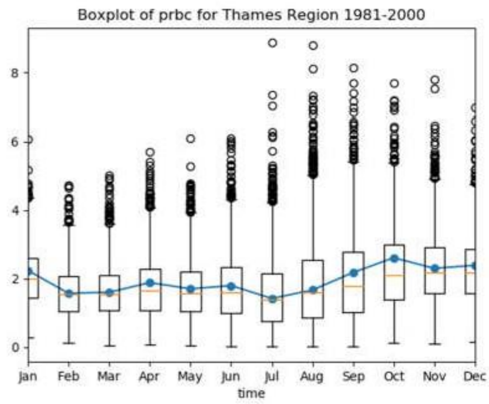



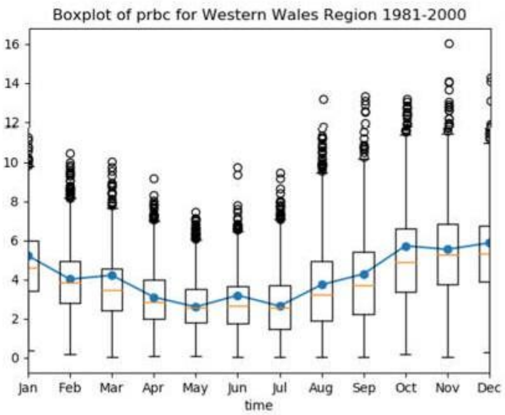



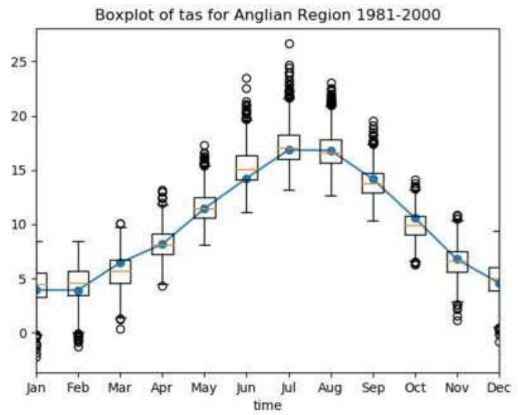



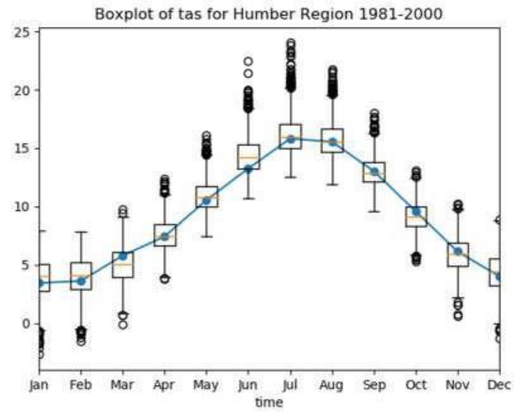

Boxplot of prbc for South West England Region 1981-2000
0
2
4
6
8
10
12
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

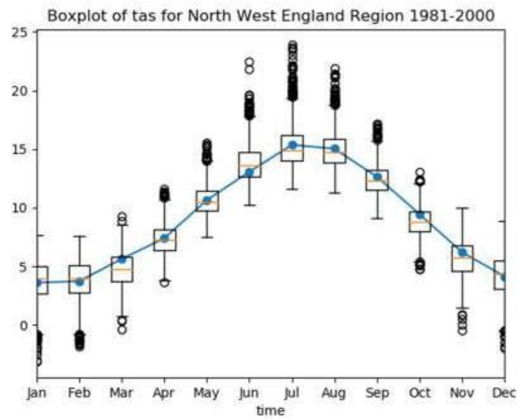

Boxplot of prbc for Thames Region 1981-2000
0
2
4
6
8
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

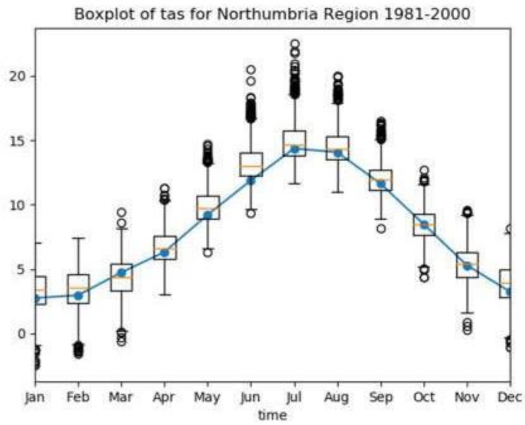

Boxplot of prbc for Western Wales Region 1981-2000
0
2
4
6
8
10
12
14
16
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

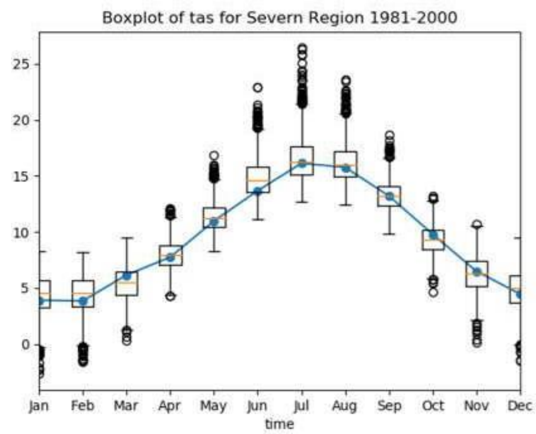
## C.14.3. Average temperature (raw)

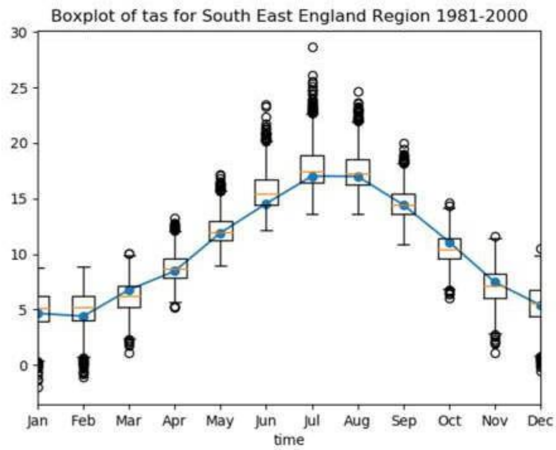


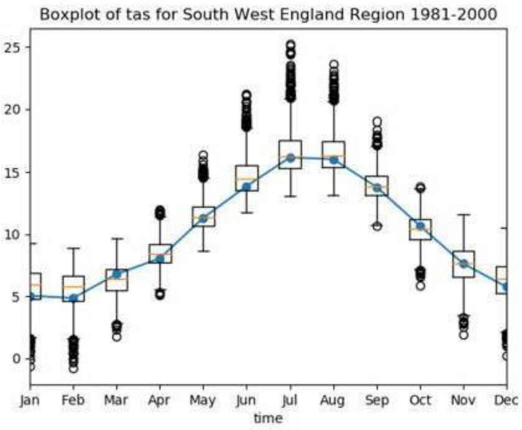



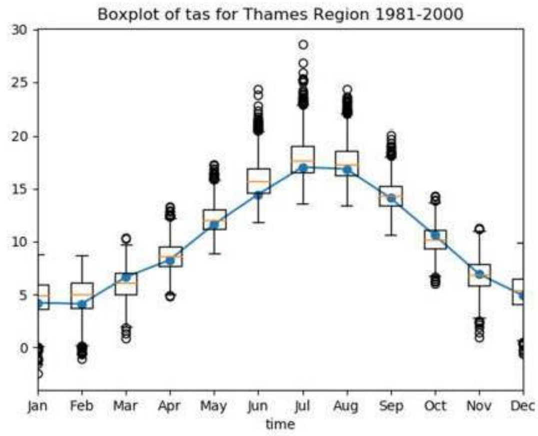



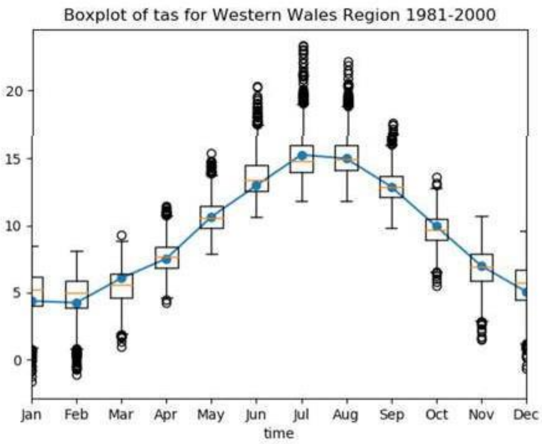




Boxplot of tas for South West England Region 1981-2000
25
20
15
10
5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time


Boxplot of tas for Thames Region 1981-2000
30
25
20
15
10
5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time


Boxplot of tas for Western Wales Region 1981-2000
20
15
10
5
0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
time

# C.15. Bias correction and visualisation codes

## A.1.1. Summary of bias correction methods

<table>
<tr><th>Method</th><th colspan="2">Description</th><th>Pros</th><th>Cons</th><th>Reference</th></tr>
<tr><td>Delta change</td><td colspan="2">An observed time series is taken, and a model-derived climate change signal is added<br>For precipitation, relative changes rather than absolute changes are applied.</td><td>Preserves the observed weather sequence - maintains (linear) interdependencies between variables in space and time.</td><td>Climatic variables in the future are expected to have a different spatial and temporal dependence structure than today.<br>Restricted to observed range of anomalies.<br>Unsuitable for extreme events</td><td>Maraun (2016)</td></tr>
<tr><td>Linear scaling</td><td colspan="2">Similar to the delta change approach (above) but makes direct use of the simulated time series by subtracting the present day model bias from simulated future time series.<br>Method can be a simple mean bias correction or adjust both mean and variance bias. A modified version also has an additional step which accounts for the number of wet days.</td><td>Retains climate change signal<br>Simple method that many have used in the literature.<br>Can be as good as more complex methods (e.g. Shrestha et al, 2013)<br>Simple to code – a useful comparator with other methods.</td><td>Assumes time invariant biases.</td><td>Fung (2018)</td></tr>
<tr><td rowspan="2">Quantile mapping</td><td>CDF-matching</td><td>Takes the model output for a future period, finds the corresponding percentile values in the CDF of the model for the training period, and then locates the observed values for the same CDF values of the observations.</td><td>Adjusts the entire distribution (i.e. the entire distribution matches the observation distribution for the training period).<br>Corrects the drizzling effect common in many models</td><td>Assumes that the historic model distribution applies to the future - the underlying assumption is that the climate distribution does not change much over time (i.e. that the variance and skew are stationary, and that only the mean changes).<br>Results can be sensitive to choice of calibration period.</td><td>Maraun (2016)<br>Lafon et al (2013)<br>Gutowski et al, (2003)</td></tr>
<tr><td>Equidistant CDF-matching (EDCDFm)<br>or<br>QM31</td><td>As above, but the difference between the CDFs for the future and historic periods are also considered. The assumption is that for</td><td>Incorporates information from the CDF model projection.<br>Explicitly considers changes in the distribution of the</td><td>Large number of parameters and danger of over-fitting to short baseline data sets.<br>Extrapolation outside the range of the</td><td>Li et al (2010)</td></tr>
</table>

| Method | Description | | Pros | Cons | Reference |
|---|---|---|---|---|---|
| | | a given percentile, the difference between the modelled and observed distributions applies to the future. | future climate, including the tails of the distribution.<br>Simple to implement | baseline data can be problematic. | |
| | Trend-preserving | This method combines two steps:<br>Linear scaling approach for the long-term trend<br>Quantile mapping approach for variability | Preserves the long term trend of the modelled data. | To correct data for input to drought models requires variability to be corrected at other timescales (i.e. weekly/monthly time scales as well as daily). Such an extension and testing of the methodology has not been carried out by ISI-MIP (Hempel et al, 2013).<br>More steps involved. | Hempel et al (2013) |
| | CDF transform | Method implemented by the Climate Data Factory. The assumption is that the model and observational distributions can be inferred by a mathematical function (the “transform”) which remains the same for past and future distributions.<br>The transform function is used to derive an “observational future” distribution where CDFm can be implemented | CDF-t does not rely on the stationarity hypothesis: model and observational distributions can evolve and be different.<br>Preserves the raw climate signals. | More steps involved. | Famien et al (2017) |
| | Scaled Distribution Mapping (SDM) | An extension of the delta change method: multiplies observed values by the ratio of the modelled values (period of interest divided by calibration period) at the same quantiles.<br>More explicitly accounts for the frequency of rain days | Does not rely on the stationarity hypothesis.<br>Outperforms other QDM methods in ability to preserve raw climate model projected changes. | The temporal evolution of climate change might not be captured without further processing e.g. if it is necessary to preserve the climate change signal across a variety of timescales, the SDM must be discretized into smaller blocks (number dependent on how strongly the user wants the bias corrected data | Switanek et al (2017) |

| Method | Description | | Pros | Cons | Reference |
| --- | --- | --- | --- | --- | --- |
| | | and the likelihood of individual events. | | to follow raw modelled temporal evolution of climate change). | |

## C.15.1. Implemented bias correction methods

For a simple explanation of bias correction, users should refer to Fung (2018) or Navarro-Racines, *et al.* (2015). For this project we have implemented three bias correction techniques: simple linear bias correction, a basic Quantile Mapping (QM) approach and a more complex method that we are calling QM31 using a 31-day window based on the method referred to as Equidistant CDF mapping (EDCDFm) in the research literature (Li, *et al.*, 2010).

### Linear Scaling

To undertake the simple linear bias correction, the following steps were undertaken:

Observed and modelled data for the baseline period of 1981 to 2000 were aggregated from the daily timeseries to a single monthly profile across all years.

Bias correction change factors for each month of the profile were calculated. For temperature the change factors were calculated by subtracting the modelled from the observed data. Whereas for precipitation, factors were calculated by dividing the observed by modelled data.

The relevant bias correction change factor for a given month was then used to correct the daily data of the modelled data for both the baseline period and future periods i.e. the January bias correction factor was applied to all January days.

This method clearly worked well for monthly averages but reduced the seasonal variance in the corrected models, which suggests it is not suitable for looking at period of low rainfall. Therefore, this method was only assessed for the baseline period and not taken any further.

Using the nomenclature of Maraun 2016 the bias for temperatures and precipitation are defined as follows based on the modelled (x) and observed (y) data:

$$\widehat{Bias}(\mu^p) = \bar{x}_i^p - \bar{y}_i^p. \qquad (1)$$

Correspondingly, the relative bias might be estimated as

$$\widehat{Rel.Bias}(\mu^p) = \bar{x}_i^p / \bar{y}_i^p. \qquad (2)$$

Simple mean bias correction for future (f) time series is calculated by subtracting the bias from the raw data or dividing by the bias for rainfall:

$$x^f_{\mathrm{i,corr}} = x^f_{\mathrm{i,raw}} - \widehat{Bias}(\mu^p) = x^f_{\mathrm{i,raw}} - (\bar{x}^f_{\mathrm{i,raw}} - \bar{y}_i^p), \qquad (5)$$

or equivalently for precipitation

$$x^f_{\mathrm{i,corr}} = \frac{x^f_{\mathrm{i,raw}}}{\widehat{Rel.Bias}(\mu^p)} = x^f_{\mathrm{i,raw}} \times \frac{\bar{y}_i^p}{\bar{x}_i^p}. \qquad (6)$$

### Quantile mapping

Quantile mapping approaches seek to adjust modelled data considering the distribution of modelled versus observed data rather than using a single annual, seasonal or monthly linear scaling factor (see Fung, 2018; Navarro-Racines *et al*., 2015). The general principles of QM are to map the values of modelled cumulative distributions to observed distributions at the chosen time scale, typically daily. Therefore, the approach is to simply convert the raw modelled value to a quantile and identify the value associated with the same quantile in the observed distribution. This simple approach creates a number of challenges related to extrapolation of variables and dealing with special cases related to non-rain days for precipitation.

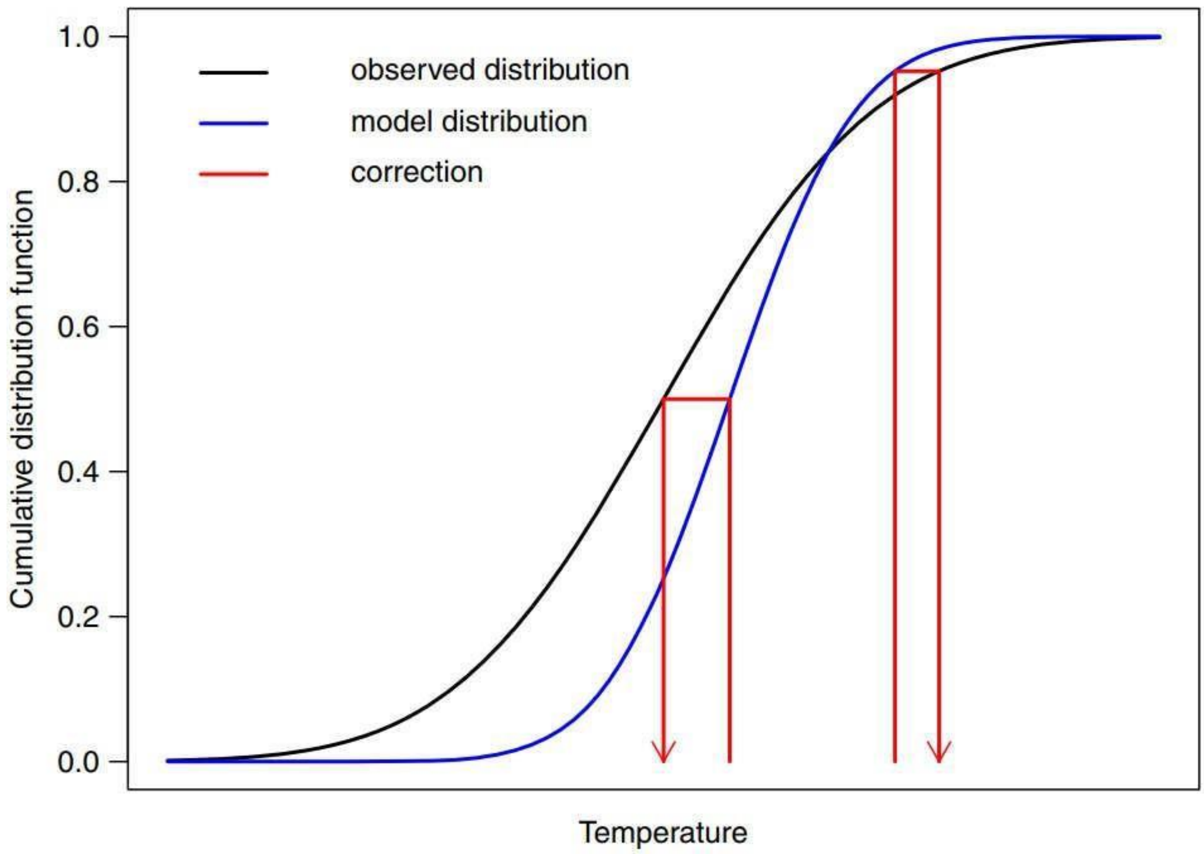
We have tested two methods of QM both on daily data for precipitation and temperature and using percentiles rather than fitting a specific distribution to the daily data sets. The use of percentiles has some disadvantages for the basic QM method, but these overcome on the QM31 approach that works from differences in baseline distributions rather than the direct mapping back the observed data.

### QM basic method

Following Maraun (2016), the quantile for a probability $\alpha$ of a distribution D will be denoted as qD($\alpha$) and is defined as the value which is exceeded with a probability 1 - $\alpha$ when sampling from the distribution. The corresponding empirical quantile q ̂D($\alpha$) can be obtained by sorting the given time series, say, xi, and then considering the value at position $\alpha \times$ N/100 (also called the rank of the data). The probabilities corresponding to a given quantile qD($\alpha$) (i.e. the cumulative distribution function) are written as pD(q) = $\alpha$. The present-day simulated distribution is replaced by the same quantile of the present-day observed distribution. For future periods the future simulated data is calculated based on relating each raw value to the probability of the simulated present-day distribution and replacing it with the quantile from the present day observed distribution.

$$x^f_{\mathrm{i,corr}} = q_{D^p_y}\left(p_{D^p_x}(x^f_{\mathrm{i,raw}})\right). \qquad (7)$$

In other words to bias correct model values for a future period, we first find the corresponding percentile values for in the cumulative distribution function (CDF) of the model for the simulated present day (control period 1981-2000 in our case) and then locate the observed values for the same CDF values of the present-day observations, as illustrated below.



### QM31 method

This method is based on Equidistant CDF mapping based on Li et al (2010). Here the equation is written using the same definitions as above, from Maraun (2016):

$$_{,} = _{,} + (P_{,}) - (P_{,})$$

This variation of quantile mapping was chosen because it incorporates the use of both the observed and modelled empirical CDFs without assuming a direct correlation. The assumption here is that for a given percentile, the difference between the observed and modelled data for the baseline period also applies in the future. The main difference between basic QM and equidistant CDF matching (EDCDFm) is that changes in the distribution of variables in the future are more explicitly considered in the EDCDFm method.

**Error! Reference source not found.** shows how raw future modelled output was corrected using raw modelled baseline data and observations for temperature. First, the ECDF distributions were generated for the observed data (black solid line) and raw modelled data (dark-blue dashed line) in the baseline period. Next, the percentile position of each future raw data point was determined (the red lines in **Error! Reference source not found.** show that the 70th percentile is located for a temperature of 15°C in the raw future data). The difference between the baseline raw data and the baseline observations at this percentile is used to adjust the future raw data (red arrows in Figure 3 show a decrease of ~1°C for data at the 70th percentile). When adjusting temperature, the adjustment made is an additive shift, but when precipitation is adjusted the adjustment is relative.

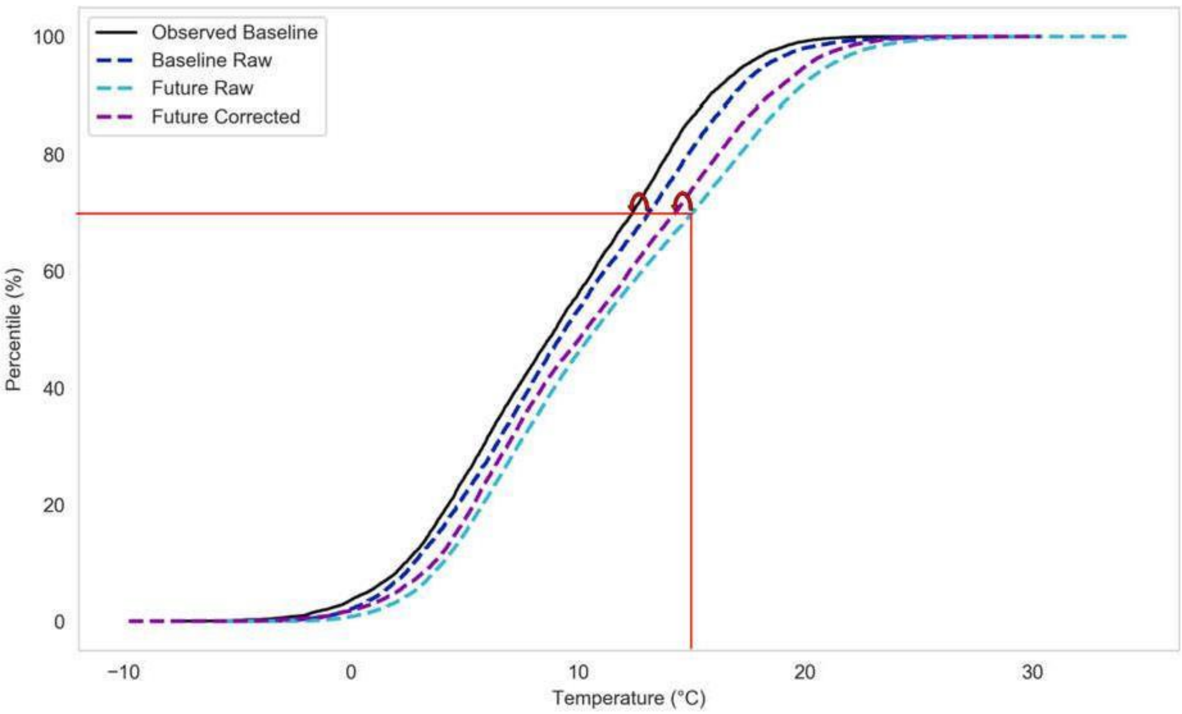



**Figure 23 EDCDFm methodology applied to RCM 15 temperature outputs over the Humber river basin for demonstrative purposes. for temperature. Red lines show how a data point of 15°C in the RAW future data is bias-corrected to 14°C using information from the baseline observed and baseline raw model distribution (see text for details).**

It was clear that UKCP data has large monthly bias for precipitation therefore, we used one ECDF for each day of the year (365 ECDFs), where each ECDF is made up of data from a 30 day rolling window about the day in question (see Thrasher, 2012 and the PyCAT library in Python). For example, to correct a value on the 32nd day of the year (1st Feb), an ECDF containing a distribution of all days from day 17 to day 47 across all years in the baseline period is constructed to determine the percentile of the value on the 32nd day. In the case of a leap year (366 days), the last day of the year shared the same ECDF as the last day of a 365-day year.

### A.1.2. Dealing with 360-day model years

RCMs operate on a 30-day month and 360 day year, so assumptions are needed to turn these data to a standard calendar year. In our analysis (i) the non-calendar dates in February are removed from the 360-day format (30th Feb and 29th Feb for a non-leap year) and (ii) missing calendar dates are then added to year (31st of Jan, March etc.). Temperature infilled to this added date is a linear interpolation between the day before and after. For precipitation it is assumed to be a dry day.

## C.16. Peer review comments

| Reviewer | Main comment | Response (Action) |
|---|---|---|
| Rob Wilby (3/3/20) | #1. The recent questioning of the credibility of RCP8.5 is acknowledged. This combined with the hot-dry end changes in the Hadley models suggests that these scenarios can only really be used for precautionary testing of options. | Agreed. The EA are yet to release guidance on choice of RCPs and on climate change in general, but we anticipate that most companies will use UKCP probabilistic factors to perturb WG outputs. Focus on use for stress testing and in cases when companies want to look a transient time series. |
| | #2. Mention of the typical confidence intervals of the gridded observations is needed – the past is probabilistic too! So bias correction to imperfect baseline data should be recognized. | Added one additional Met Office paper and will seek clarification on magnitude of uncertainties |
| | #3. The report is virtually silent about PET yet this is clearly a key ingredient for water planning. How is PET to be bias corrected? At the constituent variable or as a post-processing stage of bias correction? This may also depend on the choice of PET equation… | Based on selection of available PET data using a sampling method that aims to retain correlation with precipitation. Any PET formulae can be used, and the expectation is to work with whatever companies are using for their hydrological modelling. |
| | #4. Note that all bias correction is problematic when extrapolating outside the range of the baseline data. | Add commentary in Appendix D when validation work is completed. |
| | #5. What about the 2.2 km UKCP18 product – explain why this has been excluded. | Added a sentence on this. It can be used for planning and may have some advantages for uplands and small basins. However, it was out of scope because it was not included in our proposal. |
| | #6. Why not apply a statistical downscaling algorithm to fit the RCM output to the observations? This was done in UKCP09. At very least, this should be listed as an option in Appendix D. | Further information will be added as an alternative method in the next draft. |
| | #7. What if any cross-validation testing has been applied to the QM31 technique given that this is a massively parameterised approach? Some demo cross-validation results would really test the method. | We aim to validate for the 2001-2017 period (includes droughts, cold snaps and heatwaves) and 1961-1980 (includes 76 drought) |
| | #8. The report would benefit from a section that checks the QM31 skill at replicating PDFs of multi-season precipitation totals, as this will be a key basis for credible multiple-season extreme drought analysis further down the line… | To be addressed when the climate change work is joined up with the stochastics work. |

| | | |
|---|---|---|
| | #9. Has Met Office offered any explanation for the cold bias in their model runs? It would be good to provide some physical insight so users of the outputs can judge whether bias correction is credible, especially if there is a systemic issue with the climate models. | SDW to discuss with Met Office |
| | #10. Is there any update on new H++ outputs that are relevant to this report? | SDW to discuss with the Met Office |
| | #11 More work to be done in testing the various BC procedures using the types of drought diagnostic that will be applied further down the line. For instance, how would they all fare at reproducing the 20-year return period SPI-36, or the 100-year estimate of the SPEI-60? Maybe, this type of analysis falls out of the scope of the present report but, if planned, should be sign-posted at the end of the document. | As per comment 8. |

# Appendix D. Case studies

## D.1. WRSE – Western Rother

WRSE regional group recommended Western Rother catchment, at Hardham, as their case study location. This catchment is important to the WRSE region, as Pulborough, one of the Southern Water's strategic surface water abstractions, lies immediately upstream of the flow gauge, and there are a number of irrigators in the Western Rother catchment. Southern Water's 2019 Drought Plan also identifies an import from Portsmouth Water near to the Pulborough source as a supply-side drought option.

### D.1.1. Stochastic Drought Generation

The monthly rainfall data were randomly sampled from 1000 replicates to 400, 48-year long runs, resulting in a total of 19,200 years' worth of stochastic data. The Q-Q (quantile-quantile) plots in Figure 5-24 presents the stochastic (both before and after the random sampling) and observed rainfall data, over 3 consecutive hydrological years; the red dots along the red line are observations prior to 1950. As shown, the sampling does not have a discernible impact on the range and mean suggesting it is representative of the full stochastic dataset. The sampled monthly rainfall dataset was used to produce the daily rainfall and PET datasets using the daily resampling process.

One of the stochastic rainfall sites in the WRSE stochastic weather generator is Hardham rainfall gauge site. Therefore, this site's data was assumed to represent the Western Rother catchment's climatology and taken directly into the hydrological catchment model, with no further catchment averaging or transposing required.

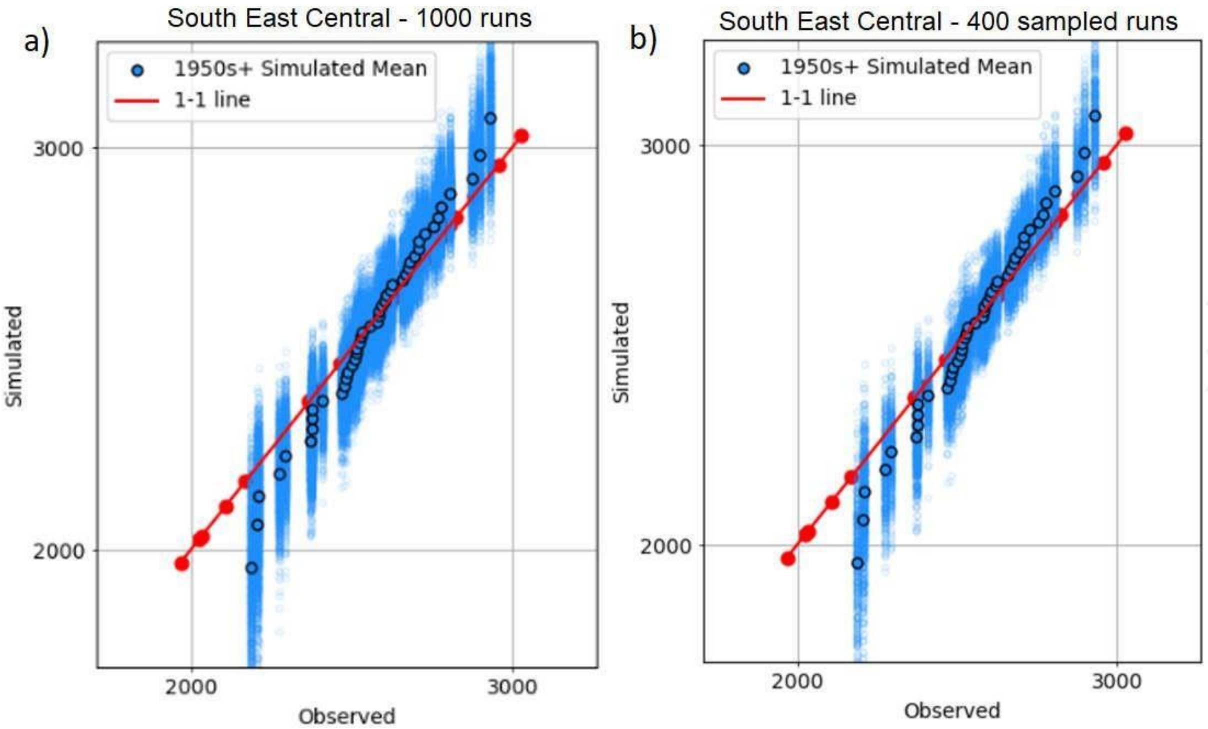



**Figure 5-24 - Q-Q plots for South East Central WRSE sub-regional rainfall (3 hydrological years). (a) 1000 runs before random sampling, (b) 400 runs after random sampling.**

### D.1.2. Hydrological modelling

Southern Water has an existing, calibrated Catchmod rainfall-runoff model for the Western Rother catchment at Hardham. Catchmod model was not calibrated based on HadUK data. However, as shown in

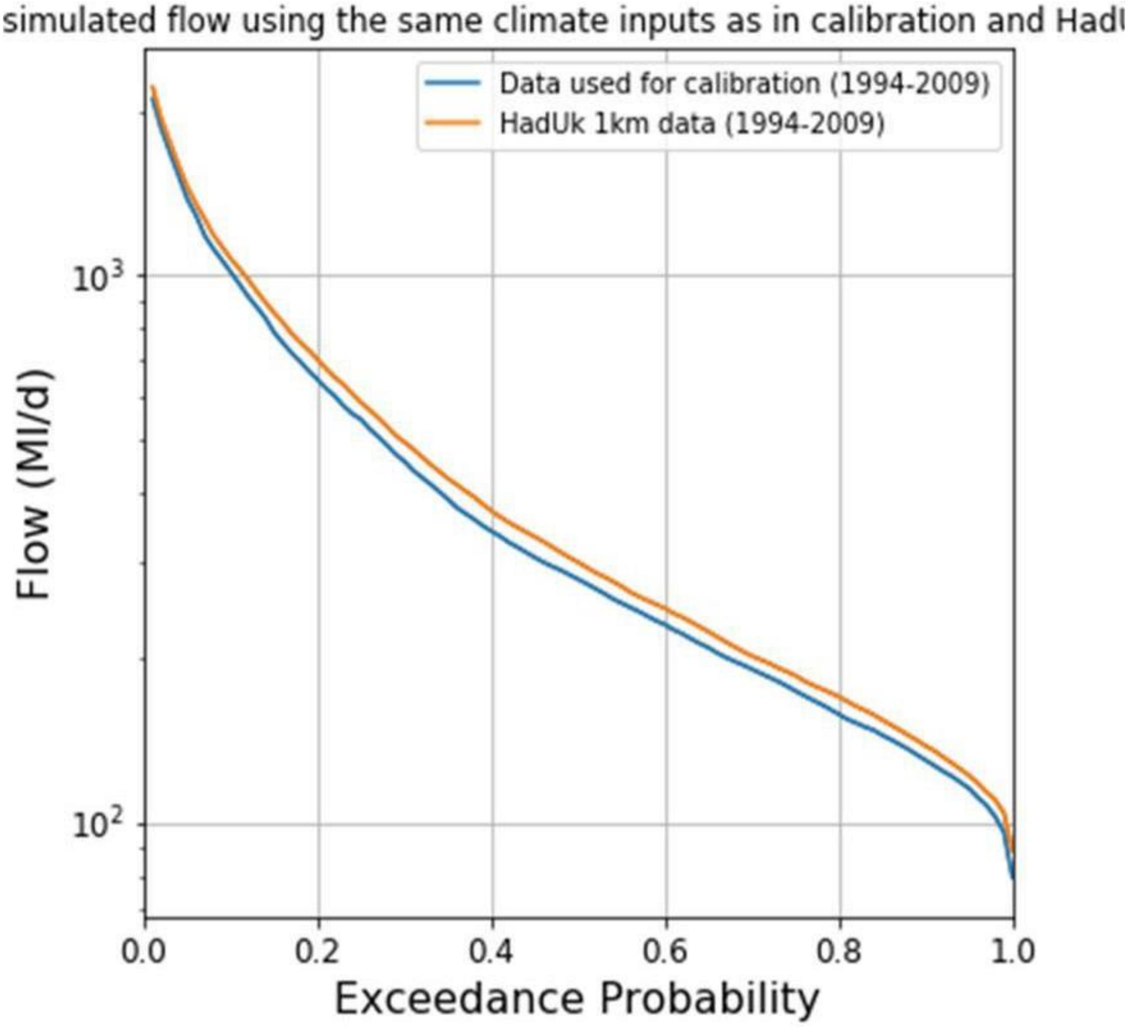



Figure 5-25, the flows derived using the same input data used for Catchmod's calibration are similar to the simulated flows derived using HadUK data as input[39] For this reason, no further calibration of the Western Rother Catchmod model was undertaken.

[39] HadUK 1 km precipitation data averaged over the catchment was used, and PET was derived using the Oudin formula based on HadUK 1 km maximum and minimum temperature averaged over the catchment. The average between maximum and minimum temperature was used.

simulate

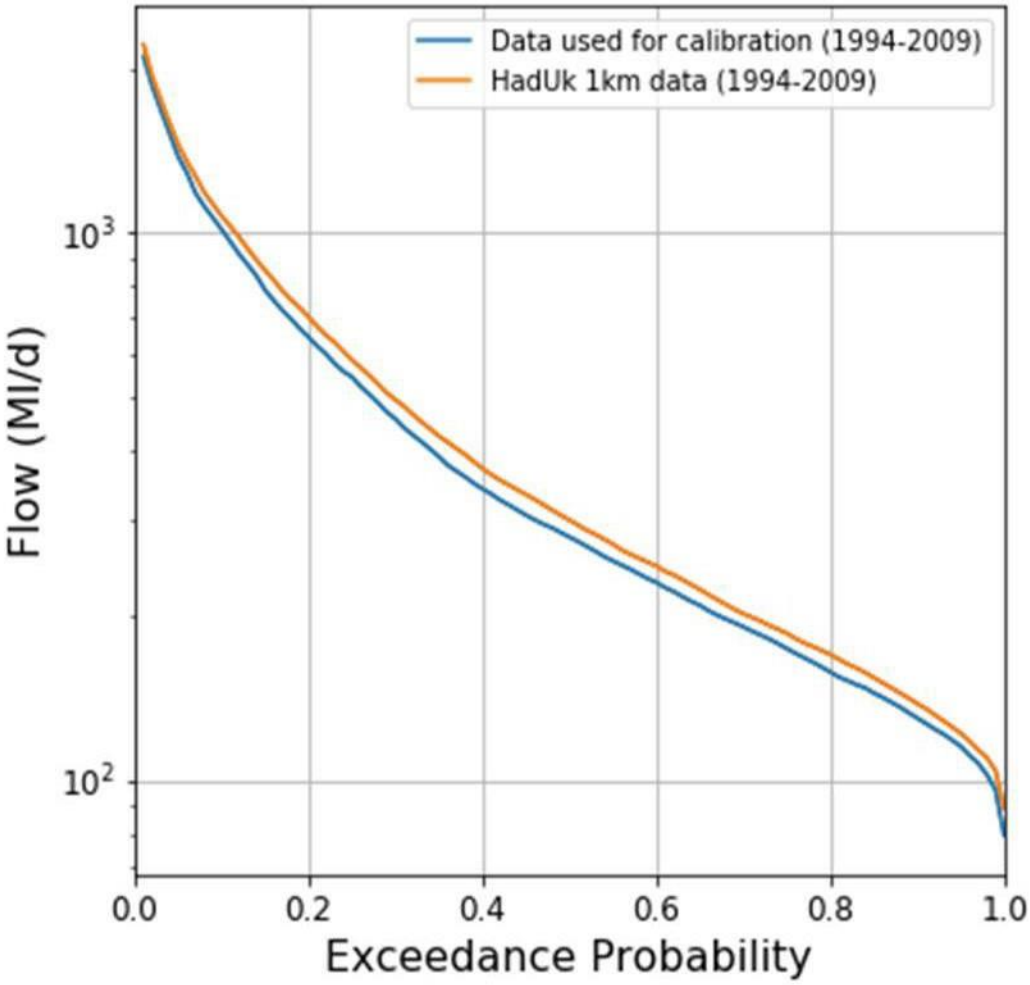



**Figure 5-25 – Simulated flows using the same data used by the water company to calibrate Catchment and using HadUK data**

This model was used to simulate flow based on the stochastic precipitation (P) and PET data. Figure 5-26 presents flow duration curves (FDC) for the sampled 400 stochastic data timeseries against the simulated flow using HadUK data There is noticeable variability between the 400 FDCs; the difference is greatest at higher exceedance probabilities, associated with low flows This shows that the FDCs for HadUK data lies within the range of stochastic flow series' FDCs, however its position within the range does vary at different exceedance probabilities. For example, between 80% and 95% exceedance probabilities (equivalent to low to very low flows), the HadUK FDC lies very close to the lowest stochastic FDCs.

The differences between flows modelled using the observed HadUK data and the 400 stochastic datasets are also presented in Figure 5-27. The median extreme low flows (95% exceedance probability) are less extreme than those produced from the HadUK data (+4%), however, as shown the stochastic data provides a large range of flows to test the Hardham system. The variability/range in the 400 stochastic replicates increases as the exceedance probability increases (as flows decrease).

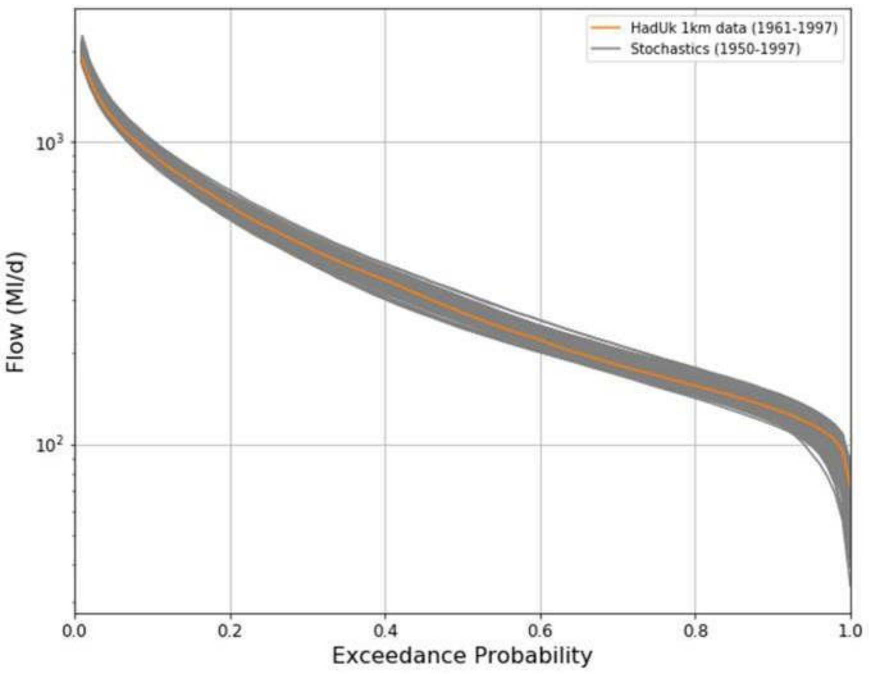



**Figure 5-26 - Hardham flow duration curves for stochastically generated flow**

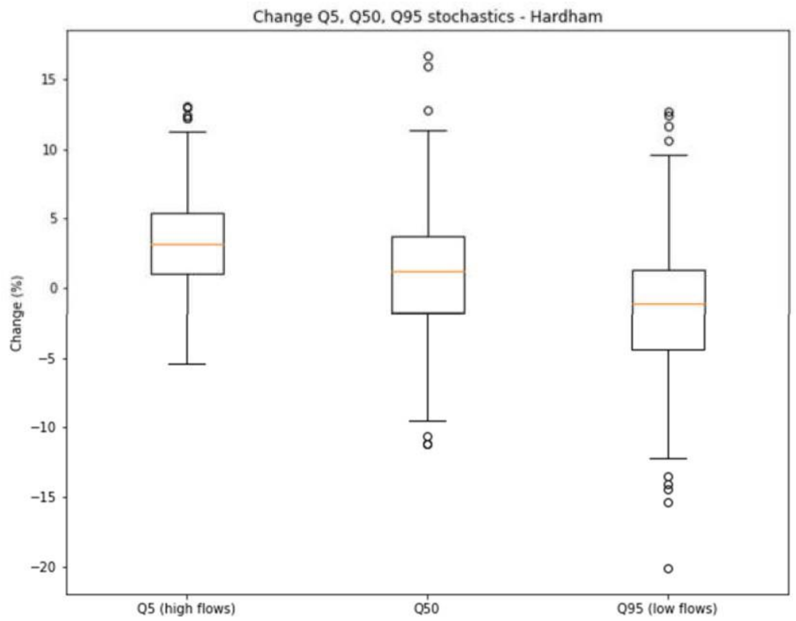



**Figure 5-27 - Percentage differences between flows at Hardham calculated using observed HadUK and those calculated using stochastic weather data (Q5: extreme high flows, Q50: median flows, Q95: extreme low flows)**

### D.1.3. Climate change scenarios

To consider the vulnerability of regional water resources to climate change, companies are likely to either perturb the stochastic time series with climate change factors or run future climate change time series through their system. There are a number of UKCP18 products that could be used for perturbing the stochastic data. As part of this project we have provided processed climate change products for each region and all river basins requested by regional groups.

To compare the impact of choice of climate model on river flows at Hardham, climate change factors were applied to the HadUK baseline (1981-2000) data. The climate change data tested is presented in Table 5-8.

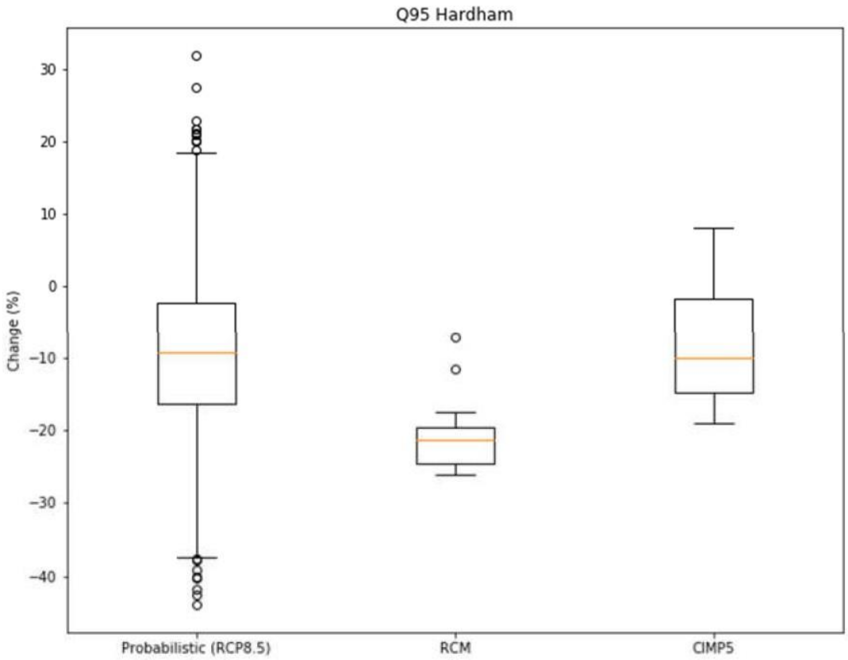
**Table 5-8 - Climate change datasets applied in Hardham case study**

| Data set | Further detail | Application |
|---|---|---|
| UKCP18 RCM (bias-corrected) factors – RCP8.5 | 12 bias corrected RCM RCP8.5. P, T and PET change factors to apply to stochastic data sets, to create stochastics *plus* climate change. Factors for the 2060-2080 period. | Climate change risk assessment. |
| UKCP probabilistic – RCP8.5 | 3000 climate change factors for P and T for the 2060-2080 period. Factors produced for the whole England and Wales area. | The 3000 factors provide a broader context to the 13 RCM data sets. |
| UKCP probabilistic – A1B scenario | 3000 climate change factors for P and T for the 2060-2080 period. Factors produced for the whole England and Wales area. | The 3000 factors provide a broader context to the 13 RCM data sets. The A1B scenario was commonly adopted for climate change planning when UKCP09 data was used. It has been reproduced in UKCP18 for comparison with the new pathways approach. |
| UKCP Global Coupled Model Inter-comparison Project (CMIP5) – RCP8.5 | 13 climate change factors for P and T for RCP8.5 for the 2060-2080 period. Factors produced for the whole England and Wales area. | CMIP5 data provide a broader context and wider range of possible outcomes. |

The section below presents a summary of the percentage change in flows, with climate change under RCP8.5, in the Western Rother at Hardham for the probabilistic, RCM and CMIP5 projections. As shown, all climate models project lower flows in the future as a result of climate change. The probabilistic data cover the full range of uncertainty captured by both the bias corrected RCMs and the CMIP5 projections.

The probabilistic projections suggest the change in flow could range from no change to a maximum decrease of approximately 75%, with an approximate median decrease of 37%. The RCM and CMIP5 provide fewer climate model ensembles than the probabilistic which is reflected in the smaller variability of projected flow changes. The RCM and CMIP5 median flow decreases are noticeably different, 55% and 30% respectively. This indicates that the bias-corrected RCM change factors project a more severe impact on river flows under future climate change than the probabilistic projections however, this lies within the range of results projected by the 3000 probabilistic projections.

The comparison of flows at Hardham under different climate change models suggests that any analysis undertaken with RCM data should be contextualised within the range of uncertainty projected by the probabilistic projections.




## D.2. WRE – River Ouse

Water Resources East (WRE) recommended producing a case study on the Great Ouse catchment to Offord, where water is abstracted to supply Grafham Water, as shown in Figure 5-28. This forms part of Anglian Water's integrated Ruthamford network, which consists of Rutland, Grafham and Pitsford Water reservoirs and supplies major towns and cities within the region, including Milton Keynes and Peterborough. The network is also of regional strategic importance, as the reservoirs supply other WRE water companies; water is transferred from Grafham to Affinity Water and from Rutland to Severn Trent Water.

In the previous round of regional planning, WRE used a stochastic weather generator (Atkins, 2018). As part of this project several improvements have been made; the aim of this case study is to test the updated stochastic weather generator, and in particular, the inclusion of additional climate drivers.

### Stochastic drought generator improvements

During WRE Phase 1, Atkins worked with Met Office and the East Atlantic Index (EAI) was added to the climate drivers in the stochastic weather generator. As part of this study two additional teleconnections have also been added to the stochastic weather generator, the East Atlantic-West Russian Pattern (EA-WR) and the Scandinavian Pattern (SCAN).

The availability and quality of teleconnection data for EA-WR and SCAN prior to 1950 is significantly poorer than that in the second half of the century. So as explained in the main report, the length of the output time series from the generator is 48 years (1950-1997), compared to 91 years (1900-1990), as produced using the previous stochastic weather generator in WRE Phase 1.

To enable comparison to the previous work, the stochastic data generated for this case study is for the same points as before, using HadUK 1km precipitation and MORECS PET data. The main differences are:

- The stochastic model (including the updated bias correction process) and length of output time series, and
- The use of HadUK 1km rather than CEH GEAR rainfall.

Therefore, in order to identify how changes made to the stochastic weather generation process affect climate and river flow outputs, this case study has two different strands of work:

1. Pinpointing the effect of the new climate drivers on stochastic monthly rainfall generation. In this strand, the only aspect of the stochastic weather generation process that differs between the two model runs is the range of teleconnections (and hence the number and length of each run).
2. Comparing the previous stochastic weather outputs to the new outputs, including how these influence river flow. In this strand, various aspects of the stochastic weather generator have changed, as well as the inclusion of additional teleconnections.

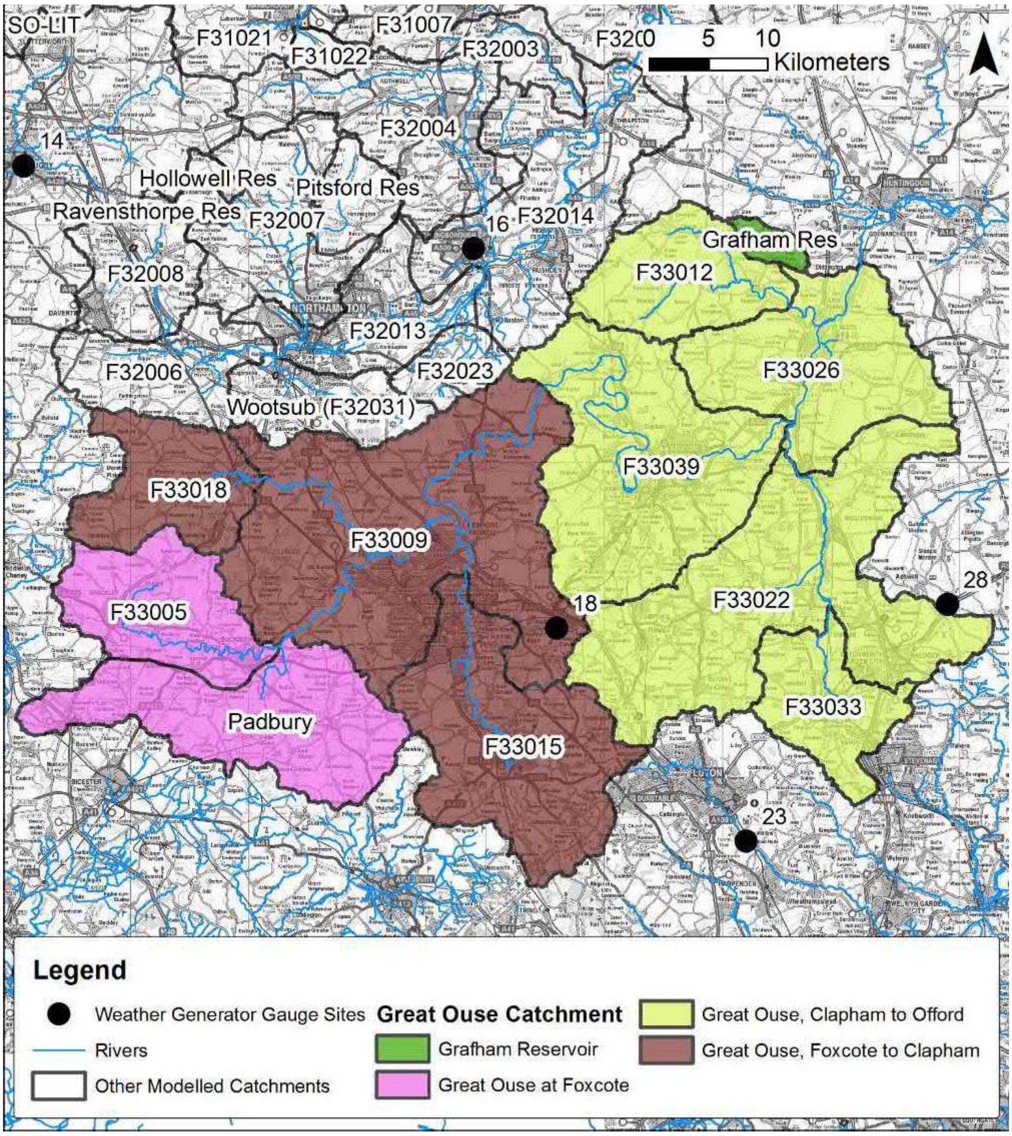



**Figure 5-28 - Great Ouse to Offord catchment**

## The effect of additional climate drivers

The two stochastic weather generator models were run:

| Model | Historical years | Teleconnections |
|---|---|---|
| 20th Century | 1900 – 1997 | Main effects and interactions between:<br>• Month factor<br>• North Atlantic Oscillation<br>• Sea Surface Temperature<br>• Atlantic Multi-decadal Oscillation<br>• East Atlantic Index |

| | | |
|---|---|---|
| 1950s | 1950 – 1997 | • Main effects and interactions between:<br>• Month factor<br>• North Atlantic Oscillation<br>• Sea Surface Temperature<br>• Atlantic Multidecadal Oscillation<br>• East Atlantic<br>• East Atlantic West Russia<br>• Scandinavia |

The raw outputs of the first stage of the stochastic weather generator have been compared; these are the pre-bias correction monthly rainfall datasets.

The new (1950-1997, referred to as the 1950s+ model) and previous (1900-1997, referred to as the 20th century model) were run through the stochastic weather generator. All other factors were kept constant and the HadUK observed data was used. The HadUK observed data indicates that the first half of the 20th century was drier than the second, hence the 1950s model does not contain some of the key droughts in the 20th century. However, the new stochastic generator using the shorter period performed as well as, or marginally better, against the observed data. For example, the percentile plot in Figure 5-29 shows that the 1950s+ model lies closer to the observed data than the 20th century model.

In many cases where the lowest historical record in the 20th Century was not represented in the 1950s model, the lowest rainfall totals for the 1950s model appeared lower against their equivalent lowest observed value, for example, as presented in Figure 5-29. This effectively covers the range that would have been represented within the 20th century model. Therefore, this indicates using a shorter period of observed data does not prevent the stochastic weather generator from producing very extreme low rainfall patterns, thus supporting the use of the 1950s+ model and that including additional climate drivers improves the stochastic climate datasets.

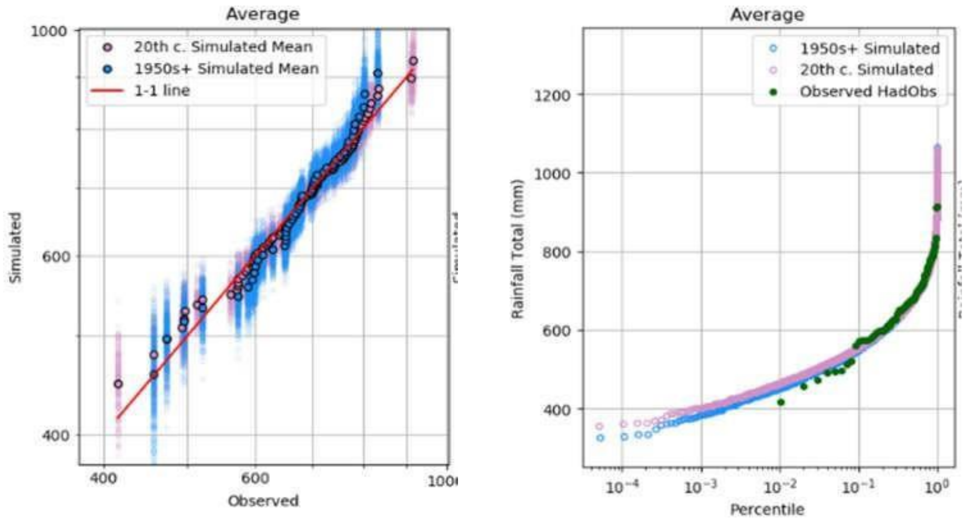



**Figure 5-29 - Q-Q (left) and percentile (right) plots for WRE region comparing stochastic monthly rainfall produced using 20th century and 1950s+ periods**

## The effect of input data

Figure 5-30 presents a comparison of the two input weather datasets; this indicates that the average and range of rainfall values that were used in the new (HadUK) and old (GEAR) stochastic weather generator are very similar. For example, the median monthly rainfall across the region is 51.8 mm from the HadUK dataset and 51.4 mm from the GEAR dataset. This suggests that the choice of input climate dataset has a limited impact on the stochastic weather datasets, and that much of the difference would arise from the other updates to the stochastic weather generator model.

The new WRE stochastic weather generator produces 1000, 48-year long series of monthly rainfall data. The bias correction process has also been updated in the new stochastic weather generator, to limit the adjustment as much as possible and ground it in probabilistic methods. This is explained in more detail within the main report. The new bias correction technique was applied at a sub-regional scale to improve the fit between simulated and HadUK observed monthly rainfall; this includes HadUK observations prior to 1950, to somewhat account for the more extreme droughts observed in the first half of the 20th century. Figure 5-31 shows the sub-regional stochastic and observed rainfall for the hydrological year; the Central and South sub-regions are the focus of this case study, as the five gauges used for the Great Ouse catchment sit within these regions. This is comparable to Figure 5-32, the same plot produced in the previous WRE regional planning phase (Atkins, 2018). The differences indicate that the new stochastic weather generator achieves its aim of reducing the extent of bias correction, which is particularly evident in the Central region.

The Q-Q (quantile-quantile) plot in Figure 5-33 presents the range and mean of the stochastic data, along with the observed total rainfall over 3 consecutive hydrological years; the red dots indicate observations prior to 1950. While the lowest ranked simulated data for both South and Central sub-regions deviate from the observed, the range covered by the simulated data takes account of the lowest observed point in the record prior to 1950. This indicates that the stochastic dataset includes droughts of magnitudes exceeding those in the historical record.

The monthly rainfall data was randomly sampled from 1000 to 400, 48-year long runs. The sampled dataset was used to produce the daily rainfall and PET datasets using the daily resampling process. This was of equivalent length to the daily rainfall and PET datasets previously produced using the former weather generator adopted by Anglian Water in PR19.

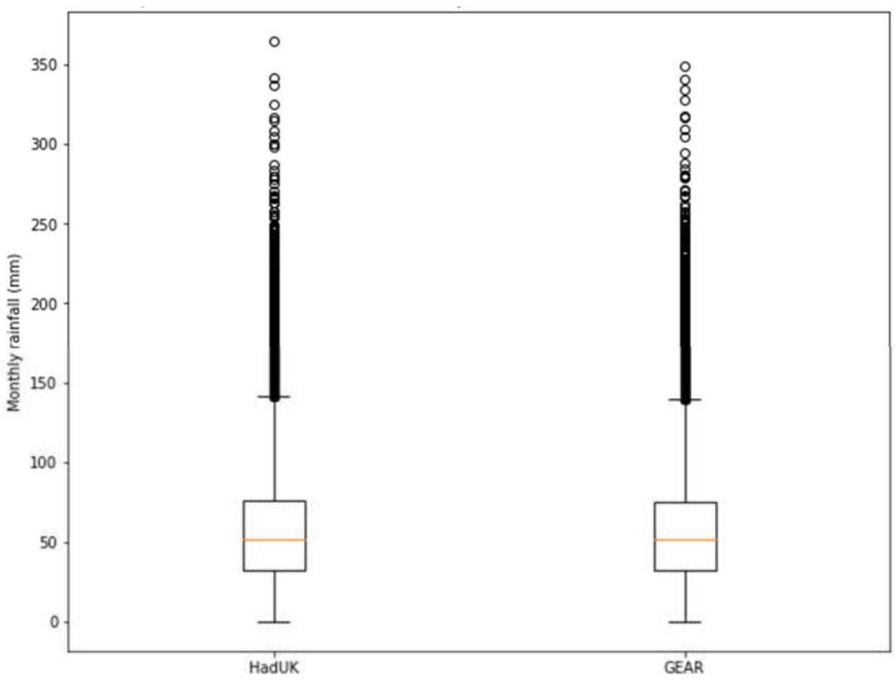



**Figure 5-30 - Comparison of HadUK (1900-1997) and GEAR (1900-1990) monthly rainfall data across all WRE stochastic sites**

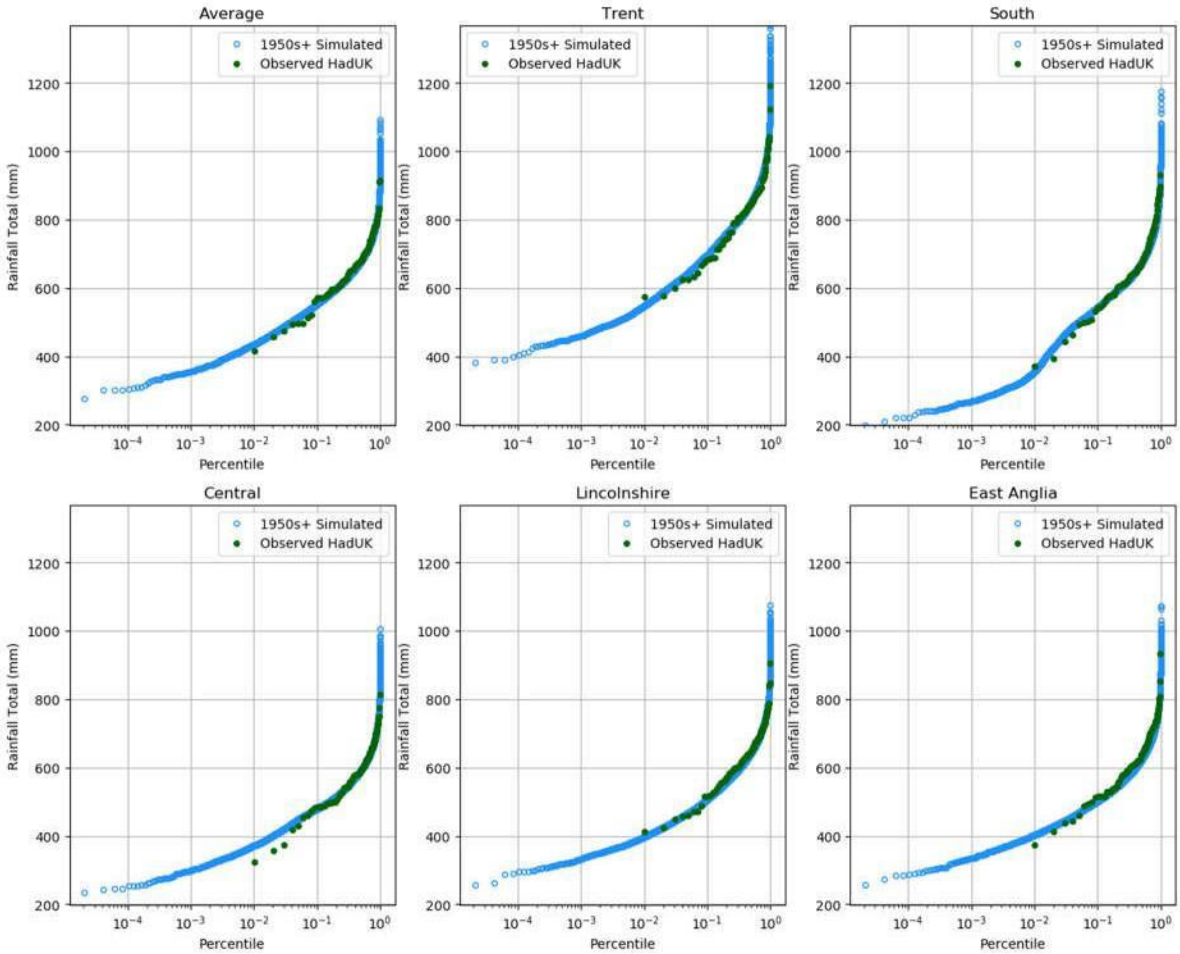



**Figure 5-31 - Updated WRE total sub-regional rainfall for hydrological year**

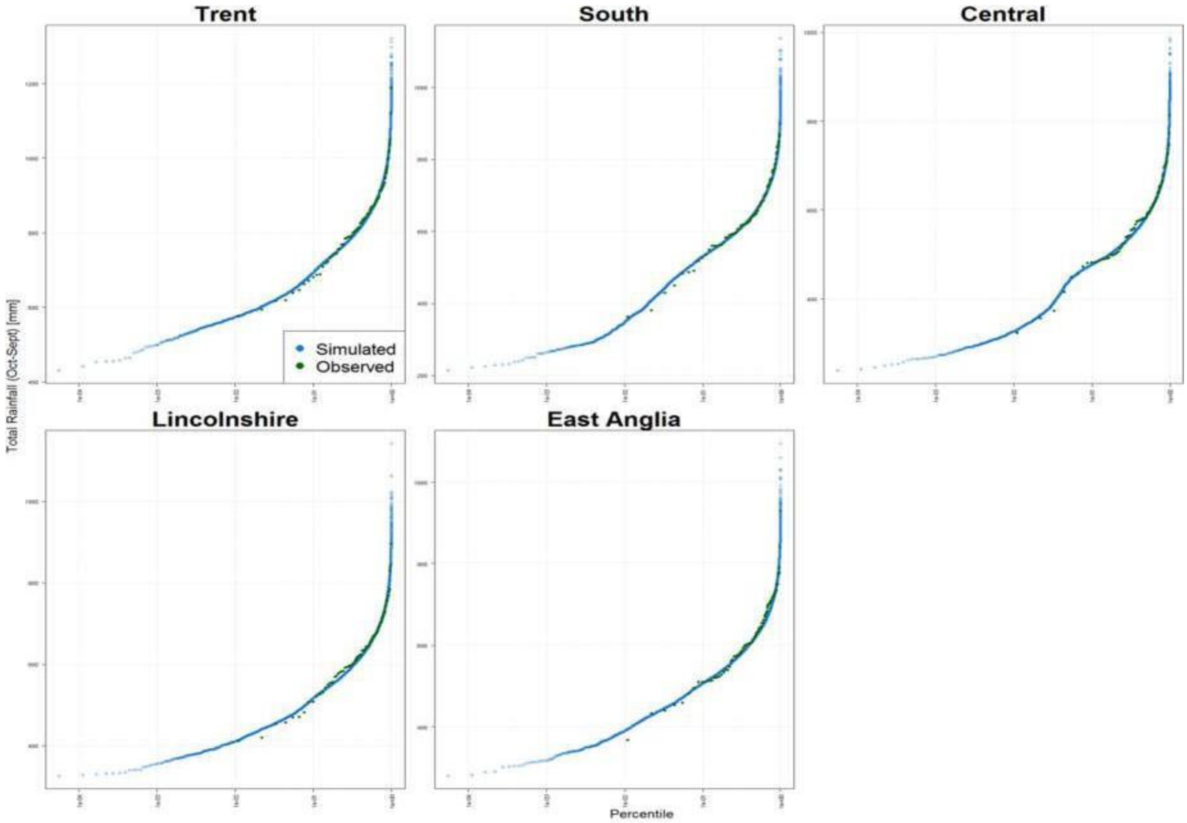



**Figure 5-32 - WRE total sub-regional rainfall for hydrological year produced using previous stochastic weather generator [1]**

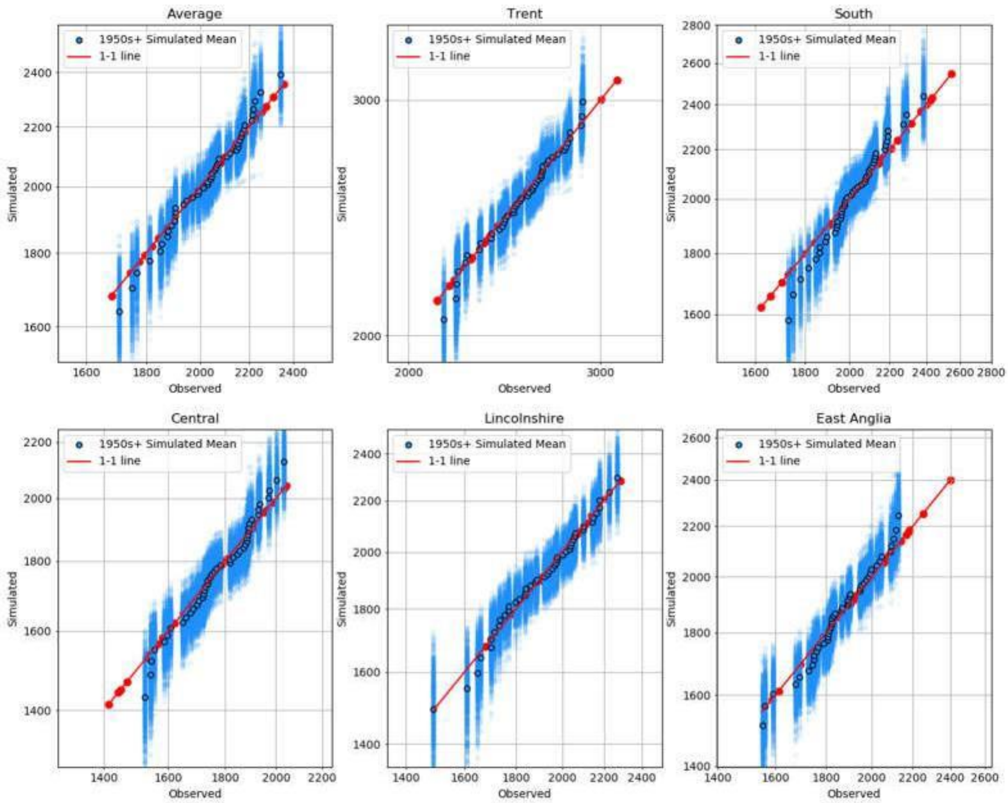



**Figure 5-33 - Q-Q plot for WRE sub-regional rainfall (3 hydrological years)**

## Impact on flows

Hydrological modelling for the Great Ouse catchment was undertaken using the Stanford Watershed Model (SWM). Both the new and old stochastic weather datasets were used to model river flows at Offord, as well as historic rainfall (GEAR) and PET time series. The catchment was split into 11 sub-catchments, with one rainfall site and PET square assigned to each sub-catchment; the rainfall data was then scaled to the catchments using pre-defined factors, as in WRE Phase 1. (Atkins, 2018).

The flow duration curves for river flow at Offord derived using the historic and stochastic climate datasets are presented in Figure 5-34. Figure 5-35 presents flow series for Q50, Q70 and Q95, comparing the new and old stochastic flow, as well as historic flow data at Offord. The historic flow data presented shows that flows in the 1950-1997 period are higher than in the 1918-1990 and 1918-2015 periods, particularly for the extreme low flows. For the Q95 flow percentile (extreme low flows), the median flow across the 400 stochastic runs is higher for the new stochastic dataset than for the old stochastic dataset (approximately 200 Ml/d compared to 195 Ml/d). However, the range of flows is greater for the new stochastics, and the lower whisker extends further, with a minimum flow of approximately 145 Ml/d, compared to approximately 165 Ml/d for the old stochastics dataset. Therefore, the new stochastic data provides a greater range of low flows to test the WRE system; this should be taken into consideration when defining design droughts.

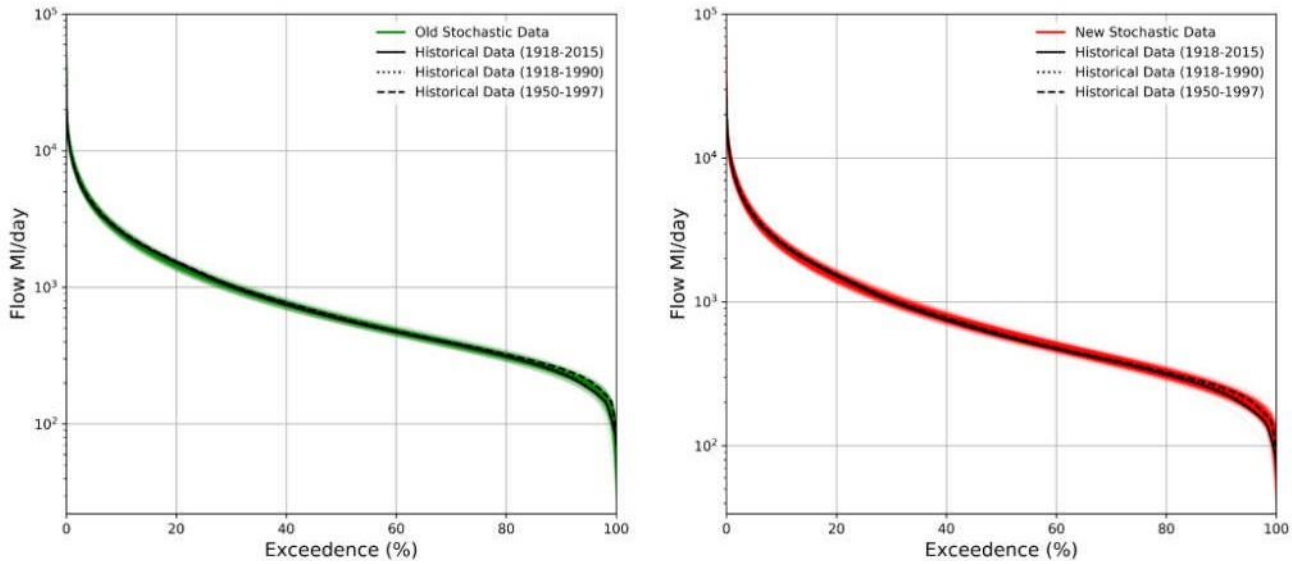



**Figure 5-34 - Flow duration curves for stochastic series compared against historical data**

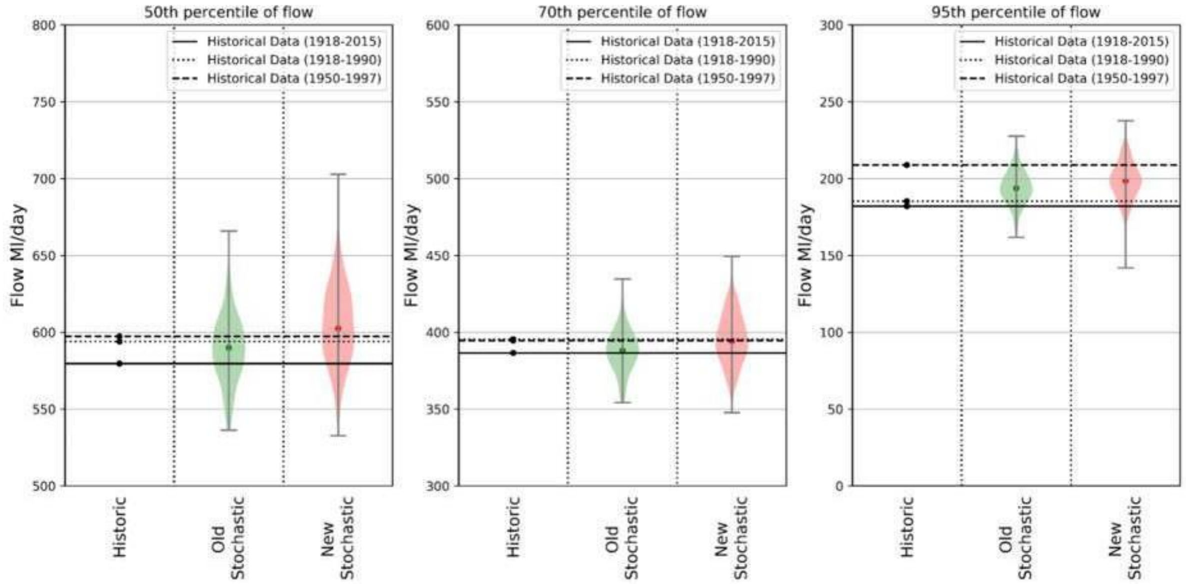



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**Figure 5-35 - Flow statistics for stochastic series compared against historical data**

# D.3. WRW

To follow.

# D.4. WCWRG –Ashton Farm and Wimbleball

## D.4.1. Introduction

West Country Regional Group recommended the Ashton Farm and Wimbleball catchments as their case study locations. Ashton Farm is a groundwater catchment comprising of Dorset Chalk. Wimbleball is a surface water catchment located on Exmoor and faces a number of pressures as it is an area of intense agriculture and is an important water supply for many parts of Devon and Somerset.

For this case study the stochastic generated flows were perturbed by climate change model projections from a range of UKCP18 products to compare the impact on groundwater levels and help inform regional groups decisions around which product/s to apply for their assessment of future drought under climate change.

## D.4.2. Hydrological modelling

Table XX summarises the climate data that was applied to the stochastic data for hydrological modelling for this case study. UKCP18 projections are based on Representative Concentration Pathways (RCPs) rather than the Special Report on Emissions Scenarios (SRES) used in UKCP09. However, UKCP18 provides projections for A1B to enable direct comparison.

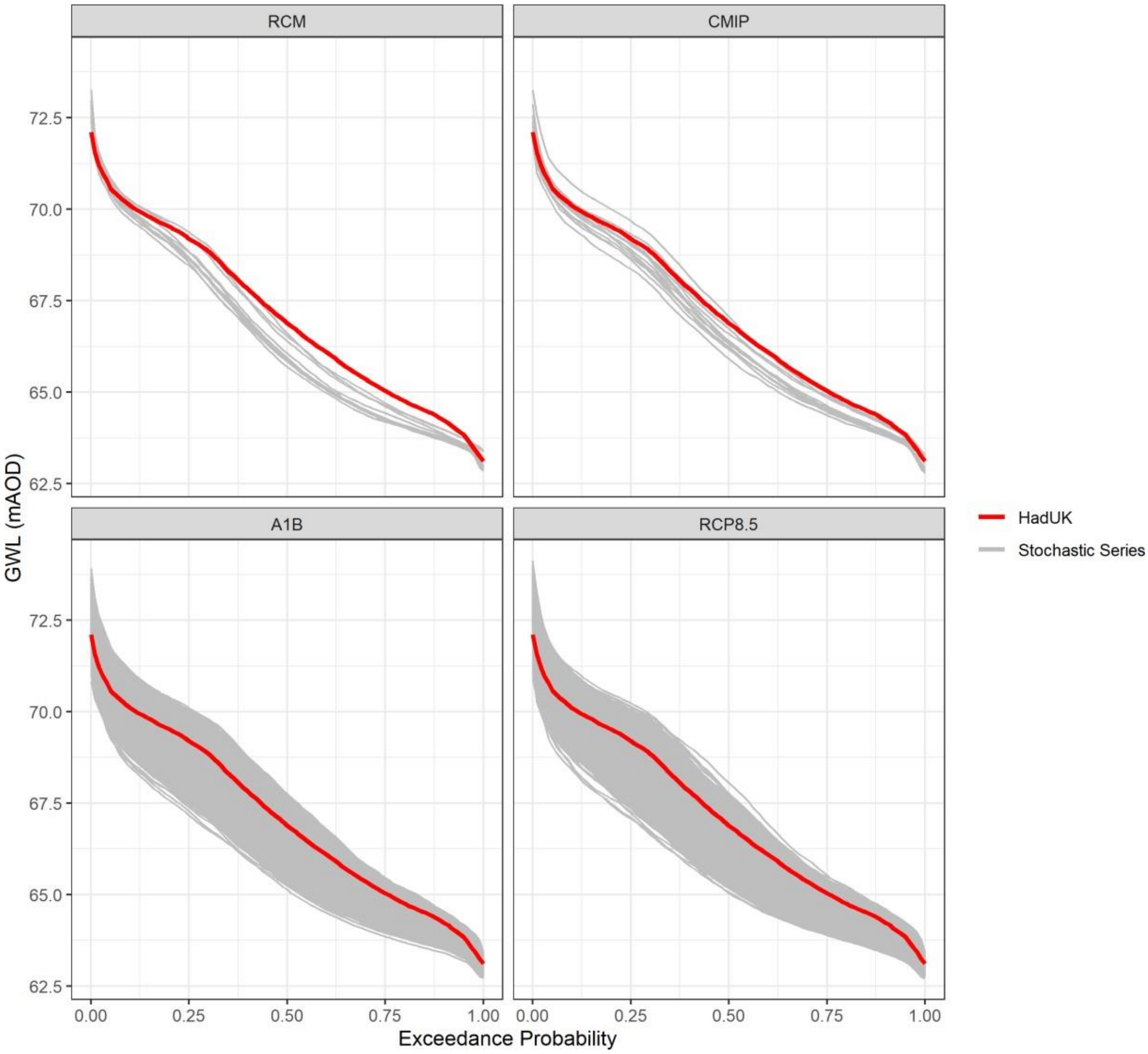
**Table 5-9 - Climate change datasets applied in WCWRG case study**

| Data set | Further detail | Application |
|---|---|---|
| UKCP18 RCM (bias-corrected) factors – RCP8.5 | 12 bias corrected RCM RCP8.5. P, T and PET change factors to apply to stochastic data sets, to create stochastics *plus* climate change. Factors for the 2060-2080 period. | Climate change risk assessment. |
| UKCP probabilistic – RCP8.5 | 3000 climate change factors for P and T for the 2060-2080 period. Factors produced for the whole England and Wales area. | The 3000 factors provide a broader context to the 13 RCM data sets. |

| | | |
|---|---|---|
| UKCP probabilistic – A1B scenario | 3000 climate change factors for P and T for the 2060-2080 period. Factors produced for the whole England and Wales area. | The 3000 factors provide a broader context to the 13 RCM data sets. The A1B scenario was commonly adopted for climate change planning when UKCP09 data was used. It has been reproduced in UKCP18 for comparison with the new pathways approach. |
| UKCP Global Coupled Model Inter-comparison Project (CMIP5) – RCP8.5 | 13 climate change factors for P and T for RCP8.5 for the 2060-2080 period. Factors produced for the whole England and Wales area. | CMIP5 data provide a broader context and wider range of possible outcomes. |

Figure X and Figure X show that for all climate models, groundwater levels at Ashton Farm are projected to decrease, relative to the HadUK 1981-2000 baseline period, for both Q50 and Q95. Probabilistic projections for both A1B and RCP8.5 were modelled. The results suggest that probabilistic projections for RCP8.5 and A1B predict similar future groundwater levels (median changes of less than +/- 1%) with a slightly greater range of future groundwater levels projected under RCP8.5.

The RCM projections, under RCP8.5, project greater decreases in median groundwater levels than the probabilistic projections with -1.5% decrease in Q50 levels. However, as expected, the range of projected changes for the 12 RCMs and 13 CMIP5 models are narrower than projected by the 3000 probabilistic predictions for all flows (Q). This suggests that to understand the full range of potential future groundwater levels the RCMs should be contextualised within the full range of probabilistic projections.



RCM
CMIP
A1B
RCP8.5
72.5
70.0
67.5
65.0
62.5
GWL (mAOD)
0.00
0.25
0.50
0.75
1.00
Exceedance Probability
HadUK
Stochastic Series

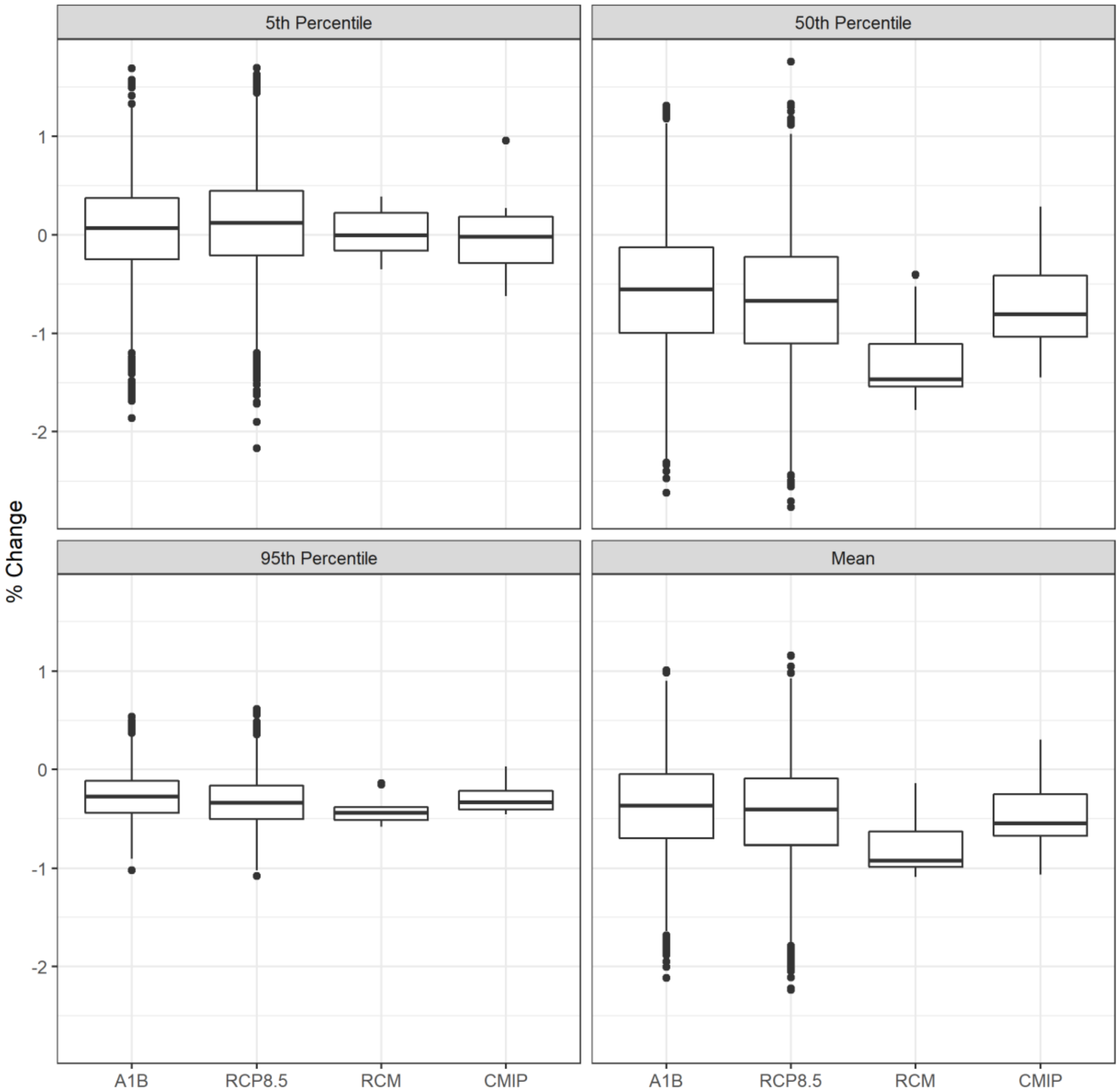
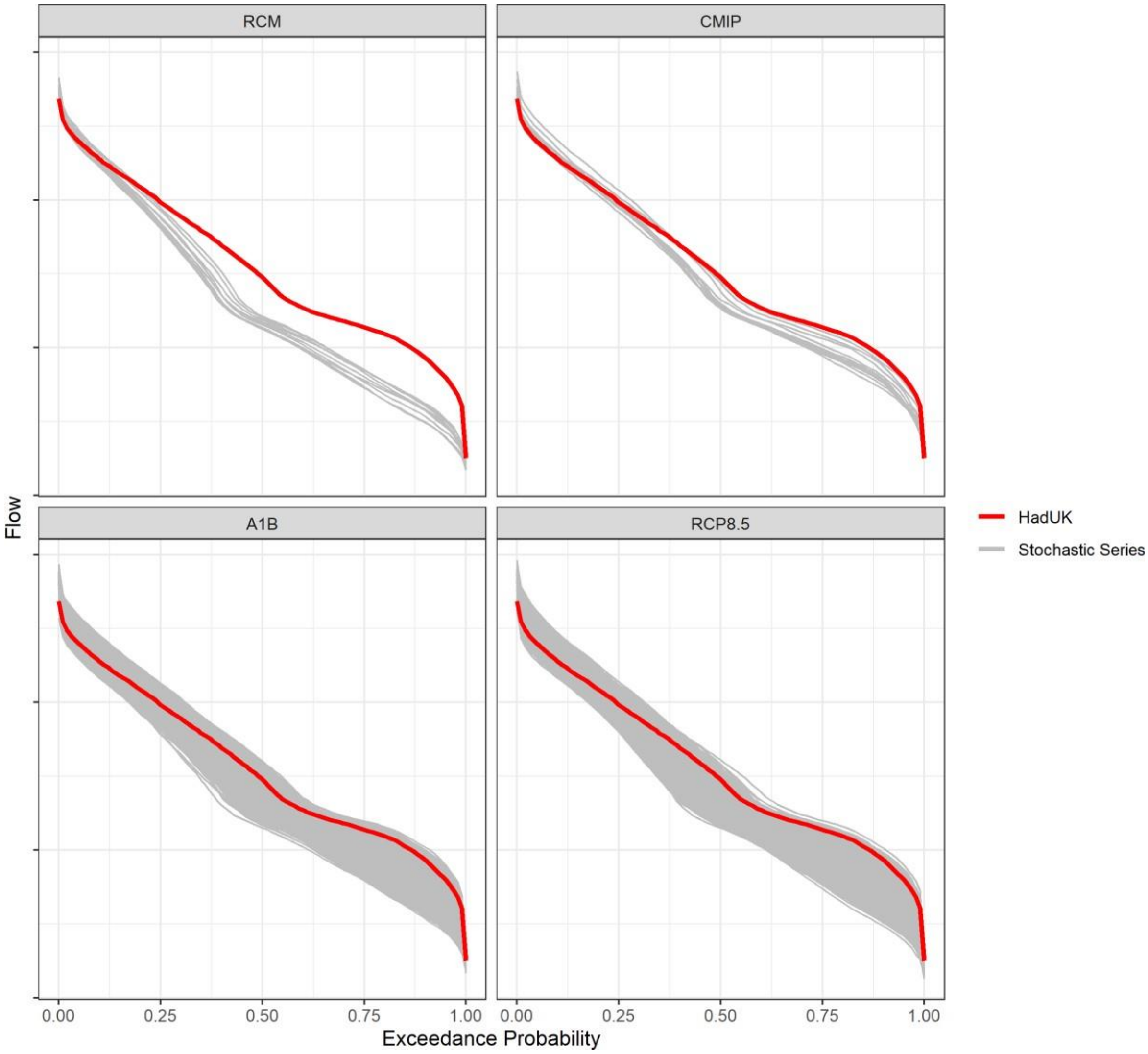
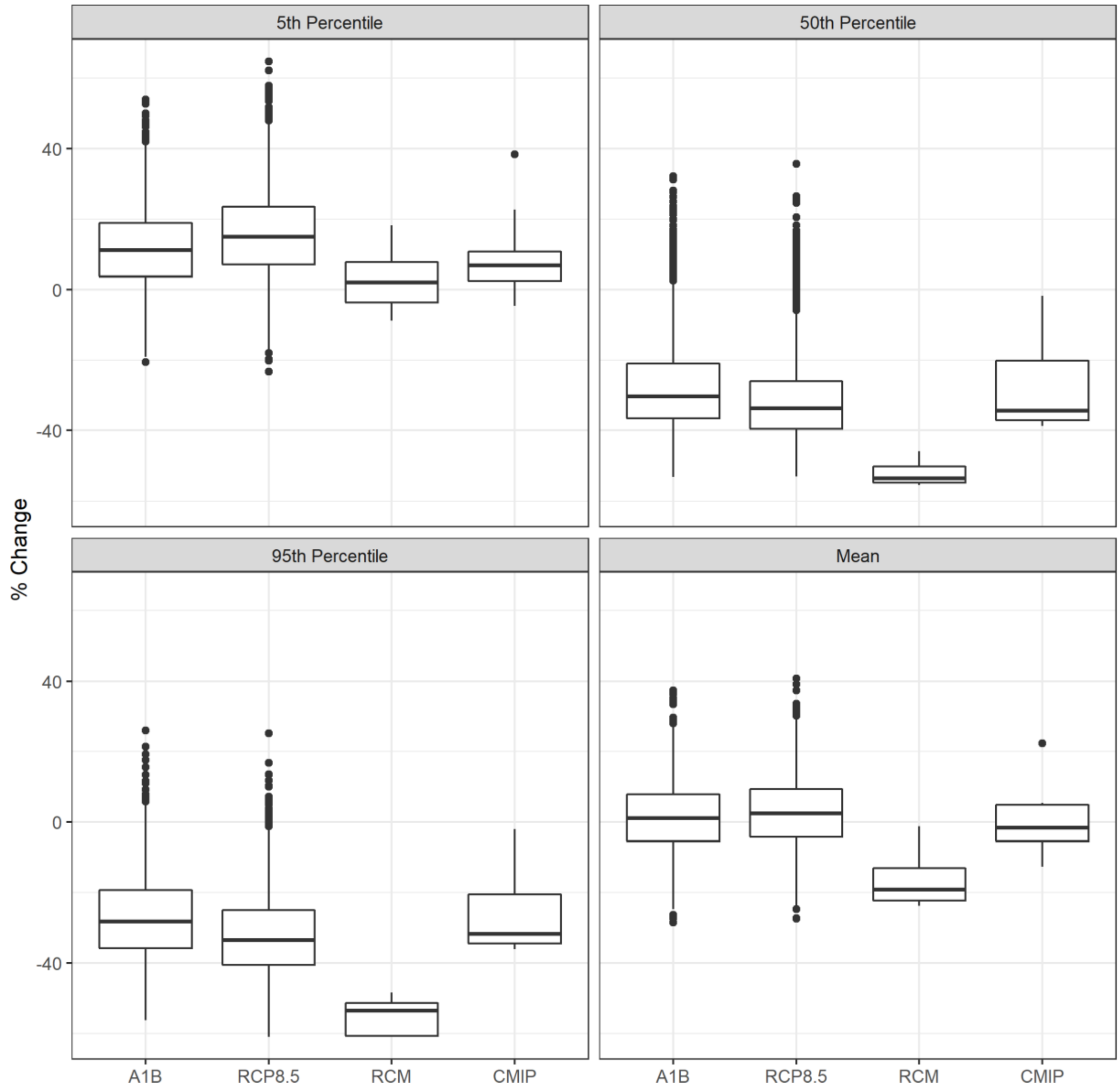



Figure X shows that for all climate models, low flows (where the exceedance probability <50%) at Wimbleball are projected to decrease, relative to the HadUK 1981-2000 baseline period. As shown in Figure X, the Probabilistic RCP8.5 and A1B results show the broadest range of percentage change to flows, ranging between approximately -50% and +30% with a median of approximately +35%. For Q5 the median projected changes are greater under RCP8.5 than A1B whereas for Q95 the median flows are lower for RCP8.5 than A1B.

Given the smaller number of change factors, the variability in flow changes for both the 12 RCMs and 13 GCM CMIP change factors are much narrower than those projected by the probabilistic models, particularly for the 95th percentile flows where the full range of flows sits below the median of the probabilistic projected flows. Again, this highlights that to understand the full range of potential future flow levels the RCMs should be contextualised within the full range of probabilistic projections.


RCM
CMIP
A1B
RCP8.5
Flow
0.00
0.25
0.50
0.75
1.00
Exceedance Probability
HadUK
Stochastic Series




## D.5. WReN – Langsett

This case study focuses on the Langsett catchment, which is defined as the Little Don catchment draining to Underbank Reservoir.. The catchment is located in the north-east limit of the Peak District National Park, and has three Yorkshire Water reservoirs: Langsett, Midhope and Underbank reservoirs. Langsett and Midhope reservoirs are used for water storage, and the downstream Underbank reservoir releases compensation flow to the Little Don River [3]. Therefore, Langsett and Midhope reservoirs moderate the magnitude of flow downstream, causing a lower than expected baseflow, with the timing and magnitude of autumn/winter high flows dependent on reservoir levels rather than directly following heavy rainfall events. The Little Don reservoirs are important for Yorkshire Water to provide water to the city of Sheffield and the town of Barnsley.

The catchment is steep, and thus has a flashy response to rainfall events. Runoff in the catchment is influenced by the three reservoirs, public water supply abstraction and regulation from surface and groundwater. Flow was measured at the catchment outlet downstream of Underbank Reservoir between 1956 and 1980 (National River Flow Archive, 2020).

(to be completed)

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# Method Statement: Regional System Simulation Model

November 2022

| Title | Method Statement: Regional System Simulation Model |
|---|---|
| **Last updated** | November 2022 |
| **Version** | Draft regional plan version |
| **History of changes made to this version** | June 2020 – First written draft<br>July 2020 – Changes made after technical working group comments, PMB comments, and QA review comments<br>August 2021 – Change made following consultation responses<br>November 2022 – draft regional plan version |
| **Author** | Peter Blair |
| **Approved by** | Meyrick Gough |
| **WRSE Director approval** | Meyrick Gough |


# Email: contact@wrse.org.uk


For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2075.

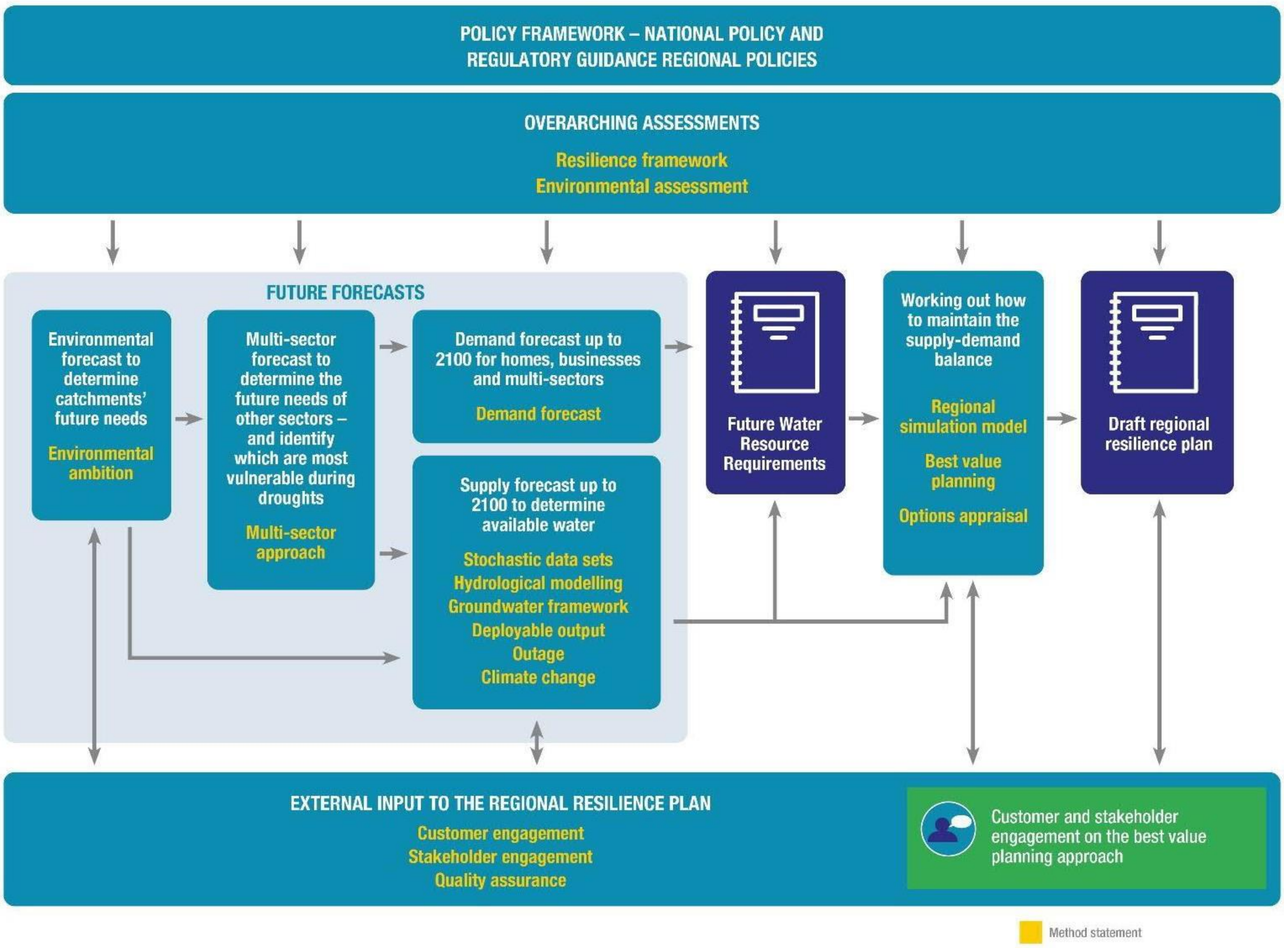
We have prepared Method Statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this regional system simulator Method Statement will contribute to the preparation process for the regional resilience plan.

The regional simulation model will provide many of the outputs required for WRSE's supply forecast, including deployable output and climate change impacts, as well as the supply benefit that different options may bring. These outputs will feed into the WRSE investment model.

The regional simulation model will also later be used to test portfolios of options, in order to test whether options selected by the investment model (both on the demand side and the supply side) bring the outcomes that are anticipated when brought together.

**Figure ES1: Overview of the Method Statements and their role in the development of the WRSE regional resilience plan**



# 1 Introduction

1.1 Simulation models are used in water resources planning to assess the supply capability of water resource systems, to assess the implications of drought for customers and the environment, and to examine the impacts that future changes and interventions may have on water resources systems and the environment. These models provide many key outputs which drive investment through the Water Resource Management Plan (WRMP) process. Simulation models are also often applied in a more operational capacity, forecasting implications that dry weather could have on available water resources, and so guiding operational responses.

1.2 For the regional plan to be most easily translated into WRMPs for water companies, outputs should be compatible with the requirements of the Water Resources Planning Guideline and suitable as inputs to water resource planning tables. As such, WRSE supply forecasting methods will be developed to be compliant with guidance and analysis will be undertaken on a water resource zone (WRZ) level.

1.3 Figure 1 is a flow chart showing an RSS-centric view of WRSE modelling that is being undertaken. This flowchart should also be read in conjunction with the **Method Statement 1318 WRSE Best Value Planning** which also references the iterative nature of testing the outputs from the investment model back into the regional simulation model.

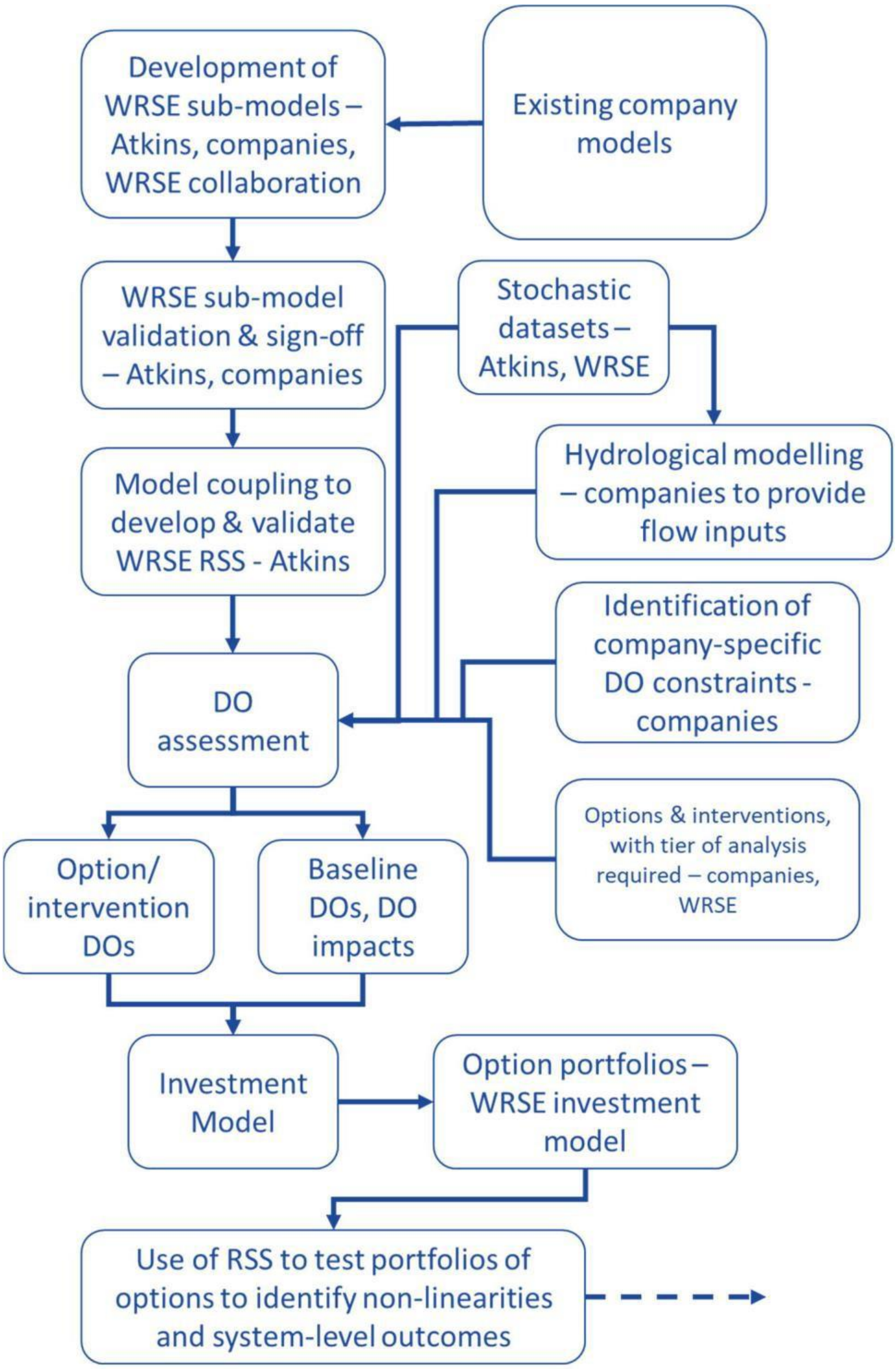
1.4 This Method Statement contains the following sections:

a. Uses for the RSS model

b. Development and validation of model(s)

c. Inputs & datasets used in the model.

**Figure 1: A view of the WRSE modelling process, centred around the regional system simulator**



# 2 Methods and approach

## Uses for the Regional System Simulation Model

2.1 The Regional System Simulation (RSS) will have three primary stages of use. The model will initially be used to produce 'traditional' water resources outputs (Deployable Output (DO) assessments of existing sources, option/scheme DO benefits, and potential impacts on DO of uncertain future changes such as climate change and licence changes) which will be used as inputs for the investment model and which will be compatible with water resource plan table requirements. The second stage will use different scenarios to test the performance of WRSE's regional plan, to see whether portfolios of options deliver outcomes as expected. The third stage of the model will be to help explore the spatial stress points in the region in order to inform and test enhanced intra-regional transfers in the South East. These potential options will be passed through the options appraisal workstream

2.2 The first stage of model use involves using the model to produce values to feed into the WRSE Investment Model and water resource planning tables. Specifically, outputs to be produced by the RSS model are:

a. Baseline deployable output (**Method Statement 1320 WRSE Deployable Output**)

b. Impact of climate change on deployable output (**Method Statement 1335 WRSE Climate Change Supply Side Methods**)

c. Assessment of DO benefit/disbenefit of sustainability reductions, water resource options and transfers (**Method Statement 1320 WRSE Deployable Output**).

2.3 Each item listed has a specific Method Statement associated with it. These methodologies are not replicated here. These items will be combined with an assessment of outage allowances (**Method Statement 1323 WRSE Outage**) , raw water losses and treatment works losses (in some cases treatment losses may be considered implicitly within DO assessments) to form a forecast of Water Available for Use (WAFU).

2.4 The second stage of model use involves taking outputs from the 'Investment Model' and testing portfolios of interventions suggested by this model to determine overall impacts on system performance. This will test whether the additive assumptions which are implicit in investment modelling hold, and so whether the outcomes for customers match those expected.

## Development and validation of model(s)

2.5 The RSS model is being built with high aspirations in mind. The aim for the model is that it is a sufficiently detailed representation of the South East such that it can be used independently (i.e. not be used in conjunction with water company water resource models), but also that it is fast enough that 'stochastic' datasets (many thousands of years long) can be run through the model.

2.6 With these goals in mind, the RSS is being developed using a platform called 'Pywr' [1], a python-based water resources model which is open source, flexible and extendable, and which is faster than many other existing water resource modelling platforms. This platform was deemed to be the most suitable for this model after an extensive review (WRSE Regional Simulation Model Scoping Report).

2.7 The RSS is being developed by Atkins, but with significant guidance on model structure and system performance from water company specialists, recognising the model development skills that consultants have, and the system knowledge possessed by those working for water companies.

2.8 A full description of model development methods used can be found in the Regional Simulation Model Report, available on the WRSE website in the document library.

2.9 The RSS can be seen as a model composed of many coupled sub-models. Existing models that water companies have developed exist for the purpose of modelling individual company WRZs and sub-regions. A key requirement of the RSS is that methods and models used are, where reasonable, consistent with existing company assessments. As such, the initial sub-models are being built to represent company WRZs and sub-region models. These sub-models will be validated by comparing outputs from existing models (e.g. WRMP19 model outputs) with those from newly developed models. Models do not exist for some company areas. In these cases, 'expert judgement' will be required to ensure that behaviours exhibited in the new models are consistent with what would be expected. The fact that some companies are moving from having no model or very simple models to a more complex modelling approach may mean that some outcomes may differ from expectations. Differences from existing assessments are certainly acceptable but should be explainable.

2.10 WRSE is an alliance of water companies, rather than a regulator or entity in its own right. As such, WRSE itself has not set acceptability criteria regarding calibration/validation of sub-models. Instead, company specialists have engaged with the RSS development team and have 'signed off' models for use when they are happy with the representation of their system(s), via examining outputs such as river flows, reservoir storage, source utilisation, and deployable output.

2.11 While it is hoped that the WRSE RSS will be universally applicable across all companies' WRZs, it may be that some WRZ/sub-region sub-models produce results which differ materially from expectations, and companies will require further investigations to be carried out to understand the differences in expectation versus outputs, before committing to the outputs. Following the sign off process, companies will determine the purposes for which each model is suitable. Once the new models have been developed and validated against existing models, there may be opportunities for updates and enhancements to the new models, for example to represent revisions to system/operational constraints, or to improve the representation of interzonal and inter-company transfers.

[1] Tomlinson, J.E., Arnott, J.H. and Harou, J.J., 2020. A water resource simulator in Python. Environmental Modelling & Software. https://doi.org/10.1016/j.envsoft.2020.104635

2.12 The second stage of model development is to couple these sub-models together to form a model for the whole WRSE regional model. Pywr relies on solving linear algebra problems, with different sources of water being used subject to 'costs'. These costs are not financial and are instead costs which the model uses to solve a resource allocation problem during each time step – i.e. the costs inform the solver which sources should be preferred at any point in time. In coupling sub-models together, it may be that unexpected interactions occur, perhaps due to inconsistencies in costs defined in different parts of the model. Validation of the whole RSS will also be undertaken to ensure that sub-models continue to produce results consistent with what would be expected.

2.13 At the time of writing, the RSS broadly exists as a 'WRSE North' model (Thames and Affinity Central area) and a 'WRSE South' model (South East Water, Southern Water, Affinity South East, SES Water, Portsmouth Water), as there is currently relatively little interaction between these two areas. The flexible nature of the Pywr model means that the WRSE North and WRSE South models will be able to be connectable, although it will be necessary to check that the model still functions as expected when this happens.

# Inputs and datasets used in the model

2.14 The regional simulator will draw together many inputs and datasets. This section summarises the key inputs and datasets used in the model.

## Climate data

2.15 Flows, groundwater yields, and other variables within the model are driven by climate data, largely rainfall and potential evapotranspiration (PET). New 'stochastic' datasets have been generated for use in regional plans and WRMP24 which will be used extensively within the RSS model (**Method Statement 1332 WRSE Stochastic Datasets**).

2.16 When considering evaporation from reservoirs, factors will be applied to PET data to scale it from PET from grass to open water PET.

## Flow data

2.17 Rainfall-runoff modelling will not be carried out within the RSS, due to the runtime penalty that would result from their inclusion. Instead, work on hydrological modelling has been carried out to support the RSS. Please see **Method Statement 1330 WRSE Hydrological Modelling** for details.

## Groundwater yields

2.18 It has been recognised that groundwater has received a lack of attention in company water resources modelling efforts to date, in comparison with surface water. Groundwater yields have generally been based on assessments of average and peak source deployable output, reflective of conditions associated with 'design droughts', but not reflecting the potential variability in yields that may be seen under extreme conditions. The groundwater framework (**Method Statement 1322 WRSE Groundwater Framework**) has applied a consistent methodology to identify those sources where the representation of time-variant yields is appropriate, either by including lumped parameter groundwater models within the RSS, or by having a time series of groundwater yields. Groundwater yields will be provided by companies; whilst differences in assessment methods may exist, the DO will still be consistent with standard groundwater DO guidance and methods. Underlying climate datasets and the consideration of time-variant yields from sources will be consistent across companies.

## Information on existing sources and assets

2.19 Data exists in company models and assessments, defining licences, source constraints and assets. These data will be carried across to the RSS. Companies may need to review and update these constraints to account for changes since WRMP19.

## Levels of service

2.20 Levels of service define the expected frequencies with which different levels of restriction on water use would be imposed by companies. Levels of service are defined as constraints within water resources modelling (for example, if a given company's level of service is that non-essential use bans would be implemented once every 50 years, but a modelling output implies they would be imposed once every 40 years, this model run would be considered a failure). Implied levels of service are, however, also an output from water resource models, as it can be the case that model outputs suggest restrictions would be necessary less often than stated in levels of service. It is expected that the driving 'level of service' constraint for companies that make up WRSE will be the 'Level 4' constraint, or the frequency at which emergency water restrictions and emergency drought orders would be imposed. This is because there has been a recent change in national policy, whereby all companies must show that they would only impose emergency restrictions not more than once every 500 years on average. Companies must achieve this level of resilience by 2039. Up to this point, companies may have a lower level of service regarding emergency restrictions.

2.21 WRSE consulted on the question of levels of service for the region in August 2020. The outcome of that consultation process will be taken into account in this aspect of the regional simulation model.

## Emergency/dead storage

2.22 Emergency storage in raw surface water storage reservoirs is an allowance that companies make to ensure that water will still be available even if drought more severe than that which is planned for occurs. Emergency drought restrictions are often defined based on the point at which companies enter their emergency storage allowance. It is recognised that different companies within WRSE make different assumptions around dead storage and emergency storage requirements due to the nature of different reservoirs and reservoir systems and the way that they operate. As such, WRSE will not align assumptions regarding emergency storage requirements. Companies must, clearly define how and why their emergency storage volumes have been calculated.

2.23 WRSE is not proposing to associate a similar 'emergency storage' concept in groundwater dominated zones, although this means that South East will have less reserve storage than regions dominated by raw surface water reservoirs.

## Drought management options

2.24 There are several interventions that water companies can make when responding to drought events. These include the imposition of demand restrictions. A recent change to water resource planning guidelines states that drought permits and orders, along with any demand saving measures, must not be included in 'baseline' deployable output runs. As such, all drought permits and orders and all demand savings measures are excluded from baseline DO. There is a facility to 'turn on' demand savings within the model, which has been used to calculate the DO benefit associated with demand savings measures, in order that these can be included as 'options'.

## Planning scenarios

2.25 All water companies must undertake assessments of 'Dry Year Annual Average' (DYAA) deployable output. For many zones companies also consider 'Dry year critical period' (DYCP) and 'Minimum Deployable Output' (MDO) scenarios. The regional simulator may calculate DYAA, DYCP and MDO values directly from simulation results, or additional analyses may be necessary to supplement model runs.

2.26 Terminology around planning scenarios has been qualified in order to avoid confusion with demand-side terminology (generally in water resource planning, DYAA DO has been a 'worst historical' DO while DYAA DI is closer to a 1 in 10 value). Deployable output has been calculated for 'average' and 'peak' scenarios, and for different return periods of emergency drought order imposition. Scenarios used have been 2A, 100A, 100P, 200A, 200P, 500A, 500P, where for example 500A refers to the 1 in 500-year annual average supply capability.

## Treatment works losses and operational use

2.27 Thames Water calculate the impact of treatment works losses and operational use using simulation modelling, while all other WRSE companies calculate treatment works losses and operational use external to simulation modelling.

2.28 In all cases, deployable output will be calculated excluding treatment works losses, and these losses will be accounted for in WAFU.

## Transfers & bulk supplies

2.29 Bulk supplies and transfers should generally not be included in baseline deployable output modelling. Instead DO benefit and disbenefit for recipient and donor zones respectively should be calculated for bulk supplies and transfers, whether these are existing transfers or options. However, in some cases bulk supplies and transfers have very important system response implications (for example releasing 'locked-in' DO). In situations where there is sound reasoning for doing so, companies may include inter-zonal/inter-company transfer(s) in baseline deployable output modelling. In such cases, however, it must be made explicitly clear that this is being done, explain why this is necessary, and both zones/companies involved must adopt the same approach. In addition, the impact of these transfers should be accounted for after DO modelling (i.e. within the baseline supply-demand balance) such that DO values used as investment modelling inputs include only DO which 'belongs' to a given zone, such that the investment model can optimise intra-regional transfers.

2.30 Existing and proposed inter-company transfers under drought conditions have previously, generally been assumed as constant requirements. The RSS allows for these to potentially be modelled more dynamically in response to spatially variable supply and demand. The rules required to model such transfers dynamically may be complex, relating to levels of service, bulk supply agreements and changing resource stresses through a drought.

2.31 For transfers and joint options, the RSS will not seek to maximise the DO-benefit brought by a given option by dynamically allocating water to participating companies/WRZs (options and transfers being a supply-demand issue, not a supply capability issue). Instead, rules regarding transfers and joint options must be pre-specified, though these rules could be based on the relative drought severity affecting different areas if it is possible to implement this in the model and if it would be possible to write the rules into a contractual agreement. This reflects the necessity of water resource modelling to represent what would happen during a drought situation.

## Representation of non-public water supply abstractions

2.32 Regional planning guidelines require that non-public water supply (non-PWS) users are included in planning.

## Potential feedback loops

2.33 There are potential feedback loops that may exist in the development of the regional simulation model. This section highlights where these may exist. In some cases, initial assessments may be used in early iterations of the regional plan (i.e. before we have 'gone around the loop' completely).

- Triggers for the implementation of demand savings - Companies may initially specify control curves for the implementation for demand saving measures. It may be that these control curves lead to outcomes which are unfeasibly different to stated levels of service, and control curves may be iteratively altered accordingly
- Assessment of groundwater source yields, particularly for peak source yields - Historically, groundwater peak source deployable outputs have been calculated considering a fixed peak period (fixed in both time during the year and duration). The introduction of the consideration of dynamic demand may imply that different peak periods exist, and this may lead to re-evaluation of how source yields are considered.
- Treatment works capacities and process losses - It may be that outcomes from initial model runs suggest that values calculated for process losses and treatment capability are not representative of scenarios driving planning. Where this occurs, these values may be changed.
- Representation of non-PWS abstractions - The detail with which non-PWS abstractions are considered will depend on the relative impact that they have. As such, more/less consideration may

be given to these abstractions, dependent on the outcome of initial assessments (see **Method Statement 1334 WRSE Multi Sector Approach**).

- Model uses - Companies may initially find that the WRSE RSS is not suitable for use in one or more circumstances. Further investigation and development may then be undertaken, and the RSS may later be applied.

# Decision points and documentation

2.34 As described throughout this Method Statement, there are several decision points when producing and using models. Examples of decisions to be made are: determining which uses a given sub-model is suitable for; and, determining whether to use the RSS or company models/ assessments for calculating baseline deployable output for different scenarios.

2.35 Decisions to be made will become apparent as the project progresses. WRSE will identify key decision points and add them to this document when necessary.

2.36 For key decisions, keeping appropriate documentation is valuable for later justifying outcomes and decisions further down the modelling chain. In this section, key decision points are identified. Decision makers, those collating decisions across the region, and required documentation are described for identified decisions. There are of course many small decisions made during the course of building a water resources model and it is infeasible that all decisions would be recorded, although all decisions should be justifiable if questioned. This section only focusses on high-level decisions.

2.37 Assumptions underlying data that companies provide in the development of RSS sub-models should be documented by companies. Again, it is recognised that there are many assumptions made in the development of models, and that documenting all of them is infeasible. However, for key assumptions companies should document and/or be able to justify assumptions, such that they can be justified when questioned.

2.38 The decision to use Pywr as a modelling platform has been documented (WRSE Regional Simulation Model Scoping Report).

2.39 Identification of key assumptions to underly deployable output assessments which will not be aligned across WRSE - Water companies should document and justify key assumptions which will underly their deployable output; WRSE will collate assumptions from companies. Assumptions considered 'key' will vary between companies and WRZs and so companies should identify those assumptions that they see as key for given WRZs. Examples of key assumptions include levels of service, emergency/dead storage assumptions, control curves, the point at which Level 4 restrictions would be implemented, and inclusion/exclusion of the benefits of demand restrictions from baseline DO.

2.40 Inclusion of bulk supplies/transfers in baseline deployable output - If any inter-zonal or inter-company transfers are to be included in baseline deployable output, this should be justified and documented by the relevant company. If it is an inter-company transfer, the company should inform the other company involved to ensure a consistent approach. WRSE should be informed of all cases where transfers are to be included in baseline deployable output.

2.41 Identification of suitability of model for different purposes. As part of the model build process, Atkins are undertaking a model validation process in collaboration with water company leads. Company model leads will 'sign off' models for use in different circumstances and scenarios based on the validation evidence presented to them. This will include a table stating the planning scenarios for which the model is suitable.

# Confidence grades

2.42 It is recognised that a methodology will be required for assigning confidence grades to deployable output. However, this has not yet been determined.

# 3 Summary

3.1 This Method Statement has outlined the steps in development and validation of the WRSE regional simulation model. It has also outlined the uses that the model will have, as well as the input datasets that are required.

3.2 For key input datasets, points of alignment between WRSE companies and/or previous assessments have been highlighted. Equally, aspects where alignment will not be sought across WRSE have been highlighted and expectations of data from companies have been outlined.

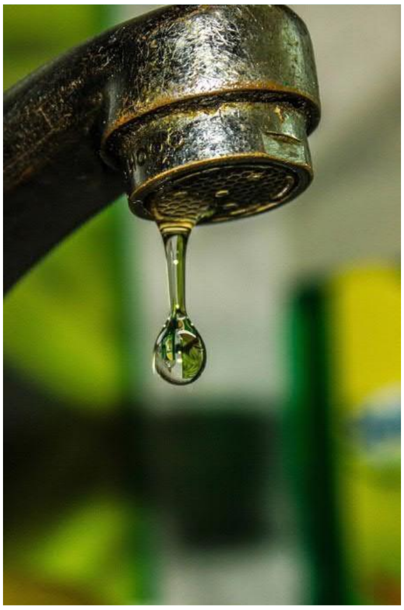
# 4 Next steps

4.1 We consulted on this Method Statement from 1st August 2020 to 30th October 2020. This Method Statement has now been updated to take into account the comments we receive during thisconsultation process and has been published on our website.

4.2 WRSE, in conjunction with the companies developing Strategic Regional Options (SROs), will be continuing to use the RSS through Autumn 2021 and into 2022. This Method Statement may be amended and updated should the approach vary as a result of this further work.

4.3 We may need to update parts of our Method Statements in response to regulatory reviews, stakeholder comments or improvements identified during the implementation phase of the methodology.

4.4 If any other relevant guidance notes or policies are issued, then we will review the relevant Method Statement(s) and see if they need to be updated.



# Method Statement: Outage

## Version 2

## July 2021

| Title | Method Statement: Outage |
|---|---|
| Last updated | 21/04/2021 |
| Version | Version 2 |
| History of Changes made to this version | Version 1 updated to include new regionally consistent methodology. |
| Summary of areas where substantive changes have been made as a result of consultation feedback | Further clarity on how nitrates/water quality issues are considered as outage included within the Abnormal Water Quality section on page 14.<br>Clearer definition of what is 'material' to the supply demand balance when discussing sensitivity testing included within Sensitivity Testing section on page 24 and Materiality Considerations section on page 26. |
| Summary of areas where substantive changes have been made as a result of the revised Water Resource Planning Guidelines | Version 2 of the Method Statement has been prepared using and in alignment with the WRPG supplementary guidance – outage. |
| Author | Andrew Halliday, Robbie MacDonald |
| Approved by | Meyrick Gough |
| WRSE Director Approval | Meyrick Gough |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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

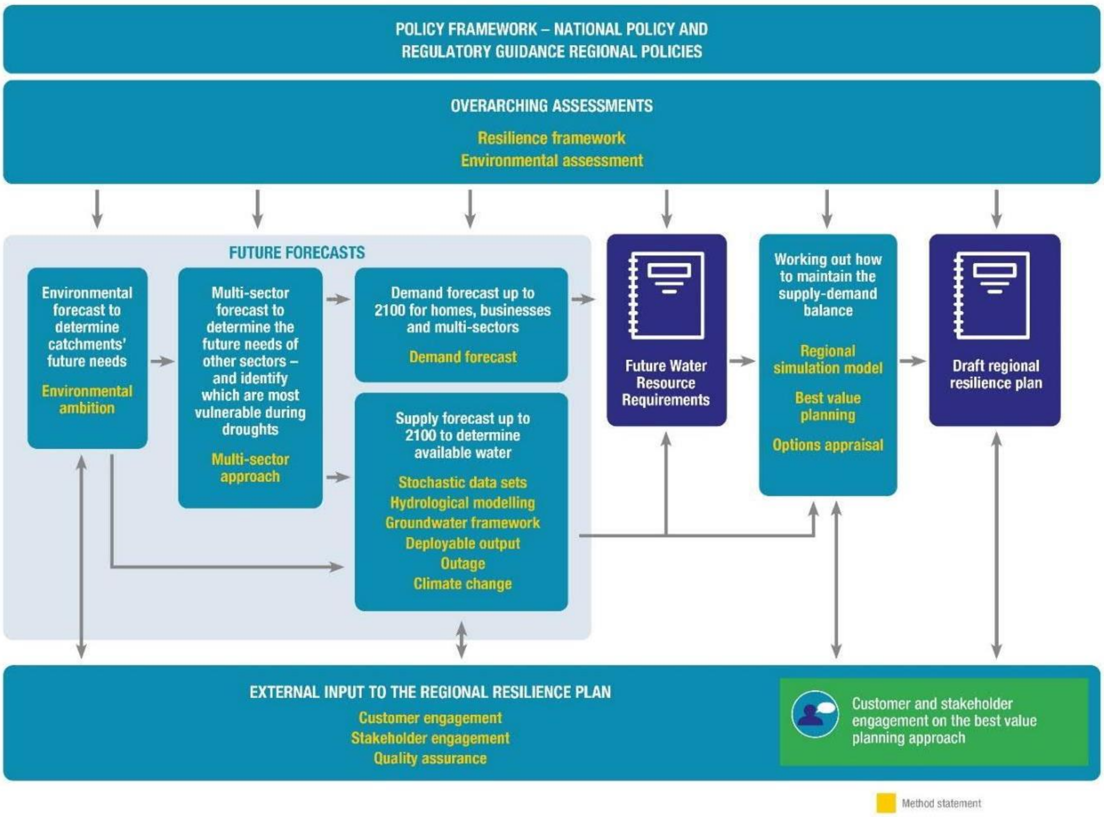
We have prepared Method Statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We consulted on these early in the plan preparation process to ensure that our methods are transparent and, as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this outage Method Statement will contribute to the preparation process for the regional resilience plan.

We need to provide a regionally consistent and improved approach for assessing outage, which is the temporary loss of reliable water due to planned or unplanned events and determine how much of a `planning buffer' we need to factor into our regional resilience plan.

Water resources and supplies are not guaranteed – the temporary loss of reliable water can be due to planned events, such as needing to carry out maintenance at water treatment works, or unplanned events such as power cuts. We need to take account of this upfront and build it into our plan, so we don't face temporary disruption to supplies.

Figure ES1: Overview of the Method Statements and their role in the development of the WRSE regional resilience plan



# 1 Background

In order to align with the ambitions of the regional planning objectives, WRSE has carried out work to develop a new outage methodology to provide a regionally consistent and improved approach for assessing outage and calculating a suitable planning allowance.

This work is now complete. In this Method Statement we outline the approach we took to developing the new methodology and provide details of the methodology itself.

# 2 Approach to develop the methodology

## Task 1

We completed a review and gap analysis to understand the current interpretations and methods for each company's:

1. reporting of outage against regulatory requirements and
2. forecasting of outage allowance for both the water resources management plans and regional plans.

A report was prepared on the interpretations, noting where there is alignment, inconsistency and their potential significance for water resource management planning. This was colour coded, using the criteria in Figure 1, below for each question across all companies.

**Figure 1: Gap analysis criteria**

| Red | Amber | Green | Blue |
|---|---|---|---|
| Material inconsistency or departure from guidance or good practice and/or hindrance to robust outage assessment | Minor inconsistency or departure from guidance or good practice and/or hindrance to robust outage assessment | Consistent with guidance or good practice with few hindrances to robust outage assessment | Inconsistent with guidance in a positive way, offering learning opportunities for WRSE |

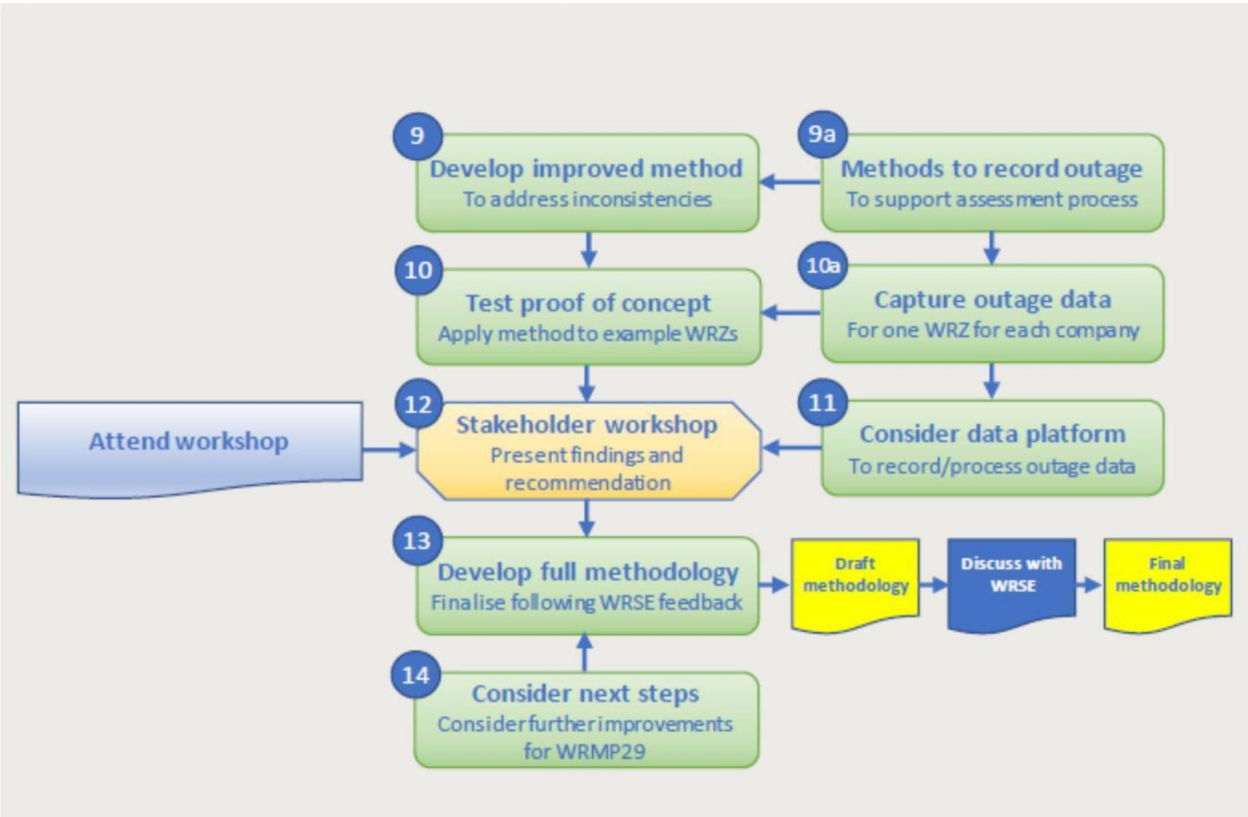
This identified areas of alignment across companies, and consistency with guidance. It also identified the inconsistencies and their potential materiality.

## Task 2

Next , we considered how we could provide consistency, promote best practice and ensure adherence to latest guidelines. We developed and tested a consistent methodology for the recording and calculation of outage and forecasting outage allowance. We also put forward the proposal for a group approved data platform to consistently record and process the data required – highlighting what this could look like and where gaps would arise.

Figure 2 below sets out the approach that was taken to move from the findings of Task 1 and develop the full methodology.

**Figure 2 – Process to develop final methodology**




A workshop took place on 5th August 2020 with companies, stakeholders and regulators to present the WRSE proposals for the new methodology.

The programme that was followed to develop the full methodology form June to August 2020 can be found in Appendix 1.

## Roles and responsibilities

The following key individuals and consultants were involved in the development of the new outage methodology:

- WRSE workstream lead – Andrew Halliday (South East Water)
- Consultant Appointed to develop the methodology – Mott MacDonald

## Maintenance of Method Statement

This Method Statement was updated in July 2021 to provide details of the new full methodology for outage in Section 4 below.

# 3 Methodology

This methodology specifies a means to provide consistency, best practice and adherence to the latest guidelines for the recording and calculation of outage for annual reporting and for dry year or critical period water resource management planning.

## Methodology overview

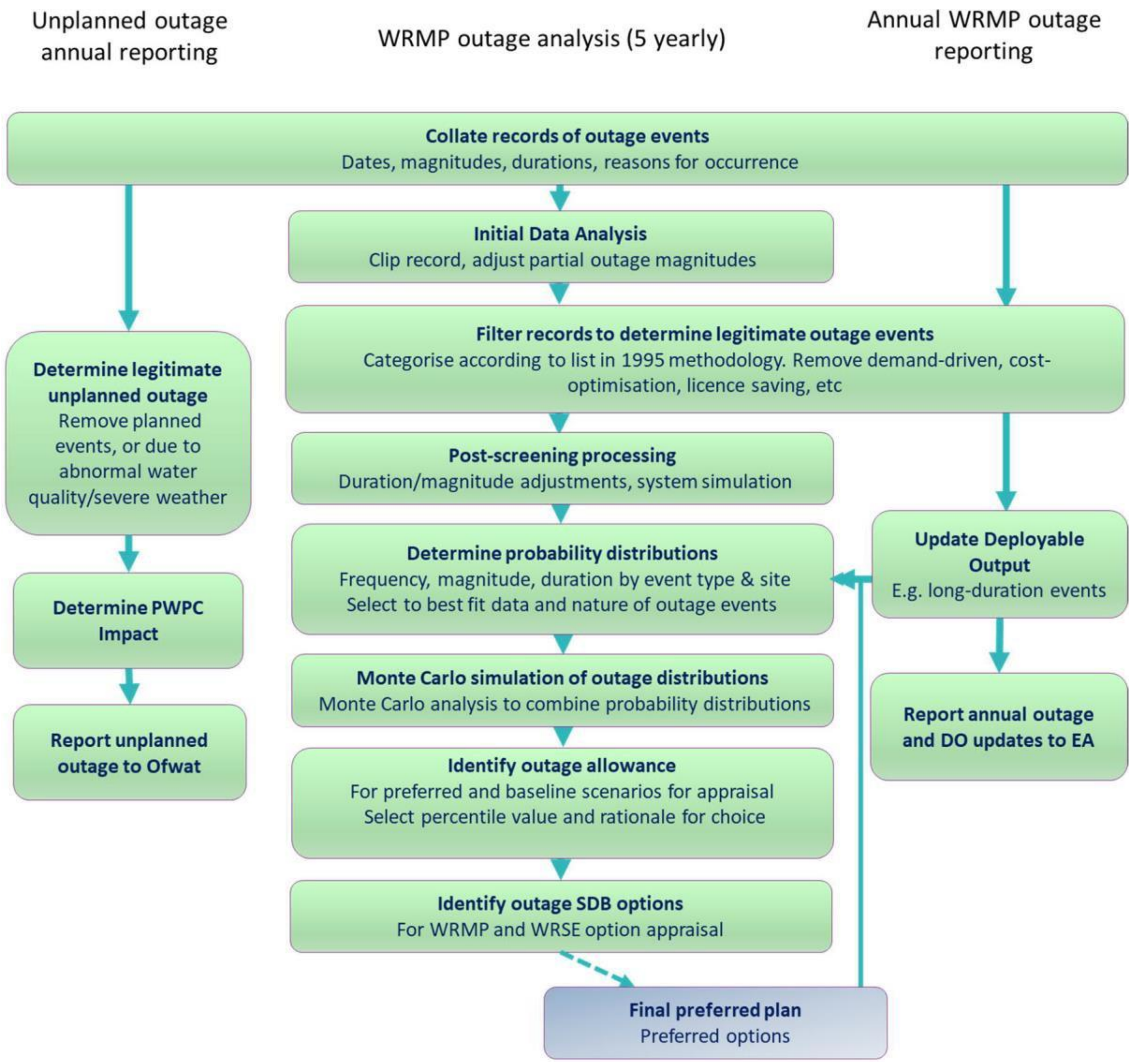
This methodology provides consistent guidance on recording, processing, analysing and modelling outage event data for annual reporting, outage allowance determination and outage option identification, for companies of the WRSE group. It is accompanied by a common outage modelling platform (see Appendix 1) to assist companies in processing and modelling the outage event data on a consistent basis. It also provides some further guidance on the unplanned outage performance commitment, to support the detailed guidance provided by Ofwat for PR19.

All potential outages may be recorded in the outage modelling tool (OMT), with screening for legitimacy carried out within this tool. This will ensure a clear and transparent audit trail for the company's outage allowance, with explanation for any variation between annual returns and outage allowances. It will show how capital investment has been accounted for, and explain any other adjustments to outage. It also provides a clear explanation for the scope of and limitations for any WRMP options to reduce outage.

An overview summary of the approach to outage across the three elements of outage is shown Figure 3 below. Figure 5 to Figure 9 provide a more detailed summary of the approach in flow-chart form – see Appendix 2.

A detailed description of each aspect of outage compilation and analysis is then presented in the subsequent sections.

**Figure 3: Summary of overall approach**




# Accounting for new options

For WRSE investment modelling, one specific area of complexity is how to account for the outage of supply options. The final sub-section of the methodology, Identifying and accounting for WRMP options, describes how an outage allowance should be made for options, but not specifically in the context of WRSE investment modelling.

There are two ways companies may account for the outage of new options for WRSE investment modelling at WRMP24:

1. Include an outage allowance in the baseline supply/demand forecast to account for new options
2. Include an allowance for outage in the DO benefit of options.

Where a significant WRZ deficit is expected in all scenarios (relative to total WRZ DI), such that making no allowance for the outage of options could significantly under-estimate the need for options, companies should apply alternative 1 prior to regional investment modelling. The simplest way of including this outage allowance may be for companies to not adjust outage allowance for losses of DO in the baseline supply forecast: i.e. use actual historical outage despite the write-down in DO.

Where deficits are expected to be relatively small (relative to WRZ DI), or vary considerably between regional investment scenarios, companies may make an allowance for new options in the baseline supply/demand forecast, but only based on the smallest expected deficit.

During post-modelling programme appraisal, companies should then review their outage allowances, given the options selected for each scenario. For small deficits, no adjustment to outage may be necessary. For more significant deficits, companies should determine an additional outage allowance to include in the next round of investment modelling. They should choose between alternatives 1 and 2 as follows:

- Alternative 1 (baseline supply/demand forecast outage adjustment) would be most appropriate where the deficit is relatively similar between scenarios and/or the outage allowance of an option varies considerably between scenarios
- Alternative 2 (option DO adjusted for outage) would be most appropriate where the deficit varies considerably between investment scenarios, and the outage allowance of any given option does not vary too much between scenarios.

Where there is significant variation in deficits between scenarios, and the outage allowance for a given option varies considerably between scenarios (for example, due to local outage recovery for certain scenarios but not others), then scenario-specific outage allowances may be required. This is considered unlikely for most WRZs.

Companies should take account of the supply of water from a given option to different WRZs and/or companies across all scenarios, when deciding on the most appropriate adjustment, and to avoid double-counting outage allowances.[1]

[1] For example, if a new reservoir is picked to supply different WRZs under different scenarios (via different transfers), and the outage allowance associate with that reservoir does not vary much between scenarios/WRZs, then adjusting its DO for an outage allowance may be most appropriate, in which case, no company should allow outage for the option in its baseline outage allowance. Conversely, if the outage associated with the option varies considerably between scenarios (through outage recovery potential for some WRZs but not others), and the deficits for all associated WRZs are similar in all scenarios, then baseline outage allowance adjustment for each WRZ may be most appropriate.

A summary of the alternatives is shown in the table below.

| Scale of Deficit (relative to WRZ DI) | Variation in deficits between scenarios (relative to WRZ DI) | Variation in outage allowance of an option between scenarios | Proposed Adjustment |
|---|---|---|---|
| Small | Minor | Any | No adjustment needed |
| Medium/large | Minor | Minor | Either update baseline outage or adjust option DO |
| Medium/large | Minor | Significant | Update baseline outage |
| Any | Significant | Minor | Adjust option DO or scenario-specific outage allowances |
| Any | Significant | Significant | Scenario-specific outage allowances |

# Data capture

## WRMP and UOPC data consistency

Where possible, companies should compile one set of data for both UOPC and WRMP/AR. This should then be processed in order to determine legitimacy, magnitude and duration for both reporting measures.

- Some companies record outage for WRMP planning at a different spatial resolution to that for the unplanned outage performance commitment: for example, WRMP outage at a source level and UOPC outage at a treatment works level. Companies should aim to specify outage at a single spatial resolution for both metrics for consistency. The Ofwat UOPC guidance states, “A company should define its peak week production capacity (PWPC) for each water production site or source works included in its water resources management plan.” In comparison, deployable output is typically specified at a resolution based on the key constraint on output in a dry year.
- Differences may therefore arise when, for example, two sources are constrained by individual abstraction licences in a dry year but their PWPC is constrained by the treatment capacity of a shared treatment works. In

this case, it may be necessary to specify different durations and magnitudes of outage for UOPC and WRMP, and/or outage may be excluded for one but included in the other, where it impacts PWPC but not DO, for example. It may occasionally be appropriate to specify two separate events in the outage modelling tool, with clear notes to explain why the event impacts are different for UOPC and WRMP.

Durations should be recorded through a start date of when the asset or source failure first impacted either DO or PWPC, and an end date of when the source could have re-entered supply at its normal capacity.

For determining magnitude, especially for partial outage, data should be recorded in terms of actual output put into supply, rather than as a % loss of output against a benchmark (DO, UOPC, etc). Actual output is more likely to be recorded accurately than losses, which may require understanding of WRMP or UOPC, and require additional information of the measure they are recorded against. Percentage loss is also non-comparable if companies measure it against different benchmarks.

Data captured should include the volume of losses associated with a non-outage lack of demand or operating philosophy decision, i.e. reduction in site output due to factors other than asset or source failure. This should be specified in Ml/d and determined as the difference between the actual site output and what the site could have produced, had unlimited demand been placed on the sourceworks.

Companies may opt instead to specify only the “potential sourceworks output” for each day of the outage, the output which would have been achievable under unlimited demand on the sourceworks.
Actual outage is determined as either [total outage recorded less demand/operational-based reductions] or [DO or PWPC less potential sourceworks output].

Example: a source with a peak week production capacity (and PDO) of 10 Ml/d and ADO of 8 Ml/d is running at reduced output of 6 Ml/d because of low demand and operationally lower cost sources elsewhere in the supply system, when it is hit by a system failure that reduces output to 2 Ml/d. In fact, it could have been run at 5 Ml/d during the event if needed, but 2 Ml/d was the optimal output when accounting for demand and other costs.

The company should record:

- the actual event output of 2 Ml/d and
- the potential sourceworks output of 5 Ml/d or
- the demand-related loss of output of 3 Ml/d

The outage magnitude for DYAA WRMP modelling would be (8 – 5) = 3 Ml/d

The outage magnitude for PWPC UOPC and DYCP WRMP modelling would be (10 – 5) = 5 Ml/d

## Outage event categories

Companies should specify events against at least one of the following categories, whichever is most appropriate: power failure; system failure; turbidity failure; pollution of source; nitrate failure; cryptosporidium failure; algae failure; other failure. Other sub-categories can be used in addition to those above.

- If a recorded event is found not to have been caused by any form of legitimate outage type in subsequent analysis, then it should be removed from the record. For example, an event recorded as a system failure, which turns out to have simply been an operational decision not to run the source into supply.
- If one asset/source failure causes another, then only the primary cause failure should be specified as the failure type.

> Example: if a source is shut down due to turbidity failure, but water quality sampling subsequently finds cryptosporidium in the raw water, and this extends the duration of the event by several weeks, the event should be classified as a cryptosporidium event, rather than turbidity.

- If two failure types occur simultaneously that are 100% related, but one does not cause the other, then the event type should be classified according to which type causes the greater magnitude and duration.
  - This may require a change in classification at the initial data analysis stage, but data capture processes should be established to provide enough information to make these decisions.
- If two failures happen simultaneously by coincidence, then both should be specified as separate rows in the data capture sheet. If possible, the potential sourceworks output should be specified separately for each failure type for each day of the outage. The duration of each event type may differ and should be specified according to the date at which normal supply could have resumed, in the absence of all other failures.

> Example: a source fails due to a system failure event and nitrate event happening simultaneously, completely unrelated to one another; under the system failure only, potential output would have been 3 Ml/d and duration is only 5 days (the time taken to repair the system); under the nitrate event only, potential output would have been 1 Ml/d (the maximum blended output possible during the event), and duration is four weeks (the time taken for water quality to have returned to a sufficiently good state for blend to operate as normal).
>
> These values should be specified as two separate events in the log, each with its own magnitude and duration.

## Recording duration and magnitude

Where outage is recorded only to the nearest day, rather than nearest hour, companies should test the sensitivity of their outage allowance to this time recording resolution, by adjusting all events up/down by half a day and noting the change in outage allowance. If the changes are material to the supply demand balance, event duration should be recorded to the nearest hour if possible.

Where failure magnitude changes significantly during the event, companies should generally average out the magnitude across the event. Companies may specify new events with a different magnitude, but only where the change in magnitude is due to a clearly defined step-change in the outage cause, whose probability of occurrence is notably distinct from the original event.

## WRSE common platform

It is not considered practical to record outage events directly into a common platform for WRSE companies at this point. Sharing data would be useful to improve the accuracy of outage allowances where individual companies have limited data records for outages of a particular type at a certain sourceworks, for example for relatively new sources or for options of a new type for the company. In these cases, we recommend bespoke sharing of data in response to specific cases.

- A company finding itself in this position should send out a request to all WRSE companies, and any other relevant companies, for outage event data for sources of the relevant type, stating key source attributes. Companies should respond where possible with data for any sources that may be relevant, along with the relevant source attributes.
- Source attributes might include: source water type (groundwater, surface water, reservoir, effluent reuse, desalination, etc); aquifer type (confined, unconfined, etc); water quality type (typical iron, manganese, nitrate levels); catchment type (arable, pasture, any industries relevant to water quality/pollution etc); high level treatment processes; any other information relevant to outage types, magnitudes, durations and frequencies.

Source names and locations should be anonymised as necessary to mitigate any security risks or commercial risks for companies.

# Initial data processing

## Data record

For Outage Allowance calculations, companies should select a period of historical outage data which is broadly representative of current conditions and resource configuration, but which also provides sufficient quantity and range of events to enable accurate magnitude, duration and likelihood distributions of event types to be determined for each sourceworks. Ideally this duration should be at least 5 to 10 years. Consideration should be given to the following:

- If historical investment activities have affected the duration or magnitude of outage events of a certain type at a given source, then events prior to the investment should be left in the record, but magnitude and/or duration adjusted to reflect the changes at the point of screening/processing (see subsequent sections for more information)
- If historical investment activities have affected the likelihood of outage events of a certain type at a given source.

Companies then have three options:

1. Clip the record of analysis to the point at which investment occurred;
2. Adjust the likelihood probability distribution manually to reflect the change in likelihood;
3. Adjust the historical record of events to account for changes in likelihood, for example by excluding certain events, in order to derive an appropriate frequency distribution.

If data before a certain date is considered unreliable, e.g. due to insufficient data recording, or unreliable recording, companies should clip their historical record back to that date only. Any adjustments should be clearly justified with evidence where possible, for example with data from other similar source works showing how investment has affected outage risks.

If there is uncertainty over the reliability of data prior to a certain date, companies should test the sensitivity of including this data in their outage allowance. If insensitive, then a best judgement decision should be made as to whether it is included or not. If highly sensitive, companies should undertake a more detailed study into the historical record for that event type and sourceworks to decide whether adjustments to the historical record should be made.

Example: treatment at a groundwater source was upgraded five years ago to mitigate turbidity failures associated with dewatering a fissure, which occurs when the source is operated at high rates under low groundwater levels. This reduces the likelihood of failure, but the treatment has a design capacity which does not mitigate all events. It does also reduce the risk of crypto failures, and system upgrades made at the same time also reduced the risk of system failures. The company has various options:

- Clip the record of events to five years ago. This would ensure that the capital investment is fully accounted for in the outage allowance, but risks limiting the record of events of other types (e.g. power failures or non-turbidity pollution), which might still be relevant, especially infrequent events.
- Look back through the record of events and exclude ones which would not have happened after capital investment. This increases the length of data record for other failure types, but requires sufficient information on the historical events to be able to say which would no longer haveoccurred
- Leave all events in place but manually adjust the probability distributions for each relevant event type to account for the investment. For example, reduce likelihood of turbidity failures by 80% and duration by 50%, and reduce likelihood of system failures by 50%. This ensures the full data record is utilised, but requires quantification of the impacts of asset investment on outage that may besubjective.

The choice of approach would depend on quality of recorded information, nature of risks for each event type, and how confident the company feels about making adjustments to PDFs directly. A hybrid of all three options could be applied.

A key consideration is the materiality of changes to the outage allowance. If turbidity/system outage at the source makes a minimal contribution to the overall allowance, as determined from the Monte Carlo analysis and tornado plots for the WRZ (see Section 3.10, Section 5 and Appendix 1 for more information), then it may be unnecessary to make any adjustments. A starting point might be to try end-member adjustments to the PDFs and re-run the allowance calculation to test sensitivity; then decide on the level of evaluation required.

## Partial outage

Companies should aim for a position where all outages, full and partial, are recorded to the same level of accuracy and can all be included in one pdf for outage magnitude. Once this standard of recording has been achieved for a number of years, the record should be clipped to the start of this period, and all events prior to this date excluded from analysis. A minimum of 5 years of data is likely to be required for this.

Where partial outage has not been recorded accurately for a long enough period (either no record of partial events, or no record of magnitudes during those events), companies have various options.

1. If an accurate partial outage record is available, but very short, companies should use the shorter period of high-quality partial outage data to determine probability distributions for magnitude, and perhaps duration. They should use the longer period of data to determine likelihood distribution (and potentially duration). Comparing duration and likelihood distributions for both periods of record would be worthwhile, potentially with sensitivity testing to confirm the final distributions used. The impact of any decisions/assumptions should be determined and reported.

2. If all partial outage data is currently unreliable, companies should search for systematic errors in the data, which can be corrected systematically. For example, was partial outage magnitude always recorded against an incorrect baseline output rather than deployable output, which can be corrected? Did partial outages of a certain type not correctly account for operational philosophies, such that actual outage is less than reported, which again can be corrected once the philosophy is considered?

3. If all partial outage data is randomly incorrect, or totally unrecorded at one or more sources, companies should update their outage distributions to account for partial outage using data from other similar sources, in the WRZ or elsewhere. This can be done within the WRSE outage data tool by basing distributions on all data within a zone or of a certain sourceworks type, for example. This should only be done where the alternative data can be shown to be representative, where outage risks are known to be similar.

4. If partial outage data is insufficient to apply any of the methods above, companies should update their distributions using information from other companies' most equivalent sourcework types. This needs a transparent audit trail to identify where and how much infill has taken place and therefore what impact it has on overall outage allowance. Sensitivity testing could also be undertaken to evaluate the materiality of the infilling.

In deciding what adjustments are required, and by what means, companies should start by testing the sensitivity of their outage allowance to partial outage magnitudes at each source and event type. A proportionate approach should be taken, starting with sourceworks and event types which are most material to the outage allowance.

# UOPC legitimate outage screening

## Planned events

> *Where assets are taken out of supply or made unavailable for supply to enable planned maintenance or capital works to be completed then these should be recorded as planned outages. The same principles for work on standby assets apply here as for unplanned outages.*
>
> *It is expected that a company will have a process whereby planned works on production assets are approved and scheduled. This may be the basis of evidence to demonstrate that the outage is planned.*
>
> *Where planned work results from an asset failure any resulting outage should also be recorded as unplanned.*

Source: Ofwat PR19 Reporting Guidance: Unplanned Outage

Generally speaking, a planned event would be specified on a planned works calendar or schedule, before the event occurred. If there is no evidence the event was planned in advance of the first impact on supply, then it is likely to be an unplanned event. Where an unplanned event is followed immediately by planned maintenance that is only partly related to the unplanned event, because this is better asset management than to delay the maintenance, we recommend that the “planned maintenance brought forward” not be included in the unplanned outage event recorded. To include this planned maintenance would create a perverse incentive for companies to delay important maintenance to avoid penalty, when the right thing is to carry out the maintenance immediately.

The onus would be on companies to clearly demonstrate that the planned element of maintenance was already planned in some way, before the unplanned outage event occurred.

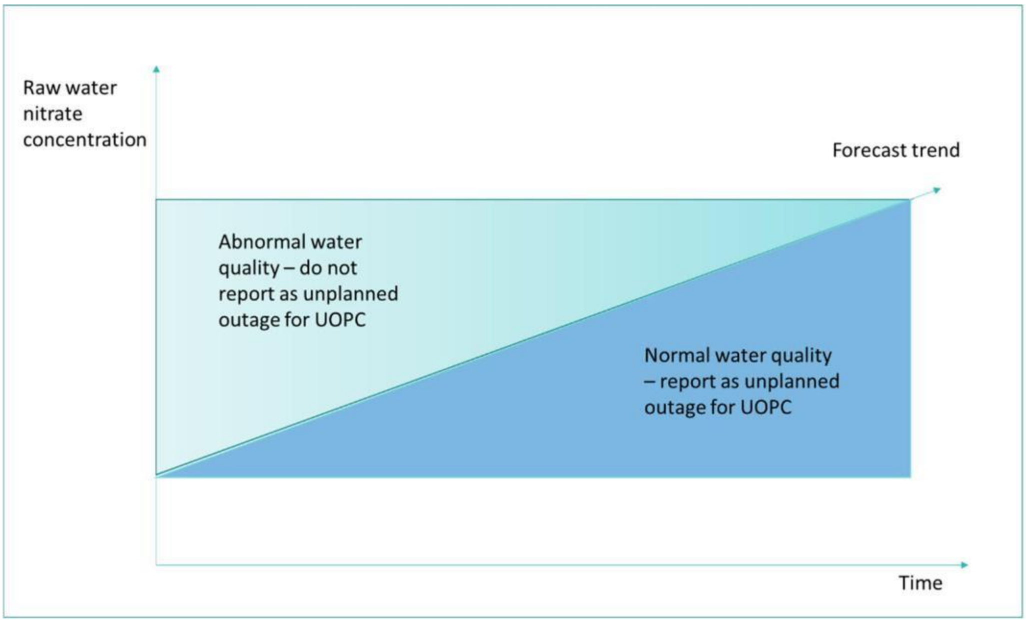
## Abnormal water quality

> *Unplanned outage arising from changes in raw water quality beyond the normal water quality operating band shall be excluded as this is not a measure of asset health. Exclusions must be evidence based including evidence to show what the normal water quality operating band for that production site is. This exclusion applies to transient changes to raw water quality such as turbidity, algae, pollution, spikes in nitrate and pesticide. If a company chooses to manage variable raw water quality by proactively temporarily restricting water production, then this should also be classed as an exclusion.*
>
> *Long-term trend-based changes in raw water quality which result in unplanned outages are not permitted as exclusions as a company should have the data to recognise a rising trend and foresee the need to plan for treatment etc.*

Source: Ofwat PR19 Reporting Guidance: Unplanned Outage

Target headroom analysis forecasting may be used to specify normal water quality operating bands for relevant water quality parameters, such as nitrate. Where nitrate concentrations rising in line with the baseline forecast cause an outage event, that event should be included in the unplanned outage performance reporting (companies should have planned around this forecast). Where outage is caused by nitrate concentrations exceeding the forecast, exclude these events from UOPC reporting. This is illustrated in Figure 4 below.

**Figure 4: Use of nitrate forecast to identify abnormal water quality for UOPC reporting**



# WRMP legitimate outage screening

## Boundary with deployable output

The Environment Agency, Ofwat and Natural Resources Wales have specified supplementary guidance regarding the boundary between outage and a loss of deployable output, for both planned and unplanned events, as shown in the box below.

***Unplanned outages***

*Where an unplanned outage extends beyond 90 days, you should present an action plan to regulators to show how you are rectifying and managing the outage. Unplanned outages longer than six months should be classed as deployable output reductions unless agreed with regulators. The table below provides a summary.*

| *Duration of loss of supply* | *Action* |
|---|---|
| ***0-3 Months*** | *Record as outage* |
| ***3-6 Months*** | *Notify regulators and prepare action plan to reduce outage. Still classified as outage.* |
| ***>6 Months*** | *Record as loss of deployable output until rectified unless agreed otherwise by regulators. You should inform regulators of the quantity of deployable output loss.* |

***Planned outages***

*Planned outages are an important part of ensuring you have a resilient and well-maintained network. If you are planning a long-term outage for one of your sources i.e. longer than 12 months, you should adjust deployable output in your WRMP accordingly.*

*Where a recurrent and predictable water quality issue exists, you should consider whether it is appropriate to reduce deployable output. For example, metaldehyde causing outage at a source multiple times in a year.*

Source: WRMP24 Draft Supplementary Guidance: Outage

If a source already has DO = 0 in the planning table, the company should identify whether it is due to re-enter supply at any point in the period. If not, and it is not due to be replaced by a very similar source, then all historical outage from that source should be excluded.

If it is likely to be reinstated, then the date of reinstatement should be specified, and an outage allowance made to account for the source from that date forward. This allowance should be based on historical outage events at the source, but only those which remain a risk in light of any capital investment at the source, and with magnitude and duration of the events updated accordingly if necessary, e.g. based on the reinstated source DO, etc.

If the source is due to be replaced by a similar source (from an asset/source failure point of view), then historical events may be deemed legitimate, although with magnitude updated considering the replacement DO. Events at this source should be included in the outage allowance from the date of replacement.

All unplanned outages up to three months in duration should be recorded as outage with no write-down in DO.

Unplanned outages of greater than three months should be recorded as outage, with an accompanying notification to regulators and an action plan to reduce future outages of this type at the sourceworks.

Unplanned outages greater than six months duration should be recorded in the outage record according to their actual duration. However, for annual reporting of that year, the outage event should be reported with an accompanying reduction in source DO equal to the magnitude of the outage, unless agreed otherwise with the Environment Agency.

For outage allowance calculations, unless agreed otherwise with the Environment Agency, a sourceworks at which an unplanned outage event of greater than six months has occurred should have its DO written down by the outage magnitude, and all outage events of that type at that source excluded from the outage allowance.

When deciding on where the boundary lies, companies should consider what would happen during a planning scenario period (DYAA, DYCP etc), and the impact of the outage as a proportion of total WRZ DO. The six month limit is specified because if a high magnitude (relative to WRZ DO) event of six months really were to occur during a dry year period, albeit with low likelihood, the Monte Carlo averaging process might be inappropriate.

If during a planning scenario period, the event duration could in fact be reduced through emergency dry year actions, then the likely duration should be determined and put to the EA for discussion regarding treating the event as outage, and not writing down DO. Where a shorter duration is agreed as being feasible in the planning scenario, this duration should be used in the outage allowance calculation.

If the outage magnitude is small relative to the total WRZ DO, then it may also be acceptable not to write down DO and to continue to treat the event as outage. In this case, the outage allowance Monte Carlo averaging process would continue to work well. See "Boundary with System Resilience" for further guidance on this.

If the likelihood of the long duration event is very low, particularly for it to coincide with a dry year, for example flooding-related outage, it may be more appropriate not to write down DO, but instead to undertake system resilience scenario testing of the event during normal year conditions, and mitigate the event through resilience investment. In this case the event should still be excluded from the outage allowance (see "Boundary with System Resilience").

The 12-month cut-off for planned outages recognises the fact that companies have more control over planned outages and therefore can avoid DO impacts more easily in a dry year than for unplanned events. The same process as for unplanned outage should be followed to establish whether or not a long-duration event should result in DO write-down or not.

There may be situations where long-term planned outages would not be planned for in a dry year, and so could be excluded from outage allowance, but the actual outage might unavoidably extend into a dry year. In this case, the duration of the outage for WRMP allowance should be specified as that which impacts DO in the dry year. If this duration exceeds 12 months, source DO should be written down, as per the EA supplementary guidance. If this duration is less than 12 months, but the impact of the outage on dry year DO is significant compared to total WRZ DO, then the event should be considered for resilience scenario planning (see section on Boundary with system resilience below).

Examples:

A pollution event causes a complete outage at a 1 Ml/d source from September 2020 to May 2021. The total DO for the zone is 4 Ml/d. The annual report for 2020 would specify the outage of 1 Ml/d and DO is not yet written down. At end of 2021, the duration of the outage (9 months) is known. Because the magnitude is significant relative to the WRZ total DO, source ADO is written down to zero, the total WRZ DO is now 3 Ml/d and all outage events at this source are excluded from the DYAA outage allowance. Reviewing the outage cause, it is decided that the risk of occurrence during critical period is very low, so DYCP DO remains in place, this outage event is not included in the DYCP outage allowance, but other legitimate DYCP outage events at this source remain included in the DYCP outage allowance for the WRZ.

A planned outage results in a 5 Ml/d source being completely removed from supply for 15 months in a zone with 50 Ml/d total DO. In a dry year it is decided the source could have been returned to supply within 9 months. In this case, the DO is relatively small compared to the WRZ and the dry year duration is less than 12 months, so the company proposes to the EA to leave the event as outage. Because the event is planned, it does not feature in DYCP outage allowance. A duration of 9 months is specified for DYAA outage allowance.

## Supply system mitigation

Where the supply system storage or balancing of sources mitigates any outage impacts on deployable output from the source, these events will be excluded.

If the event would clearly have no impact on DO in all dry year scenarios (DYAA, DYCP or DYMDO), it should be excluded from the legitimate set of events. This can be determined by considering whether the event impact (duration x magnitude) is small enough that [alternative supply + storage] is sufficient to avoid any DO impact under all scenarios. If so, then it should be excluded from WRMP outage.

## Capital investment

Where capital investment (enhancement or maintenance) has eliminated the risk of an outage event type occurring at a given sourceworks, all historical events of this type at the sourceworks should be excluded from the outage allowance calculation. Where capital investment has reduced but not eliminated the risk, relevant historical events should be included but with adjustments made to their calculated magnitude/duration/likelihood probability distributions (see WRMP processing of calculated distributions).

Where the risk of pollution outage events has been mitigated completely by 3rd party activities (e.g. catchment management, factory closure, industrial waste processing improvements, etc) relevant historical outage events should be excluded from the analysis.

## DYAA DO recovery

If the altered operation of sources on the same individual or group licence, or conjunctive use tactics with other source types in the local supply system could fully mitigate the outage event, then these events should be excluded from WRMP outage.

This can be done by considering licences and potential for conjunctive use first. If PDO, MDO and ADO are equal, and the source is not on a group licence, then there is unlikely to be room for any DYAA recovery, unless an option for conjunctive use (e.g. groundwater/surface water) is available.

If PDO is greater than ADO, and/or the source is part of a group licence, then consideration should be given as to whether other sources can be run at above ADO flow rates during the outage event, and the outage source then run above ADO to make up for its loss later in the year, resting the other sources, resulting in no net loss of ADO.

If there is some capacity for recovery, but not enough to recover all outage loss, then the event should be included, but its duration and/or magnitude adjusted as part of post-legitimacy processing.

This should take account of the month in which the event occurs relative to the licensing period. An autumn event may provide little scope for recovery if the annual licence period runs January to December; although consideration should be given to negotiating a two-year licence period if this would be material to the supply demand balance. This could enable reduced output from the source at the end of one year to be made up by increasing abstraction from alternative sources nearby above their annual licence in that year, with reduced abstraction in the following (made up by increased abstraction at the outage-loss source).

For complex water resource systems, full system simulation of some outage events at certain sourceworks may be required to determine whether events would have any impact or should be excluded.

## Boundary with headroom

If the event is captured adequately by target headroom, then it should be excluded from WRMP outage allowance (see post-screening data processing). This includes:

- When outages are short-term and temporary, driven by random, largely unpredictable and uncontrollable events. A metaldehyde spike in a river resulting in temporary shutdown of an intake is a typical outage event.
- Where headroom is an allowance for uncertainty in the SDB caused by long-term, often gradually occurring, uncertain and permanent occurrences. A pollution event with long-term consequences, such as a contamination plume in an aquifer from an industrial spill which might but hasn’t happened, which renders a sourceworks unusable without investment in treatment is a typical headroom component.
- Typical outage events with a risk of overlap with target headroom are nitrate failures, and other long-term pollution failures. Outages caused by these types of event should be reviewed and screened in/out based on whether the impact on DO is within any Ml/d uncertainty range allowed for under target headroom. See section 0 for more explanation.

- Where nitrate trends are predictable and impact available source outputs owing to changes in blending, then this should be allowed for by writing down future DO. If there is uncertainty in the nitrate trend impacting changes in DO, then this should be allowed for in target headroom.
- Should the company address the nitrate problem through installing treatment facilities, then this may restore or protect DO and reduce headroom, but such facilities will be subject to equipment failures, which should be included in the outage allowance.

## Boundary with system resilience

Some failure events are not appropriate for inclusion in the outage allowance, because Monte Carlo averaging is likely to understate their impact and therefore not provide a meaningful way of accounting for their risk. These events should be assessed separately through system resilience or scenario planning. In this case, they should not then be included in the outage allowance, as this would artificially inflate the allowance.

In order to decide whether an event should be evaluated separately under resilience, it is necessary to consider its impact relative to total DO of the supply system at a WRZ level. Outage allowance is effective for events whose total impact (product of magnitude and duration) is small relative to the total WRZ DO of the planning scenario period. In this case Monte Carlo averaging works well at smoothing out random failure events over the planning scenario.

Companies should decide upon a % threshold for the boundary between outage allowance and resilience assessments. We recommend that all events with a magnitude-duration product less than between 5% and 10% of the product of planning scenario duration and total WRZ DO, can be adequately assessed as outage. Companies may assess an event type at a given sourceworks through both outage and a resilience scenario, and then decide how best to account for it. If resilience mitigation is planned, this should be taken account of in the outage allowance.

Examples:

An event with magnitude 50% of WRZ DYAA DO lasting 1 month can always be assessed under outage under the DYAA scenario (50% ×1/12 = 4%<10%).

Similarly, an event with magnitude 20% of total WRZ DO lasting 5 months could be left in outage for DYAA (20% ×5/12 = 8%<10%).

But for a DYCP lasting only 2 weeks, a 20% WRZ DO event lasting longer than 7 days could be considered for resilience scenarios rather than outage (7/14 × 20% = 10%).

This relies on there being good connectivity between sources in the WRZ. Where connectivity is more limited, an appropriate sub-zonal area should be considered instead to determine the DO magnitude against which event magnitude should be measured.

Higher impact events should be included in annual reporting, but may be excluded from outage allowances and assessed under system resilience scenario testing instead, if considered appropriate. This resilience testing should take account of the likelihood of the event and its seasonality. Many low-likelihood events are unlikely to coincide with 1 in 200-year (or less frequent) drought, so it may be more appropriate to test them against normal year water availability and demand; however some events, such as algal blooms, may credibly coincide with drought events and should be tested against drought scenarios.

The impacts of future climate change should be taken into account when considering likelihoods of both outage events and drought conditions occurring simultaneously. Where outage events are likely to be appraised and mitigated in resilience planning, commentary could be added to the annual report to explain this, and/or commentary added to the WRMP outage report and business plan resilience sections to explain why the outage allowance is lower than that reported in the year the high impact event occurred. As for all other elements of outage allowance, sensitivity testing should be used to decide whether an event is material to the outage allowance and therefore whether it requires detailed consideration of resilience exclusion or not.

## Seasonality

The season of occurrence of an event should be accounted for when specifying events for DYCP or DYMDO planning scenarios. For example: winter flooding and freeze-thaw events should be excluded from peak summer DYCP outage allowances, though events relating to flash flooding following dry weather should be included; algal bloom events should be excluded from autumn MDO outage allowances.

Planned events should be excluded from planning scenarios where they could be avoided. Generally, this means that planned events would not be undertaken during dry year periods of peak summer demand (DYCP scenarios).

# WRMP post-screening processing

## Duration adjustments

All events should have their durations adjusted to specify the duration that would have occurred in each dry year planning scenario, based on emergency actions that would in likelihood be taken. These actions are likely to vary between scenarios and may depend on the time of year. For example, an event occurring in January in a dry year might have a longer duration than one occurring in October, when the extent of drought conditions is more accurately known.

Capping of events should only be applied to limit event duration to the planning scenario duration (e.g. 12 months for DYAA, 2-4 weeks for DYCP). Otherwise, events should either be adjusted for a dry year planning scenario, left as recorded, or excluded as a result of DO being written down.

Where an outage event spans more than one reporting year, companies should again consider whether this would have happened in a dry year. If so, the event could either be split into two events, the first with duration equal to that recorded in the first calendar year, and the second that which would be expected in a second dry year, or specified as a single event with duration equal to that expected overall in dry conditions. The decision will depend on how the event would impact DO as detailed below:

- If dry year DO is dependent on multi-year drawdowns (for some yield-constrained groundwater sources or reservoir storage), then the event should be specified as a single event

- If the dry year DO is based on, for example, annual abstraction licence constraints, which reset year-on-year, then specifying two separate events may be more appropriate.

In either case, the rules associated with DO write-down for planned/unplanned events, and for boundaries with system resilience assessments should be followed for the individual event (multi-year drawdown conditions), or for the two events individually (annual constraint conditions).

## Magnitude adjustments

Event magnitudes for outage allowance modelling should be based on the deployable output of the sourceworks for the planning scenario in question, or the partial outage magnitude, less any reductions due to reduced demand or operating philosophy. This may be equal to the magnitude at the time of failure, but significant changes in DO may have occurred.

The WRSE common outage platform automatically applies current DO, adjusted for partial outage and demand/operating philosophy effects, though manual adjustments can be made.

Manual adjustments might be, for example, to account for more recent capital investment that would have reduced the magnitude of a partial outage event, or to account for water resource system balancing, as assessed with a spreadsheet model or system simulator.

Where sustainability reductions, climate change, severe drought or water quality are forecast to impact DO into the future, magnitude should be changed accordingly at the stage of specifying probability distributions (section below).

## DYAA recovery adjustments

Where there is potential for some recovery in lost ADO during a DYAA scenario by increasing output above ADO after the event to make up for the loss, companies should adjust the magnitude and/or duration of the event accordingly for outage allowance modelling.

For example, if a source with PDO 5 Ml/d and ADO 4 Ml/d is impacted by a full outage event for the first 3 months of the year, losing 360 Ml of water into supply in total, 270 Ml of this could in theory be made up in the remaining 9 months. Therefore, the true outage loss for DYAA could be only 90 Ml. This could be accounted for either by reducing modelled outage duration to 22.5 days, or by reducing modelled outage magnitude to 1 Ml/d. Either option could be applied, but if in doing so the impact on outage is material (see section 0), then both alternatives should be tested for materiality as well, and a precautionary choice made between the two.

For conjunctive use systems, spreadsheet calculations may be needed to determine the system impact on DO across surface water and groundwater sources, taking account of all licences, including group licences.
DYAA recovery allowances should take account of the month in which the event occurs relative to the licensing period (see WRMP legitimate outage recovery adjustment). This could be accounted for by adjusting the magnitude distribution for this event type at the source to allow for a range of possible impacts depending on when it happens, allowing for any variation in likelihood between months. Alternatively, a seasonal modelling

approach could be undertaken for DYAA with outage allowances determined for each of four seasons, one of which is then selected to specify the final allowance. This should be more accurate, but should only be carried out when the effects could be material to the outage allowance. For complex water resource systems, full system simulation of all outage events at certain sourceworks may be required.

## System simulation

Water resource system simulation is only likely to be required to assess outage for supply systems comprising significant storage across multiple sources in a well-connected water resource zone. The following factors should be considered:

- Simulation required for a given event type at a certain sourceworks – first consider whether the impact of the event could be mitigated by the supply system in some way, either immediately by reconfiguring supplies from other sources, or later through conjunctive use ADO recovery. Then decide whether the impact can be calculated with sufficient accuracy using a simple spreadsheet-type model
- The materiality of the outage – if there are only a few events with limited magnitude and duration, then a simple calculation may suffice to estimate true outage magnitude and duration. If multiple higher impact events have occurred during the year, then running the system model may be necessary to determine actual outage impact
- Where a system simulator is used to model a single event – the simulator results should be used to specify magnitude and duration of the impact on deployable output
- Where a system simulator is used to model multiple events – a single "global" event should be specified in the outage allowance model, to account for all outage events simulated. All outage events and the simulated global event should be reported in annual reporting for that year, to enable regulators to properly assess outage.

## Capital investment

Where capital investment has reduced the risk of an outage event occurring, adjustments should be made to the calculated magnitude/duration/likelihood probability distributions, as required. This can be done before or after determining initial calculated distributions in the following circumstances:

- If the effects of capital investment on a specific event can be clearly quantified, then event duration or magnitude should be adjusted accordingly
- If capital investment would affect the likelihood of an event type occurring, or if the impact on magnitude/duration of specific events is uncertain, but generally duration or magnitude is believed to have reduced, this can be applied to the probability distributions themselves (see next section)
- Where the risk of pollution outage events has been reduced as a result of 3rd party activities (e.g. catchment management, factory closure, industrial waste processing improvements, etc) the duration, magnitude or frequency of historical outage events should be adjusted accordingly

- Where the impact of investment cannot be clearly quantified, then outage parameters should only be adjusted downwards where evidence supports this, for example based on changes in outage observed at other sources in response to similar types of investment
- For historic investment, there may be some post-investment evidence to support adjustment
- For future planned investment, it depends what is proposed, but again companies would want evidence from similar past investments to support a reduction in outage parameters

# WRMP outage probability distributions

## Capital investment

Where historical capital investment has reduced the likelihood of an outage event occurring, or reduced duration/magnitude below that recorded historically, adjustments should be made to the calculated magnitude/duration/likelihood probability distributions, based on post-investment outage evidence where it is available or on appropriate expert judgement.

This can be done either by specifying a factored adjustment to any of the distribution parameters, or by specifying an average distribution for the failure type, water resource zone or sourceworks type. The distributions of similar events at other sourceworks more representative of the post-investment conditions can be used to inform factor adjustments, or similar events from multi-company compiled data, where this is available.

For future capital investment, adjustments should be made by adding another distribution row to the assessment, specifying the year from which investment is scheduled to deliver improvements. The distribution parameters can be specified in the same way as for historical investment adjustments.

## Seasonality

Seasonality is important for determining whether events are valid for certain planning scenarios, as described in WRMP legitimate outage screening. It may also affect the duration, magnitude or likelihood of events.
Some events may have a shorter duration if occurring in a summer peak period because resolving them is prioritised compared to their occurrence in winter, even in a dry year (or because it may not yet be recognised as a dry year). Similarly, some events may be more likely to happen during periods of high demand on the system, because assets are being stressed beyond their typical operating range.

Adjustments should be made to probability distributions accordingly, for each relevant planning scenario.
Seasonality can also be important for planning options to reduce outage. If it is known that events of a certain type tend to occur more frequently or with higher impact at a certain time of year, then the causation factors behind these events can be better assessed, and options to mitigate them better developed.

## Forecast changes in DO

Changes to forecast DO can be made in the following circumstances:

- Where sustainability reductions, climate change, severe drought or water quality are forecast to impact DO at known times in the future
- where these changes would affect the magnitude of outage impacts on DO
- where these impacts could be material to the supply demand balance, companies should adjust outage magnitude distributions.

This can be done in the outage platform by adding an extra distribution row(s) for the relevant sourceworks and event types for relevant years in the future and adjusting the magnitude distributions as appropriate. For gradual changes, we recommend specifying new rows no more frequently than 5-year intervals. Sensitivity testing should be applied to decide what magnitude of future change in DO is sufficient to justify adjusting outage distributions.

# WRMP outage allowance modelling

## Sensitivity testing

Sensitivity testing should be carried out to test the impact on outage allowance of any outage analysis or modelling decisions based on assumptions, where these may be material to the supply demand balance.

A strategy for sensitivity testing should be based on an initial review of the contribution to outage of different event types and sourceworks. Where event types/sourceworks make very little contribution, there is no need to test assumptions relevant only to those types/sourceworks, unless the subjective decision could have dramatically reduced the outage contribution.

If materiality is in doubt, an assumption should be tested: the costs of testing are likely to be many orders of magnitude less than the WRMP investment costs or economic drought costs due to an incorrect outage allowance.

Decisions likely to require sensitivity testing are as follows:

- The clipping of historical data records
- Any data infilling
- Partial outage systematic error corrections, or application of generic partial outage distributions
- Including/excluding events that are on the boundary with system resilience: relatively high impact, low likelihood events, where it is unclear whether or not they should be included or not
- Including/excluding events that may be accounted for in target headroom
- Uncertain magnitude/duration/likelihood adjustments or exclusions to account for capital investment

- Uncertainties in DYAA DO recovery
- Uncertainties over seasonality
- System simulation uncertainties
- Event correlation uncertainties
- Applying generic WRZ or event type distributions rather than historical event-based distributions
- Future DO changes' materiality to outage.

# Identifying and accounting for WRMP options

## Final preferred scenario

Companies should take account of the final preferred programme of options when modelling outage for the final preferred planning scenarios.

How new options are accounted for depends on the option type and nature of the supply demand driver(s) is detailed as follows:

- For new options replacing supply-side losses that are very similar to the sources being lost, the original outage event data may be representative of the new sources. Outage should have been reduced over time to account for the DO loss in the baseline scenario, and in the final preferred scenario, the reductions in outage can simply be removed (outage added back in).
- For new options replacing supply-side losses, whose outage risk is very different to that of the original sources, or for options to mitigate increasing demand, generic outage distributions should be applied using average distributions for the most representative sources (with failure risk similar to that of a new source), or WRZ-average distributions, where WRZ resources are similar enough to the new option from an outage-risk point of view.
- If companies have no representative sources on which to base their outage allowance, they should consider requesting representative outage duration, likelihood and magnitude data from the WRSE group for similar resource types.

Regulators have indicated their expectation that the overall outage allowance as a % of DYAA demand would be expected to fall over time, as companies become more adept at managing outage risk and as a result of capital maintenance investment. Adding outage allowance for new options is likely to be offset by rising demand, and for sources of a similar type, the specified outage allowance should be lower than that in the baseline forecast. This may not always be possible. For example, if inherently reliable groundwater resources are replaced by effluent reuse (perhaps for sustainability reasons), then the complexity of the replacement source may increase, not reduce, outage allowance, and it would do so for legitimate reasons. The key is that companies can explain the increase and demonstrate that they have mitigated outage risks from the new source as far as they can.

## Strategic Regional Options (SROs)

For SROs, companies are unlikely to have a sufficient range of events of each type at similar sourceworks, if any, on which to base generic probability distributions. We therefore recommend that companies share their outage event data for all SRO sourcework types, to enable such distributions to be derived.

These distributions should be regularly updated as new events occur, ideally on an annual basis. Data may be anonymised to reduce any risks associated with the security of sources or commercial risks to the water company

## Identifying outage options

Companies should aim to identify options to generate DO benefit, and also options to improve system resilience, in line with the WRSE guidance on system resilience.

To identify DO benefit options, companies should review the outage allowance breakdown by source and event type, and identify those making the greatest contribution to outage under the critical planning scenario.

For each of these types, consideration should be given to what interventions could be made to reduce outage magnitude, duration or likelihood. Where feasible options exist, a new model run should be undertaken with the relevant outage distribution(s) adjusted to reflect the intervention. The reduction in outage allowance should then be used to specify the DO (WAFU) benefit of the option.

Other benefits/impacts of the intervention should be specified in line with the company's normal process for evaluating options and the option taken forward for development and appraisal.

For failure types relating to pollution of any sort, companies should look to the wider catchment to find blue-green solutions first, before identifying hard infrastructure options.

To identify potential resilience-only options for WRSE regional planning, and company resilience plans, companies should follow the resilience guidance specified by WRSE to seek out options that would materially increase the score of one or more WRSE resilience metrics. While these are still under development, the most relevant metrics are:

- Metric R3 – Vulnerability of Infrastructure to Other Hazards
- Metric R5 – Catchment & raw water quality risks

Resilience options should be taken forward in the regional planning process for appraisal and selection

# Materiality considerations

Our gap analysis showed that all WRSE companies already apply the same event-based, bottom-up method to determine outage allowance, irrespective of problem characterisation. Given data availability and the reliability of this approach, we see no reason for companies to move away from this method, whatever their problem characterisation.

Problem characterisation should be used to inform the effort to which companies go to deliver all aspects of this common methodology, within the methodology proposed.

Two key factors should be considered:

1. The materiality of the outage allowance for a particular WRZ to the water resource planning problem for both the company and WRSE. We propose a material outage allowance is one where either:
   - the outage allowance is >10% of the deficit in a WRZ or any directly neighbouring WRZs; or
   - the outage allowance is > 20 Ml/d.
2. The materiality of each item of the methodology to the outage allowance for the WRZ. We propose a material outage item is one where its impact on the allowance is the lower of:
   - 10% of the total WRZ outage allowance
   - The Ml/d difference between the P75 outage allowance and the P95 outage allowance.

For non-material outage allowances, companies should aim to adopt the methodology here but only to the extent that time and resources allow. Where a WRZ outage allowance is material, each aspect of the WRSE methodology should be tested for sensitivity and then applied as far as necessary to reduce its uncertainty impact on the overall allowance to below 10%.

Materiality is relevant in particular to: partial outage magnitudes; DYAA DO recovery; system simulation of outage magnitude/duration; capital investment adjustments; forecast changes in DO. Companies should always attempt to account for these, but where significant effort is required (e.g. system simulation modelling), this should only be undertaken where the impacts could be material to the outage allowance.

Examples:

1. A WRZ is forecast a surplus >20% of DI throughout the planning period, the WRMP19 outage allowance for the WRZ was 1 Ml/d and DI was 20 Ml/d. The company has a deficit of 5 Ml/d in a neighbouring zone, but no other deficits. In this case, the outage allowance is clearly not material to WRSE, or the WRZ itself. It is unlikely to be material to the neighbouring zone either, but 0.5 Ml/d could enable some additional transfer to be provided. Therefore, the company should only apply methodology items specified here to the extent they would (in combination) impact outage allowance by at least 0.5 Ml/d.

2. A WRZ is forecast a surplus of >20% of DI at all times, but the WRMP19 outage allowance was 30 Ml/d. In this case, the outage allowance is potentially material to WRSE. The initial WRMP24 outage run suggests WRMP24 outage of 28 Ml/d and a range in outage between P75 and P95 of 2 Ml/d. This range is less than 10% of the WRZ outage, so elements of the methodology should be applied to the extent they could impact outage by at least 2 Ml/d. If an area of uncertainty would have only 1.8 Ml/d of impact, no further work is needed to resolve that area of uncertainty.

# 4 Next steps

4.1 We consulted on this Method Statement from 31st July 2020 to 31st October 2020. This Method Statement has now been updated to take into account the comments we receive during this consultation process and has been published on our website.

4.2 We may need to update parts of our Method Statements in response to regulatory reviews, stakeholder comments or improvements identified during the implementation phase of the methodology.

4.3 If any other relevant guidance notes or policies are issued, then we will review the relevant Method Statement(s) and see if they need to be updated

# Appendix 1: Programme

| | Activity | June 05-Jun | June 12-Jun | June 19-Jun | June 26-Jun | July 03-Jul | July 10-Jul | July 17-Jul | July 24-Jul | July 31-Jul | August 07-Aug | August 14-Aug | August 21-Aug | August 28-Aug |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **2** | **Task 1 - Assess current practice** | | | | | | | | | | | | | |
| **2.1** | **Define assessment criteria** | | | | | | | | | | | | | |
| 2.1.1 | Review relevant guidelines and assessment criteria | | | | | | | | | | | | | |
| 2.1.2 | Create framework of questions and assessment criteria | | | | | | | | | | | | | |
| **2.2** | **Review practice against criteria** | | | | | | | | | | | | | |
| 2.2.1 | Circulate framework of questions to stakeholders | | | | | | | | | | | | | |
| 2.2.2 | Review outage reports/assessments | | | | | | | | | | | | | |
| 2.2.3 | Conduct interviews with companies & regulators | | | | | | | | | | | | | |
| 2.2.4 | Compile results and undertake gap analysis | | | | | | | | | | | | | |
| **2.3** | **Task 1 - Report** | | | | | | | | | | | | | |
| 2.3.1 | Assess consistency in outage reporting and assessment | | | | | | | | | | | | | |
| 2.3.2 | Prepare draft Stage 1 report and issue to WRSE | | | | | | | | | | | | | |
| 2.3.3 | Present findings to WRSE | | | | | | | | | | | | | |
| 2.3.4 | Finalise report on receipt of feedback | | | | | | | | | | | | | |
| **3** | **Task 2 - Develop improved approach** | | | | | | | | | | | | | |
| **3.1** | **Develop methodology** | | | | | | | | | | | | | |
| 3.1.1 | Develop improved method to address inconsistencies | | | | | | | | | | | | | |
| 3.1.2 | Develop methods to record outage data consistently | | | | | | | | | | | | | |
| **3.2** | **Test proof of concept** | | | | | | | | | | | | | |
| 3.2.1 | Request/receipt of sample data for 1 WRZ for each company | | | | | | | | | | | | | |
| 3.2.2 | Review data, build proof of concept models to test method | | | | | | | | | | | | | |
| 3.2.3 | Models and guidance sent to companies to complete and run | | | | | | | | | | | | | |
| 3.2.4 | Companies apply own data to models to test method | | | | | | | | | | | | | |
| 3.2.5 | Provide telephone support to companies | | | | | | | | | | | | | |
| 3.2.6 | Compile results and structured feedback from companies | | | | | | | | | | | | | |
| 3.2.7 | Consider use of data platform to record/process outage data | | | | | | | | | | | | | |
| 3.2.8 | Compile findings and present at stakeholder workshop | | | | | | | | | | | | | |
| **3.3** | **Develop full methodology** | | | | | | | | | | | | | |
| 3.3.1 | Draft complete methodology including next steps | | | | | | | | | | | | | |
| 3.3.2 | Review and QA | | | | | | | | | | | | | |
| 3.3.3 | Issue to WRSE for review and discuss feedback | | | | | | | | | | | | | |
| 3.3.4 | Update methodology | | | | | | | | | | | | | |
| 3.3.5 | Final methodology inc. next steps and further improvements | | | | | | | | | | | | | |
| **3.4** | **Project management** | | | | | | | | | | | | | |
| 3.4.1 | Regular liaison with steering group | | | | | | | | | | | | | |

# Appendix 2: Detail of outage approach

Figure 5: Data capture and initial analysis summary of approach

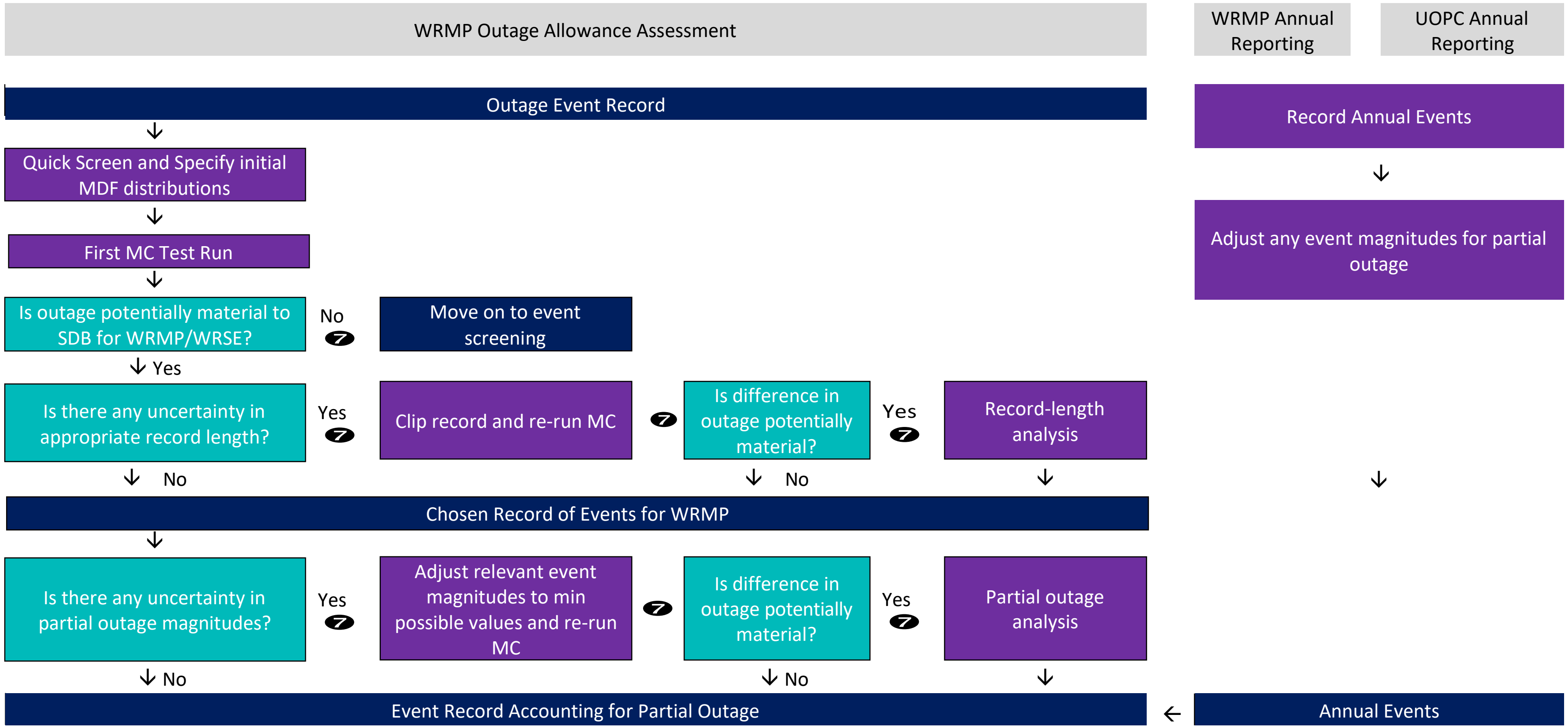


Figure 6: Legitimate event screening summary of approach

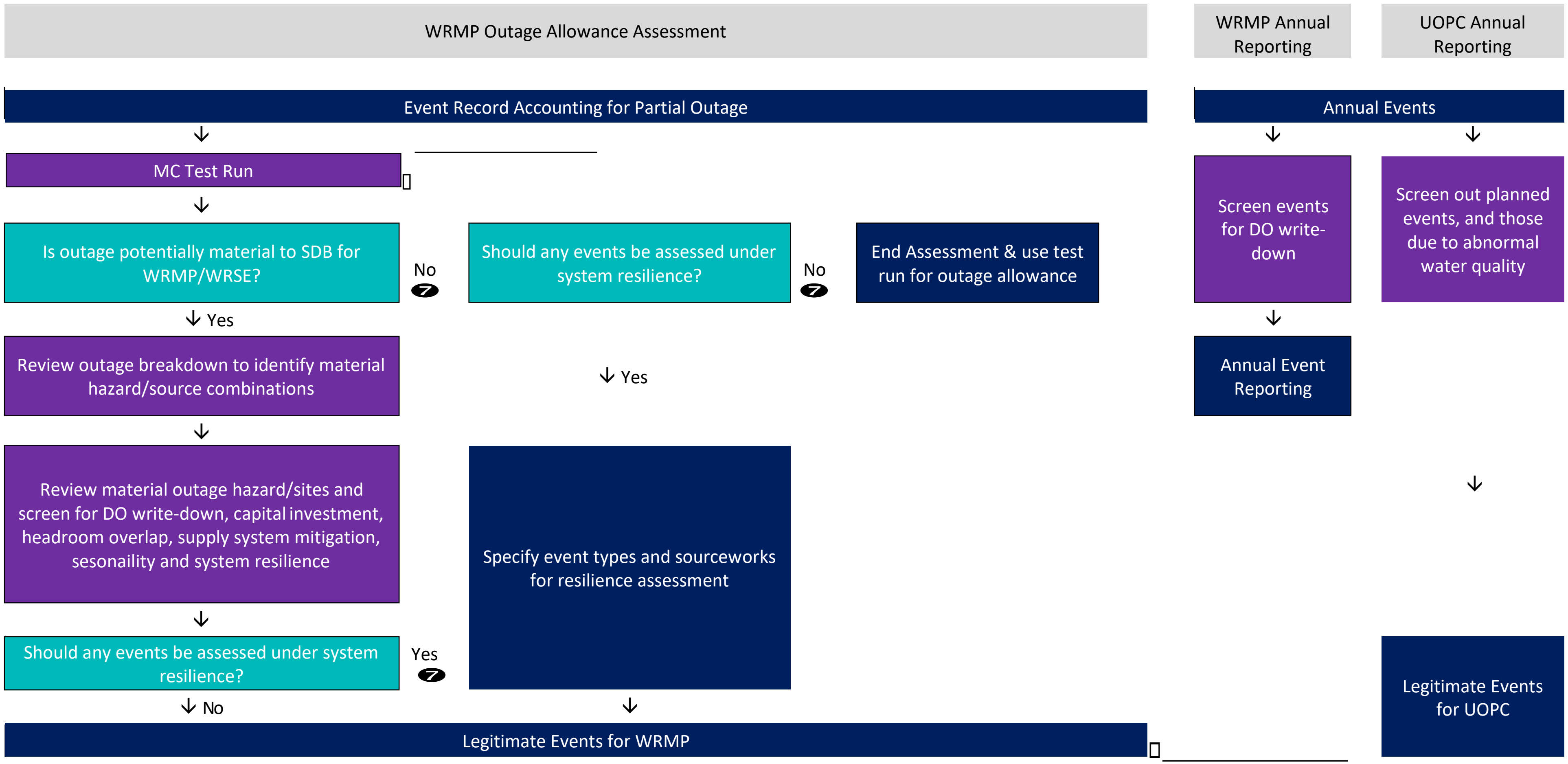


Figure 7: Summary of approach to event adjustments

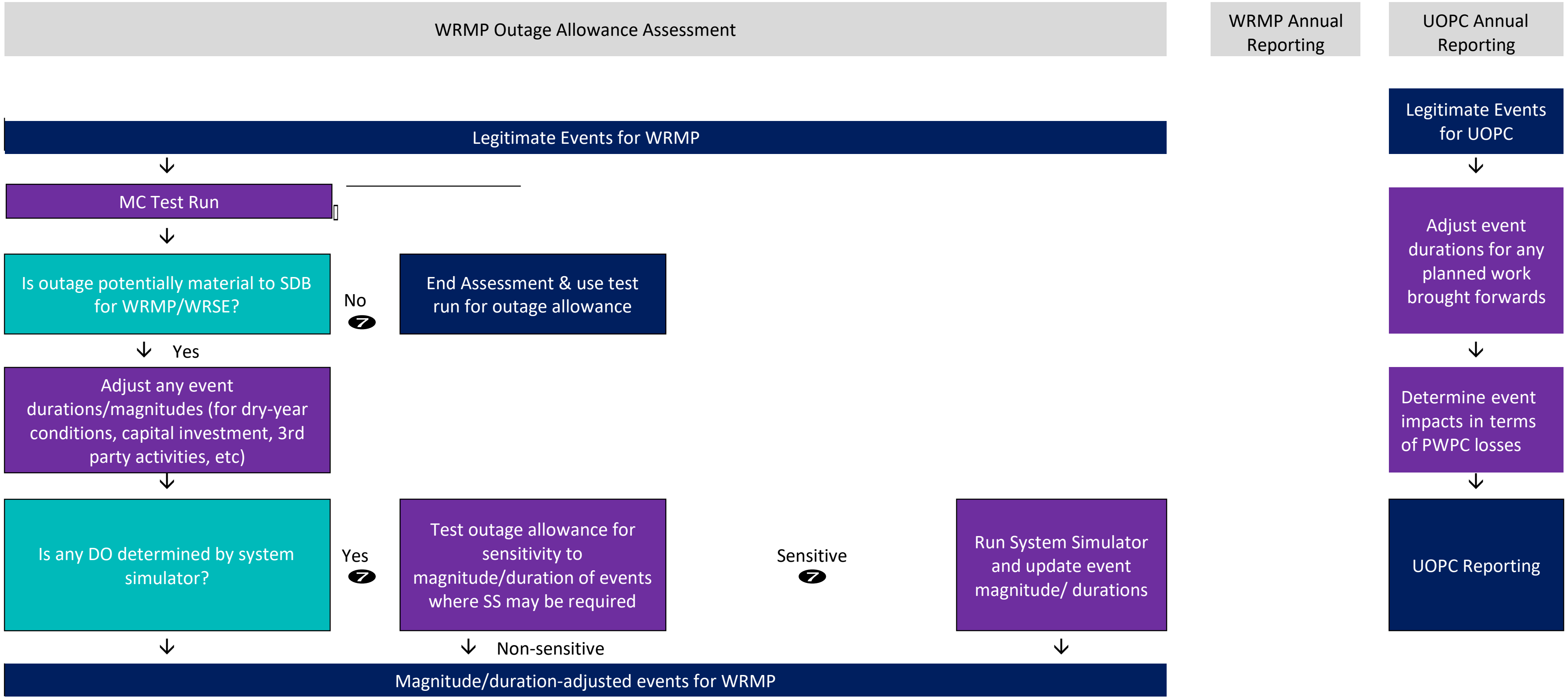


Figure 8: Probability distribution function adjustment summary of approach

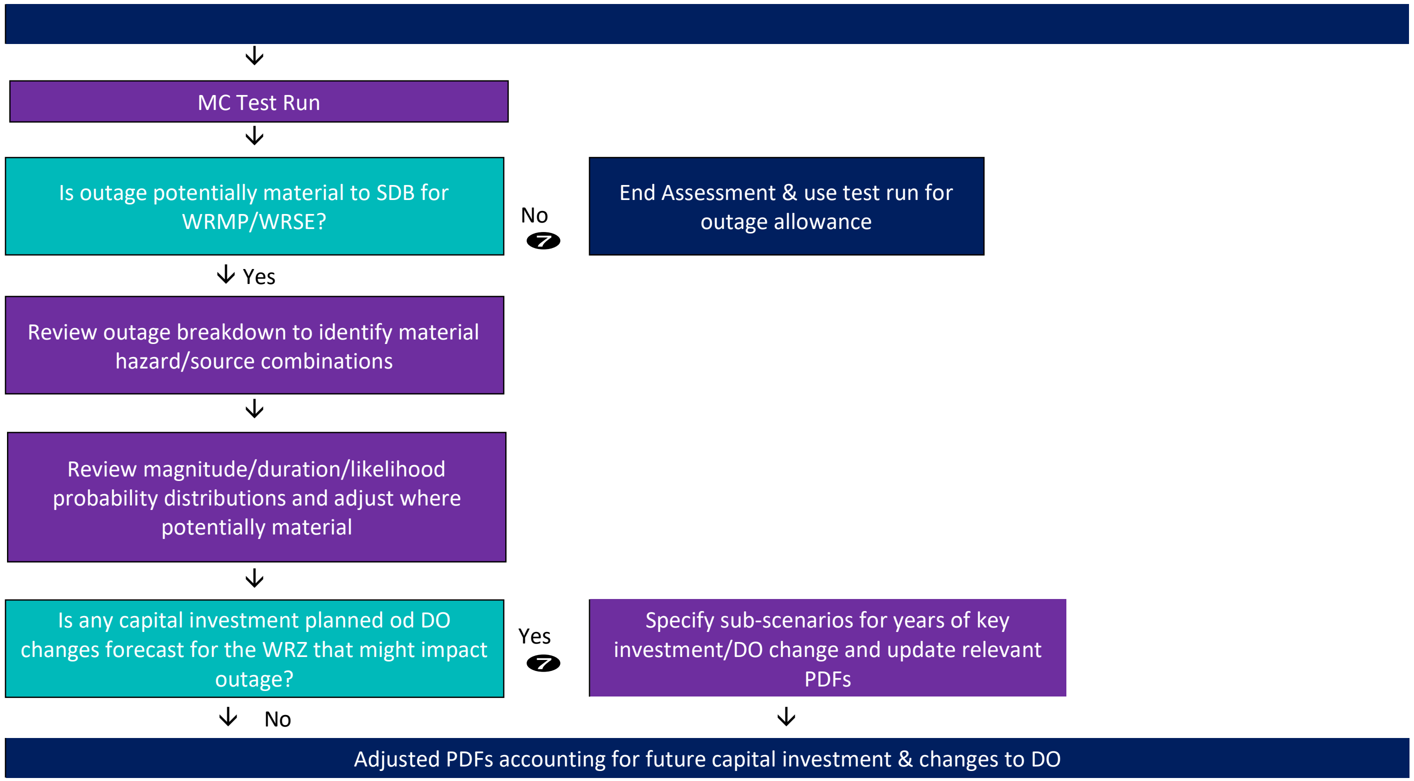
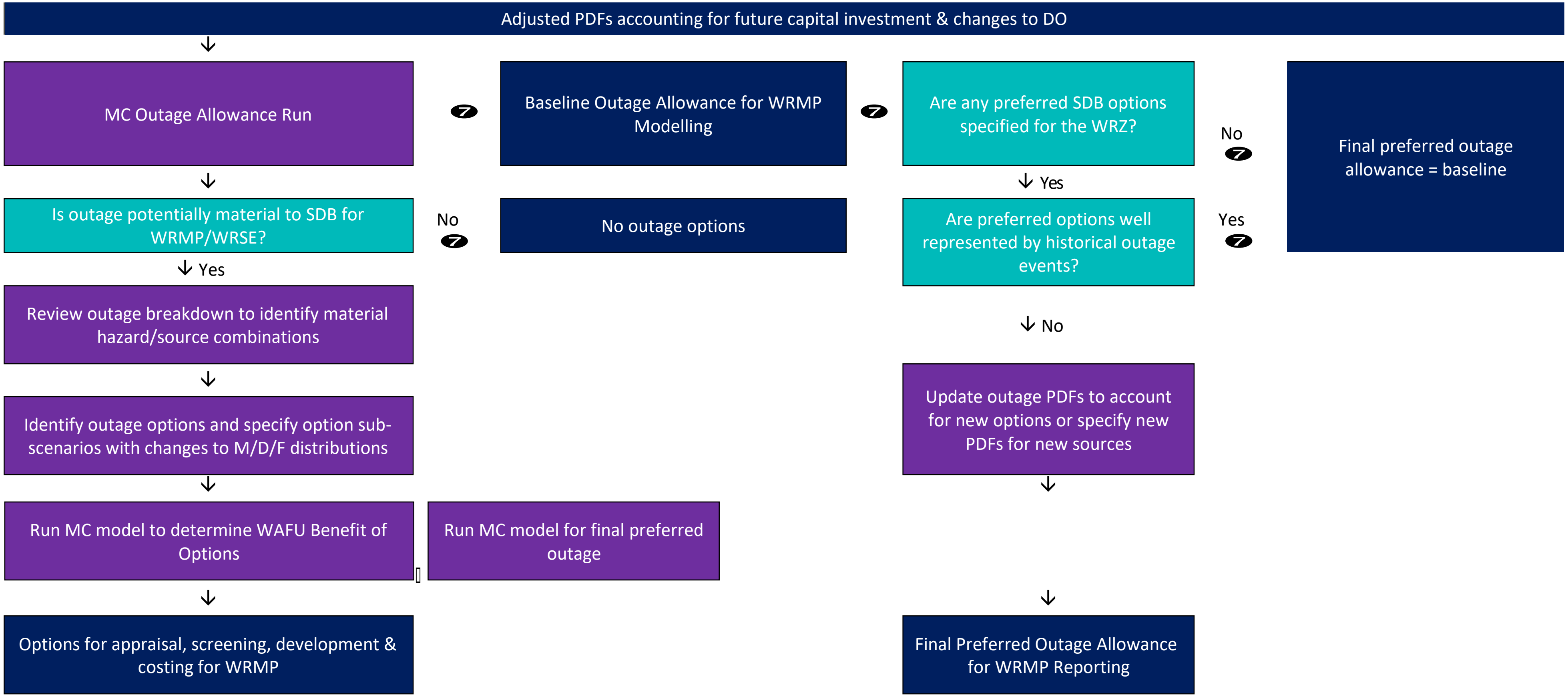


Figure 9: Summary of approach to scenarios & options



# Appendix 3: WRSE outage modelling tool

The WRSE outage modelling tool (OMT) is an Excel-based spreadsheet platform developed to enable consistent reporting and analysis for annual reporting to the Environment Agency, reporting to Ofwat for specifying performance against the unplanned outage PC, and for WRMP outage allowance determination

## Overview of the OMT

The WRSE outage modelling tool (OMT) is designed to do the following:

- Compile and process company outage events into a single consistent format for all purposes
- Enable consistent screening to identify legitimate events for both sets of annual reporting and for WRMP outage allowance calculations
- Determine appropriate probability distribution functions for the duration, magnitude and likelihood of event types at each relevant sourceworks, taking account of dry year scenario response, potential for deployable output recovery, planned capital investment, etc
- Calculate the WRMP outage allowance for each planning scenario
- Evaluate the key causes of outage and their impacts on the supply demand balance
- Identify WRMP options to reduce the outage allowance required, and therefore increase WAFU
- Determine the WAFU benefits of these options, which can then be taken forward for development and appraisal.

The tool comprises 15 worksheets, as follows.

| Worksheet | Purpose | User interaction |
|---|---|---|
| Cover | Record dates and user details.<br>Log changes to the OMT between different iterations | Text inputs |
| Instructions | Describe how the OMT should be used | Reference only |
| Process | A recommended approach to delivering the outage assessment for outage allowance, with approx. time requirements and an example programme | Reference only |
| Screening Guidance | Guidance for how to complete the Source DO and Outage Events sheets to identify legitimate events for reporting/modelling | Reference only |
| Source DO | Specify the source DO and PWPC values for determining outage magnitudes, and licensing information to help inform potential for DO recovery from outage | Data input & user interpretation |
| Outage Events | Compile all outage events; screening to identify legitimate events; adjustments to event magnitudes or durations for modelling purposes. | Data input & user interpretation |

| Worksheet | Purpose | User interaction |
|---|---|---|
| Settings | Specify the planning scenarios and sub-scenarios to be modelled and their durations, as well as the set of source names, WRZ names and event hazard types | Specification of key information |
| Fitted Distributions | An initial processing sheet to determine the statistical properties of every event type at each sourceworks | Refresh and reference only |
| Single Distribution | A review sheet to help inform choice of probability distribution for each event type/sourceworks combination | Drop-down chart review |
| Simple Fitted (2013) | A simpler version of the fitted distribution sheet for quick review of event type/sourceworks min/max/mean, for those without access to Power Query (Excel 2016) | Reference only |
| MC Inputs | Specifies the PDF parameters for duration, magnitude and frequency of event types at each sourceworks, under each modelled scenario and sub-scenario | Populate source names event types, (sub)scenarios, and specify distributions |
| MC Outputs | Outputs Monte Carlo outage allowance values for every decile of the probability distribution for all sources, event types and scenarios | Refresh and review |
| Charts | Displays the outage allowance results graphically by source and event type for selected percentiles and scenarios | Review to inform screening effort and identify interventions |
| Scenario Review | Presents graphs of probability and cumulative distribution functions for specified combinations of sources, event types and scenarios, to inform outage allowance for WRMP and specify option WAFU benefits | Drop down review and interpretation |
| Profiles | Compare outage allowance results for different sub-scenarios, to identify any changes in outage allowance over time or between sub-scenarios | Review and interpretation |
| @Risk Output | Outputs outage allowance results determined through @Risk to cross-check the Power Query results and compare to previous outage allowance determinations | Reference only, unless @Risk analysis preferred |

The OMT is built in Microsoft Excel and uses code written in Microsoft Power Query to process data efficiently via a series of pivot tables. Power query is automatically enabled in Excel 2016 or later versions, but may need Power Query installed as an add-in for earlier versions.

A summary of the process for populating and running the tool is as follows.

| Area | Ref | Task |
|---|---|---|
| Data Capture | 1.1 | Create a copy of the OMT for the WRZ |
| | 1.2 | Upload DO data and specify DYAA recovery potential |
| | 1.3 | Upload all potentially relevant outage data & categories |
| Initial Analysis | 2.1 | Run & check OMT model (refresh tables) |
| | 2.2 | Check P95 allowance for materiality to the WRMP/regional group |
| | 2.3 | Check data record length (clipping) materiality |
| | 2.4 | Update data record length |

| Area | Ref | Task |
|---|---|---|
| | 2.5 | Assess materiality of partial outage |
| | 2.6 | Adjust partial outage magnitudes |
| | 2.7 | Re-run OMT & re-check for WRSE materiality |
| Screen Events | 3.1 | Identify any material source/hazard combinations |
| | 3.2 | Screen relevant events as per Methodology |
| | 3.3 | Re-run OMT & re-check for materiality to the WRMP/regional group |
| Process Events | 4.1 | Review material site/hazard events and carry out M/D adjustments where appropriate |
| | 4.2 | Check where system simulation may be necessary and run OMT to check its potential materiality |
| | 4.3 | Scope system simulation requirements |
| | 4.4 | Carry out system simulation for outage impacts |
| Adjust PDFs | 5.1 | Refresh event distributions & review single distributions for material site/hazards. Update where necessary |
| | 5.2 | Adjust M/D/F material site/hazards distributions for future changes |
| | 5.3 | Re-run OMT & check any remaining areas of uncertainty for materiality. Identify outage allowance for the WRZ |
| Develop Options | 6.1 | Identify any material site/hazards that may be suitable for options to increase WAFU or provide wider resilience benefit |
| | 6.2 | Propose options to reduce event M/D/F & quantify the potential changes |
| | 6.3 | Adjust M/D/F distributions for options and re-run the OMT |
| | 6.4 | Re-run the OMT to identify option WAFU benefits |
| | 6.5 | Specify any resilience metric impacts |
| | 6.6 | Estimate intervention high level costs |
| | 6.7 | Identify potentially cost-effective options for the unconstrained list and inform the company's options appraisal team |
| | 6.8 | Specify rejected options for inclusion on the WRMP rejection register and inform the company's options appraisal team |

Note that in the OMT, "ADO", "PDO" and "MDO" are used interchangeably with "DYAA", "DYCP" and "DYMDO" respectively. "Sourceworks" and "outage types" are used interchangeably with "Sites" and "Hazards" respectively. "Frequency" and "likelihood" are also used interchangeably when referring to probability distributions.

# Method Statement: Environmental Ambition

**January 2022**

| Title | Method Statement: Environmental Ambition |
|---|---|
| **Last updated** | January 2022 |
| **Version** | Post-consultation version |
| **History of Changes made to this version** | Addressing consultation feedback and the revised Water Resources Planning Guidance.<br>Consultation feedback received from:<br>- River Thames Society<br>- Cotswold Canals Trust<br>- RWE<br>- Historic England<br>- Environment Agency<br>- Oxfordshire County Council |
| **Summary of areas where substantive changes have been made as a result of consultation feedback** | Restructure, and more detail added on the scenario development, wider environmental benefits and Non-PWS benefits. |
| **Summary of areas where substantive changes have been made as a result of the revised Water Resource Planning Guidelines** | N/A |
| **Author** | Meyrick Gough, Nathan Burt, Sarah Green |
| **Approved by** | Chris Lambert, Sarah Green |
| **WRSE Director Approval** | Trevor Bishop |

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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement HQ platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

# Executive Summary

Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2100.

We have prepared method statements setting out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. We have consulted on these to ensure that our methods are transparent and as far as possible, reflect the views and requirements of customers and stakeholders.

Figure ES1 illustrates how this environmental ambition method statement will contribute to the preparation process for the regional resilience plan.

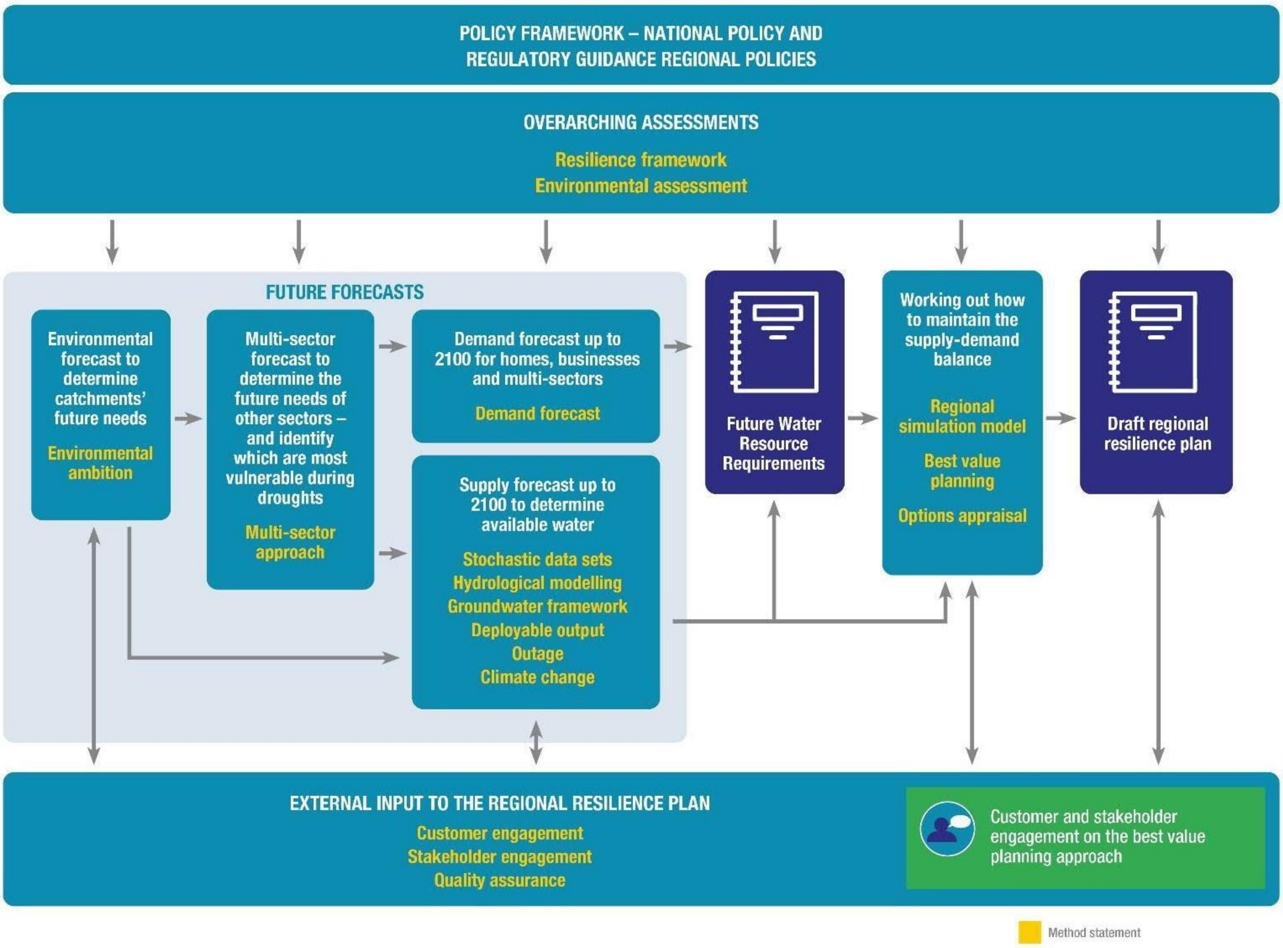
Environmental ambition is a term that was introduced through the Environment Agency's Water Resources National Framework document, published in March 2020. The term refers to the consideration of actions to build environmental resilience to future challenges, such as drought, flooding, raw water quality decline, climate change, impact from invasive non-native species, land use change, and impacts from run off. This information is important to understand to ensure we can leave the environment in a better place for future generations.

The current regulatory guidance on environmental ambition or "environmental destination" is evolving as regulators, water companies and stakeholders iteratively work through the challenges faced. Due to the changing nature of how environmental ambition is represented in the regional plan, this method statement gives an overview of the current approach and outlines the proposed next steps.

Understanding how much water can be abstracted from the environment in a sustainable way, now and in the future, is crucial when developing a regional resilience multi-sector plan. In the past the regional plan has taken account of the supply and demand forecasts, but not the longer-term needs of the environment.

This method statement outlines how sustainability reductions have been calculated and incorporated into the regional plan. The Environment Agency has recently completed a longer-term environmental water needs assessment as part of the Water Resources National Framework, and this work has established potential licence reductions which are outlined in this Method Statement.

**Figure ES1: Overview of the method statements and their role in the development of the WRSE regional resilience plan**



# 1 Environmental Ambition

1.1 Planning for the future water requirements of the region requires an understanding of the issues and challenges that the region faces today and those that it could face in the near and long-term future. This understanding helps improve the decisions around what are the best set of options to develop now and in the future. There are many competing pressures on a range of environmental objectives, surface water sources and groundwater sources. The development of environmental ambition aims to set out a path to secure environmental resilience, enable all activities to thrive, and secure future water supplies for all uses.

1.2 Historic planning approaches have always included forecasts for demand and supply. The future requirements of the environment were constrained to those outcomes defined through the Water Industry National Environment Programme (WINEP). This resulted in the requirements for the environment being restricted to an anticipated set of activities over the next 5 to 15 years. This process meant that the future, longer-term impacts to the environment and, therefore, the resilience of the environment, were never fully represented in plans. Working alongside the Environment Agency, WRSE is developing a longer-term forecast for the environment, setting out our 'environmental ambition' for the region.

1.3 The development of the region's environmental ambition combines the knowledge and understanding of the existing pressures across the 32 catchments in the South East of England from assessment methods and the river basin management plans, coupled with the knowledge of the companies and stakeholders to develop a series of potentially shared solutions. WRSE has worked and continues to work alongside the Environment Agency to develop and test the environmental ambition scenarios discussed in this method statement. This shared understanding will help to ensure a more resilient environment for the future.

1.4 The development of our environmental ambition will align with Government policies including the Defra 25-year environment plan, as well as the Environment Bill and Agriculture Bill. These are likely to significantly change the environmental regulatory framework that has been worked to in the past, particularly relating to resilience of the environment to provide clean and plentiful water, biodiversity net gain and carbon neutrality as well as working to improve wellbeing, recreation, and heritage.

1.5 This method statement sets out the development of WRSE's approach to environmental ambition undertaken to date, and the steps we will continue to take to develop our environmental ambition for the region.

1.6 The development of a regional environmental ambition will require different activities in the short-term and compared to the medium- and long-term depending on how the climate and landscapes change in the region over time.

# 2 Environmental Ambition scenarios

## Overview

2.1 The purpose of this Environmental Ambition Method Statement is to outline the approach undertaken to develop the environmental ambition scenarios which will be used to derive an adaptive regional plan which can encompass a range of possible futures.

2.2 Due to increasing future sustainability reductions, the levels of environmental protection are likely to be much greater than current levels. This enables us to move towards planning for proactive protection rather than retrospective remediation of our vulnerable water ecologies, which includes over 41% of the world's chalk streams.

2.3 Our approach is a step change to how environmental ambition has been incorporated in regional planning historically, and the adopted approach has been developed in collaboration with water companies and regulators, with consultation with stakeholders and customers.

2.4 Our approach will allow us to target existing and future environmental issues and identify potential opportunities and schemes to deliver water resource and water quality benefits in the future. These opportunities can be put forward to the water companies and other sectors to help improve the resilience of the environment under the modelled future scenarios in the regional plan.

## Integration with regulatory requirements

2.5 The historic water company approach to protecting the environment has been focused on what improvements are required in the next 5 to 15 years to deliver the improvements set out in the Water Industry National Environment Programme (WINEP). Typically, this programme delivers schemes and seeks to investigate potential issues which might then feed into the next round of water company business plans.

2.6 The WINEP investigations drive more detailed local studies being undertaken which provide a forum to discuss the current pressures; collect relevant data; create a better understanding of how the system works; and the reasons for environmental failures and then agree a set of actions to be implemented.

2.7 Whilst the WINEP provides the actions required in the short-term to be compliant with environmental legislation, the process does not lend itself to considering a more collective longer-term approach as the approach doesn't account for potential landscape changes or the impact climate change might have on the availability of water in the future. For this reason, there is a need to use other approaches to provide the additional information required.

## Current requirements

2.8 The protection of our current habitats is set out in European and UK legislation. The water industry along with the regulators have been investigating and implementing catchment and source based solutions through WINEP for several decades.

2.9 Typically these investigations focus on source abstraction investigations and potential reductions. Following the Water Framework Directive (WFD) a number of other issues, beyond just flows, were identified that prevent some water bodies reaching good ecological status. Therefore, a number of broader catchment-based schemes have been implemented by other sectors and the water industry to tackle water quality issues, invasive species, river restoration as well as licence reductions.

2.10 These investigations and solutions continue to be delivered through the WINEP process. Historic investigations also serve as a good source of evidence for previous investigations. Therefore, the environmental process will seek to integrate the immediate issues that need to be addressed in the catchment with the potential future issues of the region.

## Future requirements

2.11 The proposed approach to define the longer-term requirements of the catchments, by our environmental regulators, is to use flow indicators (Appendix 1). We propose to determine the future, longer term, requirements of the environment through our current understanding of the catchment processes, evidence collated, local knowledge obtained from the catchment workshops, the environmental assessment tool, resilience criteria, landscape changes, water quality trends and potential future flow targets. As these different data streams are uncertain, we will generate a number of potential future environmental requirements by creating a number of environmental scenarios. These are highly uncertain, therefore, WRSE will choose scenarios that provide boundaries between what we currently know we need to protect and what might be required under more extreme scenarios. We will examine the future environmental scenarios set out by our regulators as well as those developed by water companies on the basis of local investigations.

2.12 Flow indicators do not address the quality aspects within a catchment. Therefore, where there are long term trends on water quality parameters such as nitrate, phosphates, pesticides, etc we will use this information to predict what quality aspects might influence the catchments in each of the scenarios and therefore what catchment solutions might be available to address or arrest these longer-term trends.

2.13 Our environmental assessment approach is set out in Method Statement 1329 WRSE Environmental Assessments, which describes how we intend to use the approach to help assess the overall regional resilience plan.

# Approach to developing scenarios

2.14 Just as we take account of future population growth, the development of environmental ambition scenarios allows us to take account of the future requirements of the environment; allowing for a more robust regional plan to be constructed. This is a step change in approach from previous plans.

2.15 Our approach has sought to integrate the existing, well established process, with other indicators to provide a better longer-term view of the potential requirements of the environment. We have sought to blend these approaches to generate plausible future scenarios and ensure our environment is well protected in the future.

2.16 The Environment Agency has completed a longer-term environmental water needs assessment as part of the Water Resources National Framework, establishing the potential licence reductions required by 2050 to meet the Environmental Flow Indicators (EFI) so that a good ecological status is achieved or maintained. The EFI is defined by an Abstraction Sensitivity Band (ASB) allocated to each waterbody. Four scenarios were initially analysed, as detailed in the table below:

**Table 1: Environmental ambition scenarios set out in the National Framework**

| Business as usual (BAU) | Enhance | Adapt | Combine |
|---|---|---|---|
| The same percentage of natural flows for the environment that currently applies continues for the future. Uneconomic waterbodies, where reducing abstraction would imply a significant investment, were initially discarded. However, an additional scenario (BAU+) has subsequently been incorporated which includes these uneconomic waterbodies. | Greater environmental protection for protected areas and Sites of Special Scientific Interest (SSSI) rivers and wetlands, principal salmon and chalk rivers, achieved by applying the most restrictive ASB. | Same ASB as BAU but a recovery to a lower standard in some heavily modified waterbodies is assumed. | Balances a greater environmental protection for protected areas, SSSI rivers and wetlands and principal salmon and chalk rivers with a view that good status (as defined under the Water Framework Directive) cannot be achieved everywhere in a shifting climate. Hence, adopts the Enhance ASB with a lower recovery to the EFI in some heavily modified waterbodies. |

2.17 In all cases, flow balance evolves as a proportion of natural flows as these are changed by the impacts of climate change.

2.18 To calculate the deficits for each waterbody in 2050 under each of the above scenarios the Environment Agency utilised their bespoke spreadsheet, the Waterbody Abstraction tool. This tool calculates the water balance at the outlet of each waterbody for four flow regimes (Q30 – High flow, Q50 – Medium flow, Q70 – Medium/Low flow and Q95 – Low flow). The process we have undertaken to use this tool is detailed in the WRSE technical note “WRSE Environmental ambition – Sustainability reductions” which is available upon request.

2.19 The data extracted from the Waterbody abstraction tool has been transferred to a new spreadsheet designed to automatically derive the required sustainability reductions in 2050 in all waterbodies within the WRSE region. The development of the logic underpinning this tool has focused upon minimising the abstraction loss and hence the impact on deployable output (DO).

2.20 We have considered the impact on water resources in the region by applying the BAU+ and the Enhance scenarios within our investment modelling to meet regulatory guidance.

2.21 Water companies have reviewed the data for the BAU+ and Enhance scenarios in conjunction with WRSE and the Environment Agency, and using their local knowledge and existing operational data, have introduced two further scenarios – the Alternative and Central scenarios.

2.22 Developing the Alternative and Central scenarios has involved each water company assessing the delivery profiles and individual source sustainability reductions of the initial environmental ambition scenarios and delivery profiles. Water companies have assessed the deliverability of potential reductions at a water source level to develop the Alternative and Central scenarios.

2.23 Although WRSE has considered seven environmental ambition scenarios in total (BAU, BAU+, Enhance, Adapt, Combine, Central and Alternative), only four scenarios have been used as part of the investment modelling to date, as these best represent the range of environmental ambition for the region:

- BAU+
- Enhance
- Central
- Alternative

2.24 At a regional level, the BAU+ and Enhance scenarios provide the most challenging forecasts, with the Alternative scenario generally providing the least challenging forecast.

# 3 WRSE investment modelling

3.1 We have used the range of environmental ambition scenarios to forecast how much additional water may be needed to replace unsustainable abstraction beyond 2025 (not including those already included in the WINEP) in the WRSE investment model.

3.2 The WRSE investment model requires deployable output (DO) values for different time horizons and scenarios for each water resource zone (WRZ) and return period, both for average and peak period (please refer to **Method Statement 1318 WRSE Best Value Planning**). The Environment Agency methodology used to develop the environmental ambition scenarios can only provide an estimated reduction of average abstraction derived from the calculated licence reduction and the future predicted abstraction.

3.3 Estimating the final impact of the modelled sustainability reductions on DO would require system simulation, with licences for each public water supply (PWS) source modified. Likewise, the assessment undertaken following the Environment Agency approach relies on the accuracy of the prediction of future river flows as well as abstraction rates.

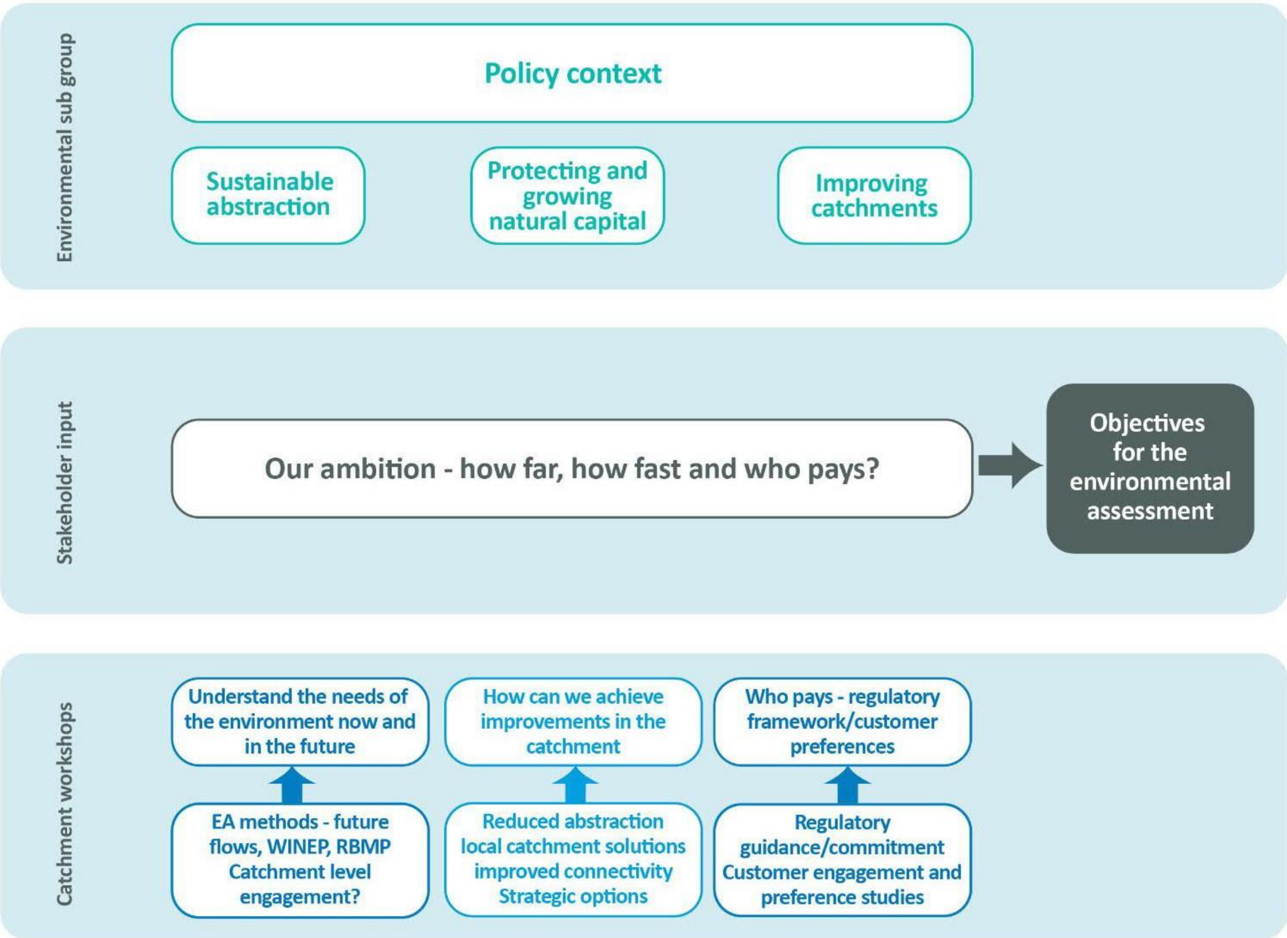
3.4 The results of the investment modelling using the different environmental ambition scenarios set out in the previous section and their effects on investment in the regional plan are being produced and shared by WRSE as part of the development of the emerging regional plan (January 2022).

# 4 Stakeholder engagement

4.1 Continuing to work collaboratively with our stakeholders will be key to the success of developing plausible environmental forecasts for the future. Working with our stakeholders will be important to develop our overall environmental ambition.

4.2 To help us with the process we have engaged with stakeholders both on a catchment area basis and at an overall regional basis through our environmental sub-group. Figure 4 sets out these groups and the range of questions we are trying to answer through these areas.

Figure 4: Range of questions for Stakeholder groups




4.3 As part of the catchment workshops held in 2020 and attended by regulators, Blueprint for Water, farmers and land managers, catchment partnerships and other potential parties who can implement solutions, an important consideration in the discussions were the reasons for environmental failure to ensure these can be represented within the environmental assessment objectives.

## Regulatory Engagement

4.4 WRSE has been engaging with the Environment Agency (EA) since the intention to move towards an environmental ambition approach was put forward in the Environment Agency's Water Resources National Framework document, published in March 2020. WRSE has worked alongside the EA to develop the sustainability reduction profiles needed to achieve the BAU+ and Enhance scenarios. We have done this by regularly engaging with local and national EA colleagues, water company officials, and broader stakeholders.

4.5 WRSE currently engages with the EA using its existing governance and engagement structure.

- Fortnightly WRSE Programme Management Board (PMB) meetings include water company and EA representatives. These meetings operate at a strategic level, discussing the development of regional plans and WRMPs.
- Decisions and actions from PMB meetings cascade down into monthly WRSE Environmental Destination meetings. These meetings consist of both PMB members, and regional EA leads. These meetings focus upon the specifics of developing national and company-specific environmental ambition scenarios and their delivery.
- Decisions and actions from these Environmental Destination meetings cascade down into meetings between the water companies and their local EA area teams. These meetings discuss technical points involved in the production of scenarios and delivery of environmental ambition at a company level.

## Approach to environmental option development

4.6 We held a series of catchment workshops in 2020 to capture additional local knowledge to understand any specific issues and the likely cause of the problems. These workshops covered each management catchment area in turn and has allowed us to better understand what the local issues (and possible solutions) are within each of the catchments that we and the other sectors abstract from in the South East. The catchment workshops were held with catchment partnerships and other local stakeholders.

4.7 The workshops were also employed to generate potential ideas for solutions and options which came from discussions upon the longer-term issues facing the catchments. These options workshops were key to enable WRSE to generate further regional and local options – please refer to **Method Statement 1328 WRSE Options Appraisal** for information on the formulation of options within the regional plan.

4.8 The options that were identified in the workshops have been collated into sets or portfolio. As noted in **Method Statement 1334 WRSE Multi Sector**, some of the issues in catchments might require a multi-sector solution. These portfolios have been put forward into the options appraisal process (see **Method Statement 1328 WRSE Options Appraisal**) which outlines the method for assessing these options in terms of their benefits. The assessments will also help to define catchment-wide solution sets for consideration in the investment model (against new supply and demand options).

4.9 Central to our method for deriving the environmental ambition for the region is to understand the needs of the environment now and in the future, and the way in which we can achieve improvements in the WRSE catchments.

4.10 When we conducted our catchment workshops in 2020 we based them around the following discussion points:

- To understand the specific **issues** that are making catchments less resilient and what can be done to improve this.
- To map out issues and identify **opportunities** and schemes to deliver water resource and water quality benefits that can be put forward to the water companies to improve resilience.
- Working with all **catchment stakeholders** to identify where these are.
- Setting out the impact to the environment under the future scenarios and discuss what other interventions might be needed in the future.

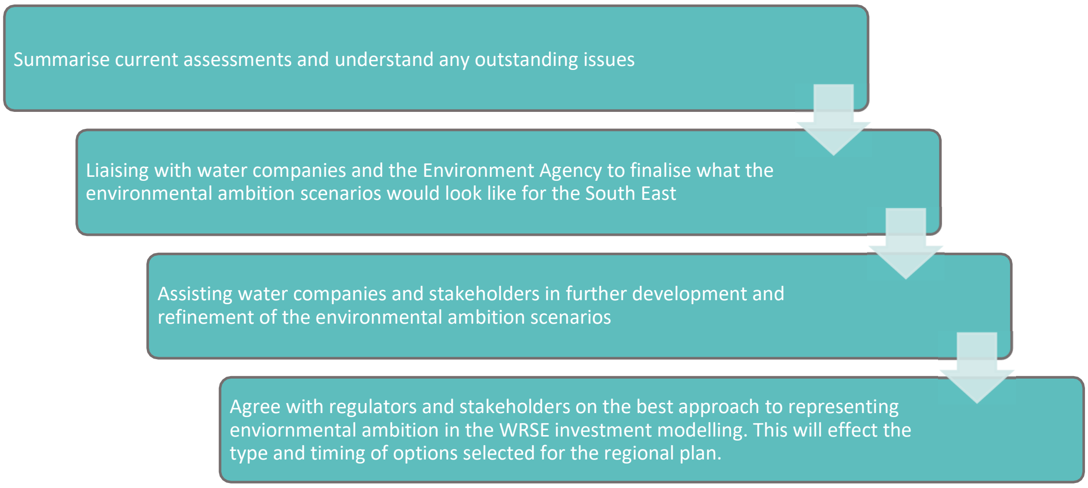
4.11 Any potential catchment solutions that came out of these workshops have fed into the catchment options workstream (see **Method Statement 1328 WRSE Environmental Assessments**) to see if they would be feasible and what benefits could be gained through the environmental assessment method and the resilience assessment framework.

# 5 Summary and Next Steps

5.1 This method statement sets out our proposed approach for defining an 'environment ambition' for the region and how it integrates with other workstreams.

5.2 The process follows a simple staged approach of understanding the issues, anticipating the potential needs, setting out the options and setting out solutions which can be considered in the regional plan, as shown in Figure 6.

**Figure 6: Developing the environmental ambition for a catchment.**




5.3 We are working with the Environment Agency and have produced a range of indicative scenarios which we have used to forecast how much water may be needed to replace unsustainable abstraction in the period from 2025 to 2050 and beyond. These consider the potential impact of climate change as well as the outputs of previous investigations and assessments.

5.4 We believe that continuation of this integrated approach will allow a robust, resilient regional plan to be developed which takes account of the current and future needs to ensure the environment in the South East is resilient for the future.

## Method Statement Updates

5.5 An initial version of this document was consulted upon between 1st August 2020 to 30th October 2020 and comments received during this time have been incorporated in this version of the method statement

5.6 If any other relevant guidance notes or policies are issued, then we will review the relevant method statement(s) and see if they need to be updated.

5.7 When we have finalised our Method Statement, we will ensure that we explain any changes we have made and publish an updated Method Statement on our website.

5.8 We will update our website with relevant information from time to time to ensure that as new information comes forward stakeholders are kept informed.

# Development of WRSE's Environmental Ambition

5.9 WRSE will continue to work with the Environment Agency using its existing governance and engagement structure, as set out in section 4, to further develop the region's environmental ambition scenarios.

5.10 We will also work closely with the Environment Agency to check and test the environmental ambition scenarios and sustainability reduction targets. The Environment Agency's "waterbody abstraction tool" will be used to independently verify sustainability reductions produced by WRSE and water companies at a water source level. At the time of writing, WRSE is working proactively with the EA to corroborate its work to date.

5.11 The Environment Agency has reviewed the BAU+ and Enhance environmental ambition scenarios used in our investment modelling. Their conclusions showed that if these reductions were implemented then WRSE would meet the EFI challenge across the South East catchments for the BAU+ and Enhance scenarios. This demonstrates that WRSE's interpretation of the Environment Agency's environmental destination targets have been validated at a regional level. More work is required to continue to validate the environmental ambition scenario forecasts against the Environment Agency data and tools.

5.12 The environmental ambition scenarios used in the emerging regional plan do not currently consider potential impacts of sustainability reductions on non-PWS sources. WRSE will need to consider these impacts as part of the development of the best value regional plan, which are likely to include impacts set out by the proposed Environment Agency licence capping policy.

5.13 The current analysis is necessarily simplified and conducted with the sole purpose of providing plausible possible futures with which to determine the preferred regional portfolio of options. More detailed investigations are needed before adopting the modelled reductions to confirm their effect on river flows, verify their ecological benefit, and establish their cost-effectiveness.

5.14 WRSE is committed to improving the environment in our region, but we need to agree the pace at which abstraction can be reduced and how we prioritise where reductions should be made. This so that activities and costs can be phased across the planning period and customers' supplies are not put at unnecessary risk. This is essential as some of the options needed to replace these water sources will take many years to plan and build and decisions on whether we develop them must be made soon. WRSE is continuing to engage with regulators and water companies to facilitate these decisions.

5.15 WRSE is working with the Environment Agency, Natural England, the Catchment Based Approach (CaBA) chalk stream restoration group and environmental organisations to develop a framework to determine where abstraction reduction should be prioritised. This will include considering whether we:

- Prioritise upper catchments, because headwater ecologies are the most vulnerable and the benefits to flow should improve the whole catchment
- Prioritise catchments where the impacts on flows are the most severe
- Prioritise catchments where there is the highest degree of certainty that abstraction reduction will restore flows and deliver environmental improvement
- Prioritise catchments where people have the most unrestricted access to rivers and streams
- Prioritise catchments where nature will benefit most, even if public access is restricted
- Focus abstraction reductions on a smaller number of catchments but fully address the issues they face
- Focus on a wider range of catchments and partially address their abstraction issues.

5.16 The proposed next steps will continue to be carried out by WRSE in collaboration with water companies, stakeholders and regulators, working up to the delivery of the draft regional plan, Water Resource Management Plans and beyond.

# Appendix 1: Water Resource National Framework Approach

## Water Resources National Framework approach

The Environment Agency's Water Resources National Framework sets out the expectation that regional plans should seek to pro-actively enhance the environment and increase ambition in this area. The EA has also produced some additional guidance on future environmental ambition.

This document sets out the proposed approach by the regulator in determining how much water would be required in the environment. This assessment is based on a number of requirements and assumptions which include:

- meeting the water requirements of sites specially protected for nature conservation
- restoring sustainable levels of abstraction to freshwater and wetland habitats of principal importance listed under Section 41 of the Natural Environment and Rural Communities Act (2006), particularly chalk rivers and other sites identified as priority habitats for restoration
- restoring river flows to support the recovery of salmonid fish populations
- embedding the principle that new developments should result in net environmental gain including 10% biodiversity net gain - the aim is for every plan to have a net positive impact on the local and national environment.

As there are a number of policy decisions that could influence the level of environmental protection required for the future, the guiding principles document categorises these potential futures into four scenarios discussed in chapters 0, **Error! Reference source not found.**, **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**. The scenarios used in the environmental assessments are based on current estimates of environmental flow indicators (EFIs) and future EFI assessments. Based on these estimates an assessment of how much water has to be left in the environment can be derived for each of the four scenarios. This therefore provides the plan with a potential range of impacts on the supply forecast.

## Business as Usual

- Policy/regulatory approach remains the same
- We continue to protect the same % of Qn for the environment
- Flow and GW balance tests evolve as a proportion of natural flow irrespective of climate change impacts
- Environment adapts to Climate

EFI evolves as a proportion of natural flow irrespective of climate change impacts

- Recover to Complaint
- No deterioration

Groundwater tests evolve around seasonal changes and response to abstraction pressure

- Recover to Good, or on pathway to Good
- No Deterioration

## Maintain the ambition for the environment

- We maintain the same environmental protection as now despite climate change
- Flow and GW balance tests set at current volumes to protect environmental flows from climate change impacts
- Abstractions adapt to Climate change

- Fix EFI at current volumes
- Fix GW allowance based on current volumes
- No Deterioration
- Recover to Complaint

## Enhance the environment

- Greater environmental protection for Protected Area and SSSI rivers and wetlands, principal salmon & chalk rivers
- Apply most sensitive flow constraint as appropriate
- Flow and GW balance tests evolve as a proportion of natural flow irrespective of climate change impacts

For Protected Area/SSSIs:

- rCSMG or equivalent
- Recover to Good in GW units linked to these rivers or wetlands

For principal salmon and chalk rivers:

- ASB3
- Recover to Good in GW bodies underlying chalk rivers

**Adapt**

- Our policy adapts to accept Good cannot be achieved everywhere with a shifting climate
- Recover to a lower standard in some water bodies
- Flow and GW balance tests evolve as a proportion of natural flow irrespective of climate change impacts

Flows
Recover to Band 1/2 boundary where WB meets following:
- Water bodies have an alternative, less stringent objective,

Or,
- HMWB designated for non WR use

Groundwater
- Create new "Moderate" GW category to define recovery objective in some "Poor" GW bodies

In summary, the overall assumptions made in the EA guidance are that it:

- Does not include local intelligence or specialised regional/ catchment scale modelling to identify ecological needs.
- Uses a single approach to model possible climate change impacts on flow rather than a wide range of scenarios to represent uncertainty.
- Assumes abstraction reduction is the only possible solution - other changes, such as altering the way reservoir storage is used to address flow issues, are not considered.
- Assumes the WRGIS database is a snapshot in time - February 2019 version – this may not represent catchments in as much detail as locally specific models and may differ from other models in assumed distribution of abstraction impacts (it includes estimates of some unlicensed activities).
- Assumes waterbodies that were at Good Ecological Status in 2016 will remain atgood.
- Assumes that the planned implementation of schemes in WINEP and AMP will enable waterbodies to achieve good by 2027.
- Assumes non-economic waterbodies have been excluded from the baseline.
- Estimates some licence reductions where exact quantities are not available.
- Assumes groundwater abstraction reductions to achieve natural flows will deliver the most environmental improvements and will improve groundwater status.
- Is more complex to model changes to surface water licences so only considered these if:
    - The licence does not have a flow constraint,
    - It is not from a reservoir or lake or level dependant catchment,

    - It does not have an upstream supported flow.
- Is based on recovery to the EFI (other than in the Adapt scenario).
- Is important! Focus is long term planning.
- Makes broad assumptions on a national scale for the purposes of the national framework.
- Should not supersede local investigations that have used more detailed modelling.

The guiding principles document was issued by the Environment Agency. However, Natural England also has a proposed approach to achieving a sustainable environment in designated areas and this is set out in the Common Standards Monitoring Guidance document(s).

## Common Standards Monitoring Guidance (CSMG)

CSMG sets out a series of water quality and water quantity targets for designated sites. The water quality objectives were adopted by Natural England and the Environment Agency. However, the flow targets have not yet been fully adopted.

The underlying principle of the flow targets set out in the guidance note is that only a certain percentage of the natural flow in the catchment should be abstracted. How much is permissible depends on whether the abstraction is taking place in the tidal reach, lower reaches or in the headwaters of rivers.

Typically, only 5% of the natural resources would be allowed to be abstracted in the headwaters of a catchment and 10% of the natural flows in the lower reaches of a river.

This approach sets out a very different approach on flow targets and what is sustainable in designated rivers. Therefore, it is important to use this approach for abstractions in these areas.

An alternative approach would be to use the Water Framework Directive assessment approach.

## Water Framework Directive (WFD)

The WFD is a European Directive that imposes legal requirements to protect and improve the water environment (including our rivers, coasts, estuaries, lakes, ground waters and canals).

In undertaking a WFD assessment any activity should support the objectives of the local River Basin Management Plan (RBMP) or meet strict sustainability criteria. It is important that any activity does not cause a deterioration to the status of a water body.

The River Basin Management Plans set out the current status of water bodies and the actions required to meet the objectives. Typically the assessments are based on the state of the environment over the last 6 to 18 years (1 to 3 WFD six year cycles).

The WFD sets out an assessment criteria which look at:

- physical habitat – the distribution and diversity of habitat including the physical processes that sustain and create new habitat. Physical habitat is essential for fish, macrophytes and invertebrates to live and thrive
- water quality – particularly physico-chemical aspects of water quality - such as levels of dissolved oxygen, phosphorus and ammonia
- fish and eels
- macrophytes - water plants visible to the naked eye, growing in the river
- invertebrates - insects, worms, molluscs, crustacea etc living on the riverbed
- diatoms - microscopic diatoms (algae) found on rocks and plants
- Invasive non-native species (INNS)

All these approaches will require an understanding of the range of flows (flood and drought) we face today and the likely range we will face in the future. We intend to use the historic flow sequences and the new regional future flow sequences in our assessments using these approaches. We also intend to use the output from our hydrological investigations to estimate the impact of groundwater abstractions on river flows. These studies coupled with potential land use changes across the region and an understanding of the potential impacts of climate change will be used to help assess the future water availability from both surface water bodies and groundwater bodies within the region. It is likely that this work will continue to be refined but it should provide enough understanding to define the range of water availability in the catchments and consequently the range of environmental ambition which we will have to plan for.

# Environmental Ambition Technical Note

Version D

February 2022

| Title: | Environmental Ambition Technical Note |
|---|---|
| **Last updated** | February 2022 |
| **Version** | D |
| **History of Changes made to this version** | This document outlines the approach undertaken by Mott MacDonald to calculate the environmental ambition scenarios for the emerging regional plan (published in January 2022). |
| **Author** | David Ocio / Nathan Burt (Mott MacDonald) |
| **Reviewed by** | Affinity Water<br>Portsmouth Water<br>SES Water<br>South East Water<br>Sothern Water<br>Thames Water |
| **Approved by** | Sarah Green |
| **WRSE Director** | Meyrick Gough |

MOTT MACDONALD

# Water Resources South East
Environmental ambition

| | | | |
|---|---|---|---|
| **Project:** | WRSE Environmental ambition | | |
| **Our reference:** | 100411624-011-SSTNB-01 | | |
| **Prepared by:** | David Ocio/Nathan Burt | **Date:** | 22/02/22 |
| **Approved by:** | David Ocio | **Checked by:** | Peter Ede/Sarah Green |
| **Subject:** | Sustainability reductions | | |

## 1 Introduction

Water Resources South East (WRSE) is undertaking a multi-sector, regional resilience plan to secure water supplies for the South East until 2100 while ensuring environmental resilience. Planning approaches have historically considered the environmental requirements as defined through the Water Industry National Environment Programme, but these only consider the following 5 to 15 years. In order to have a longer forecast for the environment, WRSE has committed to developing an 'over-arching environmental ambition' for the region that includes a holistic approach to environmental management.

The Environment Agency (EA) has recently completed a longer-term environmental water needs assessment as part of the Water Resources National Framework, establishing the potential licence reductions required by 2050 to meet the Environmental Flow Indicators (EFI) so that a good ecological status is achieved or maintained. The EFI is defined by an Abstraction Sensitivity Band (ASB) allocated to each waterbody. Four scenarios have been analysed:

- Business as usual (BAU): the same percentage of natural flows for the environment that currently applies continues for the future. Uneconomic waterbodies, where reducing abstraction would imply a significant investment, were initially discarded. However, an additional scenario (BAU+) including them has been subsequently incorporated.
- Enhance: a greater environmental protection for protected areas and Sites of Special Scientific Interest (SSSI) rivers and wetlands, principal salmon and chalk rivers is achieved by applying the most restrictive ASB.
- Adapt: same ASB as BAU but a recovery to a lower standard in some heavily modified waterbodies is assumed.
- Combine: balances a greater environmental protection for protected areas, SSSI rivers and wetlands and principal salmon and chalk rivers with a view that good status (as defined under the Water Framework Directive) cannot be achieved everywhere in a shifting climate. Hence, adopts the Enhance ASB with a lower recovery to the EFI in some heavily modified waterbodies.

In all cases, flow balance evolves as a proportion of natural flows as these are changed by the impacts of climate change.

Future predicted level of abstraction in 2050 for the different sectors as estimated by the EA is shown in Table 1.1. Power generation is the largest abstractor in the region. However, when consumptiveness is considered, public water supply would account for 92% of the total consumption.

**Table 1.1: Distribution of licences and abstraction in Ml/d per sector in 2050**

| Sector | Licence | Abstraction | Consumption total | Consumption % of total |
|---|---|---|---|---|
| Power generation | 29,190 | 10,680 | 13 | 0.4 |
| Public water supply | 8,028 | 5,108 | 3,287 | 91.8 |
| Industry | 4,499 | 2,747 | 79 | 2.2 |
| Agriculture | 1,893 | 1,489 | 68 | 1.9 |
| Amenity/environmental | 518 | 158 | 84 | 2.4 |
| Other | 67 | 49 | 48 | 1.4 |
| Total | **44,194** | **20,231** | **3,580** | **100.0%** |

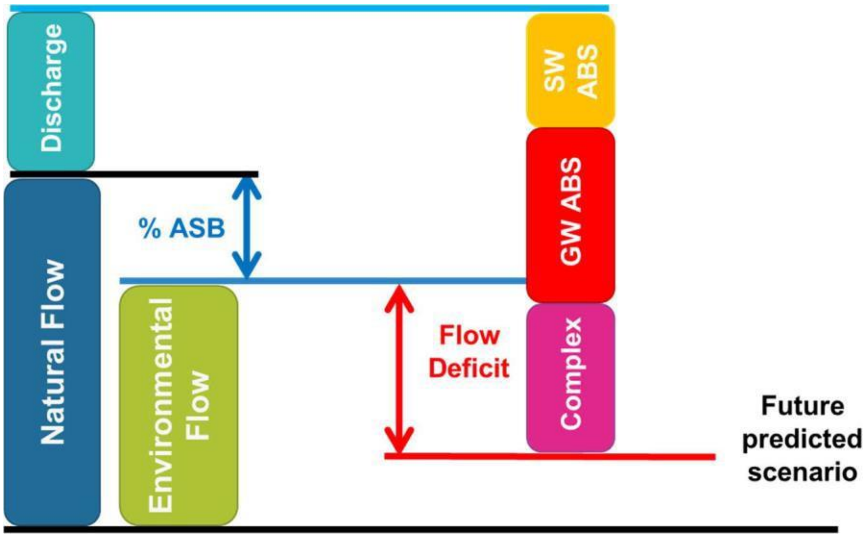
WRSE wishes to analyse the impact of the EA scenarios on the supply-demand balance of its water resources zones by establishing the potential changes in deployable output. This technical note presents the results of the analysis undertaken to feed into WRSE investment modelling.

# 2 Approach

In the Water Resources National Framework, the EA utilised a bespoke spreadsheet tool (Waterbody Abstraction Tool) to estimate the deficits in 2050 for each waterbody per scenario. The tool calculates the water balance at the outlet of each waterbody for four quantiles (Q30, Q50, Q70 and Q95) by (see Figure 2.1):

- Starting with the predicted natural flow in 2050 based on ensemble AFIXK of the Future Flows Hydrology project extrapolated to the outflow point of the integrated waterbodies in the WRGIS.
- Adding the future predicted discharge to each waterbody modifying the recent actual value with a growth factor based on water company demand projections.
- Subtracting the future predicted surface water abstractions based on the recent actual value with growth factors according to the sector.
- Subtracting the future predicted impact of groundwater abstractions based on the recent actual value with growth factors according to the sector, and the spatial and temporal impact factors included in WRGIS which have been calculated using regional groundwater models.
- Incorporating complex impacts associated with reservoirs, transfers or augmentation schemes.
- Comparing the resulting future predicted flow in the river with the EFI, the latter calculated by applying the maximum allowed abstraction as indicated in Table 2.1 with Abstraction Sensitivity Bands varying per scenario (see Figure 2.2 and Figure 2.3 showing how abstraction would be more restricted in the upper parts of the catchments)

**Figure 2.1: Process to derive flow deficit for a certain quantile**

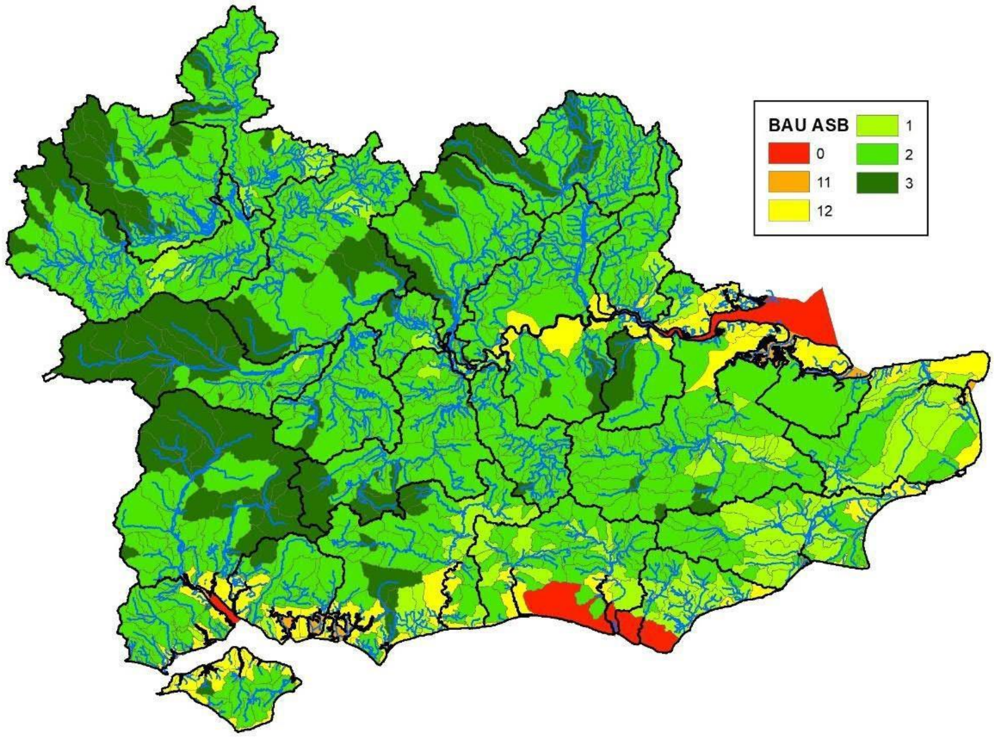



Source: Mott MacDonald

**Table 2.1: Maximum allowable abstraction as a function of Abstraction Sensitivity Band**

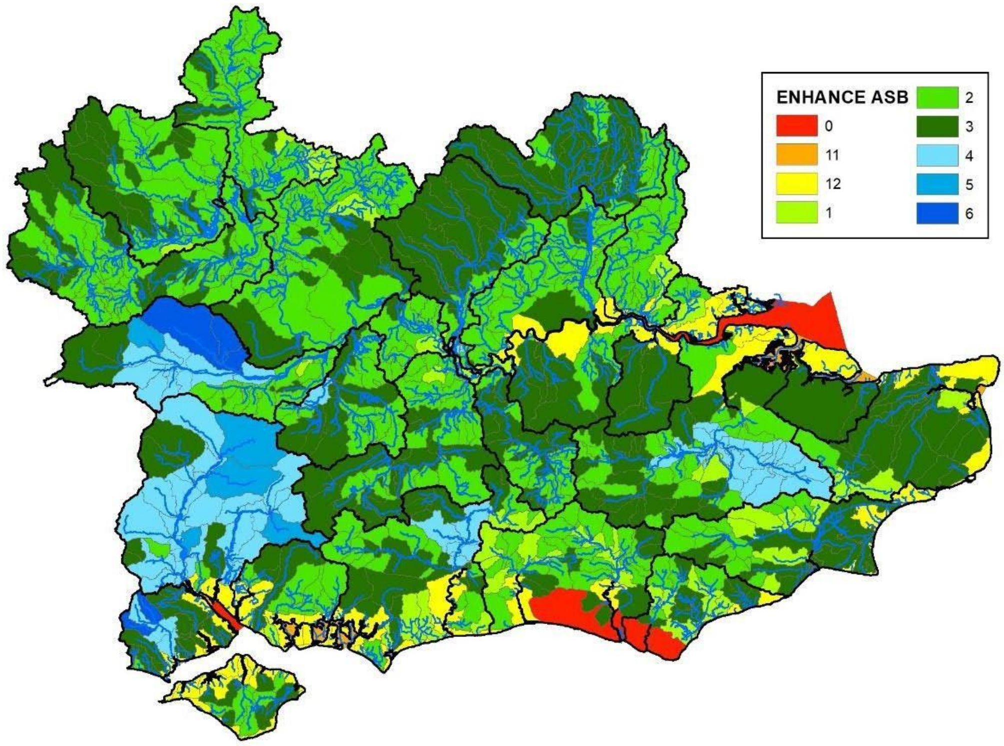
| Flow quantile | Abstraction Sensitivity Band | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0 | 11 | 12 | 13 | 1 | 2 | 3 | 4 | 5 | 6 |
| Q30 | 100% | 45% | 40% | 35% | 30% | 26% | 24% | 10% | 15% | 10% |
| Q50 | 100% | 41% | 36% | 31% | 26% | 24% | 20% | 20% | 15% | 10% |
| Q70 | 100% | 39% | 34% | 29% | 24% | 20% | 15% | 15% | 10% | 10% |
| Q95 | 100% | 35% | 30% | 25% | 20% | 15% | 10% | 10% | 5% | 5% |

**Figure 2.2: Abstraction Sensitivity Bands for BAU scenario**




Source: EA

**Figure 2.3: Abstraction Sensitivity Bands for ENHANCE scenario**




Source: EA

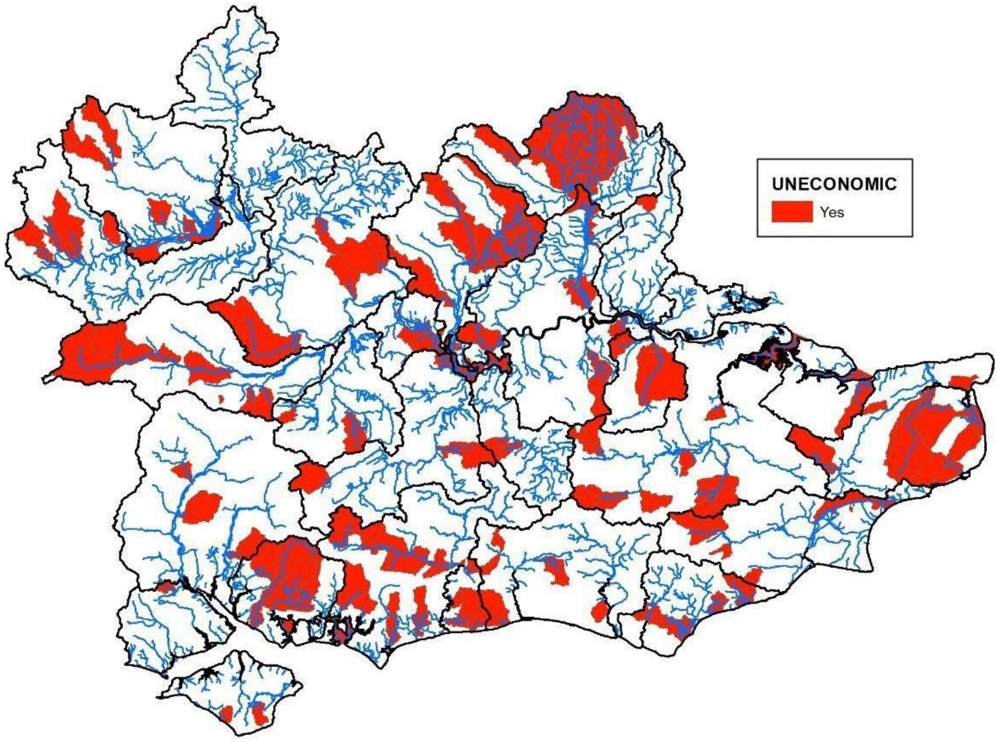
Data from the Waterbody Abstraction Tool has been transferred to a new spreadsheet tool designed to automatically derive the required sustainability reductions to remove the deficit at Q95 in 2050 in all waterbodies within the WRSE region. The logic for establishing the reductions needed has aimed to minimise the abstraction loss and hence the impact on deployable output (DO). It is as follows:

- Reductions are applied from top to bottom of each catchment so that upstream benefits (i.e. increases in river flows due to licence reductions) are considered downstream before applying the required reductions.
- Licences are reduced first to their future predicted abstraction rates as this would imply no loss of DO.
- Surface water licences are then reduced further, if existing, as they would impact DO less than reductions in groundwater licences given that availability of water for abstraction in rivers during a drought is not as guaranteed as in the case of aquifers. This reduction of abstraction from rivers during droughts is already accounted for in planning assumptions.
- Groundwater licences are subsequently reduced below future predicted abstraction rates starting from the ones that impact the deficit the most, because of either the spatial or temporal allocation of their impact.
- Licences with high consumptiveness are reduced next (licences with consumptiveness lower than 10% not adjusted).
- Licences located in the waterbody of analysis have priority in the reduction over others located upstream so as to minimise impact on DO. Thus, if for example two abstractions are causing a deficit in a certain waterbody X, one located in that waterbody X and another upstream in a different waterbody Y, and the upstream abstraction is not provoking a deficit in the waterbody Y it is located in, the reduction will be first applied to the abstraction in the waterbody X. Reducing the abstraction in waterbody Y would solve the problem in waterbody X as well but it would imply a surplus in waterbody Y.
- In equal conditions, smaller licences are reduced/removed first as they would be less economical to maintain.
- Sustainability reductions are applied at 5% steps and uniformly across the flow duration curve.

It is noted that:

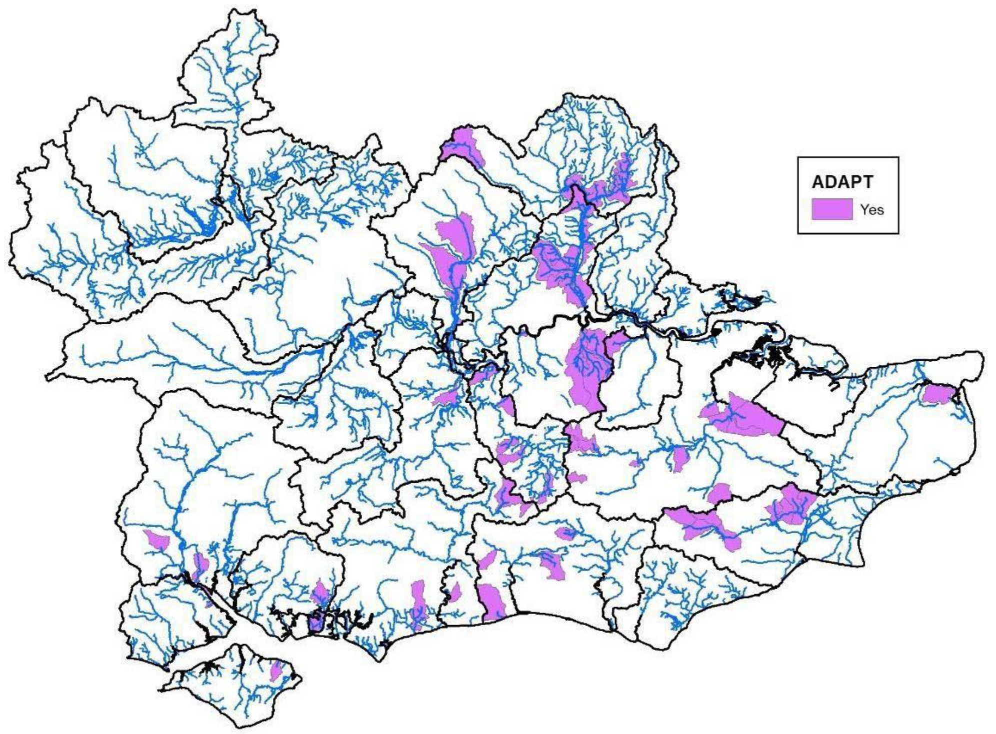
- In order to avoid PWS sustainability reductions impacting other sectors, the part of the Q95 deficit attributed to PWS abstractions was estimated and then used to derive PWS licence reductions.
- In the BAU scenario 189 waterbodies considered uneconomical were excluded from the analysis (see Figure 2.4)
- In the Adapt and Combine scenarios a 25% deficit over the EFI was allowed in 90 heavily modified waterbodies (see Figure 2.5)

**Figure 2.4: Uneconomic waterbodies**




Source: EA

**Figure 2.5: Adapt waterbodies**




Source: EA

# 3 Results

Table 3.1 presents the modelled reductions required in PWS licences to fulfil the objectives of the different EA scenarios. The largest reduction in abstraction corresponds to Thames Water followed by Affinity. Moving from the BAU scenario to the Enhance scenario would increase the reduction of abstraction required by 60% although there are differences between water companies, with Thames Water for instance only experiencing an increase of 14%.

**Table 3.1: Required licence reductions in Ml/d by sector and scenario**

| Water company | Current licences | BAU | ADAPT | BAU+ | COMBINE | ENHANCE |
|---|---|---|---|---|---|---|
| Affinity Water | 988 | -275 | -421 | -426 | -504 | -511 |
| Portsmouth Water | 302 | -84 | -133 | -134 | -142 | -143 |
| South East Water | 825 | -232 | -376 | -377 | -416 | -415 |
| Southern Water | 1179 | -320 | -640 | -645 | -694 | -696 |
| SES Water | 402 | -12 | -99 | -101 | -99 | -99 |
| Thames Water | 4190 | -824 | -878 | -939 | -960 | -1019 |
| Other | 93 | -17 | -41 | -42 | -46 | -47 |
| **Total** | **7979** | **-1765** | **-2587** | **-2664** | **-2860** | **-2930** |

# 4 Scenarios for investment model

The WRSE investment model requires DO values for different time horizons and scenarios for each water resource zone (WRZ) and return period, both for average and peak period. The EA methodology can only provide an estimated reduction of average abstraction derived from the calculated licence reduction and the future predicted abstraction. The impact on DO is likely to differ as:

- Surface water sources have Hands Off Flow conditions which would reduce the availability of water for abstraction during droughts beyond average low flow conditions,
- Storage can limit the effect of a reduced summer abstraction, or
- Groundwater sources can be operated at different rates seasonally within the annual licence.

Estimating the final impact of the modelled sustainability reductions on DO would require system simulation, with licences for each PWS source modified as established here. Likewise, the assessment undertaken following the EA approach relies on the accuracy of the prediction of future river flows as well as abstraction rates. To note, the assumptions adopted by the EA with regards to the impact of climate change and demand growth could be inconsistent with those adopted by WRSE, with an unknown impact on the results. Further work to review the methodology will be undertaken in collaboration with the EA and WRSE companies.

Based on their knowledge of the catchments, with regards the potential ecological benefit of sustainability reductions and their affordability assumptions, companies have developed two further scenarios to complement the existing five scenarios: Central and Alternative. These environmental ambition forecasts have been developed in liaison with local EA teams. In addition, companies have applied the licence reductions estimated for the EA scenarios to obtain the DO impact of some of their groundwater sources.

Four of the seven defined scenarios have been used in the WRSE investment modelling to date, to represent the range of potential future environmental ambitions: BAU+, Enhance, Central and Alternative. The adopted DO reductions for each of these four scenarios are shown in Table 4.1.

In order to develop the Central and Alternative scenarios, five of the six WRSE companies provided estimated DO losses in their WRZs. In the case of Affinity AZ3 and AZ5, the reductions incorporate some estimates from Water Resources East (WRE), who have been undertaking a similar environmental ambition assessment. Central and Alternative scenarios for one company, Portsmouth Water, have been developed slightly differently, and represent a 50% reduction of the Adapt and BAU scenarios respectively.

**Table 4.1: Adopted DO reductions per water resource zone in Ml/d**

| WRZ | BAU+ | ENHANCE | CENTRAL | ALTERNATIVE |
|---|---|---|---|---|
| GUI | -11.0 | -10.9 | -4.5 | -4.5 |
| HAZ | -5.1 | -5.1 | -11.4 | -11.4 |
| HEN | -3.3 | -3.3 | 0.0 | 0.0 |
| HKZ | 0.0 | 0.0 | -2.9 | -7.3 |
| HRZ | 0.0 | 0.0 | 0.0 | -4.4 |
| HSE | -22.3 | -35.8 | -60.0 | -60.0 |
| HSW | 0.0 | 0.0 | 0.0 | 0.0 |
| HWZ | 0.0 | 0.0 | -11.5 | -21.4 |
| IOW | -9.3 | -11.1 | -10.0 | -15.3 |
| KVZ | -9.1 | -9.1 | -7.3 | -7.3 |
| KME | -19.0 | -19.4 | -20.6 | -19.4 |
| KMW | -6.4 | -8.9 | 0.0 | -8.9 |
| KTZ | -23.1 | -29.6 | -8.1 | -29.6 |
| LON | -433.5 | -429.4 | -22.7 | -28.7 |
| PRT | -42.1 | -48.3 | -21.0 | -6.1 |
| RZ1 | -18.8 | -19.3 | -10.7 | 0.0 |
| RZ2 | -1.5 | -1.9 | -4.1 | 0.0 |
| RZ3 | -22.4 | -22.5 | -9.1 | -3.6 |
| RZ4 | -16.7 | -17.8 | -24.9 | -18.9 |
| RZ5 | -1.8 | -2.6 | -0.7 | 0.0 |
| RZ6 | -18.9 | -19.7 | -4.9 | -2.4 |
| RZ7 | -6.0 | -6.0 | 0.0 | 0.0 |
| RZ8 | -69.5 | -72.2 | -37.4 | -18.7 |
| SBZ | -25.3 | -34.5 | 0.0 | -15.7 |
| SES | -12.3 | -12.3 | -11.5 | -11.5 |
| SHZ | 0.0 | 0.0 | 0.0 | 0.0 |
| SNZ | -23.1 | -29.5 | 0.0 | -2.4 |
| SWZ | -7.9 | -16.4 | -1.5 | -13.9 |
| SWA | -12.0 | -12.0 | -9.7 | -9.7 |
| SWX | -16.8 | -16.8 | -11.7 | -11.7 |
| AZ1 | -30.4 | -33.4 | -21.4 | -21.4 |
| AZ2 | -89.5 | -102.5 | -69.5 | -10.3 |
| AZ3 | -99.4 | -102.4 | -71.4 | -71.4 |
| AZ4 | 0.0 | 0.0 | 0.0 | 0.0 |
| AZ5 | -38.3 | -39.3 | -25.2 | -25.2 |
| AZ6 | 0.0 | 0.0 | 0.0 | 0.0 |
| AZ7 | -26.9 | -31.5 | -4.9 | -4.9 |
| **Total** | **-1121.4** | **--1203.3** | **-498.5** | **-465.8** |

Note: Values for Southern Water WRZs correspond to 1:500yr

To further explore the investment scenarios so as to define robust adaptive pathways, the DO reductions for environmental ambition have been applied:

- To four time horizons – profiled assuming the reductions are realised in 2030, 2040, 2050 and 2060. Due to assumptions made around the wider environmental ambition decision making process, only the 2050 time horizon has been considered at this stage.
- To the average DO alone, or to the average and peak DO simultaneously, assuming in the latter that the ratio between the two is maintained.

Finally, it is important to highlight that the current analysis is necessarily simplified and conducted with the sole purpose of providing plausible possible scenarios with which to determine the preferred regional portfolio of options. More detailed investigations are needed before adopting the modelled reductions to confirm their effect on river flows, verify their ecological benefit, and establish their cost-effectiveness.

The iterative process for developing company environmental ambition forecasts is still evolving as WRSE work towards the draft regional plan. WRSE will continue to work with water companies and the EA to develop the most appropriate environmental ambition scenarios for the South East.

More information can be found in the WRSE Environmental ambition method statement


# Method Statement: Best Value Planning

## December 2022

| Title | Method Statement: Best Value Planning |
| --- | --- |
| **Last updated** | December 2022 |
| **Version** | Draft regional plan version |
| **History of changes made to this version** | First draft: June 2020<br>Consultation version: July 2020<br>Emerging regional plan version: January 2022<br>Draft regional plan version: December 2022<br>*[Note that previous versions have been entitled 'Investment Programme Development and Assessment Method']* |
| **Author** | David Spiller, Meyrick Gough, Sarah Green, Anna Wallen |
| **Approved by** | Sarah Green |
| **WRSE Director Approval** | Meyrick Gough |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For the full library of WRSE Method Statements, please visit wrse.org.uk/library.

A consultation on the WRSE Method Statements was undertaken in Autumn 2020 – the consultation details can be viewed on the WRSE engagement hq platform at https://wrse.uk.engagementhq.com/method-statements.

# Table of Contents

# Executive Summary

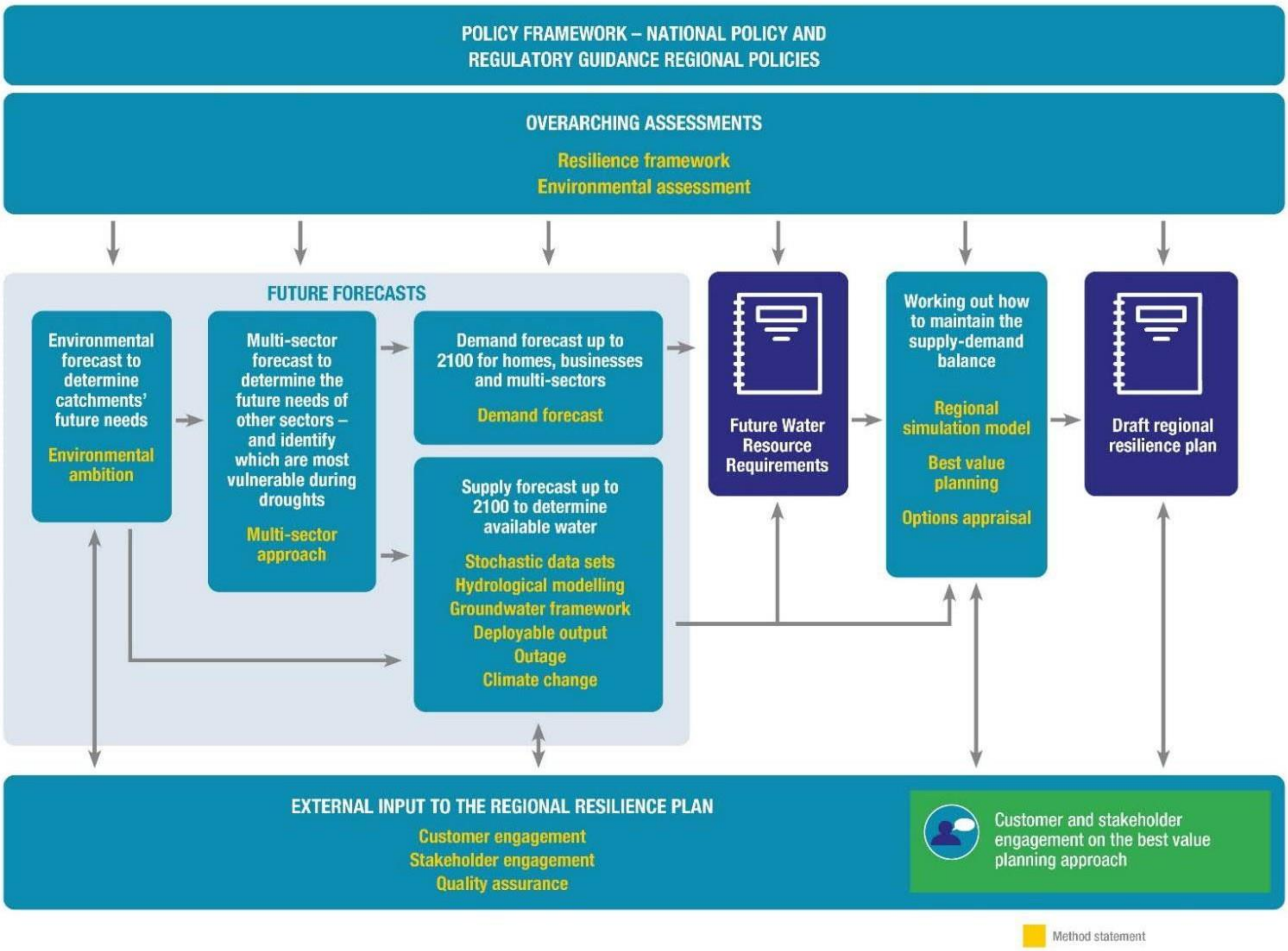
Water Resources South East (WRSE) is developing a multi-sector, regional resilience plan to secure water supplies for the South East until 2075.

We have prepared and consulted on the method statements that set out the processes and procedures we will follow when preparing all the technical elements for our regional resilience plan. This updated version reflects, as far as possible, the views and requirements of customers and stakeholders raised during the consultation. It has also been reviewed and updated to align with guidance published since work initially commenced on the regional plan, including the updated EA Water Resources Planning Guideline, the EA supplementary guidance on Best Value Planning and the UKWIR Best Value Planning Framework.

Figure ES1 illustrates how this best value planning method statement will contribute to the preparation process for the regional resilience plan.

The scale and complexity of water resources planning for the South East of England supports the use of advanced decision-making methods to ensure that a robust solution is reached. This method statement explains our approach to best value planning and the decision support tools we have used to develop a best value, adaptive regional plan.

**Figure ES1: Overview of the method statements and their role in the development of the plan**




Our approach has seven key stages:

**Stage 1** – We use problem characterisation to understand the challenges and complexities across our region to identify the technical approach we need to adopt to solve the problems in the South East of England. This approach identifies the data that we require from the companies. The companies derive, assure and validate their data that they submit to WRSE. We verify that the input data received from individual companies works within the investment model. Our investment model checks include baseline supply demand positions, uncertainties and the feasible options identified as potentially being available to resolve any water supply deficits over the planning period. A data landing platform is used to store all of the data from the companies and underpins all data flows across this process to support robust governance, quality assurance and reporting.

**Stage 2** - We define the decision-making framework, set our objectives and identify the criteria we will use to define best value.

**Stage 3** - We define problems to be solved for regional water planning, allowing exploration of uncertainties and risks. From this, we identify the range of alternative futures (known as a situation 'tree') and which pathway within the tree will be used for reporting purposes, in line with Water Resources Planning Guidance. We then use real options and adaptive planning methods within the WRSE investment model to identify a range of investment programmes (i.e. combinations of options) that resolve the integrated risk problems to 2075. These solutions can be described using a number of criteria including cost, resilience, environmental and customer preference best value plan metrics.

**Stage 4** - We use a visualisation tool to help illustrate and understand complex information and enable comparison of the alternative investment programmes produced by the investment model. This allows us to consider how different criteria affect different outcomes and consider best value in the round. From this work we identify the least cost plan and select a shortlist of reasonable alternative programmes for further investigation through the incorporation of best value planning metrics

**Stage 5** - We undertake further assessment and stress-testing of the shortlisted programmes including environmental and wider resilience testing.

**Stage 6** - We use the information provided through the previous stages to select WRSE's preferred programme – i.e. our draft best value regional plan.

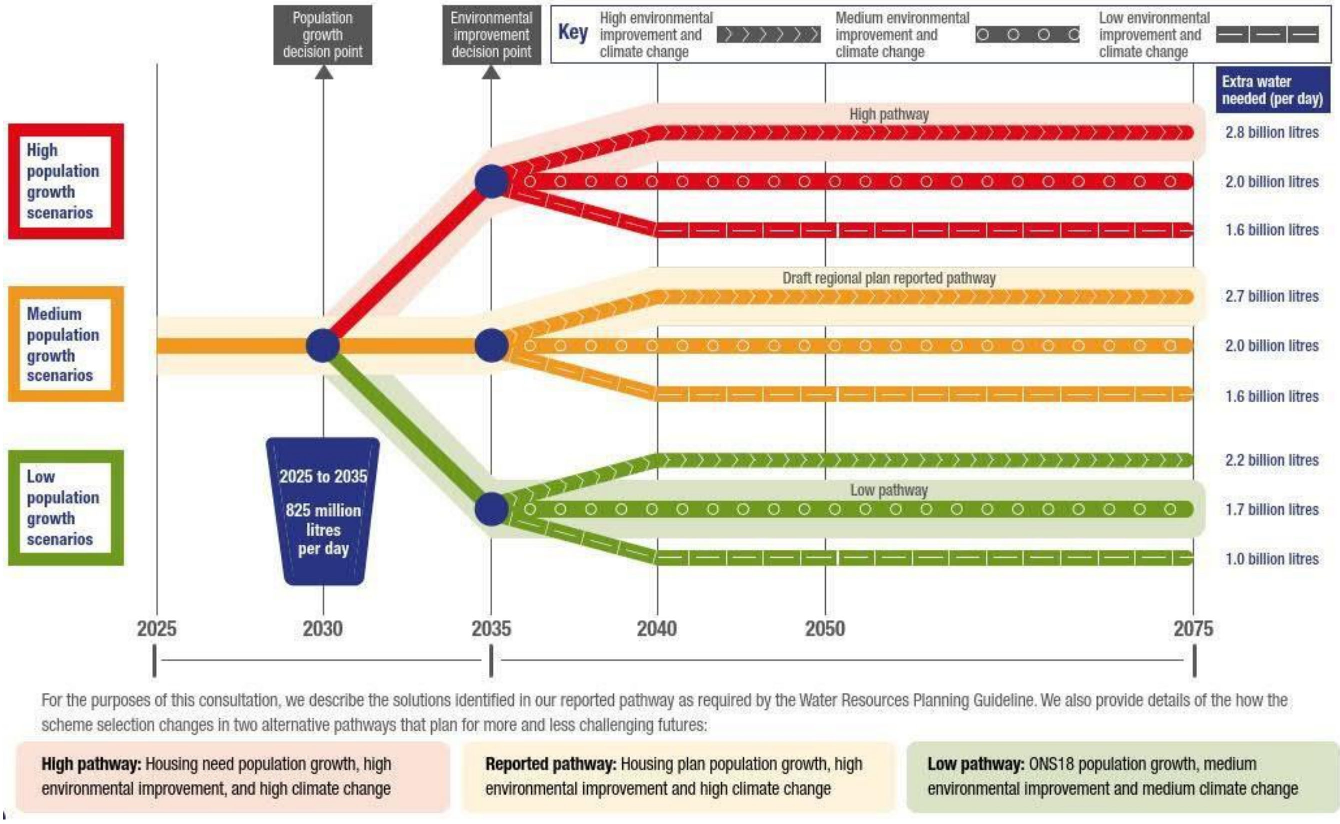
**Stage 7 -** We consult on our draft best value regional plan.

## 1 Introduction and timeline

### Introduction

By 2050, the South East of England is forecast to experience a shortfall in water resources needed to ensure a resilient water supply for the public, other users and the environment. This deficit was estimated to be between 1000[1] and 2,800 Ml/d by 2050. This range of future need is a reflection of the different combinations of environmental protection, drought resilience, population growth, and climate change (see Figure 1 below).

Figure 1: Future water resource requirements for South East England.




[1] March 2020, Future water resource requirements for South East England, WRSE.

The scale and complexity of the challenges in the South East requires a complex approach (see problem characterisation report in WRSE document library) using advanced decision-making methods, (in accordance with industry guidance), to ensure that a robust solution is reached for the regional best value plan.

This method statement explains the best value planning (BVP) approach we are following, and the decision support tools we are using to identify and test potential investment programmes and enable selection of a best value plan for the region. Our best value plan will also be an adaptive plan.

The approach was developed in line with key industry guidance and methodologies:

- Water Resources Planning Guideline (updated July 2022)[2]
- UKWIR (2002) Economics of Balancing Supply and Demand (EBSD)
- UKWIR (2016) WRMP 2019 Methods – Decision Making Process Guidance
- UKWIR (2020) Deriving a Best Value Water Resources Management Plan

We have consulted with and taken on board the comments of our stakeholders and customers throughout the development of our BVP approach, including:

- Draft Method Statements consultation: July – October 2020
- Best Value Planning consultation: February – March 2021
- Emerging regional plan consultation: January – March 2022

# Timeline

The overall timeline and milestones for the decision-making process to support the regional planning process is shown in Table 1.

**Table 1: Milestones**

| Date of Delivery | Activity |
|---|---|
| July 2020 | Method statements produced for consultation |
| October 2020 | Policies and preferences agreed |
| Winter 2020/21 | Initial resilience planning for the South East region |
| Summer 2021 | Update Future Water Resource Requirements for South East England |
| Summer 2021 | Publish updated Method Statements, and confirm the policies and preferences that we will embed in our regional plan |
| Autumn 2021 | Preparation and reconciliation of regional plans to ensure alignment across England |

[2] https://www.gov.uk/government/publications/water-resources-planning-guideline/water-resources-planning-guideline

| Date of Delivery | Activity |
|---|---|
| January 2022 | Publish WRSE emerging Regional Plan for consultation |
| May 2022 | Present the main issues raised in the emerging regional plan consultation and how they will be addressed |
| November 2022 | Publish our draft Regional Plan |
| November 2022 | WRSE water companies submit their draft Water Resources Management Plans 2024 ahead of public consultation |
| Spring 2023 | Re-reconciliation of regional plans to ensure alignment across England |
| May 2023 | WRSE publish response document to the draft regional plan consultation |
| May 2023 | Water companies publish their statement of response and their revised draft Water Resources Management Plans |
| Autumn 2023 | WRSE publish final regional plan |

## Structure

The structure of the remainder of this method statement is as follows, setting out our approach and following each of the stages through to the identification of a best value, adaptive plan.

- Section 2 – The Best Value Planning approach
- Section 3 – **Stage 1**: Input Data Validation
- Section 4 – **Stage 2**: The Decision-Making Framework
- Section 5 – **Stage 3a**: Defining the Situation Trees (Steps 1-5)
- Section 6 – **Stage 3b**: Investment Modelling and programme visualisation (Steps 6-11)
- Section 7 – **Stage 4**: Shortlisting
- Section 8 – **Stage 5**: Testing the shortlisted programmes
- Section 9 – **Stage 6**: Selecting the preferred programme
- Section 10 – **Stage 7**: Consultation on the Best Value Plan for the South East of England

There are also a set of four appendices that provide additional information on the decision support tools and data control processes.

# 2 Best Value Planning

## What is a 'best value plan'?

A best value plan, in the context of water resources planning, is one that considers a range of factors (not exclusively financial cost). As a minimum any plan must meet the legislative and regulatory requirements (including securing a supply of wholesome drinking water for customers) and other policy expectations in an efficient, affordable and deliverable way. A best value plan seeks a solution that not only secures supplies for customers, but also increases the overall benefit to customers, the wider environment and society as a whole as defined through the best value metrics.

This could result in a water resource programme being chosen for the regional plan, which isn't the most cost efficient, but delivers additional value as defined through the best value criteria.

The scale and complexity of challenges we face, and the significant uncertainties, means that we have chosen to use advanced decision making methods and develop a plan that can adapt to different future scenarios. In this way we can show how our proposals would change under different "futures" and set out when key decisions need to be made to manage the uncertainty.

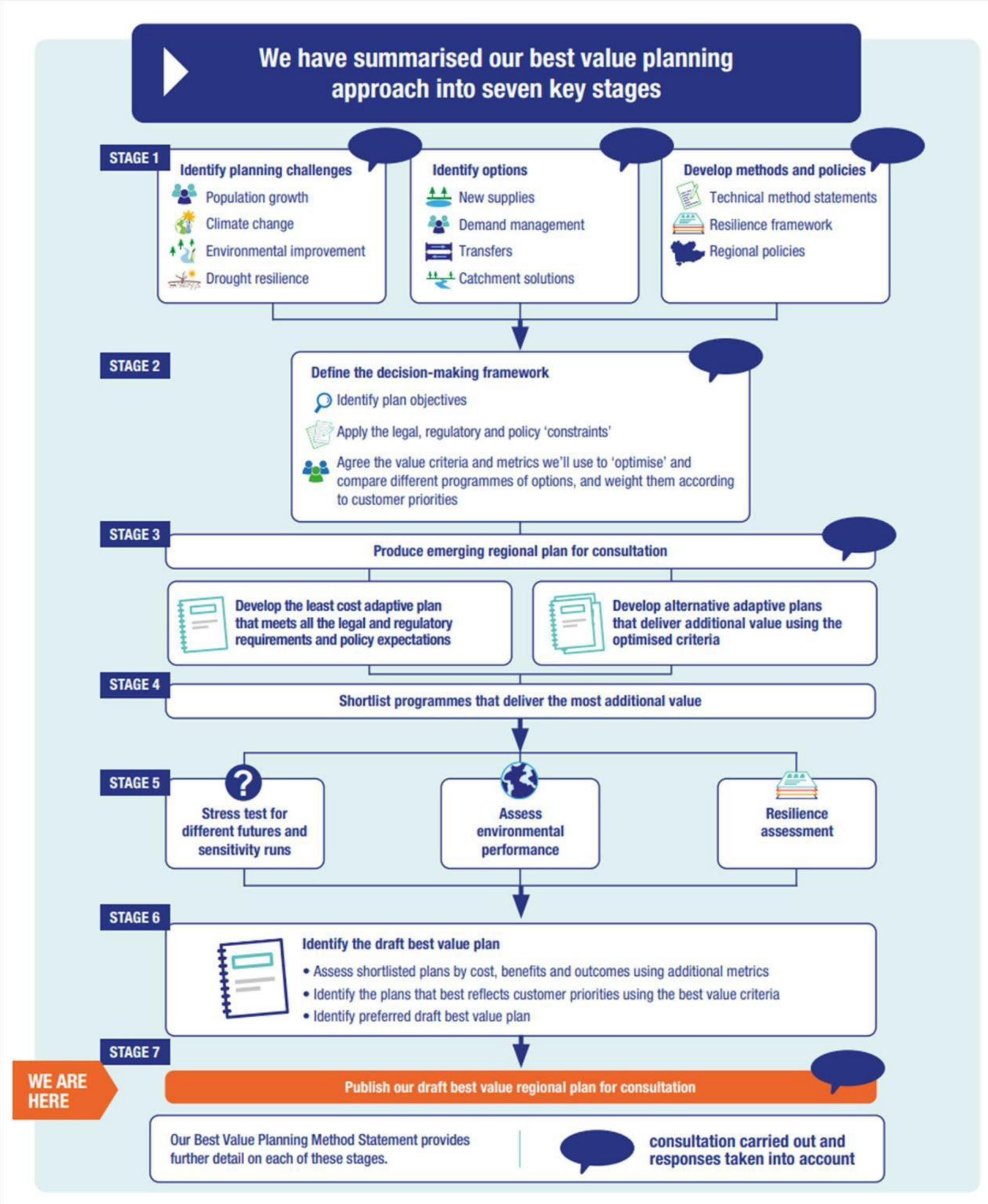
We set out our approach and the decision support tools we have used to help develop a best value, adaptive plan below.

## Our approach

Our approach for generating, testing and presenting the best value regional plan can be summarised into seven key stages, as shown in Figure 2.

These stages incorporate what was otherwise set out in the more detailed 16-step process for the development of a plan described in the WRSE Resilience Framework. The aspects of our 16-step process are shown or referenced in this method statement to show their alignment with each best value planning stage.

Figure 2: Our Best Value Planning approach – process overview



## Stage 1: Data Verification (see Section 3)

In the data verification stage, we use a tool called the data landing platform (DLP) to collate the input data required to feed our investment model. This is sourced from our member companies or developed in conjunction with them. The input data is checked before it is submitted to the DLP by the organisation that developed it. In the main this data falls into two categories:

- Information used to identify the planning challenges (i.e. data that enables us to identify the problem)
- Information on potential options that could be used to meet the planning challenges [i.e. data on options to solve the problem).

## Stage 2: Decision Making Framework (see Section 4)

To develop a best value plan, we first need to set our objectives – i.e. the specific goals that our regional plan must aim to deliver relating to 'best value'. We've used insight from water company customers and stakeholders across the South East to help us understand their priorities, so our objectives are representative of what matters most to them.

We have also consulted on a range of other policies for the region that will also be considered when generating the best value plan.

Each objective will be represented by a set of value criteria (i.e. categories against which the objective can be tested) which, in turn, will each have an associated metric that will measure the additional value it delivers. We will use the criteria and metrics to assess the different water resource programmes that are produced through our investment modelling.

In this stage we will set out our objectives, criteria and metrics, making it clear what things our plan must do (constraints), and on which metrics we can optimise to help us to make decisions on which programme best meets those objectives and delivers best value.

## Stage 3: Solution Development (see Sections 5 and 6)

In this stage we explain the range of modelled potential alternative future scenarios and how we develop programmes of options to meet those futures, including key policy delivery dates.

We have split this stage in two, with Section 5 covering the development of the adaptive plan branches (Stage 3a), which develops the alternative futures; and Section 6 covering the Investment Model (IVM) (Stage 3b), which develops the programmes of options to meet the futures.

This stage covers 11 process steps, outlined in more detail in Sections 5 and 6.

### Stage 4: Assess and Shortlist solutions (see Section 7)

Stage 3 will produce many potential water resource programmes. In Stage 4 we explain how we'll use visualisation tools to help us display, filter, and identify a shortlist of alternative solutions for further investigation, potentially trading-off performance against each of the value criteria in order to shortlist a set of high performing varied solutions overall.

### Stage 5: Test shortlisted solutions (see Section 8)

In Stage 5 the shortlisted solutions will be examined in more detail to see how they perform and how robust they are. Specifically, we undertake:

- Stress testing (i.e. how would the solution change in the face of an alternative future, or if key options were no longer available, delayed or cost more / less)
- Environmental review (i.e. examining a wider set of environmental metrics and considering in combination effects)
- Resilience review (i.e. examining a wider set of system resilience metrics as set out in the Resilience Framework).

Each and every shortlisted programme will demonstrate additional value and could therefore constitute a best value plan. However, in the context of our approach a best value plan would mean that the investment model has been used to improve the BVP metrics.

### Stage 6: Select plan (see Section 9)

In Stage 6 we will select a single preferred best value programme, taking into account our technical work, and all associated environmental, resilience and other pertinent information. We will determine which programme we consider to be our preferred best value plan.

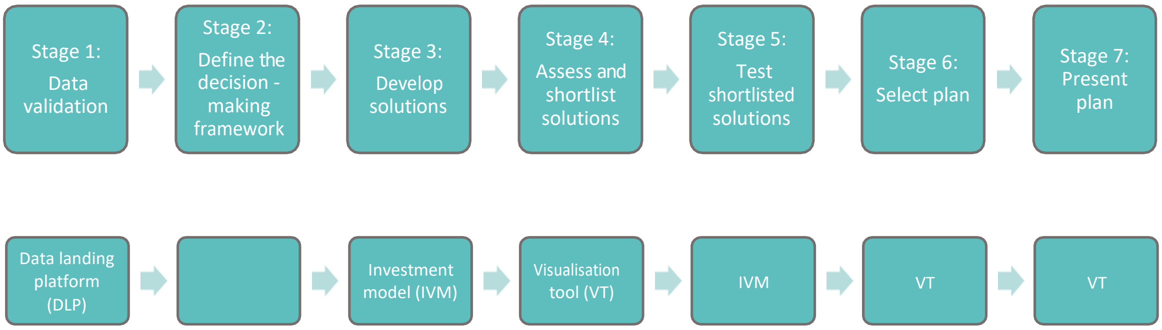
### Stage 7: Consultation on the draft plan (see Section 10)

Our preferred best value plan will be an adaptive plan, showing how the proposals take account of different futures and when key decisions need to be made in order to deliver solutions that meet key policy delivery dates. We will undertake public consultation on our proposals and then take account of feedback in finalising our plan.

## Our decision support tools

We have developed a number of decision support tools to assist the undertaking of stages of the best value planning process as summarised in Figure 3.

Figure 3: The decision support tools used at each Stage




We explain these tools and the relationship between them in our detailed description of the stages later in this document.

# Key decision points

There are a number of key decision points throughout the BVP planning and delivery stages. They can be split into:

- Decisions made in developing the plan itself;
- Decision points relating to the delivery of the plan, such as confirming when key policy objectives will be delivered
- Timing of decisions required in the lead up to delivery.

The latter point is an important part of the adaptive planning process and real options analysis. Once we have identified candidate programmes it will be possible to develop the timeline for decisions on investigation, planning, construction and operation and set out that timescale for the preferred plan in Stage 6.

Firstly, we need to set out the decisions that will need to be made in the development of the plan and who will make them, as set out in Table 2. Our approach is to ensure a robust decision making process at each critical point in the staged process.

**Table 2: Key decision points in developing the best value plan**

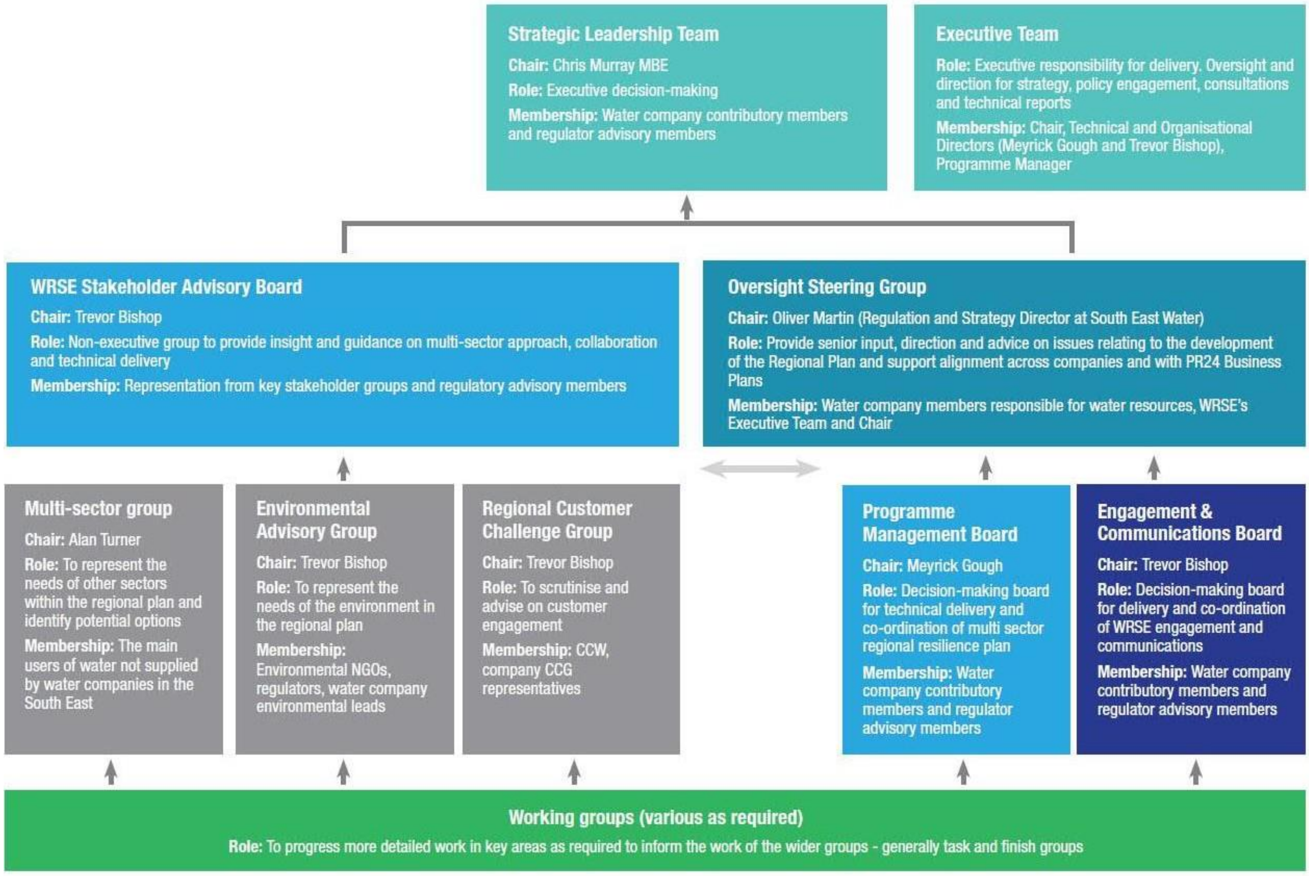
| Decision Point | When? | What? | Who? | Reviewed by | Signed off |
|---|---|---|---|---|---|
| **DP1** | Stage 2: Pre-modelling | - Problem characterisation & selection of modelling approach<br><br>- The decision-making framework, objectives, criteria and metrics. | PMB | SAB | SLT |
| **DP2** | Stage 3: Modelling | - 3a) Creation and testing of single future situations and situation trees<br><br>- 3b) Choice and number of run types to produce solutions. | PMB | SAB | |
| **DP3** | Stage 4: Shortlisting | Shortlisting a range of best value programmes for further assessment. | PMB | SAB | |
| **DP4** | Stage 5: Performance testing | Identifying themes emerging from the performance testing and how they inform the selection of the preferred best value programme. | PMB | SAB | |
| **DP5** | Stage 6: The Preferred Programme | Selection of the preferred best value programme. | PMB | SAB | |

PMB – Project Management Board[3]; SAB – Stakeholder Advisory Board; SLT – Senior Leadership Team

The role and make-up of our governance hierarchy is explained in Figure 4. Further details on the engagement and governance structure can be found in **Method Statement 1327 WRSE Stakeholder Engagement** and our Governance Policy (in our document library).

[3] In this context the water company PMB members are reflecting the considered view of their company developed from consultation within their organisations.

Figure 4: WRSE Decision making groups




As well as the formal public consultation process and the engagement undertaken throughout the development of the plan, the role of the Stakeholder Advisory Board (SAB) is particularly important as it provides a layer of independent external scrutiny to our decision-making. The SAB will work with the SLT to ensure that the multi-sector, regional plan meets the needs of all water users, the environment and supports the regional economy. The minutes of the meetings held by the SAB can be found on the WRSE website.

The SLT will ultimately make the final decision on which programme will form the draft regional plan for consultation. Its decision making will be informed by the technical modelling undertaken by WRSE, expert judgment and selection justification from PMB, plus wider input from the member water companies and stakeholders. Decision makers need to ensure they have a clear and reasoned justification for the decisions taken, documenting the consideration of alternative approaches rejected.

Sensitivity analysis will be used to assess any areas of disagreement to understand the materiality of the decision.

# Objectivity vs Subjectivity

Decision making at all levels is a balance of objectivity (things are objectively calculated) and subjectivity (expert judgement). It is not currently possible, or we would argue, desirable, to programme a model (or models) to consider all the variables within water resources planning and have it make all the decisions for us. There is always a balance of evidence as provided by the decision support tools alongside subjective assessment and judgement, taking the views of stakeholders in the round.

# 3 Stage 1: Data verification

## Input data

The methods for producing the input data required are detailed in our other workstream-based method statements. All data input to the data landing platform (DLP) is signed-off by the input workstream and the version, authorisation and author automatically captured as part of the upload. This section lists the data required and expected provenance.

## Planning scenarios and planning horizon

The Water Resources Planning Guideline (WRPG) states that a Water Resources Management Plan (WRMP) must consider the worst-case dry year combination of supply and demand forecasts for each water resource zone, together with the uncertainties incorporated in target headroom. Drought resilience must also be included, to provide resilience to 1:500-year extreme drought by 2039/40.

To enable investment modelling for dry year and drought across the region, baseline supply and demand forecasts and uncertainty profiles are imported for each of four deterministic planning scenarios:

- Normal year (1:2yr) annual average (NYAA)
- Dry year (1:100yr) annual average
- Dry year (1:500yr) annual average (DYAA)
- Dry year (1:500yr) critical period (DYCP)

Deterministic deployable outputs (DOs) are also provided for supply options for each of the planning scenarios, and demand reduction profiles for each of the demand reduction strategies.

Where possible, drought interventions are not included in supply or demand baselines; media campaign impacts, temporary use bans, non-essential use bans, and drought permits or orders may be included as options that have a DO or demand reduction available during the dry year or drought planning scenarios.

The planning horizon for the regional plan and consequently the draft Water Resource Management Plans (WRMP) will be the financial year 2025/26 to the financial year 2074/75.

# Baseline supply forecasts

Baseline supply forecasts for the adaptive plan branches in the Investment Model (IVM) define water available for use (WAFU) from each water resource zone's own sources, plus or minus any external or commercial transfers to/from the WRSE water companies, and inset appointments. These WAFU forecasts are generated by the Regional Simulation Model, based on regional weather and climate datasets, hydrological modelling, groundwater modelling and dynamic demand algorithms and methods. See **Method Statement 1331 WRSE Regional System Simulator** and WRSE regional simulation model scoping report for more details.

Existing inter-zonal transfer pipelines and existing inter-zonal bulk transfer agreements within the region are included as options, to enable existing transfer agreement inclusion as either fixed volumes representing inter-company agreements, or options for optimisation of conjunctive use of regional WAFU, as desired for different IVM runs.

As noted above, drought intervention DO reduction or enhancement is not included in the baselines, but as options available for dry or drought year planning scenarios.

# Baseline demand forecasts

Baseline demand forecasts are generated by each company, based on the spatially coherent regional population and properties forecasts generated by Edge Analytics (Population and Property Forecasts – Methodology and Outcomes). The companies provide deterministic distribution input (DI) forecasts with DI per water resource zone (WRZ) per year, for each planning scenarios required to populate the situation tree for the regional plan.

As there are several relevant population and properties forecasts, the demand forecasters will select forecasts that are most applicable for regional adaptive planning, as detailed in **Method Statement 1319 WRSE Demand Forecast**. It is feasible to include alternative demand forecasts either:

- as fixed baselines, for separate optimisations of a range of supply demand balances where the range covers supply uncertainties only; or
- as demand forecast uncertainty profiles, sampled to generate a range of supply demand balances for a single optimisation.

Testing and evaluation of the IVM with full data will enable determination of the preferred method, or combination, going forward.

# Situations and policies

Deterministic baseline forecasts require the forecaster to select appropriate forecasts from those that are feasible, using expert judgment and professional experience. Situations (i.e. circumstances beyond reasonable control of the water companies or regulators such as population growth, climate change, etc.) and policies (either internal or governmental/regulatory) are key factors that influence both system forecasts, and the uncertainty distributions around these influences are all captured as part of the supply and demand forecasting workstreams, to be input to the investment model via the DLP.

The WRPG states that situation and policy uncertainties affecting public water supply forecasting should be sampled to provide a deterministic target headroom forecast to be included in problem development and ensure that water resources management planning can meet the risk that the future deviates from the most likely forecasts. The headroom approach adopted by WRSE includes adjustments to these uncertainties according to the situational branch. Additional uncertainty profiles will also be input relating to environmental protection, non-public water supply, and wider South East systems, as defined in the WRSE Resilience Framework, so as to ensure that the problems to be solved are comprehensive enough to provide solutions resilient for all planning scenarios.

# Investment options

Both working together as WRSE and in preparation for their own WRMPs, individual water companies have identified and provided data for all regional supply, demand and transfer options not included in the baselines, whether existing, under construction, or new.

Options may be stand-alone or made up of:

- Option elements (resource, conveyance)
- Option phases (modular increases in resource DO)
- Option stages (planning, development, construction and operation)

For example, existing transfers are input with two elements:

- DO of the bulk transfer agreement under different planning scenarios (resource element)
- capacity of the transfer pipeline (conveyance element)

This enables the investment model to both run simulations of the system with the bulk transfer agreements fixed, or to run with optimisation of existing transfer pipeline utilisation.

Drought interventions may be included as options to enable better understanding of the impact of temporary use bans, non-essential use bans, drought permits and drought orders which temporarily change the conditions in an abstraction and or discharge, and to better evaluate the investment cost of resilience to different levels of service.

Demand and supply options due for completion before the start of the planning horizon in 2025 will be included in the baseline forecasts. Any sustainability reductions planned before 2025 will also be included in the baseline forecasts.

Companies have agreed with regulators any other options that are considered fixed in the plan, for instance those which planning, development or construction is due to start before 2025 but complete beyond that date, as per WRPG.

Demand reduction strategies per WRZ are developed by companies from combinations of available demand options to meet different demand reduction targets. Three per zone are envisaged, though more can be submitted to WRSE for consideration. As recirculation of WAFU through effluent discharge is a consequence of demand levels upstream, for each demand strategy in upstream zones, the associated effect on downstream WAFU is calculated by the simulation model for input via the DLP.

New supply options and transfers can include elements, phases and stages as listed above; the combination of the components by the investment model defines when or if an option is commissioned, the maximum DO available, and the combined operational expenditure, which the optimiser uses in comparison with the operational expenditure of all other options to minimise utilisation while satisfying demand across all planning scenarios.

Whether options result in a need for new treatment capacity in a zone depends on:

- Baseline demand growth
- Amount of demand reduction that frees up existing treatment capacity
- Amount of DO reduction that frees up existing treatment capacity (e.g. sustainability reductions)

If additional treatment is required these are taken into account when deriving the overall investment programmes.

WRSE's Multi-sector group and Environmental Advisory Group (part of SAB) will also provide potential options which will be considered in the investment model. These options will have to be of a comparable standard to the water company options. Customer input to options is considered through their preference of option type.

A more detailed description of options development, appraisal, and option component mapping for modelling is included in **Method Statement 1328 WRSE Options Appraisal**.

# Data flow and quality control

Regional planning input data outlined in section 2.1 is being delivered by several workstreams listed above. The majority of these workstreams are being undertaken by different contractors, and each may include local data storage and visualisation elements to streamline and audit data. To control the data sharing, data management and quality assurance across the regional planning process a centralised Data Landing Platform (DLP) has been created (see Appendix 1).

A complementary assurance process of the methods and data being used within WRSE will be undertaken to ensure the correct methods are being deployed by the companies (See Quality Assurance Method Statement).

# 4 Stage 2: Defining the Decision-Making Framework

This Stage has the following elements:

- Problem characterisation and risk-based planning
- Defining objectives for the plan
- Developing a suitable set of criteria and metrics that demonstrate whether and how the objectives are met.

Each of these points were discussed in pre-consultation on our plan and information added to our website.

## Problem characterisation

Water Resources Planning uses a risk-based planning approach. The tools you develop and methods you employ to identify an overall best value solution should be commensurate with the risks in your planning area. In order to establish the level of risk we have taken the base data gathered in Stage 1 and carried out an assessment known as problem characterisation.

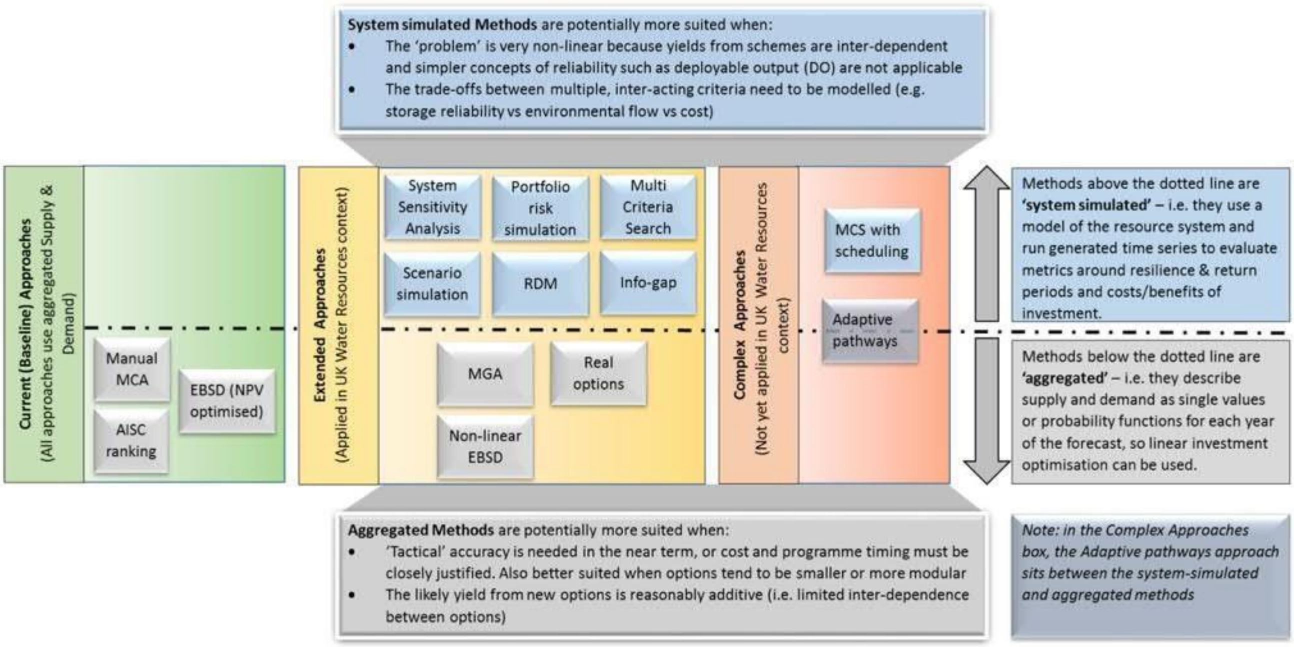
Problem characterisation enables us to examine the severity of any potential planning problems and the potential complexity of solution to those problems at WRZ-level. By combining these elements, we can establish an overall High, Medium, Low risk level for each zone, and go on to consider which tools are fit for purpose to meet those risks.

Our problem characterisation has been written up and published on our website[4]. There are a range of risk levels identified at individual WRZ level. We consider that taken together at a regional scale, the overall risk for the South East of England to be high.

The UKWIR Decision Making Process guidance describes decision-making tools and supporting methods available from the simple to the complex, cost-based to full multi-metric, system simulated adaptive planning. Figure 5 is taken from the UKWIR guidance.

[4] www.wrse.org.uk/library

### Figure 5: Decision making methods and tools for problems of different complexity




With WRSE assessing its level of risk as high, UKWIR Guidance recommends that we consider the use of extended or complex risk-based techniques to enable a thorough analysis of the planning problem. The decision support tools we have developed fit into the above matrix in Figure 5, as set out in Table 3 below.

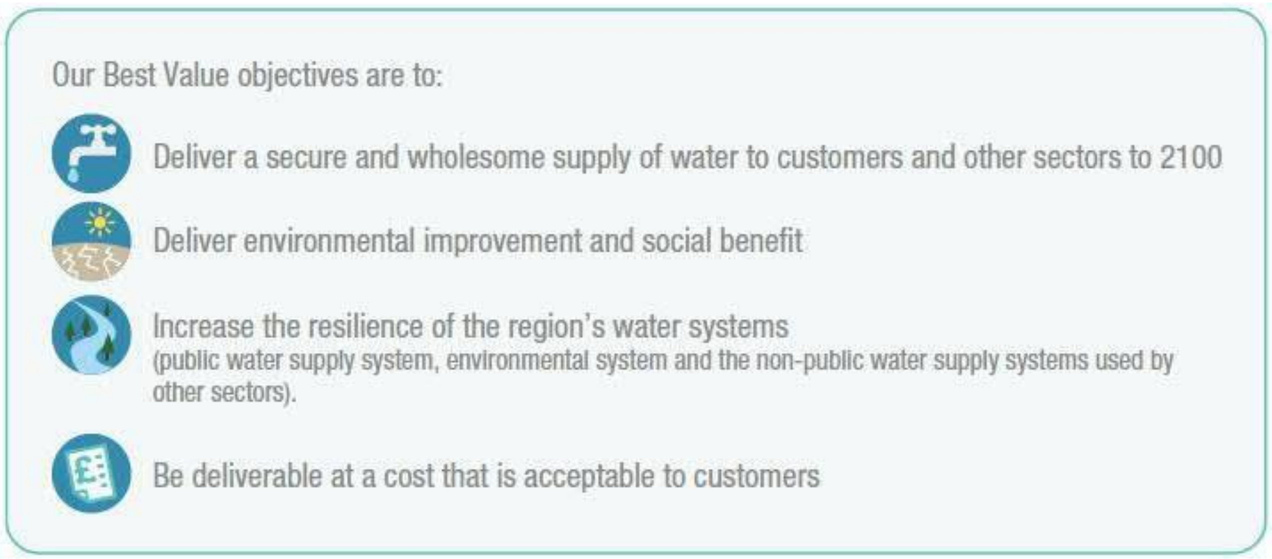
### Table 3: Our Decision Support Tools and modelling approaches

| Model | Method | | Approach | Used for |
|---|---|---|---|---|
| **Investment Model** | Current | Aggregated | NPV optimised | Future situations and solutions - All WRZs |
| | Extended | | Multi-metric optimisation | |
| | Complex | | Adaptive Pathways | |
| **Regional System Simulator** | Extended | System-simulated | Scenario simulation | Supply calculation and Performance testing |

# Our objectives

In order to develop a Best Value plan, we first need to set our objectives –the high-level goals that our regional plan must aim to deliver relating to 'best value'. Using insight from water company customers across the South East to help us understand their priorities, our objectives are representative of what matters most to customers. We shared our draft objectives with wider stakeholders to gather their views, which has resulted in the four objectives in Figure 6, below.

**Figure 6: Our objectives**




Water companies have a statutory duty to develop and maintain an efficient and economical system of water supply and to prepare, publish and maintain a Water Resources Management Plan (WRMP) which explains how this duty will be achieved.

The Water Resources Planning Guideline (WRPG) sets out the requirements for companies to follow in producing their plans and the Environment Agency's National Framework gives details of the indicative scale of challenge facing future water resource provision in England and requires water companies to work together in regional groups to meet the challenge and develop a cohesive set of water resource plans.

We developed our framework of objectives, criteria, and metrics with reference to the National Framework and the WRPG as primary reference sources to ensure our plan will meet legal, regulatory and policy expectations and is capable of incorporation/alignment with company WRMPs. Specifically, Section 9.2 of the WRPG sets out a suite of factors that need to be considered in the development of a best value plan including cost, affordability of your customers' bills and intergenerational equity; resilience to drought and non-drought events; environmental protection and improvement with specific reference to biodiversity, natural capital, net zero carbon; as well as customers' preferences.

We ensured that our proposed framework and overall approach covered all the factors identified in the WRPG. We also used insight from water company customers and stakeholders across the South East to help us understand their priorities and used this to shape the framework to reflect what matters most to them. We recognise that the four objectives are high level, but they are represented by criteria and metrics that give further detail and enable assessment of additional value.

## Value criteria and metrics

As our objectives are high-level, we need to turn them into measurable indices on which we can assess best value.

Each objective is represented by a set of value criteria which, in turn, will each have an associated metric that will measure the additional value it delivers. We will use the criteria and metrics to assess the different water resource programmes that are produced through our investment modelling. We'll also use them to compare the shortlisted best value programmes and explain the differences between them and the additional value each delivers.

Each programme will comprise a series of options and will be a different version of what the plan could look like. Some of the value criteria identified are things that we 'must do', including the legal and regulatory requirements that our regional plan must meet to support companies' WRMPs. Others are topics or policy areas (things we 'should-do') where there is a strong policy expectation that they will be achieved and/or the individual companies have already made commitments regarding their incorporation. These value criteria are described as constraints. For example, the secure and wholesome supply of drinking water to customers is an absolute requirement on companies; as is the demonstration of how all the water resource programmes we produce meet these requirements.

There are other criteria we will use to generate different programmes which deliver additional value. We will use these criteria and metrics to help us identify where value is added so we can differentiate between the programmes. These are described as optimised criteria and we will use them to shortlist the water resource programmes that offer 'best value' and help us to achieve our four objectives.

Once we have used these criteria to shortlist our 'best value' water resource programmes we will use the metrics, and potentially some additional metrics, to help compare the different programmes. This will facilitate the informed conversations we need to have with stakeholders and customers about their respective costs, benefits and outcomes, and will help us to identify any 'trade offs' in how different (optimised) value criteria are measured and weighted that need to be made before ultimately identifying the preferred water resource programme that will form the basis of our regional plan.

We will not be appraising and selecting individual options in isolation. We propose to appraise a series of programmes, each comprising options that we consider, by combination, meet our objectives, value criteria and deliver additional value.

There will be a number of potential best value programmes that could be adopted, each delivering alternative levels of value against different best value criteria. There is no single understanding of what is "best", but trade-offs will be made between different levels of value across the objectives. Tables 4 to 7 below, set out the value criteria and the metrics that represent each objective.

Table 4: Value Criteria and metrics for the secure and wholesome supply objective

**Deliver a secure and wholesome supply of water to customers and other sectors to 2100**

| Value criteria | Definition | How we'll measure it (metric) | Criteria type | Data source | Method statement / document |
|---|---|---|---|---|---|
| Meet the supply demand balance | All the water resource programmes that we consider for the regional plan must meet the supply demand balance so there is no water shortfall in any of the water companies' supply areas over the planning period. This is a legal requirement. | Public Water Supply - supply demand balance profile (Ml/day) | Constraint | Final supply demand balance for public water supply | Regional planning tables |
| | The regional plan is also looking to address the future needs of other sectors. We've worked with representatives of sectors that rely heavily on water in our region to understand how much additional water they need the regional plan to deliver to meet their future needs. | Provides additional water needed by other sectors (Ml/day) | Constraint | Non-public water supply demand forecast | Multi-sector |
| Leakage | The South East water companies have committed to reducing leakage by 50% by 2050. All the water resource programmes that we consider for the regional plan will achieve this target. | 50% reduction in leakage by each company by 2050 from 2017/18 baseline (%) | Constraint | SE water companies Annual Review 2017/18 | Options appraisal |
| | There are options that would reduce leakage further over the planning period. We will develop programmes that include leakage reduction beyond 50% and use this criterion to assess and compare the performance of the shortlisted programmes. | % leakage reduction above 50% | Optimised | Option level assessment | Options appraisal |
| Water into supply | All the water resource programmes we consider will include options to reduce water use. At present there is no formal target for water consumption that we can include in our plan so we will develop programmes that include different levels of consumption reduction and use this criterion to assess and compare the performance of shortlisted programmes.<br>Defra is considering a metric or target to encourage a reduction in the amount of water used. We'll revisit this if it is set to make it a constraint within the plan. In that event, anything beyond that target will be used to demonstrate performance of the shortlisted programmes. | Distribution input (DI) | Optimised | Option level assessment | Options appraisal |
| Customer preference | We have conducted research into customer priorities and preferences for different option types. This produces a score, and we will use this criterion to assess and compare the performance of shortlisted programmes.<br>In addition to using this criterion to assess best value, we will engage with customers to help us consider the application of weightings to the different criteria and identify the preferred programme. | Customer preference for option type (score) | Optimised | Customer research | Customer engagement |

**Table 5: Value Criteria and metrics for environmental improvement and social benefit objective**

**Deliver environmental improvement and social benefit**

| Value criteria | Definition | How we'll measure it (metric) | Criteria type | Data source | Method statement / document |
|---|---|---|---|---|---|
| Strategic Environmental Assessment (SEA)* | Regional plans are non-statutory but we will apply the SEA criteria. The SEA informs the decision-making process through the identification and assessment of the effect a plan or programme will have on the environment. We will use the SEA to calculate the individual scheme scores. This does not replace the SEA process. | Programme benefit (score max)<br><br>Programme disbenefit (score min) | Optimised | Option level assessment | Environmental assessment |
| Natural capital | Natural capital can be defined as the elements of nature that directly and indirectly produce value or benefits to people (now or in the future). There is no statutory target to increase natural capital, but it is an aspiration of the UK Government's 25-year Environment Plan. We will calculate the increase in natural capital that the different water resource programmes deliver and use this criterion to assess and compare the performance of different programmes. | Enhancement of Natural Capital Value (£m) | Optimised | Option level assessment | Environmental assessment |
| Abstraction reduction | Reducing abstraction from sensitive water sources is one element of how the regional plan will deliver environmental improvement. We will use our investment model and technical environmental work to optimise this, considering affordability, the expected benefits that will be derived and the timing of delivery. | Reduction in the volume of water abstracted at identified sites (Ml/day) and by when (date) | Constraint | Environment Agency scenarios and water company scenarios | Environmental ambition |
| Biodiversity | Improving biodiversity is required under a range of different legislation and policy and assessing the biodiversity net gain of our water resource programmes is a requirement of the Water Resources Planning Guideline. It is also an SEA objective. We will develop a net gain score** for each of our different water resource programmes and use this criterion to assess and compare the performance of different programmes. | Net gain score (%) | Optimised | Option level assessment | Environmental assessment |
| Carbon | The water industry has committed to achieving net zero operational carbon emissions by 2030. There is also an objective to reduce embodied and operational carbon emissions as part of the SEA. We will show how different water resource programmes seek to balance the additional carbon created through a combination of minimising emissions by considering alternative construction techniques and/or materials and by carbon offsetting schemes. The cost of this is included in the total programme cost but we will also use the cost of carbon offsetting to assess and compare the performance of different programmes. | Cost of carbon offsetting (£m) | Optimised | Option level assessment | Environmental assessment |

*The Strategic Environmental Assessment (SEA) is a separate part of the programme appraisal process and includes a number of objectives and metrics. We consulted on the scope of our SEA and its objectives in August 2020. In addition to looking at the overall benefits and disbenefits we will also be undertaking further checks on the in-combination effects of different options working in conjunction with each other both from an environmental perspective and the ability to deliver the options within each programme.

**We will agree an appropriate method of calculating biodiversity net gain through discussions with regulators.

**Table 6: Value Criteria and metrics for the resilience of the region's water systems objective**

## Increase the resilience of the region's water systems

Our multi-sector, regional resilience plan will plan for a wider range of shocks, stresses and events beyond drought and will assess the resilience of the region's main water systems:

- The public water supply system run by water companies
- The non-public water supply system that provides the water to other sectors
- The environmental water system.

We have developed a Resilience Framework*** so we can show how the resilience of each system is changed by the different water resource programmes. There are three components of our resilience assessment – reliability, adaptability and evolvability – which each have a set of associated metrics. We will produce a score based on the amalgamated metrics for each of these components and use this as a criterion to assess and compare the performance of different water resource programmes.

| Value criteria | Definition | How we'll measure it (metric) | Criteria type | Data source | Method statement / document |
|---|---|---|---|---|---|
| Drought resilience | Water companies currently plan for a severe drought to occur once in every 200-years. The National Infrastructure Strategy[3] set a requirement for this to increase to once in every 500-years, increasing the level of resilience, this has been endorsed by HM Treasury. All the water resource programmes we produce will achieve this level of resilience. We will use the Best Value planning approach to identify the optimum time we can achieve this increased level of resilience. | Achieve 1 in 500-year drought resilience (date achieved) | Constraint | This is included as a requirement in the National Infrastructure Strategy | |
| Resilience assessment **Reliability** | Reliability is the ability to withstand short term shocks without actively changing the performance of the system. | Programme reliability score | Optimised | Resilience assessment | Resilience Framework |
| Resilience assessment **Adaptability** | Adaptability is the ability to make a short-term change in performance of the system to accommodate the impact of a shock and recover. | Programme adaptability score | Optimised | Resilience assessment | Resilience Framework |
| Resilience assessment **Evolvability** | Evolvability is the ability to modify the system function to cope with long term trends. | Programme evolvability score | Optimised | Resilience assessment | Resilience Framework |

***We consulted on the Resilience Framework in June 2020. It sets out a method for assessing resilience across the three main water systems – public water supply, non-public water supply and the environment. We have responded to feedback and developed it further through engagement with stakeholders. You can view the final Resilience Framework Method Statement here.

[3]National Infrastructure Strategy, November 2020

Table 7: Value Criteria and metrics for the acceptable cost objective

Deliverable at a cost that is acceptable to customers

| Value criteria | Definition | How we'll measure it (metric) | Criteria type | Data source | Method statement / document |
|---|---|---|---|---|---|
| Programme cost | This represents the total cost of delivering all the options in the water resource programme. It uses the standard HM Treasury rate to calculate the total programme cost. We will use this criterion to assess and compare the performance of the different water resource programmes. | Net Present Value (£m) using the Social Time Preference Rate (STPR) | Optimised | Option level assessment | Option appraisal |
| Inter-generational equity | This criterion also looks at the total cost of the programme but calculates it using a lower HM Treasury rate that spreads the cost of the programme over the planning period delivering best value for both present and future generations. We will use this criterion to assess and compare the performance. | We are using the long Term Discount Rate (LTDR) | Optimised | Option level assessment | Option appraisal |

# How the metrics are calculated

Most of the optimised metrics used in best value appraisal are calculated using information that is evaluated at option-level. The IVM will take the option-level information and combine it to make programme-level assessments.

Combining option-level information to make a programme-level assessment can be as simple as adding option-level values together. In other cases, further calculations will be made e.g. the cost metrics, where each of the schemes have to be scheduled over the planning period and costs discounted over time.

The key data source for each of the metrics, links to the relevant method statements where further information can be found, and a summary of the programme-level calculation is in Table 8.

Table 8: BVP Metrics: Links to other method statements

<table>
<tr><th>Metric</th><th>Data Source</th><th>Option-Level Method Statement</th><th>Programme-Level Calculation</th></tr>
<tr><td>Least cost & Intergenerational equity</td><td rowspan="11">Option level assessments</td><td rowspan="3">Options appraisal</td><td>Schemes scheduled into a programme. Costs of programme elements scheduled and discounted.</td></tr>
<tr><td>Leakage (optimised post-2050)</td><td rowspan="2">Baseline demand minus savings of chosen DM programme</td></tr>
<tr><td>Water Consumption</td></tr>
<tr><td>Environmental benefit</td><td rowspan="5">Environmental Assessment</td><td rowspan="2">Sum of individual scheme scores</td></tr>
<tr><td>Environmental dis-benefit</td></tr>
<tr><td>Biodiversity net gain</td><td>Sum of impact score</td></tr>
<tr><td>Natural capital</td><td>£/yr per selected option, summed up over the planning period (expressed as £m)</td></tr>
<tr><td>Carbon</td><td>Sum of total Carbon emissions, monetised</td></tr>
<tr><td>Reliability</td><td rowspan="3">Resilience</td><td rowspan="3">Sum of scheme values</td></tr>
<tr><td>Adaptability</td></tr>
<tr><td>Evolvability</td></tr>
<tr><td>Customer preference for option type</td><td>Customer research</td><td>Stakeholder</td><td>Sum of scheme values</td></tr>
</table>

# Double counting

We recognise there is a risk of double counting or double consideration of the benefits and dis-benefits of some of the metrics, in particular between each of the environmental metrics and between the resilience metrics. Additionally, the carbon metric is a sub-set of the cost metric. We will carry out a sensitivity analysis to provide confidence that the plans are robust and to understand the impact of different scenarios. This will allow us to explain in the regional plan whether any double counting risk has been identified and how it has been accounted for in our decision making.

# 5 Stage 3a: Defining the situation trees

Stage 3 represents the core modelling stages of the BVP process and is split into two parts:

- Stage 3a – Modelling which produces the water resources planning problems over the planning period from the wide range of potential futures/situations.
- Stage 3b – Investment Modelling in which the problems provided by the IRM are solved to produce investment programmes for comparison and shortlisting.

It was intended that Stage 3a would be carried out through use of an Integrated Risk Model (IRM), however the situation trees for the draft regional plan will be developed outside of the IRM.

## Overview

For the draft regional plan, WRSE will use the investment model (IVM) to identify potential futures and combinations of futures in order to develop adaptive trees.

The IVM solves an uncertain future comprised of 9 situations. These situations are created by combining available growth, climate change and environmental destination scenarios. The definition is such that each tree of situations shares a common start date. The IVM outputs ensure that supply-demand balance of each situation is satisfied by the output adaptive programme for a feasible model run, i.e. there are no deficits.

The process steps relating to Stage 3a are set out in the remainder of this section.

## Process Steps

### Step 1: Defining futures

#### Key uncertainties

We consider that key future uncertainties in the supply demand balance relate to:

- Growth – Population and property growth in the South East
- Climate change – The impact of climate change, particularly on supply availability
- Environmental ambition– The amount of abstraction reduction that we need to plan for environmental and social reasons

These are by no means the only challenges or drivers for change, (other uncertainties include efficacy of demand management, leakage reduction and behavioural change by way of example) but they represent the areas that are most likely to cause significant medium to long-term uncertainty and potentially large step changes to the supply demand balance for water in the future.

Further details on the range of scenarios produced for each of the key uncertainties are available in the population and properties, climate change and environmental method statements respectively. However, we summarise in the following sections.

### The core baseline position

For previous regional plans by WRSE (that supported the preparation of previous company WRMPs) a single baseline situation was defined, and alternative futures used to describe the risk around that situation (as headroom), following the WRPG. This single pathway was the reported pathway.

Our approach for the draft regional plan, the first under the National Framework, will be to bring the analysis of futures earlier in the planning process, because of the levels of complexity and uncertainty we face. We will have a range of baselines with alternative futures available for the investment model to select from and solve individually or at once.

Nevertheless, we are still currently required to report a single situation as companies are still required to use one scenario to fill in their WRMP tables. This will help the integration of the regional plan with individual companies WRMPs. We have defined our core baseline scenario (Table 9) based on company information and guidance from the regulators.

**Table 9: Assumptions in the core baseline scenario**

| Area | Scenario | Description |
|---|---|---|
| Growth | Housing Plan | Growth taken from Local Authority housing plans, then ONS-18 when plans cease<br>Usage reductions assumed as per company plans to 2025 then only baseline water efficiency and optant metering as per the WRPG. |
| Climate Change | Median | A number of climate change scenarios have been developed using UKCP_18 spatially coherent climate datasets. The core baseline scenario includes the median position. |
| Environmental ambition | High | Sustainability reductions scheduled to take effect by 2025 are included, together with the "high" forecast of further reductions, which includes licence capping impacts. |
| Drought resilience | 1:500 by 2039/40 | As required by the WRPG. |

We have chosen this situation because:

- It aligns with regulatory expectations to use a Local Authority-based growth projection, to show the plan is not limiting planned growth;
- It uses a median climate change scenario which we consider a reasonable basis for uncertainty, without under or over representation; and
- Environmental destination is a policy choice to be analysed during programme appraisal.

### Alternative baseline situations

There are a large number of potential alternative future situations, based on differing assumptions for growth, climate change and environmental destination.

We have identified a range of alternative assumptions for each key future uncertainty, the basis for which are discussed further in each of the supporting method statements. Combining these assumptions leads to over 5,000 potential alternative situations.

The supply and demand forecasts input via the DLP are first combined into the following scenarios:

- Normal Year Annual Average (NYAA),
- Dry Year Annual Average (DYAA),
- Dry Year Critical Peak (DYCP), and
- A 1:100yr Annual Average drought.

The reason for a combined drought planning scenario is to take account of changing levels of drought resilience within the planning period. The draft revised guidance states that 1:500 resilience should be attained in the 2030s; and as such the baselines will represent 1:200 DO and DI until 2030, and 1:500 DO and DI from 2040, but the exact date of change from one level to the other may be varied in different SDB scenarios for optimisation in the investment model, or sensitivity testing of preferred regional plans.

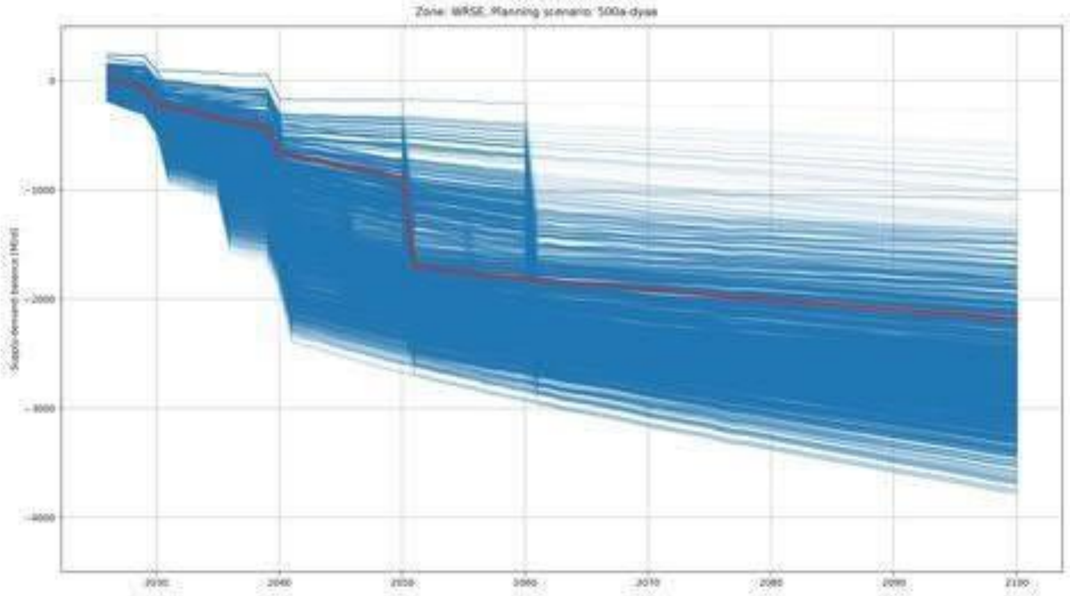
For the multi-sector non-public water supply demand, we will use the NYAA, DYAA and DYCP forecasts but there might not be significant differences between their values given the nature and maturity of the available data. We will work with the multi-sector stakeholder group to better understand their typical seasonal demand pattern use. This would be a separate investment model run.

## Step 2: Generating futures

The information for all the potential futures are combined to develop an overall spread of potential future baseline supply demand situations over the planning period, an example of which is shown in Figure 7.

Using our decision support tools it is possible to interrogate which combination of growth, climate change and environmental destination scenarios are used to generate each line on the graph. For example, the red line on the graph in Figure 7 represents the core baseline scenario compared to the other alternative scenarios shown in blue.

Figure 7: Future baseline supply-demand balance situations (example)



A range of single situations will be identified to develop situation trees (Step 3), i.e. a combination of situations will be used to form branched pathways (Steps 4 and 5), to explore the range of potential futures.

## Step 3: Choosing single situations

Single pathway analysis is the simplest and quickest method to initially test what mix of solutions will be generated by the IVM. We will select a representative range of single baseline situations (including the core baseline situation) and pass them to the IVM to produce a single, least cost solution for each selected baseline situation. These are used to verify the investment model inputs and to provide some information, however the single situation scenario cannot be used to produce a least cost or best value plan. These types of plans can only be derived using the adaptive planning approach.

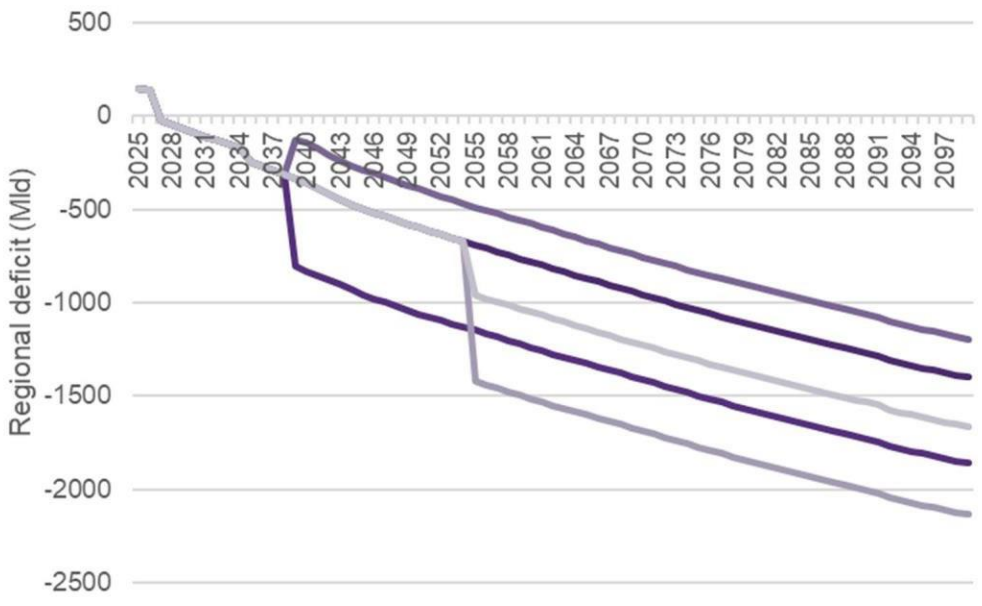
The number of situations sent to the IVM will be influenced by a number of factors. These could include discussion around the impact of specific policies where early provision of outline model outputs would inform the debate e.g. the potential impact of different environmental ambition scenarios, as well as to sample the general range.

The library of other situations not selected will still help us during the performance testing of shortlisted programmes in Stage 5 of the BVP process.

## Steps 4 and 5: Choosing branched pathways – 'situation trees'

The IVM will be able to optimise solutions across a number of different baseline situations at once. As such situation trees, like the one shown in Figure 8 below, will be generated.

**Figure 8: Example situation tree of one planning scenario**




The idea is to produce situation trees which reasonably span the potential range of future situations. Branching points emerge for a number of reasons. These can be chosen based on regular time intervals with branches wide enough to cover the spread, or they can be related to policy deadlines set within the objectives or analysis of the options database. For example, where we can anticipate decisions may be required between strategic development options.

We can use two alternative approaches to define the situation trees (and branching points):

- Probabilistic – Use a Monte Carlo approach to turn the range of situations into a probability density function and then select specific percentiles across the spread to create SDB deficits; or
- Deterministic – Combine pathways from Step 2 (e.g. follow a particular growth and climate change pathway before branching at a point in time depending on the choice of environmental destination scenario)

We intend to follow the deterministic approach as we consider that being able to explain each branch of the tree in terms of a specific set of forecasting assumptions will be more understandable for stakeholders. It will also give a clear line of sight to the datasets on which the scenario was derived.

Review, assurance and sign-off of the single pathway and situation trees will be undertaken throughout the programme appraisal process with PMB (Stage 3b).

# Visualisation

## Problem visualisation: baseline forecasts & existing transfers

The WRSE visualisation tool (VT) enables viewing of supply demand balance scenarios using a range of different types of outputs to show how the investments, connectivity, costs, metrics change over time and situations. The WRSE VT will be used to show how existing transfers are utilised through time to meet the demands in the receiving water resource zone.

The purpose of these visualisations in the VT will be to gain a better understanding of what is driving the requirements for water, where the requirements are, and how the existing infrastructure can cope (or not) with these requirements. Our investment modelling report shows examples of these outputs.

## Problem visualisation: Situation trees

The amount of water required through the planning period will change according to some key external influences such as climate change, population growth, policies and the requirements of the environment in the future.

The various plots available in the VT will help to visualise the situation trees throughout the planning period, for both problem and solution understanding.

For each of the branches we will explain the factors that influence the anticipated levels for the supply demand balances. This will provide regulators, stakeholders and customers with a better understanding of the characterisation of these branches.

In many cases, the anticipated supply demand deficits could be achieved by several different combinations of external factors. Although at the more extreme ends of the supply demand balances tend to be driven by a more limited number of factors (e.g. more extreme climate change or environmental destination scenarios).

# 6 Stage 3b: Investment modelling

## Overview

The primary purpose of the IVM is to identify and schedule programmes of options to meet the supply demand challenges passed to it.

It is able to:

- Conjunctively optimise for all planning scenarios, WRZs and years across the planning horizon.
- Ensure the supply demand balance remains in surplus each year of the planning period, for all planning scenarios, in all WRZs and years, while minimising or maximising the value of a single objective function (e.g. cost), or multiple objective functions (e.g. a cost and an environmental or resilience function).
- Optimise against a single future situation or for a situation tree.

Technical details of the Investment Model (IVM) are provided in Appendix 3, and outputs from the modelling process can be found in our separate report, Investment Model Draft Regional Plan Results, found on the WRSE website.

## Model operation

### Modes of operation

The IVM can operate in three different modes: EBSD, Adaptive and Pareto (see Table 10, below).

**Table 10: IVM Modes of operation**

| IVM Mode | Future Situations | Objective Function | Used for |
|---|---|---|---|
| EBSD | Single | Cost | Investigating different future situations and performance testing. |
| Adaptive | Tree | Cost | Investigating adaptive plans across multiple future situations. Identifying the least cost programme. |
| Pareto | Tree | All | Producing programmes optimised against alternative single and multiple objective functions. |

The EBSD mode can only consider a single future situation at a time. We will use a series of EBSD mode runs for initial investigation of the potential range of futures (Step 6) and to carry out "what-if" type analysis, where we are interested in identifying a broad indication of changes between programmes (Stage 5). As this is an investigative mode, we will optimise on least cost considerations only at this point, consistent with guidance.

The Adaptive mode optimises across all the branches of a situation tree, rather than a single branch. We will use this mode to investigate adaptive planning decisions, optimising on cost only. It is used to identify the least cost adaptive programme.

The Pareto mode, like the adaptive mode optimises across all branches of a situation tree. We will use this mode to produce programmes using objective functions other than just cost. This is a key function required for best value planning. In this mode we will first use the model to identify how far individual metrics can be improved. Based on this information we will then see how far all the metrics can be improved in combination. It is this later stage which will be used to find the best value plan programmes.

## Objective functions for programme development

In all runs of the IVM the primary objective is to ensure the supply demand balance is not in deficit in each year of the planning period, in all planning scenarios and in all WRZs. This is to ensure that statutory supply duties of the individual water companies can be met, and is a statutory function of the WRMP.

There are then optimisable objective functions (as defined in Stage 2) that can be used to focus how the model achieves the primary objective. As such, we can seek to develop investment programmes which may perform better in terms of cost, resilience, environmental impact or social value. The optimisable functions are shown in Table 11 below.

**Table 11: Optimisable objective functions**

| Optimisable function | Unit | Code | Function |
|---|---|---|---|
| Least cost | £m NPV | COST | Minimise total NPV using the declining[5] Social Time Preference Rate (STPR) discount rate |
| Intergenerational equity | £m NPV | IGEQ | Minimise total NPV using the declining[6] Health Discount Rate |

[5] HM Treasury, March 2022. The Green Book (2022) supplementary guidance, Table 7

[6] HM Treasury, March 2022. The Green Book (2022) supplementary guidance, Table 8.

| Optimisable function | Unit | Code | Function |
|---|---|---|---|
| Long-term investment cost | £m NPV | LTDR | Minimise total NPV using the declining[7] Long-term Discount Rate |
| Environmental benefit | Score | ENV+ | Maximise, for all years from commissioning, for all WRZs, the sum of the ENV+ scores for all new options |
| Environmental dis-benefit | Score | ENV- | Maximise, for all construction and commissioned years, for all WRZs, the sum of the inverted ENV- scores for all new options (to ensure poorly performing programmes can be identified) |
| Biodiversity net gain | Score | BING | Maximise, for all years, for all WRZs, the biodiversity net gain values for all new options |
| Natural capital | £m | NATC | Maximise, for all years, for all WRZs, the natural capital values for all new options |
| Carbon | £m | CARB | Minimise, for all years, for all WRZs, the total cost to offset carbon emissions. |
| Reliability | Score | RELI | Maximise, for all years, for all WRZs, the reliability score for all new options |
| Adaptability | Score | ADPT | Maximise, for all years, for all WRZs, the adaptability score for all new options |
| Evolvability | Score | EVOL | Maximise, for all years, for all WRZs, the evolvability score for all new options |
| Customer preference for option type | Value | CUPR | Maximise, for all years, for all WRZs, the value based on customer preference for option types proportional to the volume supplied by each type |

[7] HM Treasury, July 2008. Intergenerational wealth transfers and social discounting: Green Book supplementary guidance, 2.4

The IVM can optimise against:

- a single objective function (COST or NATC or CUPR)
- or dual objective functions, (i.e. COST and NATC – the model will seek to find the solution that optimises the values of both functions together).
- a weighted combination of multiple objective functions

The resulting programmes of options will be sent to the visualisation tool for appraisal (Stage 4).

## Single function optimisation runs

Single function optimisation runs will be performed in the IVM for cost functions, to minimise the NPV cost for each of the three discount rates and to identify the least cost programme as required by the WRPG. The least cost run is described below.

### Least cost

Least cost runs will be produced by optimising against the COST function. Runs will be produced with the IVM in EBSD mode (only considering a single future situation, Step 6) and with the IVM in Adaptive mode (considering a range of future situations, Step 7).

A least cost run (in either mode) minimises the cost for all selected options for all zones, following existing HM Treasury rules for discounting (using the declining STPR[8]) of:

- NPV Capital costs (annuitised)
- NPV Fixed operating costs
- NPV Variable operating costs (frequency weighted average of NYAA, worst historic DYAA, resilience target DYAA and resilience target DYCP utilisation costs)
- NPV Embedded carbon costs (annuitised)
- NPV Fixed operational carbon costs
- NPV Variable operational carbon costs (frequency weighted average of NYAA, worst historic DYAA, resilience target DYAA and resilience target DYCP utilisation costs)

A number of least cost runs will be produced for each situation tree given to the model, for example a different least cost programme can be optimised for alternative dates to reach 1:500 resilience.

Additional cost optimisation will be carried out against the IGEQ and LTDR functions, using the same cost categories and calculation, but Health and Long-term discount rates.

[8] HM Treasury Green Book *Social Time Preference Rate*.

## Combined function optimisation runs

Combined function optimisations will be run with the IVM model in pareto mode.

In this mode the model seeks to optimise the values of multiple functions at the same time, within a threshold of the least cost. This is useful as it forces the optimiser to find a balance across a range of metrics. The three key combinations are:

- Environmental and social (E&S): optimise the weighted combined environment and social functions (ENV+, ENV-, BING, NATC, CUPR) within a threshold of the least cost (0.5%, 1%, 2% etc)
- Resilience (RES): optimise the weighted combined resilience functions (RELI, ADPT, EVOL) within a threshold of the least cost (0.5%, 1%, 2% etc)
- Best value (BVP): optimise the weighted combination of all functions within a threshold of the least cost (0.5%, 1%, 2% etc)

# Process Steps

The IVM phase can be broken down into several steps which are described in the remainder of this section. In summary, the single future situations and situation trees developed in Steps 3-5 (and described in Section 5 of this method statement) will be passed to the IVM and are optimised against COST in EBSD mode (Step 6, single futures) and Adaptive mode (Step 7, situation trees). The outputs will be presented via the visualisation tool (Steps 8 and 9).

The outputs will help us form an initial view of the sort of solutions produced by the IVM and identify trends and issues. The situations run will also generate information to inform policy discussions, such as the consideration of environmental destination or the impact of non-PWS demand. The outputs will inform the ongoing stakeholder consultation process and help establish which options are selected more frequently and initial tipping points.

Taking all of this information into consideration, we will be able to identify our preferred least cost solutions to the baseline planning problem. Alternative programmes of investment will then be developed using metrics other than COST and both single and multi-objective optimisations. The outputs of these runs will also be viewed in the visualisation tool and passed to Stage 4 of the BVP process for the shortlisting.

## Step 6: Least cost assessment (single situation)

This is a model running step where the single future situations from Step 3, covering a range of growth, climate change and environmental destination scenarios and including the core and most likely baseline situations, will be passed forward to the IVM. These are input to the IVM and initial least-cost runs completed in EBSD mode, optimising only on the COST metric.

The programmes produced by the optimisation will be for information only (as we are seeking an adaptive plan, not one robust to a single future) and used to identify broad patterns and trends in the options selected and contribute to policy debates (see Step 9).

## Step 7: Least cost assessment (situation tree)

This is a model running step where the situation trees from Steps 4 and 5, including the baseline situation tree, will be passed forward to the IVM. With the IVM now run in Adaptive mode, and optimising only on the COST metric, the IVM will expand the optimisation to find the best solution that could meet the SDBs in all branches of the situation tree across the planning period. It will demonstrate solutions that can adapt to future change. The outputs will be compared and assessed in Step 9.

## Step 8: Preparation of performance testing tools

Step 8 is an internal advisory step where we will inform the resilience and environment teams of the early outputs of Steps 6 and 7 so they can prepare their tools and be aware of the option types and ranges being produced by the optimisations. This facilitates the subsequent performance testing undertaken in Stage 5 of the BVP process.

## Step 9: Comparison of least cost runs

In Step 9, all the least cost runs from Steps 6 and 7 will be compared using the visualisation tool. We will focus particularly on the parallel plot visualisation, which charts the overall performance of each optimised run against each of the value criteria and their metrics, and also option scheduling tables that give us the types of options selected, where they are selected, when they are selected and how they are utilised across the planning period. Further information can found in Section 8: Shortlisting.

This comparison will also help identify zones or areas where additional options, alternative option yields, or additional or alternative transfers could be beneficial, and identify options which are never selected in any scenario.

We can also look at conjunctive use across the region, where existing formal bulk transfer agreements between WRSE zones are waived and the model optimises the transfer of water based on capacity of existing and potential transfer pipelines only, to identify the least cost sharing of resources and identify the minimum required resource development.

The EBSD mode outputs from Step 6 will identify the least cost solution to the single future baseline (from Step 1).

The Adaptive mode outputs from Step 7 will be analysed in the same way, but additionally we will be looking to:

- Identify a sub-set of situation trees that will be taken forward for full multi-metric modelling in Step 10 and further comparative analysis in Stage 4.
- Identify the Least Cost solution to the agreed baseline situation tree.

## Steps 10 and 11: Optimisations with full suite of alternative metrics

With the IVM now run in Pareto mode, we will complete single and dual optimisation runs of the full suite of metrics across the sub-set of situation trees identified in Step 9. As before, the model will find solutions that can meet the SDBs in all branches of each situation tree across the planning period.

In Step 10 we will confirm which single and dual optimisations will be run. In Step 11 we will carry out the Pareto modelling on the situation trees identified in Step 9 and return the outputs to the DLP for visualisation. The outputs will be compared and assessed in Stage 4.

# 7 Stage 4: Shortlisting

## Overview

The IVM will output a large portfolio of optimisation runs in Stage 3b. In Stage 4 we aim to focus in on a set of potential programmes that meet the planning problems whilst providing a range of additional value.

Shortlisted runs need not only perform well (in general) against the planning metrics but also provide variety in the types of options that are being selected. Each can then be taken forward for further performance testing (Stage 5). Each optimisation run output contains information that will help decision makers and stakeholders in completing their review, particularly:

- The performance of the optimised programme against the best value metrics (which at this stage are evenly weighted) and
- The schedule in which options are selected along each path of the situation tree and how much they are used.

The visualisation tool will enable decision makers to view and interrogate outputs, and understand the overall investment programmes.

## Programme shortlisting

The following two runs will be automatically shortlisted, as they are required for consideration as set out in the WRPG:

- **Least cost programme** - this will be the programme that delivers the least cost solution to the chosen baseline situation tree.
- **Best environmental and society programme** – this programme will not be optimised on cost but will be the programme that we consider delivers best overall environment and society value outcomes. We will identify this by taking into account overall performance across the SEA, Natural Capital and Biodiversity Net Gain metrics, as well as the customer preference metric.

We will also shortlist a range of alternative least cost and best value programmes for further assessment, taking all of the programmes that were optimised, together with the chosen least cost solution and best environment and society programme.

We will plot all of these programmes, to enable our Programme Management Board (PMB) to make an initial selection of the best value programmes. This may not necessarily be the programmes which deliver the highest performance against each of the individual metrics, according to the model, as customer and stakeholder feedback, together with professional judgement will also be considered. The justification for the initial selection will be documented, before being passed to Stakeholder Advisory Boards (SAB) and the Senior Leadership Team (SLT) as part of our decision making and governance processes.

# 8 Stage 5: Performance testing

In Stage 5, we take each of the shortlisted programmes from Stage 4 and subject them to further investigation and performance testing.

The following investigations will be undertaken:

- Stress testing (using the IVM)
- Environmental review
- Resilience review

## Stress testing

At this point we will also stress test the programmes using the investment model to find key dependencies and risks that impact on selection, e.g. "what-if" testing of specific alternative growth rates, environmental destination, dates for achieving policy goals and failure to gain planning permission for solutions.

The nature of the programmes themselves will help to identify the appropriate stress tests relating to them, as explained in Table 12 below.

**Table 12: Potential stress tests**

| Area | Comments |
|---|---|
| Drought resilience (Timing) | Could we achieve the 1:500 level of resilience earlier in all or in certain water resource zones? The results from this might suggest consideration of whether achieving this resilience standard at different times across the region could be appropriate. |
| Government Water Efficiency scenarios | We would test the impact different, potential, government water efficiency campaigns will have on the regional plan. The slowest progressive campaign would be used as the default position unless directed by Defra. |
| Leakage reduction | Each company has put forward 3 different options/policies for leakage reduction. We could test each or have a different mixture of leakage reductions across the region. |
| Option availability | We could remove or pre-select certain option types or specific options and re-run to examine the impact on the solutions, should one or more not be deliverable or be delayed. |
| Tree sensitivity | We could make incremental adjustments to the shortlisted situation tree (timing and spread) to align with Ofwat's Long Term Delivery Strategies see how sensitive the model outputs are to these changes. |

Further challenges such as uncertainties around option cost and timing alternative situation trees can also be stress tested to better understand the adaptability and robustness of each shortlisted programme.

Outputs of the stress tests will be available in the visualisation tool. Observations on performance, including potential impacts on the selection of a preferred plan will be documented and subsequently considered by PMB.

# Resilience assessment

Our approach to the resilience assessment of the regional plan is detailed in the WRSE Resilience Framework.

The effect of different stresses and hazards on a proposed investment programme in terms of impact on both the public water supply and non-public water supply will be investigated. We do this through identification of a series of resilience sub-metrics as provided in Table 13, which enable a comparative assessment of the resilience of different programmes.

Observations on performance against the resilience sub-metrics will be documented and subsequently considered by PMB during programme appraisal.

**Table 13: Resilience sub-metrics used to help differentiate shortlisted programmes**

| Criteria | Reliability | Adaptability | Evolvability |
|---|---|---|---|
| System characteristic | Uncertainty of performance | Timing and warning of events | Flexibility and diversity of options |
| Metric | R1 (PWS) Uncertainty of supply/demand benefit | A1 (PWS) Expected time to failure | E1 (PWS/non-PWS) Scalability and modularity of interventions |
| Metric | R2 (non-PWS) Breach of flow and level proxy indicators | A2 (PWS/non-PWS) Duration of enhanced drought restrictions | |
| System characteristic | Ability to persist with planned functions | Ability to respond to and recover from unexpected failures | Deliverability of planned changes |
| Metric | R3 (PWS) Risk of supply failure due to physical hazards | A3 (PWS) Operational complexity and flexibility | E2 (PWS/non-PWS) Intervention lead times |
| Metric | R4 (PWS) Availability of additional headroom | A4 (non-PWS/Env) Inter-catchment connectivity | E3 (PWS) Reliance on external bodies to deliver change |
| Metric | | A7 (PWS) Customer relations enhance engagement with drought demand management | |
| System characteristic | Resilience of supporting services | System connectivity and ease of system recovery | Monitoring and management of change |
| Metric | R5 (Env) Catchment/raw water quality risks | A5 (PWS) PWS system connectivity | E4 (PWS) Flexibility of planning pathways |
| Metric | R6 (Env/All) Capacity of catchment services | A6 (non-PWS) Mean time to failure (MTTF) of enhanced drought restrictions | E5 (All) Collaborative landscape management |
| Metric | R7 (PWS) Risk of failure of supporting service due to exceptional events | | |
| Metric | R8 (Env/All) Soil health | | |

*PWS = Public Water Supply*
*Non-PWS = Non Public Water Supply*
*Env = Environmental*

## Environmental assessment

An environmental review will be carried out on each of the shortlisted programmes. This will ensure that we have an understanding of the environmental and social benefits and dis-benefits of the portfolios of options.

This environmental review is separate from the environmental assessment of the regional plan (although it will use common data and information). The environmental assessments process is outlined in more detail in **Method Statement 1329 WRSE Environmental Assessments**.

The environmental review will include:

- An examination of the environmental sub-metrics (Table 14), to identify any potential areas of concern or highlight particular benefits.
- A programme level assessment of the potential cumulative and in-combination effects of the options in the preferred programme.

Table 14: Environmental sub-metrics used to help differentiate shortlisted programmes

| No. | Environmental Sub-metric |
|---|---|
| 1 | Protect and enhance biodiversity, priority species, vulnerable habitats and habitat connectivity (no loss and improve connectivity where possible) |
| 2 | Protect and enhance the functionality, quantity and quality of soils |
| 3 | Increase resilience and reduce flood risk |
| 4 | Protect and enhance the quality of the water environment and water resources |
| 5 | Deliver reliable and resilient water supplies |
| 6 | Reduce and minimise air emissions |
| 7 | Reduce embodied and operational carbon emissions |
| 8 | Reduce vulnerability to climate change risks and hazards |
| 9 | Conserve, protect and enhance landscape, townscape and seascape character and visual amenity |
| 10 | Conserve, protect and enhance the historic environment, including archaeology |
| 11 | Maintain and enhance the health and wellbeing of the local community, including economic and social wellbeing |
| 12 | Maintain and enhance tourism and recreation |
| 13 | Minimise resource use and waste production |
| 14 | Avoid negative effects on built assets and infrastructure. |

By looking closely at the environmental sub-metrics we will be able to consider the environmental and social issues raised by the individual options selected in each shortlisted programme and compare them. We will also be able to examine opportunities to mitigate or minimise any concerns identified.

The assessment of cumulative and in-combination effects will look at the options selected and consider their combined potential impacts on the environment in the region or in any particular WRZ.

Observations on performance against the environmental sub-metrics will be documented and subsequently considered by PMB.

# Outcomes from performance testing

The outcomes from the investment modelling, including the stress-testing, resilience and environmental performance testing will be considered by PMB, SAB and SLT in accordance with our decision making and governance processes. The plan assessments will be based on aggregated BVP scores and costs and displayed through scatter plots to identify best value plans.

It may be that one or more of the original shortlisted programmes are considered to be no longer viable. For example, a set of schemes could have undesirable cumulative or in-combination effects, or the programme may not perform as well under system simulation as hoped.

If this happens, we will decide whether to:

- rule out that programme as a whole and continue with fewer programmes,
- alter the programme, re-assess it and retain it, or
- go back to the shortlisted programmes and pick another.

# 9 Stage 6: Selection of preferred plan

In Stage 6, the results of the specialised assessments (Stage 5) for each programme will be fed back into the visualisation tool for further comparative appraisal and ultimately the selection of a preferred adaptive regional plan.

During this stage, PMB will work to identify a provisional preferred shortlisted programme and adaptive overall plan, (i.e. a preferred pathway and alternatives branching from key delivery decision points).

PMB will also undertake a WRZ-level review and minor amendments, reviewing the adaptive pathways (showing alternatives) and from this select the preferred best value regional plan. In line with our decision making and governance processes, PMB's decision and justification will be considered by SAB and SLT.

## A provisional preferred shortlisted programme

Having revised, if necessary, the shortlisted programmes as a result of the performance testing, we will examine again the parallel plots and weigh up their performance against the best value metrics.

A provisional preferred programme will be recommended to PMB that draws on all of the completed assessment work and robustly justifies the selection of a preferred plan. It will make clear if any decisions are marginal.

Summary information on all the shortlisted programmes will be included in the reporting so customers and stakeholders can consider for themselves whether they would have chosen an alternative provisional plan.

## WRZ-level review and minor amendments

The provisional preferred programme will then pass to companies to enable them to assess the proposed spatial breakdown of the provisional plan to WRZ-level and to allow proposals for minor amendments to be brought forward. At this point we would expect any to be limited to minor changes driven by WRZ specific factors or the practicalities of delivering the plan in a timely fashion.

Any proposed alterations will be considered by PMB in the first instance and may require additional or updated information to be included within the various environmental or other assessments underpinning the plan.

## Adaptive Pathways

The PMB will then re-examine the adaptive pathways and ensure that key decision dates for the delivery of the plan over the planning period are clear, practical and achievable within the current water industry planning frameworks.

It will consider how progress will be monitored and how, if a trigger is met and a change in pathway is required, it will inform customers and stakeholders.

Finally, the costs and solution differences between the adaptive pathways will be clear including how customers and the environment will benefit.

# Selection of a preferred plan

At this point the PMB will have identified a preferred best value adaptive plan. PMB's decision making will be informed by the technical modelling undertaken by WRSE, performance testing, and engagement feedback, along with expert judgment. PMB will provide selection justification for subsequent consideration by SAB and SLT.

This plan will be brought to the SAB, who may challenge the rationale for the choices made from the perspectives of their stakeholders.

The plan (including the SEA, HRA and other assessments) will then be passed to SLT who will consider the plan in full alongside any report, challenge or other recommendations from SAB. The SLT may ask the PMB to review any points raised by the SAB to help inform its decision making.

SLT will consider all of the information presented to it and will accept or direct final changes to the plan and provide a reasoned justification for its decision. This justification will be provided alongside the draft plan and communicated to the water companies and the other regions, for regional and national reconciliation.

# 10 Stage 7: Consultation on thedraft preferred plan

The preferred plan, including adaptive pathways, will be put forward for public consultation in a draft regional plan. The consultation will run for 14 weeks.

A series of supporting documents and assessments, including necessary SEA, WFD and other environmental assessments will be published alongside the draft regional plan.

A Non-Technical Summary of the regional plan will also be published.

Situation 4 in the preferred regional adaptive Best Value Plan will be entered into the WRPG WRP Tables for use by individual companies, as the reported pathway. We intend for this to be done automatically as a download from the DLP.

## Actions following consultation

We will consider and respond to the public consultation submissions and adjust the plan, if required. A summary of representations and our response will follow in May 2023, confirming or otherwise any changes that will be made to the draft preferred programme before publication of the final plan.

The revised draft regional plan would then be used to inform the revised draft WRMP's of the water companies, the multi-sector plans, national reconciliation of regional plans, and the catchment-based solutions to be delivered through the appropriate parties.

We expect the final regional plan will be published in Autumn 2023.

# Appendix 1: The Data Landing Platform (DLP)

The DLP is a data warehouse/integration tool developed in Microsoft Azure with a visualisation function built in Moata.

It has been developed in two parts, to deal with input data and output data:

- Part 1 of the DLP enables all data storage, transfer and transformation to and from the integrated risk model (IRM), investment model (IVM) and visualisation tool (VT).
- Part 2 of the DLP enables reporting the final problem, options and selection in the Water Resources Planning (WRP) tables for each zone in the region.

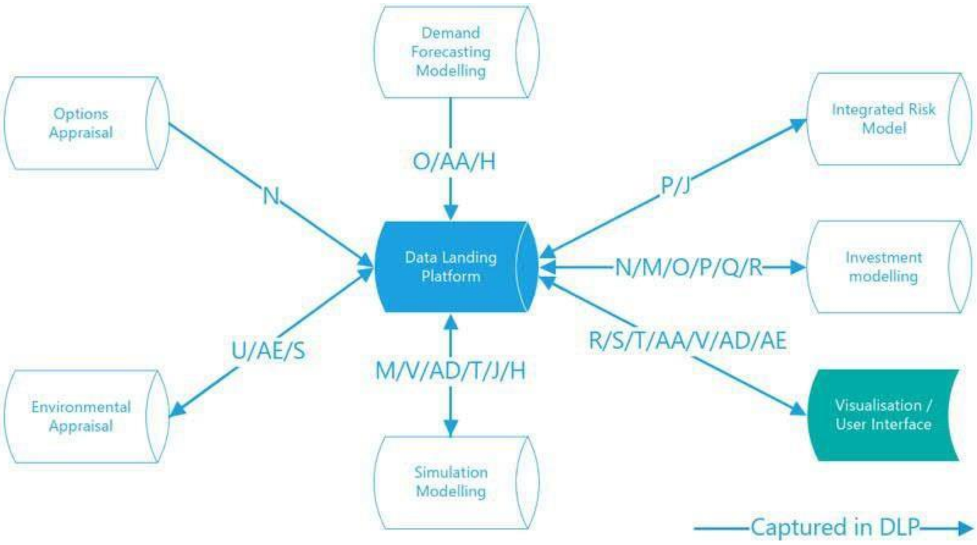
The table and figures below summarise the input data to the DLP and the data flows

**Table 15: Integrated Risk and Investment Model Input Data**

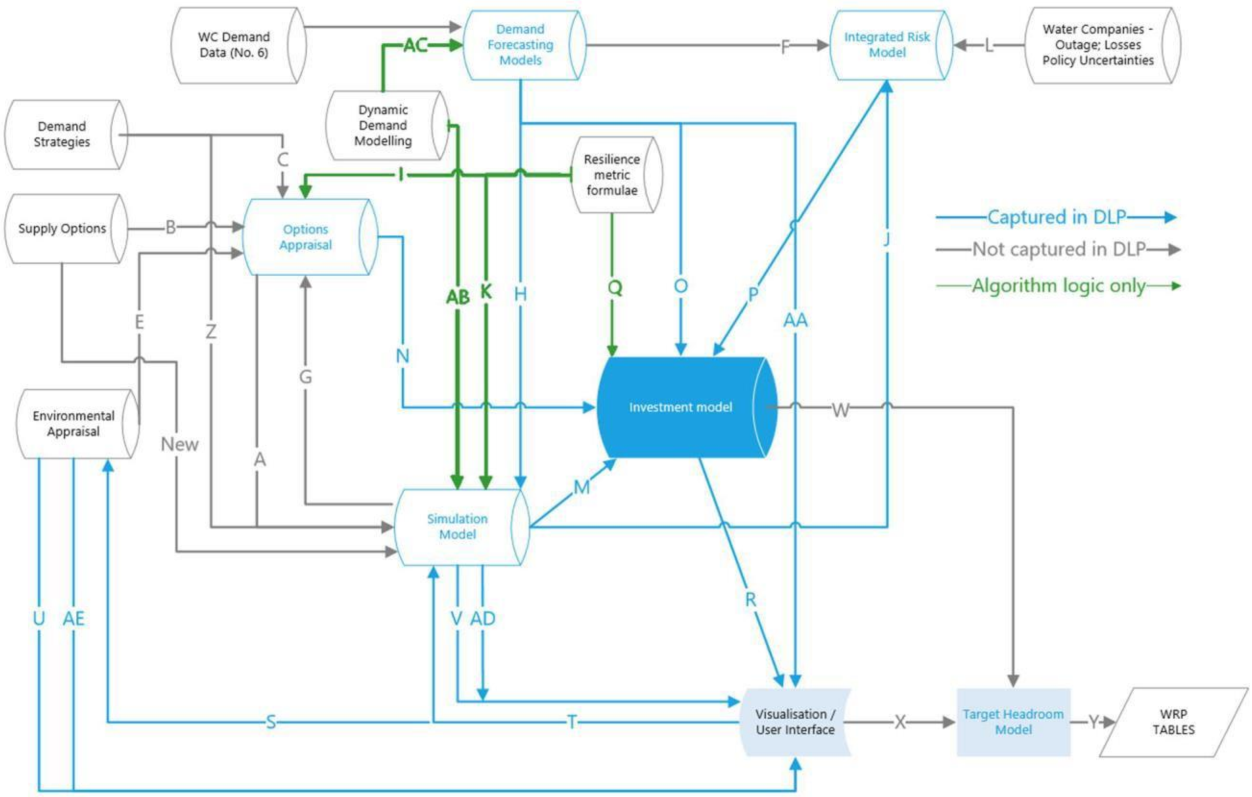
| IRM/ IVM Input Data | Provided by | ID[9] |
|---|---|---|
| Baseline supply forecasts | Simulation model (RSS) | M |
| Baseline demand forecasts | Demand forecasting models via simulation model | H→M |
| Forecast uncertainties | Simulation & demand forecasting models | F&J |
| Existing transfers | Options appraisal | N |
| New supply options and transfers | Options appraisal | N |
| Demand reduction strategies | Demand strategies via Options appraisal | C→N |

[9] Data IDs relate to the Data Landing Platform flow chart

### Figure 9: Flow of information through DLP




### Figure 10: Data flows through data landing platform



The DLP will support the quality assurance process, through either visual or automated verification or likely both. Metadata will be set up to ensure governance of inputs in terms of version control and input personnel, and to track any transformations carried out in the DLP.

The QA logic will be defined by WRSE and will include identifying gaps in data, outliers, values outside of set tolerances, and incorrect value types, using a combination of manual and automated verification to balance out the pros and cons of each.

- Manual quality assurance. Dashboards are developed with the defined logic, with WRSE visually reviewing the data for any anomalies.
- Automated verification and checking of datasets. All defined logic will be automated and applied on data upload, with alerts sent to users if anomalies are detected.

**Table 16: Manual and automated QA comparison**

| QA method | Pros | Cons |
|---|---|---|
| Manual | Can pick up anomalies that are difficult to automate<br>Can deliver contextual experience | Labour cost<br>Time intensive<br>Sometimes difficult to spot anomalies |
| Automated | Supports automated process and consistence<br>Can reduce human error | Development cost<br>Development time<br>Can be relied on too heavily |

# Appendix 2: The Integrated Risk Model (IRM)

The Integrated Risk Model (IRM) is a Monte Carlo model written in Python. It can take information from the Data Landing Platform (DLP) and return data to the DLP for use in the IVM. Its primary function is to produce plausible future supply demand balance situations based on ranges of key uncertainties. It can produce single future situations, or multiple linked futures, known as situation trees.

The model does this in two ways:

- It can accept several probability distributions regarding uncertainty of the supply-demand balance, perform a Monte Carlo simulation and then return sampled values from the output distribution.
- It can calculate the impact on the baseline SDB of alternative forecasts and combine them to produce a spread of potential futures.

It can support basic sampling of a single percentile and producing a "tree" of future situations by providing branching points (years) and several percentiles. The integrated risk model can generate multiple situations to represent different possible supply-demand balances (SDBs), known as future situations.

For the draft regional plan, WRSE have not used the IRM to create situation trees – this has been done directly in the IVM.

# Appendix 3: The Investment Model (IVM)

## Summary

The WRSE Investment Model (IVM) is a mathematical model for decision support which optimises selection and utilisation of programmes of options to prevent supply-demand deficits within the region over the planning period.

Planning for future water management requires predictions of future supply, or water available for use, which is affected by climate, weather, option operation and legislative drivers; and predictions of water demand, also affected by weather, legislative drivers, and population and behavioural change. With all of the uncertainties it is not yet feasible to model all potential futures that may occur across a suitable length of planning horizon in real time, so the IVM uses aggregates of time, space and weather to reduce the problem to situations that can be solved within a feasible runtime.

However, the deep uncertainties affecting supply and demand listed above make a solution based on a single future vulnerable to change, and so the IVM has also been developed to explore multiple potential situations that diverge from the 'most likely' path and build programmes that can bridge from one future to another as time unfolds. Using branched situations to optimise against a range of futures has encouraged the development of real, modular options that can more readily adapt from one situation to another.

The IVM does not determine the best investment programme for the future, but explores a wide variety of pros and cons in terms of investment and carbon costs, environmental impacts, resilience to current and future challenges and customer preference across all the programmes it develops. The programme outputs report metrics representing all of the values of interest together with dates of selection and utilisation volumes for the programmes of options, to aid decision support in selecting a best value plan.

## Investment Model Structure

The IVM is coded in Python[10] v.3.7, and calls specialist routines both from Python and Pyomo[11] libraries and a third-party optimiser, Gurobi[12]. Python is a flexible, open-source programming language with a wide library of established routines and compatibility with other models. Pyomo is a Python-based open-source software package that supports structuring of a diverse set of optimisation capabilities. Gurobi is a fast, accurate optimisation solver for linear and quadratic programming.

[10] www.python.org
[11] www.pyomo.org
[12] www.gurobi.com

## Input data structure

The IVM is set up so that there is no hard coding of inputs, instead data is obtained via the Data Landing Platform (DLP), which also interfaces with the Visualisation Tool (VT) and the Moata dashboard (MDB) to support input and output appraisal, auditing and reporting.

In order to reduce the size and complexity of the planning problem to be solved, the IVM input data is aggregated:

- Spatially, the WRSE region is represented as 37 Water Resource Zones (WRZs) across the six water companies. These are supplemented by six non-public water supply zones (nPWS) and 19 junction zones (Figure 11). Options can provide additional resource or demand reduction within one zone or provide connectivity between two zones.
- Temporally, the planning problem supply and demand and option capacities are aggregated into annual timesteps. In order to improve runtimes the annual timesteps can be aggregated within the IVM to AMP (5 year) timesteps; this is utilised towards the end of the planning horizon.
- Weather-wise, the planning problem is aggregated into four planning scenarios representing different key thresholds of supply, demand, target headroom and option capacity availability.

Formatted for these aggregations, two main types of data are provided to the IVM:

- Baseline forecast data defining the planning problem to be solved is provided at a zonal level across the four planning scenarios (PS) for all WRZs, at an annual timestep. Non-PWS zones represent large commercial water users, and therefore have no baseline supply but baseline demand forecasts also for each PS at an annual timestep. Junction zones have no baseline supply or demand.
- Options data is also provided representing existing and potential assets that can increase supply, reduce demand, provide treatment or connectivity, or improve best value measures. Options have donor and recipient zones, a capacity for each planning scenario and year, lead time, earliest start date, and several costs, benefits and dependencies. Option structures for modelling are explained further in the section *Option structure.*

The distinct planning scenarios allow for representation of different trigger levels for use of drought sources and behaviours in both the baselines and option capacities. Inclusion of a normal year planning scenario allows for optimisation of option utilisation to enable more representative comparison of trade-offs between high-capex and high-opex options. For any future forecast the IVM planning scenarios are:

- *normal*: combines 1:2 year annual average water available for use (WAFU), normal year annual average demand, and target headroom. Level of Service and drought options (TUBs, NEUBs, orders, permits) provide zero deployable output (DO) in the normal year scenario.
- *100a-dyaa*: combines 1 in 100 or worst historic drought annual average WAFU, dry year annual average demand, and target headroom. Around 70% of options provide DO in this scenario; for example 15-20% of the drought interventions provide zero DO in 100a-dyaa (i.e. are only available in more severe droughts)

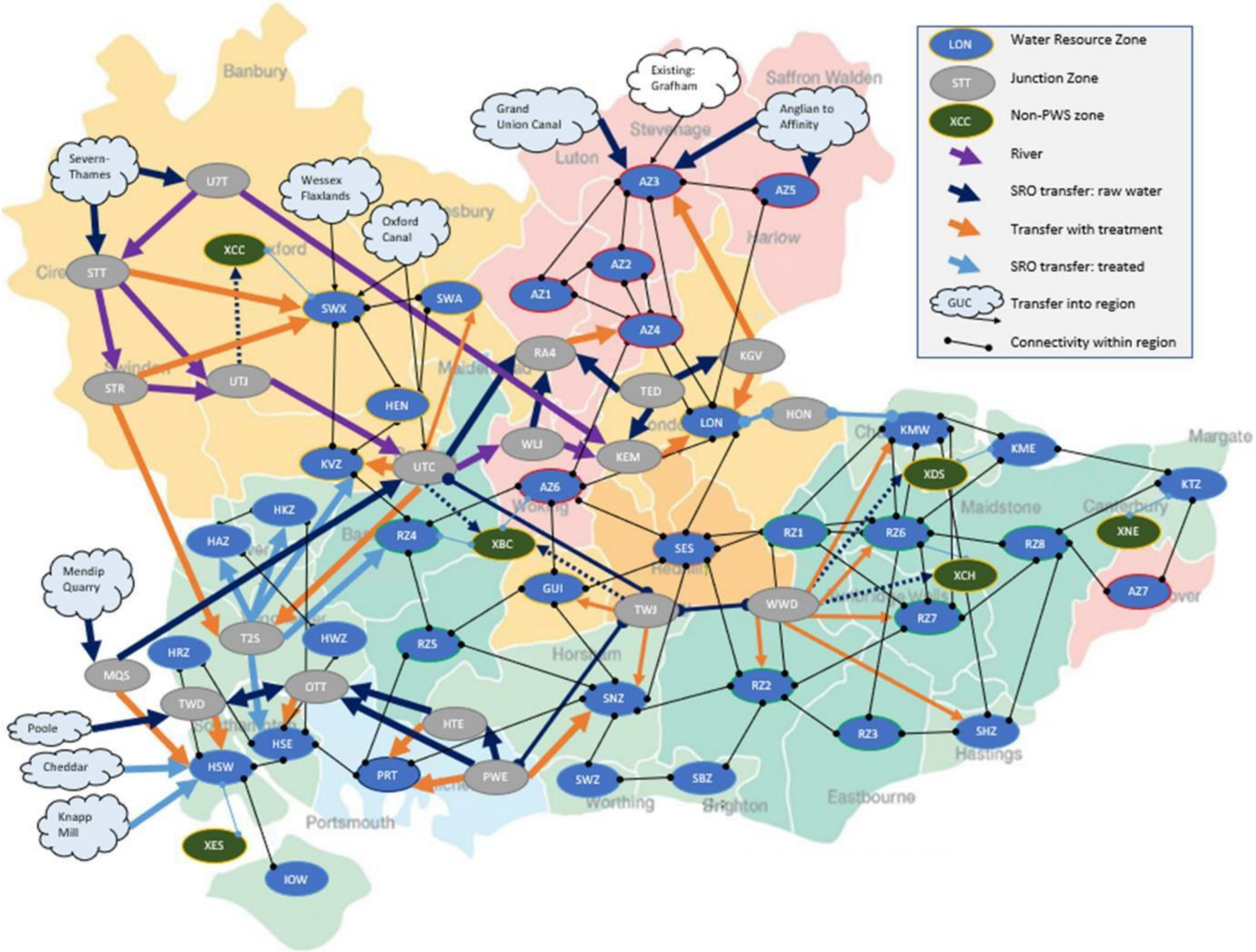
- *hybrida-dyaa*: combines an annual average WAFU profile for the maximum drought resilience target, most commonly 1:200 initially moving to 1:500 in the 2030s, dry year annual average demand, and target headroom. Around 75% of options provide DO in this scenario; the remainder generally have no DO in any scenario. Less than half a percent of options provide DO only in this scenario, mainly drought options.
- *hybridp-dycp*: combines a critical period WAFU profile for the maximum drought resilience target, most commonly 1:200 initially moving to 1:500 in the 2030s, dry year critical peak demand, and target headroom. Around 75% of options provide DO in this scenario; the remainder generally have no DO in any scenario. One percent of options provide water only in peak, mainly AR/ ASR or groundwater schemes.

The IVM solver uses Mixed Integer Linear Programming (MILP) to optimise both capacity of options across all planning scenarios, and utilisation of options over a frequency-weighted combination of the four planning scenarios, for each year and zone across the planning horizon.

**Table 17: Planning scenario frequency weightings**

| Scenario | Weighting |
|---|---|
| normal | 0.5 |
| 100a-dyaa | 0.4 |
| hybrida-dyaa | 0.092 |
| hybridp-dycp | 0.008 |

Figure 11: IVM Model schematic with transfer connectivity



## Option structure

There are two fundamental types of option structure:

- Supply or demand options increase water available in the recipient zone and so across the region, up to the capacity of the option. Donor and recipient zone are the same.
- Transfer options in the IVM (a Boolean setting) increase water available in the recipient zone and decrease it by the same amount in the donor zone, up to the capacity of the option. Since IVM transfers do not increase water available within the WRSE region, the option type 'Transfers into the region' are designated as supply options within the regional model, increasing the overall water available.

There are four types of group to which an option can belong, all of which aim to represent key aspects of option design, development and operation within the IVM:

- *mutual option groups* for options that require selection together to provide capacity
- *phased option groups* for options that have pre-requisite option phases, but phases can be commissioned either simultaneously or subsequently
- *real option groups* for options that have pre-requisites that can only be selected sequentially
- *site groups* for groups of options that have a joint restriction on capacity

Options can be stand-alone, not belonging to any group, and can also be linked as mutually inclusive or mutually exclusive.

## SDB problem structure

The primary objective of the model is to select a programme of options and transfers that can ensure supply is not less than demand in all zones across the region, across all years and planning scenarios for the problem set.

There are two types of problem that can be presented to the IVM:

- A baseline problem, with a single future situation defined by four average and peak planning scenarios that may occur under the same combination of environmental, behavioural and legislative drivers, for each zone and year across the planning horizon
- An adaptive problem, where the initial single pathway divides at key points in the future, and each subsequent pathway, defined by four average and peak planning scenarios, represents a different future due to a different combination of environmental, behavioural and legislative drivers, for each zone and year across the planning horizon.

# Appendix 4: The Visualisation Tool (VT)

The visualisation tool will be the primary decision support tool to allow quality assurance, appraisal, shortlisting, selection, communication and refinement of investment programme outputs and metrics throughout the development of a preferred plan.

As such the visualisation tool has to perform several key functions:

- To summarise each programme from the IVM outputs to aid appraisal
- To aid comparison and trade-offs between two or more programmes
- To support decision making in a way that is accessible to all audiences.

The WRSE visualisation tool has been developed and is available for WRSE through an online platform. At this time, access to the Visualisation Tool is limited to WRSE member companies and regulators who have been involved in the programme appraisal process.