Final Draft Water Resources Management Plan 2024

Annex 8: Supply forecast

May 2025

WATER for LIFE

from Southern Water

Contents

Contents

List of tables

List of figures

Glossary

Acronym	Term
HAZ	Hampshire Andover
HKZ	Hampshire Kingsclere
HWZ	Hampshire Winchester
HRZ	Hampshire Rural
HSE	Hampshire Southampton East
HSW	Hampshire Southampton West
IOW	Isle of Wight
SNZ	Sussex North
SWZ	Sussex Worthing
SBZ	Sussex Brighton
KME	Kent Medway East
KMW	Kent Medway West
KTZ	Kent Thanet
SHZ	Sussex Hastings
NYAA	Normal Year Annual Average
DYAA	Dry Year Annual Average
DYCP	Dry Year Critical Period
1:200	1-in-200 year
1:500	1-in-500 year
ADO	Average Deployable Output
DI	Distribution Input
DO	Deployable Output
GCM	Global Circulation Model
HoF	Hands Off Flow
MDO	Minimum Deployable Output
MRF	Minimum Residual Flow
PDO	Peak Deployable Output
PET	Potential Evapo-Transpiration
UKWIR	UK Water Industry Research
WRZ	Water Resource Zone

1 Introduction

The supply forecast refers to our estimation of the baseline water resources we have available to meet demands in each water resource zone (WRZ) for each planning scenario, and for each year throughout the planning period before the addition of any new schemes. This forecast is composed of several elements:

- Our baseline Deployable Output
- The impacts of climate change on the water available in the environment
- Bulk imports and exports from other water companies or businesses
- Potential reductions in the amount of water we use in order to protect the environment (See Annex 9)
- Process losses due to water used during treatment
- A risk based allowance for outage at our supply works

Each of these components is summarised briefly below:

1.1 Deployable output

Deployable Output (DO) refers to the amount of water we can take from the rivers and groundwater sources after taking account of the constraints that determine the maximum amount of water than can be taken from a source on a sustainable basis. The constraints include (UKWIR, 2014)[1]:

- Source characteristics (e.g. hydrological or hydrogeological yield)
- Physical and infrastructure constraints (e.g. aquifer properties, pump capacity, distribution networks)
- Raw water quality and treatment constraints
- Licence and other regulatory constraints on water abstraction
- Demand constraints and levels of service.

Our methodology for estimating DO is summarised in Section 2 and the results are presented in Section 4.

1.2 Climate change

The Water Resource Planning Guideline (WRPG)[2] requires that water companies make an assessment of the impact of climate change on water supplies. The impacts of climate change may materialise uncertainly between possible drier futures in which water resources will become scarcer, and wetter futures where increased winter rainfall translates to increased resource availability. Climate change can therefore act in both directions in terms of water resource yield assessments. Our assessment of impacts of climate change must account for this uncertainty. Our climate change modelling approach and the results are presented in Section 3.

[1] UK Water Industry Research, 2014. Handbook of source yield methodologies. Report ref. no. 14/WR/27/7
[2] Environment Agency and Natural Resources Wales, 2023. Water Resources Planning Guideline. Version 12, March 2023.

1.3 Bulk imports and exports

The bulk imports and exports component reflects transfers of water in and out of a WRZ. This can reflect both interzonal transfers within company as well as exports to and imports from neighbouring water companies or other formal transfers. Our bulk imports and exports are summarised in Section 4.

1.4 Outage allowance

'Outage' refers to the planning allowance made for the temporary loss of DO from a source. An allowance for outage is made in the supply-demand balance, calculated at the WRZ level. Outage reflects that sources are vulnerable to both unplanned events (e.g. mechanical failure) or may need to be temporarily removed from supply in order to perform maintenance or upgrades (planned outage). Our assessment of our outage allowance is presented in Section 5.

1.5 Process losses

'Process losses' refer to the water lost during the treatment process, including water returned to the source during treatment before it is put into distribution. Our analysis of process losses is described in Section 6.

1.6 Engagement on our supply forecast

In developing our supply forecast we have engaged with the Environment Agency at both a regional and company level as summarised below

- Discussions with the Environment Agency during Summer 2020 on the use of groundwater models
- A series of engagement sessions in the first half of 2021 with the Environment Agency as part of Water Resources South East (WRSE) group on the regional simulation modelling approach and supporting datasets
- Overview discussion of supply forecast methods during pre-consultation on our Water Resources Management Plan 2024 (WRMP24) in February 2022.

2 Deployable output assessment

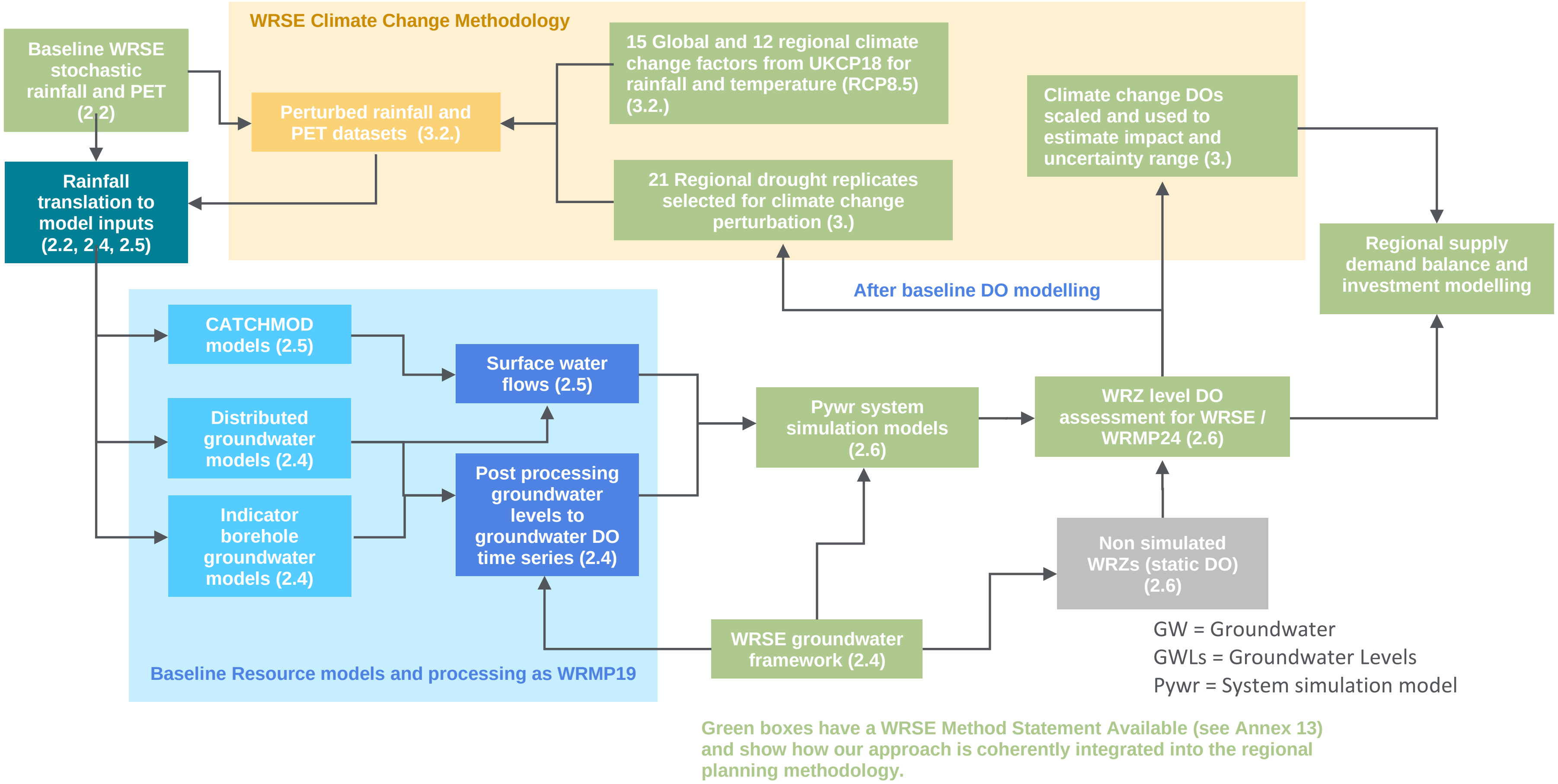
The constraints on DO vary at each site and include hydrological/hydrogeological yields, licence conditions, pump capacity, treatment works capacity, water quality etc. The DO varies during the year. Less water is available during the autumn when groundwater and river flow levels are typically at their lowest. It also varies year on year depending on the weather. DO is lower in dry or drought years that are characterised by lower-than-average rainfall. The DO decreases as the severity of the drought increases. It is therefore common to describe DO in terms of the return period of weather conditions such as 1-in-2 year or 1:2 (normal year), 1-in-10 year or 1:10 (dry year), 1-in-200 year or 1:200 (drought) etc. Average DO (ADO) is used for the volume that can obtained on average during the year whereas Peak DO (PDO) is used for the volume that can be abstracted during period of peak demand which typically lasts for 2-3 weeks in the summer. ADO and PDO vary with the return period i.e. ADO in a normal year would be different from the ADO in a dry year.

Our DO assessment methodology follows a staged process through a number of different climate, water resource and behavioural modelling approaches:

1. Generation of stochastic rainfall and potential evapotranspiration (PET) climate data for drought simulation as inputs to water resource models.
2. Water resource modelling to generate time series of river flows, groundwater levels and groundwater DO for use in the Regional System Simulation (RSS) behaviour model.
3. Conjunctive use of the RSS models to estimate WRZ level system response DO up to a 0.2% (1-in-500 year or 1:500) probability of failure.
4. Perturbation of climate inputs to assess supply uncertainty associated with climate change (see Section 3) and repeat of the above steps to determine DO impacts.

Each of these stages is described further below and the relationship between each step is summarised in Figure 2.1. The steps coloured in green in the figure illustrate where we have followed common approaches to other WRSE companies in our model assessment. This has been critical to ensure that out supply forecast is consistent and coherent with other companies in the region in order to appropriately assess combined options and transfers.

Figure 2.1: Summary flow chart illustrating our DO assessment approach and alignment with the wider WRSE modelling approach to ensure coherent supply forecasts at a regional level. Numbers in brackets indicate relevant section numbers of this Annex which describe the methodology.



2.1 Overview of modelling approach

Figure 2.2 shows how our hydrological and hydrogeological modelling fits into the WRSE RSS modelling chain. Coherent climate data across the WRSE region is fed into company owned hydrological models, feeding into back into a common RSS model, which is used to produce DO.

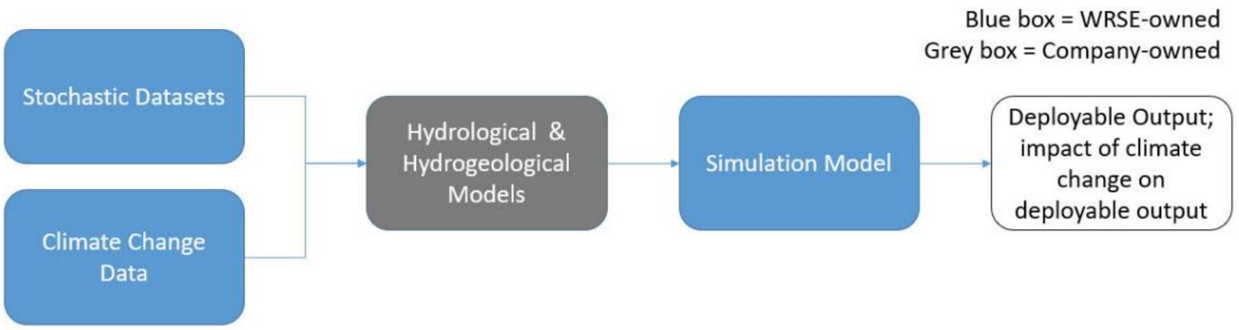


Figure 2.2: Hydrological and groundwater models are used with the climate data to produce inputs to system simulation model which in turn is used to calculate DO. The development of our supply forecast has been an integrated process with other WRSE companies and regional assessments, especially in the design of coherent stochastic climate data and climate change impacts.

2.2 Stochastic weather generation

Reliable historical records for rainfall and PET, which are two of the most important inputs to hydrological models, are generally available for about 100 years. In order to confidently assess supply capability under severe droughts equivalent to 0.2% annual probability (1-in-500 year) droughts requires a significant amount of statistical analysis of climatic drivers and historical records.

We have used weather generators to produce stochastic synthetic weather sequences of historically plausible droughts in each of our last three Water Resources Management Plans (WRMPs). This allows us to consider the impact of more severe droughts than which have occurred in the past and apply them in our water resource modelling. The approach we have adopted is consistent across all WRSE companies (Atkins, 2020)[3] and allows for generation of a spatially coherent drought dataset at a regional level.

The current weather generator for rainfall is effectively a 3rd generation evolution of the weather generator we originally used for our WRMP 2014 (WRMP14) stochastic modelling (Serinaldi and Kilsby, 2012)[4] and which was further refined for our WRMP 2019 (WRMP19). The model uses rainfall (based on the Met Office Had UK dataset) and associated regional climate teleconnections with variables including:

- North Atlantic Sea Surface Temperature (SST) and North Atlantic Oscillation (NAO) (as WRMP14, WRMP19)

[3] WRSE, 2021. Method Statement: Regional System Simulation Model. Post consultation version (included in Annex 23)
[4] Serenaldi, F, Kilsby, C.G., 2012 A modular class of multisite monthly rainfall generators for water resource management and impact studies, Journal of Hydrology, 464-465, doi: 10.1016/j.jhydrol.2012.07.043

- Atlantic Multidecadal Oscillation (AMO)
- East Atlantic Index
- East Atlantic/West Russia Index
- Scandinavia Index

There have also been further improvements to model fits and bias correction at low rainfall accumulations (Atkins, 2020)[5]. 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, as mentioned above are now used. The inclusion of a greater range of climate drivers has resulted in a better model fit and a smaller need to correct biased outputs. Where bias correction has been used, improved methods have been applied to reduce the production of implausible droughts.

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.

Rainfall locations (1km^2 cells) were selected according to the following criteria (Atkins, 2020):

- Sites with good quality data from 1950 to the present, to match the availability of the improved ‘climate drivers’ data set, based on Met Office and CEH GEAR rainfall meta-data.
- An improved spatial coverage in England and Wales, particularly in locations with important regional water supplies.
- Water company preferences to add further sites to provide improved spatial coverage and sites at higher elevations.

A total of 195 sites were selected and assigned to one or more of the UK-wide 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.
- Previous assessments, including our WRMP19 assessments, used point locations, so this approach provided a clearer audit trail from the WRMP19 work to the present study.
- Additional hydrological modelling strategies across the WRSE region were developed in parallel to this study, as the full set of catchment boundaries were not available for all regions at the start of this study

Coherent PET data in the weather generator are sub-sampled from historical data, largely as per previous WRMPs. This means that the PET generated is consistent with the input data, for example, if the Met Office MORECs PET data set[6] was supplied into the model then MORECs consistent data would be generated as

[5] Atkins, 2020, Regional Climate Data Tools Final Report, Sutton and East Surrey Water on behalf of WRSE, Report 5194482-2 (included in Annex 23)
[6] 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

output. Daily data are matched to historical observations based on closest rainfall day and month (nearest neighbour) sampling. In summer months, PET is matched based on the 'nearest neighbour' summer rainfall total (April-August) rather than on a month-by-month basis. This was implemented as, in previous versions of the stochastic weather generator, summer persistence effects around PET were not being adequately simulated.

The key climate input and output data for each of our water resource models are summarised in Table 2.1.

Table 2.1 Summary of stochastic climate inputs for water resource modelling.

WRZ*	Water Resource Model Type	Rainfall Input(s)	PET Input
HAZ, HRZ, HKZ, HSE, HSW, HWZ	Test and Itchen groundwater model (3 rain gauge MF96-VKD version as WRMP19, WRMP14)	Stochastic rain gauge inputs for River Itchen WSW, Boscombe Down and Rotherfield Park translated to model inputs via linear regression	Stochastic MOSES PET
IOW	Indicator borehole model and coupled recharge model (as WRMP19, WRMP14) CATCHMOD model for Medina and Eastern Yar	Stochastic rain gauge inputs for Cowes Water Works translated to catchment inputs via spatial analysis and linear regression	Stochastic MORECS PET
SNZ	CATCHMOD model for Western Rother, River Arun and Weir Wood Reservoir	Stochastic rain gauge inputs for Rotherfield Park, Hindhead Water Works, Balcombe and Bognor Regis apportioned to catchment inputs via spatial analysis and linear regression	Stochastic MORECS PET
SBZ, SWZ	Indicator borehole model and coupled recharge model (as WRMP19, WRMP14)	Stochastic rain gauge inputs for Poverty Bottom, Mile Oak pumping station and Bognor Regis translated to 3 rain gauge model inputs through linear regression	Stochastic MORECS PET
KME, KMZ	Indicator borehole model and coupled recharge model (as WRMP19, WRMP14) CATCHMOD models for River Medway and sub-catchments such as the Teise and Eden	Stochastic rain gauge inputs for Canterbury, East Malling Falconhurst, Goudhurst, Betsomes Hill, Dorking Pixham Lane and Barming Rain gauges, apportioned to model inputs via spatial analysis and linear regression	Stochastic PENSE and MORECS PET
SHZ	CATCHMOD models for Eastern Rother and River Brede	Stochastic rain gauge inputs for Great Dixter, Goudhurst, Balcombe. Rain gauges, apportioned to model inputs via spatial analysis and linear	Stochastic MORECS PET
KTZ	East Kent groundwater model (as WRMP19, WRMP14)	Stochastic rain gauge inputs for Canterbury rain gauge, apportioned to model inputs following same method as WRMP14, WRMP19.	Environment Agency recharge model

*HAZ = Hampshire Andover, HKZ = Hampshire Kingsclere, HWZ = Hampshire Winchester, HRZ = Hampshire Rural, HSE = Hampshire Southampton East, HSW = Hampshire Southampton West, IOW = Isle of Wight, SNZ = Sussex North, SWZ = Sussex Worthing, SBZ = Sussex Brighton, KME = Kent Medway East, KMW = Kent Medway West, KTZ = Kent Thanet, SHZ = Sussex Hastings

By adopting this approach, we are aligning ourselves consistently with the water resource modelling undertaking by neighbouring water companies as part of the regional modelling approach. The final stochastic climate datasets represent a total of 19,200 years of modelled rainfall and PET data for each site/model. However, the data are not a continuous sequence of 19,200 years but instead represents 400 different versions of what the 1950-1997 could have been, given the underlying climate drivers. This allows us to plan based on, not only what we have experienced in the past, but also what we are likely to experience in the future. Further details of the weather generator are provided in Atkins (2020) and WRSE (2021a).[7]

2.3 Benefits of demand and supply side measures on DO

Supply-side drought measures, such as environmental drought permits and orders to temporarily relax licence conditions and increase abstractions have not been included in our baseline DO. This is consistent with the WRPG. Instead, these supply-side drought measures are included as options within the supply-demand investment modelling.

Similarly, the beneficial supply and demand impacts of demand-side drought measures such as Temporary Use Bans (TUBs) or Non-Essential Use Bans (NEUBs) are not included in our baseline DO assessments but are included as options in the supply-demand investment modelling.

2.4 Assessment of groundwater yields

2.4.1 Groundwater framework

Groundwater resources are typically more complex and computationally intensive to model than surface water resources as models must consider aquifer properties, variation in groundwater levels, antecedent operation, interference effects and asset and licence constraints.

To improve the efficiency of our water resource modelling approach we worked with other WRSE companies to develop a common Groundwater Framework (WRSE, 2021b)[8]. The aim of this framework was to develop and select the most appropriate modelling method for including groundwater resources within the RSS model.

The Groundwater Framework proposes a standard assessment approach to be applied across all WRSE companies and WRZs. 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 gets, the more suitable and the more benefit would be gained from dynamic representation within the RSS model.

The framework proposed a semi-quantitative characterisation of each groundwater source over three phases:

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

[7] WRSE, 2021. Method Statement: Stochastic Climate Datasets. Updated version (Included in Annex 23)
[8] WRSE 2021 Method Statement: Groundwater Framework (included in Annex 23).

  - DO constraints and in particular the sensitivity of DO to climate factors with a higher score being assigned to sources that have drought sensitive yields. We considered DO and climate change assessments carried out for previous WRMPs.
  - Conjunctive-use benefits consider the interaction of a groundwater source 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 impacted surface water under the WFD. Sites score highly if there are downstream impacts on surface water or conjunctive use with surface water abstractions.
  - Sensitivity to antecedent conditions mostly considers the role of groundwater storage in providing a benefit to yields at a site. It considers whether operation of a source may have a later impact on groundwater yield.
  - Proportionality/threshold benefit score was used to provide an indication of the possible strategic importance of a site primarily measured through its DO volume. Whilst it was scored, this criterion was not 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.
- **Phase C - Methodology:** A review of current and available methodology and suitability of the sources as well as the outcome of the assessment and overall prioritisation assessment balancing the feasibility of implementation with the overall aim and methodology approach identified.

The final stage of the framework is to determine a proposed DO modelling approach for each groundwater source. At each stage of the framework assessment, the suggested modelling approach or score could be overridden. However, if this is done a justifying comment supporting the change had to be provided and to provide a track record of the manual adjustment to the framework outcome to ensure governance.

The (anonymised) scores for all Southern Water sources are presented in Appendix A.

2.4.2 Groundwater modelling and source assessment

Following our assessment, we determined that the yield of three highest priority groundwater sources should be dynamically simulated within the RSS model:

- River Itchen groundwater
- Twyford
- Pulborough

These sources are all constrained by Hands off Flow (HoF) licence conditions in associated surface waters and where flow sequences were to be available within the RSS model.

Many of our groundwater sources in multiple WRZs are asset or infrastructure constrained and are not sensitive to groundwater level variations or drought. The yield of these sources was supplied as a non-varying static DO time series of PDO and Minimum DO (MDO) to the RSS model.

2.4.2.1 Groundwater and river source DO constraints

In parallel to developing our water resource modelling, we undertook a company-wide review to understand the asset and infrastructure constraints of each source and, where relevant, these were used to constrain DO. Where feasible, options to remove DO constraints have been considered as part of our options appraisal.

Overall, our approach for modelling dynamic groundwater yield follows the same approach as our WRMP19; the key change being adoption of the new regionally consistent stochastic weather series as input data to our existing models. Where input locations differed, WRSE stochastic point rainfall time series were converted to equivalent model rain gauge input time series via linear regression following the same approach as for our surface water models. PET data were resampled from existing model inputs, e.g. historic MOSES PET data is used to derive coherent stochastic MOSES through our stochastic generator (Section 2.2).

As mentioned previously, we employed a combination of groundwater modelling approaches depending on resource model availability and suitability for running the large stochastic datasets.

Model runs and time series were processed in batch scripts written in Python programming language in thousands of runs to produce coherent stochastic inputs to the RSS model. These comprised time series of source level groundwater DO (for PDO and MDO scenarios) or river flows (for the Western area model). WRZ DO calculations, including assessment of average DO (ADO), were carried out within our RSS models.

Groundwater model outputs were validated against historical flows and groundwater levels and the corresponding estimates of DO from WRMP19, accepting that some changes will be introduced because of the new stochastic climate data. When converting from indicator borehole groundwater level time series to DO, we followed the standard methodology outlined in UKWIR (2000)[9], UKWIR (2014)[10] and UKWIR (2016a)[11].

A summary of source level groundwater DO and associated constraints is presented in Table 2.2 to Table 2.5.

[9] UKWIR, 2000. A Unified Method for the Determination of Deployable Output from Water Sources Volume 2. Ref. 00/WR/18/2
[10] UKWIR, 2014. Handbook of Source Yield Methodologies. Ref. 14/WR/27/7
[11] UKWIR, 2016a. WRMP 2019 Methods – Decision Making Process Guidance. Ref 16/WR/02/10

Table 2.2: Summary of constraints on groundwater DO in the Western area.

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source Capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint	1:500	1:200	1:100	Normal Year	Key Constraint	
HKZ	Near Basingstoke	5.68	5.68	5.68	5.68	Annual licence	5.68	5.68	5.68	5.68	Daily licence - Constrained by daily limit of abstraction licence	5.68
HKZ	Newbury	3	3	3	3	Annual licence	3.6	3.6	3.6	3.6	Daily licence - Constrained by daily licence limit and 7 day sustained yield.	3.6
HAZ	Andover	16.02	16.02	16.02	16.02	Annual licence. This will reduce to 13Ml/d from 2027 (confirmed licence change).	18	18	18	18		18.4
HAZ	Near Whitchurch	3.7	3.7	3.7	3.7	Constrained by BH1 output/sustained yield.	3.7	3.7	3.7	3.7	Revised PWPC[12] constraint review - Constrained by BH1 output/sustained yield.	3.75
HAZ	Overton	1.5	1.5	1.5	1.5	Annual licence	1.5	1.5	1.5	1.5	Daily licence	1.5
HAZ	Whitchurch	1.64	1.64	1.64	1.64	Annual licence	1.64	1.64	1.64	1.64	Daily licence	1.64
HAZ	Near Andover (2)	0	0	0	0	Site long term out of service (water quality)	0	0	0	0	Site long term out of service (water quality)	0
HRZ	Romsey	8.85	8.85	8.85	8.85	Constrained by well pump capacity.	8.85	8.85	8.85	8.85	Constrained by well pump capacity.	8.85
HRZ	Kings Sombourne	1.5	1.5	1.5	1.5	Source capacity	1.5	1.5	1.5	1.5	Source capacity	1.5
HWZ	Winchester	18.17	18.17	18.17	18.17	Annual licence	19.3	19.3	19.3	19.3	Source capacity	20.34
HWZ	Alresford	4.54	4.54	4.54	4.54	Annual licence	4.55	4.55	4.55	4.55	Daily licence	4.55
HWZ	Barton Stacey	1.12	1.12	1.12	1.12	Annual licence	1.82	1.82	1.82	1.82	Daily licence	1.82
HSW	River Test	0	0	0	73.54	HoF	0	0	11.85	78.8	HoF	80
HSE	Conjunctive DO for Itchen surface water,	20.49	32.46	45.65	77.97	Combined DO (from Pywr) for Itchen surface water, groundwater and Twyford	41	58.38	78.36	108.42	Combined DO (from Pywr) for Itchen surface water, groundwater and Twyford as	107.12

[12] PWPC = Peak Week Production Capacity

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source Capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint	1:500	1:200	1:100	Normal Year	Key Constraint	
	groundwater and Twyford					as all constrained by common HoF licence condition and monthly quantities)					all constrained by common HoF licence condition and monthly quantities)	
IOW	Newchurch Chalk	0.97	1	1	1	Yield at DAPWL	1.97	1.97	1.97	1.93	Yield at DAPWL[13]	8
IOW	Newchurch LGS[14]	2.4	2.4	2.4	2.4	Source Capacity	2.4	2.4	2.4	2.4	Source capacity	
IOW	Rookley	0.24	0.93	1	1	Yield at DAPWL	0.72	1.23	1.23	1.23	Yield at DAPWL	1.54
IOW	Near Cowes	0	0	0	0	Source Abandoned (poor water quality)	0	0	0	0	Source abandoned (poor water quality)	0
IOW	Newport	10.62	10.7	10.7	10.7	Annual and Monthly Licence	12.02	12.81	12.89	13	Yield at DAPWL and daily licence	13
IOW	Lukely Brook	0	0.82	0.95	1.5	Annual and Monthly Licence, MRF[15] Constraint	0.41	2.63	2.79	3	Yield at MRF constraint and Daily Licence	3
IOW	Caul Bourne	0.88	0.97	0.97	0.97	Yield at DAPWL and HoF	1.05	1.05	1.05	1.05	Yield at DAPWL and HoF	1.5
IOW	Shalcombe	0	0	0	0	Site long term out of service (water quality)	0	0	0	0	Site long term out of service (water quality)	0
IOW	Ventnor	0	0	0	0	No drought yield	0	0	0	0	Long term future of source uncertain - current DO written down to 0.	1.29
IOW	Ventnor3	0	0	0	0	Source abandoned	0	0	0	0	Source abandoned	0
IOW	Sandown	8	8	8	8	Annual licence	12	12	12	12	Source capacity	12

[13] DAPWL = Deepest Advisable Pumping Level
[14] LGS = Lower Greensand
[15] MRF = Minimum Residual Flow

Table 2.3: Summary of constraints on groundwater DO in the Central area.

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint (DYAA)	1:500	1:200	1:100	Normal Year	Key Constraint (DYCP)	
SNZ	Arun	10	10	10	10	Annual licence	15	15	15	15	Daily Licence + Church Farm	75
SNZ	Pulborough groundwater	0	13	13	13	Sustainable Yield	27	27	27	27	Source capacity	75
SNZ	Pulborough surface water	0	1.17	4.19	30.58	Yield at MRF	0	3.81	8.07	33	Yield at MRF	75
SNZ	Petworth	0	0	0	0	Long term out of service	0	0	0	0	Long term out of service	0
SNZ	Petworth South	2.14	2.14	2.14	2.14	Annual licence	2.43	2.43	2.43	2.43	Daily licence	2.43
SNZ	Petersfield	1.6	1.6	1.6	1.6	Assumed rebuild	1.6	1.6	1.6	1.6	Assumed rebuild	0
SNZ	Midhurst	2.19	2.19	2.19	2.19	Annual licence	2.88	2.88	2.88	2.88	Daily licence	2.72
SNZ	West Chiltington	3.12	3.12	3.12	3.12	Assumed rebuild	3.12	3.12	3.12	3.12	Assumed rebuild	0
SNZ	Steyning	1.2	1.2	1.2	1.2	Demand constraint	1.3	1.3	1.3	1.3	Pump capacity	1.3
SNZ	Weir Wood Reservoir	Part of conjunctive WRZ assessment see Section 2.6.1				Reservoir inflow	Part of conjunctive WRZ assessment see Section 2.6.1				Works capacity	
SWZ	Littlehampton	3	3	3	3	Source capacity	3	3	3	3	Source capacity	3
SWZ	Arundel	3.1	3.1	3.1	3.1	Source capacity	3.1	3.1	3.1	3.1	Source capacity	3.5
SWZ	Worthing	9.22	9.42	9.61	13	Yield at DAPWL	10.28	10.63	11.35	19.07	Yield at DAPWL	20.5
SWZ	South Arundel	6.38	6.64	6.64	9.32	Saline Intrusion/Turbidity Risk	8.72	8.74	9.16	11.33	Saline Intrusion/Turbidity Risk	11.75
SWZ	Long Furlong A	2.3	2.3	2.3	2.3	Source capacity	2.91	2.91	2.91	2.91	Source capacity	2.91
SWZ	North Worthing	5.9	5.9	5.9	5.9	Source capacity	5.9	5.9	5.9	5.9	Source capacity	5.9
SWZ	North Arundel	4.16	4.16	4.16	4.16	Source capacity	4.16	4.16	4.16	4.16	Source capacity	4.16
SWZ	East Worthing	4.5	4.5	4.5	4.5	Source capacity	5.1	5.1	5.1	5.1	Source capacity	5.1
SWZ	Long Furlong B	1.79	1.85	1.93	3.51	Yield at DAPWL	1.75	1.81	1.97	3.36	Yield at DAPWL	4.57
SWZ	Durrington	6.2	6.2	6.2	6.2	Source capacity	6.2	6.2	6.2	6.2	Source capacity	6.2
SWZ	South Arundel A	4.5	4.55	4.62	5	Source capacity	5	5	5	5	Source capacity	11.75
SBZ	Rottingdean	10.79	10.99	11.21	12.89	Saline Intrusion Risk	15.35	15.75	15.95	16	Saline Intrusion Risk	16

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint (DYAA)	1:500	1:200	1:100	Normal Year	Key Constraint (DYCP)	
SBZ	Falmer	1.39	1.51	1.66	5	Yield at DAPWL	2.16	2.51	2.83	7.73	Yield at DAPWL	9
SBZ	Hove	13	13	13	13	Annual licence	16.64	16.64	16.64	16.64	PWPC	16
SBZ	North Falmer A	2.21	2.28	2.39	3.79	Yield at DAPWL	5	5	5	5	Source capacity	5
SBZ	Lewes Road	0	0	0	0	Site long term out of service (water quality)	0	0	0	0	Site long term out of service (water quality)	0
SBZ	Hove B	8.52	8.65	8.65	8.65	Source capacity	8.65	8.65	8.65	8.65	Source capacity	9.5
SBZ	North Shoreham	1.67	1.83	1.99	2.9	Yield at DAPWL	2.33	2.43	2.52	3.3	Yield at DAPWL	3.38
SBZ	North Falmer B	7.71	8.50	9.72	14.58	Yield at DAPWL	9.53	10.08	11.66	14.58	Yield at DAPWL	11.95 (C/D) +2.63 (B)
SBZ	Brighton A	8.1	8.1	8.1	8.1	Sustainable Yield	9.5	9.5	9.5	9.5	Sustainable Yield	17.5
SBZ	Shoreham	4.86	4.97	5.09	6	Yield at DAPWL	7.09	7.29	7.29	7.29	Yield at DAPWL	7.29
SBZ	Sompting	8.1	8.1	8.1	8.1	Source capacity	8.1	8.1	8.1	8.1	Source capacity	8.1
SBZ	Lewes	10.6	10.6	10.6	10.6	Source capacity	10.6	10.6	10.6	10.6	Source capacity	10.6
SBZ	Brighton B	2.5	2.5	2.5	2.5	Source capacity	2.5	2.5	2.5	2.5	Source capacity	17.5

Table 2.4: Summary of constraints on groundwater DO in the Eastern area.

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint (DYAA)	1:500	1:200	1:100	Normal Year	Key Constraint (DYCP)	
KME	Sheldwich	11.7	11.7	11.7	11.7	Source capacity	11.70	11.70	11.70	11.70	Source capacity	31
KME	Capstone Chalk	2.80	2.80	2.80	2.80	Booster capacity	3.20	3.20	3.20	3.20	Booster capacity	11.5
KME	Capstone Greensand	1.40	1.40	1.40	1.40	Booster capacity	1.40	1.40	1.40	1.40	Booster capacity	11.5
KME	Sittingbourne1	3.40	3.40	3.40	3.40	Pump capacity	4.80	4.80	4.80	4.80	Pump capacity	5
KME	Hartlip Hill	3.00	3.00	3.00	3.00	Source capacity	3.00	3.00	3.00	3.00	Source capacity	3
KME	Near Herne Bay	3.31	3.37	3.64	7.27	Yield at DAPWL	3.61	4.02	4.59	7.30	Yield at DAPWL	7.3
KME	Faversham2	1.89	1.89	1.89	1.89	Source capacity	4.50	4.50	4.50	4.50	Source capacity	31
KME	Faversham1	2.09	2.09	2.09	2.09	Source capacity	4.42	4.42	4.42	4.42	Source capacity	31
KME	Newington	1.30	1.30	1.30	1.30	Source capacity	1.80	1.80	1.80	1.80	Source capacity	1.8

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint (DYAA)	1:500	1:200	1:100	Normal Year	Key Constraint (DYCP)	
KME	Gillingham	6.30	6.30	6.30	6.30	Booster capacity	8.45	8.45	8.45	8.45	Booster capacity	11.5
KME	Hartlip	14.00	14.00	14.00	14.00	Pump capacity / Turbidity	14.00	14.00	14.00	14.00	Pump capacity / Turbidity	4.31
KME	Chatham West	4.31	4.31	4.31	4.31	Source capacity	4.31	4.31	4.31	4.31	Source capacity	4.31
KME	Faversham4	13.33	13.51	13.60	13.60	Source capacity	13.60	13.60	13.60	13.60	Source capacity	13.9
KME	Chatham	2.29	2.50	2.72	4.20	Yield at DAPWL	3.18	3.40	3.67	6.20	Yield at DAPWL	6.2
KME	Faversham3	7.00	7.00	7.00	7.00	Source capacity	9.14	9.14	9.14	9.14	Source capacity	31
KME	Millstead	1.37	1.37	1.37	1.37	Source capacity	4.50	4.50	4.50	4.50	Source capacity	4.5
KMW	Cuxton	4.71	4.77	4.82	5.10	Yield at DAPWL	8.86	8.91	8.91	8.91	Yield at DAPWL	8.91
KMW	Fawkham	5.20	5.20	5.20	5.20	Source capacity	5.20	5.20	5.20	5.20	Source capacity	5.2
KMW	Gravesend South	5.56	5.59	5.60	5.60	Yield at DAPWL	5.74	5.75	5.76	7.62	Yield at DAPWL	7.62
KMW	Higham	0.33	0.36	0.39	0.73	Yield at DAPWL	0.64	0.67	0.70	1.00	Yield at DAPWL	1
KMW	North Cuxton	4.61	4.64	4.67	4.80	Yield on pump capacity	4.79	4.85	4.97	5.20	Yield on pump capacity	5.2
KMW	Meopham	2.90	2.90	2.90	2.90	Source capacity	2.90	2.90	2.90	2.90	Source capacity	2.9
KMW	Northfleet Chalk	7.00	7.00	7.02	7.20	Yield on pump capacity	7.44	7.45	7.45	7.60	Yield on pump capacity	7.6
KMW	River Medway Scheme	Part of conjunctive WRZ assessment see Section 2.6.1				Sustainable Yield	Part of conjunctive WRZ assessment see Section 2.6.1				Treatment capacity at Near Rochester	54
KMW	Strood	2.40	2.40	2.40	2.40	Source capacity	2.40	2.40	2.40	2.40	Source capacity	2.4
KMW	Rochester	0.45	0.45	0.45	0.45	Yield at DAPWL	0.70	0.70	0.70	0.90	Yield at DAPWL	0.9
KT	Deal	0.50	0.64	0.91	3.94	Yield at DAPWL	0.77	0.99	2.15	3.94	Yield at DAPWL	3.94
KT	North Deal	5.00	5.00	5.00	5.00	Source capacity	5.00	5.00	5.00	6.00	Source capacity	6
KT	West Langdon	4.70	4.70	4.70	4.70	Source capacity	4.70	4.70	4.70	4.70	Source capacity	4.7
KT	North Dover	0.79	0.87	0.91	1.20	Yield at DAPWL	0.81	0.89	0.96	1.80	Yield at DAPWL	1.8
KT	Kingsdown	3.64	3.64	3.64	3.64	Annual Licence	3.71	3.71	3.71	3.71	Annual Licence	4.36
KT	Canterbury	9.59	10.19	10.73	17.36	Yield at DAPWL	13.29	15.19	16.47	20.60	Yield at DAPWL	20.6
KT	West Sandwich	9.45	9.45	9.45	9.45	Yield at DAPWL	9.60	9.60	9.60	9.60	Yield at DAPWL	11.3
KT	Sandwich	2.45	2.45	2.45	2.45	Source capacity	2.45	2.45	2.45	2.45	Source capacity	2.65
KT	Ramsgate B	3.20	3.20	3.20	3.20	Source capacity	3.20	3.20	3.20	3.20	Source capacity	3.2
KT	Manston 2	0.20	0.29	0.52	2.75	Yield at DAPWL	1.05	1.69	2.29	2.75	Yield at DAPWL	2.75
KT	Birchington	0.19	0.35	0.64	3.74	Yield at DAPWL	0.21	0.40	0.70	4.58	Yield at DAPWL	4.58

WRZ	Source	DYAA Deployable Output (Ml/d)					DYCP Deployable Output (Ml/d)					Source capacity (Ml/d)
		1:500	1:200	1:100	Normal Year	Key Constraint (DYAA)	1:500	1:200	1:100	Normal Year	Key Constraint (DYCP)	
SHZ	Powdermill Reservoir	Part of conjunctive WRZ assessment see Section 2.6.1					Part of conjunctive WRZ assessment see Section 2.6.1					
SHZ	Darwell Reservoir	Part of conjunctive WRZ assessment see Section 2.6.1					Part of conjunctive WRZ assessment see Section 2.6.1					
SHZ	Rye Groundwater	1.2	1.2	1.2	1.2	Sustainable Yield	1.5	1.5	1.5	1.5	Source capacity	15

Table 2.5: Summary of groundwater resource modelling methods.

Aquifer Block	WRZ	Groundwater Modelling Approach	Rationale
Hampshire Chalk	HSE, HSW, HWZ, HKZ, HAZ, HRZ	The 'Old' Test and Itchen Environment Agency groundwater model (i.e. MODFLOW96-VKD) as per 2013 calibration used with the 400 WRSE climate and PET sequences to generate naturalised flows and groundwater levels. Naturalised flows are then used as time series input to Pywr and denaturalised using lumpy groundwater factors which account for abstraction impacts on the rivers. We have recently updated the lumpy groundwater factors to reflect the outcome of the more recent WINEP[16] investigations in Hampshire. We have used the 'old' MODFLOW96-VKD as it has a much faster run time than the new MODFLOW-6 model which allows us to simulate all 19k stochastic years from the WRSE climate data. We consider this is necessary because of the high DO sensitivity of our major sources in this aquifer block and for coherence with the wider WRSE methodology. Secondly, we consider the 'old' model calibrates better to low flows for the key MRF compliance points on the lower Test and lower Itchen than the new model. The head calibration of the old model is inferior, however, the DO for most of our Hampshire sources outside the Lower Itchen is not level dependent and so do not need to be modelled dynamically as they are insensitive to drought. For the Lower Itchen groundwater sources we can use an indicator borehole (Chalk Dale) along with modelled groundwater levels and established curve shifting relationships to estimate rest water level	Method covers all sources in WRZ. As most are drought insensitive having static profiles they can be used coherently with other datasets. Flow sequences for River Test and Itchen and MRF dependant DO are based on WRSE coherent climate data so are temporally compatible with modelling elsewhere. Output flow sequences for River Itchen also supplied to Portsmouth Water for use in their DO assessments for the Lower Itchen Impacts of South East Water source in the Candover Stream Catchment are included in lumpy groundwater impact factors applied to River Itchen flow within system simulation models.

[16] WINEP = Water Industry National Environment Programme

Aquifer Block	WRZ	Groundwater Modelling Approach	Rationale
		variations. We can then estimate dynamic DO via standard curve shifting methods. For WRMP24 we have applied additional regression to bias correct groundwater level fit to observed data for the old model. Validation of the assessments for a sub-sample of climate replicates against both the Environment Agency River Test CATCHMOD model and the 'new' MODFLOW6 groundwater model (as carried out assessment of the Candover scheme) indicate that the old model is more drought sensitive than the new MODFLOW6 model with river flows during severe droughts being around 10-15Ml/d lower. This will help constrain our uncertainty estimates.	
IOW Chalk	IOW	Following AMP6 WINEP WFD 'No Deterioration' investigations DO for drought sensitive sources has become less hydrogeologically sensitive as many licence changes have capped DO and source output in general at severe drought MDO. Where there is still some dynamic response (e.g. Newport, Lukely Brook, Newchurch) a lumped parameter model based on British Geological Survey (BGS) Aquimod code is used to simulate groundwater levels for an indicator borehole where we have existing RWL curve shift relationships (as used in WRMP19, WRMP14). The 400 WRSE climate sequences provide inputs to the lumped parameter model.	A subset of these assessments could be validated against the full new IOW groundwater model, however, run time of this model as such will not allow the full ~19k years of WRSE climate data to be run in a reasonable timescale hence our assessments used lumped parameter model as a 'rapid' tool. Method covers all sources on IOW. Climate sequences are coherent so DO time series are temporally and spatially coherent with other WRZs.
Brighton and Worthing Chalk	SBZ, SWZ	The 400 WRSE stochastic climate data are used with 4R recharge model from Brighton and Worthing groundwater model) and an indicator borehole (Southwick) regression model to predict rest water Level shifts at Southern Water abstractions.	Similar methodology used for WRMP 2009 (WRMP09) and WRMP14 (though recharge model has evolved) and same stochastic approach as WRMP19 (stochastic). As for WRMP19 a subset of these assessments could be validated against the full Brighton and Worthing groundwater model. However, run time of this model as such will not allow the full ~19k years of WRSE climate data to be run in a reasonable timescale hence our assessments used past validated regression relationship as a 'rapid' tool (there is still significant run time for 4R recharge model alone).
North Kent Chalk	KME, KMW	As WRMP14/19, Stochastic simulation with Environment Agency Recharge code to Indicator Borehole Model for DO Curve Shifting to produce groundwater level and yield time series	Same methodology as used in WRMP09 (with historic hind cast data and North Kent model outputs), WRMP14 (stochastic) and WRMP19 (stochastic). New North Kent and East Kent extended model still under development will eventually replace this process with a single groundwater model assessment for all Kent sources. Method covers all sources in KME and KMW WRZs. Climate sequences are coherent so DO time series are temporally and spatially coherent with other WRZs.
East Kent and Thanet Chalk	KTZ	WRSE Stochastic data used with Naturalised Environment Agency East Kent groundwater model (used under licence) to predict rest water level shifts at Southern Water abstractions. Although there are surface water impacts, we have no groundwater sources which have coupled surface water MRF conditions	Same methodology as used in WRMP09 (with historic hind cast data), WRMP14 (stochastic) and WRMP19 (stochastic). New North Kent and East Kent Extended model still under development will eventually replace this process with a single groundwater model assessment for all Kent Sources Method covers all sources in KTZ. Climate sequences are coherent so DO time series are temporally and spatially coherent with other WRZs.

2.5 Surface water hydrology

To understand the availability of supplies from our river sources such as the Rother and the Medway, we used hydrological modelling. We have used several hydrological models developed using the Environment Agency 'CATCHMOD' catchment modelling code implemented in Python ('PyCatchmod')[17]. These models primarily cover our Central and Eastern areas. River flows in the baseflow dominated River Test and River Itchen in our Western area were simulated using a regional groundwater model.

The hydrological models we used were largely unchanged from those used for our WRMP19. We updated our River Rother hydrological characterisation to improve low flow fits and to an include enhanced representation of groundwater impacts on the river.

Our hydrological modelling approach is consistent with that set out in WRSE (2021b)[18].

Hydrological models may be used to assess the potential impacts of drought on river flows. We have used CATCHMOD (Greenfield, 1984)[19] rainfall-runoff hydrological models to model river flows since 2005.

Our flow models are calibrated against observed data and are used to simulate the likely river flows which would occur in a catchment given a particular sequence of weather. The models have been developed to produce flow sequences from the synthetic stochastic rainfall and PET sequences (Section 2.2), as well as the historic records of rainfall and PET.

2.5.1 Climate data

Analysis of WRSE rain gauge apportionment was carried out for all of the surface water catchments. There were a limited number of rainfall assessment points with rainfall sequences developed for WRSE. This analysis identified nearest climate data rain gauges to the existing CATCHMOD surface water catchments, and then undertook goal-seek regression analysis to apportion the contribution of each rain gauges site (instead of Thiessen polygon approach).

As with the groundwater models, coherent PET data in the weather generator is sub-sampled from model historical input data, largely as per previous WRMPs.

2.5.2 Flow naturalisation

Flow naturalisation is the term given to the process of determining the 'natural' flow within a river. Naturalised flows represent the flows that would have occurred in the river without the influences of artificial abstractions and discharges within the catchment. The naturalised flows are then used to calibrate the hydrological models, so that the models simulate flows without these influences.

Flow naturalisation by decomposition involves estimating flows as might have occurred without the artificial influences through the re-addition of abstracted water to the gauged flow and the removal of discharges. Flow naturalisation was undertaken in line with Environment Agency guidance (2001).[20]

[17] Tomlinson, J, Arnott, J and Petch, L, pycatchmod: A Cython implementation of the rainfall runoff model CATCHMOD (Wilby, 1994), Version 1.1
[18] WRSE, 2021b. Method Statement: Hydrological Modelling. Post consultation version.
[19] Greenfiled, B. G., 1984. The Thames Catchment Model. Thames Water Authority, Reading.
[20] Environment Agency, 2001. Good Practice in Flow Naturalisation by Decomposition - Naturalisation Guidance v2.0

A dataset of abstractions in each catchment was collated from information shared by the Environment Agency and the largest 99% of abstractions based on licence volume were extracted for analysis and missing data were infilled. The impact of groundwater abstractions was represented using the 'lumpy groundwater factor' methodology described in Environment Agency (2001). Time series of discharges were developed using estimates of dry weather flows (DWFs), based on either measured discharge date, or consented DWFs.

Using the procedures outlined above, the catchment abstraction and discharge time series datasets were used to generate naturalised flow sequences from the observed gauged daily flows.

Reservoir inflows were assessed using two methods; by back calculating inflows based on reservoir water balance, and by using nearby gauged catchments which were generally unaffected by artificial influences as a proxy. Inconsistencies and anomalies in the reservoir water balance datasets meant that proxy flow data from nearby catchments was preferred for estimating historical reservoir inflow sequences.

2.5.3 Flow denaturalisation

We applied bespoke WRMP19 Medway flow denaturalisation to consider non-simulated HoF constraints and interaction of Bewl, River Medway Scheme and Bough Beech Reservoir.

Our CATCHMOD rainfall-runoff models simulate 'natural' catchment flows. To estimate the yield of surface water systems, we need to take account of the abstractions and discharges which would normally occur in the catchment. 'Denaturalisation' is the procedure by which these artificial influences are added back to the simulated natural flows.

Denaturalisation represents a sub-set of the abstractions and discharges in the catchment. The Southern Water surface water abstractions and reservoir releases are not represented in the denaturalisation process. These are modelled instead in the Pywr system simulation model for which the denaturalised flows are a key input.

Actual historical abstraction data were analysed and the 'peaky worst year' (PWY) selected to use denaturalisation, being the year with the greatest aggregate abstraction.

Denaturalisation was carried out using a bespoke script written in Python. This procedure accounted for the licenced HoF condition for each abstraction with a dynamic denaturalisation process which checked the amount of water available above the HoF for each licence, and only accounted for an abstraction if there was sufficient water available.

2.5.4 Outputs

Flow outputs from our CATCHMOD modelling comprise 400 x 48 year time series of river flows for each model consistent with the stochastic climate input data. Output flows were validated by comparison against the equivalent stochastic flow series from our WRMP19 hydrological modelling.

Once validated outputs are then passed to our RSS models where they provide input time series for both reservoir refill and/or river flows to be used in the calculation of WRZ DO (Table 2.6).

Table 2.6: Link between hydrological model output and system simulation.

Area/WRZ	CATCHMOD Flow Series	System Simulation Sub-Model
Western	Not appliable. River Test and Itchen Flows come from Test and Itchen groundwater model	Hampshire
IOW	Medina and Eastern Yar	Not applicable. New IOW model under development
SNZ	Western Rother, Arun at Pallingham, Weir Wood	Sussex North (Central)

Area/WRZ	CATCHMOD Flow Series	System Simulation Sub-Model
KME and KMW	Bewl, Teise, Teston, Allington, Stonebridge, Boughbeech, Powdermill, Brede, Udiam, Eden	River Medway model (outputs for River Medway Scheme yield are passed to Kent Medway-Thanet model')

2.6 Regional system simulation

To derive WRZ level estimates of DO as required by the WRPG, we have used a RSS model which has been developed collaboratively with WRSE and neighbouring water companies. The overall approach is set out in WRSE (2021c)[21] and is summarised below.

Our RSS models have been used to produce both our baseline DO assessments and assessments of uncertain future impacts of climate change. 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:

- Baseline DO (see WRSE (2021d) [22]
- Impact of climate change on DO (see Section 3 and WRSE (2021e)[23])

The regional level RSS is a combined model composed of many coupled sub-models. A key requirement of the RSS is that methods and models used, where reasonable, are consistent with existing company assessments. As such, the initial sub-models are being built to represent company WRZs and sub-region models.

The sub-models were constructed in Pywr to a similar level of detail as our existing Aquator system simulation models, although some demand centres were aggregated, and sources grouped to simplify the model and speed up run time. New models were developed in Pywr because it offers improved functionality for handling stochastic flow and climate sequences and more efficient run times, especially when scaled up to a regional level model.

We also updated our demand profiles to be more consistent with recent patterns of consumption. Some additional constraints were also added to model groundwater DO to mimic operational usage of the sources. Where relevant, some abstraction licence changes and network enhancements were also included.

During development of our models, sub-model performance was validated against our existing Aquator models where possible to ensure system behaviours and source operation was modelled appropriately.

The Southern Water components of the RSS model were constructed from five sub-models:

- Western area model encompassing 4 WRZs (HWZ, HRZ, HSE and HSW).
  - This was constructed to a similar level of detail to existing well-validated Aquator model.
  - Validation undertaken against the existing Aquator model (e.g. from WRMP19).
  - Updated to include:
    - Section 20 operating agreement
    - Hampshire grid schemes
    - Revised wastewater discharges
- SNZ model (Central area)
  - This was constructed to a similar level of detail to the existing well-validated Aquator model
  - Validation undertaken against the existing Aquator model (e.g. from WRMP19).

[21] WRSE, 2021. Method Statement: Regional System Simulation Model. Post consultation version. (Included in Annex 23)
[22] WRSE, 2021. Method Statement: Calculation of Deployable Output. Post consultation version (Included in Annex 23).
[23] WRSE, 2021. Method Statement: Climate Change – Supply Side Methods. Updated version (Included in Annex 23).

  - Updated to include improved impact pathway between Pulborough groundwater abstraction and the River Rother.
- SBZ and SWZ model (Central area)
  - A model incorporating network constraints and disaggregated demands and sources developed from an existing Aquator model, but not one that had been used for DO assessment.
  - For WRMP19, DO was totalled for source inputs into these WRZs. No final simulation model from WRMP19 was available for validation.
  - Validation undertaken against the DO supply forecasts.
  - Additional constraints added to the groundwater DO to mimic operational usage of the sources.
- River Medway model including SHZ (Eastern area)
  - Similar level of detail to our existing Aquator model
  - Validation undertaken against the Aquator model
  - Updated to include new licensing arrangements around Bewl and South East Water arrangements.
- Kent Medway-Thanet model encompassing KME, KMW and KTZ (Eastern area)
  - A model incorporating network constraints and disaggregated demands and sources developed.
  - For WRMP19, DO was totalled for source inputs into KTZ. No final model available for validation.
  - Validation undertaken against the DO supply forecasts.
  - Additional constraints added to the groundwater DO to mimic operational usage of the sources.

Three of the WRZs in the Western area (HAZ, HKZ and IOW) were not included as sub-models within the RSS model.

HAZ and HKZ are relatively small groundwater dominated WRZs with sources that are asset and licence constrained and hence DO does not vary with drought severity or groundwater levels. The DO for these WRZs has therefore been determined using the standard unified method and does not require system simulation. However, we are currently constructing a sub-RSS model for Hampshire to include these WRZs jointly with Portsmouth Water.

For the IOW, we calculated DO additively, but this was simulated through our combined groundwater modelling using the coherent stochastic WRSE climate dataset to determine a probabilistic estimate of drought severity and associated DO following the standard unified method. This WRZ was modelled as a single demand node within our Western area sub-model. We are currently constructing our own in house Pywr system simulation model for this WRZ.

2.6.1 Calculation of WRZ DO

DO at a WRZ (system response level) level was estimated using the ‘Scottish DO Method’[24] excluding the effect of transfers, both external and internal.

As part of this approach, the system model repeatedly runs through the full hydrological and groundwater sequences (400 x 48 years for the stochastic sequences) for a range of different overall demand levels. As the overall demand levels are changed, the individual demands for selected demand centres are

[24] UKWIR, 2014, Handbook of Source Yield Methodologies, Report Ref. No. 14/WR/27/7

incrementally increased. The analyser counts and reports the number of days with failures (i.e. when there are insufficient resources to meet demand) in each year for each demand level.

The DO is defined as highest level of demand which can be applied where emergency drought orders would not be imposed more often than once every ‘x’ number of years, where ‘x’ ranges from 1-in-2 year to 1-in-500 year drought severity.

For all of our WRZs we set the failure condition to be after four consecutive days of a failure to meet demand. This condition was consistent with other WRSE companies to ensure a coherent approach to resource modelling.

Our assessment of baseline DOs at the WRZ level is shown in Table 2.7.

This method vis system simulation does not attempt to calculate individual source DOs. It is focussed only on ‘system’ (WRZ) level DO. It is focussed only on WRZ level DO.

Table 2.7: Summary of baseline DO at the WRZ level

WRZ	DO by return period (DYAA) - Ml/d				DO by return period (DYCP/PDO) - Ml/d			
	1-in-500 year	1-in-200 year	1-in-100 year	1-in-2 year	1-in-500 year	1-in-200 year	1-in-100 year	1-in-2 year
HKZ	8.75	8.75	8.75	8.75	9.28	9.28	9.28	9.28
HAZ	22.53	22.53	22.53	22.53	24.39	24.39	24.39	24.39
HRZ	10.35	10.35	10.35	10.35	10.35	10.35	10.35	10.35
HWZ	22.52	22.52	22.52	22.52	24.4	24.4	24.4	24.4
HSE	20.49	32.46	45.65	77.97	41	58.38	78.36	108.42
HSW	0.00	0.00	0.00	73.54	0.00	0.00	11.85	78.8
IOW	23.96	25.89	26.07	26.58	30.54	34.09	34.33	34.65
SNZ*	17.6	21.46	54.84	84.94	20.81	57.32	70.6	99.16
SWZ	45.78	46.26	46.69	51.73	54.96	55.52	56.05	62.11
SBZ	77.5	80.05	81.57	86.94	93.82	96.88	98.74	105.33
KMW	59.25	59.25	59.25	59.25	65.97	65.88	65.88	65.48
KME	85.37	86.15	86.71	89.13	97.65	98.62	99.47	60.75
KTZ	44.71	46.5	47.98	51.42	52.86	54.71	55.52	59.68
SHZ	18.75	19.9	20.98	31.34	22.9	26.14	28.15	39.75

*For SNZ the DO shown is once Weir Wood WSW is fully returned to service with a 21Ml/d capacity from 2030-31

2.6.2 Our Level of service in Sussex North

One of the most significant changes in deployable output between WRMP19 and WRMP24 is that in our Sussex North Water Resource Zone as illustrated in the following table:

Table 2.8 Comparison of Sussex North DO between WRMP19 and WRMP24

Plan	DO by return period (DYAA/MDO) - Ml/d				DO by return period (DYCP/PDO) - Ml/d			
	1-in-500 year	1-in-200 year	1-in-100 year	1-in-2 year	1-in-500 year	1-in-200 year	1-in-100 year	1-in-2 year
WRMP19	17.50	42.10	46.70	74.10	39.70	69.40	73.70	98.60
WRMP24*	17.60	21.46	54.84	79.00	20.81	57.32	70.60	99.16
Difference	0.10 (1%)	-20.64 (-49%)	8.14 (17%)	9.81 (13%)	-18.89 (-48%)	-12.08 (-17%)	-3.10 (-4%)	0.56 (1%)

*With Weir Wood reservoir WSW at 21Ml/d

The greatest changes are an almost 50% reduction in deployable output for 1 in 200 drought event under the DYAA/MDO scenario and for a 1 in 500 drought under the DYCP/PDO scenario.

However, due to a number of differences in the way the supply forecast has been constructed a true like for like comparison between the two forecasts is not possible. The change in 1 in 200 year drought deployable output is significant because our target level of service against emergency drought (Level 4) restrictions for both WRMP19 and WRMP24 was initially set at 1 in 200 and reaching 1 in 500 year level of drought resilience by 2039.

The drop in baseline deployable output effectively represents a direct increase in the supply demand deficit at the 1 in 200 year level of service compared to our WRMP19 position and in this case arises wholly from the baseline supply forecast, although there are a number of factors at play that have reduced resilience in Sussex North.

- Cessation or delayed delivery of WRMP19 supply schemes, for example the Pulborough Wellfield reconfiguration, Pulborough Groundwater Licence Variation and the return to service of Midhurst and Petersfield Groundwater sources and which are discussed in chapter 3 of the main technical report
- Outage at Weir Wood supply works, which resulted in a drop in deployable output.

Both of these are discussed elsewhere, however, in the following subsection we have examined the underlying drivers in the fall in drought resilience that have arisen from a water resource and supply modelling point of view.

2.6.2.1 Climate data and flow modelling

At a high level the process for determining Deployable Output in Sussex North was very similar between WRMP19 and WRMP24, as described in table 2.9 and following the general procedure set out in section 2.1.

The key differences between WRMP19 and WRMP24 are in the updated climate modelling approach and in the final DO assessment approach via system simulation modelling.

The procedure for simulating river flows using Catchmod (see Section 2.5) was exactly the same between WRMP19 and WRMP24. The differing input data from the climate modelling mean that the result flow outputs differ.

Table 2.9 Comparison of WRMP19 and WRMP24 deployable assessment methodology for Sussex North

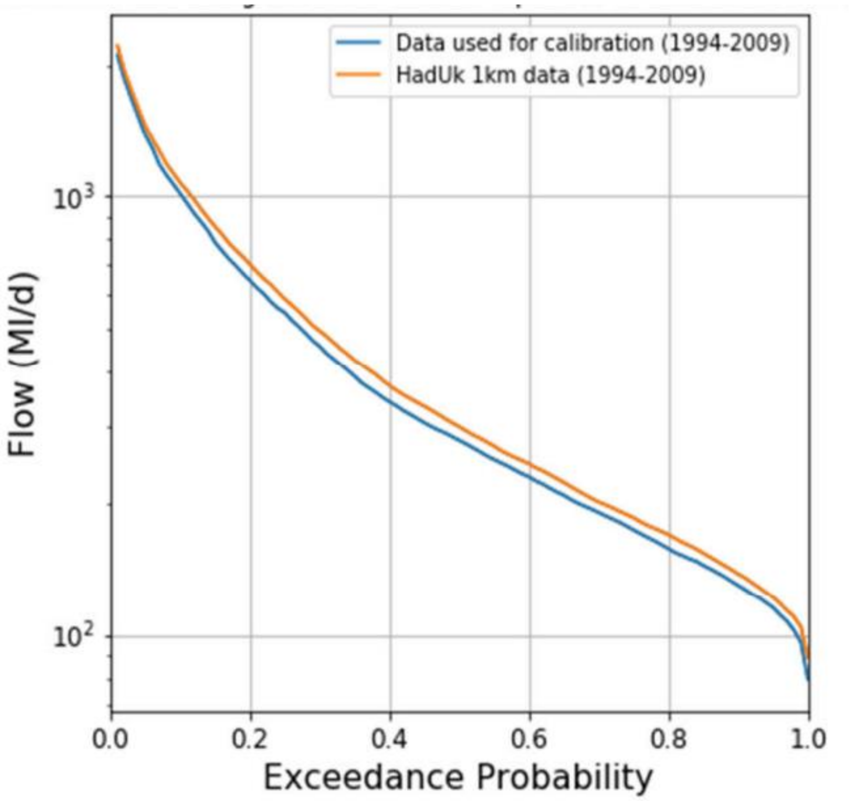
Stage	Step	WRMP19	WRMP24
1	Generation of Stochastic Rainfall and Potential Evapotranspiration Data	Rainfall - Stochastic Weather Generator based on Serinaldi and Kilsby (2012)[25] as first used in WRMP14 but updated with additional enhancements for at site (e.g. rain gauge) simulation. Generation based on historical rain gauge data (variable record length.) Potential Evapotranspiration – data sampled from historical record based on matching to stochastic monthly rainfall.	Rainfall - Stochastic Weather Generator based on Serinaldi and Kilsby (2012) as first used in WRMP14 but updated by Atkins (2020)[26] to include additional teleconnections, model fit improvements and bias correction. Generation based on historical Had UK rainfall (1950-1997.) Potential Evapotranspiration – data sampled from historical record based on matching to stochastic monthly rainfall. Some enhancements to summer and very dry month PET matching.
2	River Flow Generation	Same procedure for both WRMP19 and WRMP24 using Catchmod and Stage 1 climate data simulations generating naturalised flows for Western Rother, River Arun and Weir Wood inflow. Flows then denaturalised using “Peaky Worst Year” profiles of upstream abstractors.	
3	System Simulation to determine DO	System simulation in Aquator using Scottish DO method/ The residual of the combined groundwater sources River Arun and the conjunctive use zonal DO is used to define the DO for the variable SW sources at Pulborough and Weir Wood. Weir Wood MDO is assumed to equal the bulk supply to SEW (5.4Ml/d) unless there is insufficient water. Pulborough SW is defined as residual of conjunctive use DO and the other sources. If this is negative, then Pulborough SW DO is set at zero and Weir Wood reduced by that amount.	System simulation in Pywr using the Scottish method to determine deployable output at a system level including any conjunctive use benefits. DO not estimated separately for Pulborough SW, River Arun and Weir Wood. Follows system simulation methodology set out by WRSE[27][28] “Failure” condition assessed as four consecutive days without supply.

[25] Serinaldi, F. and Kilsby C.G, 2012 A modular class of multisite monthly rainfall generators for water resource management and impact studies, Journal of Hydrology v.464-465,pp 528-540, https://doi.org/10.1016/j.jhydrol.2012.07.043
[26] Atkins, 2020, Regional Climate Data Tools, Final Report (see annex) wrse_file_1338_regional-climate-data-tools.pdf
[27] Atkins, 2021, Regional Simulator Workstream, WRSE Regional Simulator, WRSE wrse-regional-system-simulator-report.pdf
[28] WRSE, 2022, Method Statement: Calculation of Deployable Output wrse-calculation-of-deployable-output-method-statement-november-2022.pdf

2.6.2.2 Flow modelling

When developing the updated stochastic weather generator, on behalf of WRSE Atkins undertook a case study of the Western Rother Catchment. This review showed that the historical modelled derived using the original (WRMP19) input data rain gauge data used for our Wester Rother Catchmod river flow model calibration are similar to the simulated flows derived using Met Office HadUK data as input. For this reason, no further calibration of the WRMP19 Western Rother Catchmod model was undertaken for WRMP24. To generate the inputs 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.[29]

Figure 2.3 Flow Duration Curve showing the flows derived using the same input data used for Catchmod's calibration (as per WRMP19) are similar to the simulated flows using Met Office HadUK data[30]



This model was used to simulate flow based on the stochastic precipitation and PET data. Figure 2.4 (a) presents flow duration curves (FDCs) for the sampled 400 stochastic data timeseries generated following the regional WRMP24 methodology against the simulated flow using observed historical HadUK rainfall data.

---

[29] Atkins, 2020, Regional Climate Data Tools, Final Report (see annex) wrse_file_1338_regional-climate-data-tools.pdf
[30] ibid

This shows that the FDCs for HadUK data lies within the range of stochastic flow series flow duration curves, however, its position within the range does vary at different exceedance probabilities. There is noticeable variability between the 400 FDCs; the difference is greatest at higher exceedance probabilities, associated with low flows.[31]

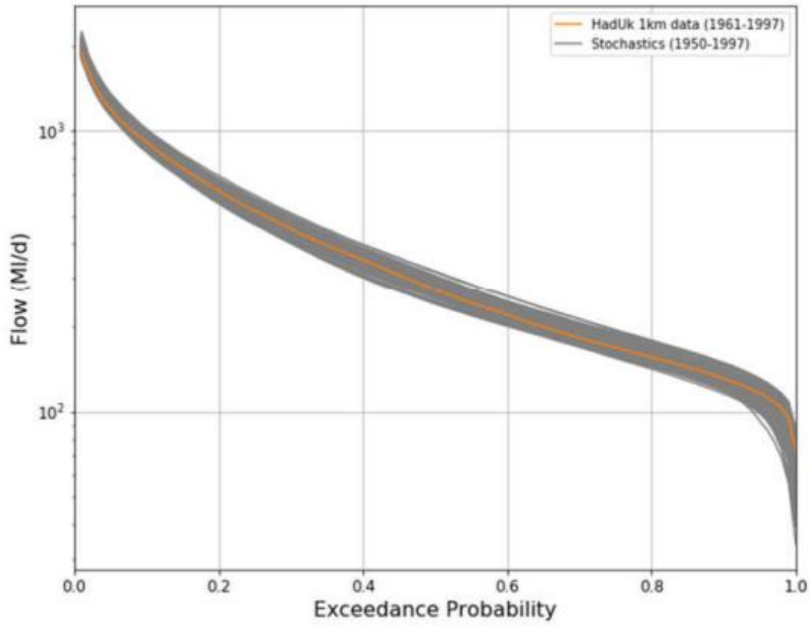
In Figure 2.4 (b) we have also compared the same data to our WRMP19 assessment, this shows a close match for the historical dataset, however the WRMP19 stochastic dataset show generally lower flows across much of the flow duration curve range except for at the higher exceedance probability (lowest flows) where there is a closer match to both historical dataset and the WRMP24 stochastic range. In the most severe droughts (above Q_{95}) over half (n=285) of the WRMP24 stochastic datasets fall below the WRMP19 stochastic data.

The differences between flows modelled using the observed HadUK data and the 400 stochastic datasets are also presented in Figure 2.5. The median extreme low flows (95% exceedance probability) are less extreme than those produced from the historical data (+4%), however, as shown, the stochastic data provides a large range of flows to test the Pulborough system. The variability/range in the 400 stochastic replicates increases as the exceedance probability increases (as flows decrease).[32]

[31] Atkins, 2020, Regional Climate Data Tools, Final Report (see annex) wrse_file_1338_regional-climate-data-tools.pdf
[32] ibid

Figure 2.4 Western Rother at Pulborough flow duration curves for stochastically generated flow (a) shows the comparison by Atkins between the historical and stochastic data based on HadUK. (b) shows a similar comparison between the WRMP24 stochastic data and the WRMP19 historical and stochastic data, including a focus on low flows (exceedance probability >80%)

(a)



(b)

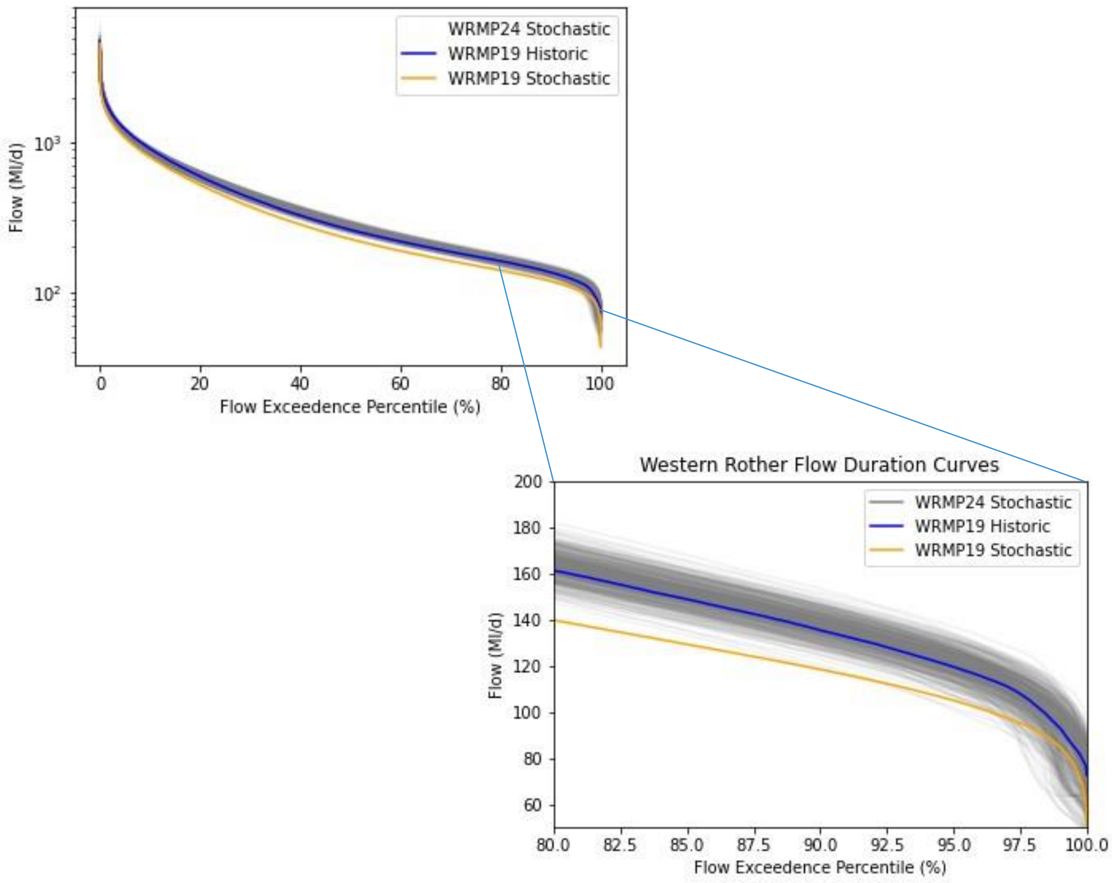
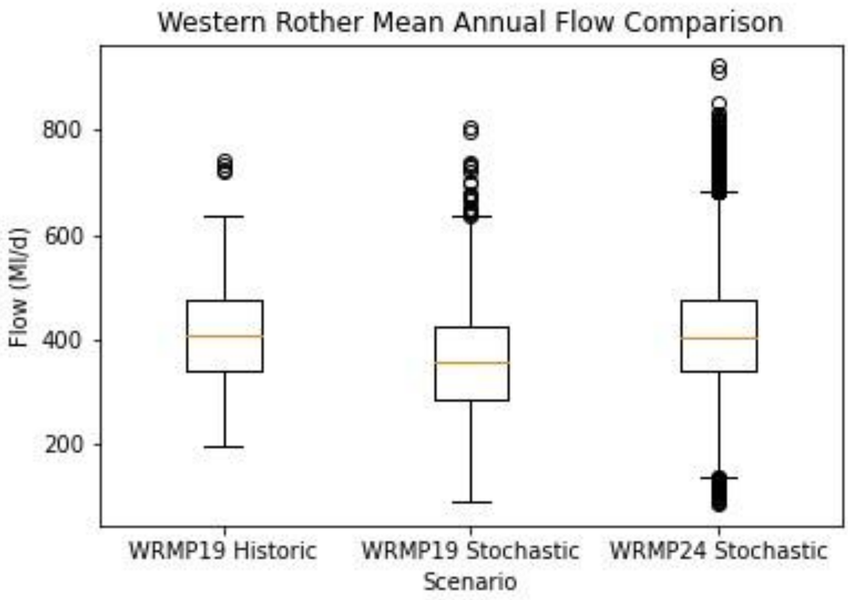
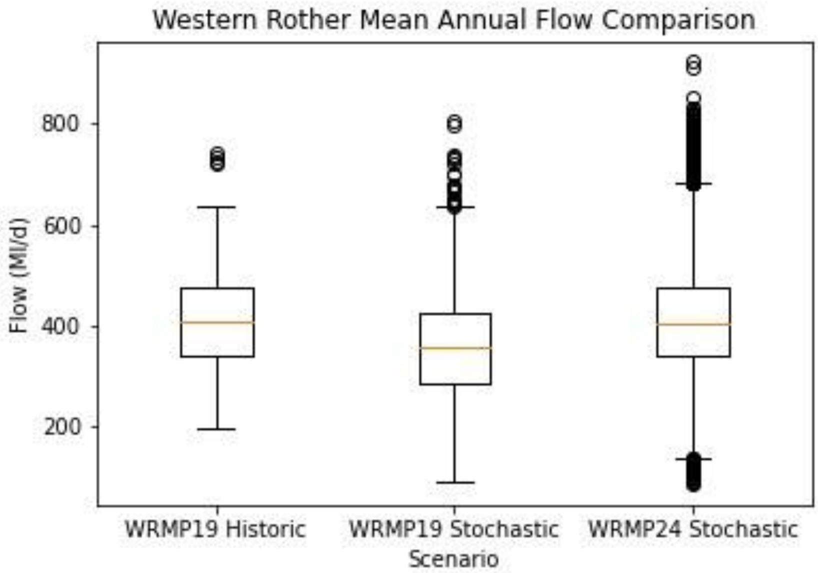


Figure 2.5 Box Plot comparison between flows in the Western Rother at Pulborough calculated using observed HADUK and those calculated using stochastic weather data at (a) mean flow (Q50) and (b) Q95 low flows

(a)

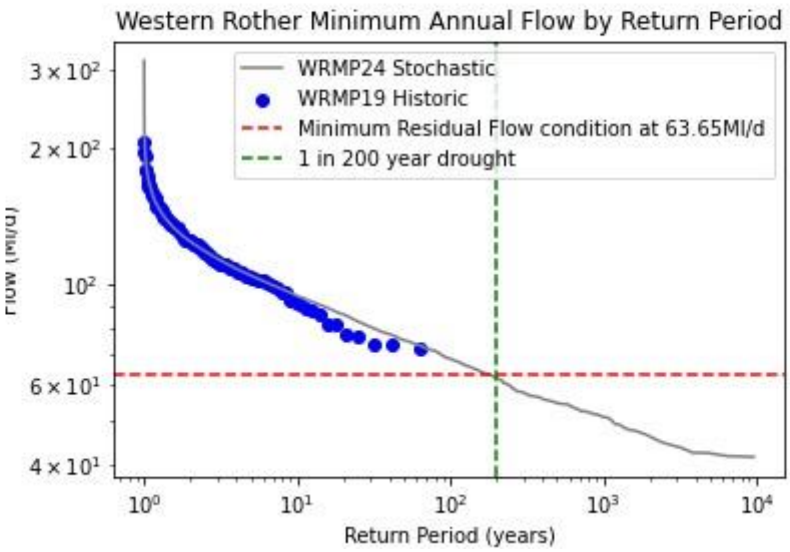


(b)



The yield from Pulborough Surface Water and its relationship with the MRF licence condition that controls both the Pulborough Surface and Groundwater deployable output is the most significant factor in determining the overall deployable output for the Sussex North Water Resource Zone. The updated climate modelling undertaken for this plan compared to WRMP19 is broadly comparable but this plan explores a greater range of uncertainty and shows a higher variance at the very low flows expected in severe droughts. Return period analysis on these data (Figure 2.6) show that the MRF condition (before any abstraction from Pulborough) is likely to be crossed at around 1 in 200 year frequency and hence has a significant impact on our level of service. We then explored this further through our System Simulation Modelling to determine the Water Resource Zone Deployable Output

Figure 2.6 Return period plot showing the relationship between modelled flows in the Wester Rother and the Pulborough MRF licence condition.



2.6.2.3 Updated Sussex North system simulation

To reflect a number of changes to our Sussex North Water Resource Zone since the original modelling for our draft WRMP we have undertaken further system simulation of the zone using an updated version of the original Pywr Model. These changes comprise the following:

- We increased the capacity of a connection between the Horsham and Crawley area from 23Ml/d to 30Ml/d based on recent testing and operational experience of network capacity.
- We increased the maximum capacity of Pulborough WSW to 75Ml/d in line with recent Peak Week Production Capacity Testing
- We added a new transfer to a model demand node in the Turner’s Hill area to represent the new 1.3Ml/d (pre 2025) and 4Ml/d (post 2025-26) transfer into the Water Resource Zone from SES Water, this transfer was not part of our original baseline modelling for our draft WRMP as this connection was not online at that time
- We set the Weir Wood starting position to full rather than starting at the minimum volume to avoid any potential artificial deficits in model warm up period. However, given the first few years of the climate stochastic datasets are relatively wet this does not make a material difference to model output.
- We have run several iterations of the model to understand and analyse the impacts of the rehabilitation of the Weir Wood Reservoir Water Supply Works at different capacities to inform the glidepath of deployable output. Our present planning assumption is as follows:
  - Weir Wood WSW will have a capacity of 5.4Ml/d from 2025-26
  - From 2027-28 Weir Wood WSW will have its capacity upgraded to 13Ml/d
  - From 2030-31 Weir Wood WSW will have its capacity upgraded to 21Ml/d

Following those changes we repeated the original deployable output analysis for the updated model and for each version of the Weir Wood WSW treatment capacity. This process followed the same steps as outlined in section 2.6.1 following the “Scottish” assessment method with a “failure” condition happening when four or more consecutive days of interruption to supply occur.

Table 2.10 summarises the change in Sussex North Water Resource Zone Deployable Output.

Table 2.10 Updated DO assessment for Sussex North

		DYAA Deployable Output*				DYCP Deployable Output**			
Scenario	**Time Period**	**1 in 2**	**1 in 100**	**1 in 200**	**1 in 500**	**1 in 2**	**1 in 100**	**1 in 200**	**1 in 500**
WRMP19	**2020-2025**	**74.1**	**46.7**	**42.1**	**17.5**	**98.6**	**73.7**	**69.4**	**39.7**
Original dWRMP (Weir Wood at 20Ml/d)	2025 Onwards	83.94	54.84	21.46	17.60	99.16	70.60	57.32	20.81
No Weir Wood WSW	Pre 2025-26	71.97	45.82	16.45	15.80	81.19	**56.38**	49.39	14.14
Weir Wood WSW at 5.4Ml/d	2025-26 to 2027-28	79.00	54.84	21.46	17.60	90.81	67.95	57.32	20.81
Weir Wood WSW at 13Ml/d	2027-28 to 2030-31	83.94	54.84	21.46	17.60	96.22	69.10	57.32	20.81
Weir Wood WSW at 21Ml/d	2030-31 onwards	84.94	54.84	21.46	17.60	100.16	70.60	57.32	20.81

*Compared to MDO scenario for WRMP19, **Compared to PDO Scenario for WRMP19. WRMP19 benefits exclude the originally planned benefit of the Pulborough Well Field Reconfiguration.

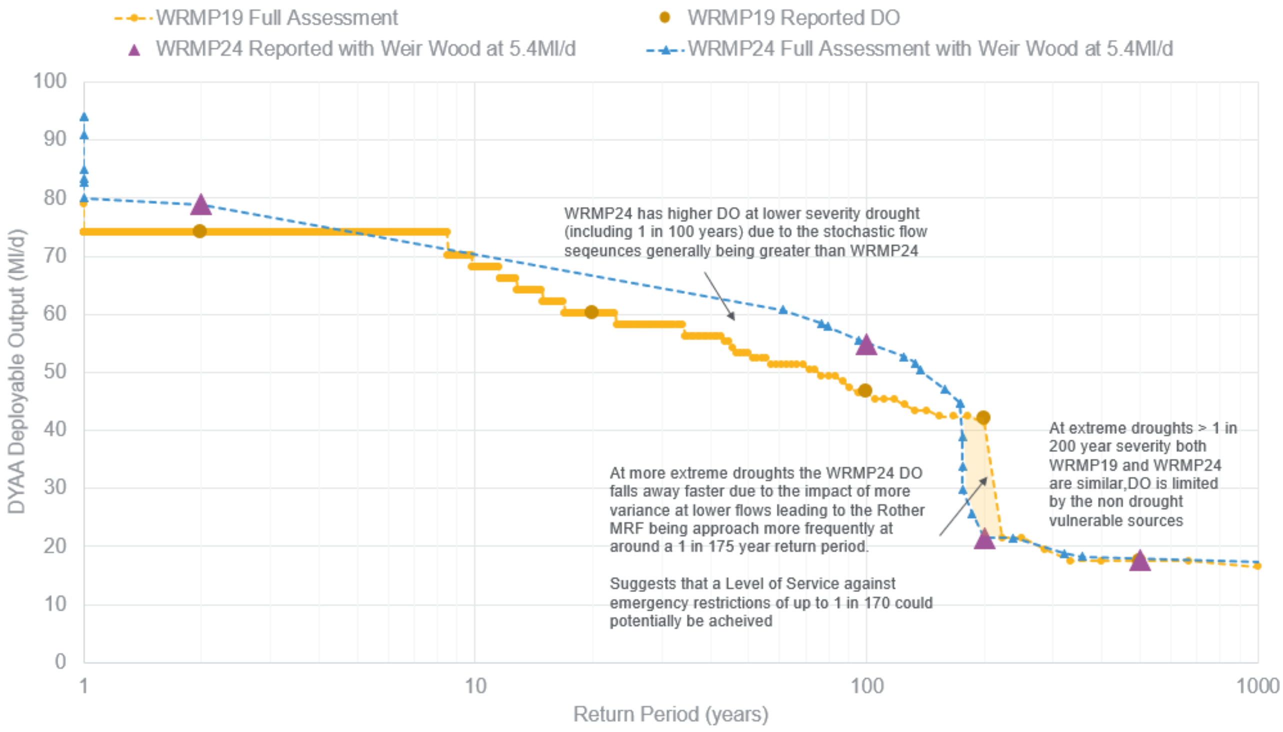
The key impacts of Weir Wood being out of service are a drop in the Water Resource Zone in deployable output of between 2-9Ml/d in the DYAA scenario depending on drought return period and up to 20Ml/d under the DYCP scenario. The greatest impacts are in normal year and moderately severe droughts (up to 1 in 100 years). This reflects that when flows in the Rother are relatively healthy and have some headroom above the MRF (see section 2.6.2.2) and Weir Wood and Pulborough WSW operate together this produces some conjunctive use benefits at the system level through maximising use of storage.

During severe droughts (1 in 200 and above) the deployable output produced by Pulborough WSW drops off significantly due to the MRF flow condition being approached and the deployable output and storage benefits from Weir Wood Reservoir also become limited by the natural inflow to refill the reservoir which is between 2-6Ml/d depending on drought severity.

Varying the capacity of the treatment works at Weir Wood WSW provides some large benefits in normal non drought years or in mild droughts when the storage can be more freely utilised but because drought yield is limited by the natural inflow to the reservoir increasing the capacity only has a limited benefit in DYAA scenario but does provide some utility in meeting short term peaks in demand under the DYCP scenario.

When compared with our WRMP19 assessment (Figure 2.7) the biggest difference can be seen in the 1 in 150 to greater than 1 in 200 year drought return period. In particular, the system DO assessment for this plan shows a steeper drop off in deployable output at around the 1 in 180 year return period. Our assessment of river flows in the Western Rother during drought (section 2.6.2.2) has indicated that both WRMP19 and WRMP24 are generally consistent, therefore this difference in WRZ deployable output appears to be a function of the way system deployable output has been assessed for this plan.

Figure 2.7 Comparison of System DO simulation between WRMP19 and WRMP24



The WRMP19 methodology, which was bespoke to this Water Resource Zone and to Southern Water has been superseded by the WRMP24 methodology which has been consistently applied across all WRSE companies. However, the impact of this is that the reduction of level of service within Sussex North is shown to be only partially attributed to lack of resilience within the WRZ (for example due to outage at Weir Wood and delayed delivery of the Littlehampton recycling scheme) but is instead primarily a function of updates to the modelling approach resulting in a more conservative estimate of WRZ for this plan compared to our previous plan. These key differences include:

- Updates to the stochastic Weather Generator for WRMP24 which has impacts on both inflow to Weir Wood Reservoir and The Western Rother. River Rother mean flows are slightly higher but WRMP24 shows greater variation at the extremes (i.e. there is a greater variance in the data for WRMP24).
- Both Pywr (WRMP24) and Aquator (WRMP19) calculate a system level deployable output following the Scottish methods (though the “failure” criteria differ). For WRMP19:
- The Baseline Conjunctive Deployable output was calculated for the Sussex North WRZ using Aquator (Scottish Method)
- Groundwater MDOs and PDOs were assessed individually for each source and are typically non varying as the Rother Valley groundwater sources are typically either licence or infrastructure constrained rather than drought limited so for the Sussex North GW sources, there is not expected to be any significant variation for different drought severities.
- The River Arun source is constrained by the licence at MDO (10), and bankside storage capacity at PDO (15)
- The residual of the combined groundwater sources + River Arun and the conjunctive use zonal DO is used to define the DO for the variable SW sources at Pulborough and Weir Wood

- Weir Wood Reservoir MDO was assumed to equal the bulk supply to SEW (5.4Ml/d) - unless there is insufficient water
- Pulborough SW was defined as the residual of conjunctive use DO and the other sources. If this is negative, then Pulborough set at zero and Weir Wood DO is reduced by the size of the residual.
- Both Pulborough Groundwater and Surface Water are also constrained by the MRF licence condition on the Western Rother whereby abstraction must cease when flows are below the MRF (63.5Ml/d). This condition was not applied within the Aquator simulation model but was instead calculated as a post processing step by reducing the DO for Pulborough GW when Pulborough SW was at zero.

For WRMP24 owing to the conjunctive use between sources, particularly Pulborough Surface Water and Weir Wood Reservoir and reflecting the change in planning guidance to require a “system response” the WRZ deployable output, including any conjunctive use benefit, as assessed by Pywr was not disaggregated between separate sources

- Pulborough Groundwater was dynamically represented within Pywr, including the role of the MRF constraint leading to cessation of abstraction from the groundwater when the MRF condition is simulated to be reached.
- This results in a significant drop in deployable output (up to 50%) during a drought of ~1 in 200 year severity because the crossing of the MRF means that both Pulborough Groundwater and Pulborough Surface Water will be unavailable.

In conclusion our review has shown that the assessment of deployable output for Sussex North is more conservative for WRMP24 than for WRMP19 and that this is likely an important contributing factor to the decline in 1 in 200 year deployable output for Sussex North in this plan.

However, it should be noted that the drop in level of service to Level 4 restrictions to 1 in 100 between 2025 and 2030 is partially driven by a limitation in the WRSE supply demand balance modelling approach which only considers 1 in 100, 1 in 500 and 1 in 200 scenarios. As our system modelling has indicated (see Figure 2.7) for both WRMP19 and WRMP24, the biggest factor in the decline in deployable output occurs as the output from Pulborough SW and GW reduces as the Wester Rother MRF is approached. Our modelling has shown that this also occurs at between a 1 in 170 to 1 in 200 year return period and so effectively the level of service for the zone is controlled by that crossing.

The positive side of this is that although a Level of Service of 1 in 100 is reported for 2025-2030 period because this is the scenario “solved” by the investment modelling the actual level of service for the Water Resource Zone and the use of the Pulborough Surface Water Drought Permits and Orders is likely to be higher as there is not a significant decline in WRZ deployable output until around a 1 in 170 year return period, thus the “true” Level of Service for the zone is likely to be closer to this order of magnitude than 1 in 100.

2.6.3 MDO scenario modelling considerations

An MDO scenario considers the water supply available in a drought at the seasonal minimum, i.e. when river flows or groundwater levels are at their lowest. In our case, this typically occurs in October before the start of the annual groundwater recharge season. The conditions that would justify use of an MDO scenario, specifically, reduced yield from surface and groundwater yields during periods of low flows or low groundwater levels, are not unique to Southern Water.

In our previous WRMPs, we considered MDO scenarios explicitly by examining available DO at annual minima of either river flows or groundwater levels. However, there are limitations to this approach as it does not fully represent a ‘system’ based response:

- It assumes that sources within a WRZ will reach annual minimum yield at the same time. In reality, this may vary due to different flow rates or local aquifer characteristics and storage.
- It takes no account of demand and the distribution of abstractions between sources.

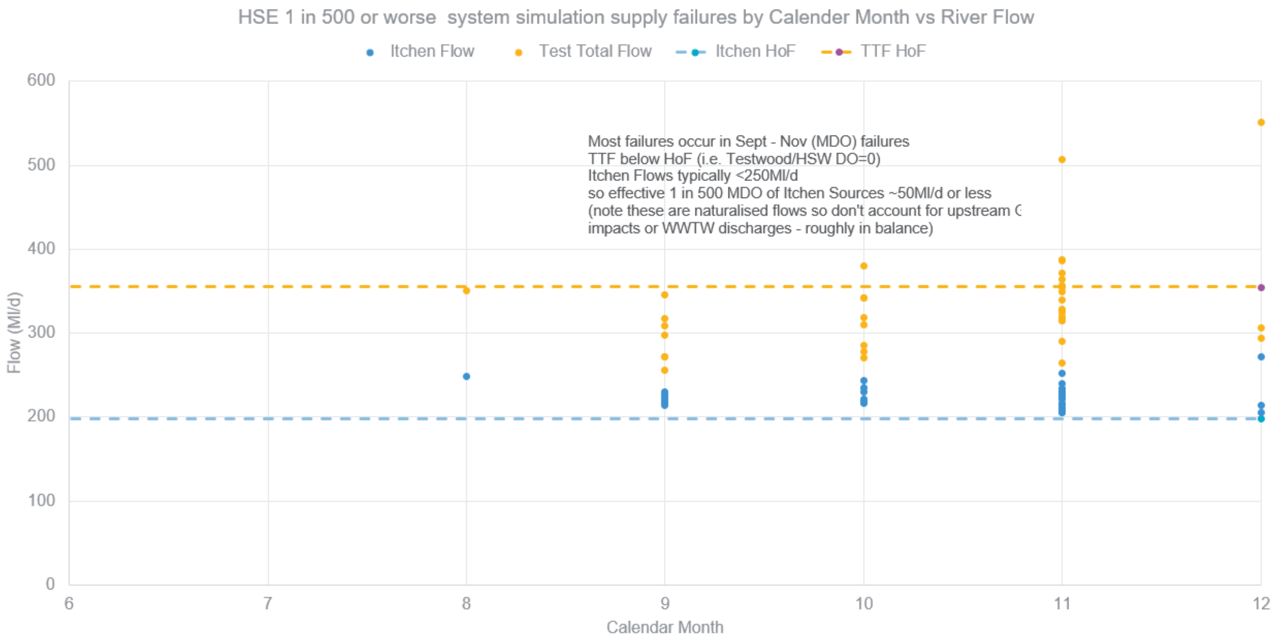
In WRZs with significant seasonal yield variations, we have used a system simulation method to better characterise system level behaviour during drought. Time-series modelling of source DO on a monthly or daily time step is used as input to the system model to capture seasonal variations in yield due to groundwater and river flow variations. These variable yields are then used by the model to ensure that each source responds coherently to drought conditions and captures local variations in both supply and demand.

In our Pywr models, we have estimated these groundwater yield input sequences by using time series assessments of DO at individual groundwater sources. This accounts for the seasonal variation in yield including reduced output in the autumn (MDO equivalent) period. However, if we were to simply add these in a linear way to calculate an MDO scenario as was done for WRMP19, it would not fully capture important system effects, such as conjunctive use benefits or the role of network constraints.

Our system level DO assessments effectively constrain DO when there have been four days of consecutive failure at a given level of demand. A key point is to note is that even though this is titled a DYAA DO, this relates to primarily to the demand assumption. There is at no point any kind of annual averaging of DO (especially in WRZs without significant storage). Supply failures can occur at any point in the year outside the critical period and are not constrained to just those which would occur only at the time of minimum flow. However, as the greatest stress between supply and demand will typically occur at the time of lowest supply, the assessment effectively becomes a de facto MDO type failure. We have validated this by looking at supply failures in HSE and HSW (which are the most MDO sensitive of all WRZs) and all of them occur at the time of minimum flow in the two rivers (i.e. between September and November), equivalent to MDO failures (Figure 2.8).

Our modelling of these ‘DYAA’ assessments (which include groundwater yield time series as inputs) also suggests that these system constraints can be more significant than DO variability (i.e., MDO vs DYAA DO). This is because our DYAA scenarios for WRMP24 tend to be less than a purely additive MDO scenario. Comparison of the WRMP24 DYAA DOs with the equivalent WRMP19 MDOs (Table 2.11) show that in all cases the WRMP24 DOs are roughly equal to, or lower than, our equivalent MDO scenario from WRMP19. We believe this results from a combination of the updated stochastics climate data and network/system factors which become apparent in our system simulation model so that the current DYAA scenarios are a higher stress on our supply demand balance than our WRMP19 MDO scenario.

No other WRSE company has estimated an explicit MDO scenario, either for this plan or previous plans. It is therefore not possible for us to create a coherent strategy with the rest of WRSE for a specific MDO scenario since inconsistent planning assumptions and availability of water would be applied to consideration of any transfers. However, all WRSE companies have similarly applied the system failure conditions described above.



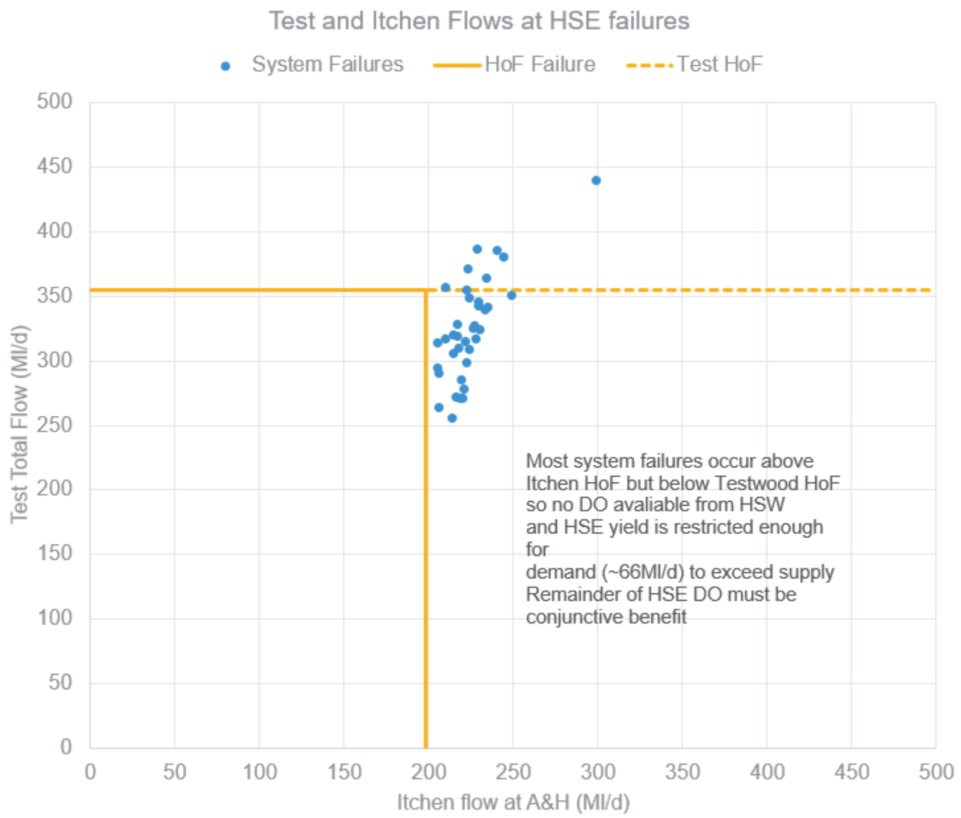


Figure 2.8 Distribution of supply failures from system simulation modelling in our Western area showing association of failure periods with minimum flow conditions and demonstrating that failures are primarily driven by supply-side failures as the River Test or River Itchen approach or fall below HoF conditions during the autumn (traditional MDO) period.

In addition to consideration of whether an MDO scenario is necessary, it is also important to consider that over the four planning scenarios we have considered as part of our supply-demand balances (normal year, 1:100 DYAA, 1:500 DYAA and 1:500 DYCP), we have, as part of our adaptive planning approach, also combined 5 population growth, 29 climate change and 4 Environmental Destination scenarios in differing combinations. This results in a total of 580 different potential future water requirements, covering the full range of challenges that we face.

Table 2.11: Comparison of WRMP19 MDO scenario DO with our updated WRMP24 DYAA scenario for a 1:500 drought.

WRZ	WRMP19 1:500 MDO (Ml/d)	WRMP24 1:500 DYAA DO (Ml/d)	Comment
HKZ	8.68	8.75	Static non drought sensitive DO, scenario agnostic
HAZ	21.43	22.53	Static non drought sensitive DO, scenario agnostic
HRZ	12.3	10.35	Static non drought sensitive DO, scenario agnostic
HWZ	23.88	23.83	Static non drought sensitive DO, scenario agnostic
HSE		20.49	DYAA scenario effectively represents MDO failure condition due to minimum yield from River Itchen
HSW	0	0	DYAA scenario effectively represents MDO failure condition (see Figure 2.8) due to minimum yield from River Test
IOW	27.14	23.96	Groundwater yields in system based on MDO constrained time series
SNZ	17.5	17.6	Effectively MDO failure (constrained by yield from River Rother yield at Pulborough surface water)
SWZ	53.87	45.78	Variable groundwater yields in system model include MDO constrained time series
SBZ	88.2	77.5	Variable groundwater yields in system model include MDO constrained time series
Eastern area WRZs	N/A	N/A	Due to conjunctive benefit of reservoir storage, we have not previously considered any MDO scenarios for Kent

While these 580 futures are formed from different combinations of the individual scenarios, these combinations can give very similar results in terms of their supply-demand balance to other futures. These combinations of discrete forecasts describe the overall supply-demand balances. While each supply-demand balance is described by a different combination of discrete forecasts, many of the overall impacts are remarkably similar. This means that there are several other combinations of forecasts that could produce a similar supply-demand balance to those described in the plan. Furthermore, the range of uncertainty we have explored through these scenarios is much greater than is likely to be the case between an MDO scenario and our baseline DYAA scenarios. Consequently, we believe that our adaptive Best Value Plan and least regret options are sufficiently robust in tackling future uncertainty that they would not provide a different overall strategy than if we had explicitly considered an MDO scenario.

In summary, we therefore are of the view that a separate MDO scenario or assessment is not necessary or appropriate for this plan based on the following considerations:

- Our underlying time series calculations of groundwater and river yield include seasonal variations due to variable flows or groundwater levels.
- The DYAA failure condition within our system simulation models implicitly includes MDO driven failures.
- Our DYAA DO estimates are consistent with or lower than our WRMP19 MDO estimates.
- The full range of supply demand balance uncertainty explored within our adaptive plan is much greater than the potential difference in supply-demand between our DYAA DO scenario and an MDO

scenario and therefore we do not expect the overall strategy to differ were an MDO scenario included.

2.6.4 Effect of system responses

Consistent with the WRPG and following the WRSE approach, we have produced WRZ level DO assessments using the behaviour RSS model that reflects potential supply failures up to a 1:500 system response. Through this approach several apparent conjunctive use and infrastructure constraints on our DO compared to the standard unified approach in our groundwater dominated WRZs were identified (Table 2.12).

To estimate the conjunctive use losses, we compared the calculated DO from our RSS model with an additive assessment of DOs calculated using the same climate dataset but following the standard unified methodology for individual sources (UKWIR, 2002)[33]. We have not been able to estimate system losses for some WRZs, for example HSE, SNZ, KMW and SHZ because sources within those WRZs are inherently conjunctively linked (e.g. through common licence conditions or reservoir storage). We will continue to investigate the cause of these apparent system level DO constraints through our system simulation modelling.

[33] UKWIR, 2000. A Unified Methodology for The Determination of Deployable Output. Ref. 00/WR/18/1.

Table 2.12: Estimate of apparent system conjunctive use benefits and constraints upon DO at the WRZ level by comparison with cumulative DO at the source level.

WRZ	DO by return period (DYAA/MDO) - Ml/d					DO by return period (PDO) - Ml/d				
	1-in-500 year	1-in-200 year	1-in-100 year	1-in-2 year	Constraint	1-in-500 year	1-in-200 year	1-in-100 year	1-in-2 year	Constraint
HKZ	0.07	0.07	0.07	0.07	ADO Benefit	0.00	0.00	0.00	0.00	
HAZ	-0.33	-0.33	-0.33	-0.33	System DO includes bulk supply to Wessex Water (outside WRSE)	-0.45	-0.45	-0.45	-0.45	System DO includes bulk supply to Wessex Water (outside WRSE)
HRZ	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	
HWZ	-1.31	-1.31	-1.31	-1.31	System constraint	-1.27	-1.27	-1.27	-1.27	System constraint
HSE	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to licence constraints	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to licence constraints
HSW	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to licence constraints	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to licence constraints
IOW	4.22	4.47	4.45	4.41	Conjunctive assessment	4.34	4.37	4.37	4.37	Conjunctive assessment
SNZ	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to reservoir storage	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to reservoir storage
SWZ	-5.52	-5.35	-5.27	-8.25	System constraint	-1.15	-1.03	-1.80	-7.02	
SBZ	-1.94	-0.98	-1.44	-9.17	System constraint in normal year	-3.62	-2.17	-2.52	-4.56	
KMW	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to reservoir storage	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to reservoir storage
KME	5.87	6.21	6.19	3.50	Conjunctive benefit with River Medway Scheme / KMW	2.04	2.39	2.39	1.61	Conjunctive Benefit with River Medway Scheme / KMW
KTZ	5.00	5.72	5.83	-6.01	System constraint / Conjunctive Benefit with KME transfer	8.06	6.89	4.30	-3.65	System constraint / Conjunctive Benefit with KME transfer
SHZ	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to reservoir storage	N/A	N/A	N/A	N/A	DO only estimated by system model as conjunctive use of sources is critical due to reservoir storage

3 Impacts of climate change on water supplies

3.1 Climate change vulnerability

Our WRMP19 assessed the outturn climate change vulnerability following our water resource modelling for all our WRZs up to 2045, the end of a conventional 25-year planning period (Figure 3.1). This vulnerability assessment found the following:

We have a few WRZs which are highly vulnerable to climate change where both the 'mid-range' forecast impacts and the uncertainty between 'wet' and 'dry' scenarios is large. This generally applies to WRZs with minimum residual flow constraints that are either imposed already, or forecast, on surface water abstractions, specifically HSW, HSE and SNZ. KTZ was also considered to be highly vulnerable owing to the range of uncertainty of climate change impacts between 'wet' and 'dry' scenarios.

- Our medium vulnerability WRZ are those where the most likely mid-range impact was small (<5% of WRZ DO) but where the range of predictions between the 'wet' and 'dry' suggested substantial uncertainty (up to 15% of WRZ DO). This included SWZ, SBZ, SHZ and KMW. These WRZs tend to have a higher proportion of drought or yield constrained sources vulnerable to the effects of climate change.
- Several of our WRZs are low vulnerability where the impacts of climate change are small and the uncertainty between 'wet' and 'dry' scenarios is also low (<5% of total WRZ DO). These WRZs are therefore considered to be low vulnerability, generally echoing the predictions of our initial (pre modelling) WRMP19 vulnerability assessment. These include HKZ, HAZ, HRZ, HWZ, IOW and KME. The vulnerability of these WRZs is typically lower as a greater proportion of their sources are licence or infrastructure constrained, reducing their overall sensitivity to drought and climate change.

For the most sensitive WRZs (HSE, HSW and SNZ), the high vulnerability arises primarily due to existing flow conditions on abstraction licences for the rivers Test, Itchen and Rother. The DO of these WRZs is directly related to available flow above the flow constraint. Changes in flow because of climate change perturbations therefore directly translate to impacts on DO. This is exacerbated under the more severe or extreme low probability droughts where the DO is already small, or even zero. The magnitude of the flow changes can therefore account for a large percentage shift in DO.

For severe droughts, especially for the River Test, the sensitivity to climate change in the severe or extreme drought conditions becomes less significant as no water is available at all under the licence conditions during these events. Under these circumstances climate change impacts are still felt for less severe (1-in-20 year) drought events and can still be large (tens of Ml/d).

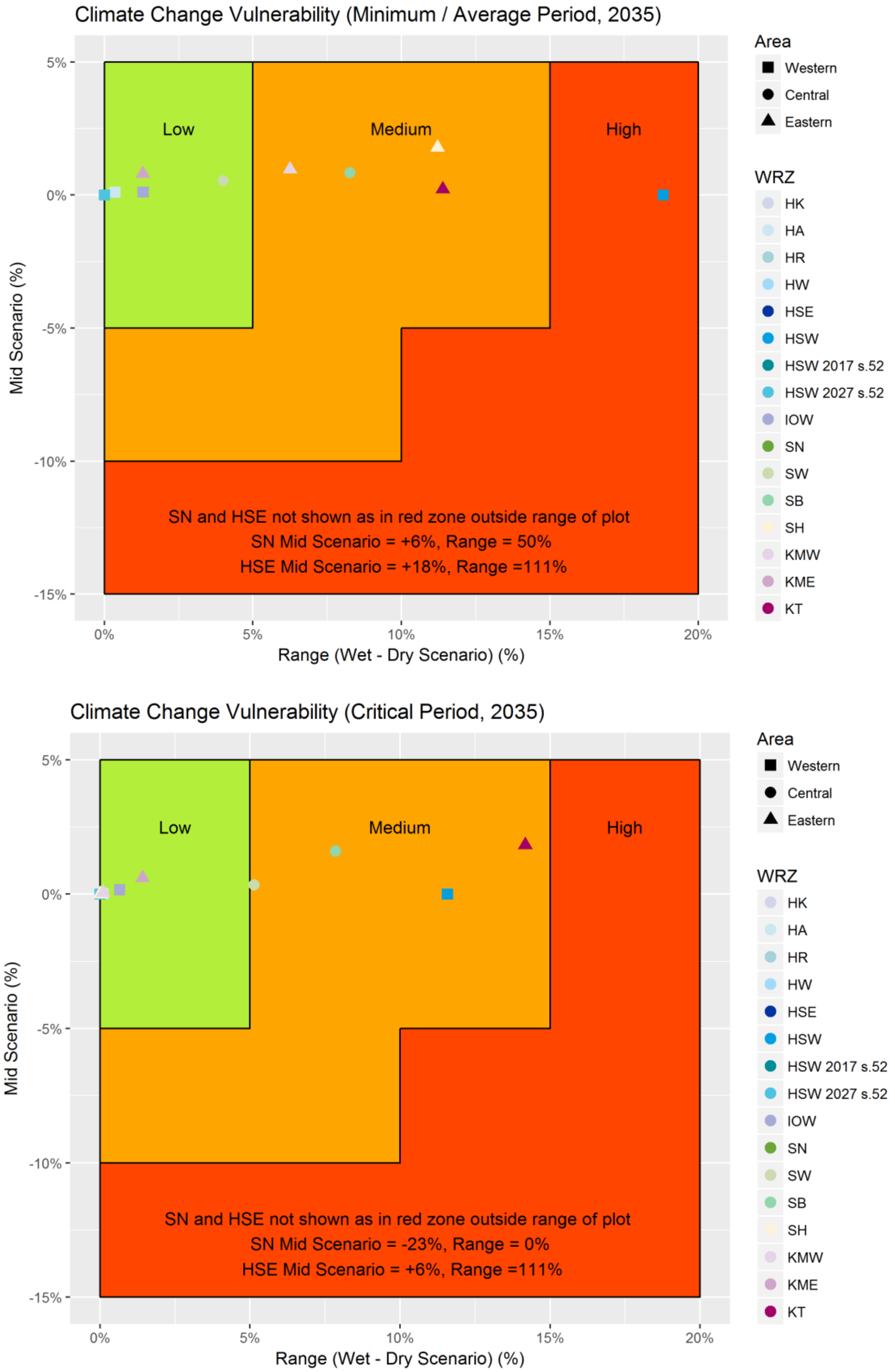


Figure 3.1: Outturn climate change vulnerability from our WRMP19 assessment.

3.2 Climate change impact assessment and modelling

To assess the uncertain impact of climate change on water supplies, we have followed a consistent approach with all WRSE companies[34]. Accordingly, we have followed a 'Tier 3' climate change assessment approach in the context of current guidance[35][36], even for our previously established medium and low vulnerability WRZs using consistent methods, models, and datasets with the other companies in our region.

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 climate data we used for both baseline modelling and climate change impact assessment are taken from a report commissioned by WRSE[37] to produce datasets and tools for all water companies in the UK for quantifying the impact of climate change on water resources.

All data products were derived either from UK Climate Projections (UKCP), UK Met Office (Hadley Centre) or CMIP5 products. Spatial coherence was a key consideration in generating the datasets. The report produced two sets of data. Firstly, a set of 1000 (subsequently narrowed to 400 for manageability) historically consistent, stochastically generated daily time series of rainfall and PET for approximately 200 UK spot locations (see Section 2.2).

Secondly, the project created a set of linear change factors that can be applied to those stochastically generated sequences to incorporate climate change effects. The latest UKCP18 climate projections have updated the UKCP09 probabilistic projections but also provide more complex choices of climate change projection products including global models at 60km resolution and regional models at 12km resolution.

The climate data tools review conducted a SWOT analysis comparing the key MET Office UKCP18 products. To understand which would be most suitable for use in this planning cycle they compared:

- UKCP18 Probabilistic Projections
- UKCP18 Regional Climate Models (RCMs) (both raw and bias-corrected)
- UKCP18 Global Climate Models (GCMs)

The comparison showed 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 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

[34] WRSE, 2021 Method Statement: Climate Change – Supply Side Methods Updated version August 2021 (Included in Annex 23)
[35] Environment Agency, 2020, Water Resources Planning Guideline Supplementary Guidance: Climate change
[36] Environment Agency, 2013, Climate change approaches in water resources planning – overview of new Methods, Report – SC090017/R3
[37] Atkins, 2020, Regional Climate Data Tools Final Report, Sutton and East Surrey Water on behalf of WRSE, Report 5194482-2 (included in Annex 23)

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.

The RCM and GCM 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.

For the RCMs and GCMs, the main advantage was the spatial and temporal coherence that these data provided. The main disadvantage for the GCMs was coarse resolution and, for the RCMs, was that the Hadley centre GCMs driving those RCMs showed higher rates of warming than the CMIP5 ensemble. GCMs (and RCMs) are only available for the RCP8.5 warming scenario. Whilst probabilistic UKCP18 data are available for a much wider range of emissions scenarios, including RCP2.6 and RCP8.5.

3.2.1.1 Climate Product Comparison and Western Rother Case Study

If there is high vulnerability of a zone to climate change, the Water Resource Planning Guidance requires a new climate change assessment to 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.

Conducting a full DO analysis for a single climate change scenario involves a significant amount of work and a large computational burden. As such companies within the WRSE sought 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

At a national level the climate data tools project considered changes in future seasonal rainfall and average annual temperature for different UKCP climate products (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 are light grey dots along with two simulated sub-samples of 100 scenarios as blue dots. The data are show that three of the RCMs are very hot or dry and three CMIP scenarios show no change or increased seasonal precipitation.[38]

[38] Atkins, 2020, Regional Climate Data Tools Final Report, Sutton and East Surrey Water on behalf of WRSE, Report 5194482-2 (included in Annex 23)

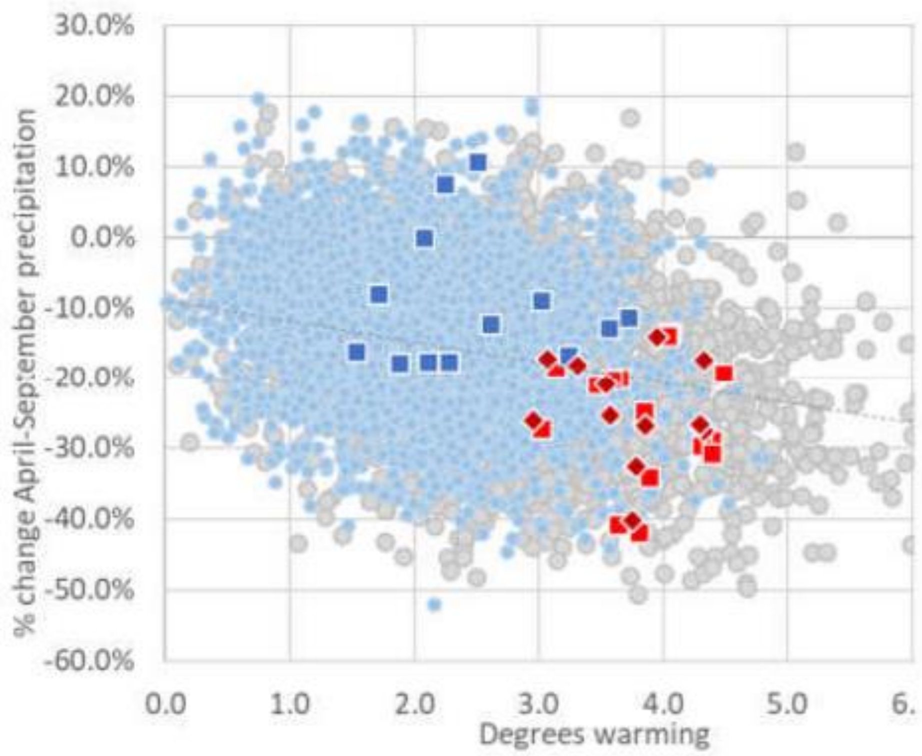


Figure 3.2 Comparison of precipitation and warming projections between the Probabilistic, RCM and GCM projections in UKCP18 for the period 2060-2079[39]

To further consider the impact of different climate products the climate data tools project[40] used the Western Rother Catchmod Model (see section 2.6.2.2) to undertake a comparative assessment of the different UKCP18 climate products. To compare the impact of choice of climate model on river flows at for the Western Rother at Pulborough, climate change factors were applied to the HadUK baseline (1981-2000) data. The climate change data tested is presented in Table 3.1.

Figure 3.3 shows a summary of the forecast percentage change in flows, with climate change under RCP8.5, in the Western Rother for the probabilistic, RCM and CMIP5 projections. For the Western Rother 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 data 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

[39] Atkins, 2020, Regional Climate Data Tools Final Report, Sutton and East Surrey Water on behalf of WRSE, Report 5194482-2 (included in Annex 23)
[40] ibid

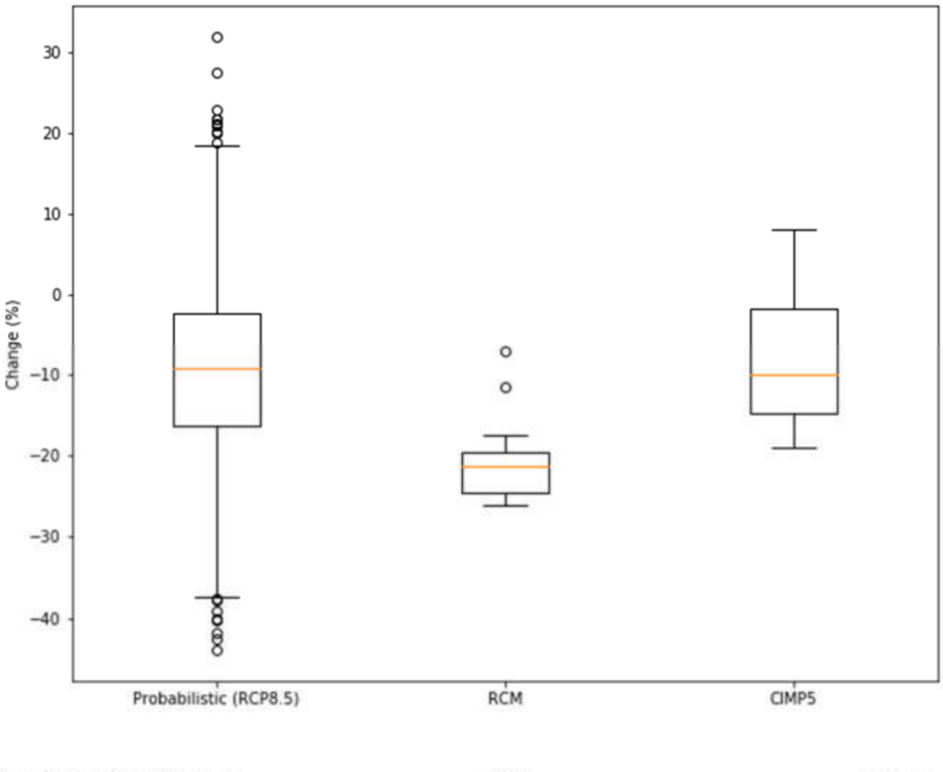
more severe impact on river flows under future climate change than the probabilistic projections however, this lies within the range of results projected by the 3000 probabilistic projections.

Table 3.1 Climate change datasets applied in the Western Rother case study[41]

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.

[41] ibid

Figure 3.3 Comparison of Flow impacts at Q_{95} (low flows) for the Western Rother between different climate change products[42]



3.2.1.2 Selection of RCM and GCMs

The comparison of climate products has shown that whilst the probabilistic data cover the widest range of climate uncertainty, the RCM and GCM forecasts do cover the interquartile range of the probabilistic projections and have the added benefit of being intrinsically spatially coherent which has been identified as a key requirement to support regional planning.

Aligned with other companies as part of WRSE we carried out water resources system modelling to determine a DO impact for 28 climate change scenarios. These are based on the 12 RCM regional projections, the 3 global projections from the Met Office Hadley Model which were not run through the regional climate model, and the 13 GCM global projections from the CMIP5 ensemble.

Our assessment 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.

[42] Atkins, 2020, Regional Climate Data Tools Final Report, Sutton and East Surrey Water on behalf of WRSE, Report 5194482-2 (included in Annex 23)

In addition to use within WRSE, 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.

The Met Office UKCP18 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 the 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 and has been shown to have similar flow average impacts (Figure 3.3)

The key drawback identified with using a probabilistic approach for regional planning is that probabilistic data has 3,000 possible outcomes which are impractical to model in totality and a sampling approach at a national and regional level would need to be agreed. In addition, the aggregated change factors for England and Wales would need to be used to ensure spatial coherence in future climate change signals.

The probabilistic data were therefore excluded based on the following:

- Lack of spatial coherence between climate change factors in different regions, so risks that national drought could be overestimated. 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)
- With 3,000 probabilistic scenarios for every Representative Concentration Pathway (RCP) and time period, a sampling approach would be required to derive a practical set of future scenarios for water resource modelling especially when working with computationally intensive system simulators and groundwater models.

The change factors were based on a set of 12 Regional Climate Models (RCMs) and 16 Global Circulation Models (GCMs) from the UKCP data resulting in 28 sets of change factors in total. One of the main drivers for choosing the RCMs and GCMs projections was because the unadjusted outputs were spatially coherent. This was considered critical for regional planning to ensure that climate impacts were consistently modelled across the WRSE region.

Following the initial baseline water resource model assessment and DO assessments (Section 2), a sub-set of the 400 stochastic climate replicates were selected through agreement with neighbouring WRSE companies. These rainfall and PET sequences were considered to contain a series of significant representative drought events across the south east region with return probabilities generally between 1% and 0.2% (equivalent to 1-in-100 year to 1-in-500 year return periods).

By adopting the RCP our approach is broadly equivalent to the 'High Climate Change' Ofwat Price Review 2024 (PR24) reference scenario. Alongside WRSE, we have also considered lower emissions scenarios (equivalent to RCP2.6) and associated uncertainty to support a Ofwat's low climate change reference scenario for PR24[29] (see section 3.2.4)

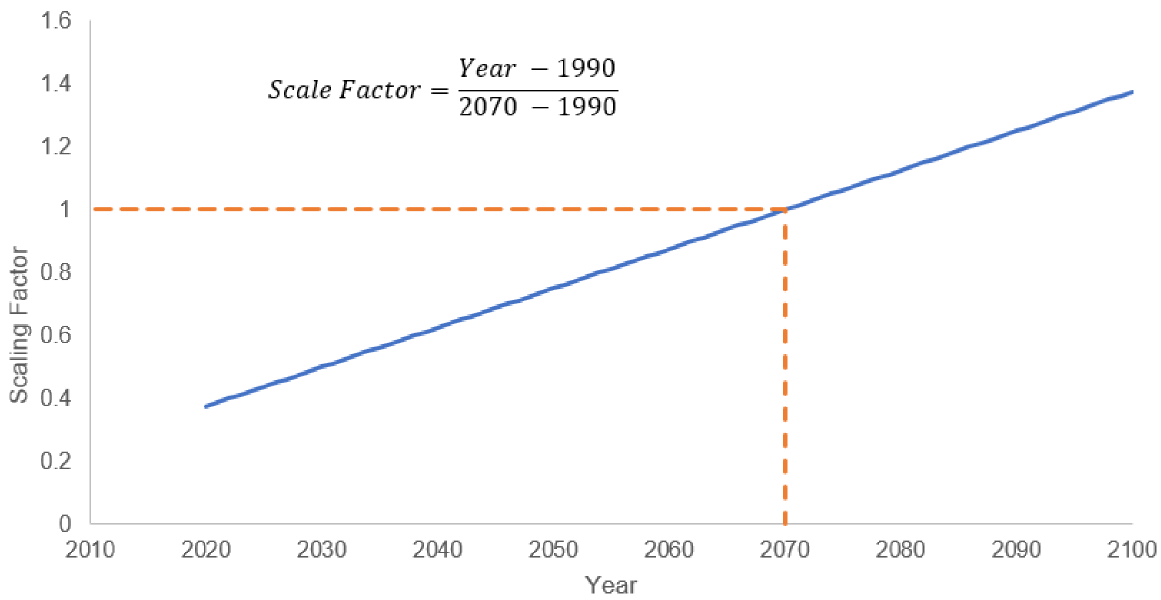
The GCM/RCM-derived change factors were used to perturb the baseline input time series of rainfall and PET to our water resource models. The resource models and system simulation models were then re-run with the perturbed inputs following the same sequence as for baseline DO to determine the change in DO for each of the 28 climate replicates and hence the impact of climate change on flows, groundwater levels and DO.

3.2.2 Climate change scaling

We adopted a consistent climate change scaling approach across all WRSE companies. We used the RCP8.5 Spatially Coherent Projections for the 2060-2080 time slice from the UKCP18 data to derive our climate change factors. We chose this period of the UKCP18 forecasts because it is most closely aligned with the end of the planning period (2075). We therefore adopted 2070, the central point of the 2060-2080 time slice, as the scaling year used in our climate change assessments.

We have applied the standard linear scaling approach suggested by the WRPG[43] to climate change in all our WRZs. The base year was selected as 1990 consistent with the baseline period in the UKCP18 data of 1981-2000 (Figure 3.4).

Figure 3.4 Summary of selected climate scaling approach we have applied, consistent with WRPG[44]



In figures 3.5 and 3.6 we have included plots for each WRZ showing how the climate change DO impacts have been applied for each Water Resource Zone.

3.2.3 Our Forecast Climate Change Impacts and Uncertainty

For our draft WRMP24 (dWRMP24), we addressed climate change uncertainty by branching the adaptive pathways or supply-demand balance 'situations' in 2040 between 'high', 'medium' (median), and 'low' climate change scenarios. From the WRSE regional climate change assessment, climate model replicates 6 and 7 were taken as being representative of the regional upper ('High') and lower ('Low') quartile impacts on DO from the 28 Global and Regional Spatially Coherent Climate Projections available under the RCP8.5 pathway from the UKCP18 dataset. Replicates 6 and 7 correspond to the HadGEM3-GC3.05-r001i1p01649 and HadGEM3-GC3.05-r001i1p01843 circulation model projections from UKCP18, respectively.

Although these replicates were considered regionally appropriate, when translated down to the WRZ level, the difference in both spatial impacts across the region (for example, Hampshire vs Kent) and the differing hydrological characteristics of different WRZs (e.g. proportion of groundwater vs surface water) mean that this assertion does not necessarily apply at a company or WRZ level. For example, in some of our WRZs, the 'Low' impact replicate (No. 7) is actually nearly as severe as the 'high' replicate (No. 6) and both are worse than the median (Figure 3.5).

---

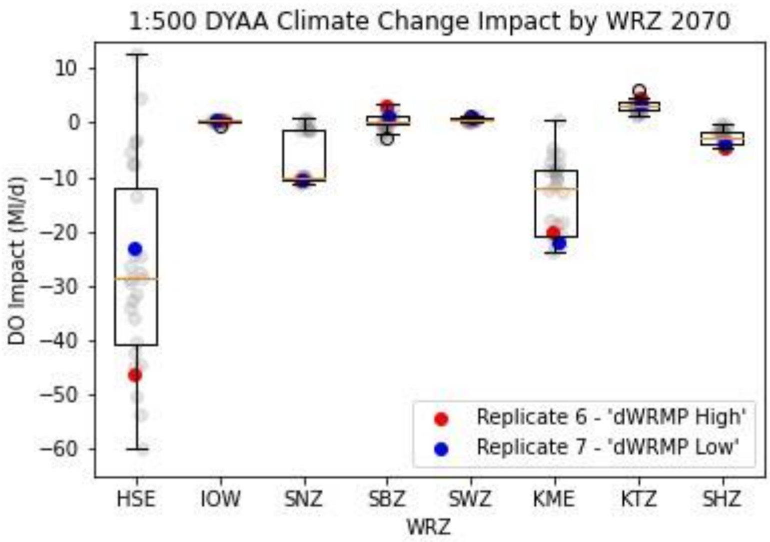
[43] Environment Agency, 2020 Water Resources Planning Guideline Supplementary Guidance: Climate change
[44] Environment Agency, 2020 Water Resources Planning Guideline Supplementary Guidance: Climate change

For our revised dWRMP24 (rdWRMP24), we have revaluated the 'high' and 'low' estimates across the full range of 28 climate change scenarios at a WRZ level. This ensures that the climate projections we have selected to represent the "high" and "low" impact of climate change to explore the range of uncertainty map more closely to the upper and lower quartiles of the underlying distribution.

However, in undertaking this exercise means that the upper and lower ranges selected for each WRZ may be drawn from different UKCP18 replicates. We have also capped the impact at the baseline 1-in-500 year DO to avoid creating negative DO (i.e. climate change impacts being greater than the baseline DO). Selection of the median impact is unchanged from the dWRMP24.

The updated range in forecast impacts on climate change on our 1-in-500 year (1:500) DO are shown for 2070 are shown in Figure 3.6 and Table 3.2 and Table 3.3.

(a)



(b)

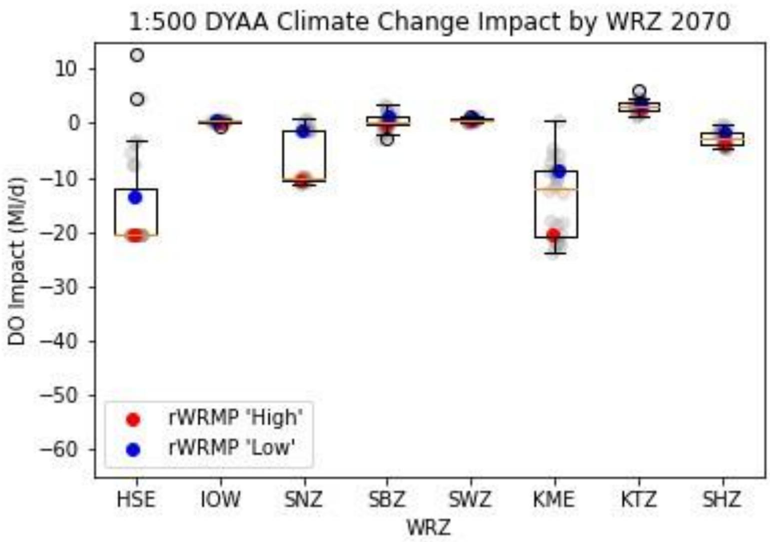
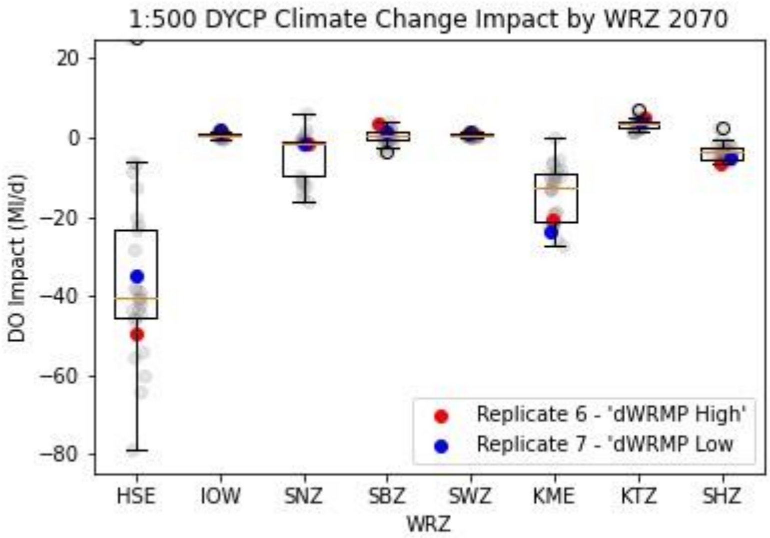


Figure 3.5: Impacts of climate change for the DYAA scenario (a) comparing the dWRMP24 regional 'High' (replicate 6) and 'Low' (replicate 7) by WRZ in 2070 against (b) the updated upper and lower quartile replicates. DO impacts have been capped to avoid negative deployable output. Impacts in 1 in 500 year drought shown.

(a)



(b)

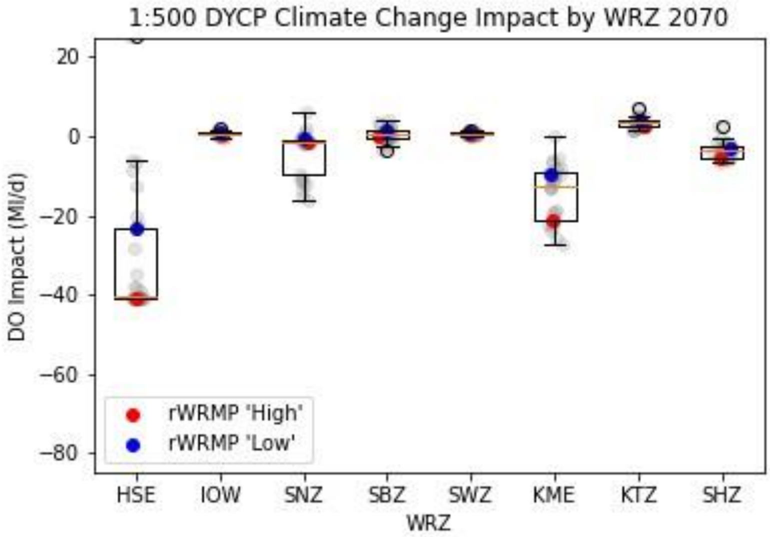


Figure 3.6: Impacts of climate change for the DYCP scenario (a) comparing the dWRMP24 regional 'High' (replicate 6) and 'Low' (replicate 7) by WRZ in 2070 against (b) the updated upper and lower quartile replicates. DO impacts have been capped to avoid negative deployable output. Impacts in 1 in 500 year drought shown.

Table 3.2: Summary of forecast climate change impacts and uncertainty by WRZ to 2070 based on UKCP18 (DYAA scenario).

WRZ	1:500 DYAA DO, 2070 Impact (RCP8.6 2060-2080 Time slice)			
	Median Impact (Ml/d)	Range (Ml/d)	Adaptive Plan 'Low' Scenario (Ml/d)	Adaptive Plan 'High' Scenario (Ml/d)
HKZ	0.00	0.00 to 0.00	0.00	0.00
HAZ	0.00	0.00 to 0.00	0.00	0.00
HRZ	0.00	0.00 to 0.00	0.00	0.00
HWZ	0.00	0.00 to 0.00	0.00	0.00
HSE	-20.49	12.65 to -20.49	-13.44	-20.49
HSW	0.00	0.00 to 0.00	0.00	0.00
IOW	0.51	0.90 to -0.51	0.51	0.12
SNZ	-10.08	0.88 to -11.27	-1.26	-10.63
SWZ	0.52	0.00 to 1.27	0.70	0.43
SBZ	0.25	3.43 to -2.97	1.25	-0.17
KMW	0.00	0.00 to 0.00	0.00	0.00
KME	-12.10	0.40 to -23.80	-8.80	-20.60
KTZ	3.13	0.40 to -23.80	3.64	2.52
SHZ	-2.775	-0.07 to -4.70	1.75	-3.90

Table 3.3: Summary of forecast climate change impacts and uncertainty by WRZ to 2070 based on UKCP18 (DYCP scenario).

WRZ	DYCP 2070 Impact (RCP8.6 2060-2080 Time slice)			
	Median Impact (Ml/d)	Range (Ml/d)	Adaptive Plan 'Low' Scenario (Ml/d)	Adaptive Plan 'High' Scenario (Ml/d)
HKZ	0.00	0.00 to 0.00	0.00	0.00
HAZ	0.00	0.00 to 0.00	0.00	0.00
HRZ	0.00	0.00 to 0.00	0.00	0.00
HWZ	0.00	0.00 to 0.00	0.00	0.00
HSE	-40.54	25.53 to -41.00	-23.46	-41.00
HSW	0.00	0.00 to 0.00	0.00	0.00
IOW	0.705	2.10 to -0.62	0.92	0.39
SNZ	-1.45	5.88 to -16.13	-0.63	-1.64
SWZ	0.61	1.45 to 0.00	0.84	0.53
SBZ	0.29	4.17 to -3.61	-0.15	-0.19
KMW	0.00	0.00 to 0.00	0.00	0.00
KME	-12.90	0.20 to -27.3	-8.80	-21.40
KTZ	3.44	7.12 to 1.35	2.73	2.73
SHZ	-3.63	2.68 to -6.35	1.75	-5.47

The data indicate that HSE is the most vulnerable WRZ with the greatest potential climate change impacts on DO. Other surface water dominated WRZs such as SNZ and KME (which includes the impacts on Bewl Reservoir) are also vulnerable. This reflects the forecast increased variability of river flows and therefore DO which in these WRZs is wholly or partially constrained by the river flow available to abstract above a HoF or MRF condition.

Median climate change impacts in nearly all other WRZs are close to neutral (near zero) or show a small positive gain. This reflects that, in general, winters are expected to get wetter under climate change (Met Office, 2022)[45] and hence our resource models forecast that groundwater yields may slightly increase.

Appendix B shows the climate change impact on deployable output (source yield) as time series profiles for each water resource zone, for all climate change scenarios used in the adaptive branches from 2040 onwards.

3.2.4 Low emissions scenario RCP2.6 assessment

Representative Concentration Pathways (RCPs) are used to project different climate change impacts under different potential scenarios for future greenhouse gas emissions. We used the spatially coherent RCP8.5 climate change projections from UKCP18 to assess the impacts and uncertainty of climate change on DO. This scenario represents an upper emissions scenario its median impact is equivalent to Ofwat's High Climate Change reference scenario[46]. This primarily reflected the need to consider spatially coherent impacts across South East England to allow coherent assessment of water resource availability across the WRSE region.

Most products are focused on RCP8.5 because this is a "business as usual" type scenario which represents a reasonable worst case scenario given delays in global action on mitigation of climate change. The scenario 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.[47]

We also considered the implications of a lower emissions scenario (RCP2.6) and Ofwat's Low Climate Change reference scenario. Accordingly, we (as part of WRSE) commissioned a study that explored and compared the uncertainty within the range of the 28 RCP8.5 spatially coherent climate change projections to the RCP2.6 projections (see Annex 10)[48].

The study mapped the forecasts of rainfall and potential evapotranspiration from the 28 RCP8.5 scenarios onto the Ofwat Long-Term Delivery Strategies (LTDS) framework through identification of the closest matching WRSE climate scenarios (i.e. the 28 RCM and GCM RCP8.5) to the requested 50th percentile RCP8.5 and RCP2.6 impacts defined within the Ofwat reference scenarios.

A set of 10 key metrics were used to undertake the mapping:

- Seasonal change factors for the 2070s (December, January, and February - DJF; March, April and May –MAM; June, July and August – JJA; September, October and November - SON) for each of precipitation and temperature (8 metrics in total)
- Rainfall seasonality index for the 2070s (1 metric)
- Annual aridity index combining precipitation and temperature for the 2070s (1 metric)

The analysis showed there is good agreement between the mapped scenarios across all metrics and river basins. Figure 3.7 and Figure 3.8 show a comparison between the monthly change factors across the

---

[45] Met Office, 2022, UK Climate Projections, Headline Findings, ukcp18_headline_findings_v4_aug22.pdf (metoffice.gov.uk)
[46] Ofwat, 2021, PR24 and beyond: Long-term delivery strategies and common reference scenarios
[47] Atkins, 2020, Regional Climate Data Tools Final Report, Sutton and East Surrey Water on behalf of WRSE, Report 5194482-2 (included in Annex 23)
[48] Atkins, 2023, Water Resources in the South East (WRSE) Climate Change Scenario Mapping, Technical Note

probabilistic data and the mapped scenarios. The spatially coherent RCM/GCM scenarios naturally show a greater level of variation but on the whole the ‘best mapped’ scenario in particular can be seen to correspond well to the probabilistic 50th percentile for both RCP2.6 and RCP8.5 emissions pathways (Figure 3.7).

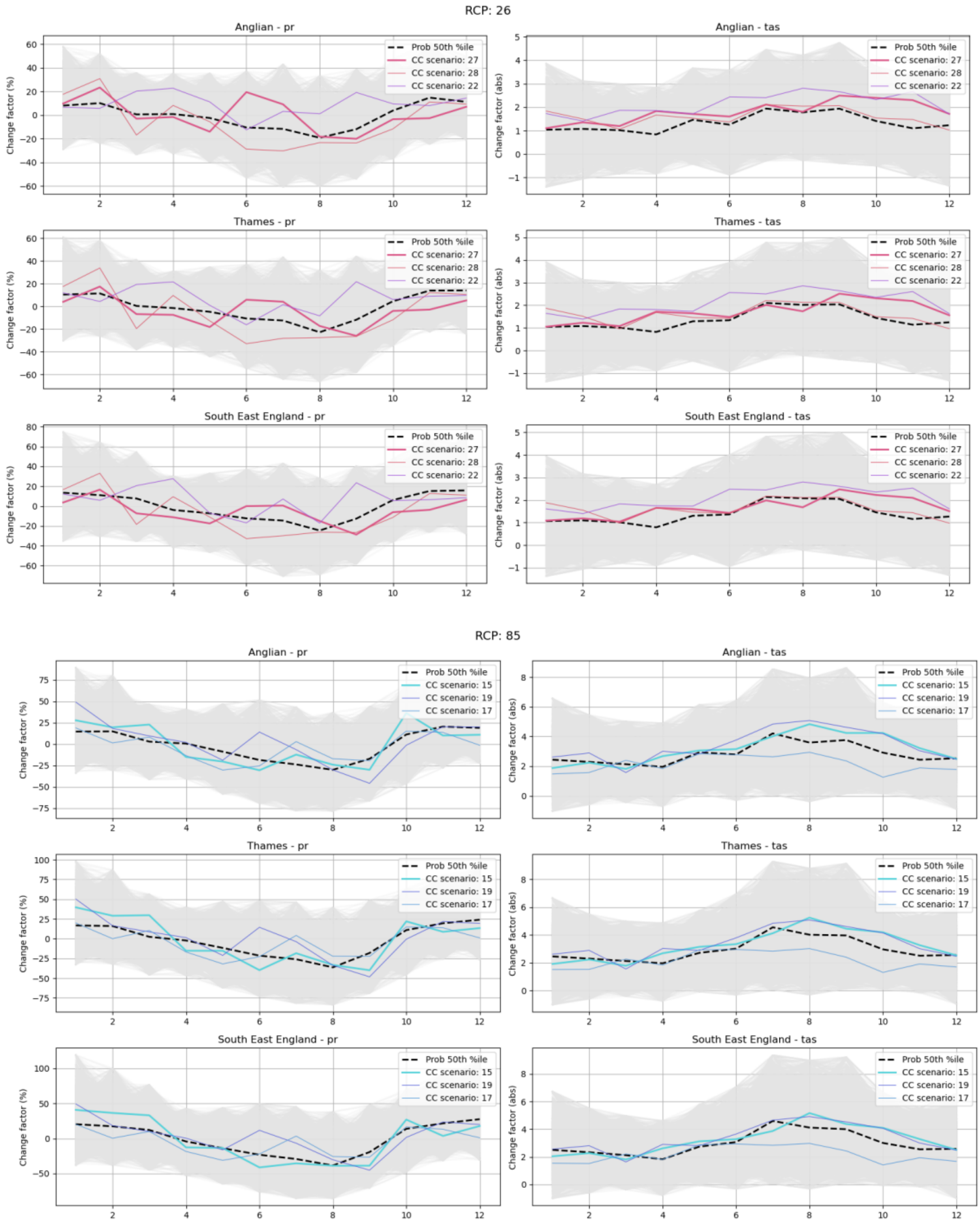


Figure 3.7: Comparison of monthly change factors for the probabilistic UKCP18 data (full range in grey) and mapped RCM/GMC spatially coherent scenarios for RCP2.6 (top) and RCP8.5. The most closely mapped scenarios are shown in bold (Atkins, 2023)[49].

The closest spatially coherent replicates for each representative concentration pathway are summarised in the following table.

Table 3.4: Summary of mapped scenario outputs. In each case showing the top mapped scenario (and next two scenarios in brackets) after Atkins 2023[50].

Representative Concentration Pathway	Regions and Metrics with Equal Weight	Prioritising Thames and South East England Regions	Prioritising Groups of Metrics
RCP2.6	Replicate 27 (28,22)	Replicate 27 (28,22)	Replicate 27
RCP8.5	Replicate 15 (19, 23)	Replicate 15 (19, 17)	Replicate 15

Given the non-linear relationship between meteorology and system response through DO, a validation or sense check against the evidence of relative impacts on DO has been undertaken (Figure 3.8). The assessment shows that the RCP2.6 scenarios fall within the range of scenarios already considered. Typically, the scenarios more consistent with a higher emissions pathway (i.e. RCP8.5) tend to shower more positive or smaller negative impacts when compared to the lower emissions pathway (RCP2.5) in WRZs with a high proportion of groundwater or baseflow fed rivers. This likely reflects the change in winter precipitation patterns with greater winter and spring rainfall (Figure 3.7) leading to greater groundwater recharge and hence a benefit (or smaller negative impact) than the drier lower emissions pathway (RCP2.6).

The overall mapped impacts for the different pathways set out in Table 3.4 are summarised in Table 3.5.

Table 3.5: DO impacts for scenarios mapped from the 28 RCP8.5 RCM/GCM projections to RCP2.6 and RCP8.5 pathways.

WRZ	RCP2.6 Mapping			RCP8.5 Mapping			
	Rep 27	Rep 28	Rep 22	Rep 15	Rep 19	Rep 23	Rep 17
HSE	-20.49	-20.49	4.50	-7.76	-3.12	12.65	-20.49
IOW	0.09	0.00	0.45	0.55	0.67	0.90	0.29
SNZ	-1.26	-1.26	-0.43	-10.34	-1.26	0.88	-9.78
SBZ	-2.05	-0.62	-0.17	2.38	1.25	3.43	-0.15
SWZ	0.26	0.52	0.44	1.10	0.84	1.22	0.46
KME	-10.30	-8.40	-4.70	-12.90	-5.90	0.40	-8.80
KTZ	2.23	3.11	3.13	4.60	4.27	6.08	3.64
SHZ	-1.9	-1.82	-0.32	-2.70	-1.52	-0.07	-1.75

[49] Atkins, 2023, Water Resources in the South East (WRSE) CC Scenario Mapping, Technical Note
[50] ibid

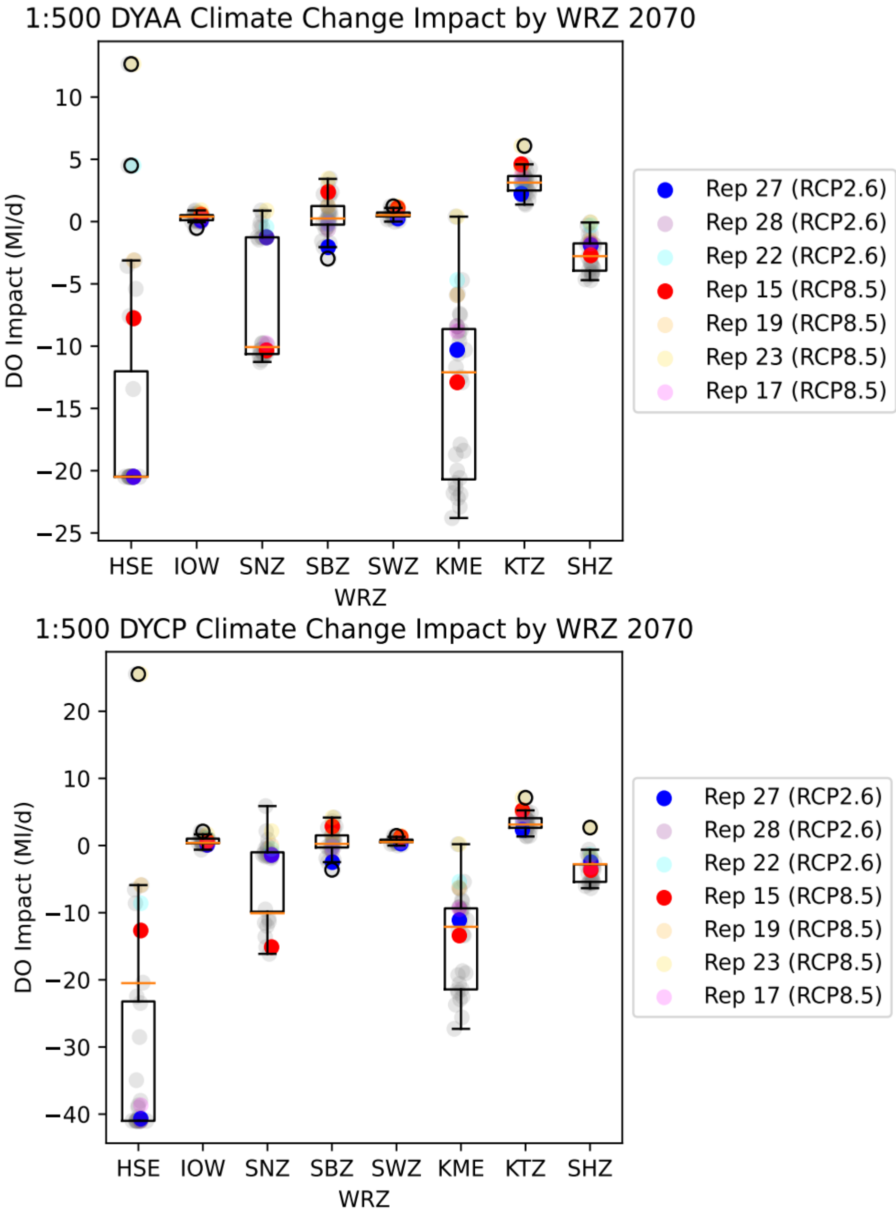


Figure 3.8: Summary of DO impacts showing mapped scenarios against RCP2.6 and 8.5 representative concentration pathways.

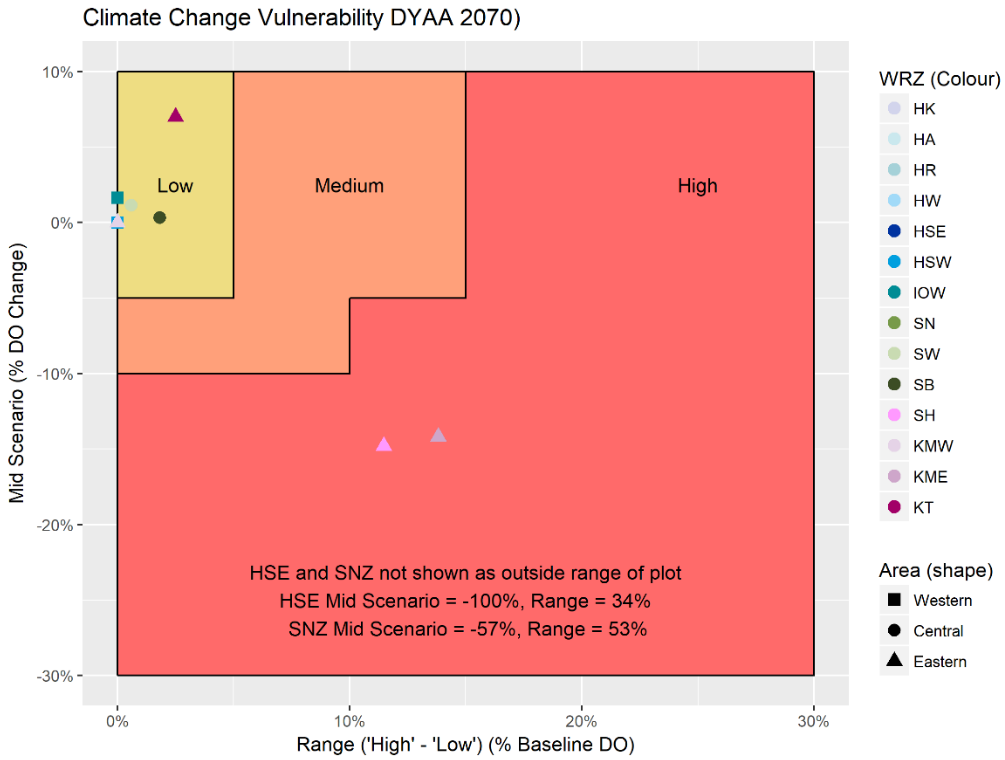
3.2.5 Updated Climate Change Vulnerability Assessment

Following our updated water resource modelling we have considered the final climate change vulnerability of our WRZs by 2070 (Figure 3.9). The year 2070 represents the mid-point of the UKCP18 regional and global climate projections (which cover the 2060-2080 time slice) that we have used in our water resource modelling and hence no scaling is applied to these forecasts. This review shows that across our supply areas, the forecast impacts of climate change fall into three broad categories, similar to our WRMP19 assessment:

- Highly vulnerable WRZs where both the 'mid-range' forecast impacts and the uncertainty between 'wet' and 'dry' scenarios is large. As previously discussed, this generally applies to WRZs where MRF constraints are either imposed already, or forecast, on surface water abstractions. These include HSE, KME and SHZ. KME is now considered to be highly vulnerable owing to the range of uncertainty of climate change impacts between 'wet' and 'dry' scenarios primarily on Bewl Reservoir. Compared to our WRMP19 assessment, HSW has moved to low vulnerability, primarily because after confirmed 2027 licence changes, there is no DO available during drought under any climate change condition. KTZ has moved to low vulnerability as the uncertainty has reduced.
- Medium vulnerability WRZs include those WRZs where the most likely mid-range impact is small (<10% of WRZ DO) but where the range of predictions between the 'wet' and 'dry' scenarios suggests greater uncertainty. This primarily applies to SNZ under the DYAA scenario and reflects variable impacts on flow in the River Rother and inputs to Weir Wood Reservoir
- Low vulnerability WRZs are those where the impacts of climate change are small and the uncertainty between wet and dry conditions is also low (<5% of total WRZ DO). This group includes most of our groundwater dominated WRZs. The vulnerability of these WRZs is typically lower as a greater proportion of their sources are license or infrastructure constrained, therefore reducing their overall sensitivity to drought and other effects of climate change or for WRZs such as SBZ, SWZ and KTZ due to small positive benefits to groundwater yield.

For the majority of the most sensitive high and medium vulnerability WRZs (HSE, SNZ and SHZ), the vulnerability arises due to the dominance of surface water over groundwater, of which the former is less robust in responding to climate change. The final highly vulnerable zone, KME, is dominated by groundwater; however, within the system simulator model, it sees greater conjunctive benefit from Bewl Reservoir due to an internal transfer from KMW and hence has a greater degree of climate change vulnerability as a result.

The greatest uncertainty is shown for HSE. Here the majority of impacts are negative from a decline in river flows. HSW is likely to be similarly vulnerable but since it has little drought resilience due to the HoF condition, it is not vulnerable to climate change as the drought yield is already lost under baseline conditions.



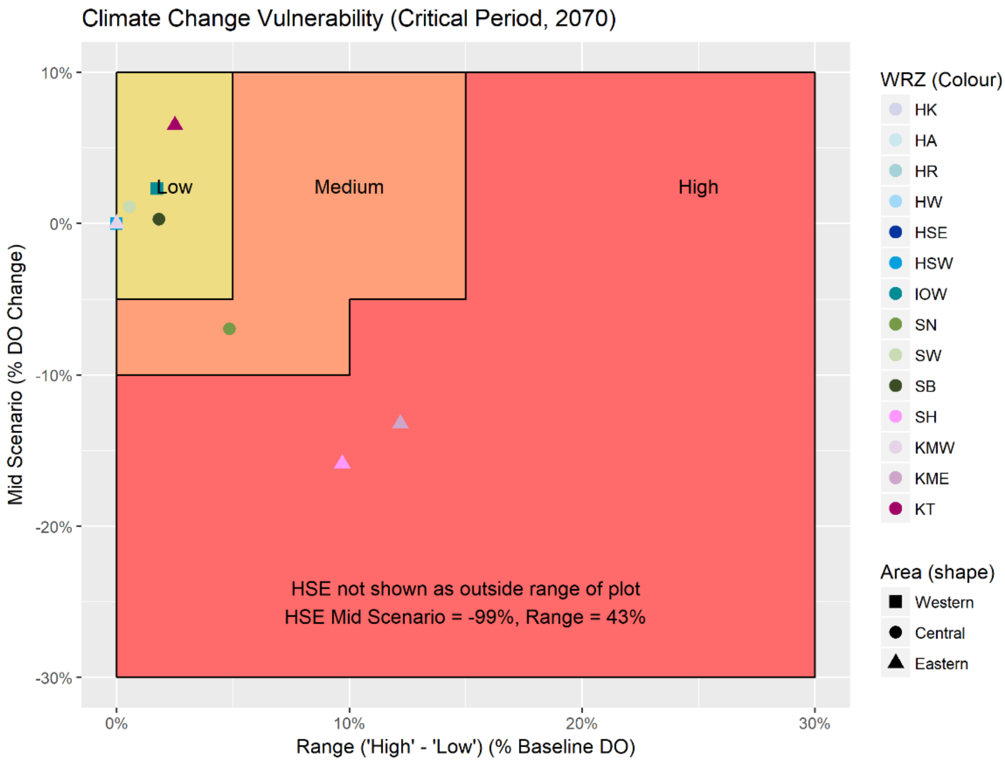


Figure 3.9: Climate change vulnerability assessments for DYAA and DYCP scenarios.

4 Transfers and bulk supplies

We have several bulk transfer agreements with our neighbouring water companies (Table 4.1). We also transfer water across our WRZs (

Table 4.2). In addition, we provide non-potable supplies to two large industrial users; one in HSW and the other in SHZ.

For this plan we have assumed that all of our existing transfers will continue, unless there is a specific option to modify any of them. Bulk transfer agreements with our neighbouring water companies are included as options in our options appraisal investment modelling upon the expiry of their current contractual term.

Table 4.1: Existing bulk transfers with neighbouring water companies.

Type	Donor WRZ	Recipient WRZ	Potable or Raw	Maximum volume (Ml/d)	Contract Expiry
Export to Affinity Water	KTZ	RZ7	Potable	1.24	
Export to South East Water	KME	RZ6	Potable	7.8	
Export to South East Water	KMW	RZ7	Potable	12.3	
Export to South East Water	KMW	RZ7	Raw		
Export to South East Water	SHZ	RZ3	Raw	8/17th of the Bewl/ Darwell Yield	
Export to South East Water	KME	RZ6	Potable	7.5	
Export to South East Water	KMW	RZ6	Potable	0.5	
Export to South East Water	SNZ	RZ5	Potable	5.4	2031
Export to Wessex Water	HAZ		Potable	0.41	
Import from Affinity Water	RZ7	KTZ	Potable	0.1	
Import from SES Water	SES Water	SNZ	Potable	0.8	2026
Import from Portsmouth Water	Portsmouth Water	HSE	Potable	15.0	
Import from Portsmouth Water	Portsmouth Water	SNZ	Potable	15.0	2026
South East Water bulk supply near Canterbury	South East Water	KTZ	Potable	2	TBC*

*This transfer is in development for 2025 as part of our preferred WRMP19 delivery

In addition to our existing interzonal transfers, our supply forecast for Western area has been developed assuming implementation of the 'Hampshire Grid' transfers which were selected as preferred options in WRMP19. The transfers are planned to improve connectivity between our Hampshire WRZs (HAZ, HRZ, HSE and HSW). These transfers are still in development as part of our Water for Life Hampshire programme. Their assumed benefits are summarised in Table 4.3.

As discussed in our WRZ integrity assessment, these new transfers are expected to improve the connectivity across our Hampshire supply area and reduce drought risks. We will revisit our WRZ arrangement in Hampshire in future plans to reflect the benefits of these transfers.

These transfer options would increase the interconnectivity and move towards a single, larger WRZ underpinned by a water grid.

Table 4.2: Existing interzonal transfers

Donor WRZ	Recipient WRZ	Link	Potable or Raw	Maximum volume (Ml/d)
HRZ	HSE	Interzonal Transfer (HSE-HRZ) Abbotswood - existing	Potable	5.1
HSE	IOW	Interzonal Transfer (HSW-IOW) Cross-Solent main existing	Potable	20.0
HSE	HWZ	Interzonal Transfer (HWZ-HSE) Existing Transfer	Potable	9.6
HSW	HSE	Interzonal Transfer (HSW-HSE) Existing Transfer	Potable	16.8
HSW	HSE	Interzonal Transfer (HSW-HSE) Existing Transfer	Potable	2.7
HSW	HSE	Interzonal Transfer (HSW-HSE) Existing Transfer	Potable	5.6
HSW	HRZ	Interzonal Transfer (HSW-HSE) Romsey Town and Broadlands Valve	Potable	3.1
SNZ	SWZ	Interzonal Transfer (SWZ-SNZ) Rock Road bi-directional - existing	Potable	11.8
SWZ	SNZ	Interzonal Transfer (SWZ-SBZ) V6 Valve Additional capacity	Potable	13.1
SWZ	SBZ	Interzonal Transfer (SWZ-SBZ) V6 Valve - existing	Potable	16.8
KME	KTZ	Interzonal Transfer (KTZ-KME) Existing Transfer	Potable	12.0
KMW	KME	Interzonal Transfer (KMW-KME) Existing Transfer	Potable	37.1

Table 4.3: Elements of the ‘Hampshire Grid’ currently being developed.

Donor WRZ	Recipient WRZ	Link	Potable or Raw	Maximum volume (Ml/d)
HSE	HWZ	Hampshire grid (reversible link HSE-HWZ)	Potable	74
HWZ	HSE	Hampshire grid (reversible link HSE-HWZ)	Potable	74
HSW	HAZ	Hampshire grid Andover link main (HSE-HAZ)	Potable	15
HAZ	HSW	Hampshire grid Andover link main (HSE-HAZ)	Potable	15
HSW	HWZ	Southampton link main (reversible link HSW-HWZ)	Potable	60
HWZ	HSW	Southampton link main (reversible link HSW-HWZ)	Potable	60
HSW	HRZ	Romsey Town and Broadlands valve (HSW-HRZ reversible)	Potable	9
HRZ	HSW	Romsey Town and Broadlands valve (HSW-HRZ reversible)	Potable	5

5 Outage

Outage refers to the temporary unavailability of DO from a source. Outages can be unplanned or planned. Unplanned outages can occur for a variety of reasons, such as mechanical failures or water quality issues. These can be either full outage, where an entire source is unable to produce water, or partial outage, where a site can produce water but not at the maximum DO. Planned outages occur where we need to undertake maintenance or improvement works. We include a provision for outages within our supply-demand forecast.

An outage allowance is a planned volume of unavailable DO that we have allocated within our WRMP in recognition that outages will occur as part of day-to-day operation. This ensures that when outages do occur, our customers are not at increased risk during the time required to resolve it.

For WRMP19, our outage allowance followed a profile of outage recovery throughout AMP7 and then remained constant from 2025 onwards. For this plan, we have followed a consistent methodology for determining our outage allowance as the other WRSE companies (WRSE, 2021f)[51]. This ensures we are aligned with the Regional Best Value Plan and consistent in our approach.

The calculation method first involves collating and checking our historical outage data. We looked in detail at data from 2015 to August 2022 inclusive to ensure that outage events were legitimate and whether outage experienced in the recent past is likely to be reflective of potential future levels.

We applied statistical distributions to the historic data to deduce the probability of these outages occurring again. For example, a normal distribution is applied if the data follows a standard bell curve shape or a fixed distribution if the outage has only occurred once in the past and there is no other information to build on. These distributions are then run through a Monte Carlo statistical model to produce thousands of simulations of outage volumes.

To calculate the outage allowance we then applied a percentile to each WRZ according to the rules set out in **Error! Reference source not found.**. For example, if a WRZ has 20 sources we would use a 75th percentile and if a WRZ has five sources we would use a 95th percentile. This approach was used in order to reflect the resilience of a WRZ. The more sources a WRZ has, the more resilience it generally has, and it is therefore not as impactful should a source fail so we can take a lower outage allowance figure accordingly.

Since publishing our WRMP19, we have been constantly improving our outage data collection. These improvements involve a more accurate capturing of partial outages, more clarity around the reasons for outage and a breakdown of different types of outages between planned, unplanned and asset constrained. This improved data collection is allowing us to pinpoint cost-efficient outage recovery as well as improving our estimation of outage.

Following the agreed and consistent regional approach, the outage allowance from 2025-26 by WRZ for each of the planning scenarios is shown in Table 5.1. Figure 5.2 shows the historic reported outage up to March 2022, the WRMP19 outage recovery plan up to March 2025 and then the WRMP24 forecast outage allowance for the DYAA scenario which is used for the WRMP24 from April 2025 onwards. This shows that, since 2018, our outage levels have been reducing significantly. We are still slightly behind the outage allowance but have plans in place to continue reducing outage in line with the recovery plan.

[51] WRSE, 2021. Method Statement: Outage. Version 2 (included in Annex 23)

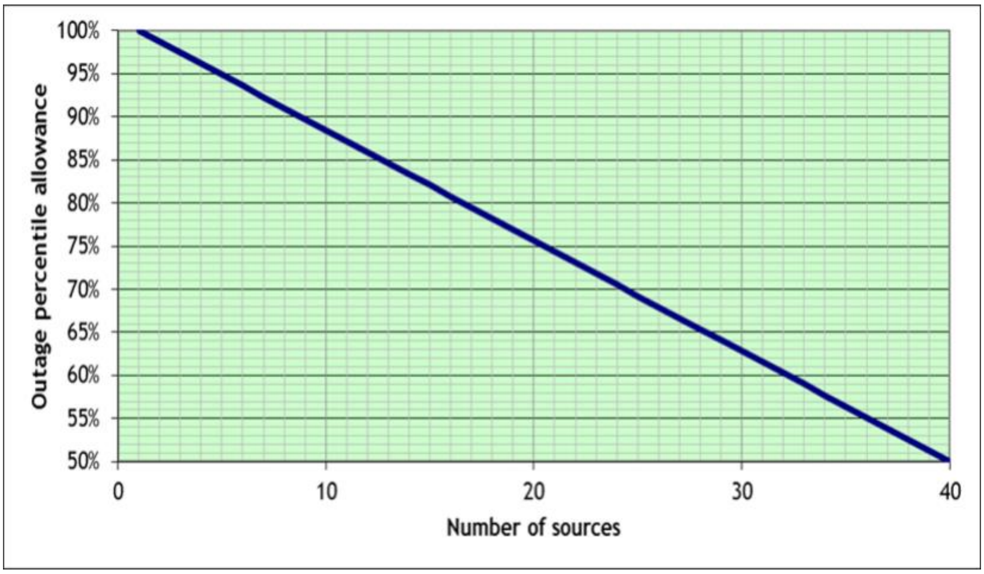


Figure 5.1: Outage percentile allowance depends on number of sources in a WRZ.

The Supply Demand Balance Index (SDBI) has increased focus on delivering the outage recovery plan and addressing new outages when they occur. Current outage levels are assessed at a monthly meeting of Southern Water executives and investment decisions taken to manage outage levels below the forecast allowance. This includes asset maintenance activities to reduce the risk of new outages occurring.

Table 5.1: Estimated outage allowance by WRZ.

WRZ	2025-26 DYAA outage (Ml/d)	2025-26 DYCP outage (Ml/d)
HAZ	0.10	0.31
HKZ	0.08	0.00
HWZ	0.10	0.00
HRZ	0.26	0.22
HSE	0.80	0.00
HSW	0.00	0.00
IOW	0.90	2.05
SNZ	0.37	0.29
SWZ	2.94	1.78
SBZ	6.75	3.92
KME	5.49	2.85
KMW	10.40	1.98
KTZ	0.70	0.32
SHZ	0.00	0.00
Southern Water	**28.89**[52]	**13.72**

[52] Refer to WRP tables for most up to date outage value. Outage for KTZ is 2.40Ml/d instead of 0.7Ml/d and the value for SHZ is 0.06M/d instead of 0.00Ml/d.

Some of our zones have an outage allowance of zero as a result of this assessment.

- HSW has zero outage for DYAA as during a drought we expect that deployable output during drought from this zone will fall to zero (owing to River Hands-off-Flow constraints) and hence outage would create negative water available for use.
- For other zones with zero outage allowance (HKZ, HWZ, HSE and SHZ at DYCP and SHZ at DYAA) there were no outage events within the data period used for assessment (2015-2022) and so consequently the Monte Carlo assessment resulted in an allowance of zero under all percentiles.

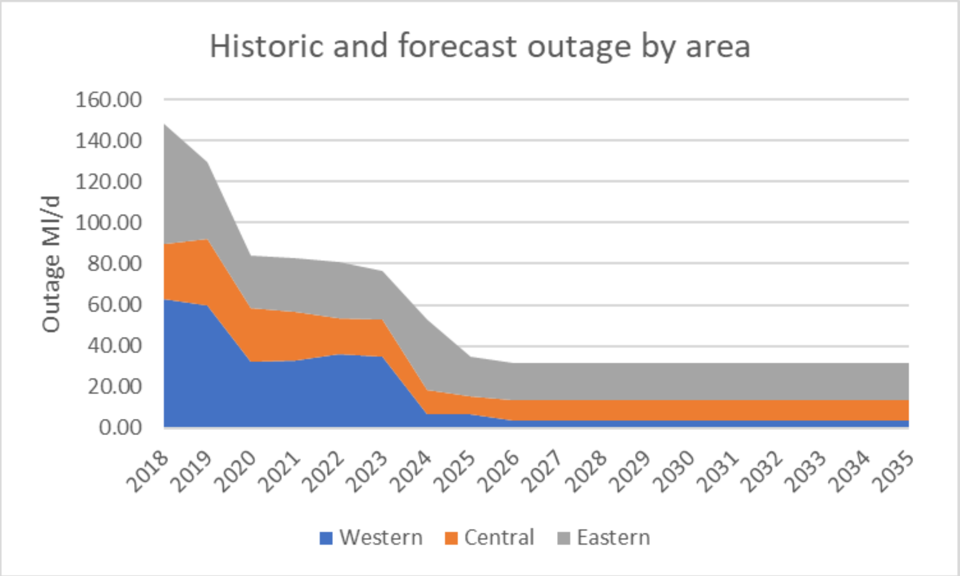


Figure 5.2: Historic outturn (to March 2022) and forecast outage allowance figures (from April 2022) for the DYAA planning scenario by supply area.

6 Process losses

When we treat water, there are some limited process and operational losses. We account for these in our supply forecast. Process losses here refer to the volume of water that is recycled back into the environment between the point of abstraction from the environment and where treated water enters the distribution network following treatment. Typically, groundwater sources have a simpler treatment process (in some cases only chlorination is required) than surface water sources and so process losses in groundwater dominated WRZs will tend to be lower.

To calculate the process losses, we look at all our surface water and groundwater sites to estimate how much process losses they incur. Where available we look at the difference between the volumes of water recorded on our abstraction meters against those recorded on our distribution meters to provide this information. This allows us to calculate a percentage process loss figure that can then be used at sites with similar treatment processes (e.g., groundwater) where we do not record both flows. We then validate the process loss volumes with our process scientists to ensure these figures are appropriate for the types of treatment technology used on each site.

The average process loss percentage for sites where data is consistent and reliable is around 5%. This assumption was applied where necessary to estimate process losses by WRZ for our WRMP19 and the same values were adopted for our dWRMP24. We have updated our process losses figures for the rdWRMP24. These are shown in Table 6.1.

Table 6.1: Estimated process losses by WRZ.

WRZ	Average (Ml/d)	Peak (Ml/d)
HAZ	0.13	0.13
HKZ	0.17	0.17
HWZ	0.33	0.35
HRZ	0.19	0.19
HSE	1.22	1.35
HSW	0.00	0.00
IOW	1.79	2.52
SNZ	1.74	3.06
SWZ	1.39	1.44
SBZ	1.25	1.48
KME	1.46	1.61
KMW	3.83	2.08
KTZ	0.85	0.92
SHZ	1.02	2.22

7 Water Available for Use

Once DO has been calculated, planning allowances (e.g. outage, process losses etc.) and net exports are subtracted, and net imports are added, to calculate the total Water Available for Use (WAFU).

In order to effectively prepare our WRMP, we need to forecast what water supplies will be available over the planning period. This is our WAFU, which is calculated based on:

- Water available from our resources
- Bulk imports and exports
- Climate change
- Sustainability reductions
- Process losses
- Outage.

The WAFU charts at company level (

Figure 7.1) show similar overall trends to those at an area level (Figure 7.2 to Figure 7.4) through the planning period.

For our baseline DO, there are generally reductions through time in all areas as we improve our drought resilience to achieve 1-in-500 year drought resilience. The fall in baseline DO represents the fact that less resources are available under a 1-in-500 year drought.

Our baseline imports and exports are relatively stable through time in all areas. Where changes occur, this reflects the nature of our current bulk supply agreements and that some existing and new transfer options are instead included in our investment modelling as options rather than being fixed in the baseline.

We only have one, relatively small (3.02Ml/d) confirmed further licence change which has a DO impact (at Andover in HAZ in 2027 – see Annex 9). However, for our potential, but presently unconfirmed licence changes which are possible through our Environmental Destination scenarios there are significant reductions forecast through to 2050, especially for supply-demand Situation 4 which represents the High Environmental Destination scenario. We are undertaking a considerable amount of environmental investigation through to 2027 to help to reduce the uncertainty around the possible magnitude of any licence changes required to achieve our environmental ambition.

Climate change presents the next largest possible reduction in WAFU. Two of the WRZs most vulnerable (HSE, SNZ) are also amongst the most environmentally sensitive and hence the Western and Central area WAFU declines significantly.

The key supply-side uncertainties our adaptive plan is designed to hedge against are the loss of supply due to climate change and the loss of supply due to licence changes we may need to make to protect the environment. Both drivers can potentially lead to large reductions in WAFU depending on which future ‘situation’ we progress towards. However, whilst the drivers of each change are to a large degree independent variables i.e. the degree of climate change will not directly influence the degree of environmental protection (though the two are indirectly related), the way that the adaptive branches are constructed means that we need to be careful to avoid double counting deficits (i.e. we cannot lose DO to Environmental Destination if that DO has already been lost to climate change. However, since both impacts have been calculated independently during our resource modelling, we have included DO adjustments which offset under scenarios where both climate change and Environmental Destination act in combination to reduce DO to avoid double counting leading to greater water losses than is available to lose (i.e. leading to negative WAFU). This is most obvious in HSE and SNZ, both of which are highly vulnerable to climate change for the DYAA scenario (SNZ is medium vulnerability for the DYCP scenario) and at risk of needing significant licence reductions to protect the environment. Although both are expected to occur in some combination, it is likely (for the purposes of our monitoring plan) than any changes in DO from licence changes are likely to be primary, and most obvious cause of WAFU loss, and will precede the losses due to climate change.

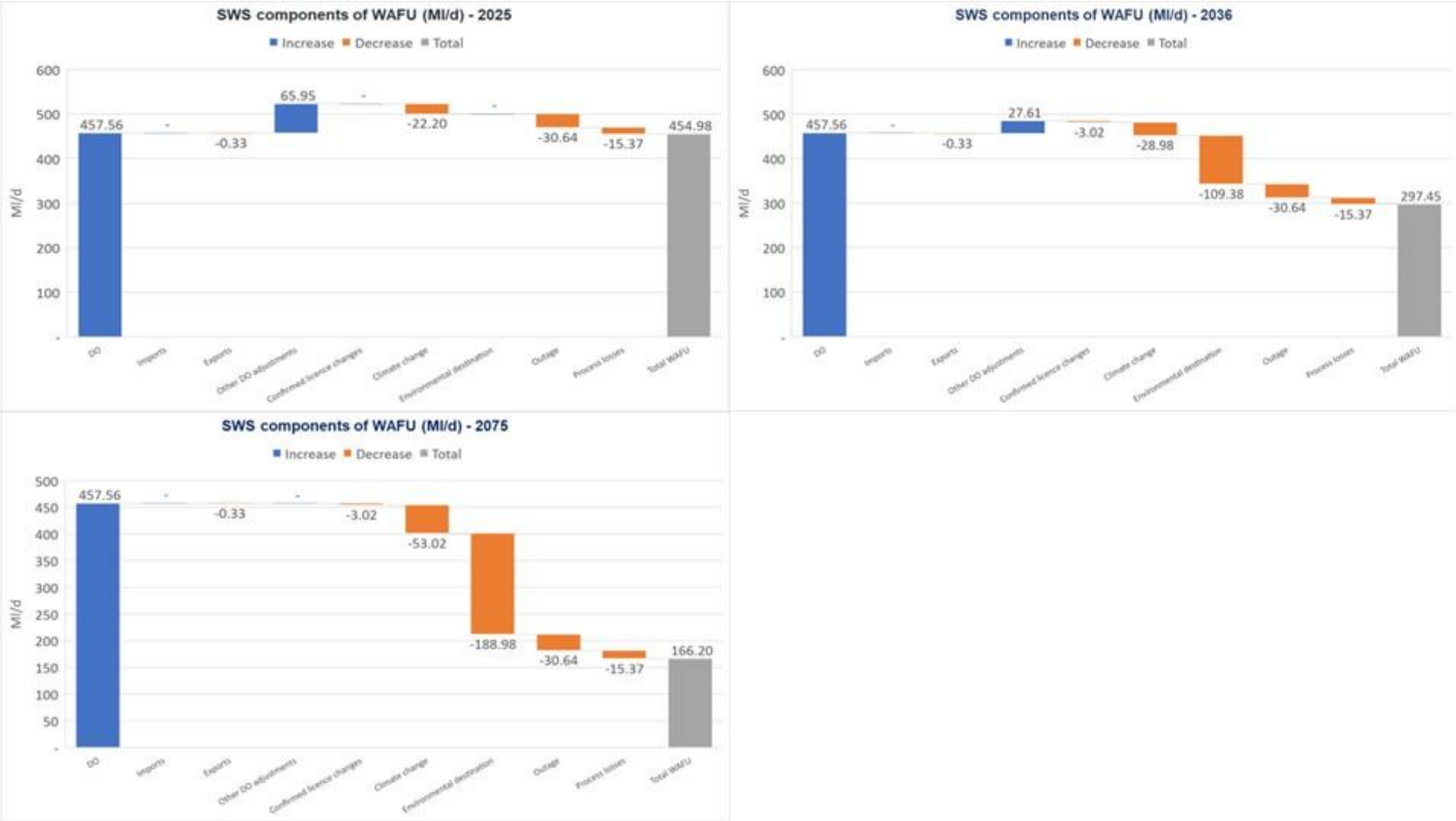


Figure 7.1 Forecast WAFU (Ml/d) at the company level for supply-demand balance Situation 4.

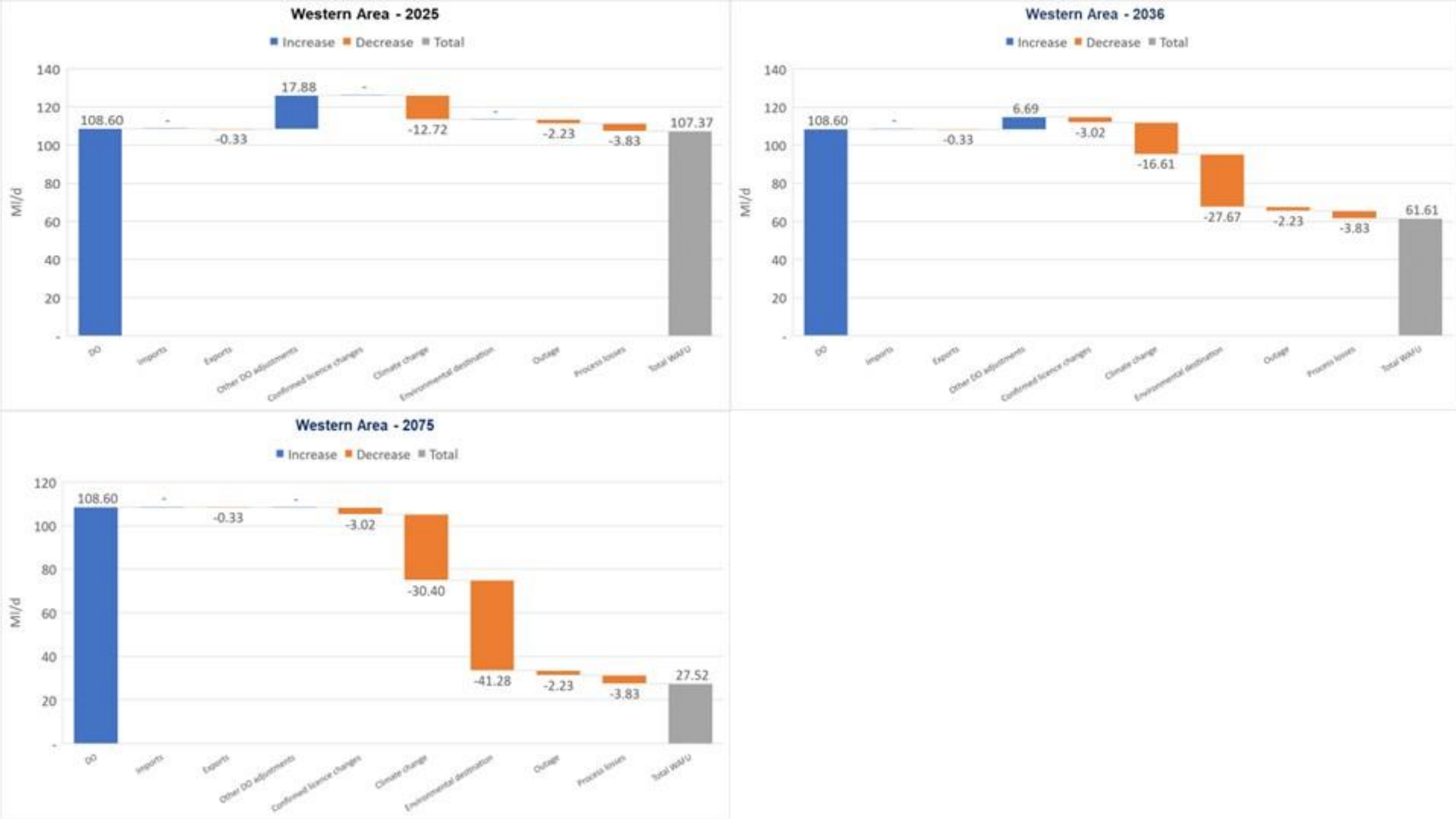


Figure 7.2 Forecast WAFU (Ml/d) in the Western area under supply-demand Situation 4.

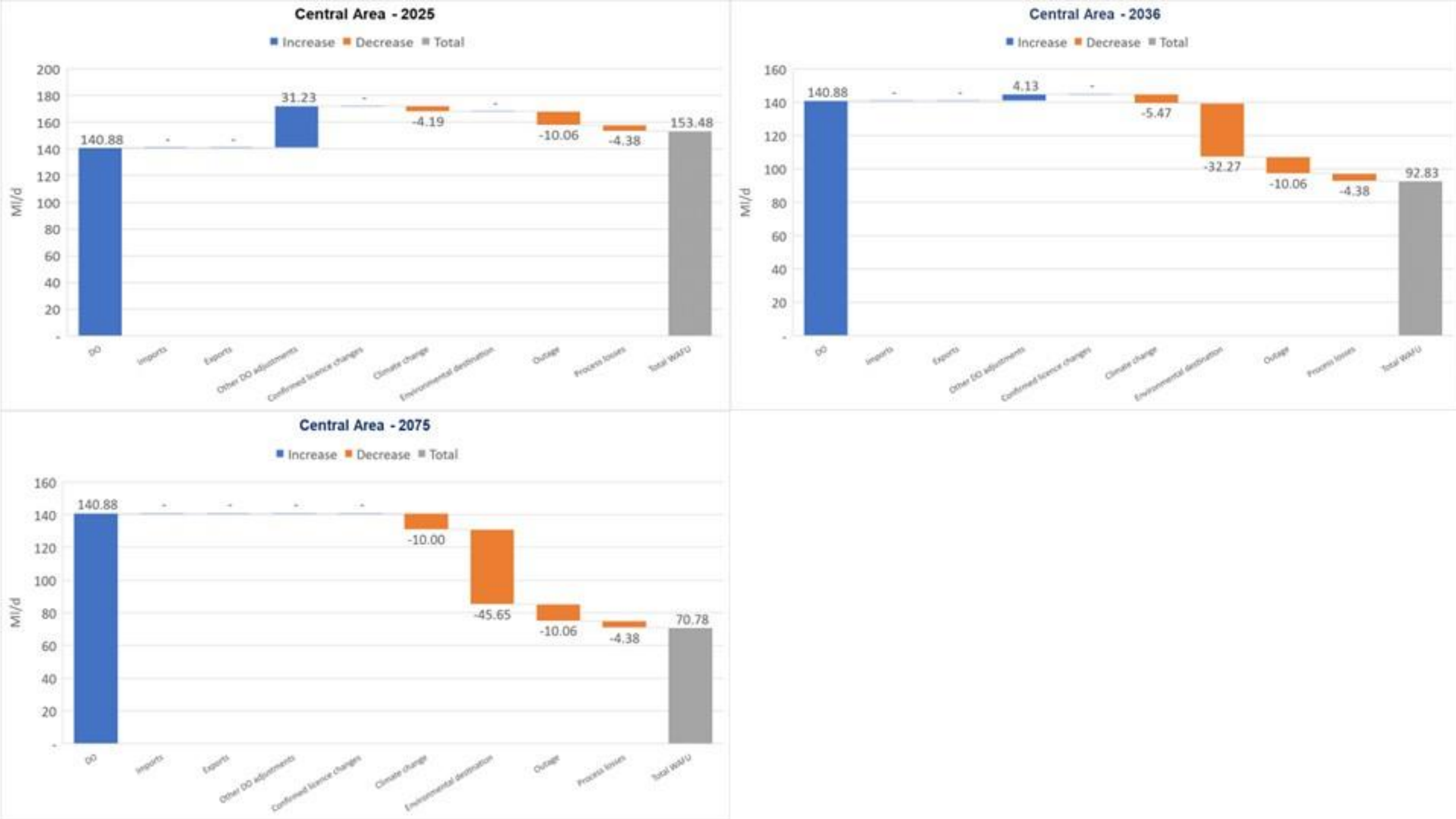


Figure 7.3: Forecast WAFU (Ml/d) in the Central area under supply-demand Situation 4.

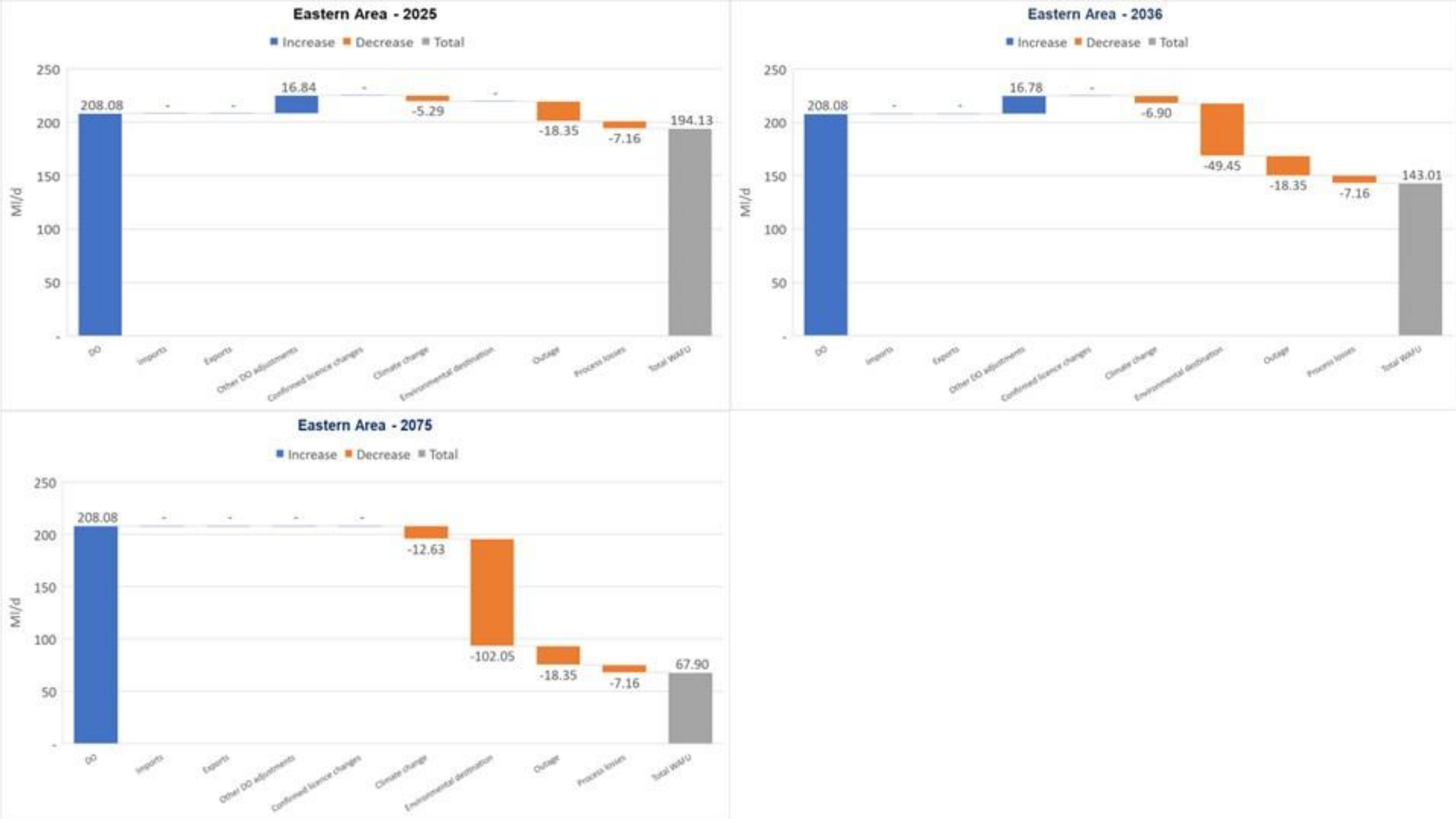


Figure 7.4: Forecast WAFU (Ml/d) in the Eastern area under supply-demand Situation 4.

Appendix A – Groundwater framework scores

Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Central area - North Sussex, 1	5	4	5	4	5	5	Internal representation	Dynamic
Southern Water, Central area - Worthing, Sussex, 4	4	4	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 4	3	4	3	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 7	3	4	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Worthing, Sussex, 5	3	3	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 11	3	2	3	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 1	3	1	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Western area - Southampton East, Hampshire, 1	5	5	1	4	5	5	Internal representation	Dynamic
Southern Water, Western area - Southampton East, Hampshire, 2	5	5	1	4	5	5	Internal representation	Dynamic
Southern Water, Western area - Winchester, Hampshire, 1	1	4	1	3	5	5	External representation - annual profile	External timeseries
Southern Water, Central area - Worthing, Sussex, 9	5	3	1	2	5	5	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 7	5	3	1	2	5	5	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 8	5	3	1	2	5	5	External representation - timeseries	External profile
Southern Water, Central area - Brighton, Sussex, 2	3	3	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Worthing, Sussex, 10	3	3	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 6	3	3	1	3	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Medway East, Kent, 16	5	2	1	1	5	5	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 6	3	2	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 10	3	2	1	2	5	5	External representation - timeseries	External timeseries

Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Central area - Brighton, Sussex, 6	3	1	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 9	3	1	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Medway East, Kent, 14	3	1	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Western area - IOW, 1	1	3	3	1	0	0	External representation - annual profile	External timeseries
Southern Water, Western area - IOW, 3	1	3	3	3	0	0	External representation - annual profile	External timeseries
Southern Water, Eastern area - Medway East, Kent, 2	1	2	3	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 1	2	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 7	2	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Western area - IOW, 5	2	3	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Eastern area - Thanet, Kent, 1	2	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 4	2	3	1	1	0	0	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 7	2	3	1	3	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 10	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Central area - Brighton, Sussex, 12	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 2	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 6	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 11	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Western area - Kingsclere, Hampshire, 1	1	3	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Winchester, Hampshire, 2	1	3	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - IOW, 7	1	3	1	1	0	0	External representation - annual profile	External profile

Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Eastern area - Medway West, Kent, 2	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 1	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 13	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 15	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 2	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 3	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 5	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 8	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 1	2	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 3	2	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 4	2	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 9	2	2	1	2	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - North Sussex, 3	1	2	1	2	0	0	External representation - annual profile	External profile
Southern Water, Central area - North Sussex, 4	1	2	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Western area - Andover, Hampshire, 1	1	2	1	3	0	0	External representation - annual profile	External profile
Southern Water, Western area - IOW, 2	1	2	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Western area - IOW, 4	1	2	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Eastern area - Medway West, Kent, 5	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 6	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 7	1	2	1	2	0	0	External representation - timeseries	External profile

Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Eastern area - Medway West, Kent, 8	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 9	1	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 3	1	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 4	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 5	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 9	1	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 10	1	2	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 11	1	2	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 12	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Hastings, Sussex, 1	1	2	1	1	0	0	External representation - annual profile	External profile
Southern Water, Central area - Brighton, Sussex, 5	2	1	1	3	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 3	1	1	1	3	0	0	External representation - timeseries	External profile
Southern Water, Central area - Brighton, Sussex, 8	1	1	1	3	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 11	1	1	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 3	1	1	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 8	1	1	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - North Sussex, 2	1	1	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Kingsclere, Hampshire, 2	1	1	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Winchester, Hampshire, 3	1	1	1	1	0	0	External representation - annual profile	External profile
Southern Water, Western area - Rural Hampshire, 1	1	1	1	3	0	0	External representation - single value	External timeseries

Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Western area - Rural Hampshire, 2	1	1	1	1	0	0	External representation - single value	External profile
Southern Water, Western area - IOW, 6	1	1	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Andover, Hampshire, 2	1	0	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Andover, Hampshire, 3	1	0	1	1	0	0	External representation - annual profile	External profile
Southern Water, Western area - Andover, Hampshire, 4	1	0	1	1	0	0	External representation - annual profile	External profile

Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Central area - North Sussex, 1	5	4	5	4	5	5	Internal representation	Dynamic
Southern Water, Central area - Worthing, Sussex, 4	4	4	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 4	3	4	3	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 7	3	4	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Worthing, Sussex, 5	3	3	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 11	3	2	3	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 1	3	1	3	3	5	5	External representation - timeseries	External timeseries
Southern Water, Western area - Southampton East, Hampshire, 1	5	5	1	4	5	5	Internal representation	Dynamic
Southern Water, Western area - Southampton East, Hampshire, 2	5	5	1	4	5	5	Internal representation	Dynamic
Southern Water, Western area - Winchester, Hampshire, 1	1	4	1	3	5	5	External representation - annual profile	External timeseries
Southern Water, Central area - Worthing, Sussex, 9	5	3	1	2	5	5	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 7	5	3	1	2	5	5	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 8	5	3	1	2	5	5	External representation - timeseries	External profile
Southern Water, Central area - Brighton, Sussex, 2	3	3	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Worthing, Sussex, 10	3	3	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 6	3	3	1	3	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Medway East, Kent, 16	5	2	1	1	5	5	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 6	3	2	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 10	3	2	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 6	3	1	1	2	5	5	External representation - timeseries	External timeseries

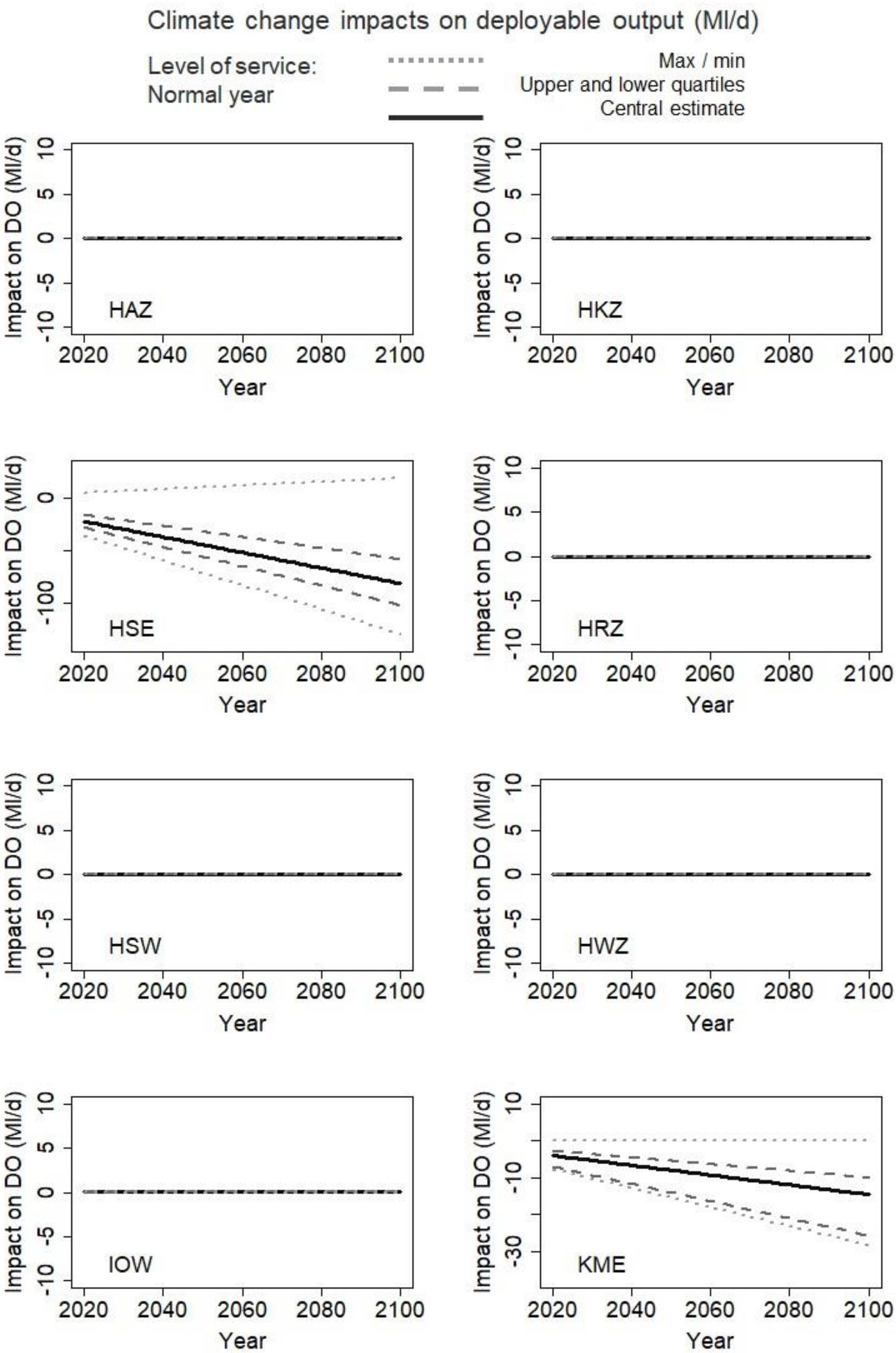
Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Central area - Brighton, Sussex, 9	3	1	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Eastern area - Medway East, Kent, 14	3	1	1	2	5	5	External representation - timeseries	External timeseries
Southern Water, Western area - IOW, 1	1	3	3	1	0	0	External representation - annual profile	External timeseries
Southern Water, Western area - IOW, 3	1	3	3	3	0	0	External representation - annual profile	External timeseries
Southern Water, Eastern area - Medway East, Kent, 2	1	2	3	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 1	2	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 7	2	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Western area - IOW, 5	2	3	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Eastern area - Thanet, Kent, 1	2	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 4	2	3	1	1	0	0	External representation - timeseries	External timeseries
Southern Water, Eastern area - Thanet, Kent, 7	2	3	1	3	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 10	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Central area - Brighton, Sussex, 12	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 2	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 6	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 11	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Western area - Kingsclere, Hampshire, 1	1	3	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Winchester, Hampshire, 2	1	3	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - IOW, 7	1	3	1	1	0	0	External representation - annual profile	External profile
Southern Water, Eastern area - Medway West, Kent, 2	1	3	1	2	0	0	External representation - timeseries	External profile

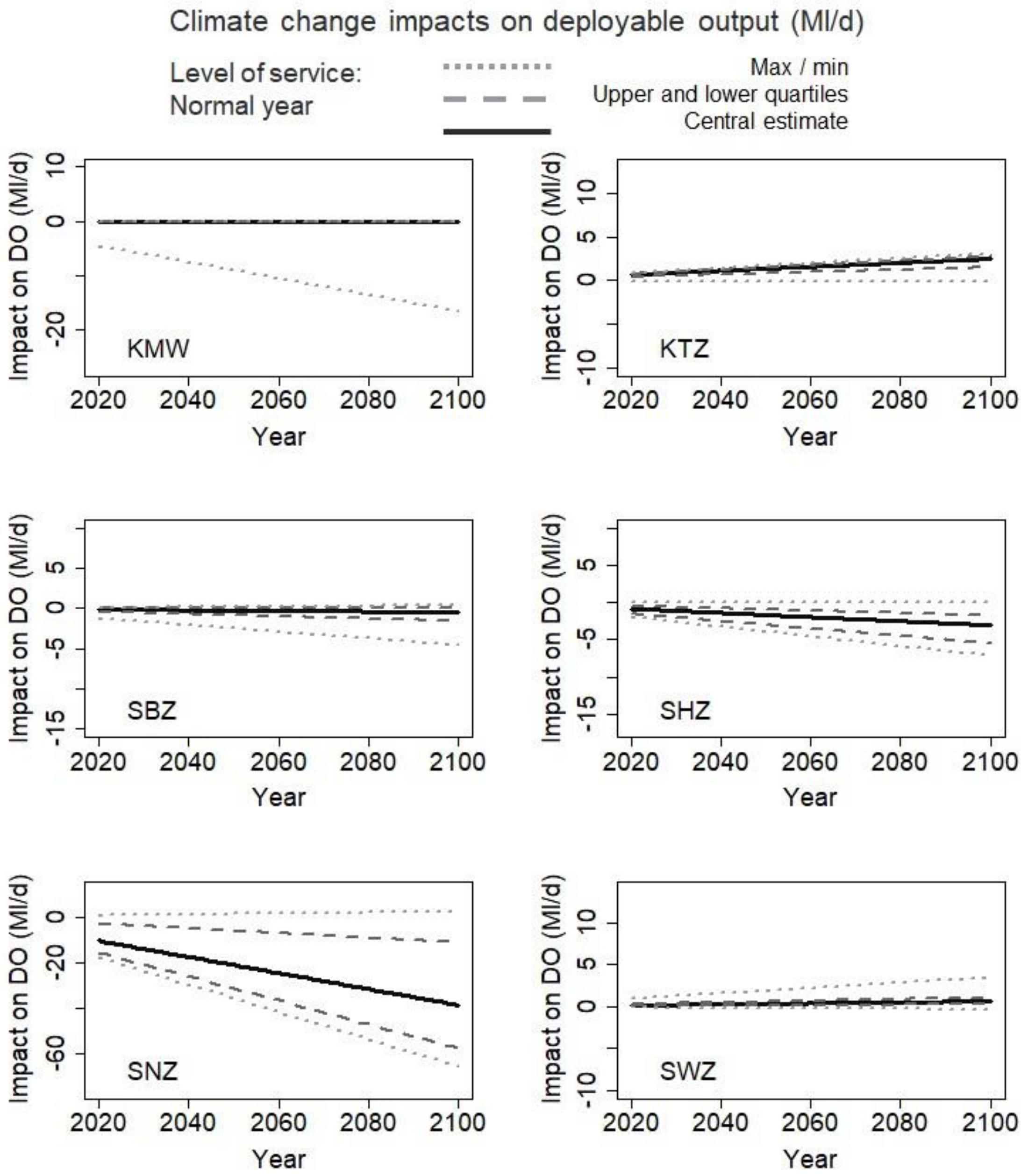
Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Eastern area - Medway East, Kent, 1	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 13	1	3	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 15	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 2	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 3	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 5	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 8	1	3	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 1	2	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 3	2	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 4	2	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Thanet, Kent, 9	2	2	1	2	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - North Sussex, 3	1	2	1	2	0	0	External representation - annual profile	External profile
Southern Water, Central area - North Sussex, 4	1	2	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Western area - Andover, Hampshire, 1	1	2	1	3	0	0	External representation - annual profile	External profile
Southern Water, Western area - IOW, 2	1	2	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Western area - IOW, 4	1	2	1	1	0	0	External representation - annual profile	External timeseries
Southern Water, Eastern area - Medway West, Kent, 5	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 6	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 7	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway West, Kent, 8	1	2	1	2	0	0	External representation - timeseries	External profile

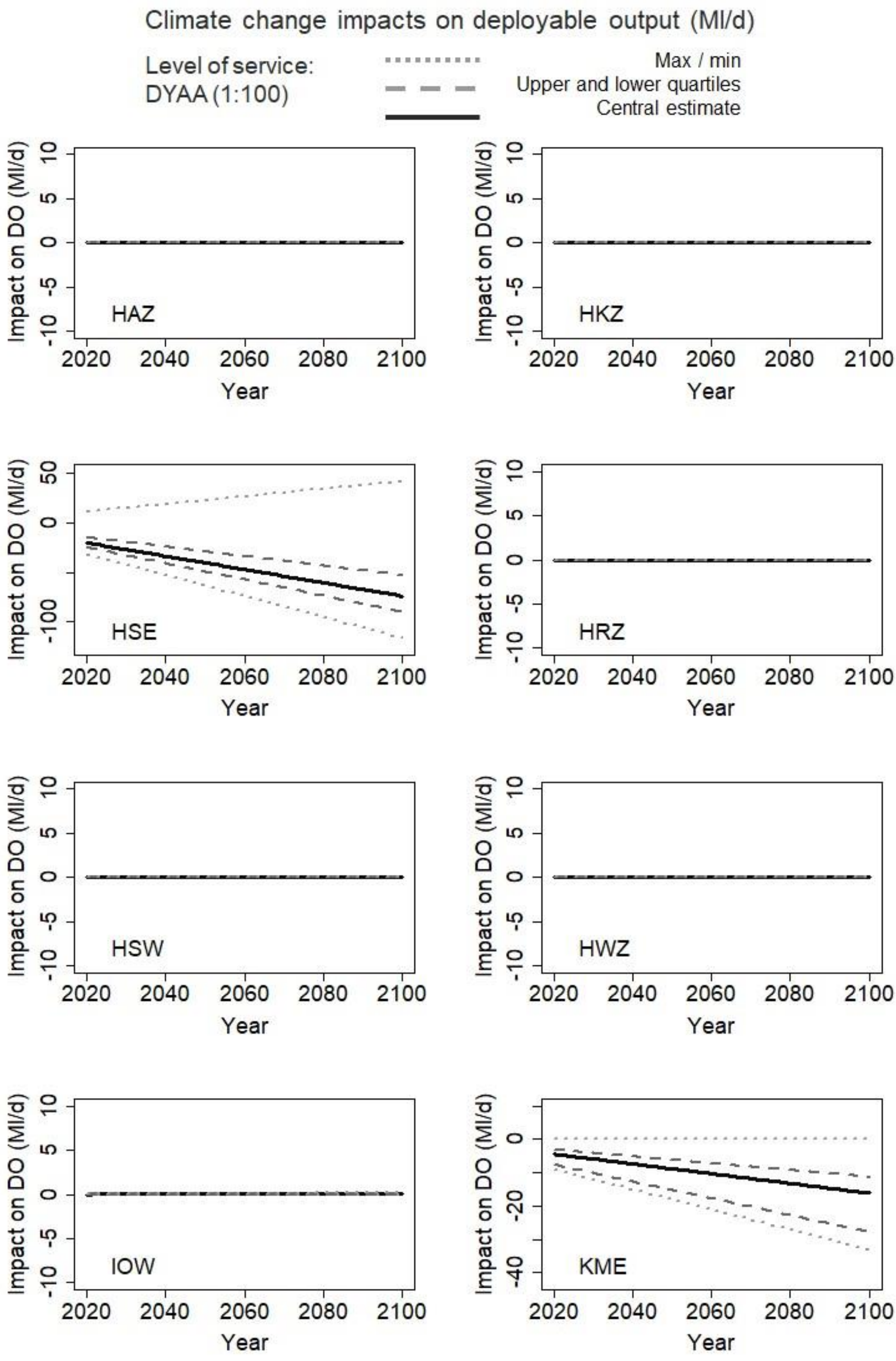
Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Eastern area - Medway West, Kent, 9	1	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 3	1	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 4	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 5	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 9	1	2	1	1	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 10	1	2	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 11	1	2	1	3	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Medway East, Kent, 12	1	2	1	2	0	0	External representation - timeseries	External profile
Southern Water, Eastern area - Hastings, Sussex, 1	1	2	1	1	0	0	External representation - annual profile	External profile
Southern Water, Central area - Brighton, Sussex, 5	2	1	1	3	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 3	1	1	1	3	0	0	External representation - timeseries	External profile
Southern Water, Central area - Brighton, Sussex, 8	1	1	1	3	0	0	External representation - timeseries	External timeseries
Southern Water, Central area - Brighton, Sussex, 11	1	1	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 3	1	1	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - Worthing, Sussex, 8	1	1	1	2	0	0	External representation - timeseries	External profile
Southern Water, Central area - North Sussex, 2	1	1	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Kingsclere, Hampshire, 2	1	1	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Winchester, Hampshire, 3	1	1	1	1	0	0	External representation - annual profile	External profile
Southern Water, Western area - Rural Hampshire, 1	1	1	1	3	0	0	External representation - single value	External timeseries
Southern Water, Western area - Rural Hampshire, 2	1	1	1	1	0	0	External representation - single value	External profile

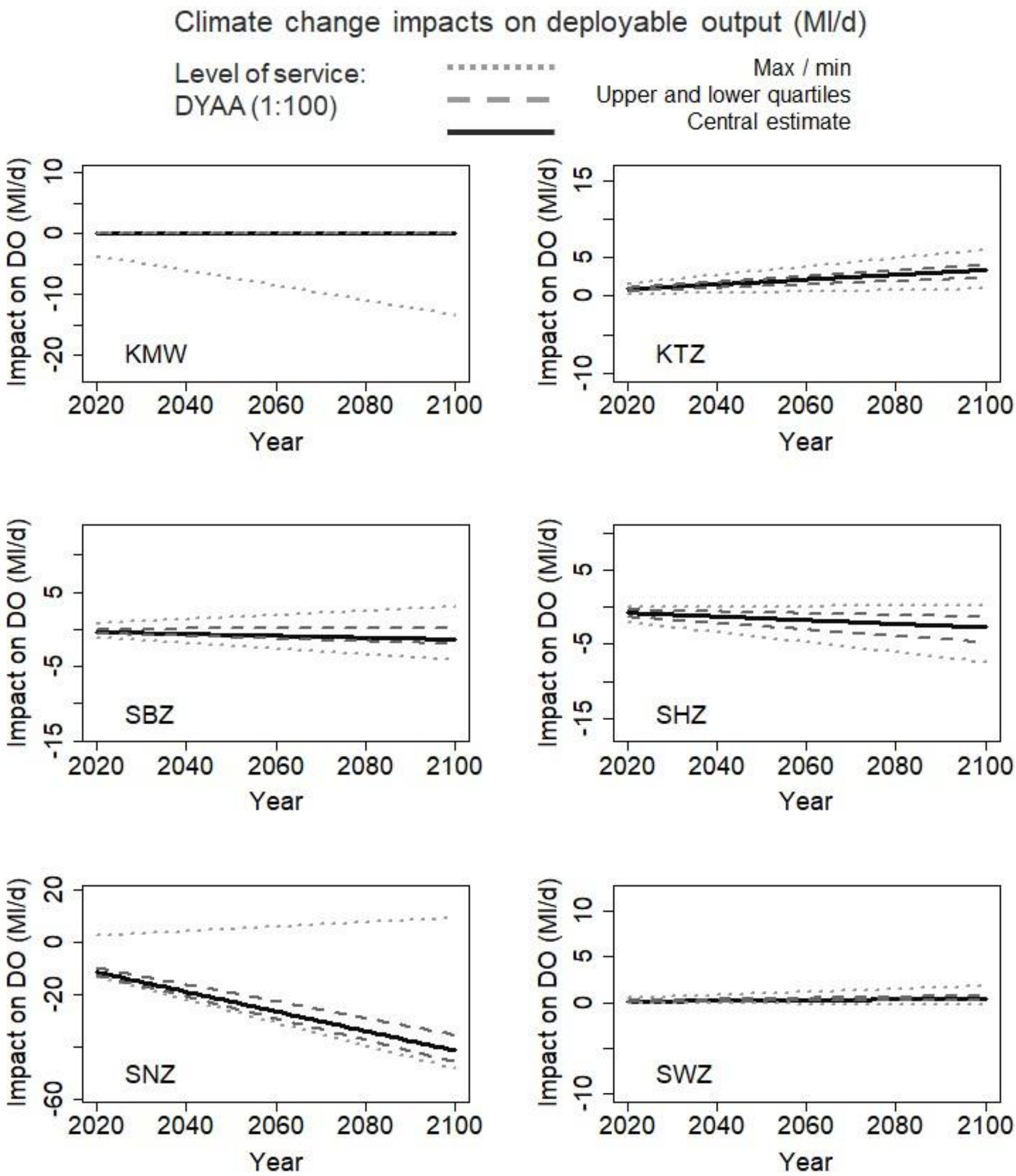
Groundwater source	Prioritisation assessment				Ranking (auto)	Ranking (final)	Proposed modelling methodology	
	Criteria 1: DO constraint	Criteria 2: Conjunctive benefit	Criteria 3: Sensitivity to antecedent conditions	Criteria 4: Proportionality / threshold of benefit			Internal/External boundary condition	Selected methodology
Southern Water, Western area - IOW, 6	1	1	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Andover, Hampshire, 2	1	0	1	2	0	0	External representation - annual profile	External profile
Southern Water, Western area - Andover, Hampshire, 3	1	0	1	1	0	0	External representation - annual profile	External profile
Southern Water, Western area - Andover, Hampshire, 4	1	0	1	1	0	0	External representation - annual profile	External profile

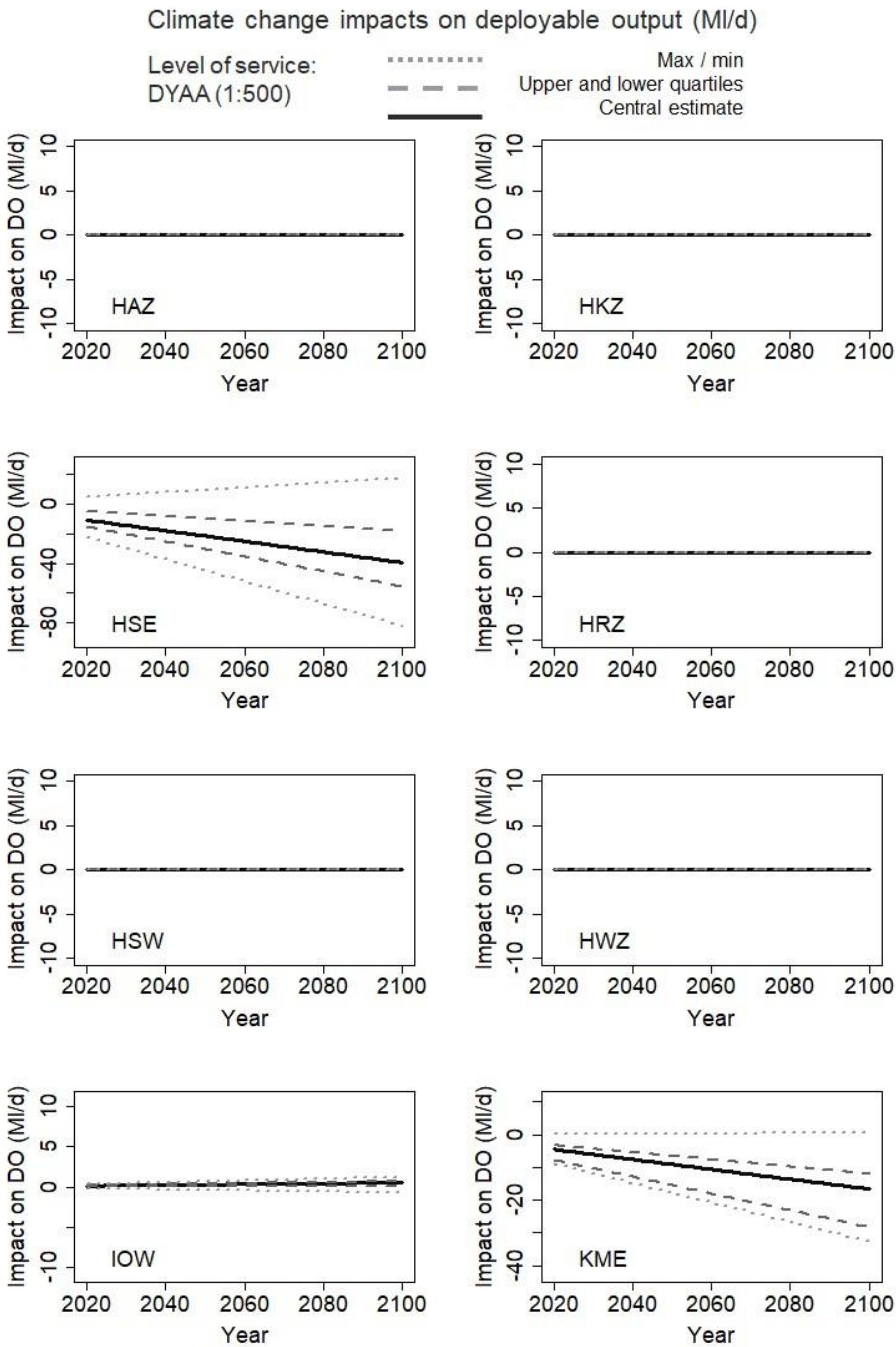
Appendix B Time series plots of climate change impacts

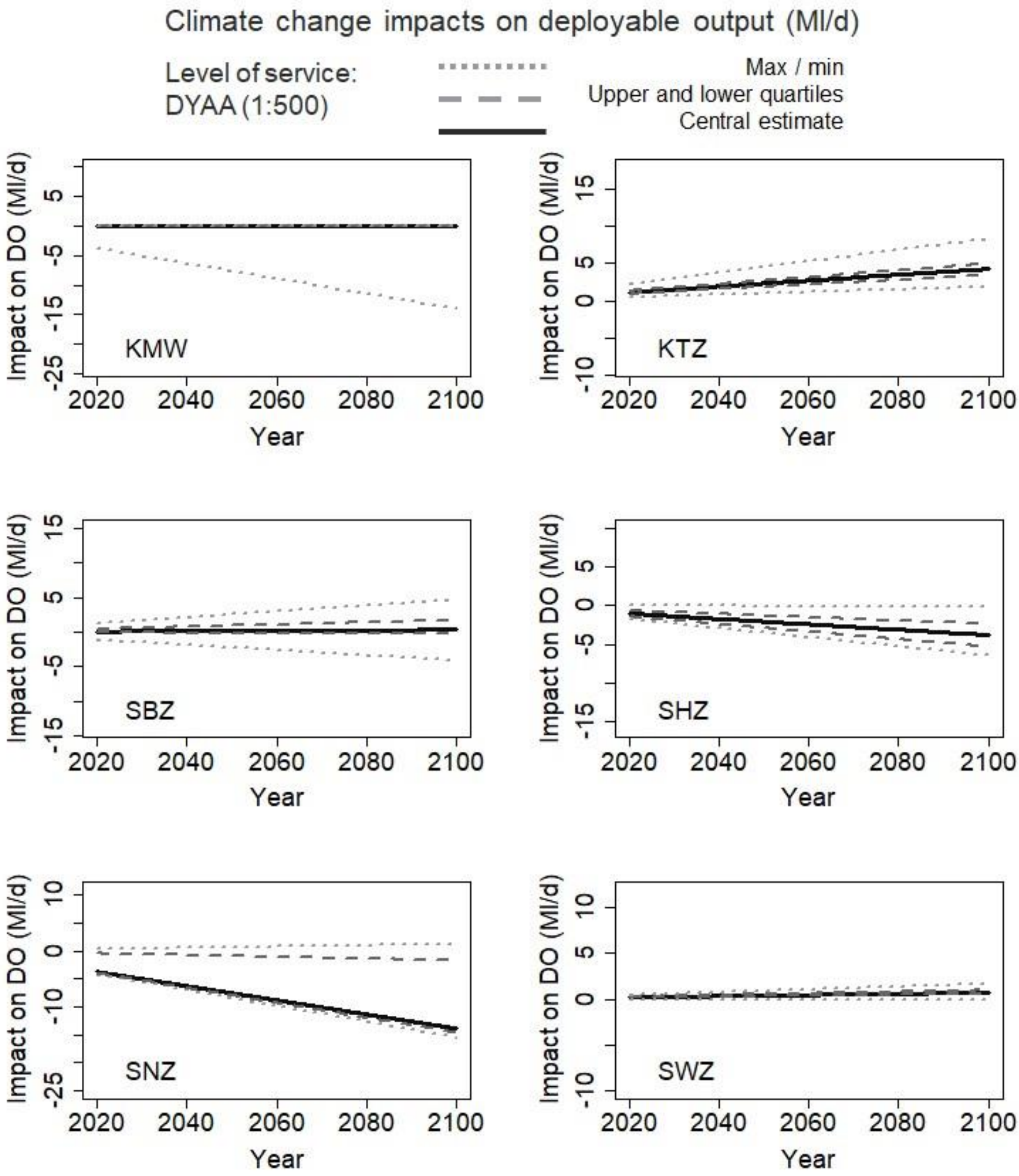



Climate change impacts on deployable output (Ml/d)
Level of service:
Normal year
Max / min
Upper and lower quartiles
Central estimate
KMW
KTZ
SBZ
SHZ
SNZ
SWZ
Impact on DO (Ml/d)
Year


Climate change impacts on deployable output (Ml/d)
Level of service:
DYAA (1:100)
Max / min
Upper and lower quartiles
Central estimate
Impact on DO (Ml/d)
Year
HAZ
HKZ
HSE
HRZ
HSW
HWZ
IOW
KME


Climate change impacts on deployable output (Ml/d)
Level of service:
DYAA (1:100)
Max / min
Upper and lower quartiles
Central estimate
KMW
KTZ
SBZ
SHZ
SNZ
SWZ
Impact on DO (Ml/d)
Year
2020 2040 2060 2080 2100


Climate change impacts on deployable output (Ml/d)
Level of service:
DYAA (1:500)
Max / min
Upper and lower quartiles
Central estimate
Impact on DO (Ml/d)
Year
HAZ
HKZ
HSE
HRZ
HSW
HWZ
IOW
KME
2020 2040 2060 2080 2100


Climate change impacts on deployable output (Ml/d)
Level of service:
DYAA (1:500)
Max / min
Upper and lower quartiles
Central estimate
KMW
KTZ
SBZ
SHZ
SNZ
SWZ
Impact on DO (Ml/d)
Year
2020
2040
2060
2080
2100