WRMP24 Supply Forecast

Wessex Water

August 2023

Document revisions

Major version number	Details	Lead contact	Date
1	Draft issued for comment	Chris Hutton	06/07/2021
2	Draft reviewed and changes accepted/made	Paul Saynor	25/09/2022
3	Final version issued for dWRMP24	Chris Hutton	03/10/2022
4	Revised draft issued to regulators	Chris Hutton	16/08/2023

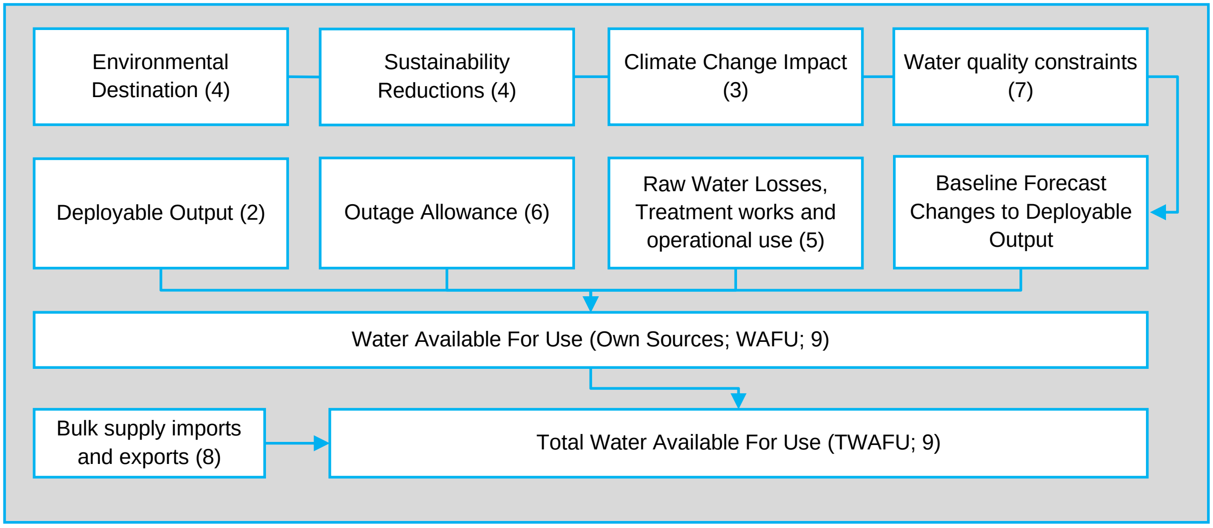
Contents

1. Background and Supply Forecast Overview

The Water Resources Management Plan requires us to forecast how much water is available in the base year, and how this forecast will change throughout the planning period from 2019/20 to 2080. This document explains the information and processes used to underpin our supply forecast. An overview of the process is presented in Figure 1-1 which references the sections of this chapter where each element of the assessment is explained.

The main component of the assessment is the Deployable Output (Section 2) calculation which determines under drought conditions the water that is available from sources to supply to customers. This is combined with an allowance for source outages (Section 6) and losses occurring due to system operation (Section 5) to derive the base year Water Available For Use (WAFU). Changes to WAFU over time during the planning period occurring due to licence reductions (Section 4), climate change impacts (Section 3) and changing water quality (Section 7) are captures in baseline forecast changes to deployable output. Finally, WAFU is combined with the forecast of bulk supply imports and exports to and from neighbouring water companies to derive the Total Water Available For Use (TWAFU).

Figure 1-1 Supply forecast development process (Section references in brackets)



The supply forecast was developed following the Regulatory Water Resources Planning Guideline[1], and the following guidance:

- Water Resources Planning Guideline Supplementary Guidance – 1 in 500, External guidance: 18646, Published 22/03/2021
- Water Resources Planning Guideline Supplementary – Outage, External guidance: 18641, Published 18/03/2021
- Water Resources Planning Guideline Supplementary – Stochastics, External guidance: 18644, Published 19/03/2021
- Water Resources Planning Guideline Supplementary – Climate change, External guidance: 18647, Published 18/03/2021

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[1] Environment Agency, Ofwat and Natural Resources Wales (2021) Water Resources Planning Guidance, Version 10 updated December 2021.

- Water Resources Planning Guideline Supplementary – Preventing Deterioration, External guidance, Published 04/04/2022
- Environment Agency (2017) WRMP19 supplementary information – estimating the impacts of climate change on water supply
- Environment Agency – Long-term water resources environmental destination: guidance for regional groups and water companies
- UKWIR (2014) Handbook of source yield methodologies
- UKWIR (2016) WRMP19 methods – risk-based planning
- UKWIR (1995) Outage allowances for water resources planning

Our approach was developed with reference to the joint regulator Water Resources Planning Guideline and the 2012 UKWIR study on *water resources planning tools*[2], The UKWIR (2014) *handbook of source yield methodologies*[3], and the UKWIR (2016) risk-based planning guidelines[4].

1.1 Supply System overview

Our forecast of available water to supply to customers is constrained by the availability of water in the environment, the licenced quantities Wessex Water is available to abstract, and the infrastructure to abstract, treat and distribute it to customers.

To supply our customers' we use more than 70 sources and over 11,800 km of water mains to treat and distribute approximately 340 million litres of water each day (Ml/d). Our sources range in capacity from less than 0.6 Ml/d to 45 Ml/d although we have a prevalence of small sources – over 50% have an average output of less than 6 Ml/d.

The main river catchments in the region include the Hampshire Avon, Bristol Avon, Frome, Stour, and Parrett. The majority (75%) of the water we abstract for public water supply comes from groundwater sources. Important aquifers for us are the Chalk aquifer located under Salisbury Plain, and the Dorset Downs and the Great Oolite Limestone aquifer in the Cotswolds. The remainder of our water supplies (25%) come from impounding reservoirs located in Somerset.

The volume of water we abstract from the environment to supply to our customers has been steadily reducing since the mid-1990s. Annual average volumes of water that we put into our supply system have reduced from around 425 Ml/d in 1995 to approximately 340 Ml/d today.

Our water supply network consists of a number of major transmission systems allowing us to move from areas of surplus to meet demand in the wider supply area (Figure 1-2). Our integrated network provides customers with a very resilient water supply service. Key network connections include:

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[2] UKWIR (2012). Water Resources Planning Tools 2012 (WR27), Deployable Output Report. Halcrow Group Ltd, ICS Consulting, Imperial College and University of Exeter Centre for Water Systems.

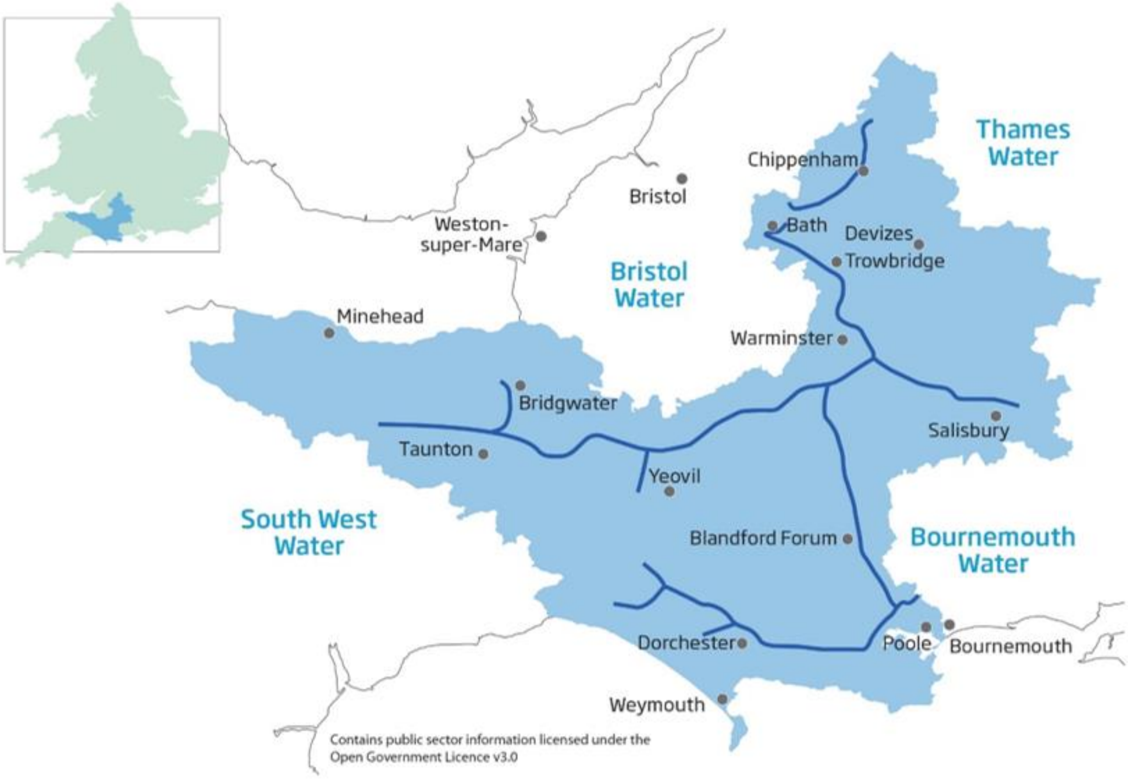
[3] UKWIR (2014) Handbook of Source Yield Methodologies. Report Ref. No. 14/WR/27/7

[4] UKWIR (2016) WRMP 2019 Methods – Risk Based Planning Report. Ref. No. 16/WR/02/11

- Transfer of water east from our major surface reservoir sources in Somerset to demand centres in the centre and north of our region, via the Spine Main and Central Area Link Main (CALM). Whilst this is our most common mode of transfer, in drier weather we have the ability to reverse this transfer and move water from the groundwater sources in the east of the area towards north Somerset.
- Movement of water south into north Bath from groundwater sources in Malmesbury and the Great Oolite aquifer near Chippenham.
- Transfers across the East/West link main in the south of our supply system, transferring water from the Poole region, across to Dorchester and Weymouth, and from Dorchester to Poole.
- Most recently (2010-2018) our integrated GRID project has added new pipelines to connect sources in the south of our region to Salisbury in Wiltshire via Blandford and Shaftesbury. This scheme, first proposed in our 2009 Water Resources Management Plan, enables us to reduce abstraction at environmentally sensitive sources in the upper Hampshire Avon Catchment, improve resilience for our customers without the need to develop new sources.

The GRID project involved over 50 individual schemes with investment totally £230m over eight years. It has not just included investment in traditional asset infrastructure, but also investment in innovative technology, referred to as ‘The optimiser’ – which models the operation of the GRID and the demand placed upon it up to 72 hours in advance, repeating this modelling at least hourly to account for potential operational or customer demand changes. The optimiser automatically recalculates the best way to operate the network to mitigate the outage and improves the resilient operation of our water supply system.

Figure 1-2 Wessex Integrated water supply network showing strategic mains



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1.2 Historical Rainfall, Hydrology and Drought Vulnerability

From a water resources perspective, a drought is defined as a water shortage resulting from an extended period of dry weather. The extent to which a given period of dry weather leads to water shortages depends on how a period of below average rainfall affects the amount of water in rivers, reservoirs, and groundwater, which in turn affects the amount of water available for public water supply. Therefore, in order to consider the drought vulnerability of the Wessex Water supply area, we need to understand how rainfall variability leads to variations in river levels and groundwater levels, which in turn affects water availability for public water supply.

1.2.1 Rainfall

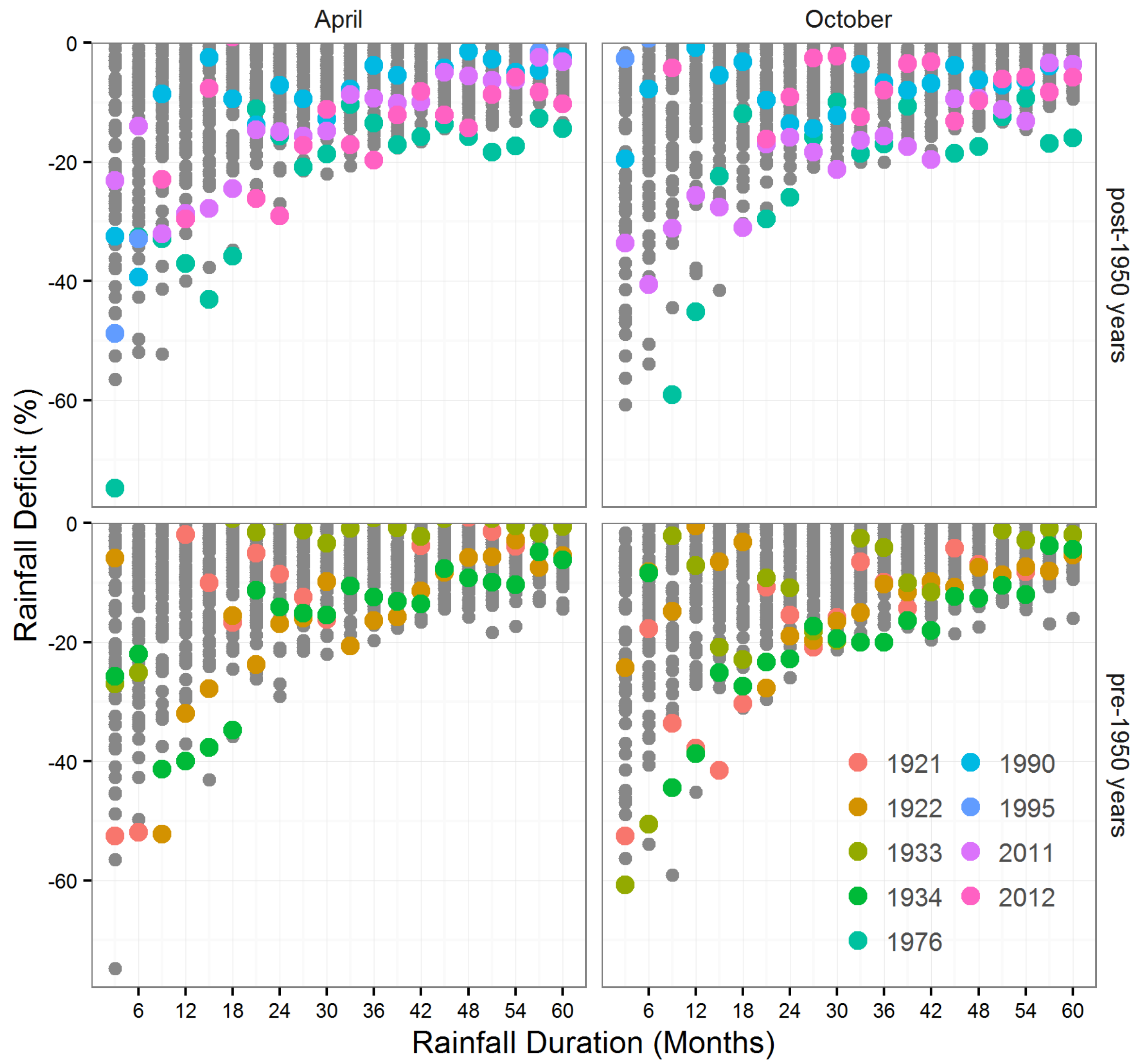
Mean annual rainfall for the Wessex Water region in the last one hundred years was 914 mm (1922-2021), and over the last 30 years averaged 949 mm (1992-2021). There is considerable inter-annual variability around the mean with an annual standard deviation of 136 mm over the last 30 years. The extent to which periods of below average rainfall lead to water resource shortages and drought conditions depends on three key metrics, which are typically used to classify meteorological droughts:

- **Deficit –** the absolute magnitude of rainfall deficit compared to average rainfall.
- **Duration –** the duration which rainfall is below average conditions.
- **Start date –** time in the year at which the deficit starts.

Figure 1-3 shows how rainfall deficit – a period of below average rainfall - varies as a function of the time-period over which the deficit is calculated, with selected years highlighted. We have considered drought deficit durations starting from both April and October to see when summer and winter deficits occurred.

The graphs confirm that rainfall deficits tend to be larger, as a percentage of mean rainfall, for shorter duration events. As rainfall duration increases, so percentage deficits decrease compared to the mean. The worst summer rainfall deficits occurred in 1976 and in 1921. The driest winters occurred in 1933 and from 1975 to 1976. For longer duration droughts starting in April, 1976, 1934, and 2012 consistently appear with high deficits, and for longer duration droughts. Starting in October, high deficits occurred in, and leading up to, 1976, 2011 and 1934. The year 1976 is a notable dry period when Wessex Water last imposed water use restrictions. Figure 1-3 indicates that the magnitude of rainfall deficit that occurred in 1976 was the result not only of a dry summer, but that the five years leading up to the drought were the driest five years on record. Therefore, the historic record shows rainfall deficits across multiple consecutive seasons.

Figure 1-3: Rainfall deficit as a percentage of mean rainfall plotted as a function of duration for October and April start months.



Grey points: each point is a year from 1911-2016 (same points appear in all sub-plots). Coloured points indicate specific years (see key), separated for clarity, into post-1950 (top row) and pre-1950 (bottom row). Note: the years indicated in colour correspond to the year in which the rainfall duration ends. For example, the worst 18, 30, 39, and 42-month rainfall deficits starting in October all ended in 2011. The worst 12-month rainfall deficit starting in April ended in 1934 and saw a deficit of 40% when compared to the long-term average rainfall for all 12 month periods starting in April from 1911-2016.

1.2.2 *Hydrology*

Groundwater levels and reservoir storage typically reach their lowest levels in October and November before higher rainfall in late autumn and winter, coupled with lower evapotranspiration rates, replenishes water storage (Figure 1-4;
Figure **1-5**). Groundwater tends to be slower to respond to rainfall and not recover as quickly as reservoir storage. The highest annual groundwater and reservoir levels are typically observed in February and March, following winter rainfall.

Exceptions to this typical annual pattern are sometimes observed; for example, the winter leading into 2012 was relatively dry, and failed to replenish groundwater storage at the usual time (Figure 1-4). Significant rainfall early in the summer that followed led to increased summer groundwater levels, which also prevented significant drawdown of our reservoir storage (Figure 1-5).

Figure 1-4: Groundwater levels in example years for Woodyates, Ashton Farm and Allington boreholes

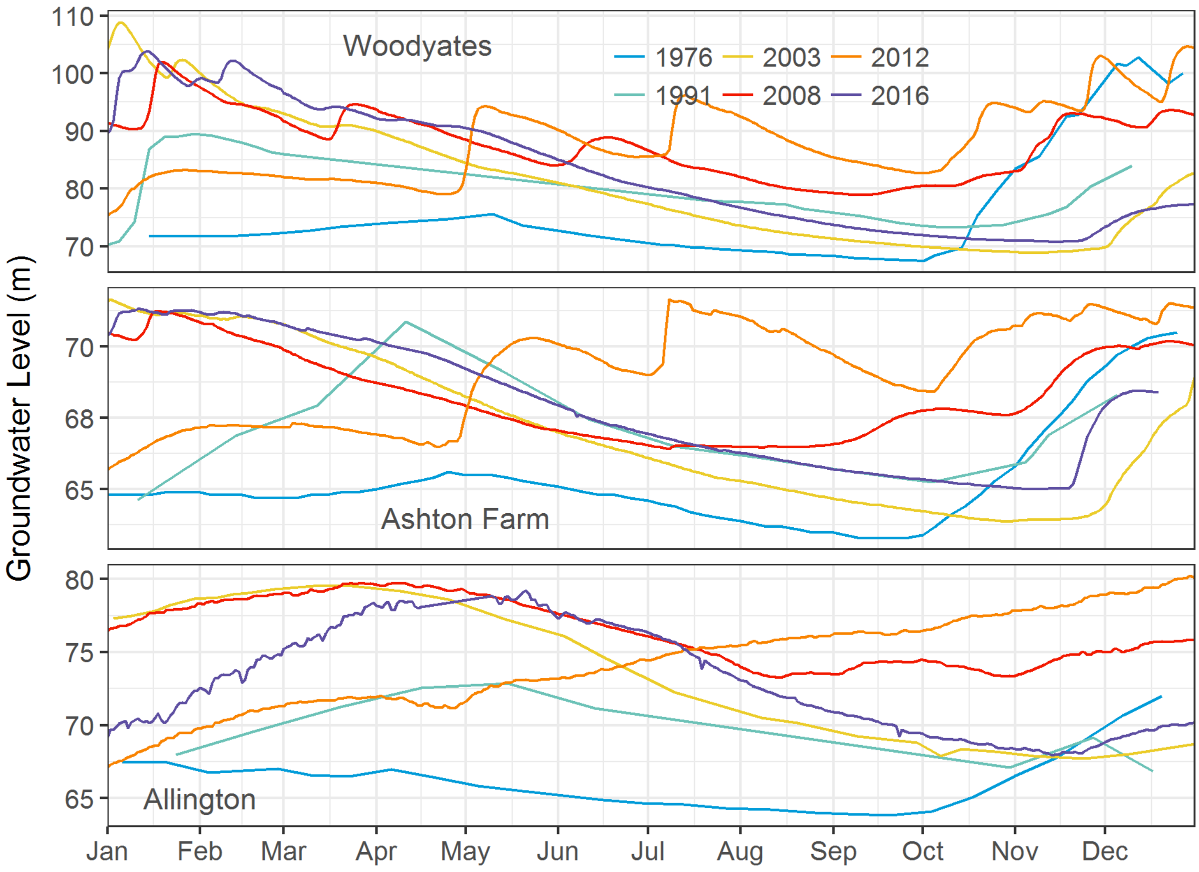


Figure 1-5: Total reservoir storage (excluding Wimbleball) in example years

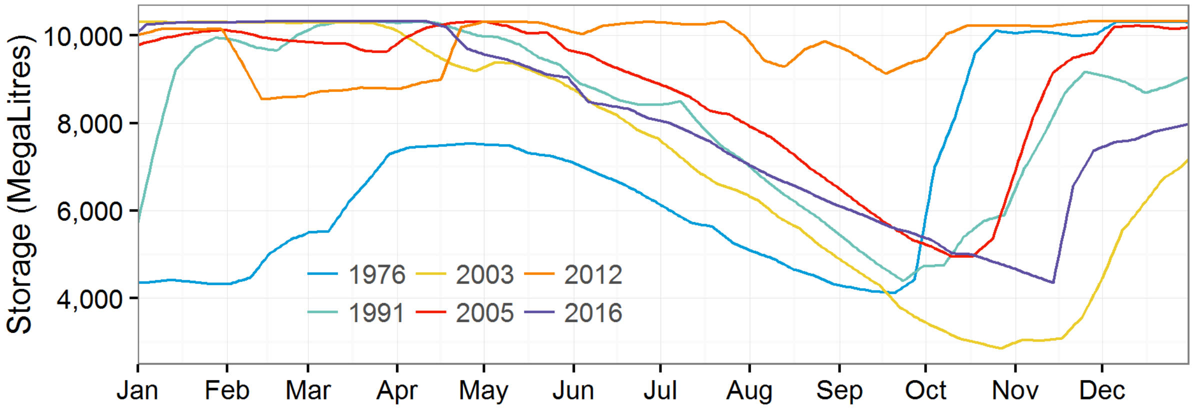
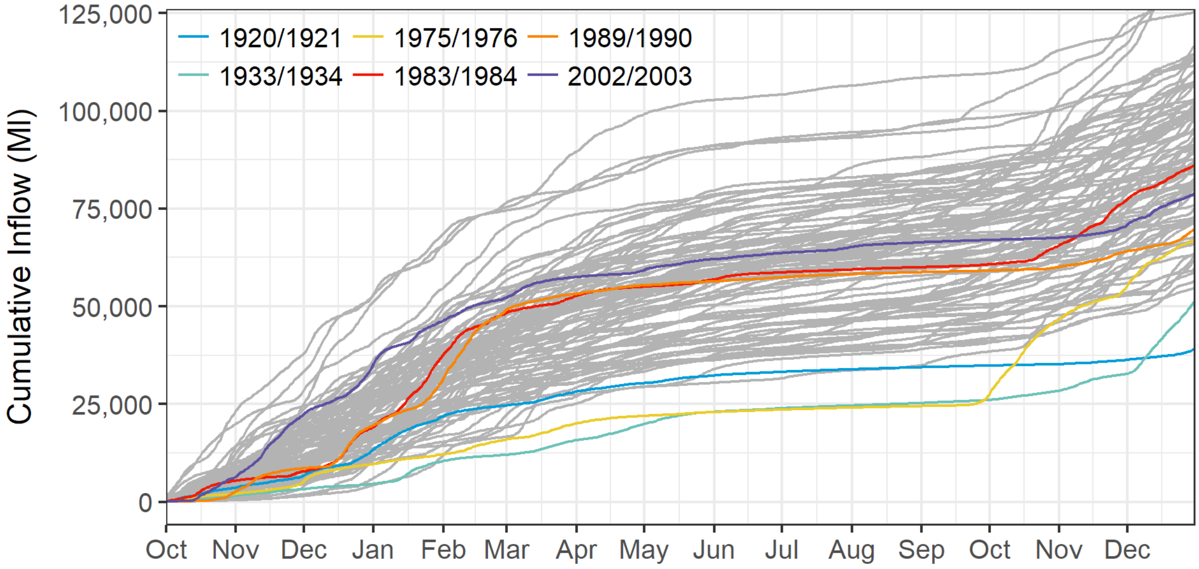


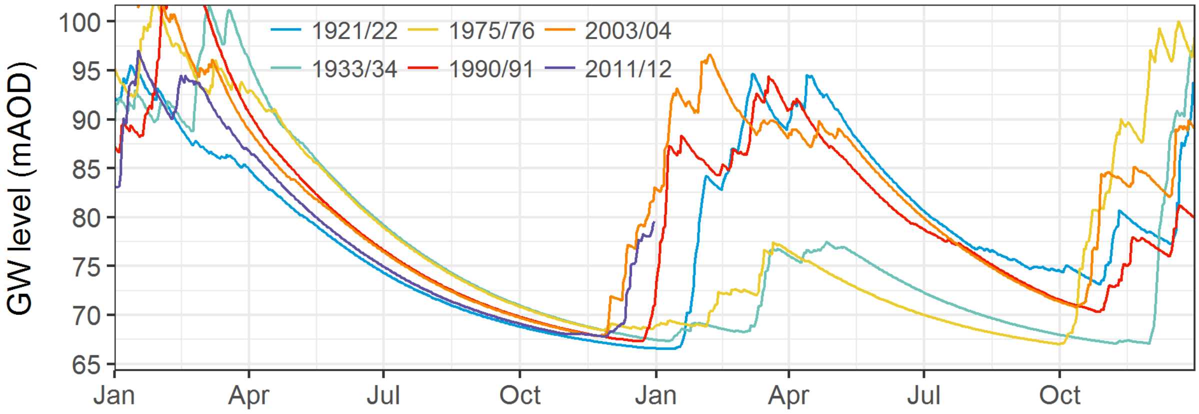
Figure 1-6 shows cumulative simulated reservoir inflows for all 15-month periods starting October from 1911 to 2016, with selected dry periods and years with dry summers highlighted. Figure 1-7 shows the lowest simulated groundwater levels at the Woodyates groundwater borehole, with the lowest levels recorded in the winters of 1921/22, 1933/34, 1975/76, 1990/91, 2003/04, and 2011/12. The periods from 1975/76 and 1933/34 are notable for a lack of groundwater recovery over the winter period. Therefore, we see that the largest rainfall deficit periods (Figure 1-3) also lead to the lowest discharge and groundwater levels.

Figure 1-6: Cumulative simulated inflows into all* impounding reservoirs for (1911-2016), with selected years highlighted



* Reservoirs included: Ashford, Clatworthy, Durleigh, Fulwood, Hawkridge, Sutton Bingham, and Wimbleball.

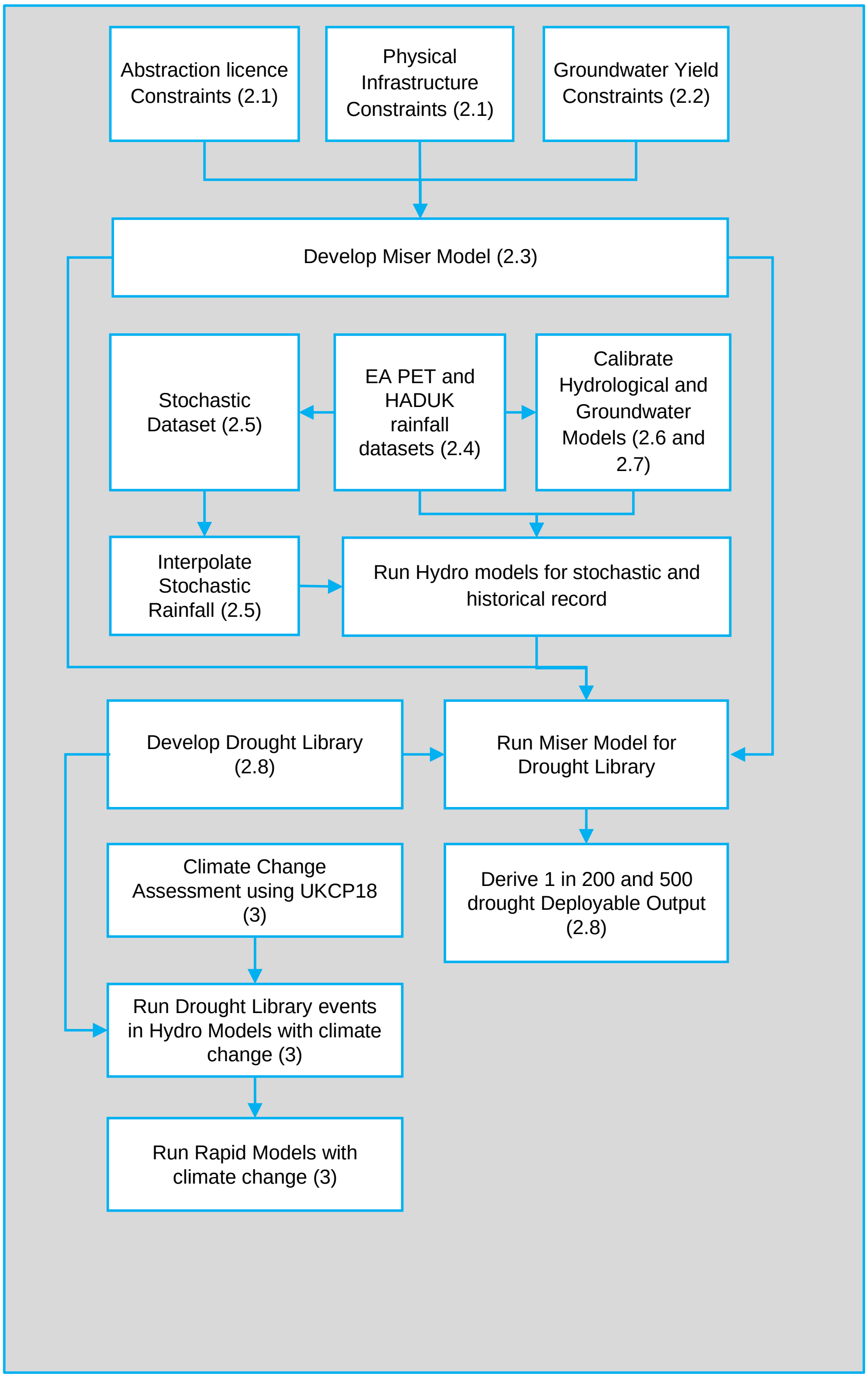
Figure 1-7: simulated groundwater level at Woodyates regional borehole for years with lowest groundwater level



2. Deployable Output

The Deployable Output (DO) is our assessment of the maximum volume of water a source can provide as a Dry Year Annual Average (DYAA) and Dry Year Critical Period (DYCP). The numbers are generated via a range of processes which are detailed in the following sections. The approach is summarised in Figure 2-1.

Figure 2-1: Summary of the approach to establish DO



2.1 Licence and Physical Infrastructure and Constraints

The following section details how the licence and physical constraints of the supply network have been captured and modelled within the Miser[5] model for DO modelling.

2.1.1 Licence constraints

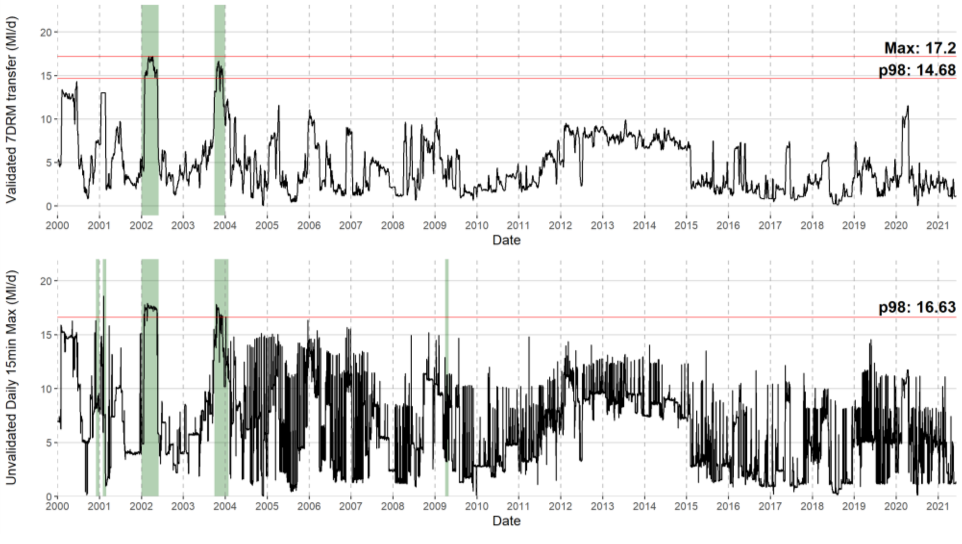
All licence conditions, including daily and annual licences as well as licence constraints relating to flows and certain times of year are maintained and updated for day-to-day compliance and annual reporting in our Abstraction Licence Compliance Handbook. Our Miser system model used to derive our system DO is kept up to date with the handbook and updated for development of this plan.

2.1.2 Network transfer capacities

We have developed an internal process to understand and review our network transfer capacities around our supply network. The aim of this is to ensure the Miser model is reflective of the network so we can model the pinch points around and hence understand how sensitive potential supply restrictions are to network constraints. We have identified a “soft” and “hard” limit for each key transfer capacity where relevant. In context, the soft limit might reflect what the transfer can operate at comfortably day to day, however if needed the transfer can be increased over the soft limit for short durations during peak demands.

To establish the capacities, first historical data for each key system transfer was automatically analysed by looking at the weekly and 15-minute observed values from our internal databases. The data were summarised by deriving key statistics of maximum capacity, and summary graphs produced.

Figure 2-2 Example summary chart of a transfer showing weekly average data and 15-minute daily max data



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[5] Miser is our the model used in water resources planning on the short and long term. It models sources of supply, the transfer of water and areas of demand.

2.1.3 Source Production Capacities

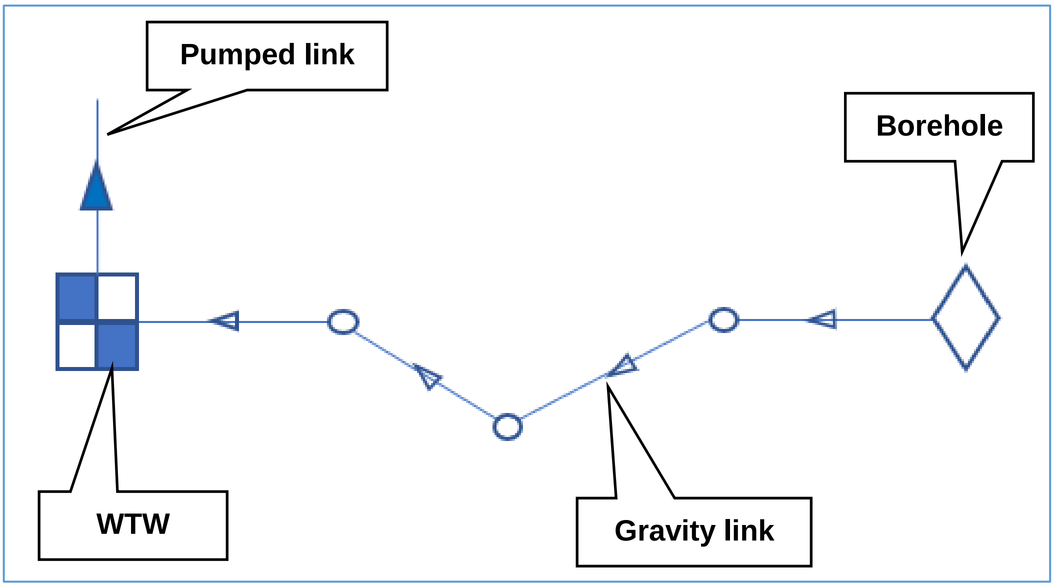
The Maximum Production Capacity (MPC) for each water treatment works (WTW) can be a constraining factor in our DO, as the WTW may not be able to produce the maximum daily licenced volume or a source yield constraint. The MPC of our 64 WTW is established by reviewing production outputs over the past five years to identify the recent peak demands using both instantaneous data (15-min logging), daily averages and a rolling 7-day average.

These values are then reviewed with colleagues from our Operations teams in Production, Science and Strategic Supply who provide insight on any local site constraints which may influence the MPC. Following this review, there is an agreed MPC per site with a Red, Amber, and Green (RAG) status which informs the priority order for any maximum flow trials which are required to improve the confidence of the MPC.

Selected MPC are then updated within MISER as a constraint. This review is carried out annually, which feeds into our Annual Performance Review (APR), outage logging procedure and maintenance of our production planning MISER base model. The MPC over a 7-day period was selected as MISER works on weekly timestep. Figure 2-3 below shows different components within our MISER model, and where different constraining factor information would be applied:

- Borehole – this node would hold the licence data for the source
- Gravity link – from source to WTW, this would hold the source yield equation which would be linked to a groundwater node elsewhere within the model (y=mx + c)
- WTW – this node would contain the MPC value for the treatment works
- Pumped link – this node holds the £/Ml for the source and water treatment works

Figure 2-3: MISER representation of constraining factors



2.1.4 Reservoir Capacity

The reservoir capacity volumes are based on our 2007 volumetric surveys as per WRMP19. These volumes formed the basis of our latest Drought Plan and operational reporting. In 2021/22 we commissioned updated reservoir volumetric surveys via APEM Ltd. The updated surveys aimed to quantify the difference between the hard bed and the soft bed of the reservoir to account for reservoir sedimentation over time. These surveys were not completed in time for WRMP24 and therefore will be used for future WRMPs. Table 2-1 details the reservoirs and the reservoir volumes.

Table 2-1: Reservoir volumes used in WRMP24

For security reasons this table has been redacted and edited for the version that is published on our website.

Reservoir	Gross capacity (Ml)	Net capacity (Ml)
Total	**31966.3**	**30853.5**
Total excluding shared reservoirs	**10323.2**	**9443.4**

2.2 Groundwater yield assessment

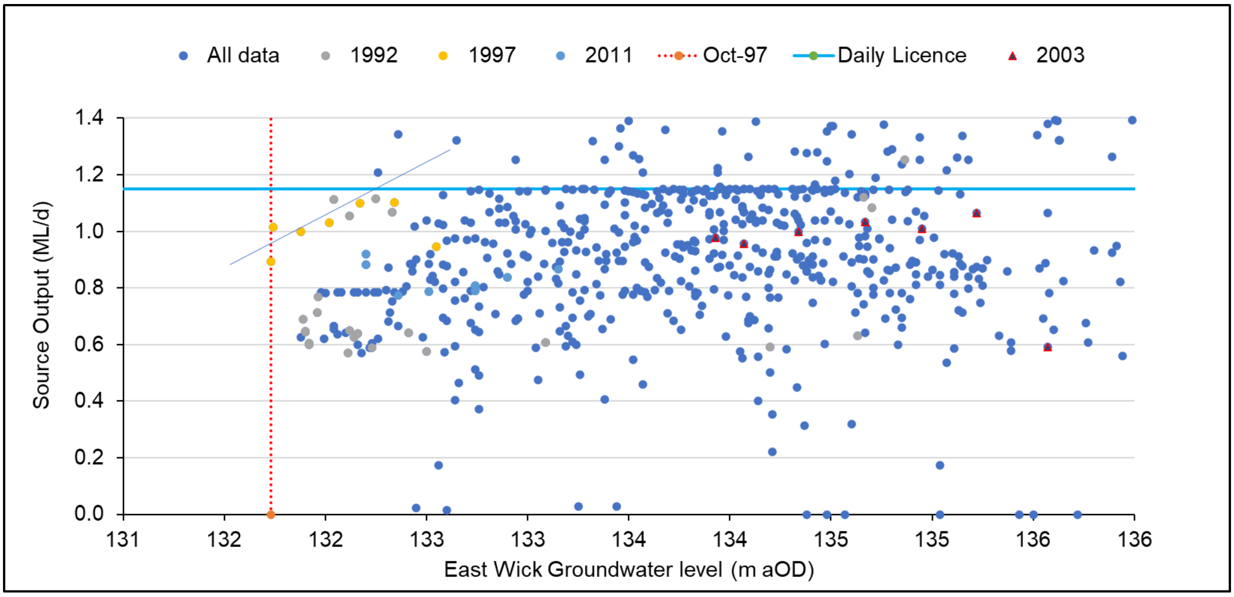
Groundwater (including springs and boreholes) makes up around 75% of our DO. A number of our sources are yield constrained where the yield is dependent upon local groundwater levels, with the remaining groundwater sources being annual licence constrained. Our approach to calculating yield constraints is via two key approaches which is detailed in the following sections.

Groundwater v’s yield relationships

The majority of our source yields have been calculated via an established relationship between historic source yields against key regional borehole groundwater levels within the Wessex Water region (i.e., the source yields at historic periods of low groundwater levels). This develops a line equation ($y = mx + c$) used in the Miser modelling. An example is shown in Figure 2-4. The outputs are subject to further qualitative review based on expert knowledge of the source (i.e., water quality, treatment, or demand constraints).

Assessments are on a rolling basis of which the current assessments ranging between around 2012/13 and 2021/22. The 2021/22 assessments were undertaken by an external consultant with Wessex Water peer review (by the water resources team and internal hydrogeologists) based on local site knowledge (i.e. water quality, operational challenges etc) via a series of review meetings. The accepted $y=mx + c$ equations are held within the Miser model against the relevant source.
The yields for forecasted against a 1 in 500-year groundwater water levels. Details of the forecasted groundwater levels are detailed Section 2.6. Uncertainty of the assessments is captured via a Low and High estimate for the source yields based on expert judgement. This has fed into the headroom assessment.

Figure 2-4: Example groundwater v's source output



2.3 Miser System Simulation Model

Supply system simulation modelling in Wessex Water is undertaken in the Miser modelling software.

2.3.1 Miser Background

We have been using Miser modelling software to help manage water resources since 1997. The model represents every source, distribution main, service reservoir, connections with neighbouring companies and demand centre within an integrated conjunctive use model. We use the same base model for strategic planning for the water resources management plan and business plan that we do for monthly operational planning of source utilisation, i.e. selection of sources and outputs to ensure prudent operation in droughts and cost-effective operation at other times. An illustrative schematic of part of the system is shown in Figure 2-5.

Figure 2-5: Schematic from the Miser model showing main transfers, service reservoirs, sources, and demand centres

For security reasons this figure is redacted and not available in the version of this document published on our website.

The model is run on a weekly timestep and includes all supply sources, 134 demand nodes, and is built on the constraint information that is maintained of the supply system for sources and transfers:

- Licence conditions (Section 2.1.1)
- Hydrological inflow sequences for reservoirs and rivers (Section 2.7)
- Groundwater yield constraint relationships with regional groundwater levels (Section 2.2 & 2.6)
- Water Treatment Works production capacities (Section 2.1.3)
- Flow transfer capacity constraints (Section 2.1.2)
- Reservoir control curves and capacities (Section 2.1.4)

2.3.2 Miser Development for WRMP24

To inform the Deployable Output assessment for WRMP19, the Miser model was run using whole horizon optimisation where single historical drought events such as 1975/76 were run through the miser model, and the model optimised to maximise deployable output to the drought event simulated. Following feedback from the Environment Agency on the last plan, and to meet the new requirements for deriving deployable outputs for 1 in 200 and 1 in 500 drought event, the Miser model has been developed to undertaken continuous simulation.

The main changes are as follows:

- **Control curves** have been developed and added to the model to manage both reservoirs and annual licence use from sources. These control curves are used to balance abstraction from different sources in the conjunctive use system.
- **Outage allowance** is now directly incorporated into the miser model with nodes representing an outage “demand”. The recommended methodology for deployable output assessment is that demand is successively uplifted to a point of failure in the model. The demand immediately prior to the point of failure is then used as the system Deployable Output that feeds into a lumped supply-demand balance calculation, from which outage allowance is the removed. The problem with the approach of using a system simulation model to derive DO that then feeds into a lumped supply demand balance calculation is that it takes the constraints on the Deployable Output in the wrong order. As a result, removing the outage allowance in the supply-demand balance calculation over-estimates the amount of water that would need to flow through transfers in the system simulation model, thereby potentially artificially constraining peak outputs. Further, removing outage from demand in the SDB calculation assumes that outage is consumptive as opposed to limiting peak source outputs, such that the outage allowance effectively artificially draws down reservoir storage and annual licence use.

The Miser model is now capable of running against a longer period of record in the order of 100-200 years of continuous simulation to more reliably understand deployable output across a broader range of drought events and simulate the selected drought library drought events (Section 2.8).

2.3.3 Miser Demand Profile

The base demand profile used in Miser for the DO simulations is an annual repeating demand pattern developed in combination with the peak factor analysis undertaken as part of the demand forecast (see Demand Forecast Technical Appendix), and has the same characteristics as the base-year DYAA and DYCP demand. The shape and timing of the demand pattern across the season was determined through analysis of the historical water into supply data, as undertaken as part of the peak factor analysis work. The rolling peak season (90 days), month and week across the 1990-2020 record were analysed. The highest peaks for each factor were filtered from the dataset (including 1995, 2003, 2006, 2018), and the timing of the peak season, peak month and peak week were taken as the average of those dry years.

2.3.4 Miser DO assessment

To undertake the DO assessment in Miser the drought library drought events were run through Miser using an “uplift to failure” approach to identify critical period and annual average yield. Given that the model will fail at different points for both annual average and critical period yield, the following approach was taken for each simulated drought event:

1. 11 increments of demand uplift were applied to the model at 2% increments of global demand and model results exported.
2. The model deficits export file – which contains the size, timestep and demand node of each deficit failure in the model, alongside the reservoir storage outputs, was analysed to identify deficits occurring because of annual average constraints (e.g. when reservoirs reach emergency storage and annual licence constraints where deficits typically occur in March during low demand) and deficits occurring due to critical period constraints (e.g. occurring during the critical demand period in July/August).
3. To identify the deficit volume, the relationship between deficits and the demand increments modelled was used to interpolate between demand increments to identify the total demand at the point of failure.

2.3.5 Mass Balance Calculation for Miser and Supply-Demand Balance

Some of the components of the mass balance equation in the supply-demand balance planning tables are already included in the Miser model. These need to be accounted for appropriately to avoid double counting. The following calculations were made when post-processing the Miser outputs to derive the DO figures to be used on the supply-demand balance calculation:

First DO is calculated as the demand met prior to the point of failure plus the outage allowance minus the imports and plus the exports used in the miser model so that the DO reflects the total demand met by Wessex Water sources:

$$DO = Demand_{Miser} + Outage_{Miser} - Imports_{miser} + exports_{miser} \tag{1}$$

The (Total) Water Available For Use calculations in the supply-demand balance calculation then remove outage add imports and remove exports:

$$WAFU = DO - \Delta DO - RWL - Outage \tag{2}$$

$$TWAFU = WAFU + Imports - Exports \tag{3}$$

2.4 Weather Datasets

Two primary sources of data are used inform about historical weather patterns in the Wessex Supply Area, form the basis of the stochastic dataset development, and used to develop and calibrate the hydrological models:

- **Rainfall** – Met Office HadUK (v1.0.2.1) 1km gridded rainfall aerially averaged to catchment areas and provided by the Environment Agency on May-2021 for the period 01/01/1891 to 31/12/2019. The data is provided under an Open Government Licence[6].
- **PET** – Potential Evapotranspiration dataset provided by and licenced by the Environment Agency (EA daily PET v1.0) and were provided as aerially averaged datasets for each catchment.

2.5 Stochastic Dataset Development

A stochastic weather dataset (rainfall and Potential Evapotranspiration (PET)) was used to simulate a range of more extreme droughts to inform the calculation of 1 in 200 and 1 in 500 deployable output return periods. The dataset used was that developed by Atkins as part of the Regional Climate Data project. The dataset is briefly described here and further technical information on datasets development can be found in the main report[7].

The dataset consists of 400 stochastic replicates of the weather (precipitation and PET) for the 1950-1997 period, resulting in a total of 19,200 years of data. The data was based on the HadUK 1km daily data and the EA PET dataset, as also used in hydrological model calibration. Spatially coherent precipitation series were generated at 195 locations across England and Wales using a stochastic model that predicts precipitation using a range of climate drivers such as the North Atlantic Oscillation (NAO) and Sea Surface Temperature (SST). The dataset was validated against the 1920 to 1949 period. In development of the dataset we liaised with Atkins to identify the most appropriate rain-gauge locations for generation of the dataset, a process which considered the rain gauge locations relative to topography, the catchments ultimately being simulated and the quality and completeness of

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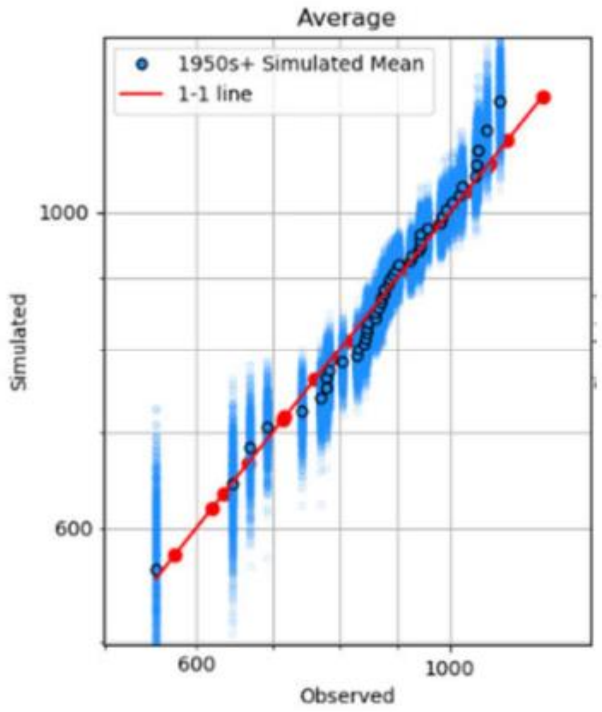
[6] Open Government Licence (nationalarchives.gov.uk)

[7] Atkins (2020) Regional Climate Data Tools: Final Report

the records at each gauge over the 1950-1997 period. Figure 2-6 and Figure 2-7, respectively, show example Q-Q plot and percentile plot comparisons of observed versus stochastically generated data; the latter showing the greater sampling of the stochastic dataset of more extreme, driver conditions.

The stochastic weather generator runs on monthly data; daily rainfall and PET is obtained by matching the monthly stochastic data on a “nearest neighbour” basis to the observed record, and taking the daily pattern of rainfall and PET from the month within the historic record that most closely matches the rainfall in the stochastic data for each month.

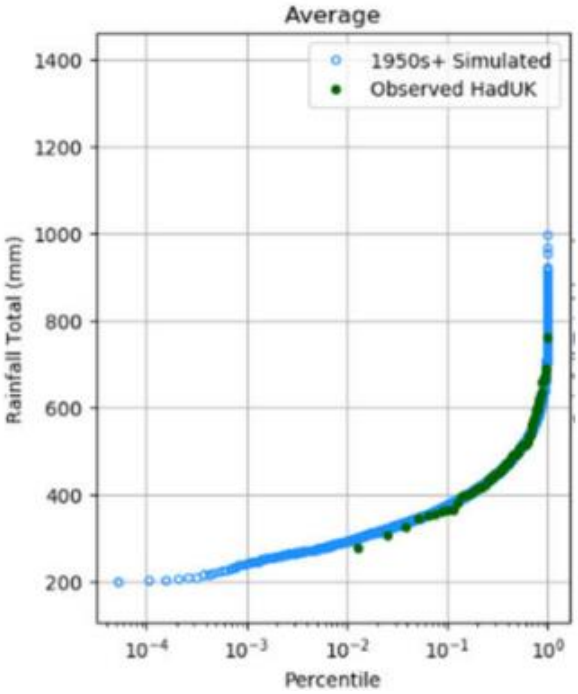
Figure 2-6 Example ranked rainfall QQ-plot[7]



These curves show the Q-Q plots of the observed versus simulated total rainfall (mm) (i.e. ranked years from driest to wettest for each simulation compared with the historic record). The black circles represent the mean of the simulation and the individual simulations form the blue ‘scatter’. The red line represents the 1-1 mapping between the simulated and observed values – i.e. if the black circles plot on the red line, then the average of the simulations is the same as the historic ranked value (i.e. the historic value falls close to the ‘expected’ ranked value based on the stochastic).

For additional context, the bold red dots on the 1-1 line indicate observed values that have not contributed to the simulated data (i.e. occurred before 1950).

Figure 2-7 Example percentile plot comparing observed to simulated percentiles[7]



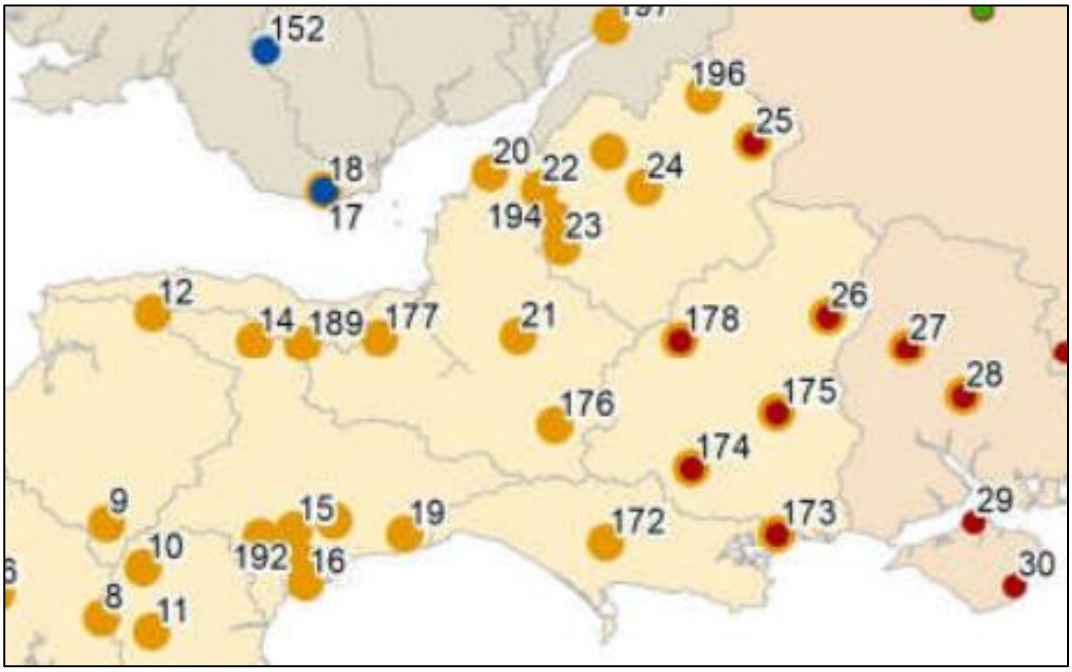
These curves show the cumulative percentile plots of the stochastic and observed rainfall. The blue dots show all the simulated data sorted from driest to wettest. The green dots show the sorted observed data from driest to wettest.

The observed data may contain more points than used to generate the stochastics. For example, in the plot the observed record includes data prior to 1950.

2.5.1 Stochastic dataset interpolation

For each of the catchments that are simulated in the Wessex Water area to provide inflows to our system simulation modelling, aerially averaged PET data was provided from the stochastic dataset for each catchment. However, the stochastic rainfall data was provided at the point gauges where it was generated (Figure 2-8, Figure 2-6), and therefore required interpolation to derive a stochastic rainfall time-series for each catchment.

Figure 2-8 Location of rain gauges used to generate the stochastic dataset[7], with gauges used by Wessex Water (and the West Country Water Resources Group) in yellow (or yellow outline).



To interpolate the rainfall, we identified the 3 nearest point rainfall locations to each catchment and calibrated multi-linear regression models between the aerially average historical rainfall for each catchment and the historical point rainfall data. These models were then applied to interpolate the stochastic rainfall. The coefficient of determination of the models for each catchment is shown in Table 2-2.

Table 2-2: Performance of the multi-linear regression models used to interpolate the stochastic point rainfall

For security reasons individual catchment names and not available in the version of this document published on our website.

Catchment	R^2
	0.906
	0.981
	0.995
	0.977
	0.929
	0.975
	0.943
	0.970
	0.994
	0.972
	0.976
	0.988
	0.959
	0.981
	0.901
	0.999
	0.900
	0.984
	0.986

2.6 Groundwater Modelling

The DO assessment for Wessex Water's supply system uses observation borehole groundwater levels to predict yield constraints at groundwater sources. Predictive models are therefore required for how the observation borehole groundwater levels respond to drought conditions to simulate source yield constraints in Miser DO assessment.

2.6.1 Observation borehole model structure

A lumped conceptual model is used to simulate groundwater borehole level at observation boreholes. The model is based on the HBV conceptual model structure, as implemented in the TUWmodel R package[8], as shown in Figure 2-9. The model structure consists of a snow routine, a soil moisture store which controls the balance of input rainfall and

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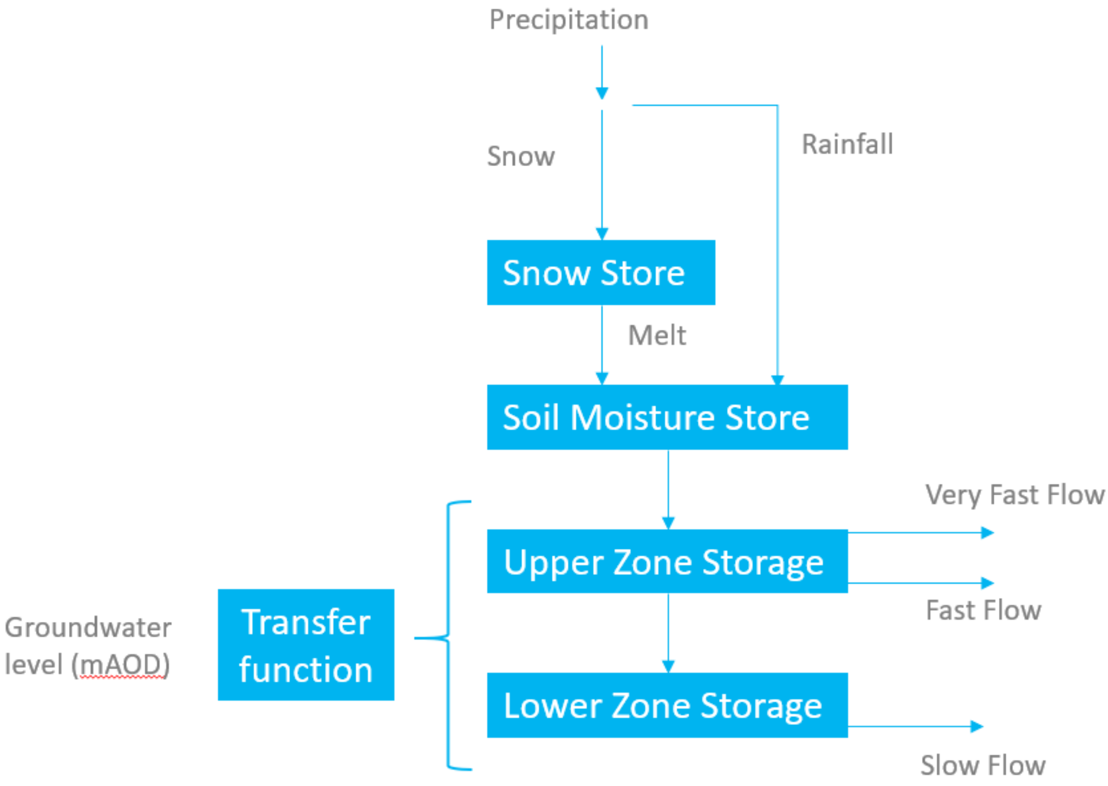
[8] Alberto Viglione and Juraj Parajka (2020). TUWmodel: Lumped/Semi-Distributed Hydrological Model for Education Purposes. R package version 1.1-1. https://CRAN.R-project.org/package=TUWmodel

evapotranspiration, and a flow routing routine. Excess rainfall leaves the soil moisture routine and enters the upper zone storage where it leaves through two faster flows, or is percolated into a lower zone storage. Water in the lower zone storage leaves through a slow flow component[9]. The rate of flow leaving upper and lower zone storage in the three outflows is controlled by three time-constant parameters.

To model the groundwater level, the combined total of lower zone and upper zone storage (in mm) are converted to a groundwater level (in meters AOD) using a transfer function – a power law model. The parameters of these transfer functions effectively represent the storage coefficient of the aquifer, as they scale mm depth of water storage in the aquifer to the aquifer depth (in meters)

Figure 2-9 Groundwater model structure based on the conceptual HBV model



2.6.2 *Calibration methodology*

The groundwater model is calibrated in a two-stage procedure:

- The TUWmodel is first calibrated by running 100,000 Monte Carlo samples from the prior parameter space to maximise the correlation between the depth of total storage in the model (mm) and the groundwater level (mAOD). The best 50 models when correlated to all groundwater levels and low groundwater levels (<Q75) are retained.

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[9] For further details see: Parajka, J., Merz, R., and Bloschl, G., (2007) Uncertainty and multiple objective calibration in regional water balance modelling: case study in 320 Austrian catchments, *Hydrological Processes,* 21, 435-446.

- Second, for each of these retained models, the power law model is fitted to minimise the Root Mean Square Error (RMSE) between the predicted and observed groundwater levels.

The best models are then manually appraised through time-series visualisation to identify the best model fit between observed and predicted groundwater level.

2.6.3 Example Model: Woodyates Borehole

Woodyates borehole is situated in Cranborne Chase measuring groundwater levels in the Wessex Chalk aquifer (Seaford Chalk) between Blandford Forum and Salisbury (see Table 2-3). The borehole has been measured since 1942, and groundwater levels can be quite flashy, with typical annual fluctuations of 25 metres, with evidence of rapid recharge (Figure 2-10)[10].

The borehole records are notably drier in the early part of the record, prior to ~1970, with the major droughts of 1975-76, and more recent dry periods of 1990-92, 2011-12 and 2003 observable in the record. Based on understanding of rainfall analysis contemporaneous with the groundwater level record, several groundwater level minima worse than or on a similar order of magnitude to 1975/76, suggests the earlier part of the record is unreliable. Based on this, and that the rainfall records for the region are better for the most recent part of the record, data from 1970 onwards is used in the calibration and validation.

Table 2-3: Woodyates observation borehole key information

Observation Borehole	West Woodyates Manor
Further Information	West Woodyates Manor | British Geological Survey (BGS)
Flows of interest	Primarily low groundwater levels
Observed data source(s)	Environment Agency
Observation record available	12/01/1942 – 31/12/2019
Calibration window (and dry periods)	01/01/1975 to 31/12/1994 (1975/76, some of 1989-1992)
Validation window (and dry periods)	01/01/1995 to 31/12/2019 (1995, 2003, 2011)

Figure 2-10 Historical Time-series of Groundwater Level (mAOD) at Woodyates borehole

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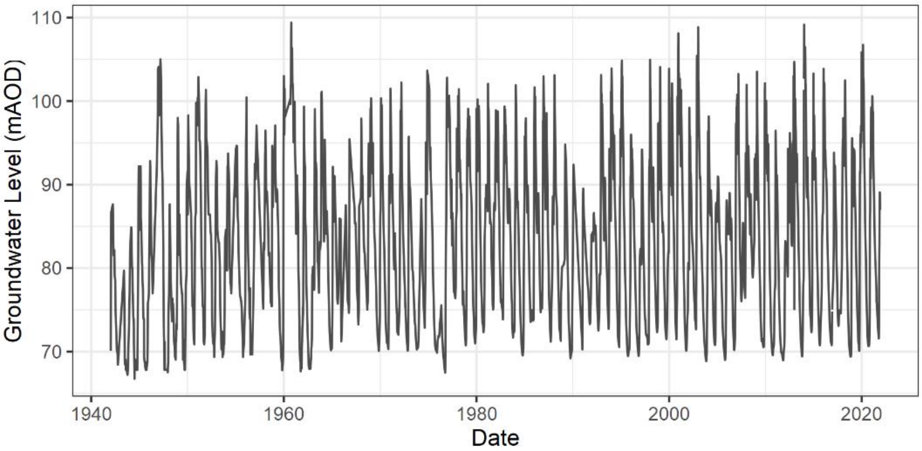
[10] West Woodyates Manor | British Geological Survey (BGS)



The calibration window was chosen from 1975 to 1994, to include the 1975/76 drought and some of the dry period from 1989-1992, although some of the data are missing for this period. The validation period is from 1995 to 2019, and includes the dry periods in 1995, 2003, and 2011.

The groundwater observation record since 1942 has different monitoring frequencies. The record prior to the early 1990’s had observations between 0 and 50 days apart (mean ~10 days), and a continuous daily record since the early 1990’s. For calibration and validation purposes, and so as to avoid biasing the model calibration fit to the more frequently observed, recent part of the record, the observation record was thinned to retain observations with a 14-day frequency, whilst also retaining each annual minima in the record to keep the low flows of primary interest in the dataset.

Figure 2-11 shows a scatterplot comparison of Woodyates observed and predicted groundwater level, and Figure 2-12 and Figure 2-13 show an example time-series of performance in, respectively, the calibration and validation periods. During the calibration period the R^2 between observed and modelled is 0.89 and during validation 0.91. the calibration RMSE at low flows is 3.06m.

Figure 2-11 Scatterplot comparison between Observed and Modelled Woodyates groundwater level

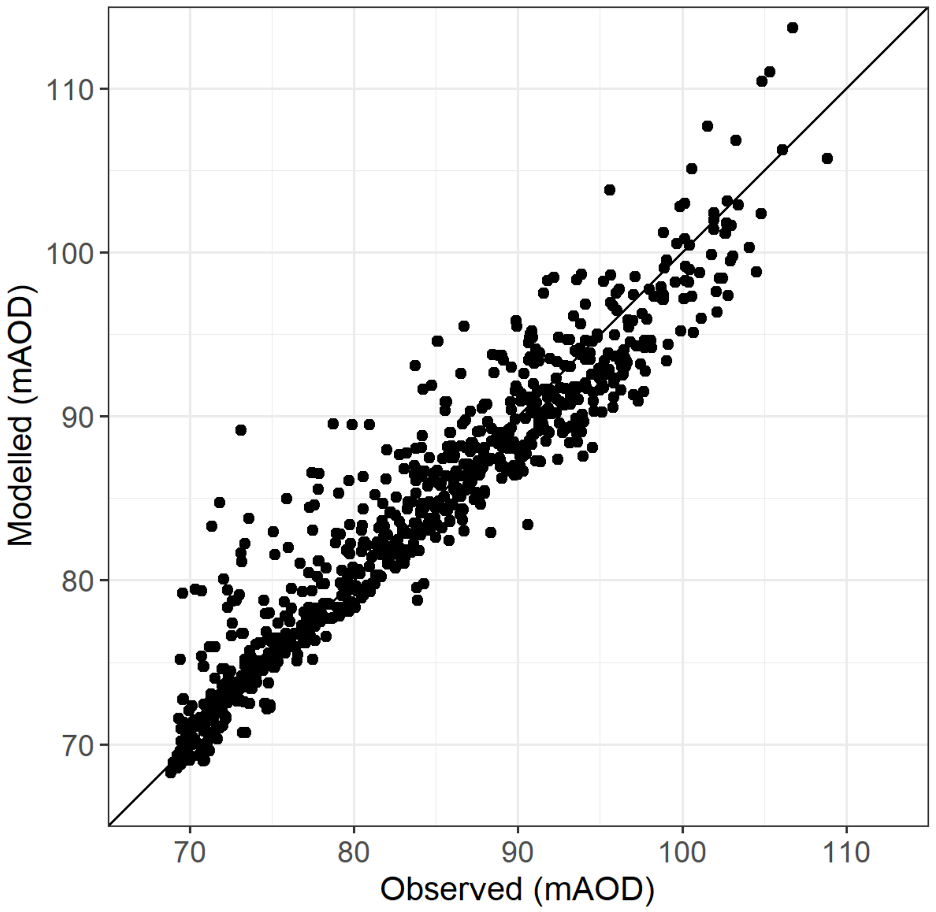


Figure 2-12 Time-series comparison of predicted and observed woodyates groundwater level from 1974 to 1982

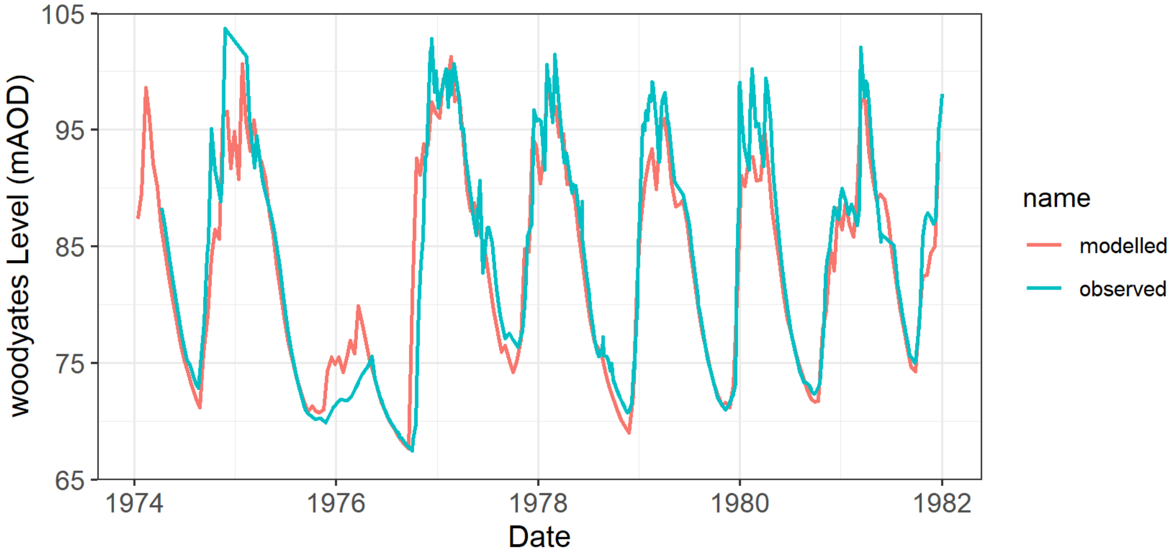
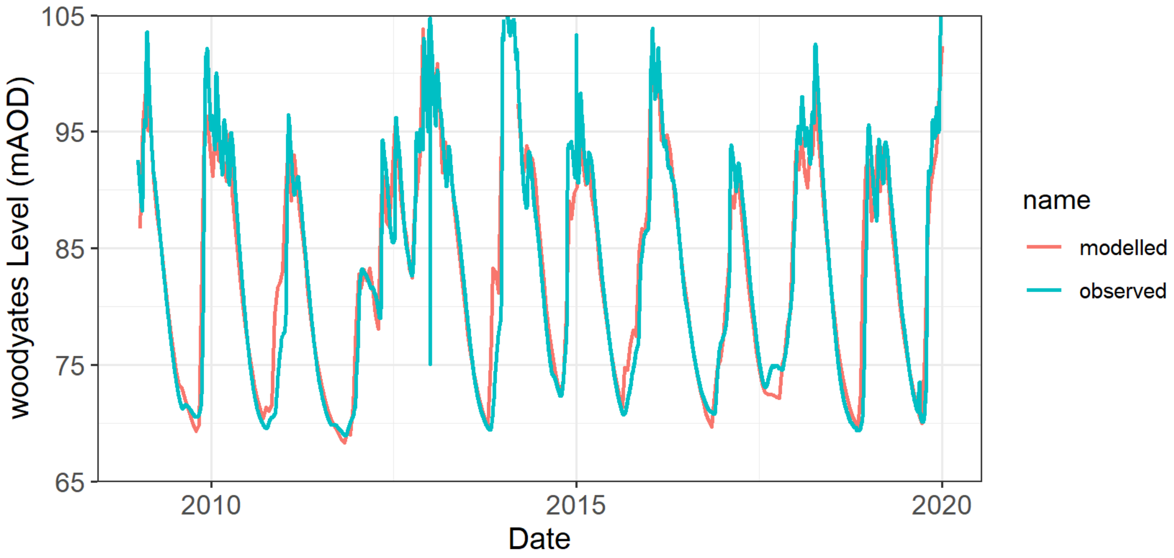


Figure 2-13 Time-series comparison of predicted versus observed for Woodyates borehole from 2008 to 2020



2.7 Surface Hydrological Modelling

Models of river flows are required as they constrain DO in two ways:

- Determine the amount of water that flows into reservoirs from upstream catchments.
- Determine licence conditions that control when water can be abstracted from specific groundwater and river sources.

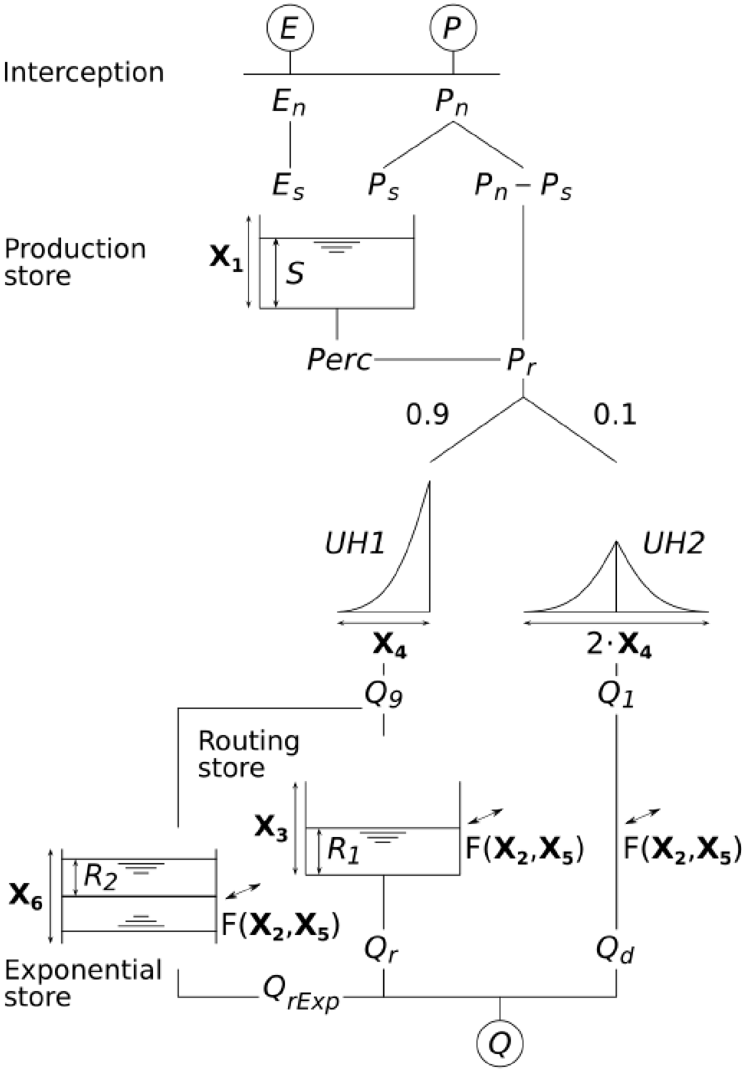
Simulated or observed river flows for key droughts are therefore included in the Miser system simulation model to constrain DO, and models are needed to translate stochastic weather datasets into stochastic inflows for simulated drought events (drought library events) in the miser model.

In this section the model applied to simulate surface flows – the GR6J hydrological model – is first explained (Section 2.7.1). Following a description of the general methodology, a more detailed description of the specific approach taken for calibration of low flow condition models, with an example catchment, and a description of the approach taken for reservoir catchments, is provided.

2.7.1 GR6J hydrological model

The GR6J model framework is a modification of the GR4J which adds two additional parameters, X2 and X5, which allow to water to enter or leave the system. The framework is a lumped model which take in precipitation and potential evapotranspiration at a daily time step to produce a river flow time series. See Figure 2-14. Further details of the model structure can be found in Pushpalatha et al (2011)[11].

Figure 2-14: GR6J model framework[11]



There are 6 model parameters to tune within the framework:

- X1: production store capacity [mm]
- X2: intercatchment exchange coefficient [mm/d]
- X3: routing store capacity [mm]
- X4: unit hydrograph time constant [d]
- X5: intercatchment exchange threshold [-]
- X6: exponential store depletion coefficient [mm]

2.7.2 General methodology

The main outcome of the calibration work is to produce a model that can simulate a weekly inflow for miser, which can be interpreted to reflect how a source might be restricted under a given licence. There are several types of licence which can be modelled in Miser, such as

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[11] Pushpalatha, R., C. Perrin, N. Le Moine, T. Mathevet, and V. Andréassian (2011), A downward structural sensitivity analysis of hydrological models to improve low-flow simulation, J. Hydrol., 411, 66–76, doi:10.1016/j.jhydrol.2011.09.034; R: Run with the GR6J hydrological model (r-project.org)

stream support, threshold licence changes in order to calibrate a model to predict when licences will impact DO, and reservoir inflows.

2.7.3 Calibration set-up and methodology

For each catchment a data file was created which summarises all the key data that is needed to create a target flow. The target flow could simply be data from a flow gauge which might be cleaned of missing data or spurious values, but it can involve naturalising the flow so this can be used in miser to predict the impact on DO more accurately. An example of this might be removing stream support from a river so miser can then model how much to augment the river.

Calibration and validation windows are set up so that both windows have average and dry years – the latter being the primary point of interest for WRMP modelling - to help calibrate the model but to see how it performs in dry years it hasn't seen before.

To undertake calibration, GR6J was calibrated using a multi-objective optimisation algorithm in R called NSGA-II. The output of the calibration is a population of parameter sets that are on the pareto front reflecting the trade-off across the calibration objectives. The population of calibrated models is then run for the validation period to calculate validation model performance.

Calibration Objectives

Performance of hydrological models is often or traditionally assessed (e.g. in calibration or validation) in terms of generic metrics of model performance such as a Root Mean Square Error (RMSE) or Nash-Sutcliffe Efficiency (NSE). The general nature of these metrics, calculated across the full range of flows, means that when used to choose a "best" model for a specific application, they are not necessarily tailored to the specific needs to which the model is to be applied. There are further issues in that some of these metrics, in the manner in which they aggregate the errors across observations, over-emphasise the importance of some types of error – e.g. metrics based on squared errors will typically over-emphasise the importance of fitting high flows.

More specific information may be derived from how well a given model reproduces different parts of the hydrograph that are relevant to the specific purposes of a model application. These more specific metrics of performance are often termed signatures, which are used in hydrology for characterising catchment behaviour, and for calibrating specific parts of hydrological models and their structures.

What is key is that when developing hydrological models for a specific applications, the metrics need to capture how well a model performs in achieving a specific outcome. The outcome of this work is to use the hydrological models to constrain available abstraction as part of the DO assessment under severe 1 in 500 drought conditions.

The metrics used to undertake model calibration need to represent how well the model performs in predicting the constraints on available abstraction in time, with particular focus on dry/drought conditions. This will depend on how the supply system interacts with the specific flows gauge point, and the licence conditions that the flow prediction constrains.

For the two different types of model type as input to system simulation modelling, Table 2-4 summarises the metric types/hydrograph characteristics of most interest.

Table 2-4 Metric types for simulation modelling

Calibration type	Relevant Metrics/Hydrograph characteristics
Reservoir Inflow Model	Total winter recharge inflows to re-fill the reservoir; receding flows during dry periods and drought; speed of recovery from dry/drought conditions following rainfall.
Licence condition/Flow trigger	low flows near to flow thresholds; prediction of flows above and below flow thresholds, and timing of when flows cross low flow thresholds that constraint licenced abstraction availability.

2.7.4 *Licence condition catchments*

The catchments that have had models calibrated to them as they control licence conditions in our system and miser model are shown in Table 2-5. The next section shows an example calibration for a catchment.

Table 2-5 Summary of catchments for calibration

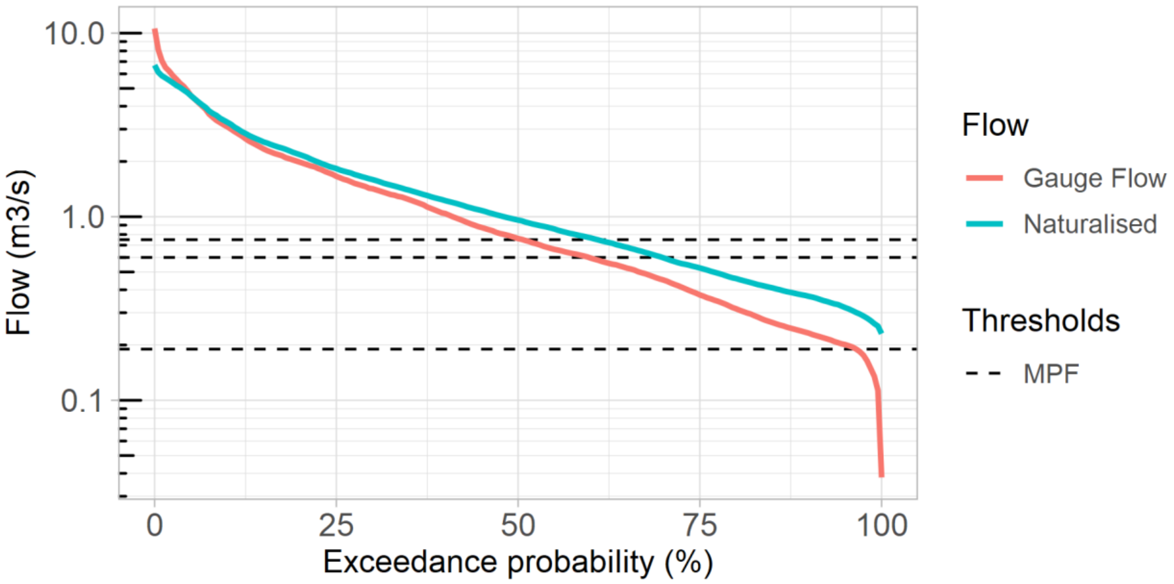
For security reasons this table is redacted and not available in the version of this document published on our website.

2.7.5 *Example Calibration: Catchment*

For security reasons parts of this section have been redacted and not available in the version of this document published on our website.

Figure 2-15 shows a comparison of the flow duration curve between gauged flow and naturalised flow (note the log x axis scale). At Q95 – e.g. dry weather representative of drought conditions to be modelled - the difference between naturalised and gauged flow is 0.12 m^3/s, which compares to a 9Ml/d stream support of 0.1 m^3/s.

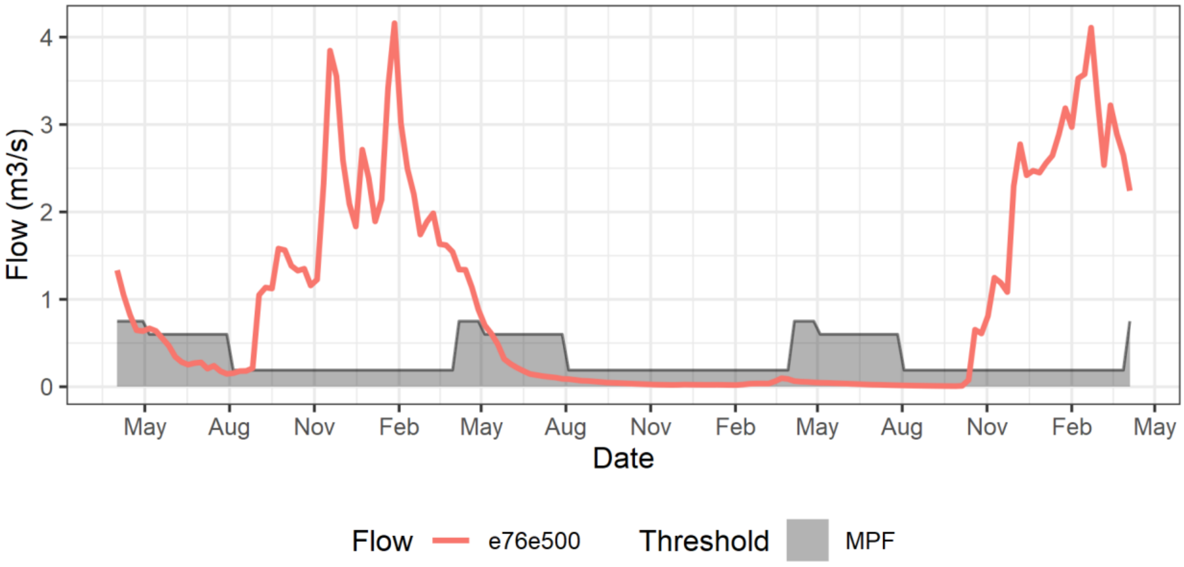
Figure 2-15 Flow Duration Curves for naturalised flows and gauges flows and dashed lines showing the prescribed licence flows for stream support



Sensitivity of Deployable Output to flow simulation during drought

Figure 2-16 shows a simulated 1 in 500 drought plotted against the licence flows, based on the HBV model calibrated models from WRMP19. The flows show that for the core of the drought period the flow is below the licenced flow conditions requiring stream support. Therefore, critical period DO at the source during the peak of a drought has no sensitivity to the flow threshold. Annual Average DO will be sensitive to the timing of when the flow crosses the low flow threshold and then flow returns above, following the end of the drought; during the dry winter in the middle of the drought period, the flows do not re-cross the flow threshold. The simulations show that sensitivity will be low given that the flow crosses the thresholds once at the start and once at the end of drought. We therefore conclude that the annual average flow sensitivity to the flow threshold prediction is also low.

Figure 2-16: 1 in 500 drought flow simulation using previous calibrated models plotted against flow thresholds



Flows used for calibration and prediction in Miser

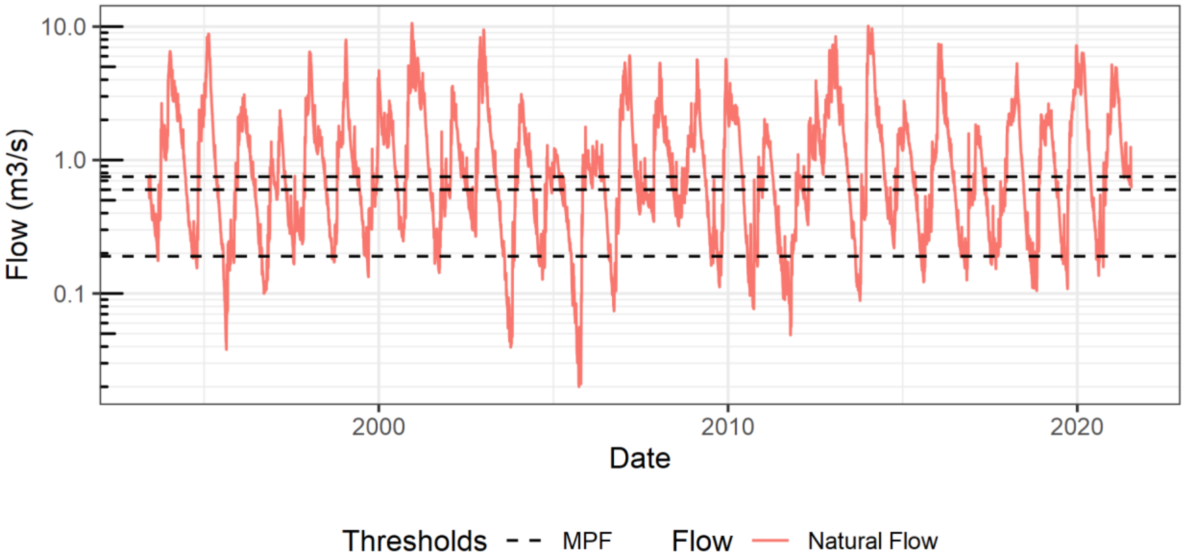
The Miser model uses as the flow threshold to determine available licenced water the combination of stream support and the upstream inflow. Given that at low flows (e.g.Q95) the stream support input is the main difference between the naturalised and unnaturalised flow, the flow used for calibration is taken as gauged flow minus stream support influence.

Whilst other abstractions upstream will influence the flow prediction, the difference between gauged and naturalised when stream support is accounted for is low. Licence reductions over time mean abstractions in the historical calibration record are likely to be higher than in the future scenarios modelled. This means it is possible in the future scenarios modelled, when calibrated to the historical record, that the flows will be lower than would occur, therefore we will trigger meeting these low flow thresholds earlier. It is therefore unlikely we will over-estimate available DO from the source. The approach is deemed proportionate given the low sensitivity of DO in drought to the flow threshold. Any temporal variations in flow threshold accuracy can then be captured in headroom.

Calibration period

Figure 2-17 shows a time-series plot of the flow; key dry periods occur in 1995, 2006 and 2012. For calibration we have chosen from 1993 to 2009 to capture these dry periods in calibration – the primary interest for model application – with dry periods in 2012 in particular in the validation period. Both calibration and validation periods include multiple years where the flow thresholds in the licence are crossed, which are the primary flows of interest to capture in the model.

Figure 2-17: Time series plot of flow of flows for Catchment



Calibration metrics

Based on the flows of interest, the following calibration metrics have been included in multi-objective calibration:

- **RMSE: Q50 to Q100** – the root mean square error in flow prediction at low flows between Q50 and Q100, covering the flow percentiles of interest.

- **MPF error** – the number of days (timestep in model) that the flow prediction is incorrectly above or below the licenced flow threshold of interest compared to the observe value. This captures how well the model captures the binary signal that controls water available for DO.
- **RMSE: MPF** – RMSE of all flows below the MPF – e.g. focussing on low flows. The purpose of this metric is to help capture the timing of when the flows go below and then back above the MPF

Calibration Results

Table 2-6 shows a summary of the model prediction results. The optimal model for each objective is similar– e.g. there is no real trade-off in the model run between identification of the best performing model in validation. This is perhaps not surprising as all calibration metrics are focussed on the portion of the flow regime of interest, and the low flow thresholds.

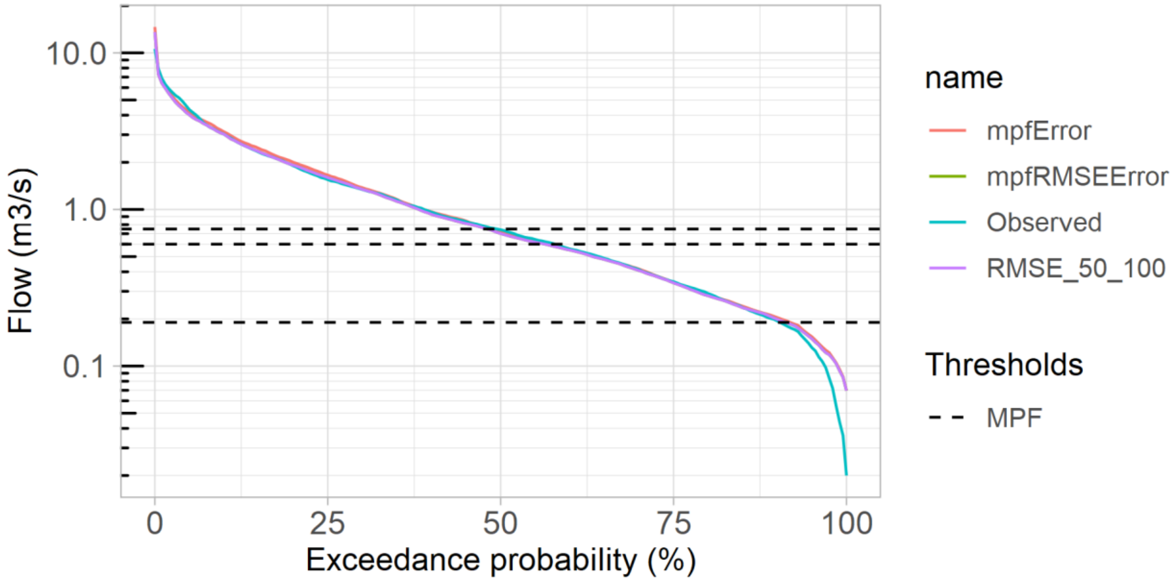
Table 2-6: Summary results of model performance in validation for each model optimised to each calibration objective*

Metric	val_mpfRMSEError	val_RMSE_50_100	val_mpfError
val_mpfRMSEError (m^3/s)	0.052	0.052	0.055
val_RMSE_50_100 (m^3/s)	0.081	0.081	0.088
val_mpfError (fraction)	0.070	0.070	0.065
Cal. % flows wrongly above	2.5%	2.5%	2.2%
Cal. % flows wrongly below	3.0%	3.0%	2.7%
Cal. AA Daily DO error (Ml/d)	-0.05	-0.05	-0.04
Val. % flows wrongly above	0.8%	0.8%	1.1%
Val. % flows wrongly below	6.1%	6.1%	5.4%
Val. AA Dailt DO error (Ml/d)	-0.47	-0.47	-0.39

*each column shows prediction performance when the model is calibrated to that specific metric: against all calibration objectives considered (top three rows); percentage of mis=classifications and resultant Annual Average Deployable Output error compared to observed flows in calibration and validation.

The observed and predicted flow duration curves are shown in Figure 2-18 and Figure 2-19 for the calibration and validation windows, respectively, with an example time-series plot shown in Figure 2-20. The plots show a strong fit in particular during calibration for flows less than Q50, covering the range of the low flow thresholds, as reflecting the calibration metrics. The model fit is slightly less strong in validation with some larger predictive error between Q50 and Q75, but close prediction at the low flow thresholds.

Figure 2-18 Comparison of predicted and observed model performance when calibrated to each objective during calibration, with low flow thresholds (MPF) shown.



As shown in the summary table, the predictive errors in the metrics have been converted into a binary error during calibration and validation of where the model mis-classifies flows being above or below the predictive threshold. The model calibrated to the mpfError show total errors of 4.9% in calibration and 6.5% in validation. When converted into DO errors on an annual average basis, the error is -0.04 Ml/d in calibration and 0.39 Ml/d in validation, which compares to a dry year 1 in 500 DO of 10.81 Ml/d.

Figure 2-19: Comparison of predicted and observed model performance when calibrated to each objective during validation

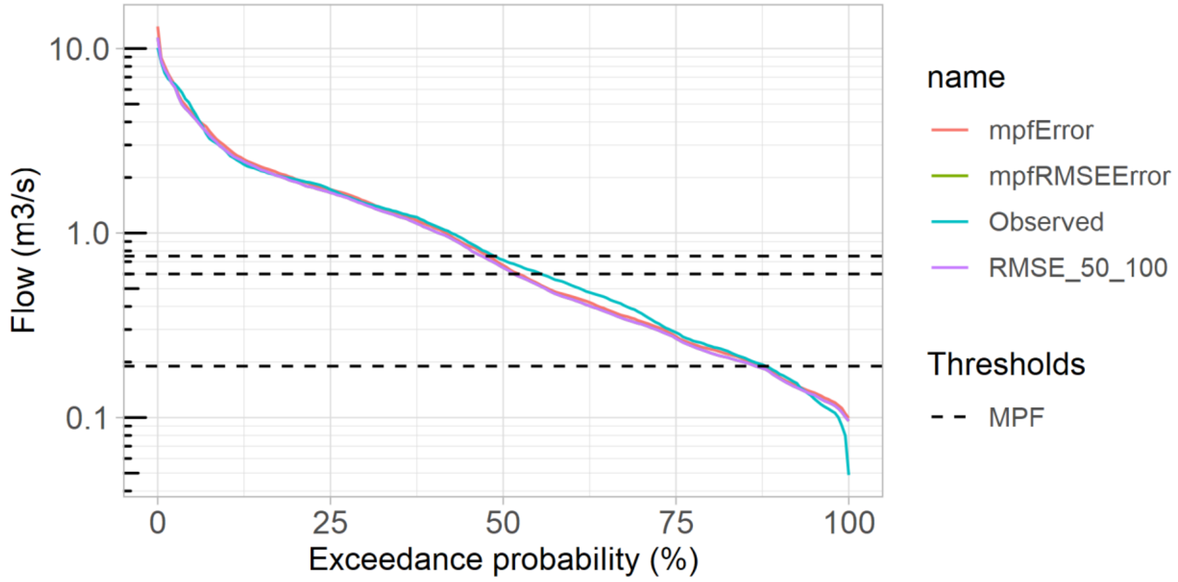
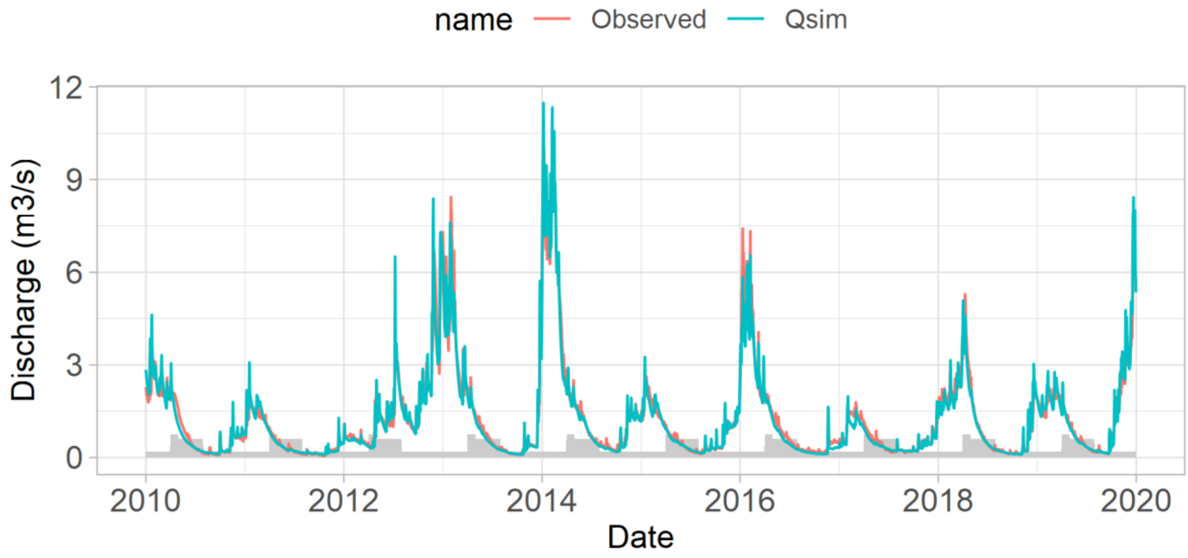


Figure 2-20: Observed versus Predicted flows in the validation time-series when calibrated to the MPF error metric



Calibration conclusion

Given the strong model fit to the observed data, and that the same single model was optimal across all objectives in validation, this model was chosen for input to the Miser model.

2.7.6 Reservoir Modelling

The amount of water that flows into reservoirs and how this varies over time determines, alongside pump storage and the size of the reservoir, the amount that reservoir storage draws down over time, and therefore the amount of DO available from reservoirs into supply.

Wessex Water has 7 reservoirs that require inflow prediction from the upstream catchments (Table 2-7). A number of different data sources have been used to calibrate the inflow model for each reservoir, depending on data availability. A two-step approach for reservoir model calibration has been applied:

1. Data source identification and validation
2. Model calibration

Table 2-7 Wessex Water Reservoirs Summary

For security reasons this reservoir names have been redacted from the table and not available in the version of this document published on our website.

Reservoir	Catchment Area (km^2)
	3.36
	10.8
	28.59
	16.34
	18.2
	3.54
	28.8

<u>Data source identification and validation</u>

The main aim of stage one is to collate and evaluate the data available to define an inflow timeseries for each reservoir for calibration. In most cases, several inflow records were identified, which were subsequently compared and evaluated against one-other. This comparison facilitated the identification of potential erroneous time-windows in the data, which were either omitted, changed, or accepted to produce a final inflow timeseries to be used in calibration. Sources of hydrological data are typically uncertain, and so several different sources of data were identified to calibrate each reservoir:

- **Mass balance inflows** – inflows derived from re-arranging other components of the reservoir mass balance equation (e.g. storage, compensation flow and abstraction).
- **Gauged streams** – gauged inflows for streams flowing into the reservoir.
- **Regionalised inflows** – gauged flow from near-by or similar catchments adjusted to derive a reservoir inflow based on some regionalisation method such as catchment-area ratio.
- **Qube data**[12] - time-series of flows forecast using Qube is available from 1961-2015.

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[12] Qube is the latest web-based software development of the LowFlows Enterprise software, and can provide flow time-series for gauged and ungauged stream locations in the UK: Qube Technical Note – Time-Series Modelling (WHS).

Reservoir Mass Balance data validation

To derive an inflow timeseries to be used in model calibration, observed data of components of the reservoir mass balance can be collated on changes in storage and outflows, and re-arranged to calculate the reservoir inflow using the mass balance equation. This equation differs slightly with the functioning of each reservoir, but is broadly defined as:

$$inflow_{t-1} = \frac{S_t - S_{t-1}}{\Delta t} + pumpedStorage_{t-1} + compFlow_{t-1} + abstraction_{t-1} \qquad (1)$$

Where S_t is the reservoir storage at each timestep. Where necessary, timeseries of data for each component of the mass balance equation have been stitched together from multiple sources to maximise the date range, given changes in measurement technology over time. This is most common in the case of the compensation flow, where records are commonly available from differing gauges as they change over time (v-notch and v-crump).

Once all mass balance data is collated, and an inflow calculated using Equation 1, the data are validated using a triangulation approach to identify and process any errors in the mass balance data. To achieve this, the following stages are applied:

1. A prediction of the inflows is obtained independently from the mass balance data - e.g. from Qube data or regionalised model (regionalised either by parameter set or catchment transposition of a flow time-series). This inflow acts as a benchmark model.
2. The benchmark model is used in the mass balance equation, which is re-arranged accordingly to derive for each mass balance component, two time-series.
3. These two time-series are compared through a cross-validation, with a series of automated data checks and visual comparison, to identify any errors in the mass balance data. Data that is identified as potentially erroneous is either:
    a. removed from the calibration/validation dataset;
    b. accepted as legitimate data;
    c. or an adjustment is made to correct the data – e.g. a transposing a component of the mass balance data in time.

   The decision on which of these approaches to take depends on the nature of the error, as well as on the length of the data record, and in particular whether this may cover a dry part of the record, and whether there may be any particular additional information content in the data that is worth preserving in the inflows.

For step 3, the validation proceeds as follows:

1. The available time-series was broken up into distinct, numbered windows depending on whether the reservoir was full or not full. This resulted in a population of individual windows, in which metrics measuring the quality of the data can be calculated.
2. For each window, depending on whether the reservoir was full or not full, 4 error metrics were calculated, and thresholds defined in these metrics to flag potentially erroneous parts of the time-series (Table 2-8).
3. These error metrics were visualised alongside time-series plots of the different time-series to help validate the data (Figure 2-21 and Figure 2-22). This analysis is done

using zoomable interactive graphs produced using the dyGraphs package[13] from the R programming environment[14].

Table 2-8 Error metrics used for reservoir mass balance validation

Error Metric	Description (flag threshold)	Notes
Inflow correlation	Correlation of the benchmark and mass balance derived inflows (< 0.6)	Measures the performance of all the data components by comparing the derived mass balance inflow with the independent benchmark model
Inflow-Outflow mass balance error	Percentage error of the sum of benchmark inflows and the sum of raw outflows (> 30%)	By calculating the percentage error in each "full" or "not full" window, any error in reservoir storage data is removed (as from the start to the end of the calibration window there is no net-change in storage), and the data compares total inflows to total outflows.
Inflow Outflow error	Percentage error of the modelled inflow and derived inflow (> 30%)	Measures the performance of all the data by the end of each window – similar in scope to metric 2
Compensation flow flags	Compensation Flow Flags based on how long the percentage tolerance of the compensation flow is violated in any given window.	Validates the compensation flow data by looking at where compensation flow (compensation flow plus gauged spill) is near to the expected compensation flow if the reservoir is full or not full.

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[13] Dan Vanderkam, JJ Allaire, Jonathan Owen, Daniel Gromer and Benoit Thieurmel (2018). dygraphs: Interface to 'Dygraphs' Interactive Time Series Charting Library. R package version 1.1.1.6. https://CRAN.R-project.org/package=dygraphs

[14] R Core Team (2021). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Figure 2-21: Flagged windows superimposed on the error metrics calculated for that window

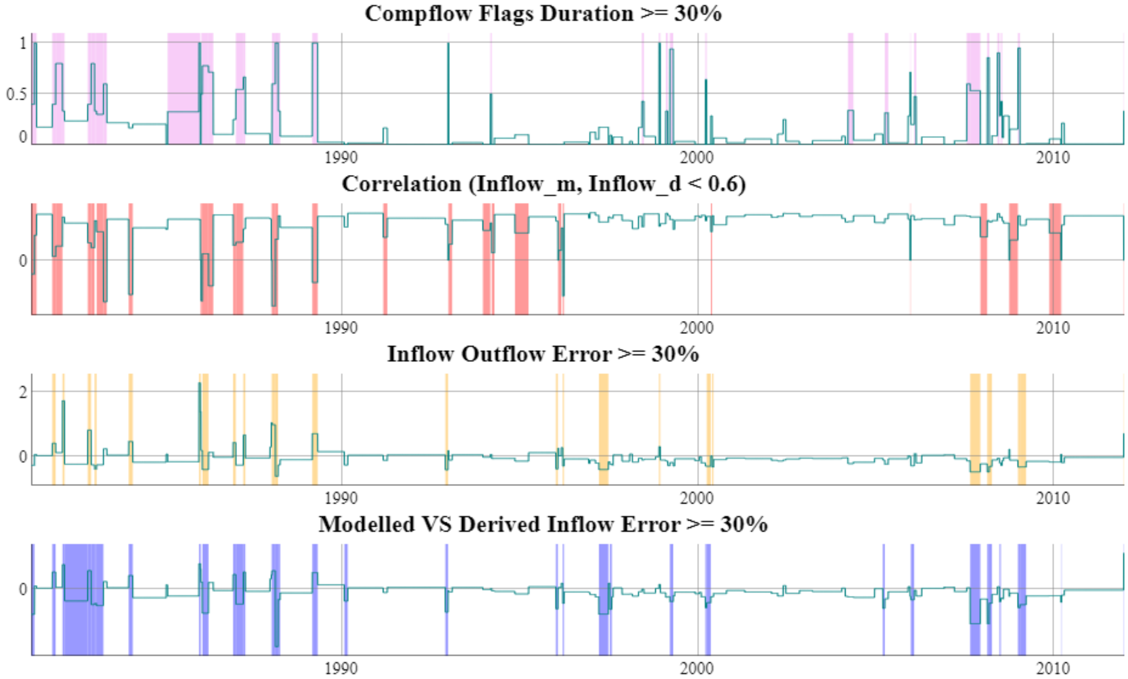
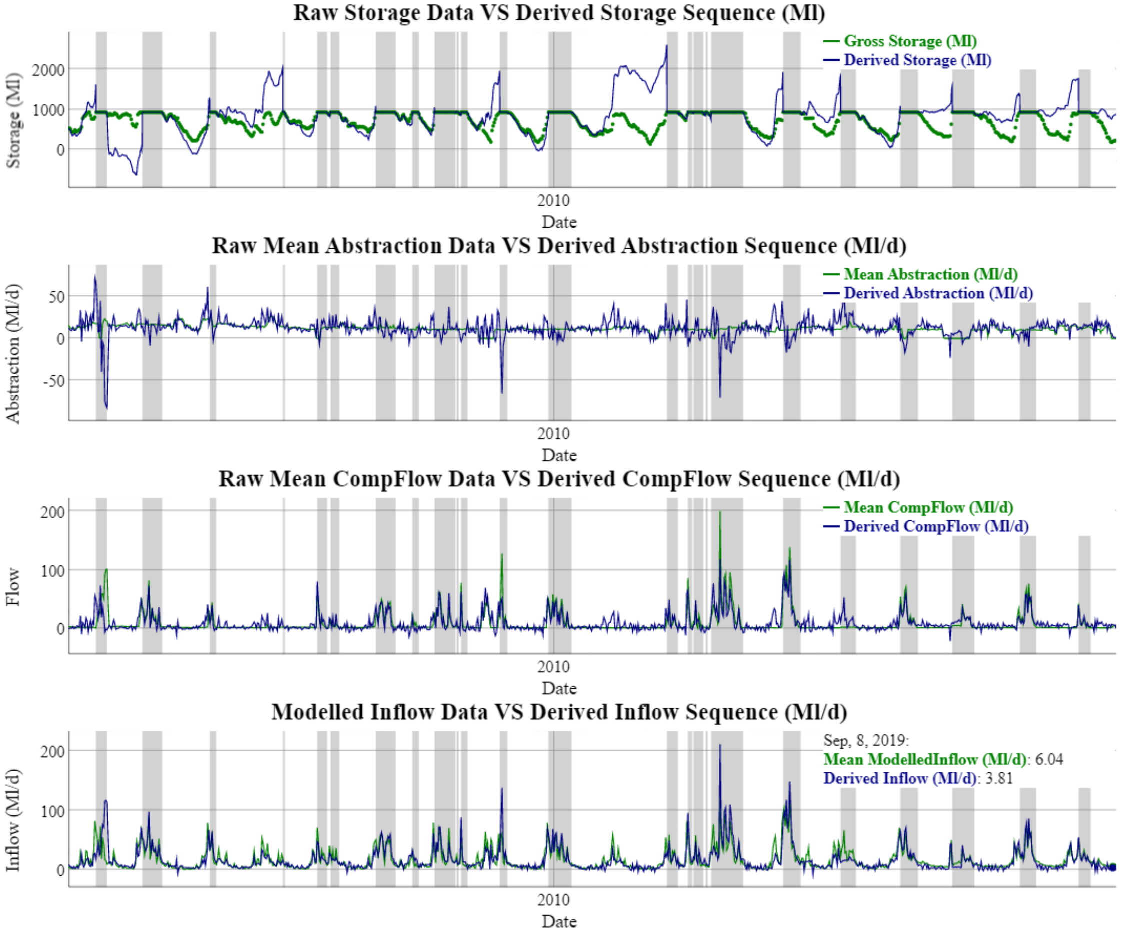


Figure 2-22: Mass balance components compared between observed and those derived using the benchmark model. grey bars indicate periods of the time-series when the reservoir is full



The main output from this stage to feed into model calibration is an inflow time-series derived from the reservoir mass balance data, with the time-windows of the time-series that are to be used in calibration accepted (the windows of the inflow data that are either full or not-full), and those other parts of the time-series with potential bad data, rejected.

An implicit assumption of the approach taken for validating the reservoir mass balance derived inflows is that the independent benchmark inflow data used is in and of itself correct. The main purpose however of this validation stage is to identify and process more obvious and significant deviations in the mass balance data that lead to erroneous looking time-series that could significantly bias the calibration.

Timeseries comparison

Once the different reservoir inflows time-series were derived, they were compared through a series of plots to check for consistency between the datasets to use for calibration:

- **Hydrograph time-series plots –** to check the timing and agreement of the data as well as against any available spot flow gauging data.
- **Cumulative inflow plots –** to check the mass balance and deviation in mass balance between inflows over time, which is particularly important for reservoir modelling.

Through this process, and screening of the datasets, appropriate datasets, and time windows for calibration and validation of the data were chosen. Whilst errors were screened through cross-comparison of datasets for calibration, calibration error was also accounted for in the headroom analysis. (see Technical Appendix - WRMP24 Supply-Demand Balance, Decision-Making and Uncertainty).

Model Calibration

The calibration approach for reservoir inflows follows the same general steps as defined in Section 2.7.3. However, for reservoir catchments a specific set of calibration metrics were chosen based on those aspects of the flow regime that are relevant to reservoir storage drawdown and deployable output assessment.

DO of reservoir storage – the amount of available water that can be supplied during drought periods – is the key application of the inflow models. This is controlled by how full the reservoir is following the winter recharge period, and how quickly the reservoir draws down from its post-winter storage level during the spring, summer, and autumn. Given the buffering/filtering effect of the reservoir storage itself, the ability of the model to capture peak winter flows is not of interest; what matters is that the model predicts the total winter inflows to the reservoir which control the total storage, and time at which the reservoir starts drawing down. In addition, the primary application of the models are in drought periods when conditions in the catchment are dry and reservoir storage is drawing down during receding inflows. Figure 2-22 shows the difference in the flow regime between high and low flows (Bottom sub-figure) when the reservoir is full and not full (shaded areas and storage change in top sub-figure).

Therefore, the most relevant metrics are total winter recharge inflows; receding flows during dry periods and drought; and speed of recovery from dry/drought conditions following rainfall. The three chosen calibration metrics are therefore:

1) **RMSEnotFull** - which calculates the root mean squared error of the timeseries across the timesteps where the reservoir is not full – this captures the variability in flows controlling reservoir draw-down and recovery
2) **MBnotFull** - which is the cumulative mass balance error during the windows where the reservoir is not full – during off-full windows this metric captures the total mass balance during drier periods.
3) **MBfull** - which is the cumulative mass balance error during the windows where the reservoir is full – captures total winter inflows when the reservoir is full.

Three metrics have been chosen for use in the multi-objective calibration, which each focusing on evaluating performance where the reservoir is either full or not full. To determine which parts of the data to use for calibration and validation, a roughly 80:20 split of the data is used – the split is partly motivated by the length of the reservoir calibration records, which are largely based on more recent data over the last 20 or 30 years. When determining the split, the inflow time-series and reservoir storage data were examined to identify appropriate dry periods in both calibration and validation. The split was not done on a continuous basis, but on different windows of the datasets.

Once the optimisation has been run, a table of possible output parameters is produced, alongside the error metrics associated with each parameter set. All parameter sets are run through the GR6J model to produce the following outputs:

- Interactive graph of the ensemble of optimal inflow timeseries, where the inflow data collated in the initial data identification is also added to the graph.
- Cumulatively inflow plots.

2.7.7 Example Calibration: A Reservoir

For security reasons parts of this section are redacted and not available in the version of this document published on our website.

Inflow mass balance data was derived for the reservoir using reservoir storage data, compensation flow, abstraction and pump storage inflows. The mass balance data was then compared to regionalised inflows from three sources:

- Qube – comparison to Qube regionalised data
- Halsewater flow gauge (station number 52003) - 87.8km^2 catchment, draining the south western side of the Quantock Hills. Data was regionalised based on the catchment area ratio.
- Currypool flow gauge (station number 52016) – 15.7km^2. Data was regionalised based on the catchment area ratio.

Total cumulative reservoir inflows across the available datasets show good agreement between the different data sources (Figure 2-23). More differences are observed between datasets when looking at cumulative inflows when the reservoir is full (Figure 2-24; generally higher flows) and when the reservoirs is off-full (Figure 2-25; generally lower flows); when the reservoir is full there is good agreement between different reservoir inflows except the mass balance data, which is higher than all other inflows; when the reservoir is off-full, mass balance data has lower inflows than the other data sources.

Figure 2-23 Comparison of cumulative inflows across calibration datasets

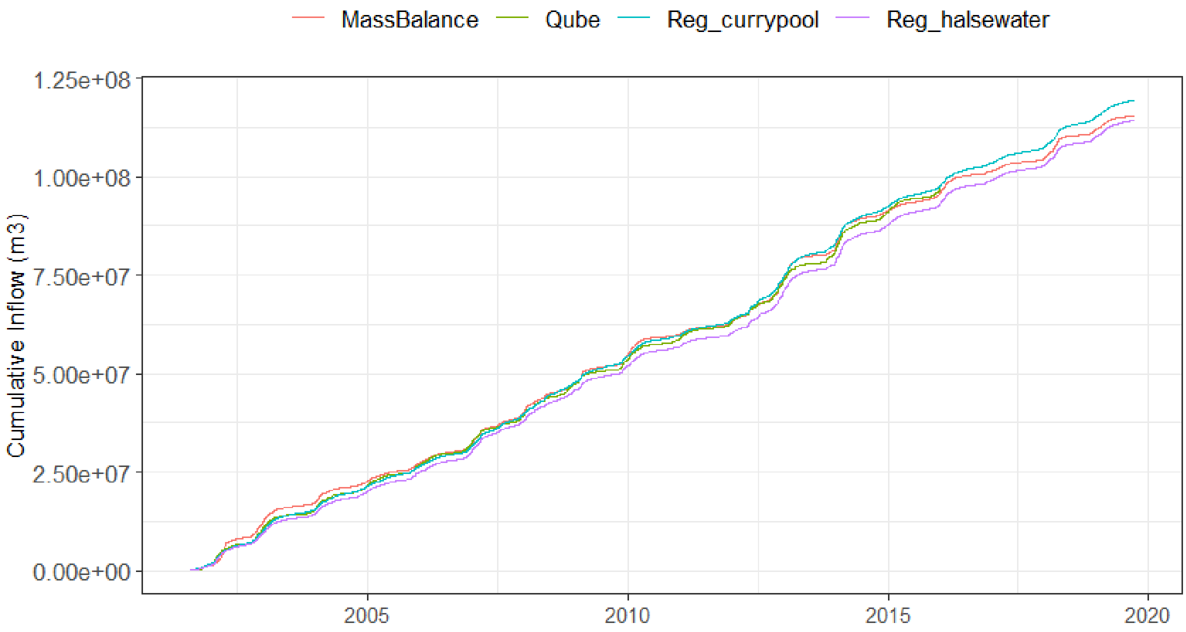


Figure 2-24 Cumulative reservoir inflows when the reservoir is full

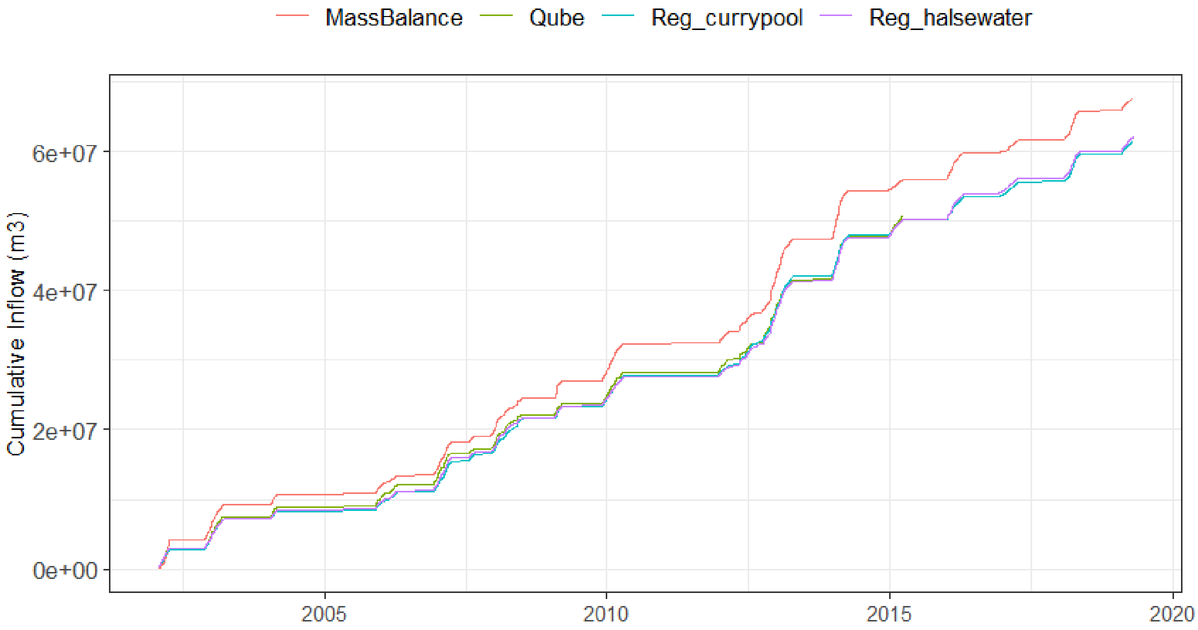
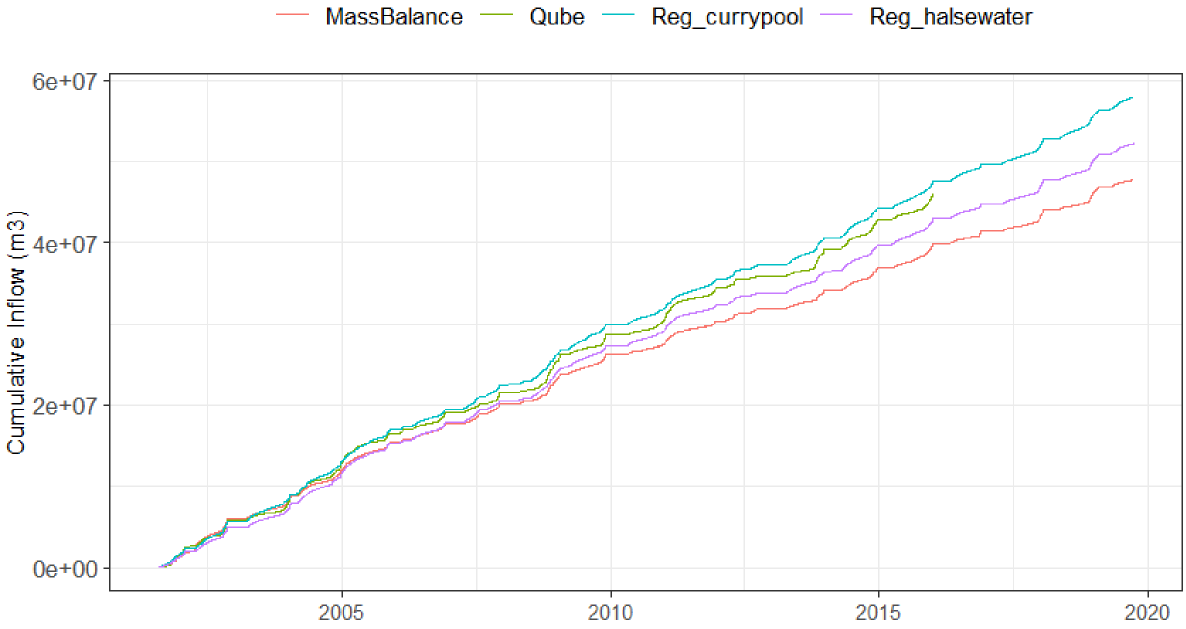
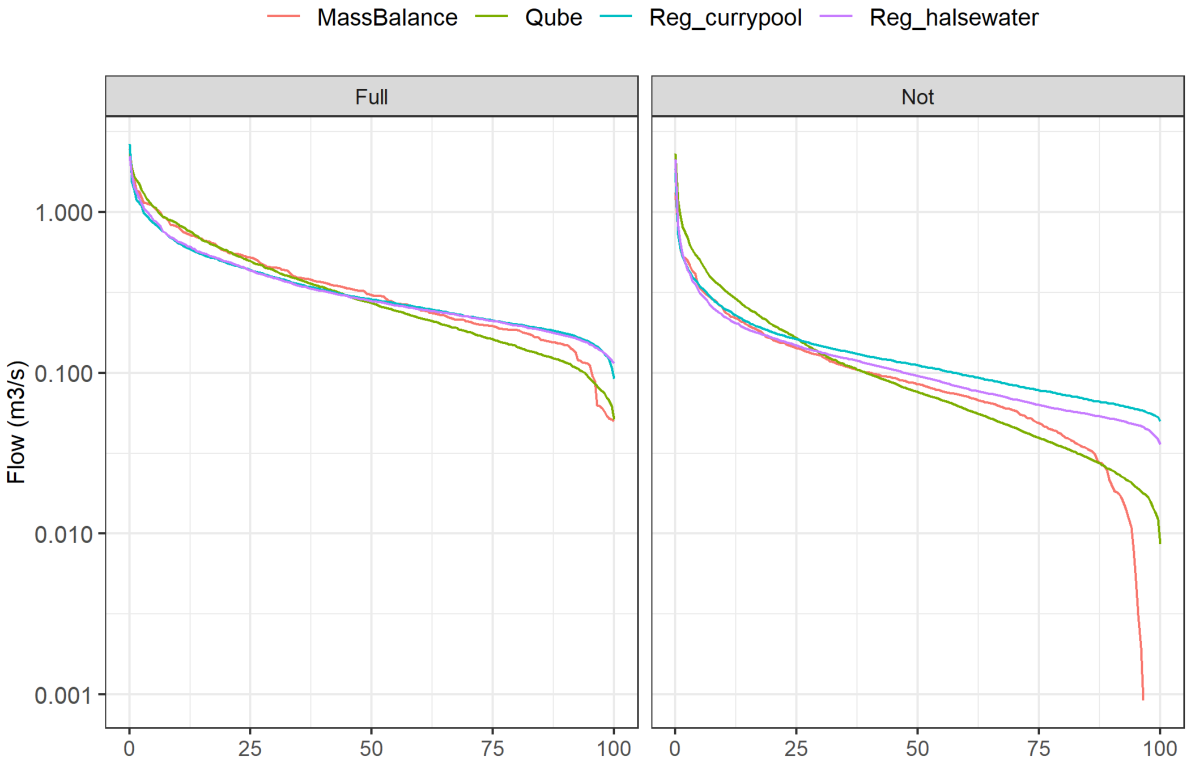


Figure 2-25 Cumulative reservoir inflows when the reservoir is off-full



The flow duration curves for different data sources (Figure 2-26) show good agreement when the reservoir is full, and more spread when the reservoir is not full, particularly at lower flows with the Currypool and Halsewater regionalised inflows higher than the mass balance and Qube derived data.

Figure 2-26 Flow duration curve for reservoir inflows when the reservoir is full and not full for the different data sources



Based on the observed data, data from 2001 to 2012 was used for calibration, and data from 2012 used for validation. The model was calibrated to Halsewater gauge as the cumulative inflows, in particular when the reservoir was not full, were between the other datasets.

The model was calibrated using the three calibration metrics described in Section 2.7.6, and pareto optimal plots across metrics compared in calibration (Figure 2-27) and validation (Figure 2-28) to identify the best models. There is a low trade-off between calibration to the RMSE when the reservoir is not full and the other metrics in both calibration and validation, and more of a trade-off between models when looking at mass balance. Based on the trade-off plots, Models 19, 22, and 6 were chosen for further analysis.

Figure 2-27 Comparison of model performance across calibration objectives during calibration (note: models in the lower left of each plot are the best performing; MB – Mass Balance; RMSE – Root Mean Square Error)

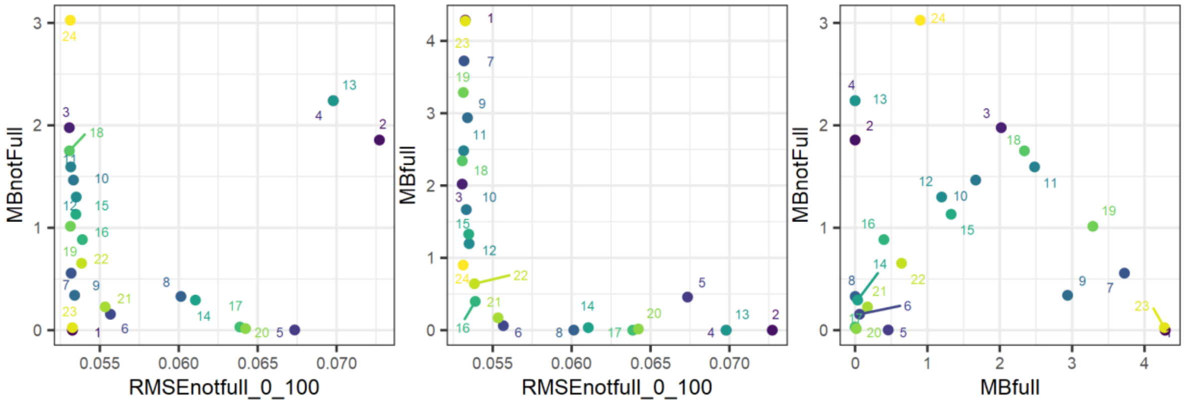
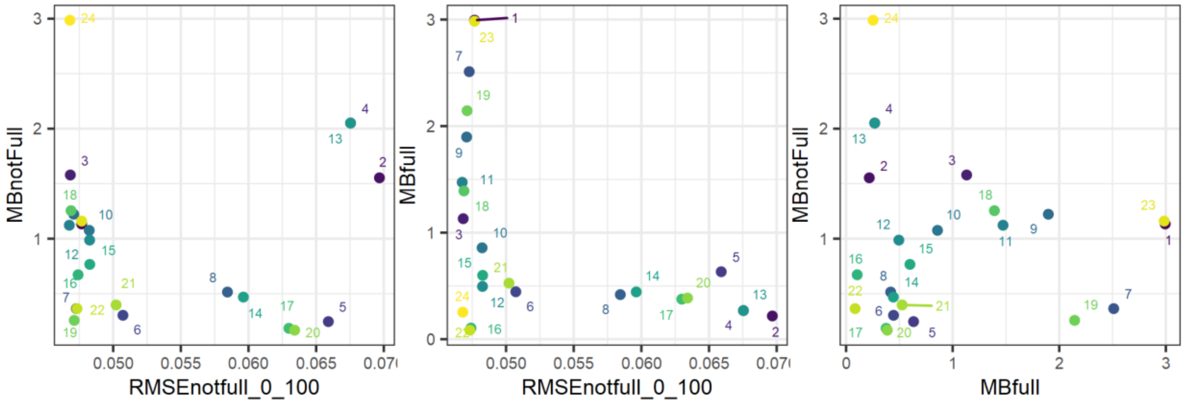


Figure 2-28 Comparison of model performance across calibration objectives during validation (note: models in the lower left of each plot are the best performing; MB – Mass Balance; RMSE – Root Mean Square Error)



The three chosen models perform similarly when looking at cumulative inflows when the reservoir is full and not-full for cumulative inflows, in particular in comparison to the Halsewater data to which the model was calibrated (Figure 2-29; Figure 2-30).

Figure 2-29 Cumulative inflows for the three chosen models against the observed data when the reservoir is full

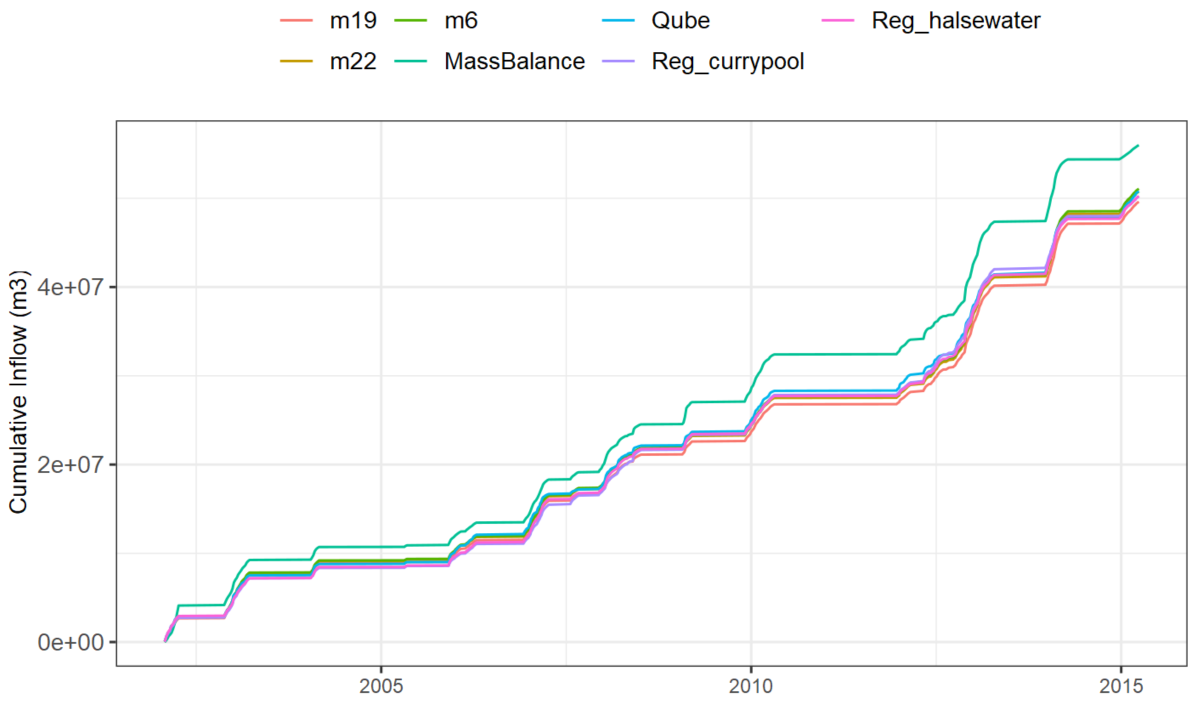
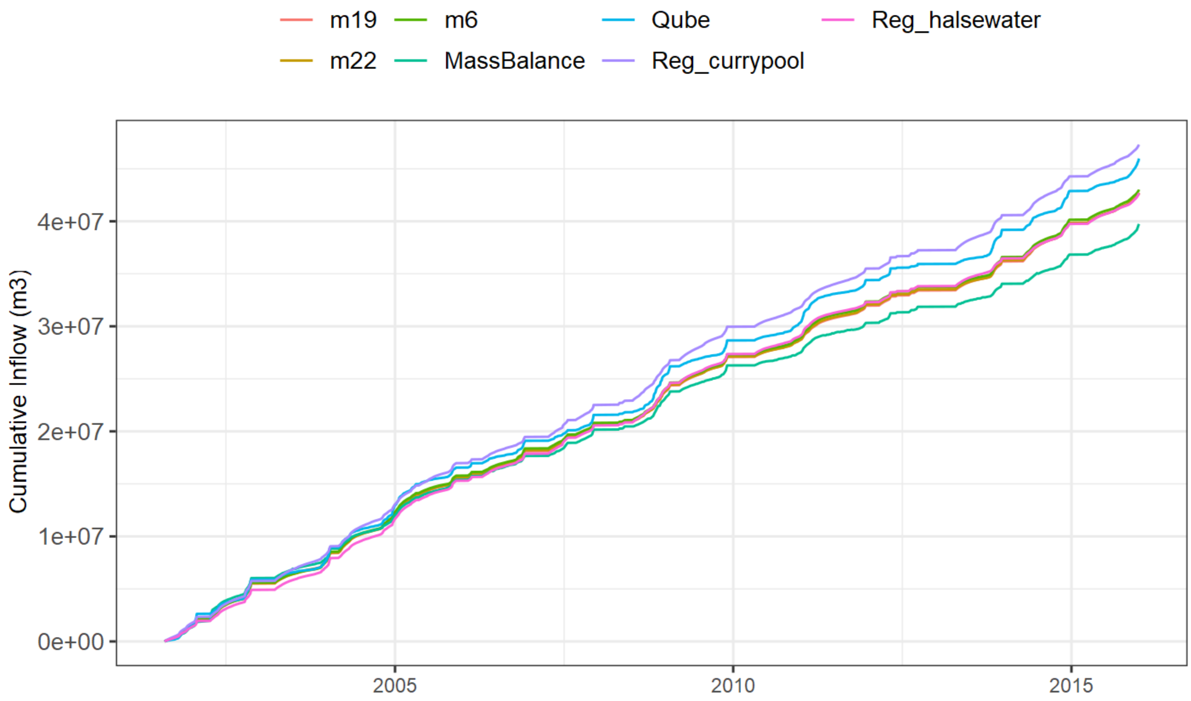
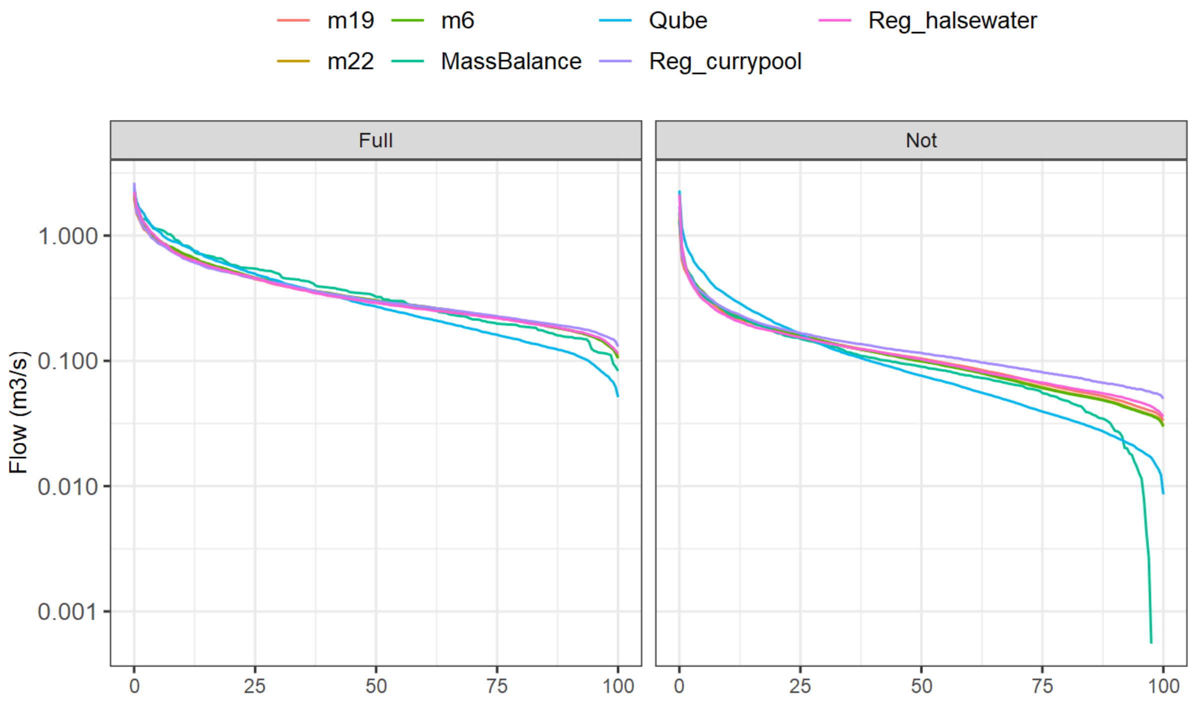


Figure 2-30 Cumulative inflows for the three chosen models against the observed data when the reservoir is not full



The flow duration curve model comparison (Figure 2-31), shows good agreement between the model and the observed data, in particular when the reservoir is not full. There is also good agreement between the models and the mass balance data above Q75, before the mass balance flows at lower flows drop off. This is because of noise in the mass balance data at very low inflows when the reservoir is not full.

Figure 2-31 Flow-duration curve model comparison to observed data when the reservoir is full or not full



Based on the above analysis, model 22 was chosen for prediction. As shown in the headroom analysis (see Technical Appendix - WRMP24 Supply-Demand Balance, Decision-Making and Uncertainty) the uncertainty in the inflow model was chosen based on plus/minus 10% of the cumulative inflows.

2.7.8 Prediction uncertainty

The output from the calibration stage is a set of chosen models, alongside a single preferred model, based on prediction performance against the different available inflow time-series. To feed into the deployable output assessment, the different hydrograph time-series are run through a reservoir storage model to quantify the uncertainty in deployable output that is attributed to reservoir inflow uncertainty. This value then feeds into the headroom assessment of the supply-demand balance calculation.

2.8 Drought Library Development, 1 in 200 and 1 in 500 DO assessment

WRMP supplementary guidance for 1 in 500 drought[15] states that the 1 in 500 drought should be determined using the system level response deployable output, That is, a water resources model is run multiple times using a long record (e.g. a stochastic dataset) for different demand increments, and the number of years of failure is counted at each demand increment to determine the demand/DO at a 1 in 500 frequency of failure.

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[15] Water Resources Planning Guideline Supplementary Guidance – 1 in 500, External guidance: 18646, Published 22/03/2021

The complexity of the Miser system model means we cannot run the whole stochastic dataset through the model multiple times under a permitted failure approach to calculate the 1 in 200 and 1 in 500 system level response deficit. Whilst analysis for determining 1 in 500 drought based on weather metrics is not appropriate, the regulatory guidance[15] states that where it is not practicable to run system simulator models for large stochastic datasets, drought library type approaches can be used, provided it can be demonstrated there is a reasonable understanding of the relative return periods of the droughts within the drought libraries.

2.8.1 Drought Library Generation

As per the UKWIR risk-based planning guidelines[16], a drought library can either consist of individual drought events, or timeseries of specific lengths (e.g. 100 years), or ‘stitched together’ timeseries that contain large numbers of drought events without large amounts of intervening ‘non-drought’ years. We have developed a drought library to run through the Miser system model (and undertake climate change impact assessment). The drought library consists of 40 drought events: 3 historic droughts (1921, 1933/34 and 1975/76) and 37 stochastic droughts. The 27 stochastic droughts were chosen using the stochastic weather dataset and the rapid models.

The stochastic weather record was run through the following rapid models, to derive the following metrics:

- **Minimum summer groundwater level return period** – minimum summer (June, July, and August) groundwater level return period calculated from inverse ranking of the Woodyates groundwater level as a hydrogeological metric of critical period source yield constraint. The metric is relevant for selection of a drought library as Woodyates groundwater level correlates strongly with Ashton Farm groundwater level ($R^2 = 0.91$) and these two observation boreholes are those used to predict source yield constraint at all yield constrained sources, using piecewise linear relationships (Section 2.6). Minimum groundwater level during the summer months was used as it is low groundwater levels during times of critical period demand that create the critical period constraint. Given the calculation of critical period DO, the return period of critical period DO is equivalent to the return period of Woodyates borehole.
- **Reservoir Deployable Output Return Period** – the combined reservoir deployable output from three reservoirs reservoir as representative of annual average yield was used to screen the stochastic dataset. For each of these sources, the stochastic dataset is run through a stand-alone reservoir model that simulated reservoir deployable output for each source using an uplift to failure approach.

The stochastic and historical record was run through each model to generate the metrics, and the return-period of each metric calculated using inverse ranking across the stochastic record. This was then also used to calculate the return period of the minimum historic level/DO. Figure 2-32 shows the return period of Woodyates borehole. The worst historic drought on record was 1975/76, with a minimum groundwater level of 68.4mAOD. The return

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[16] UKWIR (2016) WRMP19 Methods – Risk Based Planning, Report Ref. No. 16/WR/02/11

period of this level is 1 in 210. Figure 2-33 shows the return period of reservoir storage from the stochastic dataset simulations. The worst historic drought was the 1921 drought with a return period for DO of 1 in 197.

Figure 2-32: Return period of Woodyates groundwater level derived through simulation of the stochastic dataset. Red lines show the level and return period of the worse historic drought (1976)

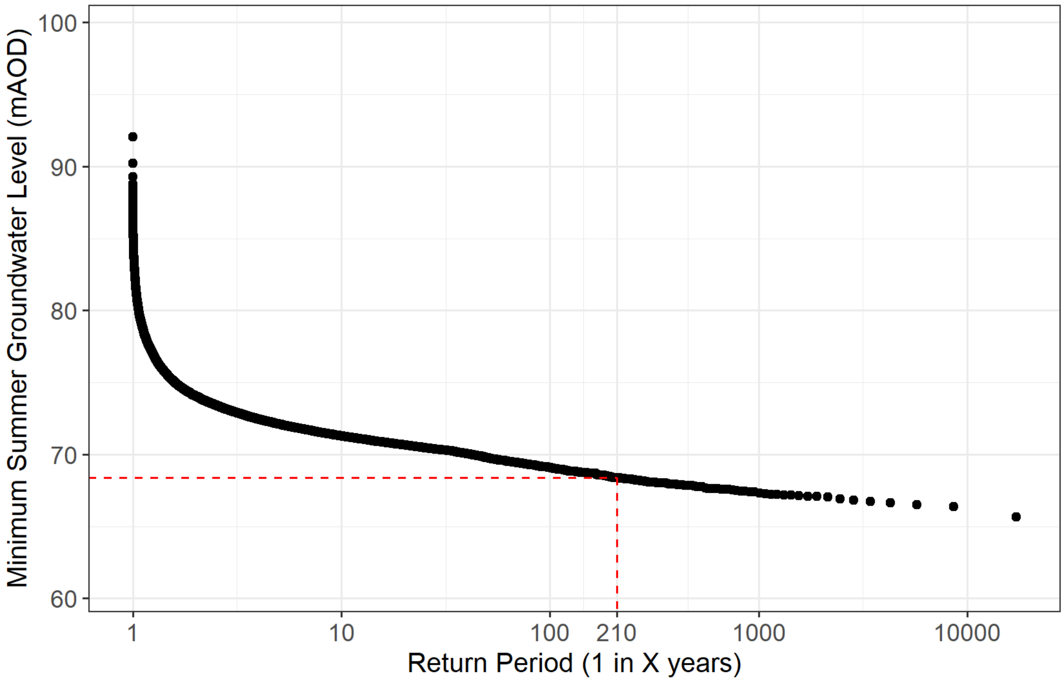
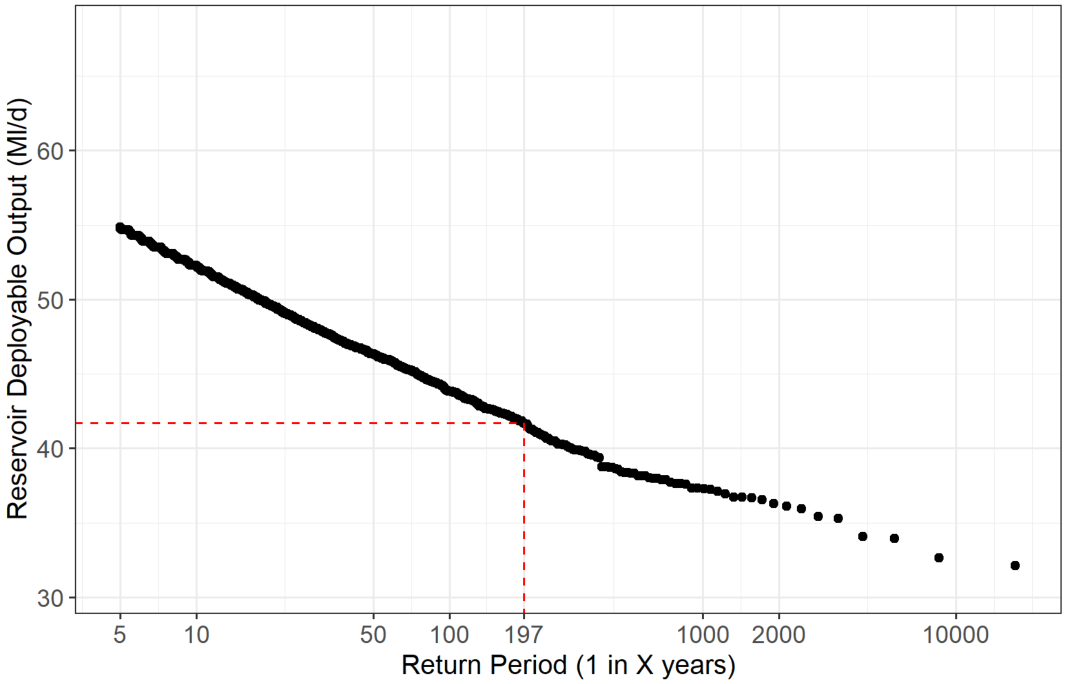
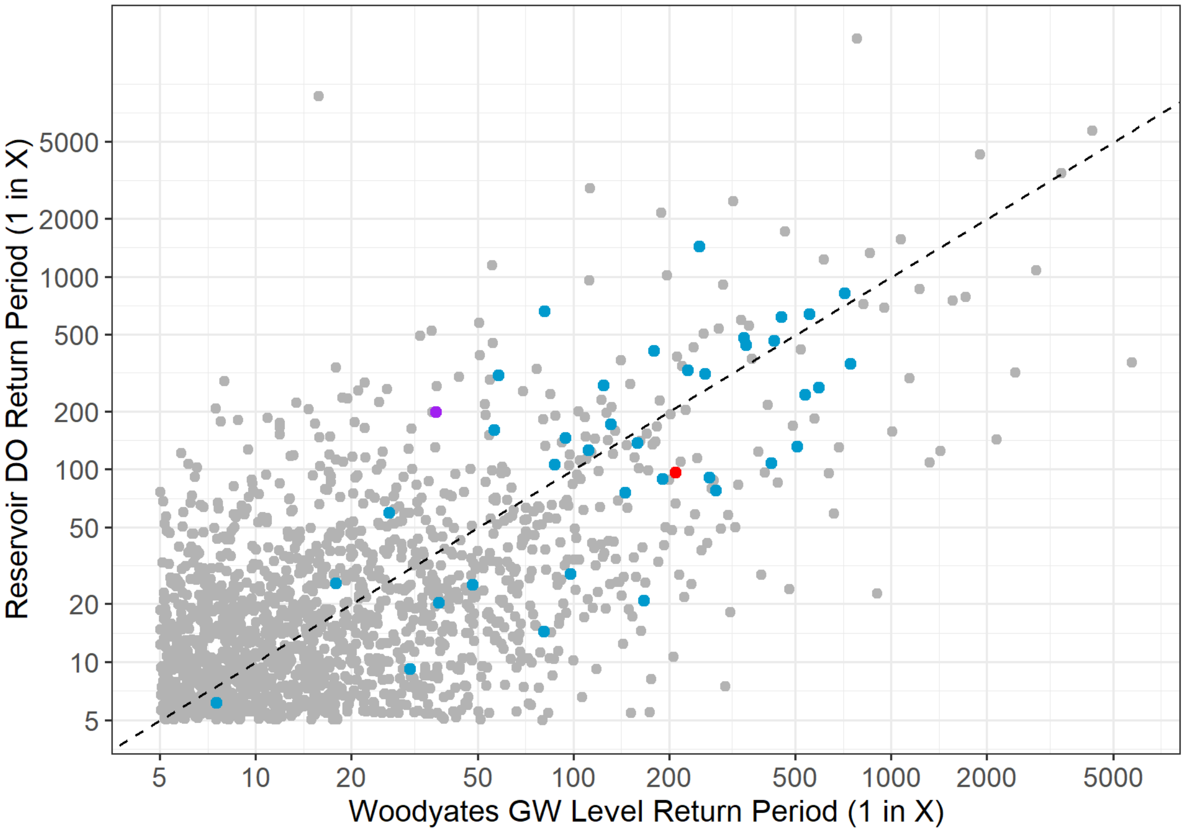


Figure 2-33 Return period of reservoir storage Deployable Output derived through simulation of the stochastic dataset for 3 reservoirs (Clatworthy, Durleigh and Ashford and Hawkridge). Red lines show the DO and return period of the worst historic drought (1921)



Based on the return periods for reservoir deployable output and minimum summer groundwater level, a drought library of 37 stochastic droughts events were selected from the stochastic dataset to go alongside the three worst historical drought events: 1921, 1933/34 and 1975/76. The stochastic droughts were selected to cover a range return periods, in particular in the range of plausible extreme droughts between 1 in 100 and 1 in 1000 (Figure 2-34; Table 2-9).

Figure 2-34 Stochastic drought events plotted against reservoir and Woodyates groundwater level return period, alongside selected stochastic drought library events (blue), 1975/76 historical drought (red) and 1921 historical drought (purple)



Given the stochastic drought dataset was developed using the 1950 to 1997 period, the periods of the drought record that tend to give the more extreme droughts are focussed on those known dry/drought periods within the historical record (Figure 2-35, Figure 2-36: 1965, 1976, and the early 1990’s period from 1990 to 1993. The majority of extreme droughts are from the 1975/76 period (Table 2-10). To ensure some diversity on the droughts chosen, a number of extreme droughts were selected from other periods of the record, including other multi-season drought periods similar to 1975/76, which occur in the early 1990’s, and some notable single season droughts including from 1995.

Figure 2-35 Woodyates Minimum Summer Groundwater Level range of return periods by year for the stochastic record

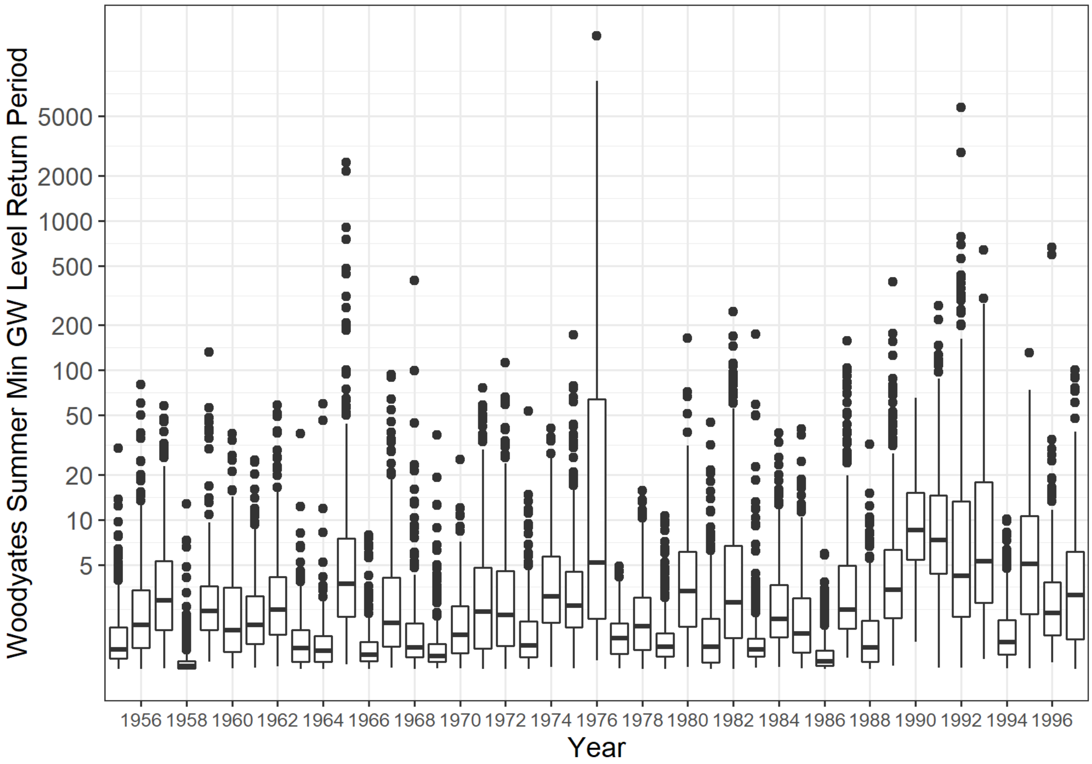


Figure 2-36 Reservoir DO range of return periods by year for the stochastic record

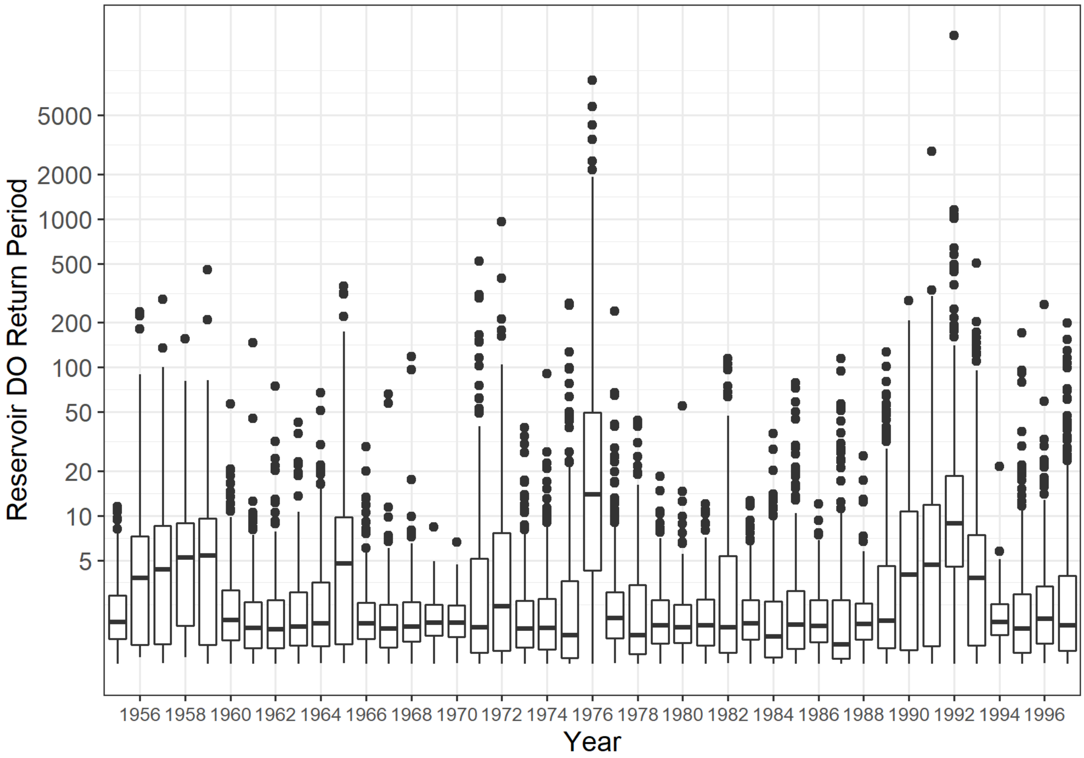


Table 2-9 Selected drought library drought events (h = historic drought; s = stochastic drought)

					Return Periods	
Event ID	Stochastic Replicate	Start Date	End Date	Critical Period Year	Woodyates Min Summer Level	Reservoir DO
h1	NA	Apr-1974	Apr-1977	1976	210	96
h2	NA	Apr-1920	Apr-1923	1921	37	197
h3	NA	Apr-1932	Apr-1935	1934	NA	NA
s1	133	Apr-1964	Apr-1967	1965	261	313
s2	53	Apr-1991	Apr-1994	1992	430	465
s3	361	Apr-1994	Apr-1997	1995	131	170
s4	271	Apr-1990	Apr-1993	1991	269	90
s5	287	Apr-1974	Apr-1977	1976	179	410
s6	338	Apr-1974	Apr-1977	1976	48	25
s7	92	Apr-1974	Apr-1977	1976	506	131
s8	52	Apr-1995	Apr-1998	1996	593	265
s9	185	Apr-1974	Apr-1977	1976	453	614
s10	72	Apr-1975	Apr-1977	1976	26	59
s11	252	Apr-1991	Apr-1994	1992	56	159
s12	379	Apr-1974	Apr-1977	1976	81	14
s13	183	Apr-1970	Apr-1973	1971	58	307
s14	282	Apr-1990	Apr-1993	1992	159	137
s15	301	Apr-1974	Apr-1977	1976	125	273
s16	53	Apr-1963	Apr-1966	1965	95	145
s17	384	Apr-1991	Apr-1994	1992	351	441
s18	382	Apr-1990	Apr-1994	1992	555	637
s19	235	Apr-1974	Apr-1977	1976	229	325
s20	269	Apr-1991	Apr-1994	1993	112	126
s21	100	Apr-1964	Apr-1967	1965	191	89
s22	208	Apr-1974	Apr-1977	1976	81	662
s23	80	Apr-1974	Apr-1977	1976	282	77
s24	97	Apr-1974	Apr-1977	1976	538	242
s25	203	Apr-1974	Apr-1977	1976	717	819
s26	372	Apr-1963	Apr-1966	1965	748	351
s27	340	Apr-1964	Apr-1967	1964	18	26
s28	332	Apr-1994	Apr-1997	1995	31	9
s29	143	Apr-1955	Apr-1958	1957	8	6
s30	112	Apr-1982	Apr-1985	1984	38	20
s31	308	Apr-1974	Apr-1977	1976	344	478
s32	309	Apr-1985	Apr-1988	1987	98	29
s33	16	Apr-1991	Apr-1994	1992	420	108
s34	213	Apr-1981	Apr-1984	1982	87	106
s35	397	Apr-1974	Apr-1977	1976	167	21
s36	166	Apr-1974	Apr-1977	1976	249	1433
s37	395	Apr-1990	Apr-1993	1991	146	75

Table 2-10 Years from stochastic record for the drought library events

Drought year	Drought Events
1956	1
1965	5
1971	1
1976	15
1982	1
1984	1
1987	1
1991	2
1992	5
1993	2
1995	2
1996	1

2.8.2 1 in 200 and 1 in 500 Deployable Output

To calculate deployable output, the drought library was run through the miser model using an uplift to failure approach to determine the annual average and critical period deployable output for each event (Section 2.3.4 and Section 2.3.5).

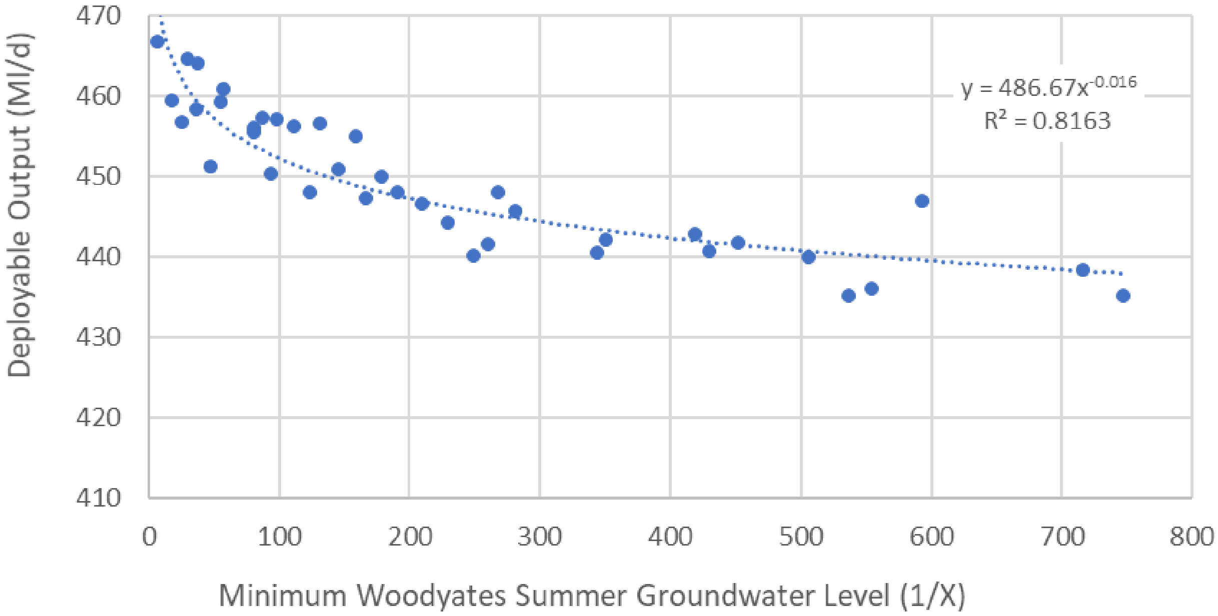
Critical Period Deployable Output

To determine the 1 in 200 and 1 in 500 return periods, the deployable output for each drought library event was plotted against the Woodyates minimum summer groundwater level return period, and a power law model fitted to the resultant data (Figure 2-37). The resultant fitted model gives the critical period deployable output as:

- 1 in 200 - 447.11 Ml/d
- 1 in 500 – 440.61 Ml/d

The difference between these levels of service is a change in DO of 6.51Ml/d.

Figure 2-37 Critical Period deployable output plotted against Woodyates borehole groundwater level



<u>Annual Average Deployable Output</u>

To determine the 1 in 200 and 1 in 500 return periods, the deployable output for each drought library event was plotted against the annual average return period DO assessment undertaken with a rapid model (Figure 2-38). This model worked as follows:

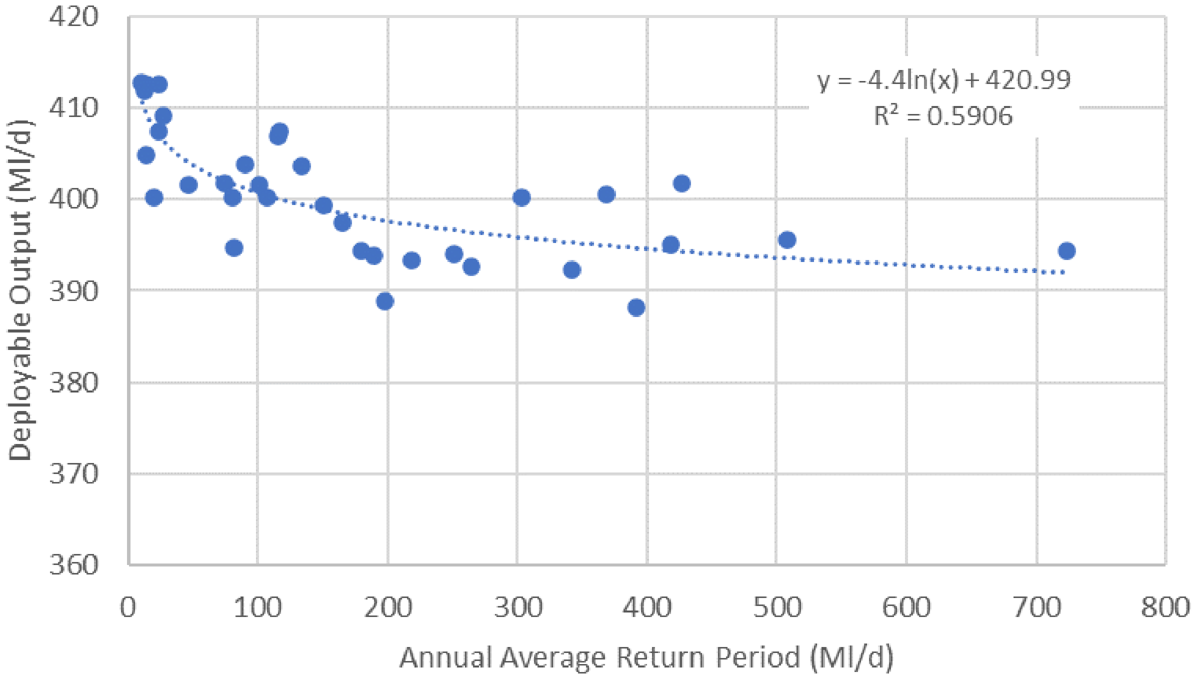
- For the stochastic and historic drought time-series, for each groundwater source daily deployable output was constrained with all constraints included in the Miser model:
  - Treatment works production capacities
  - Daily licences
  - Low river flow constraints
  - Hydrogeological constraints
- Stand-alone reservoir models were run for each reservoir source using an uplift to failure approach.
- The total output across each licence year was then constrained with annual licences
- The annual average deployable output was then summed across sources, and an inverse ranking of annual average deployable output across the stochastic record used to determine the return period of annual average DO across the drought library.

The resultant fitted model gives the annual average deployable output as:

- 1 in 200 – 397.68 Ml/d
- 1 in 500 – 393.65 Ml/d

The difference between these levels of service is a change in DO of 4.03Ml/d.

Figure 2-38 Annual Average deployable output plotted annual average DO return period



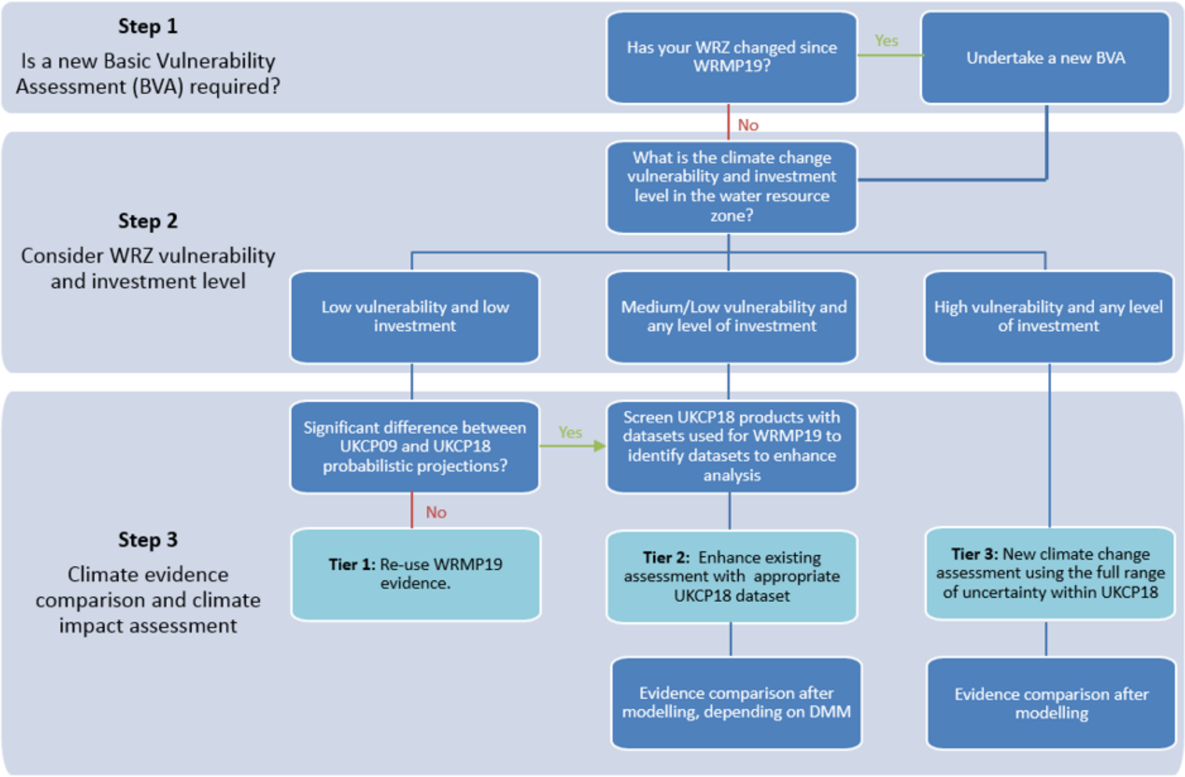
Climate Change Impact

The UK climate is changing[17]: Average temperatures and winter precipitation from 2009-2018 have been, respectively 0.9ºC warmer and 12% wetter than the 1961-1990 average, and the top ten warmest years for the UK have occurred since 2002.

The met office's latest assessment of climate change impact on the weather in the UK – called UKCP18 – projects a greater chance of warmer, wetter winters and hotter, drier summers. The recent trend in warming is forecast to continue[17]: the hot summer of 2018 was the equal warmest summer for the UK along with 1976, 2003 and 2006; climate change will increase the chance of hot summers by the mid-century, to become even more common, near 50%. Winter precipitation is also expected to increase significantly.

The assessment of climate change impact on DO was assessed following the water resources planning guidelines supplementary guidance – climate change[18], as shown in Figure 0-1.

Figure 0-1 Climate change assessment methodology[18]



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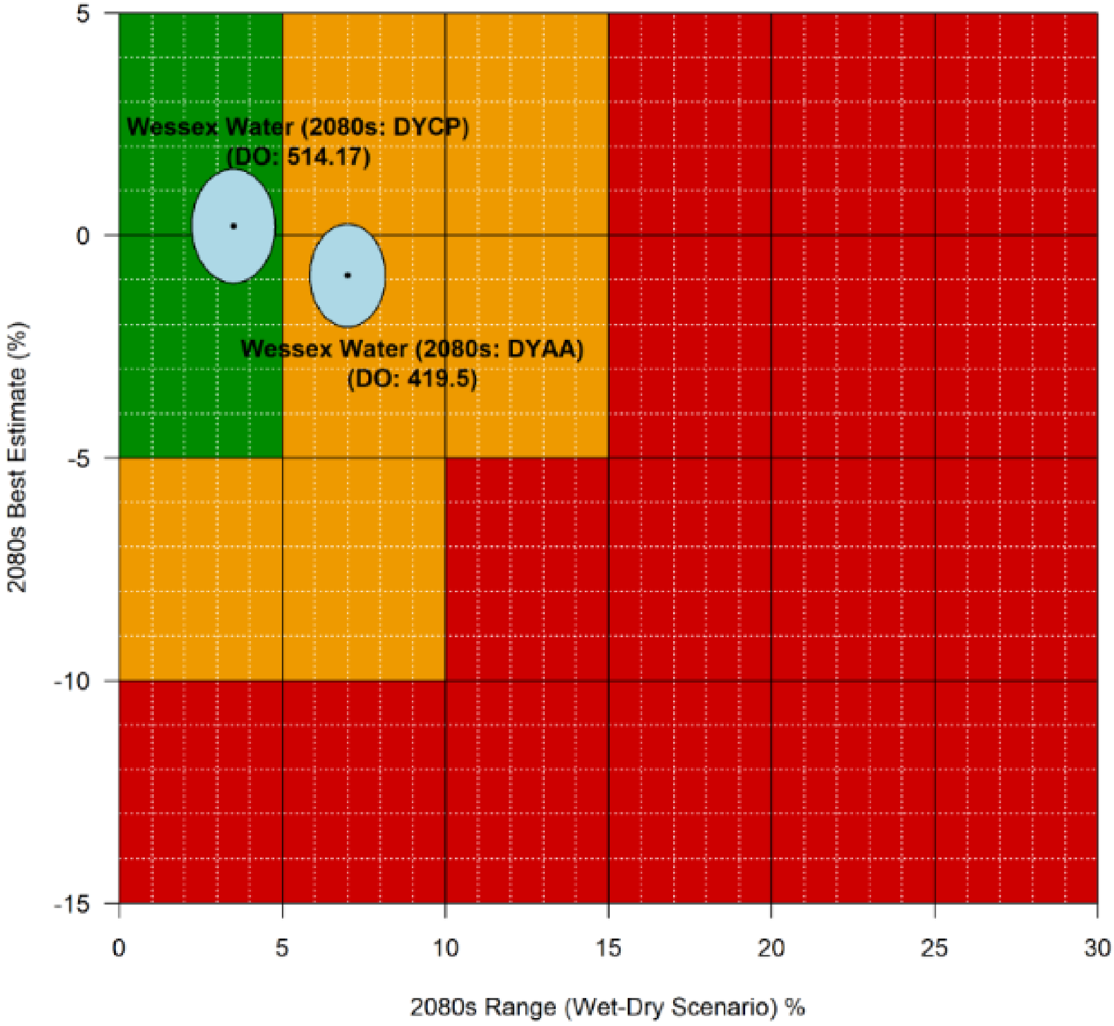
[17] Met Office (July 2021) UK Climate Projections: Headline Findings: ukcp18_headline_findings_v3.pdf (metoffice.gov.uk), last accessed June 2022.
[18] Water Resources planning guideline supplementary guidance – climate change, External guidance: 18647, Published 18/03/2021

2.9 Basic Vulnerability Assessment

The first stage of the process is to complete a Basic Vulnerability Assessment (BVA) where significant changes have occurred in a water resource zone since the last plan. Based on our problem characterisation assessment, and significant potential supply demand balance changes, a new BVA assessment was undertaken. Figure 0-2 shows the revised BVA assessment undertaken for Wessex Water and shows a low level of vulnerability for critical period assessment (DYCP) and a Medium level of vulnerability for the annual average assessment (DYAA).

Figure 0-2 Basic Vulnerability Assessment for Wessex Water Supply Zone



Based on the outcomes of the BVA assessment, Stage 2 of the guidance (Figure 0-1) suggests that Tier 1 or Tier 2 assessment is appropriate for the Wessex Water supply zone. However, given a likely increased level of investment we decided to undertake a **Tier 3 assessment: new climate change assessment using the full range of uncertainty within UKCP18[19].**

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[19] As also required by Ofwat's Strategic Planning Framework (PN 25/22 Price Review 2024: Ofwat sets out framework to deliver better outcomes for customers and the environment - Ofwat)

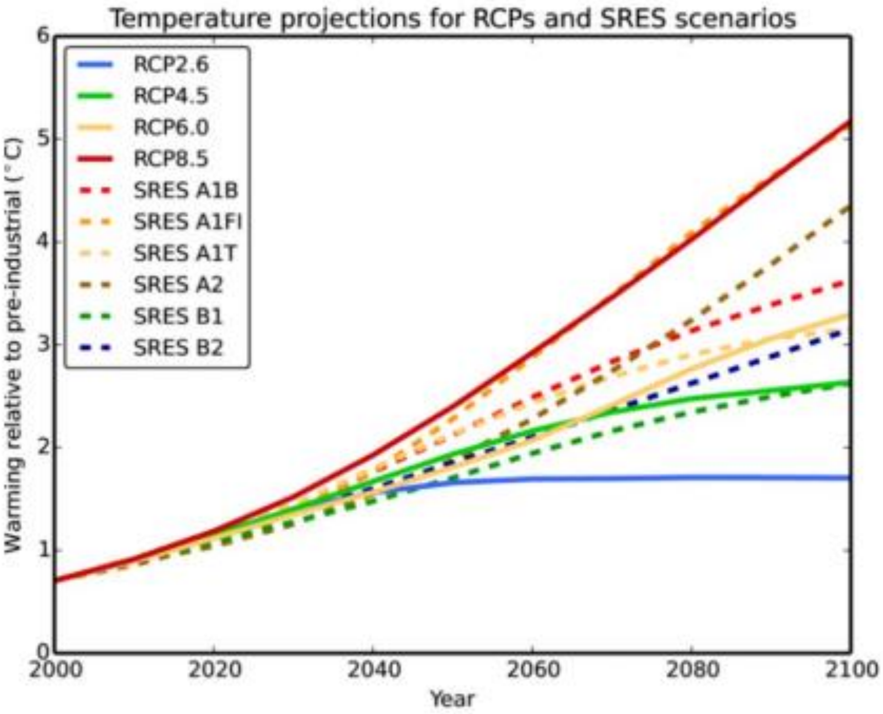
2.10 UKCP18 dataset and high-level screening

The UKCP18 dataset consists of a range of products that can be used for climate change impact assessment, each with different features, strengths and limitations[20]. The key factors are as follows.

2.10.1 Emissions scenarios

A range of scenarios are included in the UKCP18 dataset to account for uncertainty in future emissions scenarios based on the scenarios used in the Fifth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC), called Representative Concentration Pathways (RCPs). Each RCP follows a different emissions trajectory, and based on future radiative forcing targets in 2100 are called 2.6, 4.5, 6.0 and 8.5 (Watts per square meter). These are shown in Figure 0-3.

Figure 0-3 Global mean temperature projections from a climate model (MAGICC6) relative to pre-industrial average (1850-1990) compared to older SRES scenarios (dashed coloured lines)[21]



2.10.2 Products

There are three relevant UKCP18 products to water resources planning, as shown in Table 0-1, that are derived from different models and available for different emissions scenarios.

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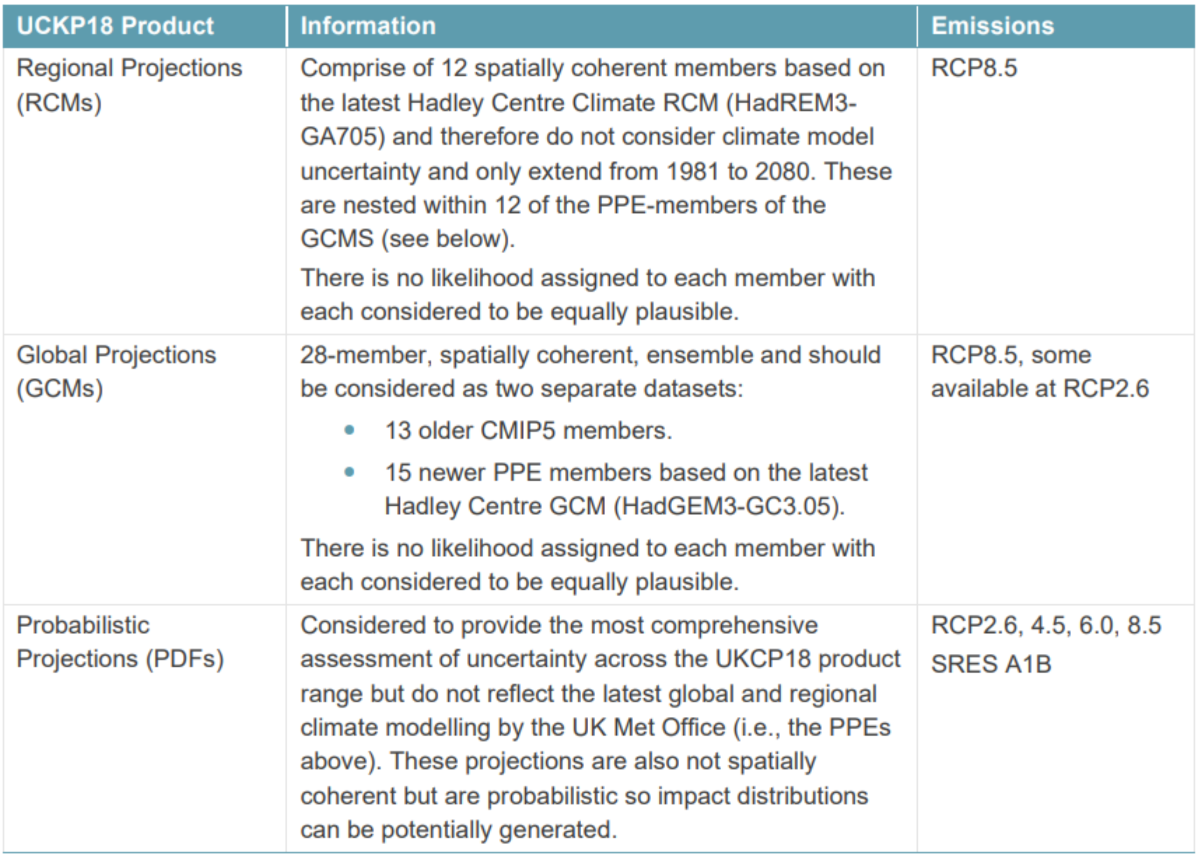
[20] These are summarised here, and further details can be found in: and HRW (2021) – Regional Planning Climate Change Assessment – Climate Change Methodology for WCWRG.

[21] Met Office (2018). UKCP18 guidance: representative concentration pathways https://www.metoffice.gov.uk/binaries/content/assets/metofficegovuk/pdf/research/ukcp/ukcp18-guidance---representative-concentration-pathways.pdf

Table 0-1 UKCP18 relevant products for water resources[18]



UCKP18 Product	Information	Emissions
Regional Projections (RCMs)	Comprise of 12 spatially coherent members based on the latest Hadley Centre Climate RCM (HadREM3-GA705) and therefore do not consider climate model uncertainty and only extend from 1981 to 2080. These are nested within 12 of the PPE-members of the GCMS (see below). There is no likelihood assigned to each member with each considered to be equally plausible.	RCP8.5
Global Projections (GCMs)	28-member, spatially coherent, ensemble and should be considered as two separate datasets: • 13 older CMIP5 members. • 15 newer PPE members based on the latest Hadley Centre GCM (HadGEM3-GC3.05). There is no likelihood assigned to each member with each considered to be equally plausible.	RCP8.5, some available at RCP2.6
Probabilistic Projections (PDFs)	Considered to provide the most comprehensive assessment of uncertainty across the UKCP18 product range but do not reflect the latest global and regional climate modelling by the UK Met Office (i.e., the PPEs above). These projections are also not spatially coherent but are probabilistic so impact distributions can be potentially generated.	RCP2.6, 4.5, 6.0, 8.5 SRES A1B

Alongside the basic vulnerability assessment, a high-level screening of the UKCP18 datasets[22], and a comparison of UKCP18 to UCKP09 datasets. As with the overall UKCP18 headline messages, the analysis shows that warmer, wetter winters and hotter, drier summers are projected. UKCP09 projections were found to be largely within the bounds of the UKCP18 projections. Figure 0-4 shows a comparison of data products for UKCP18 data; the regional and global projections (blue, orange and red points) are within the distribution of the probabilistic projections (grey points), but plot generally to the drier and warmer end of the distribution, most notably for the regional projections and for the Hadley Centre Global Projections Model (GCM).

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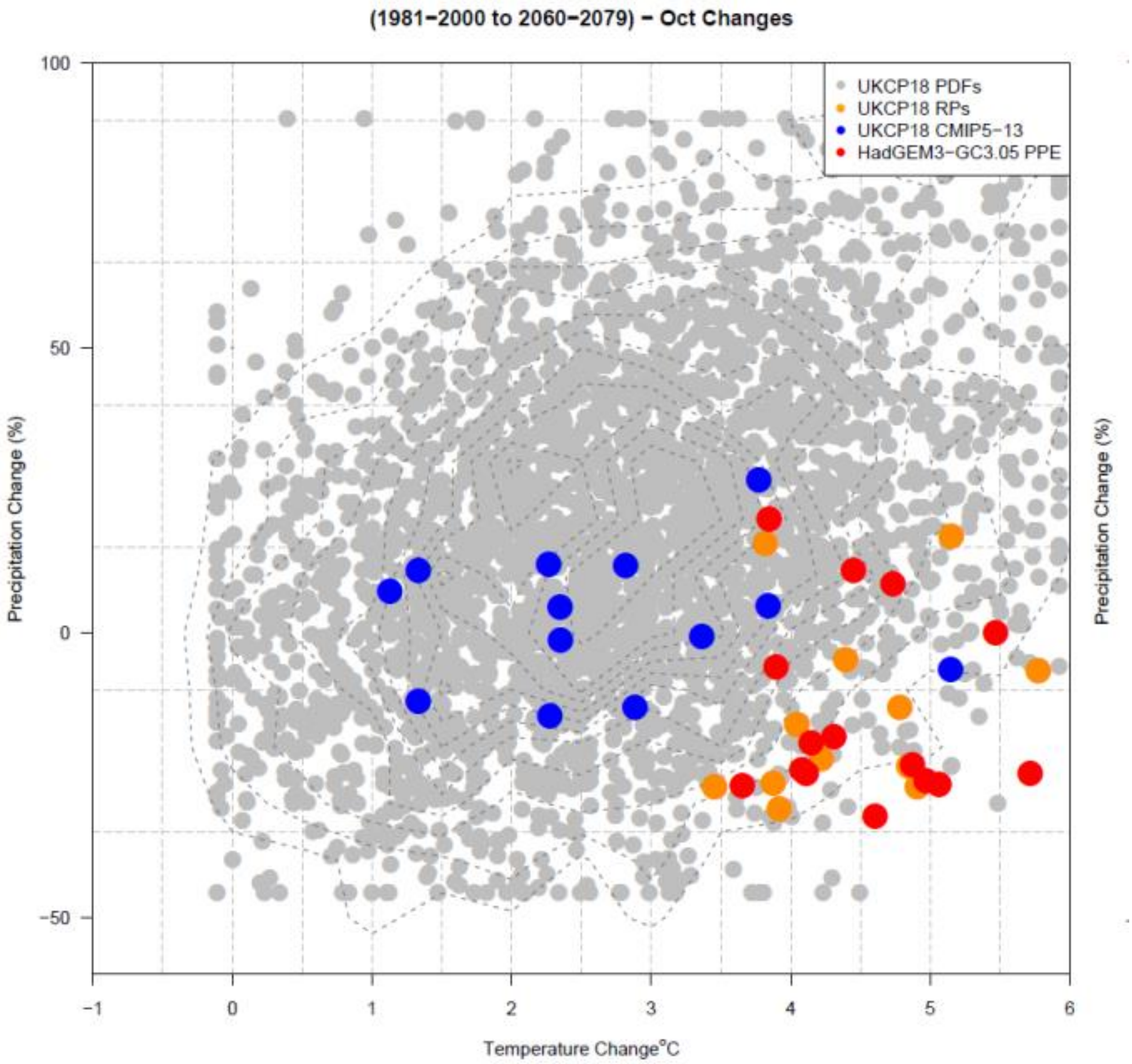
[22] HRW (2021): Regional Planning Climate Change Assessment: high-level screening of UKCP18 for WCWRG.

Figure 0-4 Wessex Water UKCP18 October changes for temperature and precipitation, 1981-2000 baseline, 2060-2079 future period. Global and regional projections at Wessex Water scale, probabilistic projections at South West England river basin scale[22]



2.11 Methodology and results

Climate change impact assessment has been undertaken using the rapid models of the Wessex Water supply system. The overall assessment method was run as follows:

1. 328 climate change perturbation factors were derived for each catchment to cover the range of UKCP18 data products.
2. Input weather data for historic droughts and selected droughts from the drought library (Section 2.8) were perturbed with the climate change factors and ran through each flow hydrological model and groundwater model to generate for each event 328 realisations of flows for each catchment and groundwater model.
3. These “inflows” were run through the rapid models – reservoir and peak DO models - to derive distributions of DO and change in DO due to climate change.
4. The distribution of climate change impact across data products was analysed to derive for DYAA and DYCP planning scenarios, low, central, and high climate change DO impacts.
5. The future impacts were scaled back in time using linear scaling to derive time-series of DYAA and DYCP climate change impacts across the planning horizon.

2.11.1 Climate change perturbation factors

An ensemble of 328 climate change factors were run through the models, using a **baseline period of 1981-2000 and a future period of 2060-2079**:

- **RCM** - 12-member ensemble of Regional Projections (RCMs) at RCP8.5, which are nested within 12 of the PPE members of the 28 GCMs
- **GCM** - 16-member ensemble of the Global Projections (GCMs) at RCP8.5 of the 28-member ensemble (12 RCM + 16 GCM gives 28-member ensemble in total)
- **Probabilistics** - 100 samples each of the probabilistic dataset at RCP2.6, RCP6.0 and RCP8.5

The monthly distribution of change factors for PET and precipitation across products is shown in Figure 0-5 and Figure 0-6 respectively, for Woodyates regional borehole towards the east of our supply system in the chalk groundwater area, and Clatworthy Reservoir in the west of the supply system on Exmoor. The pattern of change factors between products and across months is very similar across catchments: the GCM product and to a greater extent the RCM product have a larger positive increase in PET change. The greatest difference between products is seen for rainfall; whilst the GCM and probabilistic datasets are quite similar, showing a reduction in rainfall in the summer and an increase in rainfall in the winter, the effect is more pronounced for the RCM dataset with a notably drier autumn period, as the drier summer extends into September, and higher positive change factors for January and February rainfall.

Figure 0-5 Distribution of climate change factors for PET and precipitation for each UKCP18 product for Woodyates Regional Borehole

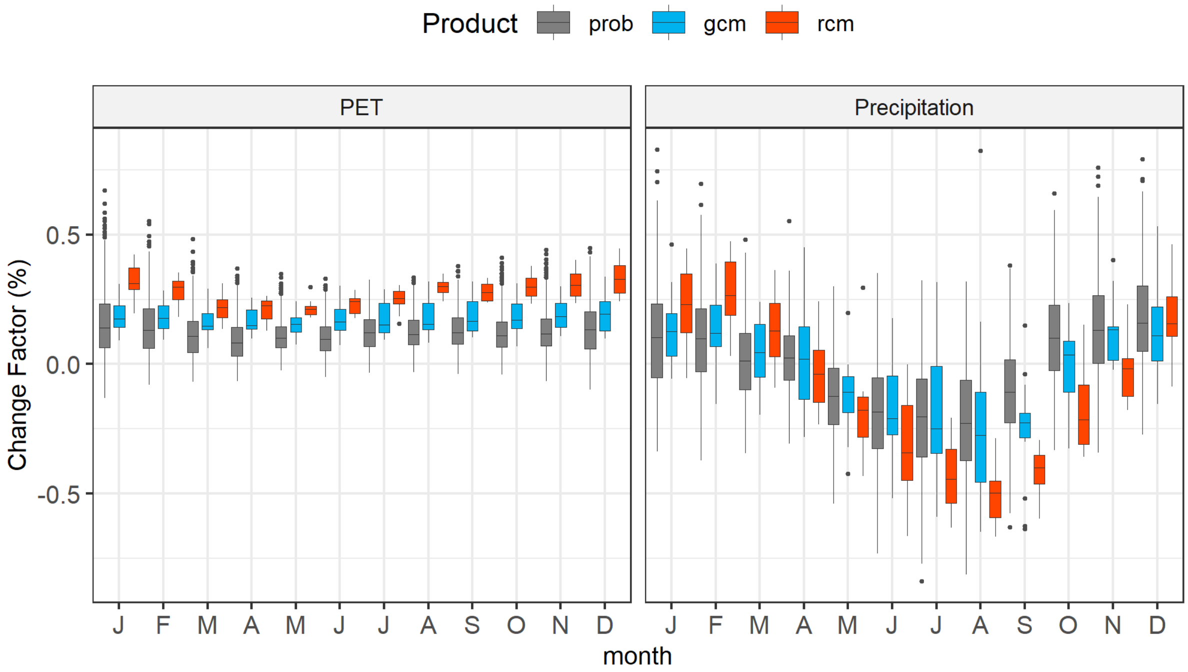
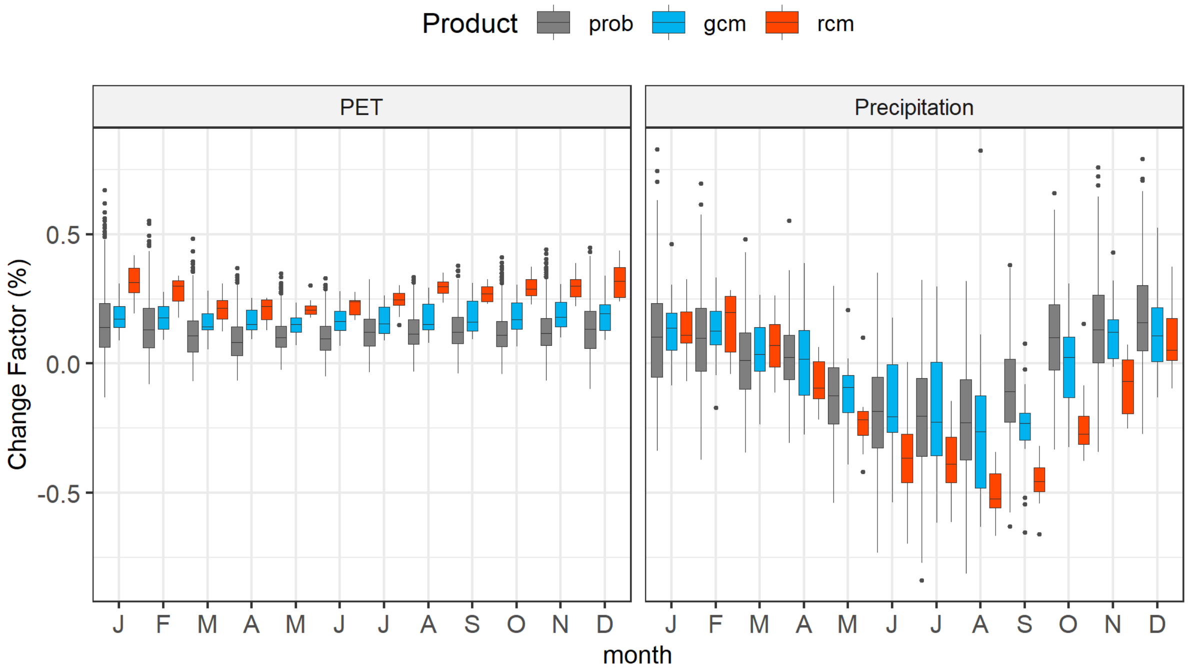


Figure 0-6 Distribution of climate change factors for PET and precipitation for each UKCP18 product for a Reservoir



2.11.2 Drought inflow modelling

To calculate the impact of climate change 13 droughts from the drought library were selected for assessment, as shown in Table 0-2. The droughts were selected to include the main historical droughts, and to cover a range of “extreme drought” return periods including 1 in 200 and 1 in 500.

Table 0-2 Drought Library events used in climate change impact modelling

Event ID	Stochastic Replicate	Start Date	End Date	Critical Period Year	Return Periods	
					Woodyates Min Summer	Reservoir DO
h1	NA	Apr-1974	Apr-1977	1976	210	96
h2	NA	Apr-1920	Apr-1923	1921	37	197
h3	NA	Apr-1932	Apr-1935	1934	NA	NA
s1	133	Apr-1964	Apr-1967	1965	261	313
s2	53	Apr-1991	Apr-1994	1992	430	465
s5	287	Apr-1974	Apr-1977	1976	179	410
s8	52	Apr-1995	Apr-1998	1996	593	265
s9	185	Apr-1974	Apr-1977	1976	453	614
s18	382	Apr-1990	Apr-1994	1992	555	637
s24	97	Apr-1974	Apr-1977	1976	538	242
s25	203	Apr-1974	Apr-1977	1976	717	819
s26	372	Apr-1963	Apr-1966	1965	748	351
s31	308	Apr-1974	Apr-1977	1976	344	478

The 328 climate change factors were applied to the PET and Precipitation datasets for each drought event, and run through the inflow models to generate an ensemble of flows and groundwater levels for each catchment. To calculate climate change impact on DO, the inflows were then run through the following models:

- **DYCP DO assessment** – using the perturbed groundwater levels, the variability in available critical period DO was calculated using source yield equations for hydro-geologically constrained sources, and combined across all sources between baseline and perturbed dataset to calculate the overall DYCP DO impact. DYCP DO is not sensitive to low flow conditions on licences, as under the extreme 1 in 200 and 1 in 500 droughts of interest, flows are already below relevant licence condition thresholds**.**
- **DYAA DO assessment** – Each stand-alone reservoir model was run for each drought event and climate perturbation, alongside the base run for each event without any perturbation, using an uplift to failure approach to identify each reservoir's DO change due to climate change impact. Alongside reservoir modelling, for each source with either a hydrogeological yield constraint or a low flow licence constraint that impacts on yield, the variability in available annual DO was calculated using stand-alone source assessment[23]. These were then combined across each source to get the Total DO impact for each drought event and climate change perturbation. To derive distributions of total climate change impact, the variability in DO due to climate change was aggregated across drought events and UKCP18 products.

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[23] For each source, the time-series of available yield is calculated based on the minimum of the daily licence, production capacity, hydrogeological or licence constraint, and across the year, annual licence.

For both DYAA and DYCP assessment, the distribution of climate change impacts for each UKCP18 product was assessed jointly across the drought events simulated.

2.11.3 Critical Period (DYCP) future impacts (2060-2079)

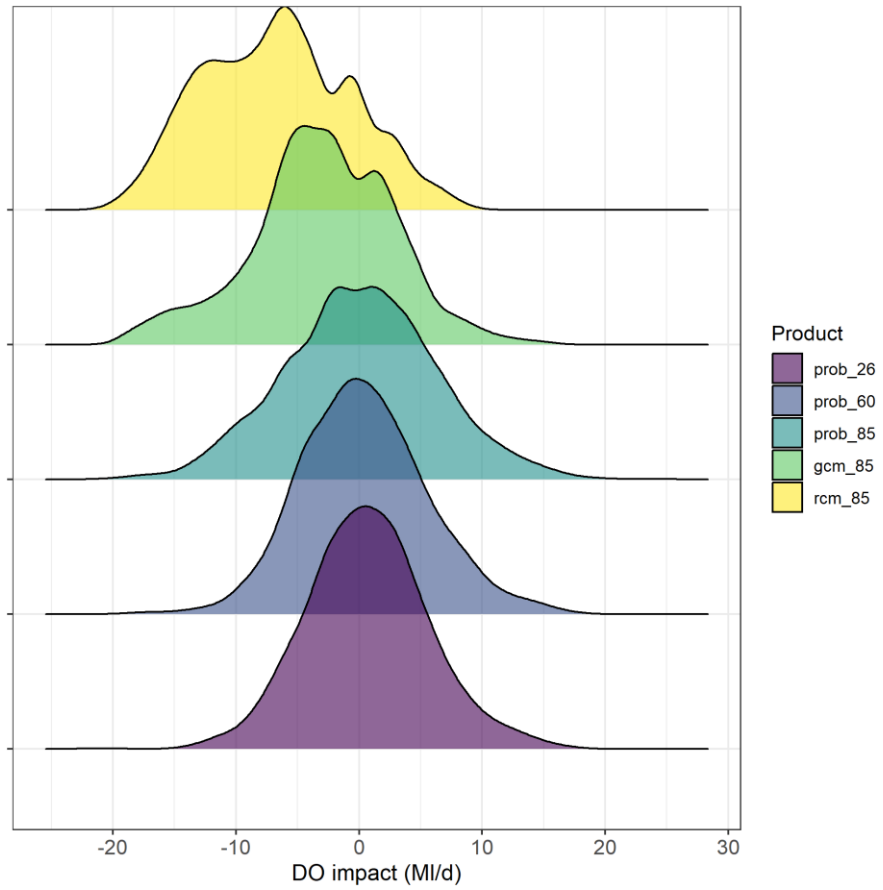
There is relatively little variation in the impact of climate change on DYCP DO across UKCP18 data products (Table 0-3, Figure 0-7); the distribution of all the probabilistic products are relatively normal, with slightly positive means and medians showing the range of potential climate change impact could be either positive or negative. The GCM and RCM 8.5 products show more negative distributions with median impact of -2.9Ml/d and -6.6Ml/d, respectively.

Table 0-3 Climate change impact summary for critical period (DYCP) DO (Ml/d) in 2060-79

Product	Mean	Median	Max	Min
Prob 2.6	0.67	0.57	17.93	-22.22
Prob 6.0	0.39	0.11	18.07	-19.29
Prob 8.5	0.09	0.13	25.06	-21.05
GCM 8.5	-3.01	-2.90	15.28	-19.13
RCM 8.5	-6.66	-6.60	8.75	-20.24

These climate change impacts are relatively small compared to the overall DYCP distribution input DI. Based on the change factor patterns shown in Figure 0-5, the wetter winters seem to compensate for the drier summers to produce a relatively small impact on the DO of hydro-geologically constrained sources.

Figure 0-7 Distribution of the impact of climate change on critical period DO for different UKCP18 products



2.11.4 Annual Average (DYAA) impacts (2060-2079)

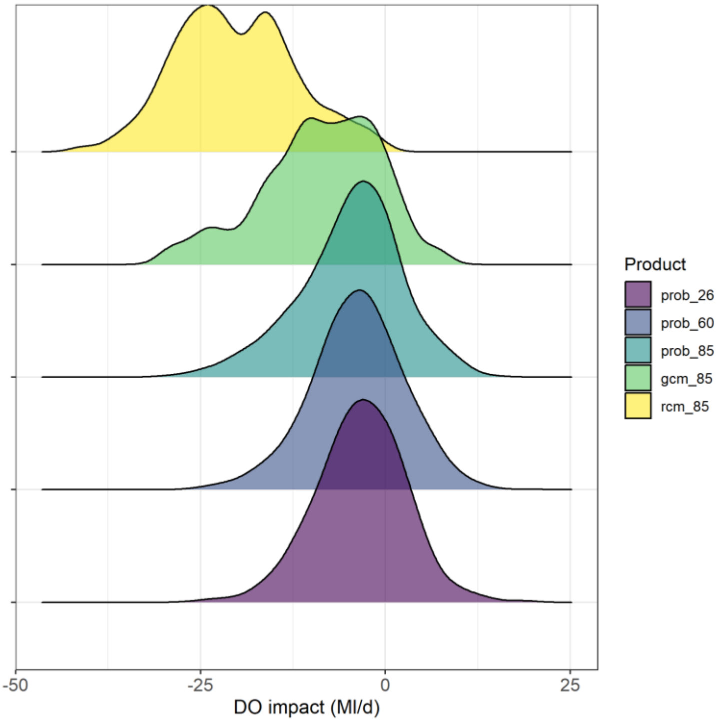
Unlike the DYCP planning scenario, there is a more negative impact of climate change on annual average water availability across UKCP18 products (Table 0-4, Figure 0-8). There is relatively little variation in the impact of climate change on DYAA DO across UKCP18 probabilistic data products, with a small negative impact of -3.3 to -4.07Ml/d.
There is, however, more of an impact for the GCM and RCM products, with median impacts of -8.06Ml/d and -21.22Ml/d, respectively.

Table 0-4 Climate change impact summary for critical period (DYAA) DO (Ml/d) in 2060-79

Product	mean	median	max	min
Prob 2.6	-3.37	-3.30	19.40	-26.18
Prob 6.0	-3.82	-3.68	19.66	-26.21
Prob 8.5	-4.79	-4.07	15.72	-30.05
GCM 8.5	-8.83	-8.06	7.34	-29.41
RCM 8.5	-20.32	-21.22	-0.54	-40.95

These climate change impacts are relatively small compared to the overall annual average DI. The majority of the impact of climate change on annual average DO is due to the impact of climate change on reservoir deployable output (around 60-75%), in comparison to groundwater systems, the reservoir inflow catchments have lower base flow indexes and a more sensitive to shorter term (reductions in rainfall), particularly over the period of the reservoir critical period. Similarly for sources controlled by river flow licence conditions, climate change impact reduces annual flows, thereby extending over the year the period where source abstraction is restricted.

Figure 0-8 Example of distribution of climate change impact on DO for the DYAA from the different UKCP18 products



2.11.5 *Scenarios and temporal scaling*

The following datasets were chosen as the low, central and high climate change impacts on DO for the future period of 2060-2079 for both DYAA and DYCP scenarios to capture the range of impact across products:

- Low – median of the probabilistic RCP 2.6 distribution
- Central – median of the probabilistic RCP 8.5 distribution
- High – mean of the median RCM RCP 8.5 distribution and GCM RCP 8.5 distribution

The medians of the distributions were chosen consistent with the requirements of Ofwat's PR24 and beyond: Final guidance on long term delivery strategies (April 2022) – the low and central scenarios here mapping to the low and high scenarios required by Ofwat. The high scenario here therefore represents a higher stress test to cover the range of uncertainty represented in the UKCP18 dataset.

The climate change impacts for the future period were scaled across the planning horizon using the linear scaling approach, as recommended in the EA WRMP24 planning guidance, and unchanged since the 2017 guidance. Given the baseline and future period used to derive the change factors, the scaling equation takes the following form:

$$Scale\ Factor = \frac{Year - 1990}{2070 - 1990}$$

The years used in the scaling equation represent the mid-points of the baseline period (1981-2000) and the future period (2060-2079).

Table 0-5 Variability in climate change impact across the planning horizon

Plan Scenario	Impact Scenario	2019-20	2029-30	2039-40	2049-50	2079-80
Critical Period (DYCP)	Low	0.21	0.29	0.36	0.43	0.64
	Central	0.05	0.06	0.08	0.10	0.14
	High	-1.78	-2.38	-2.97	-3.56	-5.35
Annual Average (DYAA)	Low	-1.24	-1.65	-2.06	-2.47	-3.71
	Central	-1.52	-2.03	-2.54	-3.05	-4.57
	High	-5.49	-7.32	-9.15	-10.98	-16.47

3. Sustainability Reductions and Environmental Destination

All of the water that we supply to customers comes from our local environment. Approximately 75% of our water supplies come from boreholes and wells that tap into the chalk and limestone aquifers of Wiltshire and Dorset and 25% from reservoirs in Somerset. Our region contains a wide range of important landscapes and habitats, and we take our responsibility to minimise the impact of abstraction very seriously.

The main way of ensuring our water supply activities do not have an unacceptable adverse impact on the environment is through abstraction licensing. Our licences specify the maximum amount of water that can be taken each day and each year, and in some cases also link abstraction rates to flow thresholds in local watercourses. For example, for one of our groundwater sources in Dorset, the licence allows us to abstract up to 4.5 Ml/d if the flow in the river is greater than 12.9 Ml/d. When the flow drops below 12.9 Ml/d we must reduce our abstraction to no more than 3.4 Ml/d, thereby helping to protect the river at times of lower flow.

At other sites, when river flows are low we add water to the river, and this is termed stream support. In the upper reaches of the Bristol Avon catchment we can increase flows by more than 30 Ml/d using water taken from boreholes that are nearly 100 metres deep. In the early 1990’s the river used to run dry in the summer, but stream support now helps maintain a good flow through the town of Malmesbury even in the driest of years. Licence information for all sources is specified within Miser so that deployable output modelling (see Section 2) takes account of these constraints on source outputs.

At some sites we have committed to the Abstraction Incentive Mechanism (AIM) where we reduce abstraction at key sites during periods of low groundwater and river flows to protect the local river environment.

In our deployable output assessment, we have not included any future changes to deployable output from abstraction reform. Our planning tables identify sources that have unused licence volumes according to our deployable output assessment.

3.1 Historical Licence Changes Made and Pending

At some sources concerns have been raised that the existing licences do not adequately protect the environment – in response we have worked in partnership with the Environment Agency and Natural England to investigate the issues and identify mitigation measures where appropriate. Table 3-1 summarises the investigations we have undertaken and the outcomes from the studies. It should be noted that several of the investigations have identified unacceptable impacts and the Environment Agency have then required changes to licence conditions (i.e. reductions) or other mitigation measures to be made.

For the AMP6 and AMP7 studies some outcomes are not yet concluded and therefore the expected sustainability reduction has not yet been confirmed. These expected changes will be accounted for as Sustainability Reductions, alongside future reductions from Environmental Destination reductions.

Table 3-1: Recent investigations on the impact of abstraction on the environment

For security reasons the source/licence name has been redacted and is not available in the version of this document published on our website.

Investigation period	River / environmental feature	Source	Outcome and mitigation if appropriate
AMP2 (1995-2000)	River Piddle		**Impact of abstraction unacceptable –** when river flows are low abstraction now reduced by up to 9 Ml/d and this water is used for stream support instead
AMP3 (2000-2005)	Chalfield Brook		**Impact of abstraction unacceptable –** stream support trigger raised to a higher flow threshold to increase mitigation
	Currypool Stream		**Impact of abstraction unacceptable –** increased compensation flow
	St Catherine's Valley		**Impact of abstraction not significant – no licence change required**
	South Winterbourne		**Impact of abstraction not significant – no licence change required**
	River Marden		**Impact of abstraction not significant – no licence change required**
	Semington Brook		**Impact of abstraction unacceptable –** source abandoned and licence revoked
AMP3 & AMP4 (2000-2010)	Tributaries of the Upper Bristol Avon		**Impact of abstraction unacceptable –** licence to be reduced by 4 Ml/d and up to 22.5 Ml/d of additional stream support to be provided. **See also section below this table.**
	Codford Brook		**Impact of abstraction unacceptable –** licence reduced by 14 Ml/d and up to 5 Ml/d stream support to be provided
	River Piddle		**Impact of abstraction unacceptable –** licence reduced by 1.3 Ml/d for public water supply and up to 2.5 Ml/d stream support to be provided
AMP4 (2005-2010)	River Bourne		**Impact of abstraction unacceptable –** licence to be reduced by 11 Ml/d in 2018
			Impact of abstraction unacceptable – licence for public water supply to be reduced by 1.5 Ml/d and instead provided as stream support in 2018
	River Wylye		**Impact of abstraction unacceptable –** licence to be reduced by 5 Ml/d in 2018
			Impact of abstraction unacceptable – licence to be reduced by 6 Ml/d in 2018
	River Avon SAC		**Impact of abstraction not significant other than for the sources identified for the River Bourne and the River Wylye – licence changes as above.**
	Shreen and Ashfield Water		**Impact of abstraction not significant – no licence change required** (see Section 4.5.4 on AIM for further information)

Investigation period	River / environmental feature	Source	Outcome and mitigation if appropriate
	Avon Valley SPA		**Impact of abstraction not significant – no licence change required**
	Fonthill Brook		**Impact of abstraction not significant – no licence change required**
	Upper River Yeo		**Impact of abstraction not significant – no licence change required**
	Stowell Meadow SSSI		**Impact of abstraction not significant – no licence change required**
	Bracket's Coppice SAC		**Impact of abstraction not significant – no licence change required**
	Middle River Stour		**Impact of abstraction not significant – no licence change required**
	Exmoor & Quantock Oakwoods SAC		**Impact of abstraction not significant – no licence change required**
	Tadnoll Brook (Dorset Heaths SAC/SPA)		**Impact of abstraction not significant – no licence change required**
	Cannington Brook		**Impact of abstraction not significant – no licence change required**
	Isle of Portland to Studland SAC		**Impact of abstraction not significant – no licence change required**
AMP5 (2010-2015)	River Avon SAC		**Baseline monitoring of the impact of licence changes to be made in 2018.**
	Heytesbury Brook		**Impact of abstraction not significant – no licence change required**
	Teffont Brook		**Impact of abstraction unacceptable** – daily licence to be reduced by 1.5 Ml/d in 2018
	Upper Hampshire Avon (western)		**Impact of abstraction unacceptable** – daily licence to be reduced to current 'summer' limit all year at two sources (reductions of 1.15 Ml/d and 2 Ml/d respectively) in 2018. River restoration measures also to be undertaken on SSSI stretch.
	Bere Stream (SSSI and BAP)		**Impact of abstraction not significant – no licence change required**
	Biss Brook		**Impact of abstraction unacceptable** – daily licence of boreholes to be reduced by 5.4 Ml/d and hands-off flow for springs abstraction to increase from 1.0 to 1.5 Ml/d in 2018
	River Wey		**Impact of abstraction not significant – no licence change required**
	Sutton Bingham Stream		**Investigation showed the need for trials in AMP6 involving variations in compensation flows, introduction of spate flows and river restoration measures.**
	Upper River Tone		**Impact of abstraction not significant – no licence change required**

Investigation period	River / environmental feature	Source	Outcome and mitigation if appropriate
	Durleigh Brook		**Investigation showed the need for trials in AMP6 involving variations in compensation flows, introduction of spate flows and river restoration measures.**
AMP6 (2015-20)	Durleigh Brook*		**Trialled spate flows to drive ecological improvements** – no licence change required.
	Sutton Bingham Stream*		**Introduced sediment to drive ecological improvements**– no licence change required.
	Cannington Brook/Currypool Stream*		**Investigation ongoing: monitoring of flows and ecology to understand impact**
	Horner Water		**Source abandoned: investigation** ceased and abstraction licence reduced **to** 1.5Ml/d.
	Upper Hampshire Avon (western)		**River restoration to improve channel morphology.**
	Devils Brook		**Impact of abstraction unacceptable –** peak abstraction licence reduced **by 3 Ml/d to 6.09 Ml/d..**
	Lam Brook		**Impact of abstraction unacceptable** –abstraction licence reduced to 2.5 Ml/d daily average.
	River Tarrant, Pimperne Brook, North Winterbourne		**Impact of abstraction unacceptable – trial Abstraction incentive Mechanism in AMP7**
	Maiden Bradley Brook		**Impact of abstraction unacceptable – Flow constraint to be increased to protect brook during low**.
	River Jordan		**Impact of abstraction not significant – habitat enhancements in AMP7.**
	River Avon SAC		**Investigation ongoing:** Ecological monitoring of the impact of licence changes to be made in 2018.
AMP7 (2020-2025)	River Otter		**Investigation complete: awaiting direction from EA over outcome.**
	Ashford Reservoir and Currypool Stream		**Adaptive Management of reservoir compensation flows. Licence change expected but not yet confirmed.**
	Upper Hampshire Avon (western)		**Investigation complete: abstraction licence changes and habitat improvement measures expected.**
	Pimperne Brook		**Adaptive Management, changes to timing of stream support expected.**
	Hampshire Avon		**Investigation complete: abstraction licence changes and habitat improvement measures expected.**
	Devils Brook		**Sustainability change comes into force in 2024. Licence change submitted.**
	Durleigh Brook		**Adaptive Management implementation – ecological monitoring of ‘natural’ flows whilst WTC is refurbished.**

Investigation period	River / environmental feature	Source	Outcome and mitigation if appropriate
	Hampshire Avon		**Investigation complete: abstraction licence changes and habitat improvement measures expected.**
	South Brook (Bristol Avon)		**Investigation ongoing: monitoring of flows and ecology to understand impact – licence change expected.**
	Chalfield Brook (Bristol Avon)		**Investigation ongoing: monitoring of flows and ecology to understand impact – licence change expected.**
	Bristol Avon		**Investigation ongoing: monitoring of flows and ecology to understand impact – licence change expected.**
	Bydemill Brook (Bristol Avon)		**Investigation ongoing: monitoring of flows and ecology to understand impact – licence change expected.**
	Ozleworth Brook, Horsley Stream, Nailsworth Stream		**Investigation ongoing: monitoring of flows and ecology to understand impact – licence change expected.**
	River Isle		**Investigation ongoing: monitoring of flows and ecology to understand impact – licence change expected.**
	River Till		**Investigation complete: abstraction licence changes and habitat improvement measures expected.**
	River Tarrant		**Currently part of an Abstraction Incentive Mechanism (AIM) study to reduce abstraction during periods of low river flow.**
	River Jordan		**Habitat improvements implemented in upper catchment autumn 2021.**

4.2 Overall Methodology Future Sustainability Reductions and Environmental destination

This following section details how we have accounted for losses to Deployable Output (DO) due to Sustainability Reductions and the longer-term Environmental Destination. Building on our ongoing liaison with the (local) Environment Agency as part of current investigation work (see Table 3-1), we have held regular, approximately bi-monthly workshop meetings during draft WRMP development and pre-consultation, to derive a set of potential licence change related Deployable Output losses during drought conditions, building on the information currently available from ongoing investigation work, and available from the Environment Agency's National Framework on Environmental Destination. These figures have been used in our supply-demand balance scenarios to help build the adaptive plan.

It is important to state that the outcomes of current investigation work are still uncertain as the investigations are ongoing[24]. Furthermore, the licence changes required by 2050 under environmental destination are also uncertain, reflecting both the detail with which modelling is currently undertaken, and uncertainty in how climate change will impact upon catchments between now and 2050. We have therefore derived low, central and high scenarios for potential deployable output changes to account for these uncertainties, which are reflected in our adaptive plan; further work is required, in particular over the coming two business plan cycles (5 to 10 years), through further environmental investigation and modelling work (as per the WINEP programme) to narrow down uncertainties to inform decision making on the right scale and timing of reductions.

The overall reductions shown below are a result of a range of drivers and guidance, which have been considered by Wessex Water and the Environment Agency in their production, and are reflected in the Environmental Destination, as well as in those sites currently under investigation as part of the WINEP programme, including:

- WRMP supplementary guidance "actions required to prevent deterioration – England" - Regulatory actions required to avoid deterioration and meet targets for Protected Areas.
- Actions required to meet the abstraction plan for 2027 (where applicable) and those required to achieve WFD regulations objectives, as defined in RBMPs
- Measures in the Water Industry National Environment Programme (WINEP)
- Environmental obligations, including obligations towards SSSIs, covered by the Wildlife and Countryside Act 1981, sites designated under the Conservation of Habitats and Species Regulations 2017, and any international agreements.

Environmental Destination Scenario and Sustainability Reduction Scenario Generation

Starting with the Environment Agency's National Framework scenarios for Environmental Destination[25], the overall methodology for developing Environmental Destination scenarios to include in the Water Resources Management plan is summarised in (Figure 3-1).

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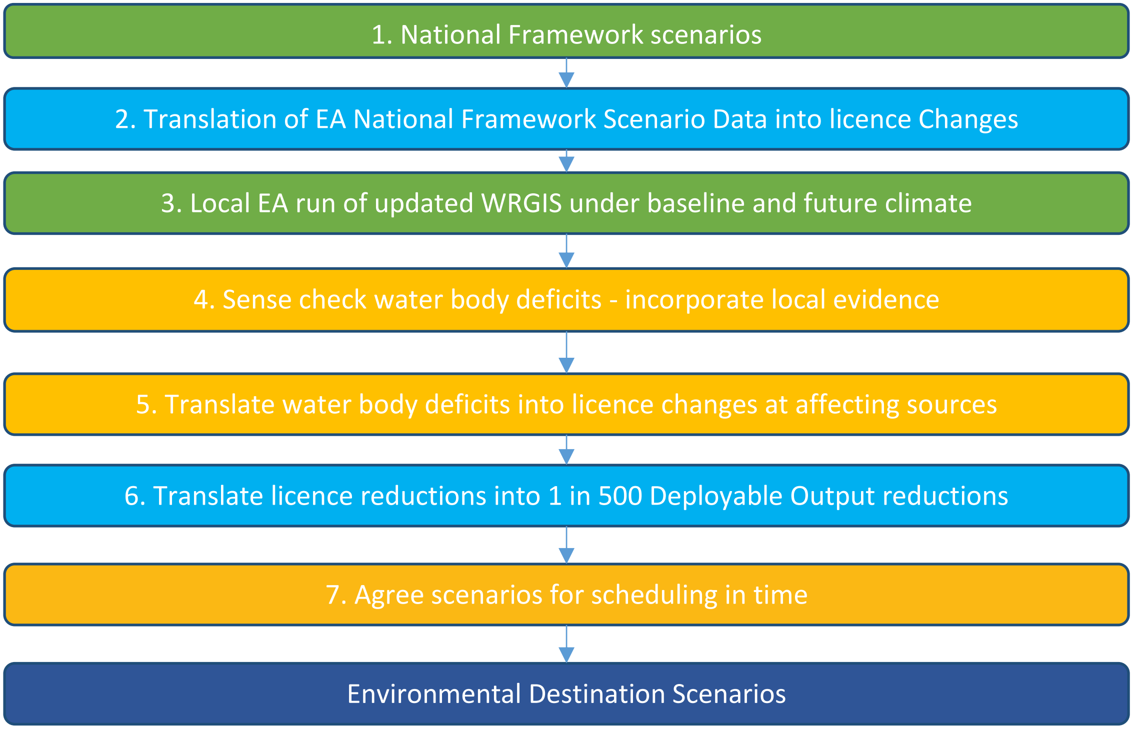
[24] Appropriate updates will be made to the final plan reflecting new investigation information

[25] Meeting our future water needs: a national framework for water resources - GOV.UK (www.gov.uk)

Figure 3-1 Methodology overview for developing Environmental Destination Scenarios



Starting with the Environment Agency’s National Framework data, these data were initially translated into licence changes at sources based on work undertaken at a regional plan level. Local EA then made further runs using the EA’s WRGIS software to derive under the baseline and future climate scenarios water body deficits. These deficits were then sense checked through workshop discussions between Wessex Water and the local EA. This incorporated the current understanding of the catchments, as informed by past investigation work, and knowledge of other likely factors affecting the ecology of these water bodies, including water quality and morphology, to inform the actual water body deficit scenarios (low, central and high – see below). The water body deficits for each catchment were then translated into required licence changes in Wessex Water abstractions that affect each of the water bodies, accounting for the relationship between abstraction reduction and flow benefit. The proposed licence changes and water body deficits derived from the EA’s WRGIS are based on the assumption that all of the licence is used. During a drought, not all water available on a licence is available to abstract due to low flow licence restrictions and hydro-geological constraints. Therefore, the licence changes for each source were translated into deployable output reductions during a 1 in 500 drought. These reductions were agreed between Wessex Water and the Local EA based on the requirements for licence reductions in 2050. The final stage was to translate these reductions into scheduling of when those changes can be achieved.

To derive the scenarios of DO changes relating to outcomes of ongoing investigations, during the workshops the anticipated outputs of current environmental investigations, alongside information available to date, was used to derive low, central, and high scenarios.

Licence Change Scenarios

For both sustainability reductions and environmental destination, 3 alternative scenarios to reflect the different sources of uncertainty affecting the licence reductions have been derived. This includes not only uncertainty in policy as included in the EA National Framework in terms of the extent to which the environment could be protected in the future, but also epistemic uncertainty, to reflect the relative simplicity of tools applied at this stage of planning, and the uncertainties in actual licence reductions that may be required based on further investigation work[26]. The three scenarios are:

- **Central scenario** - central estimate of licence reductions needed by 2050, **equivalent to the EA National Framework's BAU+ scenario**, and the statutory minimum requirement.
- **High scenario** - a high/upper estimate of licence reductions needed, which may represent policy to an enhanced environment scenario from the EA National Framework, or additional need resulting from for example climate change impact.
- **Low scenario** - to reflect epistemic uncertainty in the relationship between flow reductions identified according to the WRGIS and associated environmental flow indicators, and the ecological and biological need required, where flow reductions may not need to be as large as stated in the WRGIS, particularly if other factors like morphology and water quality can/should be improved. This may be considered equivalent to the Ofwat low scenario.

As per Ofwat's expectations, the low and high scenario have been derived to represent an envelope to mark the boundaries of potential changes in both directions.

To explore the impact of the timing of these licence changes, we have also looked at three different timings of licence changes for these three alternative potential magnitudes of licence change:

- **Main scenario –** licence changes made as soon as practically possible, with the majority of source licence changes occurring in 2035
- **Later scenario –** licence changes made later, when large strategic schemes in the region are available (from 2042) to explore the effect of delaying the timing of licence changes
- **Mixed scenario –** a mixture of the above two-timing scenarios, where licence changes are delayed with the exception of those required in the Hampshire Avon

Figure 3-2 and Figure 3-3 show the losses in Deployable Output for the nine resulting scenarios when the three potential licence change volume scenarios are combined with the three potential timing scenarios. Table 3-2 shows the total DO losses under each scenario by 2050/51, when the timing scenarios converge. Our central planning scenario is the "Main – Central" scenario with the majority of licence changes occurring in 2035.

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[26] As would be undertaken in future pending more detailed environmental investigations and modelling as part of the WINEP programme.

Figure 3-2 Reductions in Deployable Output under different licence change scenarios – Dry Year Annual Average Scenario

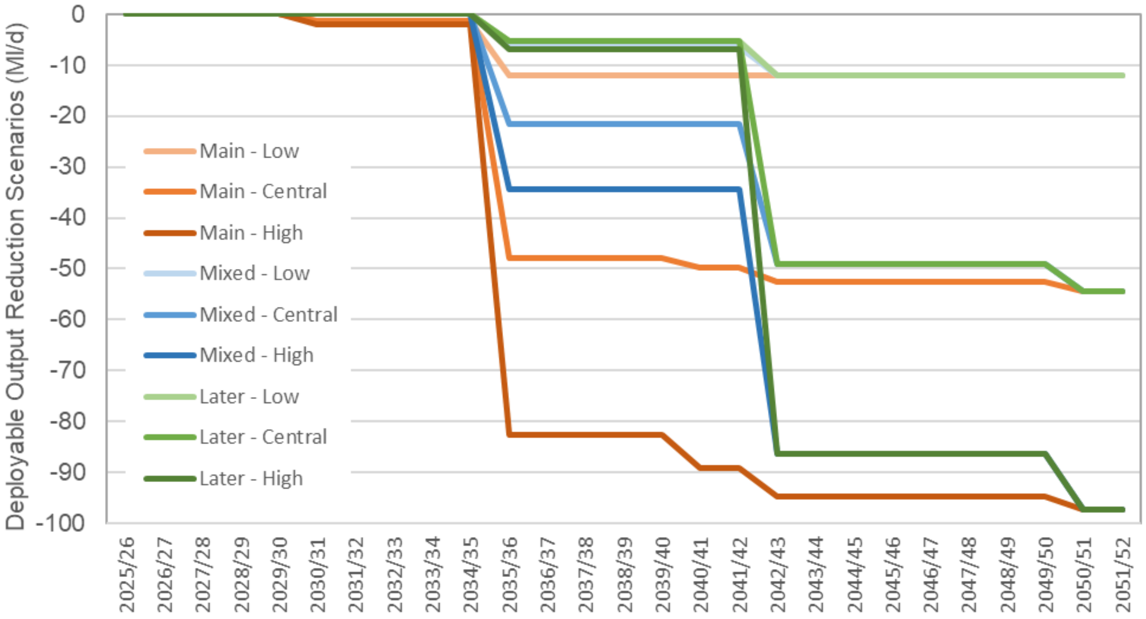

Figure 3-3 Reductions in Deployable Output under different licence change scenarios – Dry Year Critical Period Scenario

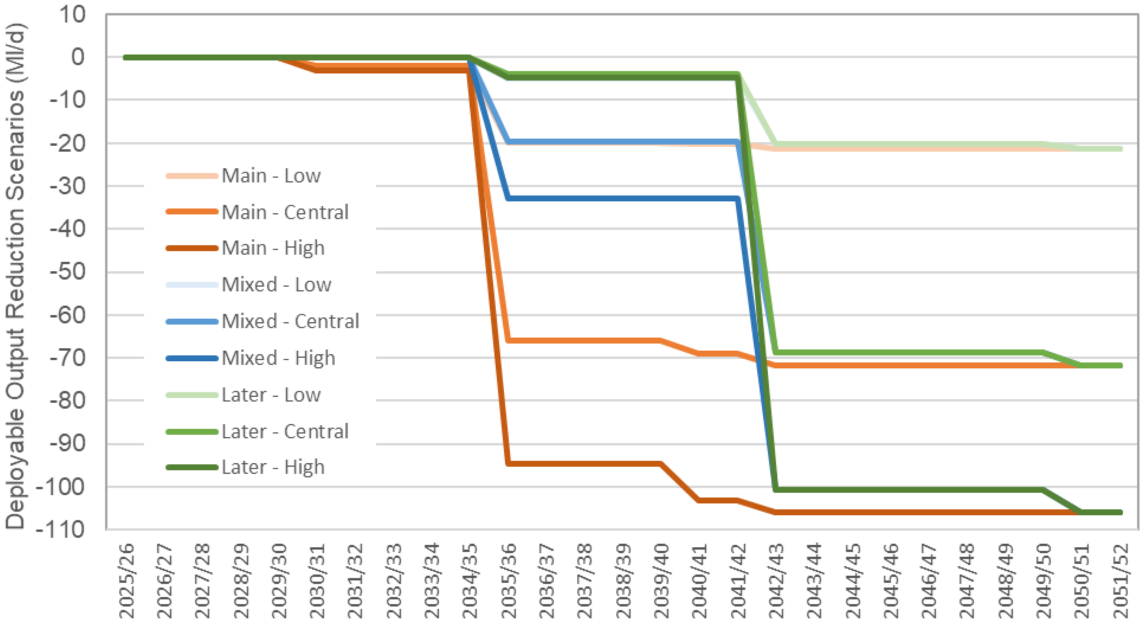

Table 3-2 Summary of total licence changes required across scenarios

	DYAA			DYCP		
Source	**Low**	**Central**	**High**	**Low**	**Central**	**High**
Sustainable abstraction (WINEP AMP7) and Environmental Destination for 2035-36	-17.61	-53.69	-87.58	-25.02	-70.91	-98.67
Sustainable abstraction (WINEP AMP7) and Environmental Destination for 2050-51	-17.69	-60.13	-102.36	-26.35	-76.84	-109.96

Reductions to restore sustainable abstraction (WINEP AMP7) and Environmental Destination

Licence reductions to restore sustainable abstraction are largely related to the WINEP programme and Environmental Destination which are geared towards reducing or eliminating the effects of unsustainable abstraction on designated sites.

No licence losses impacting DO have been proposed earlier than 2035 due to both the need to reduce the uncertainty of the scale of future licence reductions in some river catchments, and the need to ensure that the right solutions are in place to make up any shortfalls in supply. Both of these will be addressed through the ongoing WINEP programme (in AMP8) to investigate the impacts of abstraction from new candidate abstraction sites, and also to investigate solutions for those sites now known to require abstraction changes to protect the environment.

It is important to ensure that the right holistic solutions are in place prior to sustainability reductions being made in order to maintain supplies. This is particularly the case where impacts are known in one catchment, but are only just being investigated in a neighbouring catchment. It could therefore be the case that the optimum solution both for the environment and in maintain supplies is a solution that crosses both catchments in this example. Further discussions will be held with the EA to determine what licence losses could be made sooner, where these do not affect deployable output. This could include abstraction licences which are no longer in use or where there is headroom within the licence that cannot be utilised. Further analysis is also required to quantify the resilience and redundancy impacts of some DO losses via detailed modelling and analysis.

Within the decision making and uncertainty we have accounted for two scenarios, where some licence losses are made in 2035 and the remaining in 2050 and where all licence losses are made in 2050 to review how these reductions influence any investments or interventions required.

A range of investigations will be undertaken during AMP9 to confirm the reduction volumes as the number in the following sections are indicative of likely expected losses.

The following tables outline our assumptions for DO losses resulting from licence losses in 2035 and then later in 2050 (Table 3-3). The drivers for these potential reductions are outlined in Table 3-4. The spatial distribution of these losses in our supply system is shown in Figure 3-4 and Figure 3-5 for the high scenario under the DYAA and DYCP scenarios respectively; the main reductions are in the south and east of our supply system associated with reductions in the Chalk catchments of the Stour and Piddle, and in the north of our supply system in the Bristol Avon and Hampshire Avon.

Table 3-3: DO losses in the baseline SDB resulting from sustainable abstraction (WINEP) and Environmental Destination in the main central scenario

For security reasons the source/licence name has been redacted and is not available in the version of this document published on our website. The Catchment name has been included in the table instead.

Catchment	Proposed year of licence/DO reduction	Investigation type			Reductions in DO - DYAA			Reductions in DO - DYCP		
		Environmental Destination	No Deterioration	Regular Investigation	Low	Central	High	Low	Central	High
Piddle	2035/36	AMP8	AMP8		0.03	0.86	0.55	0.00	2.64	3.12
Wylye	2035/36	AMP8		AMP8	0.00	0.00	0.00	0.00	0.00	0.00
Cannington Brook	2035/36	AMP8		AMP7	1.96	1.96	2.94	0.00	0.00	0.00
St Catherine’s Valley	2035/36	AMP8	AMP8	AMP8	0.00	0.58	1.17	0.00	0.48	0.72
Upper Hampshire Avon	2035/36	AMP8		AMP7	1.02	1.02	1.02	1.06	1.06	1.06
Dorset Stour	2035/36	AMP8			0.00	0.00	0.00	0.00	0.00	0.00
River Parrett	2040/41	AMP8	AMP9	AMP9	0.00	0.50	1.80	0.00	0.50	2.00
Upper Hampshire Avon	2035/36	AMP8		AMP7	0.95	0.95	0.95	0.78	0.78	0.78
River Piddle	2035/36	AMP8	AMP8	AMP8	0.00	4.05	4.68	0.95	9.00	9.00
Wylye	2035/36	AMP8		AMP8	0.00	1.81	3.81	0.00	3.42	3.42
Dorset Frome	2050/51	AMP8			0.00	0.00	0.00	0.00	0.00	0.00
Bristol Avon	2035/36	AMP8		AMP8	0.00	0.00	0.00	0.00	0.00	0.00
Bristol Avon	2040/41	AMP8	AMP9	AMP9	0.00	0.62	1.40	0.00	0.39	0.96
Upper Hampshire Avon	2035/36	AMP8		AMP7	0.00	0.00	0.00	0.00	0.00	0.00
Wylye	2035/36	AMP8		AMP8	0.00	5.68	5.68	0.00	4.03	6.03

River Bourne	2035/36	AMP8		AMP8	0.00	0.00	0.00	0.00	0.00	0.00
Wylye	2035/36	AMP8		AMP8	0.00	0.97	3.97	0.00	0.00	0.00
Upper Hampshire Avon	2035/36	AMP8		AMP7	0.00	0.00	0.00	0.00	0.00	0.00
River Parrett	2035/36	AMP8			0.00	0.00	0.38	0.00	0.00	0.00
Dorset Stour	2035/36	AMP8	AMP8	AMP8	0.00	0.00	0.00	0.00	0.00	0.00
Bristol Avon	2035/36	AMP8		AMP8	0.50	2.50	3.50	0.50	2.50	3.50
River Bourne	2035/36	AMP8		AMP7	0.00	0.00	0.00	0.00	0.00	0.00
Devil’s Brook	2042/43	AMP8			0.00	0.00	2.08	0.00	0.00	0.00
Bristol Avon	2040/41	AMP8		AMP9	0.00	0.00	1.50	0.00	0.00	1.50
Bristol Avon	2035/36	AMP8		AMP6	1.20	1.60	2.00	1.50	2.00	2.50
Upper Hampshire Avon	2035/36	AMP8		AMP7	0.00	0.52	1.02	0.00	2.01	4.01
Dorset Frome	2042/43	AMP8			0.00	0.00	0.00	1.03	2.72	2.72
River Nadder	2040/41	AMP8	AMP8	AMP9	0.00	0.00	0.99	0.00	0.00	1.53
West Dorset Streams	2042/43	AMP8			0.00	2.78	3.48	0.00	0.00	0.00
Wylye	2035/36	AMP8		AMP8	0.00	4.52	6.78	0.00	5.00	7.50
Bristol Avon	2035/36	AMP8		AMP7	0.00	0.00	2.70	0.00	0.00	3.00
River Hooke	2040/41	AMP8	AMP9	AMP9	0.00	0.00	0.00	0.00	0.80	0.80
Bristol Avon	2035/36	AMP8		AMP7	0.00	0.00	1.50	0.00	0.00	1.50
Bristol Avon	2035/36	AMP8		AMP7	0.00	0.00	3.00	0.00	0.00	3.00
River Bride	2040/41	AMP8	AMP8	AMP9	0.00	0.14	0.14	0.30	1.06	1.06
Dorset Frome	2040/41	AMP8	AMP9	AMP9	0.00	0.00	0.32	0.00	0.00	0.23
Dorset Stour	2030/31	AMP8		AMP7	7.00	7.00	7.00	7.00	7.00	7.00
River Piddle	2042/43	AMP8			0.00	0.00	0.00	0.00	0.00	0.00
Bristol Avon	2035/36	AMP8		AMP8	0.00	0.00	0.00	0.00	0.00	0.00
St Catherine’s Valley	2035/36	AMP8	AMP8	AMP8	0.00	1.20	2.40	0.00	0.84	1.26
River Bourne	2035/36	AMP8		AMP8	0.00	1.53	4.03	0.00	0.00	4.16
Bristol Avon	2035/36	AMP8	AMP8	AMP8	0.00	0.87	1.74	0.00	0.61	0.91
River Isle	2035/36	AMP8		AMP7	0.00	0.40	0.80	0.00	2.17	2.65
Bristol Avon	2035/36	AMP8		AMP8	0.50	2.50	3.50	0.50	2.50	3.50
Dorset Stour	2035/36	AMP8	AMP8	AMP8	1.86	4.28	4.28	4.30	4.30	4.30
River Thames	2035/36	AMP8			1.36	1.36	1.36	1.38	1.38	1.38
Wylye	2035/36	AMP8		AMP7	1.23	1.23	1.23	1.30	1.30	1.30
Dorset Stour	2042/43	AMP8			0.00	0.00	0.00	0.00	0.00	0.00
Dorset Stour	2035/36	AMP8	AMP8	AMP8	0.00	1.21	10.49	5.76	12.89	18.06
River Yeo	2050/51	AMP8			0.08	1.95	2.57	0.00	0.00	0.00
Bristol Avon	2035/36	AMP8	AMP8		0.00	0.10	0.10	0.00	0.00	0.00

Bristol Avon	2035/36	AMP8	AMP8	AMP8	0.00	0.00	0.00	0.00	0.00	0.00
River Parrett	2040/41	AMP8	AMP9	AMP9	0.00	0.45	0.50	0.00	0.45	0.50
River Exe	2035/36	AMP8			0.00	5.00	5.00	0.00	5.00	5.00
Wylye	2035/36	AMP8		AMP8	0.00	0.00	0.00	0.00	0.00	0.00
Bristol Avon	2035/36	AMP8			0.00	0.00	0.00	0.00	0.00	0.00
Total					**17.69**	**60.13**	**102.36**	**26.35**	**76.84**	**109.96**

Figure 3-4 Spatial Distribution of DYAA distributed input losses resulting from sustainability reductions by 2050

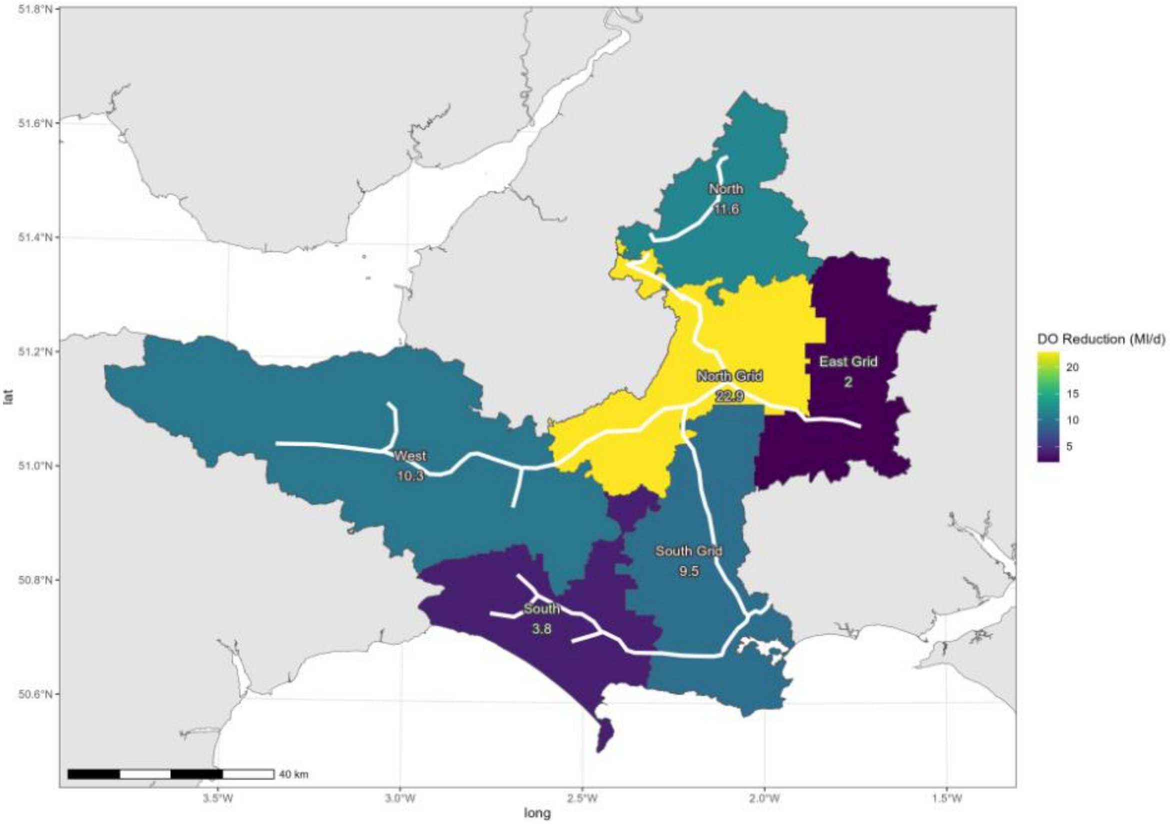

Figure 3-5 Spatial distribution of DYCP distribution input losses resulting from sustainability reductions by 2050

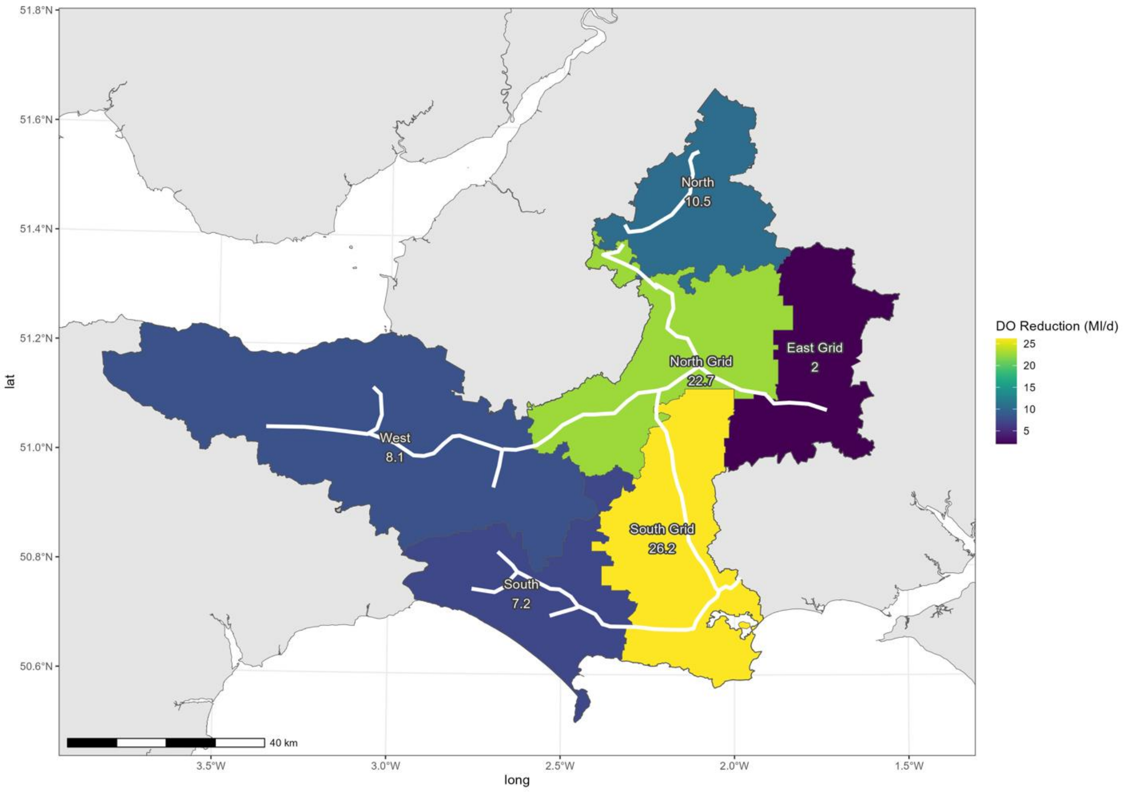

Table 3-4: Drivers for potential reduction at each of our sites*

For security reasons the source/licence name has been redacted and is not available in the version of this document published on our website. The Catchment name has been included in the table instead.

Catchment	Driver for potential reduction
Piddle	AMP8 ND investigation
Wylye	AMP8 investigation
River Parrett	AMP6 WINEP. Assessing impact on WFD status on stream
St Catherine's Valley	AMP8 investigation
Upper Hampshire Avon	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Dorset Stour	N/A
Parrett	AMP9 investigation
Upper Hampshire Avon	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Piddle	AMP8 ND investigation
Wylye	AMP8 RCSMG investigation
Dorset Frome	N/A
Bristol Avon	N/A
Bristol Avon	AMP9

Upper Hampshire Avon	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Wylye	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
River Bourne	AMP8 investigation
Wylye	AMP8 RCSMG investigation
Upper Hampshire Avon	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Parrett	AMP8 Environmental Destination
Dorset Stour	AMP8 - No Deterioration
Bristol Avon	AMP8 investigation
River Bourne	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Devil's Brook	Licence change 2024, WFD categorisation does not reflect this. ED risk in future due to CC
Bristol Avon	AMP9 investigation
Bristol Avon	AMP6 WINEP. Assessing impact on WFD status on stream
Upper Hampshire Avon	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Dorset Frome	Environmental Destination only investigation
River Nadder	AMP8 no-deterioration investigation
West Dorset Streams	AMP8 ED - implementation post amp 9
Wylye	AMP8 investigation
Bristol Avon	AMP7 WINEP. Assessing impact on WFD status on tributaries and River Avon
River Hooke	AMP9 investigation
Bristol Avon	AMP7 WINEP. Assessing impact on WFD status on tributaries and River Avon
Byde Mill Brook	AMP7 WINEP. Assessing impact on WFD status on tributaries and River Avon
River Bride	AMP8 WFD-ND investigation, but implementation post AMP9
Dorset Frome	AMP9 investigation
Dorset Stour	Voluntary scheme to improve stream flows. Reductions in DO included in planning tables reflect reduction to restore stream flows if a solution is not implemented.
River Piddle	No WFD driver in short term, possible deterioration post 2040
Bristol Avon	N/A
St Catherine's Valley	AMP8 investigation
River Bourne	AMP8 RCSMG investigation
Bristol Avon	AMP8 investigation
River Isle	AMP7 WINEP. Assessing impact on WFD status of surrounding streams
Bristol Avon	AMP8 investigation
Dorset Stour	AMP8 - No Deterioration
River Thames	AMP8 - No Deterioration

Wylye	AMP7 WINEP: Impact on River Avon SSSI and SAC reaches. Determining abstraction necessary to meet rCSMG river flow criteria
Dorset Stour	N/A
Dorset Stour	AMP8 - No Deterioration
River Yeo	AMP8 Environmental Destination
Bristol Avon	AMP8 investigation
Bristol Avon	AMP8 - No Deterioration
Parrett	AMP9 investigation
River Exe	AMP8 investigation
Wylye	AMP8 investigation
Bristol Avon	AMP8 - WFD

*WFD = Water Framework Directive; ND = No Deterioration Water Framework Directive; SSSI = Site of Special Scientific Interest; rCSMG = revised Common Standards Monitoring Guidance.

3.1.1 *Licence capping*

For security reasons individual source names have been redacted from this section and are not available in the version of this document published on our website.

Wessex Water were notified on the 15th November 2021 of the EA's intention to cap abstraction licences at some sites to the recent maximum abstraction to avoid any deterioration due to population growth and additional demand.

The guidance states 'where licence change is necessary to prevent deterioration in England, licences will either be capped at recent actual average abstraction or at the maximum peak volume of water abstracted in any one year of a representative abstraction period, depending on the risk that deterioration will occur. Where licences are capped at maximum peak abstraction, this will give you some flexibility to meet short-term peaks in demand. However, you must not plan to service future growth in demand through unsustainable increases in abstraction under licences that fall into this category".

Following our plan consultation period, we have had further engagement with the Environment Agency and Natural England through the WINEP process, and also following receipt of representations on the draft version of this plan. Specifically Natural England have raised concerns about the impact of our current abstraction on the integrity of the River Avon Special Area of Conservation and Sites of Special Scientific Interest (SSSI) in the catchment, as well as the impact on the Somerset Levels and Moors Ramsar site. Of key importance was the requirement from the EA and NE to ensure first that new growth in the catchment is not met through additional abstraction, so that abstraction would remain at recent actual levels, and second, that abstraction will be reduced as soon as practicable. A key cited driver is to keep abstraction at recent actual levels is to avoid the imposition of "Water Neutrality" which may inhibit planned development growth.

We have liaised with the EA to calculate our recent actual abstraction in the five-year period since the implementation of the grid project in 2018 for the Hampshire Avon and compared this to our proposed abstraction in the Water Resources Management Plan Deployable Output (DO) calculation to understand the extent to which our WRMP DO effectively includes headroom to meet new catchment growth. Our annual average DO in our WRMP for the catchment sources totals 62.36 Ml/d compared to a recent peak actual abstraction of 62.87 Ml/d (in 2021-22). As a result of licence changes already implemented in the catchment in 2018, that led to the construction of the grid project, we already abstract to these new licences, and therefore there is no proposed headroom on our licences in the WRMP that is available to meet new growth at the catchment level.

On an individual source level, we have agreed to cap abstraction at a source at the recent actual level of 1.26Ml/d in the Wylye catchment. The only other source in the Hampshire Avon where recent actual abstraction is notably below that proposed in the WRMP is in the Nadder where recent actual abstraction is 90% of that proposed in the WRMP. This is as a result of winter water quality issues that have, in recent years, reduced available abstraction. We are currently implementing a blending scheme at this site to increase winter abstraction from the source. Assessment of the impact of the source at full abstraction at the top of the

Hampshire Avon SAC in the Nadder (e.g. at the point of maximum potential impact) shows at full licence the abstraction is within 10% at Q95 and therefore compliant with CSMG (Common Standards Monitoring Guidance).

We have worked closely with the EA to identify these licence changes and have ensured that in deriving the overall sustainability reductions in the supply demand balance, we have not double counted licence capping and environmental destination licence changes.

Time-limited licences

For security reasons this section has been redacted and is not available in the version of this document published on our website.

3.2 Invasive Non-Native Species (INNS) and Eels (for AMP7 implementation)

For security reasons the source/licence names have been redacted and are not available in the version of this document published on our website.

In AMP6 Wessex Water undertook a National Environment Programme (NEP) investigation into invasive non-native species (INNS). The investigation consisted of:

- A review of INNS presence on land holdings
- Surveys where insufficient information was available
- Completion of a risk assessment of land, assets, and operations
- Prioritisation of control/eradication opportunities and development of a programme of works for 2020-2025.

This investigation was completed and signed off by the Environment Agency in April 2017. The risk assessment element of this work included developing a risk matrix that focussed on the pathways by which INNS can be spread. The 25 highest risk sites identified in the assessment were included in our WRMP19 business plan (2020-25) and includes[27]:

- Biosecurity implementation at reservoirs – we are installing wash down facilities so that sailing clubs can wash their boats and will install new dip tanks for anglers. We will also provide new boot scrub stations and signage. The company also perform annual surveys to monitor INNS.
- Partnership working – we are funding a Centre for Agriculture and Bioscience International (CABI) biological control trial, which involves infecting the invasive plant, New Zealand pigmyweed to restrict its growth. These trials are underway.
- Contributing to a national campaign – we are involved in a partnership formed between the government, environmental organisations, and other water companies to help reduce the threat of INNS and improve aquatic biosecurity. This partnership is led by the Animal and Plant Health Agency.

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[27] Invasive non-native species (wessexwater.co.uk)

Wessex Water is required to ensure that its operations are compliant with the Eels Regulations (England and Wales) 2009. In AMP6 we undertook investigations at ten of our water supply sites to assess the risk that they pose to eel entrainment and act as barriers to eel migration. Through this work we identified sites where improvements to screening and upstream and downstream eel passes may be required. The outcome concluded that improvement for Eel screening was needed. Any new water resource options will be assessed against potential impacts on Eels as part of the environmental assessments.

The risk of spreading INNS and potential impact on Eels for new water resources schemes will be reviewed as part of the various environmental and assessment assessments undertaken as part of the Feasible Options list (please refer to the Technical Appendix on Options Development and Appraisal).

3.3 Abstraction Incentive Mechanism

For security reasons the source/licence names have been redacted from this section and are not available in the version of this document published on our website.

Abstraction investigations like those described earlier in this section can be inconclusive or the impact assessed to be small, or despite the lack of impact assessed on a scientific basis, there remains significant local community concern about the impact of abstraction.

In such cases, and where there is flexibility in a system to use other sources, the operation of an abstraction incentive mechanism (AIM) can be a useful tool to achieve reductions in abstraction without formally changing an abstraction licence. An AIM provides an incentive for a water company to reduce its abstraction from a particular source when abstraction is happening at a sensitive time – i.e. during periods of low river flows.

If necessary, due to a lack of water availability at other sources in the system, abstraction can occur from the source at the full licence, but the company will have to pay an additional cost for doing so. Although this may involve some abstraction at times when river flows are low, ecological systems are usually robust enough to mitigate the impact of temporary abstractions even during periods of low flow.

We introduced a trial AIM scheme in the upper Dorset Stour Catchment in our last Plan and AIM has been implemented here since April 2015. Since the application of the AIM programme we've reduced the volume of water abstracted to export from the local catchment by around 60%. This is described further below. This Plan proposes the continuation of the AIM at Mere for the next 5-year period from 2025-30. The plan includes implementation of a permanent stream support solution in 2025-30 window, for delivery in 2030.

In WRMP19 we introduced a new AIM site in the Middle Dorset Stour. The groundwater source is located in the River Tarrant Valley. The source draws water from the underlying chalk aquifer, which is drained by the River Tarrant, a tributary of the River Stour. The source has been used since the 1950s and in the last 20 years abstraction has been close to 85% of full licence (2.18 Ml/d) all the time. The River Tarrant is a winterbourne stream and the whole river can dry during extended dry weather (as experienced in 1976). The AIM measure limits abstraction a 1.09 during periods of lower groundwater levels. AIM will continue for the 2025-30 period.

3.4 Unused Licences

Wessex Water has a number of unused abstraction licences (Table 3-5) which could in theory be considered for revocation within the wider discussion of the abstraction licences. Revoking these licences could potentially offset any abstraction losses as per Section 3.

Table 3-5: Unused abstraction licences

For security reasons this table has been redacted and is not available in the version of this table published on our website.

4. Raw Water Losses, Treatment Works Losses, and Operational Use

4.1 Overview

Treatment Works Operational Use (TWOU) is the water abstracted from sources that does not enter distribution as it is ‘used’ during treatment processes and other losses. We have two methods for calculating TWOU which is 1). To calculate DI from Water Into Supply and 2). To calculate any DO losses from TWOU for the Supply Demand Balance Index and for WRMP planning. At some Water Treatment Works (WTW) the water is discharged into local watercourses under permissions granted by a Discharge Consent from the Environment Agency; at other sites the water enters the sewer system or is returned to raw water reservoirs. Depending on the pathway of the water this can result in DO losses and therefore needs to be accounted for in WRMP24 planning as a loss in DO.

Please note since WRMP19 we have updated our approach to calculating TWOU and therefore the numbers are not comparable to historic numbers. The key difference is:

- Reservoir TWOU where the volume has been removed as the water is returned to the reservoir, and therefore no DO loss occurs. This is valid only at reservoir sites where the volumes are returned to the reservoir.
- Inclusion of groundwater run to waste volumes which previously were not included. Run to waste from boreholes has increased in recent years due to higher water quality standards and therefore is now included.

4.1.1 Groundwater Sites

At most groundwater borehole sites the TWOU losses are small and relate only to the volume of water passing through water quality monitors that is not recovered into the treatment stream (as these sites there is only disinfection treatment). The largest TWOU volumes are associated with sites with filter backwashing at Iron removal plants which results in modest usage ranging from 0.6 – 7.4% of the abstracted volume. A small number of sites have additional treatment such as nitrate removal which also results in a TWOU DO loss. Groundwater borehole sites can also be run to waste on an ad hoc basis and therefore these volumes need to be accounted for in TWOU.

4.1.2 Surface Water Sites

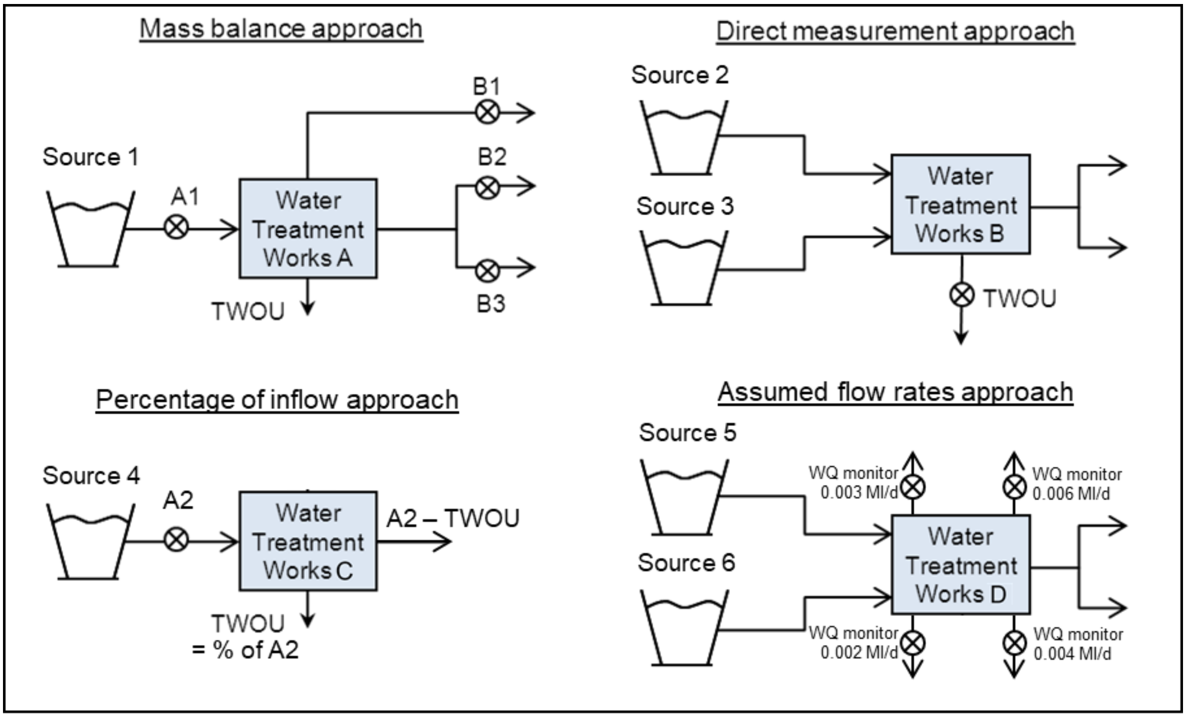
At surface sites, a significant volume of water is used in the treatment processes, but for most of these sites, this water is returned to the raw water reservoir so there is no loss in DO. Therefore, the only raw water loss reported from these sites is the difference between the total TWOU volume and the volume returned to raw water reservoirs, usage ranges between 0.9 – 1.4%. Only one surface water site has TWOU volumes which are not returned to the reservoir.

4.1.3 TWOU Calculation Approach

The calculation approach for TWOU is undertaken via a number of approaches, outlined in Figure 5-1, which includes:

- Direct metering on the discharge
- Mass balance approach (inflows v's outflows of the works)
- Percentage of inflow via approaches such as back wash frequency to calculate an average percentage loss
- Use of assumed flow rates for varying types of water quality monitors, such as turbidity and chlorine with volumes proportional to the number of days in supply.

Figure 4-1: Schematic illustrating how treatment works operational use is calculated



4.1.4 *Run to Waste volume approach*

Run to waste from boreholes is calculated in a number of ways which include a mass balance between the abstracted volume and a downstream meter and using run to waste meters. Where run to waste occurs at the same time as an outage this has been removed from the analysis as the loss in DO has already been accounted for in the outage records and therefore avoids double counting.

4.1.5 *Total TWOU for WRMP24*

Based on the approach detailed above our TWOU calculation for DO losses for WRMP24 is detailed in Table 4-1.

Table 4-1: TWOU for WRMP24 components

TWOU	Description	2019/20 volume Ml/d	2020/21 volume Ml/d	Comments
Membrane treatment works	Associated with membrane cycles	0.025	0.019	
Iron treatment works	Associated with filter backwashing. Accounts for 0.6-7.4% of works output.	0.480	0.557	
Nitrate treatment works	Associated with regeneration brine waste.	-	0.03	Only began accounting for in 2020/21.
Water quality monitors	Associated with flow through water quality monitors at all sites.	0.753	0.795	An increase in 2020/21 following a review of WQ monitors.
Running to waste	Associated when abstracted water is ‘run to waste’ (typically because it does not meet the necessary quality parameters, i.e. short lived turbidity peaks).	1.699	1.608	This is only accounted for when the site is not logged as being ‘out of supply’ for more than 24 hours.
TOTAL		2.957	3.009	

The operational use volumes stated above collectively amount to 2.957 Ml/d in 2019/20 and 3.009 Ml/d in 2020/21. Both figures have been used in the Supply Demand Balance Model, with the 2020/21 figure being used as the constant over time, being the latest value. In the context of the planning period, we considered whether upcoming maintenance programmes at any of our surface water treatment works would significantly affect the appropriateness of using past TWOU throughout the period, but concluded that operational uses would not be significantly impacted.

Given the low volume of TWOU no options have been considered to reduce losses. For PR24 a study into turbidity treatment is being undertaken. The primary AIM is drinking water standards, rather than a reduction in TWOU and therefore has not been considered.

5. Outage Allowance

5.1 Introduction

For security reasons source/licence names have been redacted from this section and are not available in the version of this document published on our website.

At any one time the actual achievable output from our sources could be less than the total DO, owing to source outages and restrictions. Outages are defined as a temporary loss of DO (UKWIR. 1995[28]) due to planned maintenance and capital work, or unplanned events such as power failure, asset failure or water quality issues (including source pollution). Sufficient allowance needs to be made for temporary reductions in DO.

In late May 2020 we experienced unprecedented high demand for the month, which was significantly above the demands normally expected in May and was our peak week for 2020-21. During this period the region was under lockdown measures with many people at home, in a period of hot dry weather, which resulted in demand well above expected levels. Additionally, at this time a number of our groundwater sites were still out of supply due to high winter nitrates. This coupled with a rapid rise in demand meant we needed to engage with the Environment Agency to undertake a planned minor breach of an abstraction restriction (which had just come into force) for a period of 3 days, in order to safeguard supplies. Following this event, we have reviewed our supply planning to ensure we have production headroom earlier in the year to account for unexpected periods of demand outside of the typical June to August period where we typically have winter outages.

Please note since 2020/21 we have changed our approach for reporting outages which historically was against the Design Capacity and excluded outages >90 days and planned outages. In the assessment we assess capacity lost against the Dry Year Annual Average (DYAA) and Dry Year Critical Period (DYCP). This was to ensure we aligned our outage reporting to the Supply Demand Balance Index (SDBI). Therefore, historic outage reporting is not comparable to the outage numbers presented in this section.

5.2 Outage methodology

To conduct our outage analysis, we have followed the supplementary EA guidance on outage[29], and used the UKWIR outage analysis[30] methodologies as a basis to provide us with an appropriate outage allowance. As per the guidance, we have considered the magnitude and duration of outage events, as well as the frequency, in deriving a total outage allowance for DYAA and DYCP scenarios.

We have also taken into account the relevance of different outage types with regards to our 1:500 drought planning scenario, adjusting the database to remove outages that should not occur within a drought. In addition to these adjustments, we have also reviewed the

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[28] UKWIR (1995). Outage allowances for water resources planning.

[29] Environment Agency (March 2021). Water resources planning guideline supplementary guidance - Outage

[30] UKWIR (2016). Risk based planning.

database with regards to new treatment improvements and network adjustments within our water supply system. For example, we have removed cryptosporidium related outages at sites where we have installed UV treatment in the past few years, as these outages should not occur in the future.

5.2.1 Outage record

For our water resources management plan, we used a single resource zone outage model. The data used to support this model came from the company's Outage Database, which contains over 2,500 individual records of outage events at all sources since 2006/07. This database is updated twice weekly by our Water Resources Team and reviewed twice yearly with staff from our Operations department. Outages are logged in accordance with the Unplanned Outage Metric in terms of categories, data recorded and assurance. As a result, we have a strong understanding of the level of outage at any given time which is reviewed monthly for our monthly Water Resources Strategy.

The outage database is designed to store the outage information in a format that is ready to analyse, clearly stating the reduction in DO, outage duration and cause of the outage. An example of this is shown in Table 5-1.

Table 5-1: Example extract from our outage database

Source	Design capacity (M/d)	Current max output (Ml/d)	Loss of output from design capacity (Ml/d)	Start date	End date	Duration (days)	Category	Issue	Magnitude of outage event (Ml)
Source A	4.5	0.0	4.5	01/04/19	07/04/19	6	D: Raw water quality	Turbidity	27.0
Source B	0.85	0.45	0.4	10/04/19	16/05/19	36	E: Operational	Pump failure	14.4

Outages are recorded against twelve categories:

- A: Long-term – capital investment
- B: Planned – on programme
- C: Planned – outside programme
- D: Raw water quality
- E: Operational
- F: Supply risk – Production
- G: Supply risk – Network
- H: Not legitimate outage or risk
- I: Yield
- J: Planned – from unplanned
- K: Raw water quality – Asset health
- L: Site conditions

5.2.2 Analysis methodology

We used the UKWIR 1995 methodology as a basic reference method from the risk-based planning guidelines. Unlike the WRMP19 methodology, which followed the structure of the work carried out by consultants at Mott MacDonald for WRMP14, we have not implemented monthly analysis to output a single frequency distribution for outage events in a resource zone. We have instead analysed data in two distributions in the following periods: DYAA and DYCP. The methodology was implemented as follows:

- Downloaded and reviewed the historical outage record from the company database to assess the accuracy of the recorded data, and whether the outage is legitimate within our planning scenario. For example, we have filtered out events that are less than one day, filtered out events that are longer than 90 days, and filtered out events linked to water quality which are already accounted for in our Miser modelling with annual profiles (such as seasonal nitrates).
- Taking into account changes in the water supply system – relating to both network and treatment improvements. For example, in recent years we have installed UV plants at some of our water treatment centres, which should eliminate cryptosporidium outages at these sources. Therefore, any water quality outage events at these improved sources, and at sites which are no longer in supply, would no longer cause a reduction in DO and have been removed.
- Taking into account relevance with regards to our 1:500 drought planning scenario. For example, we have removed planned outage events, as we would not proceed with these during a 1:500 drought scenario and removed outages that would not occur within a drought – such as operational outages that would be resolved more quickly, and any that were a result of heavy rainfall or flooding.
- Represent the frequency magnitude and duration of each outage issue at each source by fitting a range of probability distributions to the magnitude, duration, and frequencies of the outage event. In defining the magnitude of outage at each site we incorporated the outputs of deployable output assessment for each site alongside the historical outage record, to set appropriate outages for both the DYAA and DYCP.
- Select the most appropriate distributions for each outage types at each source, using expert judgement considering the validity of the historical record as representative of outages in the future, and also considering the quality of the underlying data in supporting a given model fit. In most cases, outage data were insufficient to justify particular model fits (which for statistical robustness ideally require 10s of samples), and so we used a triangular distribution, as recommended in the original 1995 methodology, or a fixed distribution for most outages.
- Run the Monte Carlo sampling from each source and set of distributions to derive an overall outage allowance. The original 1995 methodology recommends 500 iterations, and in WRMP19 100,000 iterations were ran in the R statistical software package[31] to get as representative distribution as feasible, given lower computational constraints.
- A percentile value for outage was chosen by comparing the results with historical distributions of annual and monthly averages.

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[31] R Core Team (2015). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

5.3 Outage results

Figure 5-1 shows the sampled DYAA outage distribution. The median of the DYAA outage distribution is 16.57 Ml/d, with a range from 13.56 Ml/d to 22.42 Ml/d, which equates to between 3.4% and 5.7% of deployable output, depending on the chosen risk percentile. Figure 5-2 shows the equivalent distribution for the DYCP. The DYCP outage distribution median is 11.89 Ml/d, and ranges from 8.88 Ml/d to 21.93 Ml/d, which equates to between 2.0% and 4.9% of deployable output.

The UKWIR risk-based planning guidelines state that there has been no guidance as to the percentile to choose to derive the outage allowance and suggests that although academic theory might suggest a lower percentile, practicalities associated with physical resource management and the management of drought risk indicate that a planning allowance in the range 75% to 90% should be used. In our previous plan, we adopted the 85th percentile for both the annual average and critical period planning scenarios.

Following a comparison of the results with the historical distributions of annual and monthly averages, we have selected to use the 90th percentile for outage throughout the planning period for both the DYAA and DYCP, giving an outage allowance of 17.78 Ml/d (4.5% of deployable output) and 13.63 Ml/d (3.1% of deployable output), respectively.

Figure 5-1: Sampled outage distribution for dry year annual average

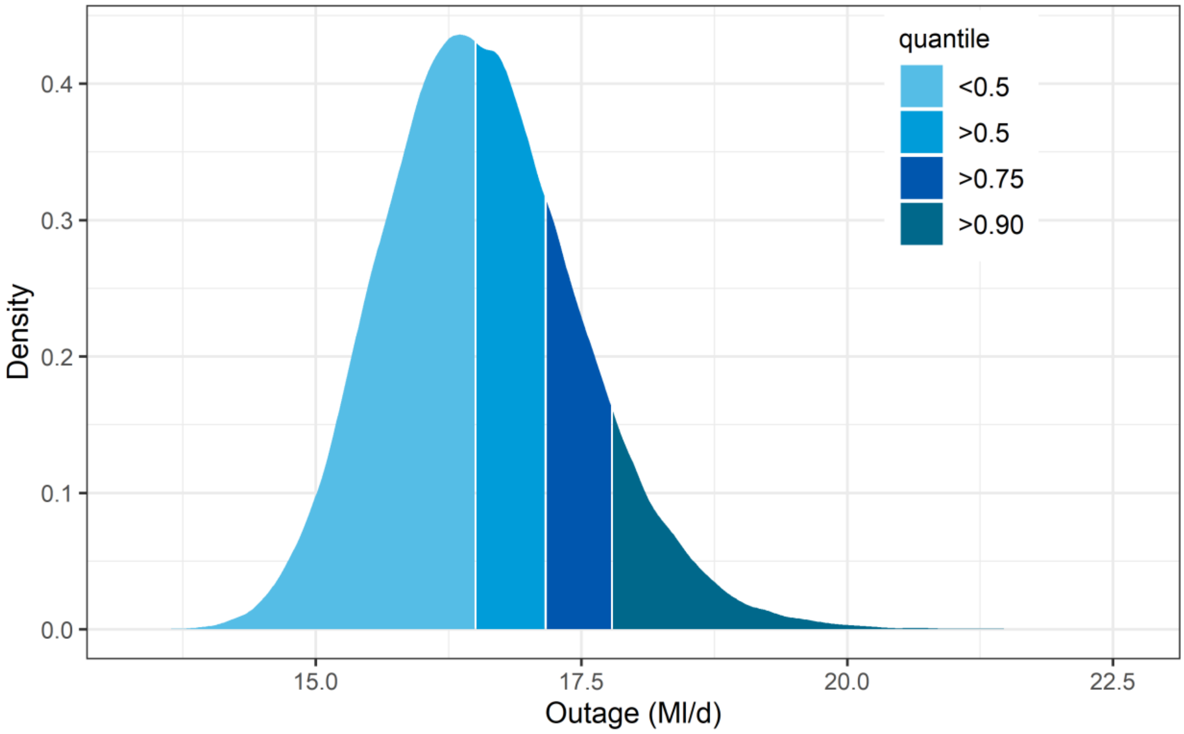


Figure 5-2: Sampled outage distribution for the dry year critical period

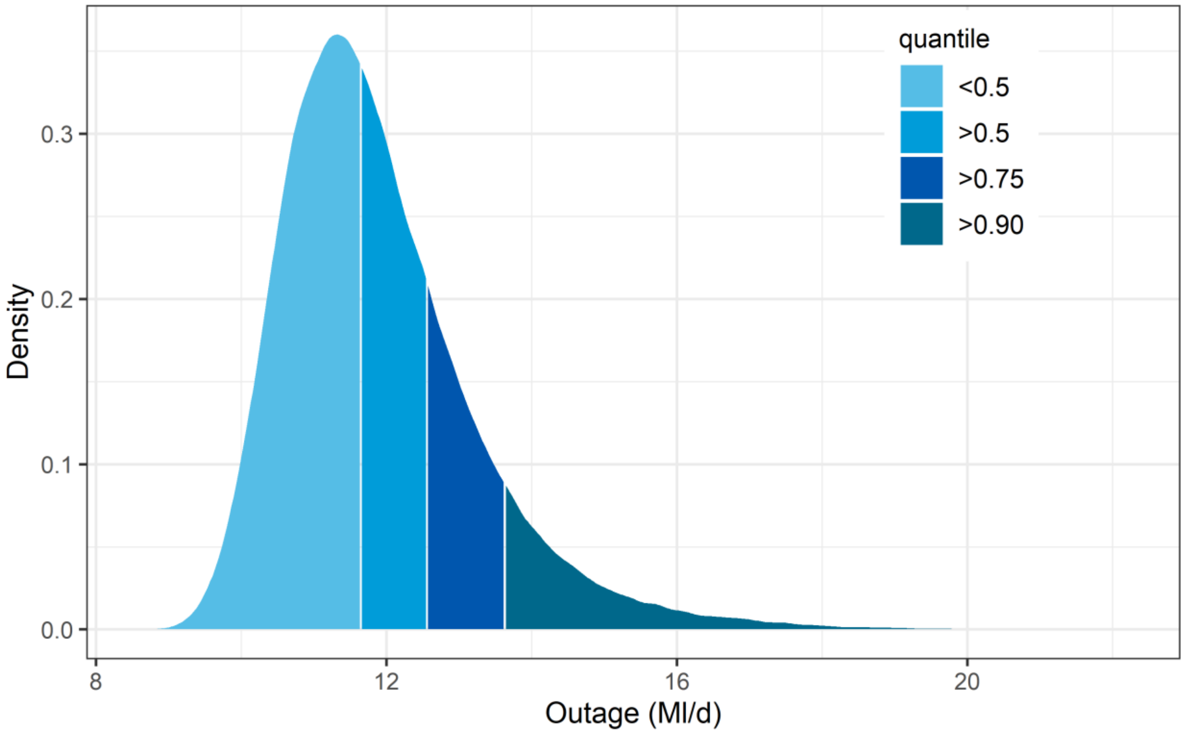


Figure 5-3 shows the contribution of outage type to overall outage at the 90th percentile for the DYAA planning scenario. Individually, planned work contributes the most to the DYAA outage allowance at 28.8%. Water quality issues combined, however, contribute to over half of the DYAA outage allowance, 53.7%, with nitrate issues being the main problem. Unplanned maintenance only contributes 16.7% to the DYAA outage allowance.

Figure 5-3: Contribution of outage type to overall outage (90th percentile) for the dry year annual average scenario

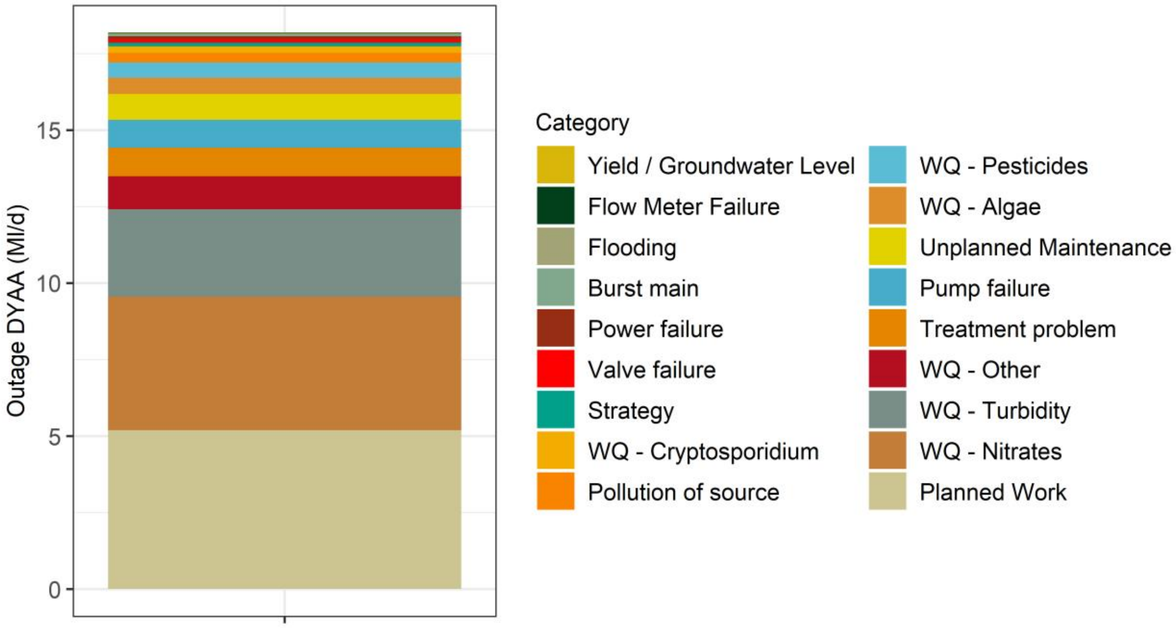
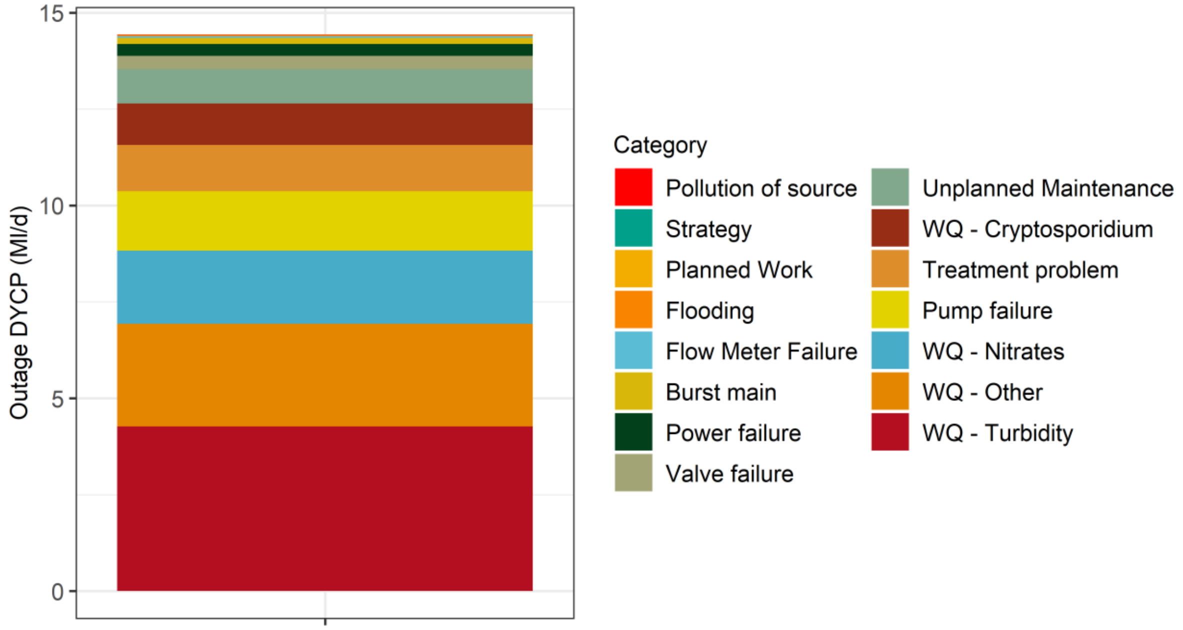


Figure 5-4 shows the contribution of outage type to overall outage at the 90th percentile for the DYCP planning scenario. Planned work has been excluded from this planning scenario on the basis that it would not be carried out during this period. Water quality issues combined, again contribute the most to the DYCP outage allowance with 67.5%, but with turbidity instead being the main problem in this planning scenario, contributing 27.3% to the total. Nitrate issues are associated with seasonal trends, typically increasing in the winter months with heavy rainfall. Therefore, they have been removed from the DYCP analysis due to their unlikely occurrence in this DYCP scenario. Unplanned maintenance contributes to the majority of the remaining DYCP outage allowance at 32.5%.

Figure 5-4: Contribution of outage type to overall outage (90th percentile) for the dry year critical period scenario



5.3.1 *Future changes to outage volume*

For the baseline scenario there are no investments planned which would alter our level of outages and therefore there are no changes to the outage figure over the planning period. Outage has also been considered separately from target headroom; our analysis of headroom is covered in the Technical Appendix on WRMP24 Supply-Demand Balance, Decision-Making and Uncertainty. Due to our baseline supply demand balance deficit options to reduce outage and increase deployable output have been considered. Reducing outages caused by nitrate issues is the main priority due to their dominant contribution to the total DYAA outage allowance.

5.3.2 *Reduction in DO*

Where current outages constrain DYAA and DYCP (against the Maximum Production Capacity) these outages were removed to avoid double counting as the capacity lost is already accounted for in the DO numbers.

5.3.3 *Reducing outage in a drought*

The number and duration of outages is dependent upon the level of demand throughout the year and secondly our overall water resource position. During periods of drought / dry weather the speed at which outages are resolved would be much shorter in comparison to a period of low demand and plentiful water resources, where we may choose to leave the site out of supply over a weekend or not fast track a capital scheme. Reducing outage in these periods is detailed in our latest Drought Plan.

5.3.4 Comparison against WRMP Annual Return Outage

The calculated outage figures for both scenarios are lower than the values calculated in the 2021/22 WRMP annual return: for DYAA and DYCP these are 31.862 Ml/d and 46.6 Ml/d, respectively. Seasonal nitrate outages have again been removed due to their inclusion in the DO assessment, but the annual return figures do account for all planned, unplanned, and long-term capital investment outages of all durations. This includes a large strategic outage at one of our production sites which was detailed in WRMP19. In the DYCP this accounts for 28.5 Ml/d of total outage volume. The site has been out of supply since September 2019 for a rebuild of the water treatment works. The site is due back in October 2022 and therefore our 2022/23 outage volumes should be significantly lower. Removing outages greater than 90 days from the annual return figure gives a new DYAA value of 14.421 Ml/d, this is within the range of 13.56 Ml/d to 22.42 Ml/d generated from the WRMP24 analysis. Removing these same outages and the planned outages from the DYCP annual return figure gives a new value of 7.3 Ml/d. This is just below the WRMP24 range of 8.88 Ml/d to 21.93 Ml/d.

6. Water Quality Constraints

The Water Supply (Water Quality) Regulations include mandatory standards for the quality of drinking water and the management of risk, in order to protect public health. It is therefore essential that our drinking water quality obligations are fully taken into account in the long-term planning of water resources. In July 2022 the Drinking Water Inspectorate (DWI) issued their guidance on the long-term planning of drinking water quality[32]. The guidance highlights there are no new policy initiatives and no new legal obligations, and that our focus should be on delivery of existing obligations using current good practice, within a long-term planning context. We can confirm that this Plan is integrated with our drinking water quality programme and our maintenance programme across our business planning and delivery functions.

This section describes our strategy for managing drinking water quality, including catchment management, our maintenance programme, and the approach we have taken to incorporate water quality risks into this water resources management plan.

6.1 Outcome – Excellent drinking water quality

Our long-term priorities are described in our Strategic Direction Statement, which reconfirmed a commitment to providing the highest quality drinking water. The Strategic Direction Statement[33] informs and supports both our water resources management plan and business plan proposals. The drinking water quality outcome and actions points (reproduced below) include use of source-to-tap drinking water safety plans, continued use of catchment management and proactive maintenance of our sources and water treatment works.

6.2 Drinking water quality management

Seventy-five per cent of the water we abstract comes from groundwater sources and the majority of this is of good quality requiring minimal treatment other than disinfection before being suitable for supply to customers. The remaining 25% is provided by impounding reservoirs in Somerset. The raw water from these sources requires multiple complex treatment processes, as well as disinfection.

The Water Supply (Water Quality) Regulations 2018 include mandatory standards for drinking water, including nitrates and pesticides, to protect public health. These standards are enforced by the Drinking Water Inspectorate (DWI). We aim to uphold these standards at all times. Wessex Water is recognised as one of the top performing water companies in the latest annual report from the Drinking Water Inspectorate's Chief Inspector.
The report shows that we are the only water and sewerage company (WaSC) in the country to achieve zero failures at our water treatment centres in 2021. We also had the lowest compliance risk score (the lower the score the better) and the lowest number of recommendations of all WaSCs. Our rate of discolouration complaints also improved significantly

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[32] Long-term-planning-guidance-for-drinking-water-quality-July-2022.pdf (dwi.gov.uk)
[33] Our strategic direction | Wessex Water

Our approach to long term planning and identifying proposals for drinking water quality improvements involves a combination of the following methodologies:

- Drinking water safety plans – further details provided below
- Review of compliance and operational performance, including customer contacts
- Horizon scanning of future obligations, include DWI's guidance note on long term planning.

6.3 Drinking water safety plans

Drinking Water Safety Plans (DWSP) enable us to understand risk to water quality from source to tap. The plans, or risk assessments, have transformed the way we think and act about drinking water safety. The Drinking Water Safety Plans comprise a detailed site-by-site risk assessment. For each of our sources, water treatment works, distribution sites and water quality zones they comprise:

- Four stages from source to tap: catchment, treatment, distribution and customer
- Three categories: public health, compliance and serviceability
- Risk scoring of hazards based on consequence and likelihood in a 5 x 5 matrix
- Mitigation actions for each hazard/hazardous event.
- As part of the commitment to continuous improvement we are in the process of developing and implementing a new GRC (Governance, Risk and Compliance) tool which will form the location for operational supply (and waste) risk registers. This will comprise of a single risk score for each hazard, replacing the three categories used in the current DWSP application.

The company DWIRMAS (Drinking Water Inspectorate Risk Management Approval Scheme) accredited DWSP process is reliant on the compilation and continual assessment of data, knowledge and information by catchment specialists, process scientists, production and network operatives and customer services staff. The accompanying DWSP methodology is a 'live' document kept under continuous review to ensure further changes and improvements can be captured as plans continue to develop. We have a DWSP team to ensure that risks are scored consistently, which is then verified by a monthly meeting to further ensure consistency.

The DWSP process generates a large database of actions and risk scores, which are then used to prioritise investment and inform a rolling programme of capital maintenance and other interventions. Particular strategies arising from our DWSP reviews are described in the following sections, including:

- catchment management to mitigate rising nitrates and pesticides
- cryptosporidium risk reduction
- strategic maintenance.

The WRMP will support the objectives of the DWSP and not hinder the objectives. We have many Business-as-Usual activities which support and minimise any DO losses such as catchment management.

6.4 Catchment Management

For security reasons source/licence names have been redacted from this section and are not available in the version of this document published on our website.

With a large number of sources abstracting water from unconfined chalk aquifers, maintaining drinking water quality compliance in the face of rising nitrates is a major challenge. In addition, our surface water sources (and one groundwater source) are at risk from elevated pesticides.

The traditional approach to achieving compliance is by building treatment works, and in some cases we have had to do this. But treatment works are expensive to build, expensive to operate, have high carbon costs, are inflexible (nitrate treatment is not effective for pesticides and vice versa), and in the case of metaldehyde only partially effective.

Therefore, for the last 17 years we have been taking a catchment management approach. This involves working very closely with farmers in the areas around our reservoirs and boreholes – collecting detailed information on nitrate and pesticide concentrations and providing this to farmers to help them optimise their applications. In the direct catchment to a reservoir we have successfully reduced metaldehyde by subsidising farmers to use of an alternative slug control product that does not include metaldehyde.

Whilst this is clearly the right approach in most circumstances – and it has been strongly supported by the Government – it does involve the water company taking more risk. We have sought to mitigate the risk by interconnecting our sources as far as possible, particularly with our integrated water supply grid developments (Section 1) but monitoring nitrate concentrations and active catchment management remains a key activity to maintain a robust supply position.

Table 6-1 lists the sources where we are currently implementing a catchment management programme. The average and peak DO are specified to indicate the scale of the issue to us. Further details are given in the following sections.

Table 6-1: Sources with current or planned catchment management programmes

For security reasons source/licence names have been redacted from this table and are not available in the version of this document published on our website. Catchment names have been included instead.

Catchment	Average deployable output (Ml/d)	Peak deployable output (Ml/d)	Risk	Start of catchment management
River Bourne	10.12	12	Nitrate	2005
Dorset Frome	7	8.2		
Dorset Frome	12.63	24		
West Dorset Streams	8.24	7.84	Pesticides	
West Dorset Streams	0.73	0.45		
River Yeo	6.28	18		
Parrett	11.83	28		
Nadder	0.76	0.76	Nitrate	2010
River Nadder	5.56	5.5		
River Hooke	2.42	1.49		
Dorset Stour	5.6	7.09		
Dorset Stour	15.95	15.95		
Piddle	2.44	3.51	Nitrate	2015
Frome	4.4	7.22		
West Dorset Streams	8.24	7.84		
River Piddle	3.98	6.57		
West Dorset Streams	8.74	5.6		
Dorset Frome	2.48	1.79		
Cannington Brook	7.87	14	Pesticides	
Piddle	12.32	9	Nitrate	2020
Bristol Avon	1.11	0.91	Nitrate	2020
Bristol Avon	0.46	0.29	Nitrate	2020
River Bride	3.07	3.4	Nitrate	2020

Bristol Avon	4.31	3.94	Nitrate	2020
River Thames	1.5		Nitrate	2020
River Tone	N/A	N/A	Pesticides	2020
River Tone	(Inc. in DO for Durleigh)	(Inc. in DO for Durleigh)		
Total	**148.04**	**193.89**	-	-

6.5 Nitrates Forecasting for WRMP24

Since 2020 we have reviewed the nitrate trends of all of our sources using simple linear regression analysis in order to identify any sources where rising nitrates may be of concern over the next thirty years (until 2050). Any sources of concern were identified for more detailed modelling in order to provide a realistic forecast of nitrate trend behaviour.

The modelling approach that was developed with EntecUK in 2008 and updated in 2013, was reviewed in 2020-21. The review was carried out by consultant RukHydroUK, working with Wessex Water's hydrogeologists, with aim of improving and updating the modelling approach. The project was titled NMod20.

The actual nitrate data was updated within the modelling spreadsheets to check the robustness of the 2008 - 2013 trend model. Whilst the original modelling approach was deemed to be robust (industry leading), some of the actual nitrate trends had moved away from the forecasts, providing reduced confidence in the trends. As a result, the modelling team, reviewed all elements of the original approach to identify any weaknesses and areas for further improvement. This work was completed in September 2021.
The modelling approach was to forecast the underlying nitrate trend. Seasonality was dealt with, for the purposes of blending calculations, by applying historic monitoring data to the underlying trend; it was not modelled.

The components of the nitrate modelling approach were land use data, recharge data (4R infiltration recharge) and nitrate leaching rates based on land use and recharge. These were brought together to produce a modelled, historic, nitrate leaching trend. This data was then applied to the catchment areas of the sources being modelled. It was then necessary to calculate the travel time of the recharge from ground-level to the water table and then from the water table to the abstraction point. Improvements to the modelling approach included updated catchment areas, the use of NEAPN[34] data to better constrain historic nitrates leaching and improved assessment of saturated zone travel time (it had been assumed as instantaneous in the original model, because in relation to the unsaturated zone travel times in the Chalk it was negligible).

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[34] The NEAPN coefficients for crops can be considered as the N at risk of leaching over the winter.

The improved NMod20 modelling approach provided improved confidence in the predictions at most sources although the fit at some remained poor. RukHydroUK identified several lines of investigation to further improve the model. As a result, it has been agreed that the modelling should continue to be improved and reviewed on an annual basis. Nmod20 has provided more robust justification for Red, Amber and Green (RAG) risk categorisation of all sources with elevated nitrate trends (see Table 6-2).

Table 6-2: Red, Amber, Green status of the sources with elevated nitrate trends

For security reasons this table has been redacted from this section and is not available in the version of this document published on our website.

The updated nitrate trend modelling has then been used to provide peak nitrate concentration data for DO calculation and revised blending calculations. This is achieved by calculating percentile differences (99.9%, 99% and 95%) of observed historic data from the long-term trend for summer (Jul-Aug), winter (Sep-Mar) and ‘shoulder’ (Apr-Jun) periods.

6.6 Calculating nitrates DO losses for WRMP24

For security reasons source/licence names have been redacted from this section and are not available in the version of this document published on our website.

For WRMP19, we accounted for the risk of nitrates through a component of headroom analysis. For WRMP24, and within the overall approach of accounting for future uncertainty through scenario analysis, we have applied the nitrate forecasting approach developed to understand the risk of source DO losses during drought. Whilst source nitrates are generally lower in dry weather, as seen in the winters of 2011, growing trends over time may still pose a future risk to source outputs during our drought planning scenarios.

For each source that is considered a potential nitrate risk, and for which there is a model forecast (as per the section above), the following was undertaken.

- Fitted a Low, Central and High nitrate trend model to the underlying historic data for dry periods to account for inherent uncertainty in the forecasts. Several review meetings occurred with subject matter experts which looked at the uncertainty in the model fits to the historical data, the occurrence of dry periods within the historical record and the relationship between dry weather and nitrates (i.e. 2011/12).
- Based on the source DO assessment, and a conservative threshold of 10.5mg/l N Nitrate concentration applied as the acceptable limit, the potential loss in source DO for each scenario under the DYAA and DYCP scenarios was derived. For the DYCP scenario, source DO loss was calculated based on the model fits for the summer Nitrate period, whereas for the DYAA scenario a weighting of DO over the year was undertaken.

Out of the all the sources identified, a total of eight were identified as at risk of DO losses. Of these sources, the following were excluded from future scenario analysis for the following reasons:

- 3 sites have been excluded on the basis of current blending within the Water Supply Grid that is assessed sufficient in drought based on concentrations and volumes
- 2 sites that already have existing Nitrate treatment.
- Nitrates at one source, which are already accounted for in our current DO/Outage assessment, and are not forecast to increase in the future.
- 2 sites are being considered for potential future nitrate treatment.

The remaining sites are:

- A source: this site has existing Nitrate blending arrangements. However, the two sites that are currently blended with the source are currently under investigation as part of the WINEP programme; losses in these source outputs would also lead to a loss in DO from this source. To account for this in our planning, we have excluded the site from our Nitrate trend forecasting and included the DO loss as part of our scenario analysis in relation to sustainability reductions.
- A source: This source only has a DO loss within the high nitrate scenario in both the DYAA and DYCP planning scenarios in 2043 and 2050 respectively (8Ml/d DYAA and 5Ml/d DYCP). However, the DO loss has not been considered for the central forecasts (only in scenario analysis) for the following reasons:
    - The DO losses only occur under High nitrate scenario.
    - The DO losses occur at a time when a range of sustainability reductions are due to come into force in the region and therefore it would be expected DO losses would be mitigated via nitrate treatment if at the time it would be needed to avoid a DO loss.

7. Bulk Imports and Exports

For security reasons site names have been redacted from this section and are not available in the version of this document published on our website.

This following section details the imports and exports for WRMP24 with neighbouring companies. From WRMP19 there have been a few changes which include the removal of an import from Bournemouth Water and the cessation of an export to Bristol Water. Table 7-1 details the current imports and exports which aligns with the Ofwat 'Bulk supplies' register[35]. For completeness bulk supplies which are not routinely used, are inactive or used for resilience purposes have been included but the expected DYAA and DYCP volumes are reported as zero.

For WRMP24 discussions were held with the neighbouring companies to confirm and agree a DYAA and DYCP value to include in the planning assumptions. No company is expecting any changes in the DYAA and DYCP over the planning period and therefore the numbers used in Table 7-1 were used over the entire planning period. The only exception is Bristol Water import into Bath which for the DYAA will drop from 11.37 to 4.4 post 2024/25 as per WRMP19.

Additional new NAV exports have been included for WRMP24. We currently have agreements with 25 new NAV sites yet property developments at most of these sites is not yet complete and the contractual maximum agreed volume therefore cannot be used as the forecasted demand volume. Therefore, the forecasted export volume is calculated as follows:

$$NAV\ demand\ (Ml/d) = NAV\ build\ rate \times (287.5 \times 1.042) + 50.26$$

Where the NAV build rate is the number of properties built on each site each year, forecasted as outlined in Section 4.4 of the Demand Forecast technical appendix, 287.5 l/prop/d is Wessex Water's measured NYAA PHC, 1.042 is the headroom adjustment of 4.2%, and 50.26 l/prop/d is 50% of Wessex Water's 2022-23 leakage per property estimate. The leakage estimate is halved to account for the assumption that the new infrastructure on NAV sites should have less leakage.

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[35] Water trading ('Bulk supplies') register 2021-22 - Ofwat

Table 7-1: WRMP24 Imports and Exports with DYAA and DYCP values

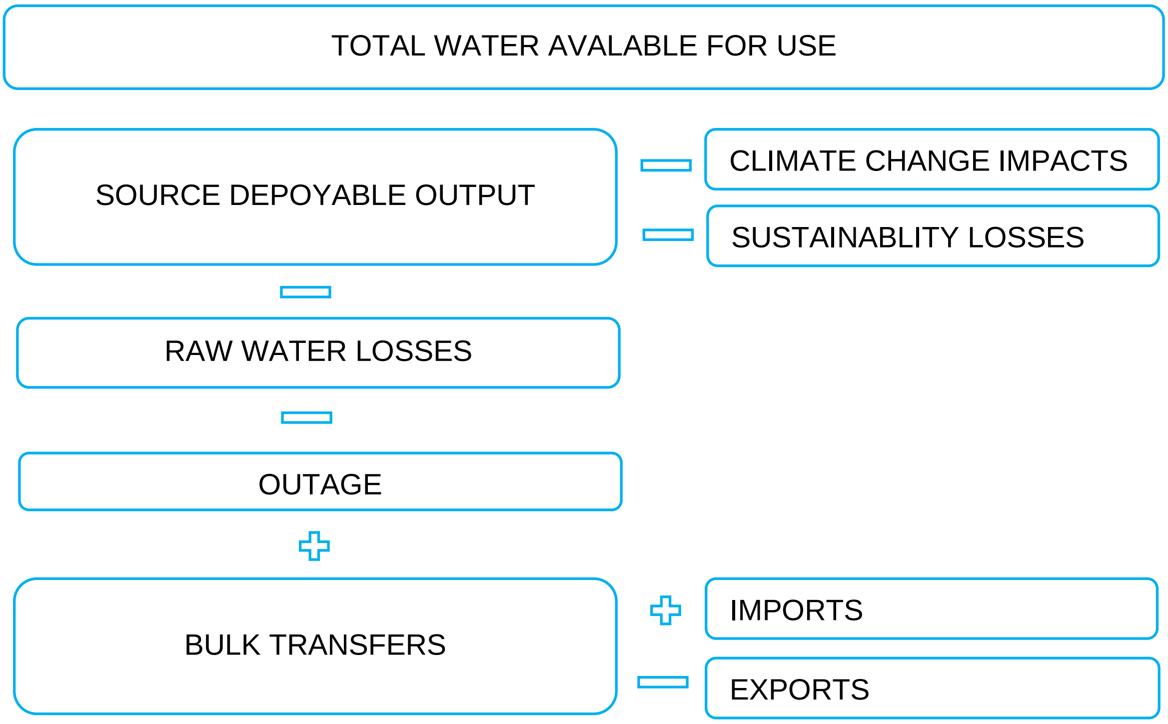
For security reasons this table has been redacted from this section and is not available in the version of this document published on our website.

[1] Only transfers which have agreements or are in use are included in the WRMP24 planning tables.

8. Total Water Available For Use

Total Water Available For Use (TWAFU) is made up of the components detailed in preceding sections. The TWAFU is calculated for each reporting year over the planning period to account for changes in climate change and sustainability reductions over the planning period. The components of TWAFU are summarised in Figure 8-1.

Figure 8-1: Components of TWOU



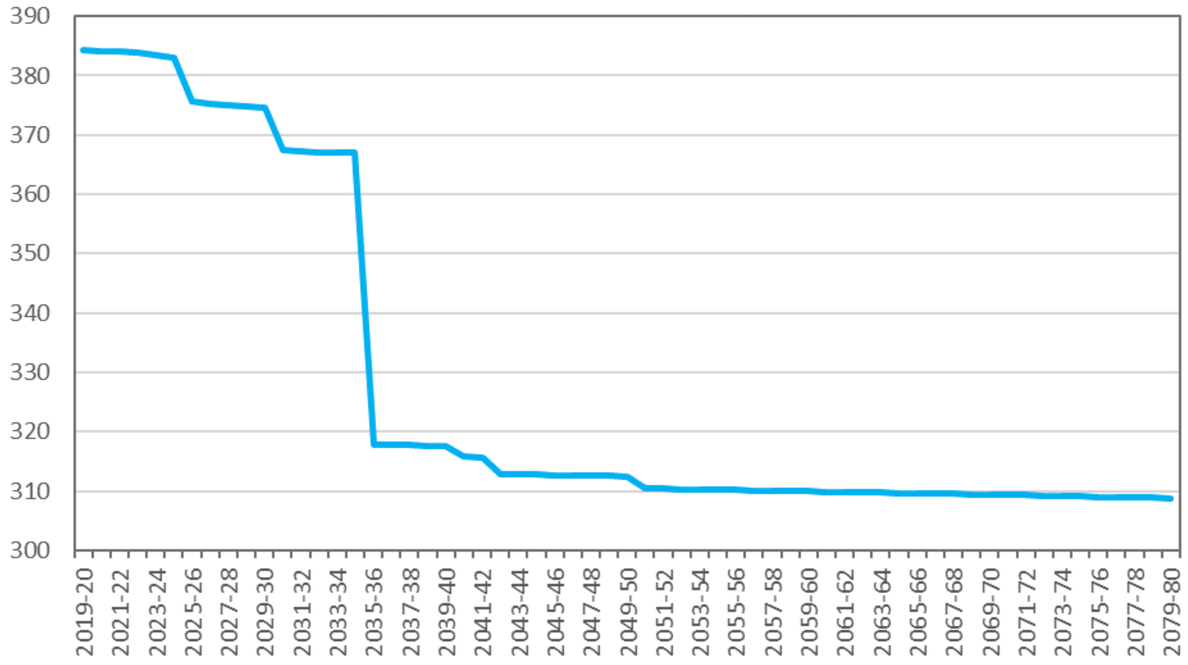
8.1 TWAFU DYAA

Table 8-1 presents TWAFU over the planning period for selected years. TWAFU goes from 384.27 Ml/d in 2020/21 to 308.80 Ml/d in 2079/80. The key changes are a gradual impact of climate change and a loss of imported volumes, however the key driver is a 60.13 Ml/d loss in DO by 2050 as a result of sustainability changes. TWAFU is presented as a timeseries in Figure 8-2 which highlights the significant changes in TWAFU.

Table 8-1: TWAFU DYAA over the planning period for selected years

Component	2020-21	2024-25	2029-30	2034-35	2044-45	2054-55	2064-65	2079-80
Deployable Output Ml/d	393.65	393.65	393.65	393.65	393.65	393.65	393.65	393.65
Climate Change Ml/d	-1.6	-1.8	-2.0	-2.3	-2.8	-3.3	-3.8	-4.6
Sustainability Changes Ml/d	0.0	0.0	0.0	-7.0	-58.18	-60.13	-60.13	-60.13
Raw Water Losses Ml/d	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01
Outage Losses Ml/d	-17.78	-17.78	-17.78	-17.78	-17.78	-17.78	-17.78	-17.78
Bulk Imports Ml/d	+15.04	+15.04	+8.07	+8.07	+8.07	+8.07	+8.07	+8.07
Bulk Exports Ml/d	-2.16	-3.15	-4.32	-4.70	-7.23	-7.28	-7.34	-7.42
Total WAFU	**384.27**	**382.97**	**374.58**	**366.95**	**312.72**	**310.21**	**309.65**	**308.80**

Figure 8-2: Timeseries of TWAFU over the planning period for the DYAA scenario



8.2 TWAFU DYCP

Table 8-2 presents TWAFU over the planning period for selected years for the DYCP scenario. TWAFU goes from 436.90 Ml/d in 2020/21 to 354.48 Ml/d in 2079/80. The key changes are a 76.84 Ml/d loss in DO in 2079/80 as a result of sustainability changes. TWAFU is presented as a timeseries in Figure 8-3 which highlights the significant changes in TWAFU.

Table 8-2: TWAFU DYCP over the planning period for selected years

Component	2020-21	2024-25	2029-30	2034-35	2044-45	2054-55	2064-65	2079-80
Deployable Output Ml/d	440.61	440.61	440.61	440.61	440.61	440.61	440.61	440.61
Climate Change Ml/d	+0.05	+0.06	+0.06	+0.07	+0.09	+0.10	+0.12	+0.14
Sustainability Changes Ml/d	0.00	0.00	0.00	-7.00	-76.84	-76.84	-76.84	-76.84
Raw Water Losses Ml/d	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01	-3.01
Outage Losses Ml/d	-13.63	-13.63	-13.63	-13.63	-13.63	-13.63	-13.63	-13.63
Bulk Imports Ml/d	+15.48	+15.48	+15.48	+15.48	+15.48	+15.48	+15.48	+15.48
Bulk Exports Ml/d	-2.65	-3.81	-4.93	-5.55	-8.09	-8.14	-8.19	-8.28
Total WAFU Ml/d	**436.90**	**435.70**	**434.39**	**426.97**	**354.62**	**354.58**	**354.54**	**354.48**

Figure 8-3: Timeseries of TWAFU over the planning period for the DYCP scenario