WRMP24 Stochastic and Climate Change DO modelling: Technical report

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Report for South Staffs Water
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Quality assurance record

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1. Introduction and approach

1.1. Background

The overarching aim of the project was to undertake supply-side stochastic and climate change Deployable Output (DO) modelling in Aquator XV/XM. The DO assessments form a key component of the supply forecasts inputting to the Water Resources West (WRW) regional plan, and ultimately support South Staffordshire Water's (SSW) towards their WRMP24 submission. They are designed to meet the latest EA's 1:500 drought resilience guidance, through application of system response methods using the Scottish DO approach; the approach broadly follows the same process as applied previously for Severn Trent Water Limited (STWL).

The DO assessments utilised SSW's Aquator XV model, which was migrated earlier in 2021, and which is based upon the Aquator v4.3 model used in WRMP19 (with targeted improvements or refinements applied). In addition to assessing the DO under stochastic baseline and climate change scenarios, tested of the DO benefits of demand saving measures was also completed.

Given the acute delivery pressures for SSW to meet the milestones towards the August 2021 WRW pre-conciliation tables deadline, a collaborative approach has been required between both parties. This was important to ensure a pragmatic, yet robust approach to be taken to applying stochastic and UKCP18 climate change projections data to the SSW models for the first time, with inevitable choices required during the project following the first stochastic runs.

This report documents and summarises the overall project activity, whilst the detailed outputs and deliverables have been shared previously with SSW via Microsoft OneDrive. The report complements and supports SSW's own regulatory and modelling audit trails.

1.2. Deliverables and project scope

Based on the project as delivered, the project scope included:

- Assessment of baseline DO, using stochastic datasets of 19,200 years of data, in line with the latest 1:500-year drought DO guidance;
- Assessment of climate change DO impacts using 12x RCM and 20x probabilistic UKCP18 climate change scenarios, using two batches' of 2400 years from the full stochastic dataset in line with those sampled for STWL;
- Assessment of the impacts of demand savings in mitigating the impacts of stochastic drought events and DO.

The key deliverables for this project are summarised below, and have been provided to SSW by Hydro-Logic for review and use via a secure Microsoft OneDrive share area:

1. Tables and plots of DO versus number of Level 4 restrictions (combined demands and storage failures) and associated DO versus return periods based on impacts of stochastic and climate change datasets.
2. Tables and plots of DO versus number of Level 2 (also referred to in the report as Level of Service 2 or LoS 2) and Level 3 Level of Service failures and associated DO versus return periods based on impacts of stochastic and climate change datasets.

3. Outputs as described in 1 and 2 above, for baseline stochastic DO without demand saving implemented in addition to RCM scenarios 07, 13, and 12 & 15 (representing the lowest, greatest and central estimates for the 1:500 DO respectively

4. Aquator XV database used in each scenario modelling.
5. A report outlining the modelling analysis completed and the methods used, including post processing procedures (this report).

It is important to note that, to meet the needs and challenges for this complex modelling work, precise aspects of the approach have evolved through the project from that originally envisaged in the proposal. For example, significant additional work has been completed in some cases to understand and investigate the initial model outputs, and refine the approaches beyond what could have been defined by SSW and Hydro-Logic in advance of the detailed modelling. This technical report therefore focusses on the approach finally taken and delivered for, and in agreement with SSW, and explains any evolution of approach through the process.

1.3. Structure of this report

The report is structured as follows:

- Section 1 – Background context and summary of deliverables
- Section 2 – Explanation of detailed changes to the baseline model to run stochastics
- Section 3 – Summary of baseline stochastic DO assessment approach and results
- Section 4 – Summary of climate change DO assessment approach and results, including related model alterations
- Section 5 – Conclusions and future considerations

2. Baseline model preparation

Summary: The SSW Aquator XV model used for this project is a close relative to the Aquator v4.3 model used in WRMP19 (i.e. direct migration with minor amends applied only). The basis of the SSW model was originally developed with the application of English and Welsh DO analysis in mind using historic (or climate impacted historic) hydrological data, albeit using a relatively long hydrological record back to the 1880s.

Meanwhile, the use of the 19,200 years of stochastic data to assess the 1:500 year DO for Level of Service 4 events has been driven by new regulatory guidance, and fundamentally changes the modelling approach required from previous WRMP rounds. The model was updated to allow for stochastic DO assessment to meet the Environment Agency's Water Resource Planning Draft Guidance related to 1:500 year DO. Given the nature of the SSW system, a systems-based approach has been followed using the Scottish DO method.

To enable the use of stochastic hydrology, refinements have been made to the model, in particular to set appropriate failure criteria linked to Level of Service 4 failures and implement suitable resetting of model states every 48 years to enable continuous DO simulation across batches of stochastic data. Inflow data was either provided by STWL, or derived from simulating the STWL Aquator XV model at the 1:500 DO level to export required time series (equivalent to those used in the legacy model and previous WRMPs).

The first-time application of stochastic data was anticipated to be challenging. This involved significant testing and model investigation in the early stages of work, which through the process has allowed an effective and efficient approach to 1:500 DO estimation to be achieved both for this project and in the future.

In particular, as DO modelling progressed through to the climate change stage, further improvements to the approach were applied, especially given the known severity of some UKCP18 scenarios. However, given the tight timescales to complete the work, and as a 'first cycle' assessment of DO using this approach, an overriding requirement or principle agreed with SSW was to retain the basis of the original Aquator model as far as practical for the purpose of this assessment.

2.1. Collation and preparation of stochastic inflows and 1:500 DO simulation variables

SSW sits within the same broad spatial area as the STWL system, as part of WRW, and various resources are represented in both models albeit to different extents. For example, the SSW system is coarsely represented in the STWL model, whereas the STWL model represents in significant extra detail the full representation and regulation of the River Severn.

Given this interlinkage, stochastic inflow data from the STWL WRMP24 DO and climate change modelling project were used for the modelling of stochastics, such that there was a consistent basis to the datasets. Data was gathered for all eight batches (2,400 years each, which in combination represent the full 19,200-year stochastic dataset). Batches 4 and 7 were of particular interest given their statistical similarity[1] to the combined batches from analysis undertaken as part of the STWL modelling project.

[1] In terms of the DO Vs return period trend.

Each column in each file comprised a 48-year (common start and end dates) stochastic scenario. It should be noted that during the WRMP24 modelling project for STWL, a comprehensive review of the data to ensure completeness and no negative flow values was carried out. SciLab macros were also created to extract and concatenate flow data (into continuous records) for the selected stochastic batches (4 and 7). Post-processing was carried out to remove any extra days owing to leap years.

Series R28000BLI and A28000NET, representing upper and lower flows at Blithe were collated from the inflow spreadsheets for each of the eight batches. It should be noted that no PPT and PET data was available from STWL for Blithfield reservoir (this type of data was also excluded from their own modelling exercise), and so this was excluded from the modelling exercise on the understanding that this was a minor influence only on DO derivation.

In line with the approach taken to producing model inputs for the SSW model in WRMP19 for historic data, the STWL models were run to produce appropriate time series. The STWL model was run at the 1:500 DO demand level in simulation mode with additional variable capture; this was completed using the baseline stochastic model with demand saving (DS) restrictions applied for each of the eight batches. The requisite export variables for which this process was carried out are tabulated below (Table 1):

Timeseries name in SSW model	Equivalent STWL variable name
Hampton Loade	Model.Severn regulation. Abstraction regime
STWL Trimpley DC	AB9.Supply.Total amount
Severn Inflow1	GS5.Flow.Net (Bewdley)
Nethertown & Emergency Transfer (Trent)	GS30.Flow.Net (North Muskham)

Table 1: Component and timeseries names

Timeseries for the 1:500 variables above, and including the stochastic inflow data, were collated together into one Excel spreadsheet file for each batch. These files were titled Batch X data (where X denotes respective batch number). Each batch file covers 2,400 years of data totalling 19,200 years of data.

Prior to importing the timeseries into the database, it was necessary to differentiate between the different batches in the database, and therefore batch numbers were added to all the timeseries. For example, BT4 was added to all of the timeseries associated with batch 4. The data type was also specified in order for Aquator to read the timeseries correctly. 'Flow (Ml/d)' data type was specified for 'R28000BLI_Ml/d', 'A28000NET_Ml/d', 'AB9.Supply.Total amount', 'GS5.Flow.Net' and 'GS30.Flow.Net'. A custom data type 'None3DP' was specified for the 'Model.Severn regulation.Abstraction regime' series, in line with that used for the historic data in Aquator XV.

A summary of the provenance of the data used for each of the relevant components in the SSW model is shown below in Table 2:

Timeseries name in SSW model	Data Source	Timeseries saved in SSW model database as	Component ID data assigned to in SSW model
Blithe Inflow 1	Stochastic inflow spreadsheet	R28000BLI_Mld_BTX	CM1
Blithe Inflow 2	Stochastic inflow spreadsheet	A28000NET_Mld_BTX	CM2
Hampton Loade	1:500 simulation and subsequent extraction from STWL model	Model.Severn regulation. Abstraction regime_Mld_BTX	AB3
STWL Trimpley DC	1:500 simulation and subsequent extraction from STWL model	AB9.Supply.Total amount_Mld_BTX	DC29
Severn Inflow 1	1:500 simulation and subsequent extraction from STWL model	GS5.Flow.Net_Mld_BTX	CM4
Nethertown & Emergency Transfer (Trent)	1:500 simulation and subsequent extraction from STWL model	GS30.Flow.Net_Mld_BTX	AB1 & AB2

*where X denotes batch no.

Table 2: Timeseries and assigned component ID for stochastics

It was noted that the 1:500 output from the STWL model, namely the 'Model.Severn regulation.Abstraction regime' series, ranged from Bands 1-4. From inspection of Page 10 of the Mott MacDonald WRMP19 technical note[2] provided to Hydro-Logic during the Aquator XV migration project, there was a need to decompose Band 1 (no regulation), to distinguish

[2] Aquator model update (9th August 2017)

between flows at Bewdley (>1100 Ml/d equates to Band 0, <1100 Ml/d equates to Band 1), with the flow bands then setting maximum abstraction limits at Hampton Loade in line with legacy VBA code logic in the model.

As such, further post-processing was carried out on the aforementioned series along with 'GS5.Flow.Net' (Bewdley flows) to produce a new abstraction regime output for the Hampton Loade abstraction (component ID: AB3).

No groundwater DO update was provided by SSW for modelling under 1:500 DO conditions, and so these remained as the original Aquator model.

2.2. Database preparation

It was necessary to prepare the model database 'SSW Aquator XV WRM v1.03 - based on MMA_V4.3.7 (backup copy).axvdbs' (noting the model has since evolved, with the database version currently standing at v1.13) such that the stochastic data (discussed above) was implemented correctly and efficiently. In the case of the SSW model, all stochastic and, later, climate change data has been retained in a single master database, which also includes historic inflow data. Whilst this results in a larger database size, for which there is no known limit for Aquator XV, this has the significant benefit of allowing SSW to re-run and use these datasets again in future whilst mastering a single version of the model itself.

As such, a total of 16 scenario and sequence sets were prepared (i.e. 8 stochastic batches to be run *with* and *without* demand saving restrictions), recognising that focus was to be centred on stochastic batches 4 and 7 (i.e. climate baseline).

To facilitate quick switching between the scenario sets (and associated parameter, state, sequence and variable sets), the database was set up as shown in Table 3, noting X denotes the stochastic batch to be modelled:

Scenario set	Parameter set	Sequence set
Stochastic_BTX	1995 Set	Stochastic_BTX
Stochastic_BTX (NR)	1995 Set (no restrictions)	Stochastic_BTX (NR)

Table 3: Scenario setup (with associated parameter and sequence sets) in model databases

The state and variable sets are not included in the table, given these sets were not directly impacted by any updates upon receipt of climate change data. For reference, the 'Default' state set was defined for the period 1902-4301 (the years for convenience to place the 2,400 years of stochastic data). The variable set 'Minimal' was customised and implemented for analyses to capture model failures only. The two parameter sets reflect the *with* and *without* demand saving restrictions scenarios to be modelled, but are otherwise consistent.

Following completion of database preparation, independent checks and reviews were carried out to ensure a robust, error free starting point prior to undertaking of subsequent analyses.

2.3. Model changes

A full account of the requisite changes made to successive versions of the model to run the Scottish DO has been made available through the OneDrive link for audit trail purposes, however an overview of the most prominent changes is outlined below.

Firstly, the schematic was reconfigured (Figure 1) through the addition of a non-PWS demand centre (DC30) and discharge component (DG1) at Hamstall Ridware to better align to the data and representation in the STWL model. This was required because prior to the STWL DO modelling exercise, STWL had disaggregated nature of this nature from the catchment inflow series, to improve transparency and schematical representation.

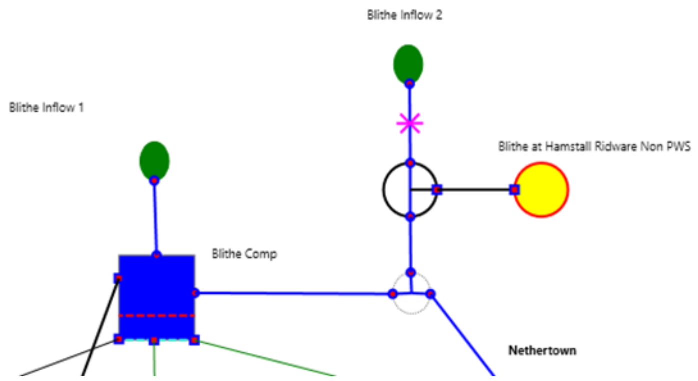

Figure 1: Reconfiguration of model

It was also noted that Service Reservoir components were included as members of the Demand Saving Group and where thus removed and unenforced from the group (as they were triggering Level 2 and 3 counts on stochastic runs and/or model errors), leaving Blithfield (RV1) and Chelmarsh (RV2) reservoirs as the only members. These latter two reservoirs are the raw water resource storage units upon which drought triggers or control curves are applied.

Parameter changes (comprising 2x licence value changes and 4x licence value additions) as outlined below were also replicated in this model database. During the Aquator XV model migration phase, a recommendation was made to review the provenance of model parameters. An extensive review of the Aquator model inventory was subsequently completed by SSW[3], with this recommendation then explored during the model update phase[4]. In some cases, future consideration of the parameter data was identified, and so HLSI applied only firm or confirmed changes from the inventory review into the SSW model at this stage.

To implement changes to component parameters to align with the SSW model inventory review, two parameter sets cloned from PS3 were created: **PS5 1995 set Updates A**, and **PS6 1995 set Updates A&B.** (Note that PS6 includes all changes in PS5, plus additional changes – this was undertaken so as to distinguish any potential cause of DO change).

The changes are summarised below in Table 4:

Component	Parameter	Value in 1995 set	Value in Update set A	Value in Update set B	DO Impact
AG3 abstraction group – AG3_DL1 daily licence	Licence amount	18.19	19.19	19.19	LoS DO Run Updates A:

[3] SSW model inventory.xlsx
[4] SSW Aquator XV model migration with model updates

AG3 abstraction group – AG3_AL1 annual licence	Licence amount	4917.80	5117.30	5117.30	no change to DO, 334 Ml/d
GW1 groundwater source – new daily licence GW1_DL1	Licence amount	N/A	N/A	9.82	LoS DO Run Updates A&B: no change to DO 334 Ml/d
GW1 groundwater source – new annual licence GW1_AL1	Licence amount	N/A	N/A	2572	
AG1 abstraction group – new daily licence AG1_DL1	Licence amount	N/A	N/A	310	
RV1 Blithfield Reservoir – new daily licence RV1_DL1	Licence amount	N/A	N/A	136	

Table 4: Parameter updates to database

In summary, the two changes did not impact DO:

- LoS DO[5] re-test (Parameter updates set A): 334 Ml/d i.e. no change
- LoS DO re-test (Parameter updates set A and B): 334 Ml/d i.e. no change

Three abstraction components required daily licences to be added, to align with the information in the SSW model inventory; these are AB1 (Nethertown R.Blithe), AB2 (Nethertown R.Trent) and AB5 (Hampton Loade put-and-take). For each of these components there is a maximum daily supply constraint of an equal or lower value to the peak daily licence, so the addition of a daily licence will not impact on the DO assessment. Notwithstanding this, the aforementioned changes have now been applied to the master database for completeness.

Running stochastic data in the model was initially showing false failures against a 0 Ml/d flow constraint. As such, these failures were removed from AB4 and AB5. A failure margin of 0.01 was applied and the 'report failure' parameter was set to 'Never' for the aforementioned components as well as abstractions at Hampton Loade (AB3) and Trimpley (AB6).

2.4. Recurring reset of starting conditions

One of the prerequisites of the analysis is to run the 400 stochastic scenarios without interferences between them. The goal is to obtain an unbiased simulation of the 48 years scenarios, albeit achieved within a continuous modelling process in Aquator for efficiency.

As applied to the STWL modelling project, VBA code was added to the model, controlled by a custom Model parameter "Operation. Stochastic and CC reset year (VBA)" to which a default value of 48 years has been assigned.

The code resets the initial condition of the model every number of years, as specified in the custom parameter. The initial conditions subject to reset include reservoirs storage and period licence quantity left.

[5] It should be noted that the DO quoted is historic under LoS conditions

If a value of 0 is assigned to the “Operation. Stochastic and CC reset year (VBA)” parameter the code is disabled, and no reset is applied.

2.5. Bespoke variable – Combined failures

Level 4 triggering for the 1:500 DO calculation is based on reservoirs hitting the defined minimum level (i.e. dead or emergency storage) and/or demand centre failures. To allow both of these failures to be included in the post-processing of DO results without recourse to extensive variable capture that both slows down the model and results in high memory usage, a bespoke variable named “Failures (VBA). Combined failures” has been implemented to capture and extract information regarding these level of service events. This also allows exploration as to the drivers of failure, for example, if demand failures (e.g. due to capacity constraints) are occurring without emptying reservoir storage.

By the default each day without failure, the variable has a value of 0. Numbers are then added to this depending on the model status as below:

- Model failure due to any active failure criterion = +100
- Level of Service 1 restriction in DS0 = +1
- Level of Service 2 restriction in DS0 = +2
- Level of Service 3 restriction in DS0 = +3
- Level of Service 4 restriction in DS0 = +4

At the end of each day the current level of service is saved into the custom variable to which a value of 100 is further added if the model also reported as a demand failure. As an example, the combined failures variable for a day with a model failure due to demand not met and a Level of Service 4 event being triggered, will have a value of 104. A value of 100 would denote a demand centre failure only.

The demand saving is read from the group DS0 that has been added to the model for this purpose.

For technical reasons linked to the way that the resource allocation optimiser reports failures in Aquator XV, LoS 4 has been set at emergency storage. This does not impact the DO calculation for combined Level 4 failures, which are still based on failure criteria in the model, but simply allows the pattern of storage only Level 4 failure to be compared to the combined failures.

As raised in the Aquator XV migration project, profiles relating to LoS 2, 3 and 4 events in Aquator do not link to the actual Drought Plan definition. As such, amends were made to the stochastic VBA code to remap the capturing of LoS events. If there is a LoS 4 (dead water storage level) failure, the combined failure value will be 2 and if there is a LoS 5, failure the combined failure value will be 3.

2.5.1. Validation of bespoke variable combined failures

The variable combined failures have been extracted in Excel and compared with the daily level of service and the model status.

A check in Excel was implemented to determine whether the demand saving level plus the value of 100 on days when the model status was “Failure” matched the bespoke variable or not. An example of results from the combined failures validation is shown in Table 5.

	Model status	Demand saving level (DS0)	Bespoke variable Combined failure	Validation
23rd July 1902	Fail	0	100	100 for demand failure + 0 for no DS0 LoS
24th July 1902	Fail	2	102	100 for demand failure + 2 for DS0 LoS 4

Table 5: Illustration of combined failures function

2.6. Bespoke variable – Track deficit

A bespoke variable “Failures VBA. Track deficit” has been created in the model to capture the deficits in the demand centres labelled as “Track deficit”. This is supplementary information that is available for further interrogation of the location of demand centre failures (i.e. exports) in a single dataset if required. The advantage of using this variable as opposed to extracting individual demand centre deficits is that this is less memory intensive. The custom variable provides binary information: 1 = Deficit 0 = Demand supplied, assigning each of these demands to a specific position in the variable.

Demand centre component ID	Demand centre name	Position in the variable
DC29	STWL Trimpley DC	1st number from right
DC28	Dark Lane Bulk Export	2nd number from right
DC27	Elan Valley Bulk Export	3rd number from right
DC26	Romsley Boys Bulk Export	4th number from right
DC25	Gayfield Bulk Export	5th number from right
DC24	Warley Bulk Export	6th number from right
DC23	Middlemore Bulk Export	7th number from right
DC22	Perry Barr Bulk Export	8th number from right
DC21	Polesworth Bulk Export	9th number from right
DC20	Bower Lane Bulk Export	10th number from right
DC15	Trimpley Bulk Export	11th number from right
DC10	STW Bulk Export	12th number from right

Table 6: DCs relative position in the bespoke variable Track deficit

The variable always has a maximum of 12 digits that can be either 0 or 1. If at the end of the day, any of the demands listed in Table 6 is left with a deficit, the digit corresponding to this demand centre will be showing a 1.

For example, if deficit is found in DC15 and DC25 the digits associated to these centres: 11th and 5th respectively from the right, will be set to 1. The variable in this case assumes the value of 10000010.

2.6.1. Track deficit validation

A Demand Centre validation has been carried out on the supply and track deficit on the model. A demand scaling factor of 2 to force a supply deficit was applied.

Table 7 shows a value for the track deficit as 110100010. The variable indicates deficit for the digits 4, 5, 7 and 11 from right to left which is translated in deficits for the demands: DC26, DC25, DC23 and DC15.

The variable has been validated extracting from the same day the demand deficits for DC10, DC20, DC21, DC22, DC24, DC27, DC28 and DC29 as shown in Table 7.

1st March 1903	
Track deficit	110100010
DC10 supply deficit	0.00
DC15 supply deficit	3980.00
DC20 supply deficit	0.00
DC21 supply deficit	0.00
DC22 supply deficit	0.00
DC23 supply deficit	20.34
DC24 supply deficit	0.00
DC25 supply deficit	41.00
DC26 supply deficit	60.24
DC27 supply deficit	0.00
DC28 supply deficit	0.00
DC29 supply deficit	0.00

Table 7: Demand centre supply and track deficit

2.7. Demand centres failure criteria

Table 8 shows the demand centres that have been scaled in the DO runs and have been set to fail following review and subsequent agreement with SSW (the purpose of which was to confirm the basis of Scottish DO derivation up front); the sum of these demand centres constitutes the reported DO in the context of the Aquator model analysis in this report. The remaining export demand centres have not been scaled (and as such are not included in the reported DO number), but have been left set to fail in the model in agreement with SSW as they constitute obligations or needs to supply water from the SSW system. The scaled demands are consistent with those to derive DO in WRMP19 within Aquator[6].

Component	Type	Name	Scale in DO runs	Current set to failure?	Scottish DO Failure (Level 4 Emergency DO restrictions
DC1	Demand	Uttoxeter Zone	Yes	Yes	Yes
DC2	Demand	Cannock High Zone	Yes	Yes	Yes
DC3	Demand	Outwoods combined Zone	Yes	Yes	Yes
DC4	Demand	Winshill Zone	Yes	Yes	Yes
DC5	Demand	Hopwas combined Zone	Yes	Yes	Yes
DC6	Demand	Barr Breacon Zone	Yes	Yes	Yes
DC7	Demand	Cannock Low combined Zone	Yes	Yes	Yes
DC8	Demand	Sedgley combined Zone	Yes	Yes	Yes
DC9	Demand	Cawney Hill Zone	Yes	Yes	Yes
DC10	Demand	STW Bulk Export	No	Yes	Yes (record exports failures)
DC12	Demand	Hayley Green Zone	Yes	Yes	Yes
DC13	Demand	Springsmire Zone	Yes	Yes	Yes
DC14	Demand	Shavers End Zone	Yes	Yes	Yes
DC15	Demand	Trimpley Bulk Export	No	Yes	Yes (record exports failures)
DC17	Demand	Sutton Coldfield Zone	Yes	Yes	Yes
DC18	Demand	Walsall Zone	Yes	Yes	Yes
DC19	Demand	West Bronwich Zone	Yes	Yes	Yes
DC20	Demand	Bower Lane Bulk Export	No	Yes	Yes (record exports failures)
DC21	Demand	Polesworth Bulk Export	No	Yes	Yes (record exports failures)
DC22	Demand	Perry Barr Bulk Export	No	Yes	Yes (record exports failures)

[6] It should be noted therefore that the DO numbers quoted in the Aquator results, as in previous work, do not include the non-scaled export demands in the DO values quoted. However, as they have been included in the modelling approach as static demands, they could be deemed to constitute part of the "Gross DO" of the system. As with other companies, care should be taken by SSW to note the basis of DO reported from the Aquator model to ensure that these are suitably integrated into calculations of WAFU.

DC23	Demand	Middlemore Bulk Export	No	Yes	Yes (record exports failures)
DC24	Demand	Warley Bulk Export	No	Yes	Yes (record exports failures)
DC25	Demand	Gayfield Bulk Export	No	Yes	Yes (record exports failures)
DC26	Demand	Romsley Boys Bulk Export	No	Yes	Yes (record exports failures)
DC27	Demand	Elan Valley Bulk Export	No	Yes	Yes (record exports failures)
DC28	Demand	Dark Lane Bulk Export	No	Yes	Yes (record exports failures)
DC29	Demand	STWL Trimpley DC	No	Yes	Yes (record exports failures)

Table 8: Demand centres Level 4 failure criteria

2.8. Reservoir failure criteria

A review was completed on the failure criteria for reservoirs prior to completing the Scottish DO analysis. This is to ensure that the failures which occur in the model that are used to derive the 1:500 DO from a reservoir storage perspective are legitimately linked to hitting suitable reservoir minima, in line with SSW Drought Plan or operational logic. Importantly, only reservoirs that are considered relevant to Level 4 restrictions should report failure in the analysis linked to water resource zone failure and typically strategically relevant resources. Failures are limited to Blithfield and Chelmarsh; these are set to fail at emergency storage and dead water respectively as seen in Table 9 below.

Component	Type	Name	Scale in DO runs	Current set to failure?	Scottish DO Failure (Level 4 Emergency DO restrictions
RV1	Reservoir	Blithfield Reservoir	N/a	Emergency storage	Emergency storage
RV2	Reservoir	Chelmarsh Reservoir	N/a	Dead water	Dead water
RV3	Reservoir	Holly Grange SR	N/a	No	No failure
RV4	Reservoir	Outwoods SR	N/a	No	No failure
RV5	Reservoir	Overseal SR	N/a	No	No failure
RV6	Reservoir	Gentleshaw SR	N/a	No	No failure
RV7	Reservoir	Hednesford SR	N/a	No	No failure
RV8	Reservoir	Hopwas SR	N/a	No	No failure

RV9	Reservoir	Barr Beacon SR	N/a	No	No failure
RV10	Reservoir	Cawney Hill SR	N/a	No	No failure
RV11	Reservoir	Shavers End SR	N/a	No	No failure
RV12	Reservoir	Sedgley SR	N/a	No	No failure
RV13	Reservoir	Springsmire SR	N/a	No	No failure
RV14	Reservoir	Hayley Green SR	N/a	No	No failure

Table 9: Reservoir Level 4 failure criteria

3. Baseline DO stochastic runs

Summary: The first-time application of stochastic data was anticipated to be challenging. This involved significant testing and model investigation in the early stages of work, which through the process has allowed an effective and efficient approach to 1:500 DO estimation to be achieved both for this project and in the future.

Baseline stochastic DO assessments were completed across all 19,200 years of stochastic inflows in the STWL Aquator XV model using Aquator XM. The runs completed demonstrated a clear step up in the Level 4 failure frequency at between 350-355 Ml/d. Further interrogation of the model showed that upon hitting these levels of demand, demand centre failure occurs in most or all years due to system capacity constraints. Investigations showed this to be driven by a specific demand profile peak in June, noting the seasonal demand profile in the SSW model uses a daily profile and is essentially flat outside the peak summer months.

DO estimates for Level 2, 3 and 4 events were produced, noting that in all cases the Level 2 DO is the clear overall constraint to DO as with previous modelling using English and Welsh DO (which does not directly account for Level 4 frequency). Therefore, whilst the aforementioned step increase in failures under Level 4 failures is informative of underlying system resilience considerations, it does not influence the overall reported DO.

The overall DO produced (~341 Ml/d) was over 7 Ml/d higher than the equivalent English and Welsh DO assessment using historic inflows in the Aquator XV model (or around 3 Ml/d than those quoted in WRMP19), noting that the base 48-year period underpinning the stochastic scenarios excludes some of the earlier historic drought years. To understand the benefit of customer use restrictions, a DO scenario was assessed without demand saving benefits included, which resulted in a reduction of around 5 Ml/d.

Later in the project, as part of the climate change assessments explained in Section 5, a further rebaselining of DO was completed for the purpose of climate change impact assessment (reflecting refinements to the representation of the River Severn area of the model). This assessment was applied only to 2 batches of stochastic data (Batch 4 and 7), however is a useful reference and produced an equivalent (Level 2 constrained) DO of 338 Ml/d. Similar tests of the DO without demand saving reduced DO by around 3 Ml/d.

3.1. Baseline DO with demand saving restrictions

The database used to capture results for the 'baseline with demand saving restrictions' scenario was 'SSW Aquator XV WRM v1.09 – based on MMA_V4.3.7 (backup copy), using model 'SSW XV migrated v1.09'.

As outlined in Section 2.3, in this model version false failures at zero flow were removed from the model for AB4 and AB5 and failure margins and report failures were changed. These changes were also applied to AB3 and AB6. This followed various initial test runs, investigations and refinements of the baseline setup for the final results outlined below.

The analysis for all eight batches was set to run from 01/01/1902 – 31/12/4301, a total of 2400 years per batch, with the demand centres to be scaled during the DO runs as tabulated in Section 2.7.

An example of a template used during analyses with Aquator XM is shown below for Batch 1 (BT1). This process was identical for all other templates, albeit analysis IDs, parameter and sequence sets required changing for each batch. The demand for each batch was set to run from 270 Ml/d to 370 Ml/d.

DO models runs	Parameter value
Use worksheet matrix	FALSE
Start demand	270.00
End demand	370.00
Initial demand step	20.00
Modelling start date	01/01/1902
Modelling end date	31/12/4301
Step reduction factor	4.0
Minimum step size	5.000
Failure demand precision	5.000

Table 10: Template setup for BT1

Once the analyses were complete, a post-processing tool was used to combine results from all 8 batches to calculate the 1:500 (combined failures), 1:200, LoS 2, and LoS 3 DOs, all by interpolation and concurrently produce a single DO plot. The post-processing tool count date was set to run from 1st January to 31st December, in line with the setup and counting of Level of Service events in SSW's previous plans.

Summarised below in Table 11 are results for the baseline scenario with restrictions, with the DO being constrained by Level 2 events at 341.41 Ml/d, as with modelling of DO in previous plans.

	Return period	Demand (Ml/d)	Difference from Historic LoS DO
Level of Service 2	**40**	**341.41**	
Level of Service 3	80	347.40	7.41
1:200	200	350.56	
Emergency Drought Order (Combined failures)	500	350.31	

Table 11: Baseline with restrictions DO demand failures

Figure 2 and Figure 3 show the Level 2 and 3 DO Vs return period plots respectively. Due to the profile of DO being influenced by the capacity constraints (as outlined further below), an equivalent smooth profile curve was not able to be produced as such for Level 4 events (explained further below).

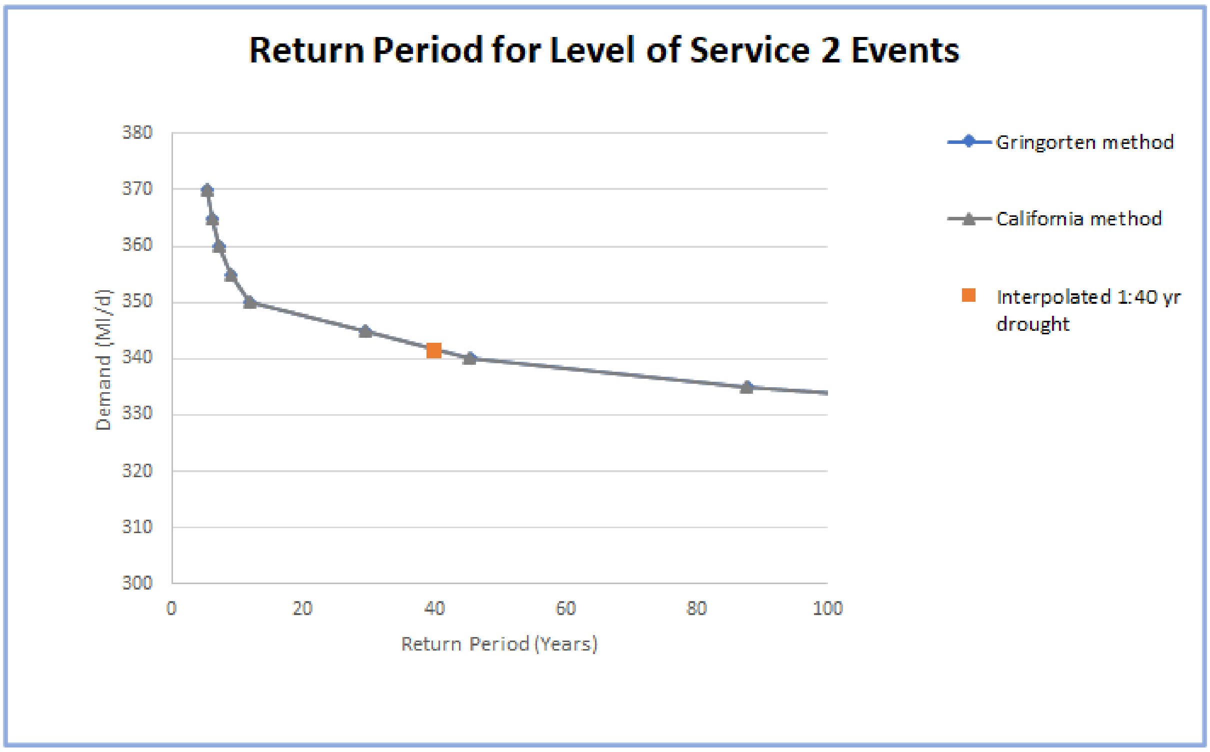

Figure 2: Level of Service 2 return period

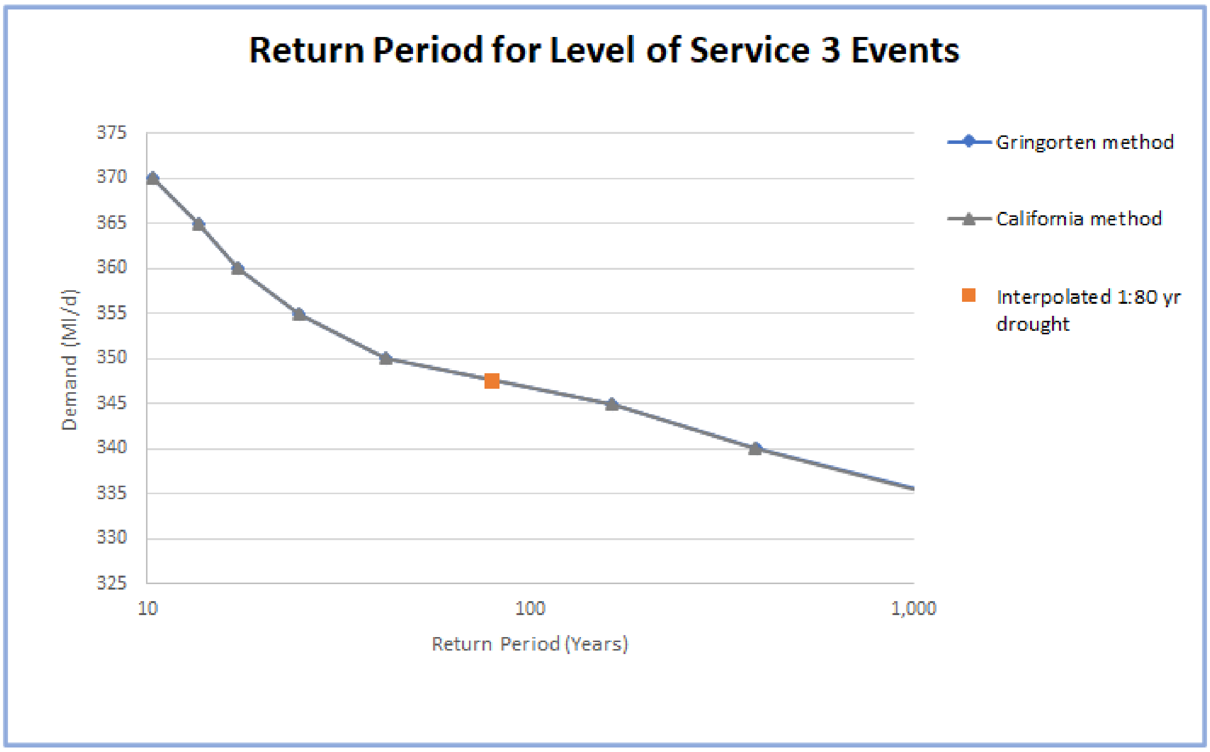

Figure 3: Level of Service 3 return period

The 1:500 DO level is higher than that for both Level 2 and 3 event types. Level 4 event occurrence is relatively low until demands of around 350-355 Ml/d. Further interrogation of the model showed that up to this point, storage-based failure linked to the Level 4 implementation trigger point was negligible, however, upon hitting these levels of demand, demand centre failure occurs in most or all years due to system capacity constraints (Table 12). Investigations showed this to be driven by a specific demand profile peak in June, noting the seasonal demand profile in the SSW model uses a daily profile and is essentially flat outside the peak summer months.

Ml/d	350.00	355.00	360.00	365.00
Annual failures	9	17183	19184	19200

Table 12: Annual failures of Level 4, showing clear step up in failures due to system capacity constraints

Analysis of the combined failures shows, in terms of modelling, this pattern to be explainable in the context of the DO analysis. The step increase in combined failures, driven by demand type failures, are particularly influenced by the seasonal demand profiles (as a legacy model input) occurring in June. Most water resources models tend to use weekly or monthly factors; however, this model is based on a daily profile from 1995 (see Figure 4 and Figure 5) and may therefore be more susceptible to capacity type failures. The results would be invariably influenced if the peaks are now considered too high compared to reflect current seasonal demand expectations around June and to a lesser extent August. However, the Level 4 DO sits above those of other levels of service, and thus does not influence the overall DO at this current time (this could be the case if the demand peaks were deemed to be too low, as higher peaks would relatively reduce the Level 4 DO level to other types).

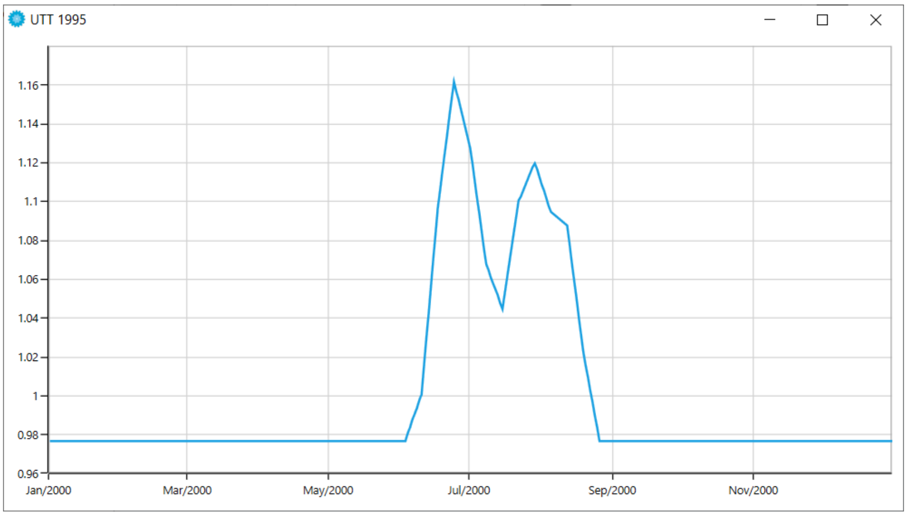

Figure 4: UTT 1995 analysis

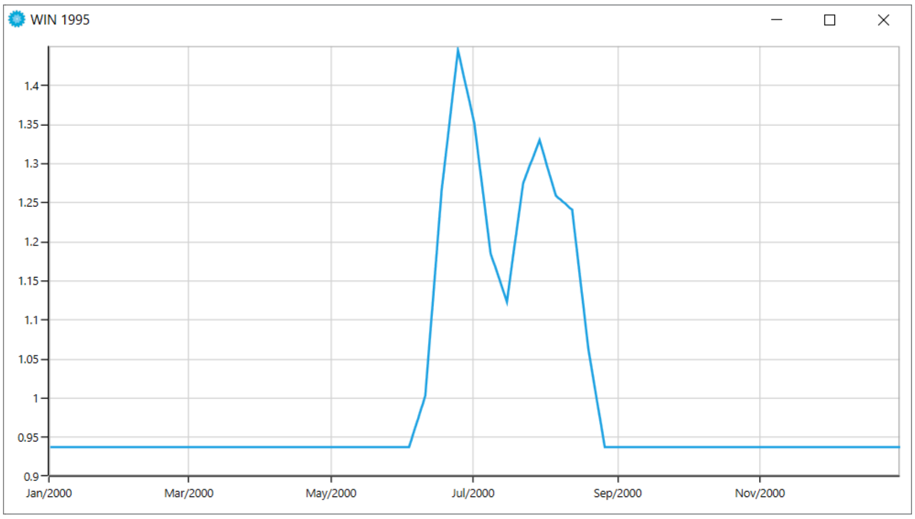

Figure 5: WIN 1995 analysis

3.2. Baseline DO with no demand saving restrictions

The model was then set up in order to run the baseline scenario with no demand restrictions. The EA planning tables separate out the DO with and without demand restrictions, and so model testing without restrictions informs the benefit assessment of restrictions in the planning tables.

This was achieved through the cloning of the PS3 - '1995 Set' and subsequently setting the 'Apply demand saving' parameter to false on all demand centres (with the exception of bulk exports, which were already set to false and are not subject to SSW enforced demand saving restrictions).

Summarised below in Table 13 are results for the baseline scenario with no customer restrictions benefits applied in the model run. Level 2 events still constitute the constraint to DO.

	Return period	Demand (Ml/d)	Impact from Baseline DO with restrictions
Level of Service 2	**40**	**336.08**	-5.33
Level of Service 3	80	340.56	
1:200	200	348.27	
Emergency Drought Order (Combined failures)	500	345.30	

Table 13: Baseline with no restrictions DO demand failures

3.3. Re-baselined DO for climate change impact assessment

It was noticed during the initial modelling of climate change scenarios (Section 4) that failures were observed at low demands in the River Severn locale; this resulted in zero or negative flow in the River Severn even before SSW abstractions had been taken into account. As such, flows in the River Severn necessitated re-naturalisation to account for the two exports at Trimpley (as discussed in due course in Section 4.3). Following the implementation of this change, the model no longer produced failures at low demands under climate change scenarios, yielding more plausible DO results. However, alteration of the database at that stage for climate change also necessitated a re-baselining for DO impact assessment (which should be done to a suitable base model without climate change), and also to allow SSW an understanding of the variance in DO in the baseline case to understand the materiality of the change.

Re-baselines with and without restrictions (with stochastic Batches 4 and 7 *only*) were carried out, with the results summarised below with restrictions, again showing Level of Service 2 as the continuing constraint to DO under baseline conditions.

	Return period	Demand	Impact from the original baseline DO
Level of Service 2	**40**	**337.94**	-3.47
Level of Service 3	80	350.00	
1:200	200	355.00	
Emergency Drought Order (combined failures)	500	355.00	

Table 14: Re-baseline with restrictions DO demand failures

A re-baseline scenario without demand restrictions was also run, showing a slightly lower demand saving benefit in this case, albeit the outright differences are relatively small in the context of overall DO.

	Return period	Demand	Impact from rebaseline DO with restrictions
Level of Service 2	40	**335.14**	-2.80
Level of Service 3	80	340.46	
1:200	200	348.51	

Emergency Drought Order (combined failures)	500	345.01	

Table 15: Re-baseline DO demand failures

4. Stochastic climate change scenarios

Summary: Two stochastic batches (known as Batch 4 and 7) were taken through to climate change assessments. These stochastic batches were previously selected and sampled for STWL, and thus the appropriate inflow data (or models to produce time series data at 1:500 DO) were available. In total, 32 UKCP18 climate change scenarios have been assessed using the Scottish DO method. Alterations to the River Severn representation were applied to allow plausible assessment of climate change impact, due to the legacy representation of the Severn essentially resulting in negative river flows.

The 12 UKCP18 RCM scenarios (using RCP8.5 high emissions as modelled) broadly show the most severe 1:500 DO impacts. The highest impact for the RCMs was RCM13 (-29.84 Ml/d DO impact) and with RCM15 the lowest (-12.8 Ml/d). The P90 probabilistic DO impact was comparable with the RCM scenarios at -17.2 Ml/d, but the P50 showed a much more modest -9.6 Ml/d DO impact. In all cases, Level 2 events constrain DO as with the stochastic baseline, albeit in the most severe scenario the ‘gap’ to Level 4 1:500 DO closes.

The overall trend of probabilistic DO impact followed the general rank expected from the provided sampled probabilistic scenarios. However, given the system modelling exercise is influenced by system non-linearities (which is the benefit of using a water resources model), individual events may not be fully in line with the expected rank, and the sampling was also conducted based on the STWL system (albeit the SSW area lies geographically within that of STWL).

Additional impact assessments of DO without customer use demand savings applied showed negligible impacts on DO, with 3 of the 4 RCM scenarios assessed showing <1 Ml/d impact and thus may be expected to be within the uncertainty bounds of the modelling exercise.

4.1. Inflow datasets

As described in Section 0, the SSW system sits in the same spatial area as STWL, and there are common sources represented in both Aquator models. Updates to the baseline stochastic inflow data with climate change impacts applied utilised data from STWL inflow datasets and/or simulations of the STWL model (consistent with the approach taken to the baseline outlined earlier in this document). The STWL DO modelling of climate change used two batches of stochastic data following sampling, which necessitated the same two batches to be applied to the SSW assessment.

From their own DO modelling project, STWL had available CSV format spreadsheets containing inflows impacted by 32 UKCP18 climate change scenarios (12 RCM and 20 Probabilistic) for eight stochastic batches, categorised in subfolders and based on catchment names. The post-processing steps outlined in Section 2.1 were also undertaken for the climate change scenarios, with flows at Blithe (upper and lower) subsequently collated from the inflow spreadsheets.

In addition to timeseries collated from the stochastic inflow spreadsheets, the STWL model was used to extract additional variables (via simulation at the 1:500 DO level) for each of the RCM and probabilistic scenarios. The following variables listed below were captured during the 1:500 DO simulations, as defined and applied in previous WRMPs.

- Model.Severn regulation.Abstraction regime (River Severn regulation flow bands)
- AB9. Supply.Total amount (Trimpley)
- GS5.Flow.Net (Bewdley)
- GS30.Flow.Net (North Muskham)

Prior to setting off simulations, STWL WRZs were fixed at scenario specific 1:500 DO levels.

The simulations were set to run from 01/01/1902 to 31/12/4301 for stochastic batches 4 and 7 (i.e. the climate baseline). Post completion of simulation runs, the requisite variables were exported and subsequently imported into the SSW model.

To distinguish between batch and climate change combinations, timeseries were saved in the SSW model[7] using a naming convention e.g. for Blithe Inflow 1, timeseries were saved to the database as R28000BLI_RCMX_BTY_Mld where X and Y denote RCM/probabilistic scenario number and batch number respectively.

Timeseries name in SSW model	Data Source	Timeseries saved in SSW model database as	Component ID data assigned to in SSW model
Blithe Inflow 1	Stochastic inflow spreadsheet	R28000BLI_RCMX_BTY_Mld R28000BLI_ProbScX_BTY_Mld	CM1
Blithe Inflow 2	Stochastic inflow spreadsheet	A28000NET_RCMX_BTY_Mld A28000NET_ProbScX_BTY_Mld	CM2
Hampton Loade	1:500 simulation and subsequent extraction from STWL model	Model.Severn regulation. Abstraction regime_RCMX_BTY Model.Severn regulation. Abstraction regime_ProbScX_BTY	AB3
STWL Trimpley DC	1:500 simulation and subsequent extraction from STWL model	AB9.Supply.Total amount_RCMX_BTY AB9.Supply.Total amount_ProbScX_BTY	DC29
Severn Inflow 1	1:500 simulation and	GS5.Flow.Net_RCMX_BTY GS5.Flow.Net_ProbScX_BTY	CM4

[7] SSW Aquator XV WRM v1.13 - based on MMA_V4.3.7 (backup copy).axvdbs

	subsequent extraction from STWL model		
Nethertown & Emergency Transfer (Trent)	1:500 simulation and subsequent extraction from STWL model	GS30.Flow.Net_RCMX_BTY GS30.Flow.Net_ProbScX_BTY	AB1 & AB2

Table 16: Timeseries and allocated component ID for climate change scenarios

4.2. Database preparation

Prior to the running of 32 climate change scenarios, it was necessary to prepare the model database, such that the climate change data (discussed above) was implemented correctly and efficiently.

As such, a total of 32 scenario and sequence sets were prepared (i.e. one per climate change scenario) with demand restrictions implemented. Four additional sets were created for additionally running RCM07, RCM12, RCM15 and RCM13[8] without restrictions as a sensitivity test of the impact value estimated in baseline conditions.

To facilitate quick switching between the scenario sets (and associated parameter, state, sequence and variable sets), the database was set up as shown in Table 17, noting X denotes the RCM/probabilistic scenario to be modelled, and stochastic batches 4 and 7 were selected for climate change analysis:

Scenario set	Parameter set	Sequence set
X_BT4	1995 Set	X_BT4
X_BT7		X_BT7
X_BT4 (NR)	1995 Set (no restrictions)	X_BT4 (NR)
X_BT7 (NR)		X_BT7 (NR)

Table 17: Scenario setup (with associated parameter and sequence sets) in model databases

The state and variable sets are not updated in the table, given these sets were not directly impacted by any updates upon receipt of climate change data. For reference, the 'Default' state set was defined for the period 1902-4301. The variable set 'Minimal' was customised and implemented for analyses to capture model failures only, to maximise the speed of running the Scottish DO assessment.

[8] These were chosen with SSW on the basis that they represented a suitable range of the RCM impacts, and also on the basis of some of these being explored more broadly in the WRW regional plan.

Following completion of the database preparation, independent checks and reviews were carried out to ensure a robust, error free starting point prior to undertaking of subsequent analyses.

No groundwater DO update was provided by SSW for climate change modelling, and so these remained as the original Aquator model.

4.3. RCM scenarios - with demand saving restrictions

During the initial round of testing of a handful of climate change scenarios, failures were observed at extremely low demands in the River Severn locale, which essentially indicated insufficient flow in the River Severn under stochastic conditions even prior to SSW abstraction. The existing representation of this part of the system is in line with legacy SSW models, and whilst as such a full review and revision of this area of the model was outside the project scope (or available timescales), further review was carried out of this issue with reference to the basis of the STWL model data provided.

Two exports at Trimpley were noted and queried with SSW given it was unclear as to why there are two exports to the same location, and most importantly, as to why net Bewdley flows were used as the input to the model (above the abstractions) even though in the STWL model Bewdley sits *downstream* of these abstractions. This seemingly resulted in double counting or subtracting these abstraction points, leading to zero flows being observed in the River Severn in the model. As such, the catchment inflows in the Severn were partially re-naturalised to account for the STWL 'exports'. Prior to re-naturalisation, Bewdley flows in the model were cross-checked against historic flows in the spreadsheet to ensure Trimpley offtakes were not accounted for. It was found that the Trimpley abstractions did not form part of the flows and were therefore added on through VBA customisation on each day of the model run[9]. The change ultimately resulted in more plausible climate change DO results as seen below.

Below in Table 18, is an example of the set up used for the Aquator XM analyses. It should be noted that start and end demands were altered for each climate change scenario (i.e. the demands were kept the same within the same overall analysis of stochastic batches 4 and 7), based on severity, i.e. if no failures were found in the range shown below, the range was increased accordingly until failures were found. This is because at the outset, a degree of searching out of the DO range was required given UKCP18 scenarios had never been run previously for the SSW system.

DO models runs	Parameter value
Use worksheet matrix	FALSE
Start demand	270.00
End demand	370.00
Initial demand step	20.00
Modelling start date	01/01/1902
Modelling end date	31/12/4301

[9] This allowed use of the Bewdley net inflow data based on the STWL model outputs without change, but each day of the model run the associated STWL demand / abstraction (that had already been subtracted from the inflow data) were added onto the time series value to give a larger inflow. It is recommended that in future a fuller review and baselining of model representation between SSW and STWL models is undertaken in future model revisions.

Step reduction factor	4.0
Minimum step size	5.000
Failure demand precision	5.000

Table 18: Template setup for RCM01 BT4

A post-processing tool was then used to obtain a 1:500 (upon completion of BT4 and BT7 analyses in Aquator XM), 1:200, LoS 2 and LoS 3 DO levels, yielding the following results as seen in Figure 6 and Table 19, which includes the DO impacts relative to the stochastic LoS 2 re-baseline DO (337.94 Ml/d). Level 2 constrains DO in all cases, albeit the most severe scenario RCM13 evidences that as scenario severity increases the 'gap' between DO constrained by Level 2 and 4 events closes[10].

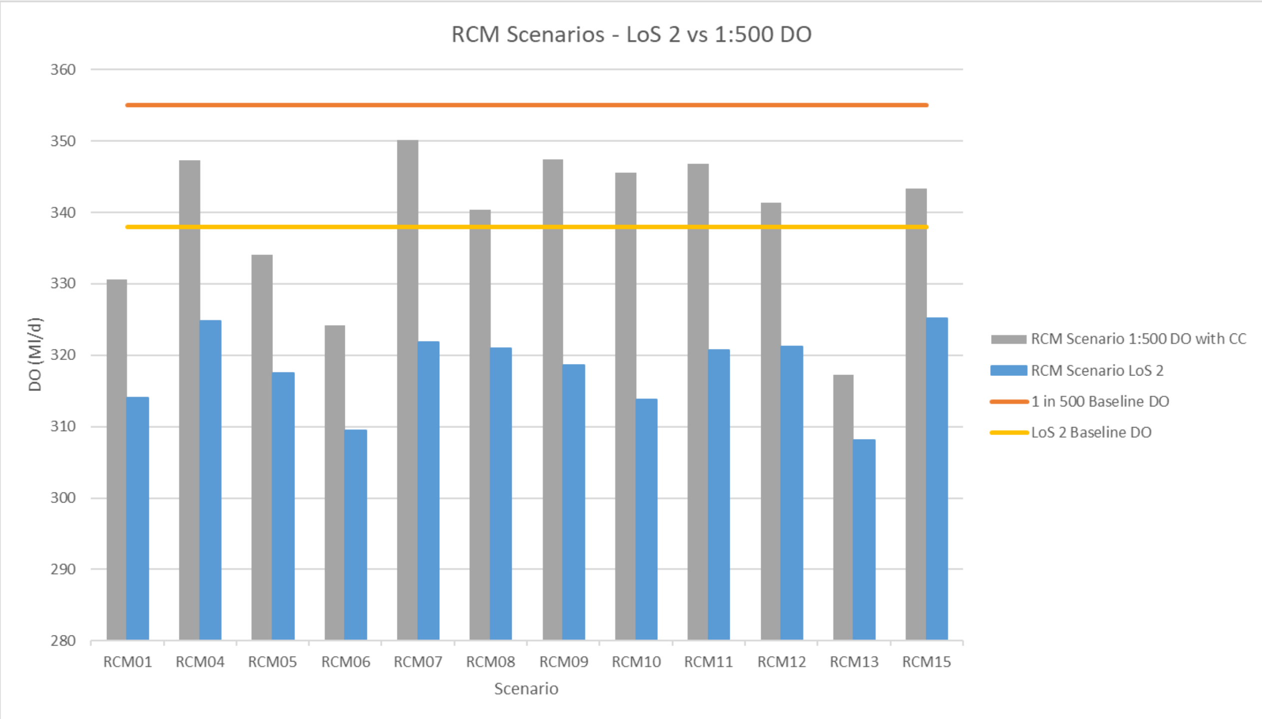

Figure 6: LoS and 1:500 DO for Global Zone RCM with restrictions Scenarios

Scenario	LoS 4 DO with CC – 1 in 500 years	1 in 200 DO	LoS 2 DO 1 in 40 years	LoS 3 DO 1 in 80 years	Impact from Stochastic DO (BT4/ BT7 CC re-baseline)[11]	% reduction (to CC updated baseline)

[10] It is not implausible that under different system or scenario configurations that the SSW system could result in DO being constrained by resources in some cases rather than Level 2 events.
[11] Based on the true DO constraint being Level 2 events.

RCM01	330.67	336.81	314.06	327.54	-23.88	-7.07
RCM04	347.28	348.89	324.80	335.25	-13.14	-3.89
RCM05	334.04	340.16	317.54	328.76	-20.40	-6.04
RCM06	324.18	333.71	309.44	326.67	-28.50	-8.43
RCM07	350.19	350.49	321.83	333.75	-16.11	-4.77
RCM08	340.41	347.76	321.00	330.75	-16.94	-5.01
RCM09	347.42	349.14	318.65	331.03	-19.29	-5.71
RCM10	345.57	347.18	313.74	328.29	-24.20	-7.16
RCM11	346.85	348.55	320.74	329.90	-17.20	-5.09
RCM12	341.34	347.09	321.18	329.91	-16.76	-4.96
RCM13	317.25	330.65	308.10	326.17	-29.84	-8.83
RCM15	343.37	350.01	325.14	332.90	-12.80	-3.79

Table 19: RCM with restrictions DO summary table

Having tested the 1:500 DO with climate change, LoS 2 remains the constraint to DO. As noted in Section 3.1, capacity driven failures materialised before storage trigger failures for some of the wetter climate change scenarios (e.g. P5, P15, P20 and P25, to name a few), linked to the legacy 1995 demand profiles in the SSW model.

Plots showing LoS 2, LoS 3 and LoS 4 events (denoted by the green, blue and orange lines respectively) based on counts of trigger crossing at any time of the year, for each of the modelled climate change scenarios have been provided through the OneDrive link. In line with the current operational logic of the model and historic DO derivation, the plots show that Level 2 (the 1:40 event) is the constraint to system DO.

4.4. RCM scenarios - with no demand saving restrictions

Having ranked the RCM (with demand restrictions) plot, RCM scenarios 7, 12, 15 and 13 were found to represent the least impact, central estimates and worst case for SSW, respectively. As such, DO analyses for these scenarios *without* demand saving restrictions were undertaken as a sensitivity test of DO impact values to those conducted on the baseline, with results presented below in Figure 7 and Table 20.

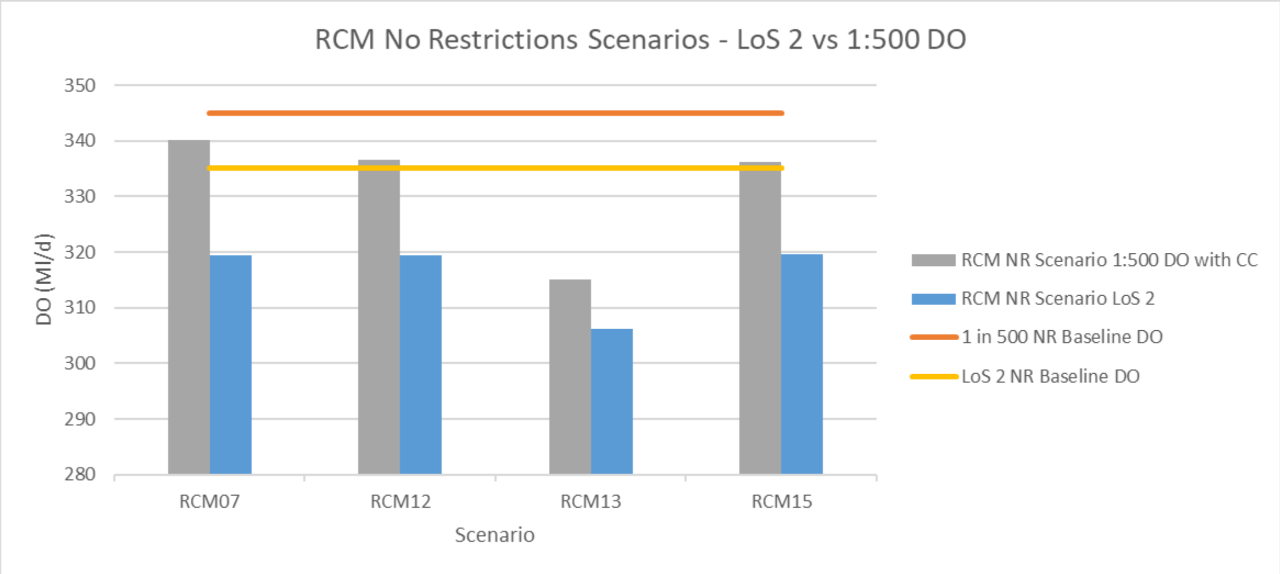

Figure 7: LoS and 1:500 DO for Global Zone RCM with no restrictions Scenarios

Scenario	1 in 500 DO with CC	1 in 200 DO	LoS 2 1 in 40 years	LoS 3 1 in 80 years	Impact from equivalent RCM (with restrictions) (BT4/BT7 CC)	% reduction (to equivalent RCM with restrictions)
RCM07	340.15	341.52	319.36	331.83	-2.47	-0.77
RCM12	336.57	339.75	319.39	327.93	-1.79	-0.56
RCM13	315.05	325.13	306.24	315.16	-1.86	-0.60
RCM15	336.28	339.90	319.59	329.14	-5.55	-1.71

Table 20: RCM with no restrictions DO summary table

As can be seen LoS 2 remains the constraint for the RCM scenarios without restrictions.

4.5. UKCP18 Probabilistic scenarios

An identical approach, as outlined in Section 4.3, was carried out for the probabilistic scenario analyses. The outputs from the Global Scottish DO analyses (in ascending order of expected sampled rank, based on the STWL area) for the Probabilistic scenarios are shown in Figure 8 along with impacts relative to the 1:500 stochastic DO (355 Ml/d) (merely presented for reference) and the LoS 2 DO (337.94 Ml/d), noting the latter is the baseline DO, given LoS 2 is the constraint to SSW DO. The broad trend of DO follows the expected order based on the scenario percentiles, albeit given the SSW specific system responses individual scenarios may legitimately be out of the original sampled rank.

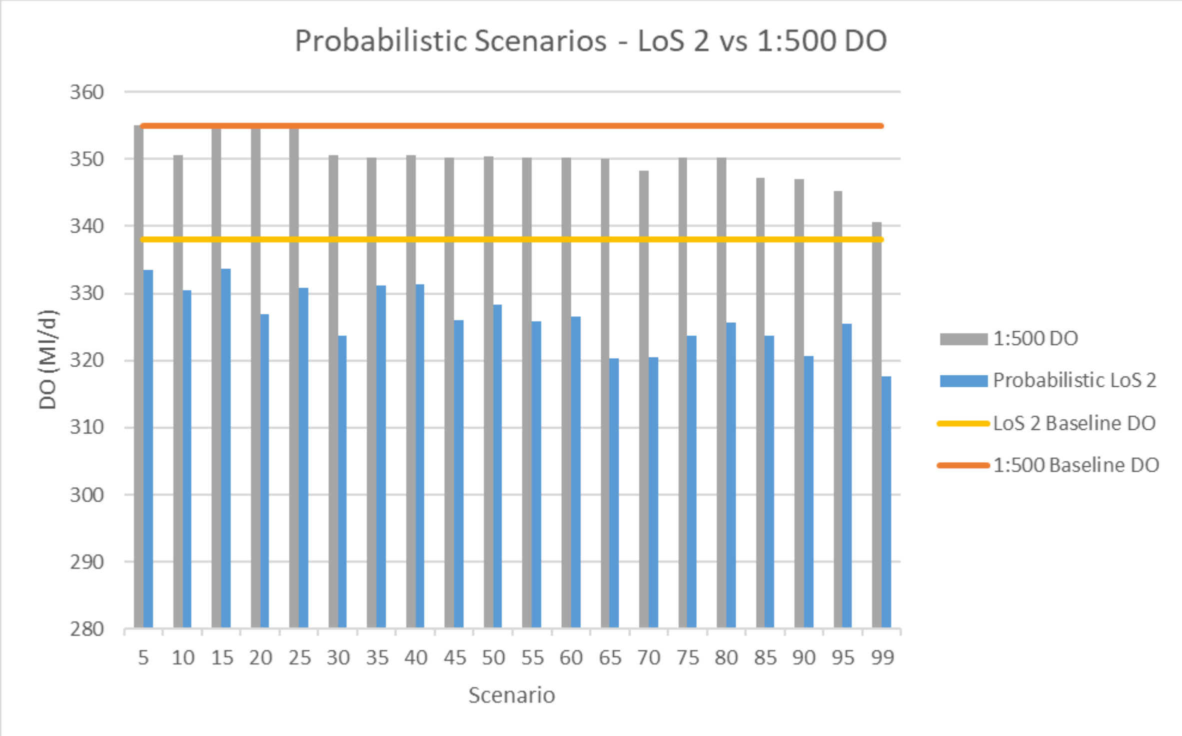

Figure 8: LoS 2 and 1:500 DOs for Probabilistic Scenarios

Scenario	Selected Rank	1 in 500 DO with CC	1 in 200 DO	LoS 2 1 in 40 years	LoS 3 1 in 80 years	Impact from Stochastic (BT4/ BT7 CC rebaseline)	% reduction (to CC updated baseline)
Sc2	90	346.92	348.68	320.74	330.04	-17.20	-5.09
Sc17	95	345.29	349.02	325.44	331.82	-12.50	-3.70
Sc19	55	350.19	350.49	325.89	337.77	-12.05	-3.57
Sc21	80	350.25	350.53	325.72	336.87	-12.22	-3.62
Sc37	20	355.00	355.00	326.90	350.00	-11.04	-3.27
Sc44	10	350.48	350.73	330.38	342.23	-7.56	-2.24
Sc61	85	347.24	349.29	323.65	331.78	-14.29	-4.23
Sc68	65	350.07	350.37	320.22	334.27	-17.72	-5.24
Sc72	15	355.00	355.00	333.67	350.00	-4.27	-1.26
Sc77	5	355.00	355.00	333.45	350.00	-4.49	-1.33
Sc79	25	355.00	355.00	330.74	350.00	-7.20	-2.13
Sc80	45	350.24	350.52	326.01	336.35	-11.93	-3.53

Sc82	99	340.59	346.56	317.61	328.34	-20.33	-6.02
Sc83	70	348.17	350.06	320.40	332.63	-17.54	-5.19
Sc85	40	350.50	350.76	331.41	344.16	-6.53	-1.93
Sc86	50	350.42	350.72	328.35	338.41	-9.59	-2.84
Sc87	30	350.49	350.74	329.80	341.99	-8.14	-2.41
Sc88	75	350.24	350.53	323.72	337.24	-14.22	-4.21
Sc96	35	350.24	350.53	331.10	341.36	-6.84	-2.02
Sc100	60	350.24	350.52	326.61	338.51	-11.33	-3.35

Table 21: Probabilistic scenarios DO summary table

5. Conclusions and future considerations

5.1. Conclusions

Stochastic hydrology and the latest UKCP18 climate change scenarios have been applied to the SSW Aquator model for the first time. Through use of the Scottish DO method, in a broadly consistent manner with STWL, this ensures that SSW DO estimations are based on system response in line with the latest EA 1:500 drought guidance note. The application of such methods marks a significant step forward in SSWs modelling DO capability.

As would be expected from the first-time application of stochastic hydrology to the SSW system, a degree of iterative approach has been required to ensure suitable outputs from the project. Similarly, additional insights have been gained on the SSW system and the associated model that will allow SSW to further target refinements and improvements in future, on balance of risk linked to their supply-demand balance position in the WRMP. Timescales to produce the set of results outlined in this report were necessarily time constrained to meet deadlines to input to the WRW regional plan.

This report has summarised the key results and outputs from the SSW DO and climate change project, which accompanies supporting spreadsheet and model files provided by Microsoft OneDrive for SSW's audit trails. With reference to legacy DO modelling conducted by SSW, the following key conclusions of may be drawn:

- When assessing, using new techniques, the 1:500 DO with stochastics and climate change, the frequency of Level 2 events remains the constraint to overall DO for SSW in line with WRMP19. Under baseline conditions, broadly speaking, the DO remains similar to those previously modelled in previous plans and model versions.

- As with legacy DO modelling, this position means that SSW are relatively resilient to Level 4 events against the 1:500 resilience standard being applied. In historic DO modelling (noting that SSW had a relatively long inflow record from the 1880s to present) this can previously be seen, where typically there is a material amount of storage retained above minimum levels at the point of DO failure; the findings with stochastic hydrology are consistent.

- Examination of combined Level 4 failures (demand and storage) show that asset capacity driven demand failures tend to kick in earlier than Level 4 storage trigger driven failures. These are linked to high summer demand peaks in the SSW demand profiles.

- Climate change impacts are likely moderated through the fact that Level 2 constrains overall DO. Whilst there may be more some drought events hitting the triggers, as previously moderate events become more severe, it doesn't matter *as much* if some of the existing events are more severe unless they trigger overall 1:500 DO failure for Level 4 events (they would have counted as a LoS 2 event before, and now). In the most severe RCM13 it may be observed that the 'gap' between Level 4 and Level 2 DO levels closes, but not completely.

- It is also worthy of note that the stochastics used are based on variations of a historic 48-year period, yet it is known that Level of Service has historically been influenced by events in years earlier than the stochastic range.

The insight gained from this project, beyond provision of the DO numbers themselves, is informative to help SSW target future model update and/or refinement on balance of risk with other influences on their supply-demand balance.

Appendix 1: Change in Level of Service count tests

Whilst working with the SSW model, further refinements to the DO set up that could have an influence on the overall DO were noted. The triggering of Level 2 events in the derivation of the DO in this project has followed the setup of the existing Aquator model and that as used at WRMP19, whereby events are determined by crossing the relevant trigger lines at any time of year. However, this logic could be explored by SSW in future to refine DO in future (both Aquator and the post-processing tools used in this project can be customised to alter the logic to event counting).

As part of exploring the setup of the model on the project, it was also noted that the demand saving *benefits* (associated with a profile of % saving for the different demand saving reductions) in the SSW model are only applied in the summer months. This brings a potential inconsistency with the inclusion of all trigger crossings in the DO analysis, irrespective of the time of year that the demand saving trigger line is crossed. As shown in the results so far, Level 2 is a dominant constraint on DO and changes to the counting of these events therefore could have potential to further increase the DO, if this would potentially screen out winter trigger events that wouldn't in practice potentially apply demand savings.

To validate and sensitivity check the impact of an alternative setup at this stage, HLSI performed further analysis on the baseline runs, and the four most important or 'key reference' RCMs (RCM07, RCM12, RCM15 and RCM13). These were re-processed to calculate the DO with only summer event triggering as a comparison.

Based on the baseline runs, if this logic is applied the baseline DO could increase to 343 Ml/d using the latest v1.11 model variant using BT4 and BT7. This would be about 5 Ml/d higher than the equivalent baseline (re-baselined DO as used for climate change) without this change, so could be relevant depending on SSW's supply-demand position. In all cases, Level of Service 2 remained a constraint to DO, as would be expected.

On the counter, it was also observed that the customer demand saving assumptions were relatively high for SSW, and so it would be recommended that the overall logic for Level of Service is reviewed holistically if changes are to be formally adopted.

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**343.36**
Level of Service 3	80	354.84
1:200	200	355.00
Emergency Drought Order (combined failures)	500	355

Table 22: Re-processed baseline (climate baseline) DO demand failures

	Return period	Demand (Ml/d)

Level of Service 2	**40**	**339.22**
Level of Service 3	80	345.94
1:200	200	348.51
Emergency Drought Order (combined failures)	500	345.01

Table 23: Re-processed baseline with no restrictions DO demand failures

For the RCMs, the LoS 2 remained the DO constraint in all cases except for the most extreme RCM13 where it switches to the 1:500 level. Looking across the 4 RCM, this showed the potential to reduce the average climate change impact value by around 3 Ml/d based on the sensitivity tests.

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**331.43**
Level of Service 3	80	346.60
1:200	200	350.49
Emergency Drought Order (combined failures)	500	350.19

Table 24: Re-processed RCM07 with restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**330.98**
Level of Service 3	80	346.14
1:200	200	347.09
Emergency Drought Order (combined failures)	500	341.34

Table 25: Re-processed RCM12 with restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**326.18**

Level of Service 3	80	330.76
1:200	200	330.65
Emergency Drought Order (combined failures)	500	317.25

Table 26: Re-processed RCM13 with restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**329.62**
Level of Service 3	80	346.05
1:200	200	350.01
Emergency Drought Order (combined failures)	500	343.37

Table 27: Re-processed RCM15 with restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**330**
Level of Service 3	80	337.63
1:200	200	341.52
Emergency Drought Order (combined failures)	500	340.15

Table 28: Re-processed RCM07 with no restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**328.17**
Level of Service 3	80	336.48

1:200	200	339.75
Emergency Drought Order (combined failures)	500	336.57

Table 29: Re-processed RCM12 with no restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**318.56**
Level of Service 3	80	325.86
1:200	200	325.13
Emergency Drought Order (combined failures)	500	315.05

Table 30: Re-processed RCM13 with no restrictions DO demand failures

	Return period	Demand (Ml/d)
Level of Service 2	**40**	**327.06**
Level of Service 3	80	335.95
1:200	200	339.90
Emergency Drought Order (combined failures)	500	336.28

Table 31: Re-processed RCM15 with no restrictions DO demand failures

Key offices:

Clevedon

Reading

Stirling

Warrington

Registered office

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