DOCUMENT REVIEW SHEET FOR RESTRUCTING SUB-MODELS		Water Resources in the South East	
Water Company:	SES Water	**Document No.**	1
Sub-models:	Bough Beech + groundwater network	**Page**	1

Build status	Check status	Internal Review status	External Review & Sign-off status
Validation completed	Completed	Completed	Sent for review
Model file path location:	Azure DevOps Repository		

No.	Name of Reviewer (Internal and or Technical Working Group reviewer)	Date Rec'd	Review Carried out			Review Complete	
			Initials	Date	Remarks	Initials	Date
1	A Murphy	16/09/2020	AM	18/09/2020	Sign off of Bough Beech standalone build report confirmed	AM	21/10/20
2	A Murphy	21/07/2021	AM	06/10/21	Sign off of Bough Beech + groundwater network build report confirmed	AM	06/10/21

Notes for Reviewers:

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1. <u>Review sheet purpose</u>

The purpose of the document is to capture the restructuring of sub-models and any updates following coupling of the models and combining them into a regional simulator.

The review sheet provides some background on the model build process, and documents the:

- Action and risk logs, to be kept live and reviewed regularly
- Outputs of the original PyWR sub-models to help steer the direction of the sub-model restructuring
- Technical Working Group priorities for the model build process, including indicative simplifications that can be applied
- Model build outputs provided to the consultant model lead
- Model checklist to ensure robust checking of the models
- Internal and Technical Working Group review records

2. Action List and risk log

Key actions and risks are to be recorded in this section and reviewed on a regular basis with the company model leads. Any ongoing or major risks will be fed back to the WRSE project management team for further discussion and detailed assessment.

Table 1 Key action list

Key Action	Description	Owner	Target date	Progress
Regular Data entry	Populate the Pywr model with existing Information, in order of priority (WRSM, WRMP19, AMP5 workpack Aquator) to confirm current set-up	T Norris	08/01/2021	Completed
Network development	Review Pywr network and feedback revisions to the team	T Norris	12/01/2021	Completed
Validation	Identify a set of validation runs with which to test model.	T Norris	15/01/2021	Completed
Coupling	Couple the Bough Beech model with the groundwater network and review performance with SESW	T Gribbin	19/02/2021	Completed
Test BB WTW min flows	Minimum flow constraints were added to BB WTWs for testing purposes. However, it was confirmed that the min flow constraint would be 0 Ml/d by 2025.	T Gribbin	26/02/2021	Completed

Table 2 Outline risk log

Risk	Description	Mitigation	Status	Reported to PM team?
Revised demand saving approach impacts baseline DO	The demand saving approach in the Aquator model is not fully aligned with operational reality, and requires refinement which could impact Dos when demand savings are accounted for.	Maintain close communication with SES Water on the refinement and highlight potential impacts as soon as possible.	Completed	No
Representation of water quality abstraction constraints	The current abstraction protocol contains Autumn water quality constraints which have not previously been represented. Though a simplification is possible in a water resources model, in reality, Autumn water quality abstraction constraints are likely to be highly variable due to dependency on factors such as farming practices, antecedent conditions, and	Discussion with SESW about typical Autumn abstraction delays due to water quality issues suggested that a couple of weeks could be typical. We used observational data as an additional test of the model in order to check whether the 2-week delay to abstraction was too high in past events. The analysis showed that including the Autumn	Completed	No

	other rainfall event characteristics. Overestimation of the water quality limitation on abstraction is to be avoided due to the fact that the water quality constraint can ultimately be bypassed should water resource concerns dictate.	quality constraint brought the model closer to the observed data in almost every year of the available data. No further tuning was attempted in order to avoid 'lumping' other errors in the model/data into this variable.		
Bough Beech WTW capacity unknown	Confirm Bough Beech WTW capacity to simulate for WRSE.	Email communication with Daniel Woodworth (SESW) on 02/07/20 confirms value of 65Ml/d	Complet ed	No
Bough Beech sub-model behaviour in regional simulator	Components of the sub-model may interact in an unrealistic way with other components in the regional model. For example, the balance of 'costs' may correctly prioritise the sources and constraints in the submodel, but not once connected in the regional model.	A system of costs for standard model components has been developed and applied across the various submodels in order to ensure that that the model applies a standard prioritisation between model component types. In addition, submodel specific automated tests are being written to allow inadequate performance in the regional simulator to be rapidly identified.	In progres s	No

3. Model build background

Model build approach
The design of the simulator is governed by a series of trade-offs, the most important of which is system detail and accuracy versus run speed. Another crucial consideration is model flexibility and adaptability. Creating a regional simulator which both: (i) has a good match against water company models using the same input data; and (ii) adapts to the new types of conditions that will be present in the WRSE scenarios; is significantly more challenging than simply reproducing the existing water company model outputs. There is an important trade-off between these two objectives that will need to be balanced and factored into the model review process.

Model requirements
The model requirements were prioritised in a stakeholder workshop held in August 2019 and should be considered as part of the model build and review process (see table 3 - the blue shaded cells represent simulator requirements directly relevant to the subsystem builds). The table lists the functionalities, with the priority set at high or moderate. In general, these may be classified as:

- High priority: means that the functionality must be included within the Phase 2 simulator build ready for testing in 2020;
- Moderate: means that it is important but that there is some flexibility around the timing and/or level of detail;
- Low: means that it is a functionality that is either not needed or that can be added at some unspecified point in the future. These are not included in the table.

Table 3 Scoped simulator requirements from scoping stage prior to project inception

Simulator requirement	Priority
F1. Stochastics	High
F2. Timesteps (Daily)	Moderate / high
F3. Identification and optimisation of transfer options	High
F4. Adaptability of simulator to different conditions	High
F6. Option/Portfolio testing	High
F7. DO	High
F8. Dynamic groundwater	High
F9. Water Quality	High/ Moderate
F12. Multisector representation	Moderate
F13. Visualisation	High
F14. Usability	High
F15. QA	High
F15. Data Management	High
F16. Costs	Moderate
F18. Bidirectional links	Moderate
F19. Inter-regional transfers	High

Model performance metrics and acceptance criteria
As part of the model build and review process, the models will be assessed against a range of agreed metrics (table 4) and sub-metrics (table 5). It will not be necessary for all of these metrics to be checked across all parts of the simulator, as this would be inefficient. Comparisons should focus on key nodes and metrics, which will vary across different parts of the model and according to the outputs of other WRSE workstreams. A final set of metrics and common standards across the subsystems will need to be agreed at the beginning of the model build process.

Table 4 Performance metrics from scoping stage prior to project inception

Data type	Metric	Calibration / validation approach	Acceptance criteria	Other specific metric considerations
Time series	River flow	Compare using: 1. Hydrographs / timeseries plots (daily and rolling averages) 2. Summary statistics 3. Flow / storage duration curves 4. Double mass plots 5. Where appropriate, relevant goodness of fit statistics, e.g. NSE1	The tests will be largely qualitative but quantitative tests (including specifying thresholds) may be applied once the Technical Working Group is meeting and the potential performance level of the simulator becomes clearer. Therefore, the key objectives will be to: 1. Achieve a good visual fit in plots 2. Achieve goodness of fit statistics that are commensurate with the type of data and modelling approach.	Focus on downstream river reaches as these will incorporate the behaviour of upstream nodes (river reaches and assets)
	Reservoir level			-
	Aquifer level			This only relates to one model (Thames Water WARMS2) and is dependent on dynamic groundwater simulation being deemed as a priority here in the WRSE simulator
	Transfer flow			Focus on existing connections but review future behaviour where possible.
	Abstraction rate			Focus on environmentally sensitive sites
	Supply-demand deficit rate (i.e. occurring during failures)			
	Influences (if simulated)			Could be a comparison of WRSE simulation vs company denaturalisation process
Frequency	Levels of service / drought trigger crossings	Output return period / annual probability of crossing triggers[1]. For the regional simulator this should involve both the historic and stochastic datasets (which should have the same characteristics with climate change effects excluded).	Results show good levels of agreement. Thresholds may be applied once the Technical Working Group is meeting and the potential performance of the simulator becomes clearer.	Can only relate to triggers that are simulated in both the WRSE simulator and company models. This will need to take into account the treatment of drought interventions such as supply options and drought permits and orders.
	Failures (i.e. emergency storage / dead water)			
Analyser outputs	Deployable output	Full historic sequence and selected events	Results show good level of agreement. Thresholds may be applied once the Technical Working Group is meeting and the potential performance of the simulator becomes clearer	In some cases, e.g. for Thames Water's London and SWOX RZs, it will be necessary to sequence the analysis as per the company approach. This requirement will need to be

1 The exact metrics will require careful selection to avoid misleading results such as false positives or negatives.

				considered integrally to regional simulator design and development. Care will be required to ensure that updated base year DOs do not lead to supply-demand balance deficits.

Table 5 Draft sub-metrics (draft for review)

Sub-metric	Description
Change in Q75 flow	Assessment of the ratio of denaturalised to naturalised Q75 (using Pywr outputs for denaturalised) for relevant catchments. Other flow metrics can be used
Vulnerability to PWS drought interventions	Measure of the average expected duration of Drought Permits and Orders weighted by environmental risk.
Expected time to failure	Use baseline Pywr run to set initial metric by sub-region. Options and portfolios then assessed to evaluate impact on this.
Duration of enhanced drought restrictions	Long term expected duration (days/annum) with Drought Orders/Permits and NEUBs in place.
Reliance on Drought Orders and Permits	<u>Portfolio level assessment only</u> (i.e. not run at modelling Stages 5 and 6). Run Pywr with different portfolio types with and without Permits and Orders to assess how much reliance there is on their benefit within a given portfolio.
Connectivity	Sum of the capacity for transfer between different WRZs. *Could increase complexity of the metric to evaluate average proportion of transfer capacity used?*
Availability of surplus	Based on EBSD modelling. Indication of the amount of 'incidental' surplus generated by interventions (the plan still seeks to balance, but there will be periods of surplus). Need to cap where surplus is excessive in a given WRZ (i.e. there is a limit to benefit)
Inter-company and regional connectivity	As per connectivity above, but based on treated and raw water links that connect across catchments/regions (idea is that having this in place allows for management of unexpected supply and environmental stress events, reducing interruption risk from pollution events and allowing for management of environmental abstraction stresses).
Diversity of intervention type	Simple calculation of the probability-weighted relative contribution of yield/DM benefits from the interventions selected in a given portfolio.

WRSE simulator role

The table below outlines the key role of the simulator and these should be considered when developing the sub-model structure to facilitate the requirements of the simulator work once the sub-models are brought together.

Table 6 Key simulator role identified in scoping stage prior to project inception

<table>
<tr><th>WRSE simulator role</th><th>Critical metrics (in order of priority)</th></tr>
<tr><td>Upfront identification of transfer and operational change options</td><td>• Transfer flow (sensible behaviour)
• Flow and storage metrics in adjoining sources
• Supply-demand deficit rates in adjoining demand centres / RZs</td></tr>
<tr><td>Supply forecast as investment planning input</td><td rowspan="2">• RZ deployable output</td></tr>
<tr><td>Conjunctive option DO benefit as investment planning input</td></tr>
<tr><td>Option system simulation ahead of investment planning (to help prioritise data input)</td><td rowspan="2">• Performance of downstream model nodes (which encapsulate upstream model behaviour)
• Performance of nodes which are key to RZ behaviour, e.g. key sources, bidirectional links etc.
• Performance of nodes which are key to capturing the wider WRSE performance metrics (i.e. from Resilience Framework workstream – still to be established), e.g. frequency of customer restrictions or interruptions, flow or storage at environmentally sensitive sites.</td></tr>
<tr><td>System simulation of portfolios emanating from investment planning</td></tr>
</table>

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4. Existing Pywr and company model performance and schematics

Updates made to the Bough Beech standalone model have been validated against Aquator and reviewed in a separate review document issued on 18/09/2020 and signed-off by SESW on 21/10/20. The present review document describes the development of the groundwater network and the behaviour of the final SESW model used in the WRSE modelling (coupled Bough Beech + groundwater model).

Table 7 Performance table

Model	Input data	Approximate Run Time
Bough Beech standalone model	Full stochastic flow series (19200 years)	7 minutes (~18,000 timesteps/second)
Final WRSE SESW model (coupled Bough Beech + groundwater network)	Full stochastic flow series (19200 years)	13 minutes (~10,000 timesteps/second)

5. Technical Working Group model lead prioritisation

In this section, the water company model lead outlines the simplifications to start with in their company models using the existing PyWR model performance as a benchmark to determine the level of complexity required. Please refer to the WRSE simulator role section above when considering simplifications to the model and prioritisation of model performance metrics.

Table 8 will record the proposed model development plan highlighting key proposals including simplifications but also red lines where the model must maintain complexity from the water company's perspective.

In table 9, the water company model lead will highlight the key metrics, links and nodes that will be the priority of the sub-system model build process. In table 10, key options and transfers (where known) that should be considered in the build process, to minimise the risk of the model requiring re-development later on. A set of proposed company model set-ups and runs for validation should be recorded in Table 11.

It is important that groundwater coupling is considered in advance, to enable the groundwater algorithms to be readily applied in the next phase of work.

Table 8 Model change plan

Description	Proposal (simplification, change, no change)	Proposal priority (H, M, L)
Bough Beech reservoir	No change - the Pywr model will replicate the setup of SES Water's Aquator model for the scenarios used in WRMP19. This now includes representation of precipitation/evaporation.	L
Groundwater sources	SES Water doesn't currently have a working conjunctive use water resources model of its whole area, so representation of groundwater sources will be newly done in Pywr. This will be built as a separate sub-model and added to the Bough Beech model at a later date.	H
Demand centres	Representation of demand centres other than the one associated with Bough Beech Reservoir will depend upon the necessary level of aggregation and therefore simplification of groundwater sources.	M
Network	As with the proposal for the groundwater sources, there is not currently a model for the SES Water area. There is a MISER model of the network that was developed for resilience purposes, from which it may be possible to obtain some necessary information, But the level of detail required will depend upon the way in which groundwater sources and demand centres are represented/aggregated.	M
Abstraction	Change – represent minimum pumping constraint and water quality condition.	H

Description	Proposal (simplification, change, no change)	Proposal priority (H, M, L)
Demand savings	Following model review and discussion with SESW it was decided to align demand savings approach with SWS method. Further details in Section 8.	M

Table 9 Water company key performance metrics (highlight the ones important to you)

Data type	Metric	Priority (H, M, L)	Performance review locations in the model
Time series	River flow	H	Bough Beech MRF
	Reservoir level	H	Bough Beech Reservoir
	Aquifer level	n/a	
	Transfer flow	n/a	
	Abstraction rate	M	Chiddingstone Pump Station
	Supply-demand deficit rate (i.e. occurring during failures)	L	Deficit node
	Influences (if simulated)	n/a	
Frequency	Levels of service / drought trigger crossings	H	Demand Saving Index
	Failures (i.e. emergency storage / dead water)	H	Bough Beech Reservoir (Dead Water). Defined in config file within model simulator.
Analyser outputs	Deployable output	H	Determined in post-processing stage of WRSE simulator

Table 10 Key regional options to consider (where known) through the model build process

Key regional options	Description
Bulk export to South East Water (from Bough Beech to Riverhill)	Options included: - 2.5 Ml/d in average conditions and 9 Ml/d at peak, from 2042 (this formed part of SES Water's preferred plan at WRMP19). - 10Ml/d at average and 15Ml/d at peak.
Bulk import from Thames Water (from London WRZ to SES Water at Merton)	Options included: - 5Ml/d (maximum existing capacity requiring no mains upgrade works). - 15Ml/d at average and peak. - 30Ml/d at average and peak.
Bulk import/export from/to South East Water (RZ2 – Maidenbower/Whitely Hill) to/from SES Water (Outwood PS)	Options included: - 5Ml/d at average and peak. - 10Ml/d at average and peak.
Bulk imports from Thames Water (Shalford WTW, Guildford WRZ) to SES Water (Effingham SR, East	10Ml/d at average and peak.

Key regional options	Description
Surrey WRZ)	
Bulk treated water export from SES Water (Bough Beech) to South East Water (Blackhurst)	Options included: - 5Ml/d at average and peak. - 10Ml/d at average and 15Ml/d at peak.
Release from Bough Beech reservoir to South East Water (Forstall, on River Medway)	Options included: - 1.5Ml/d at average and 5Ml/d at peak, resulting in 1.8Ml/d loss of ADO to SES Water. - 3Ml/d at average and 10Ml/d at peak resulting in 3.6Ml/d loss of ADO to SES Water.

6. Model build

This section includes the key components of the model build process which has been undertaken and documented.

Network development

No prior strategic water resources model existed for the SESW groundwater network prior to this work. A detailed Miser model designed for outage assessment and operational planning was used to aid conceptualisation of the important flows and connections in a drought event. In order to reflect the different model purposes, and to enable multi-thousand year stochastic inflow series to be tested, significant simplification was necessary with respect to the Miser model.

The groundwater network is joined to the Bough Beech model in pywr (updated and reviewed separately) at runtime in order to simulate conjunctive use across the SESW system. Figure 1 shows the fully developed SESW model. The groundwater network consists of:

- 12 demand centre output nodes containing a monthly demand profile peaking in July, and demand weightings derived from the Miser model.
- 7 Groundwater ADO input nodes containing maximum daily groundwater abstraction.
- 7 Groundwater PDO input nodes containing additional groundwater abstraction available during peak month demand.
- 7 WTW link nodes containing maximum daily constraints.

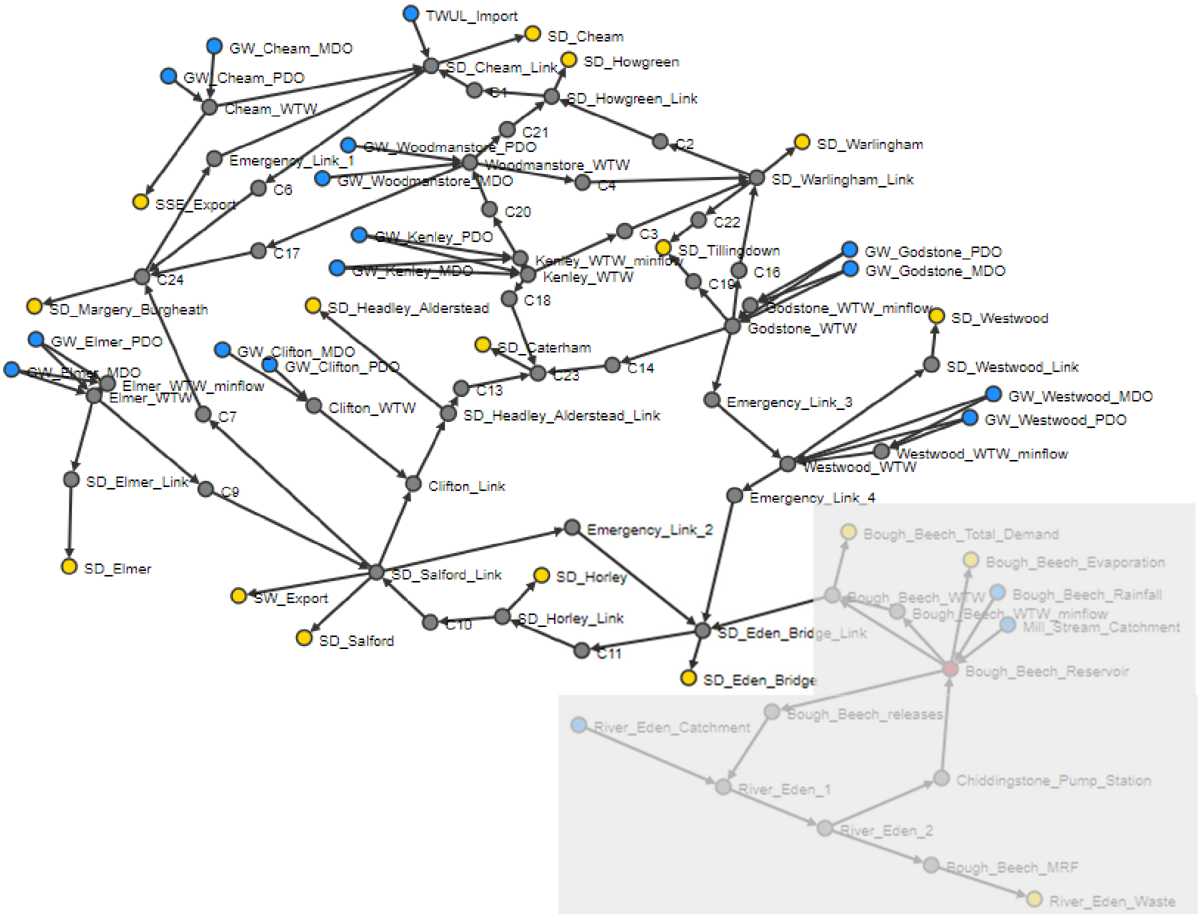

Figure 1 Final SES coupled model (Bough Beech + groundwater network). The Bough Beech part of the network has been reviewed elsewhere and is shown in grey.

Data entry

Demand centres

Following the conceptualisation of the key connectivity required and important constraints, where possible, demand centres from Miser were grouped together for efficiency. Table 11 shows the demand centre groupings identified for inclusion in the pywr model. The demand centre splits are shown for the baseline run, where total zonal demand is 160.98 Ml/d. In a DO run these demands are scaled to meet the total zonal demand, with demand centre weighting is kept constant across the zone. The monthly demand centre profile applied to Bough Beech in WRMP19 was applied to all demand centres.

Table 11 Demand Centre splits

Demand Centre	Demand required in baseline [Ml/d]
SD_Cheam	47.22
SD_Warlingham	12.15
SD_Westwood	4.45
SD_Tillingdown	3.92
SD_Caterham	7.82
SD_Headley_Alderstead	14
SD_Margery_Burgheath	12.87
SD_Horley	10.62
SD_Edenbridge	7.23
SD_Salford	7.12
SD_Elmer	22.96
SD_Howgreen	10.62

Groundwater

A groundwater deployable output review undertaken by Atkins on behalf of SES provided MDOs and PDOs for key sources in the pywr model. PDOs values were assessed for a 1 month period and are available for use in the pywr model only during the peak month demand factor (July).

Table 12 Groundwater MDO and PDO

GW node	MDO	PDO
Cheam	42.68	23.69
Kenley	21.34	20.14
Woodmansterne	29.03	2.32
Godstone	15.6	0.40
Westwood	6.77	0.49
Elmer	60.9	19.71
Clifton	2.26	0.26

WTWs

WTW costs were assigned relative costs in the pywr model based on operational pumping costs provided by SESW. These were scaled to appropriate costs in the pywr model (Table 13). Where demand can be met from multiple points of supply, the optimiser chooses supply based on least cost. A high dummy cost of 45 was applied to Clifton Lane in order to better simulate function as a seasonal/emergency use WTW.

Table 13 WTW pywr cost

WTW	Pywr cost
Bough Beech WTW	3.89
Cheam WTW	8.22
Clifton Lane WTW	~~8.86~~ 45
Elmer WTW	8.86
Godstone WTW	15.79
Kenley WTW	4.75
Westwood WTW	10.01
Woodmansterne WTW	9.13

Network constraints

The Miser model was used to identify important network constraints. Model behaviour was presented to SESW in a meeting on 10/02/2021 and an action taken away for SESW to review the constraints in the model. These constraints were confirmed on 15/02/2021 by SESW following a meeting on 10/02/2021 in which

Validation

In the absence of a prior model against which to validate behaviour, a list of model constraints and simulated flow data was provided to SESW to be checked against available operational information. Table 14 shows the summary data provided to SESW for all nodes in the model for a typical year (period 1 in Figure 2) and an extreme 1 in 500 drought event (period 2 in Figure 2). The constraints were reviewed and confirmed by Daniel Woodworth on 15/02/21, following presentation of key model behaviour in a meeting on 10/02/21 (see also Figure 4).

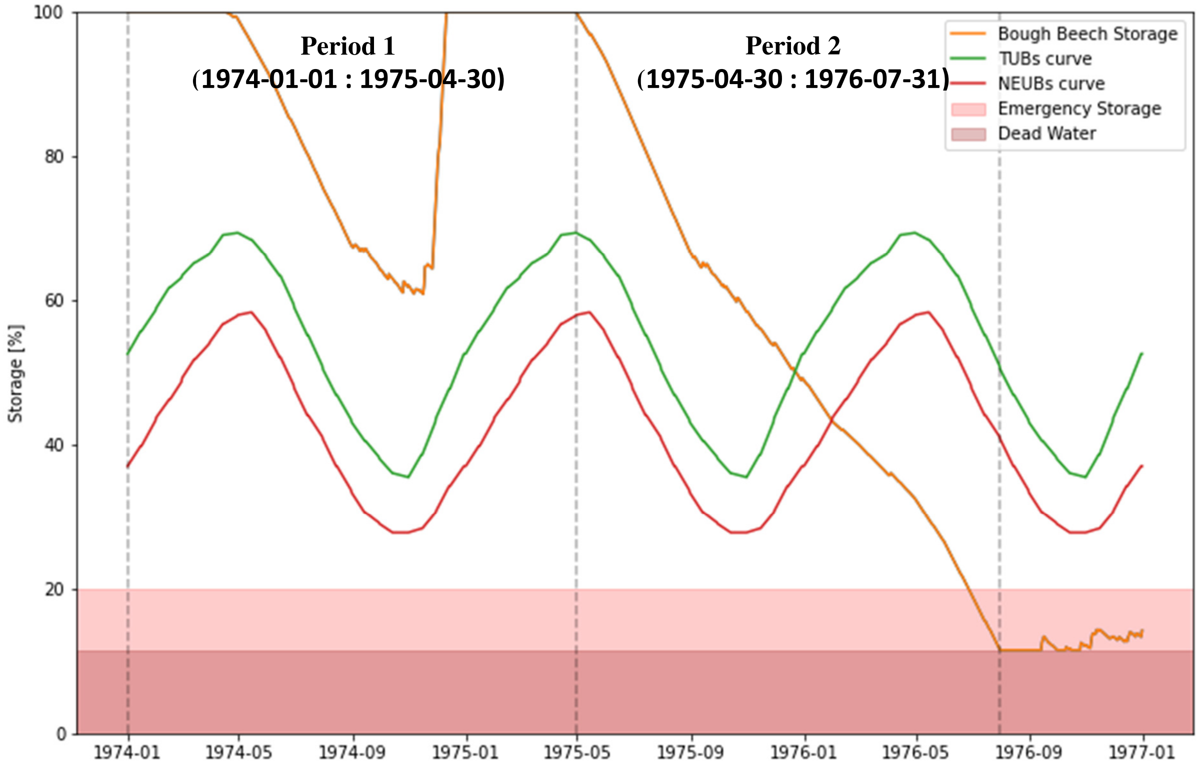

Figure 2 Storage at Bough Beech used to select two periods for model validation. Period 1 is a typical year including the winter refill period. Period 2 shows drawdown at Bough Beech during a severe drought event where EDO s would be implemented.

Table 14 Daily flow (Ml/d) through all nodes in model during typical year (period 1) and drawdown in stochastic drought event (period 2)

Node name	Constraint in model (Ml/d)	Period 1 (1974-01-01 : 1975-04-30)							Period 2: (1975-04-30 : 1976-07-31)						
		Count	Mean (Ml/d)	Min (Ml/d)	25% (Ml/d)	50% (Ml/d)	75% (Ml/d)	Max (Ml/d)	Count	Mean (Ml/d)	Min (Ml/d)	25% (Ml/d)	50% (Ml/d)	75% (Ml/d)	Max (Ml/d)
Bough_Beech_WTW	65	485	21.84	20.1	20.23	20.39	21.05	49.73	459	20.41	11.95	18.26	20.27	24.69	26.32
C1	32	485	11.66	10.49	10.66	11.1	12.55	14.89	459	12.13	10.49	10.82	11.37	13	14.89
C10	40	485	0.97	0	0	0	0.4	29.5	459	0.96	0	0	0	0.74	4.32
C11	52	485	13.38	11.96	12.03	12.15	12.52	41.54	459	13.7	11.96	12.03	12.42	15.96	17.27
C13	5.2	485	1.08	0	0	0	2.77	5.2	459	1.3	0	0	1.15	3.02	3.22
C14	8	485	5.96	0	5.2	5.69	8	8	459	7	5.2	5.69	8	8	8
C16	1.88	485	1.46	0	1.23	1.88	1.88	1.88	459	1.52	0.45	1.23	1.88	1.88	1.88
C17	30.5	485	12.23	0	11.27	11.87	14.04	18.44	459	13.46	7.86	10.98	14.54	14.66	18.44
C18	6	485	2.1	0	0	1.53	3.3	6	459	1.08	0	0	0	1.22	6
C19	None	485	4.52	0	4.43	4.46	4.62	5.62	459	4.7	4.41	4.44	4.59	4.78	5.62
C2	16	485	7.33	0	5.88	7.34	8.16	16	459	9.29	6.31	8.16	8.41	8.83	16
C20	0	485	0	0	0	0	0	0	459	0	0	0	0	0	0
C21	32	485	16.75	10.59	14.99	17.16	17.76	23.2	459	15.57	10.59	14.37	14.49	18.05	21.17
C22	None	485	0.07	0	0	0	0	4.46	459	0	0	0	0	0	0
C23	None	485	9.14	8.81	8.83	8.91	9.22	11.2	459	9.38	8.81	8.86	9.15	9.53	11.2
C24	None	485	15.05	14.49	14.54	14.66	15.17	18.44	459	15.44	14.49	14.58	15.05	15.69	18.44
C3	32	485	20.12	15.14	17.84	19.92	21.14	32	459	22.34	18.33	20.78	21.14	21.14	32
C4	16	485	0.02	0	0	0	0	3.07	459	0	0	0	0	0	0
C6	2.7	485	0	0	0	0	0	0	459	0	0	0	0	0	0
C7	30	485	2.82	0	0.45	2.85	3.22	14.66	459	1.98	0	0	0	4.19	7.83
C9	27	485	26.97	14.21	27	27	27	27	459	27	27	27	27	27	27
Cheam_WTW	90	485	43.55	42.68	42.68	42.68	42.68	56.29	459	44.52	42.68	42.68	42.68	42.68	56.29

Node name	Constraint in model (Ml/d)	Period 1 (1974-01-01 : 1975-04-30)							Period 2: (1975-04-30 : 1976-07-31)						
		Count	Mean (Ml/d)	Min (Ml/d)	25% (Ml/d)	50% (Ml/d)	75% (Ml/d)	Max (Ml/d)	Count	Mean (Ml/d)	Min (Ml/d)	25% (Ml/d)	50% (Ml/d)	75% (Ml/d)	Max (Ml/d)
Clifton_Link	None	485	17.45	15.76	15.95	17.07	18.92	21.15	459	18.09	15.88	16.96	18.6	18.96	20.06
Clifton_WTW	4.8	485	0.64	0	0	0	2.09	2.52	459	1.59	0	0	2.26	2.26	2.52
Elmer_WTW	84	485	53.82	40.22	52.93	53.15	54.07	59.9	459	54.54	52.85	53.02	53.86	54.99	59.9
Emergency_Link_1	Custom[2]	485	0	0	0	0	0	0	459	0	0	0	0	0	0
Emergency_Link_2	Custom[2]	485	0	0	0	0	0	0	459	0.93	0	0	0	0.17	5.31
Emergency_Link_3	Custom[2]	485	0	0	0	0	0	0	459	0.43	0	0	0	1.1	1.23
Emergency_Link_4	Custom[2]	485	0	0	0	0	0	0	459	1.01	0	0	0	2.62	2.96
Godstone_WTW	16	485	11.94	0	10.86	11.95	14.47	14.66	459	13.66	10.45	11.54	14.5	15.57	15.6
Kenley_WTW	45	485	22.22	21.14	21.14	21.14	21.14	38	459	23.42	21.14	21.14	21.14	21.14	38
River_Eden_1	None	485	195.36	16.82	32	86.82	278.62	1228.38	459	22.05	0.14	6.05	17.97	29.79	160.66
River_Eden_2	None	485	195.36	16.82	32	86.82	278.62	1228.38	459	22.05	0.14	6.05	17.97	29.79	160.66
SD_Cheam_Link	None	485	55.21	53.17	53.34	53.78	55.68	67.66	459	56.64	53.17	53.5	55.23	57.57	67.66
SD_Eden_Bridge_Link	None	485	21.84	20.1	20.23	20.39	21.05	49.73	459	22.35	18.42	20.23	20.88	26.08	26.32
SD_Elmer_Link	None	485	26.84	25.85	25.93	26.15	27.07	32.9	459	27.54	25.85	26.02	26.86	27.99	32.9
SD_Headley_Alderstead_Link	None	485	17.45	15.76	15.95	17.07	18.92	21.15	459	18.09	15.88	16.96	18.6	18.96	20.06
SD_Horley_Link	None	485	13.38	11.96	12.03	12.15	12.52	41.54	459	13.7	11.96	12.03	12.42	15.96	17.27
SD_Howgreen_Link	None	485	24.07	22.45	22.65	23.2	25.52	27.84	459	24.87	22.45	22.86	24.97	26.59	27.84
SD_Salford_Link	None	485	27.94	27	27	27	27.4	43.91	459	27.96	27	27	27	27.74	31.32
SD_Warlingham_Link	None	485	21.6	16.19	19.72	21.14	21.88	33.41	459	23.87	20.21	21.88	22.66	23.02	33.41
SD_Westwood_Link	None	485	5.2	5.01	5.03	5.07	5.25	6.38	459	5.34	5.01	5.04	5.2	5.43	6.38
Westwood_WTW	8	485	5.2	5.01	5.03	5.07	5.25	6.38	459	6.35	5.01	5.05	5.43	8	8
Woodmansterne_WTW	45	485	29	23.58	29.03	29.03	29.03	29.03	459	29.03	29.03	29.03	29.03	29.03	29.03

[2] Emergency links are only enabled when Bough Beechs is below the NEUBs control curve.

Deployable output

Scottish DO runs using the 19,200 year' stochastic inflow series were undertaken as part of model validation stage. The return period of demand centre deficits (i.e. failure in the model to meet the demand requested by demand centres) was tracked for each demand step in the model. Figure 3 shows that as demand is pushed higher, the first demand centres which fail to meet demand more frequently than 1 in 500 years are at Horley and Edenbridge (between 185 – 190 Ml/d).

To fully meet demand, Horley and Edenbridge demand centres require supply from Bough Beech reservoir. When Bough Beech reaches deadwater deficits occur at these demand centres because demand cannot be fully met from elsewhere. System-wide deployable output is therefore constrained by the resilience of Bough Beech reservoir.

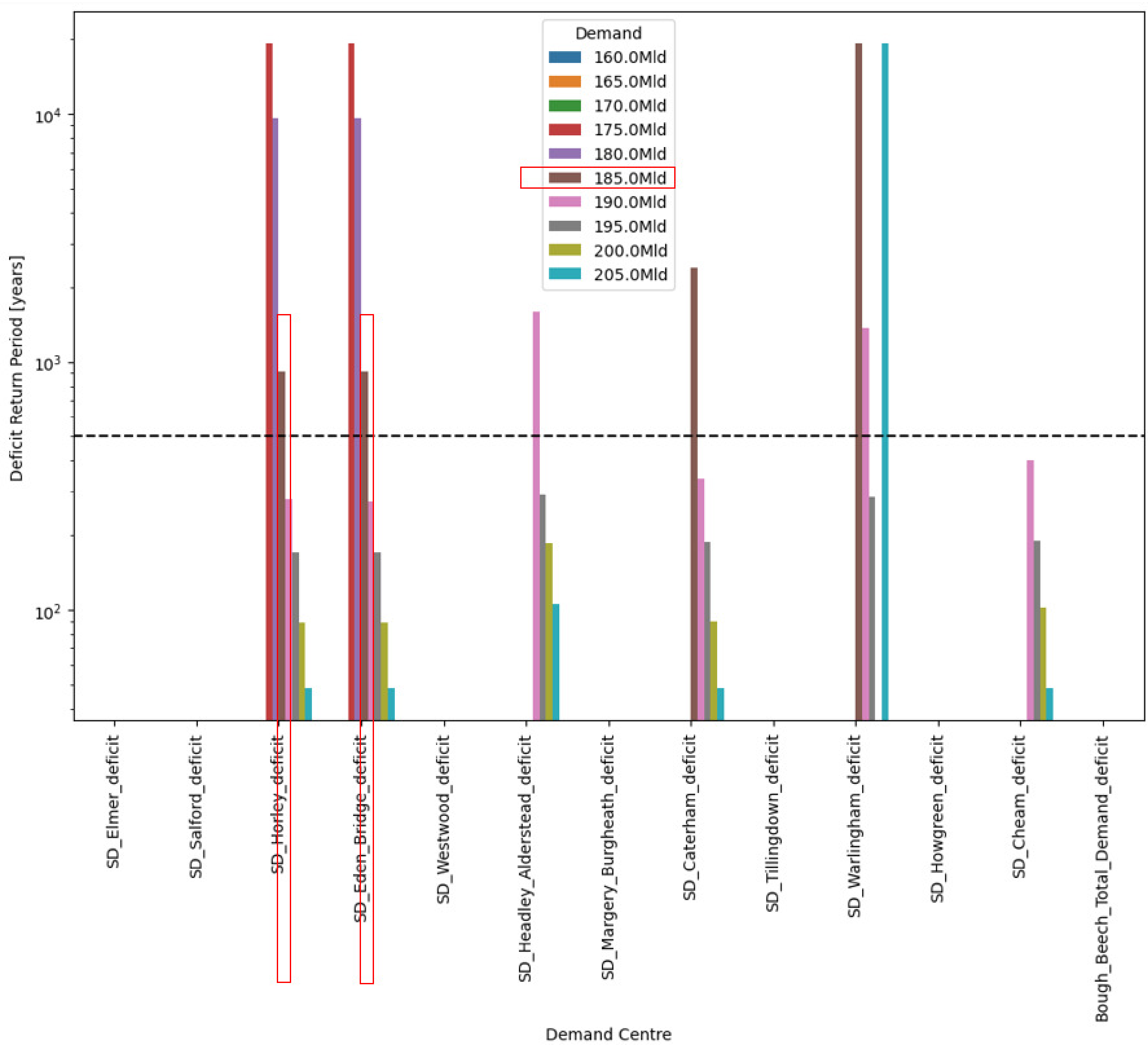

Figure 3 Return period of demand centre deficit. 1 in 500 year level shown as dashed line. Between 185 – 190 Ml/d

Figure 4 displays the model behaviour during a drought event in the key DO defining region of the model (Bough Beech area and associated demand centres). In a typical winter (e.g. Jan 1975) Bough Beech refills completely. When Bough Beech is full the model supplies other areas of the network in addition to Eden Bridge and Horley (note flow through link C10 in January 1975). Once Bough Beech has begun drawing down, storage is conserved by supplying only Eden Bridge and Horley from Bough Beech. In the example shown Bough Beech does not refill in the winter of 1975, and Bough Beech crosses the NEUBs trigger in February 1975. At this point the 'emergency links' are enabled, allowing limited supply from Elmer, Westwood and Godstone to partially meet supply at Eden Bridge and Horley via the emergency links. Constraints and required demand elsewhere in the model limit the supply available from emergency link 2 and emergency link 4 to approximately 5 Ml/d and 3 Ml/d respectively (see Table 14).

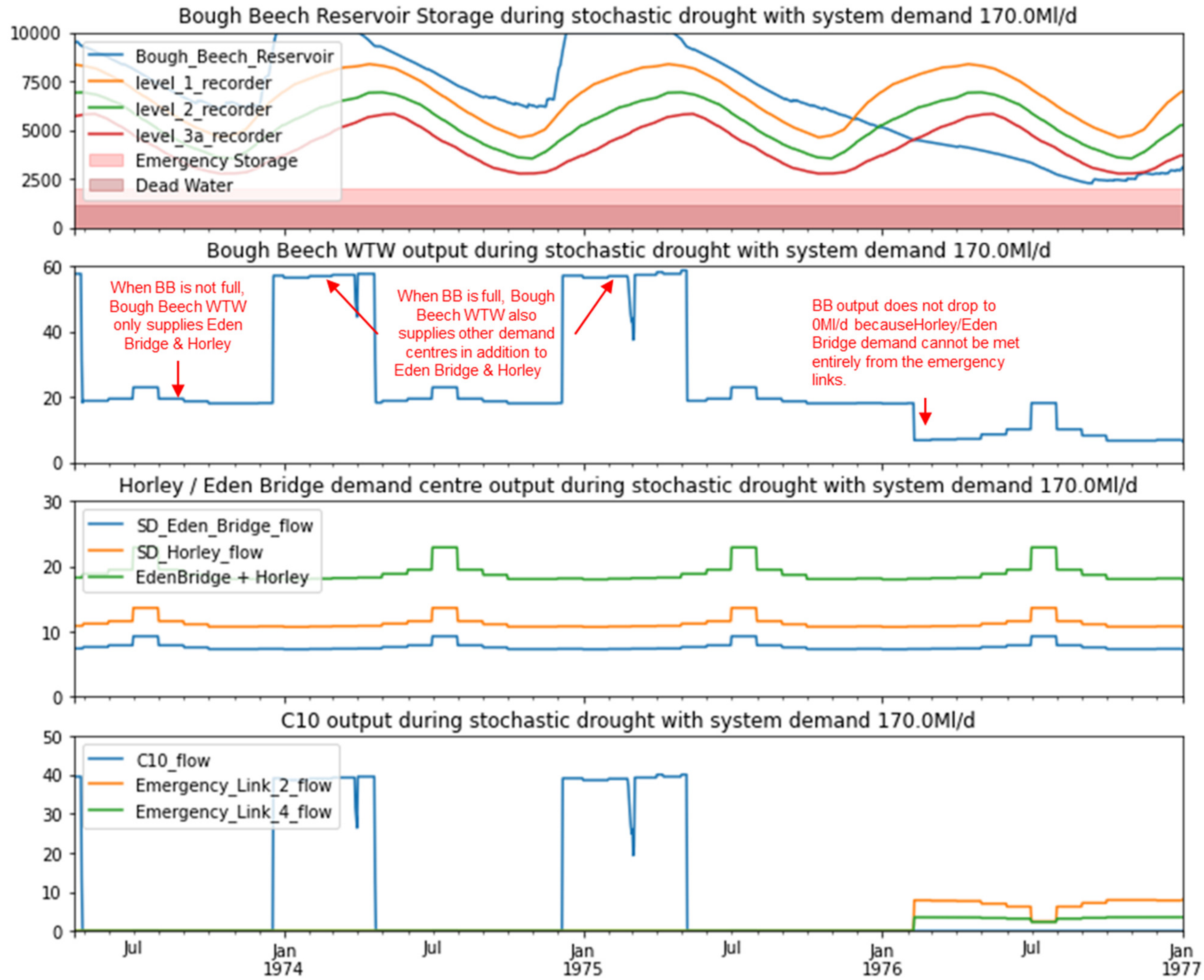

Figure 4 Validation of model behaviour in the Bough Beech area during an example stochastic drought event

7. Model development checklist

The model checker will run through a series of checks to ensure that the information from the company models have been transferred across correctly to PyWR. The tables below provides a checklist against which the checker can work through the model at different stages of the model build process.

The checker should also undertake a consistency check with other sub-models in collaboration with the Technical Working Group.

Table 15 Model build checklist

Build stage	Component	Check status	Date	Check description
Validation	Network review and constraints	Comments addressed	05/11/2020	AG reviewed model conceptualisation. Identified constraints to add and simplifications to representation of ADO/PDO nodes.
Validation	Model behaviour	Comments addressed	26/11/2020	AG reviewed model conceptualisation again with final comments made
Validation	Coupling with Bough Beech	Complete	10/02/2021	TG provided model outputs for SESW to review internally

Table 16 Model build detailed checklist

Check Area	Description	Check Date	Checker comments	Modeller responses
Connectivity	Comparing against the model conceptualisation has the Pywr model been put together properly? Are the links flowing in the correct direction? Are there any inline input or output nodes?	05/11/2020 (AG)	Bough Beech WTW is fed from a reservoir. No need for an ADO/PDO node.	TN - Removed, node changed to output and network constraint added
		05/11/2020 (AG)	Link from Elmer WTW to Elmer is the wrong way around. Otherwise SD Elmer will be in deficit	TN - Switched
		05/11/2020 (AG)	You are missing links and link nodes between Cheam DC and Margery DC as per my schematic.	TN - Added
		05/11/2020 (AG)	Please remove link between Godstone WTW and Westwood. There is no connection	TN - Removed
Demands and Aggregation	Have the demands nodes been included correctly? Have the demands profiles been built up correctly? Have demand centres been aggregated correctly? Has the aggregation obscured any network/DO constraints?	05/11/2020 (AG)	Please review and add in demand profiles and average demands provided by Jo W	TN - Complete
		26/11/2020 (AG)	Demands – I have not checked them. Could you get someone to check you have added in the demands and profiles correctly please. If you export the data you could get Jo W another to do this.	TN – Exported and sent to Jo TG – updated weightings received from Jo, these were tested but not included in the final model as it did not improve results.
Inputs and Aggregation	Same as above but for inputs.	05/11/2020 (AG)	I don't think you need an ADO-PDO node like for Southern Water as these are static ADO-PDOs,	TN – Kept in. See RD

Notes for Reviewers:

1. *Please enter the received and forwarded dates and indicate whether or not there are remarks/comments made.*
2. *Each reviewer should use a different colour ink or otherwise clearly identify his/her annotation of a circulation copy.*
3. *On completion of the review please record your conclusions, sign-off the review & return the review package to the nominated person.*

DOCUMENT REVIEW SHEET	**Sub-system**	SES Water
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Check Area	Description	Check Date	Checker comments	Modeller responses
			not dynamic. If you ask Adam he can show you how he added them in to the other Southern models.	
WTWs	Have any WTW nodes been correctly configured? Max and min flows? Any other capacity constraints?	05/11/2020 (AG)	Godstone will require a profile as it is shut for 6 weeks from Dec – Jan.	TN – Outstanding TG – Not included in DO runs Confirmed with SES Water that Godstone will be operated to be on all the time in the future.
		26/11/2020 (AG)	I can't see the WTW constraints on the table for Woodmansterne (45), Bough Beech (65), Kenley (45), Westwood (8). Please make sure you have all of them I as per my schematic.	TN -Updated
		26/11/2020 (AG)	As discussed – please provide a BB output of 26.1 Ml/d as a max capacity, for the validation. Then try 18.26 Ml/d for validation. Actual capacity is 65 Ml/d	TN -Updated
		26/11/2020 (AG)	Woodmasterne WTW – can you please make it 45 rather than 50 Ml/d please.	TN - Updated
Reservoirs	Have any reservoir nodes been correctly configured? Max and min volumes? Any other capacity constraints? Compensation flows? Control curves and abstraction limits? Abstractions licences?			
Groundwater	Have any groundwater nodes been correctly configured? Max and min flows? Any varying DO constraints? Abstraction licences?	05/11/2020 (AG)	Please add ADO-PDO information as agreed with Vicky. You should be able to link this to each WTW. Remember PDO is constrained based on a fixed number of weeks and fixed period as agreed with Vicky.	TN - Complete

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Check Area	Description	Check Date	Checker comments	Modeller responses
				TN – VC confirmed that no annual, daily or group licenses required for groundwater abstractions. Abstractions constrained by MDO/PDO before licence.
Network Constraints	Have the network capacity constraints been correctly put into the model? Max and min flows on pipework? Any pumping stations?	05/11/2020 (AG)	You have no or very little link node constraints in the model? Please add them in based on my schematic. These should always be the coloured number. The exception is Cheam DC to Margery DC which is 2.7 Ml/d, and Salford to Margery Heath which is 20 Ml/d	TN - Added see table and new schematic
		05/11/2020 (AG)	Kenley WTW to WoodmansterneWTW – please set this link to zero with the addition of a link node.	TN - Added
		05/11/2020 (AG)	The link from Salford to Margey will need to be linked to the drought trigger curve on bough beech reservoir. When reservoir goes below top trigger, this flow reduces	TN – post coupling action for TG. TG - Added
		26/11/2020 (AG)	C12 is 4.8, not 48	TN - Updated
		26/11/2020 (AG)	C16 should be 1.88, not 1.38	TN - Updated
		26/11/2020 (AG)	You are missing the capacity between Woodmansterne WTW and How Greene of 32 Ml/d. Please see my schematic.	TN - Updated
		26/11/2020 (AG)	Make C1 32 Ml/d	TN - Updated
		26/11/2020 (AG)	C19 – has no upper constraint. Can you remove it please.	TN - Updated

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Check Area	Description	Check Date	Checker comments	Modeller responses
Licences	Have all the licences been applied in the model? Any group licences? Refresh dates? Volumes?			
Custom Parameters	Is the code readable and properly notated? Does it run and have the intended effect?			
Costs	Do the costs on nodes follow a convention? Are any deviations commented properly in the JSON file?	05/11/2020 (AG)	Clifton will need a really high dummy cost as it is a seasonal / emergency WTWs	TN - 500 added on WTW
		05/11/2020 (AG)	Please add costs based on those provided. If unclear just ask.	TN – WTW costs added from RD processing. Links not given cost.
		26/11/2020 (AG)	Clifton WTW and the Warlingham_Link to ST_Tillingdown edge needs a very high dummy cost as they are rarely used. This is denoted by a * on my schematic, although it wasn't very clear I admit.	TN - Updated
		26/11/2020 (AG)	SD Caterham runs the risk of being an inline node as there is a reverse main back to Headley Alderstead. Is it easy enough to do this? The reverse main has no limit but isn't operational at the moment so I wouldn't put it in but we may need to add it in later. So having an inline node wouldn't be good	TN – Pulled SD Caterham out for future
Naming Conventions	Are nodes and parameters named in an understandable manner?	26/11/2020	Change names in pywr to those in JW sheet	TN - Updated
Validation	How does the model perform against the validation criteria? This will be looked into in more detail during the review, however, at this stage the checker will be looking to see that the model meets the criteria and that there's understanding of the differences from it.			
Other comments				

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Check Area	Description	Check Date	Checker comments	Modeller responses

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8. Model Reviews

Internal Model review

Groundwater network conceptualisation was checked by Andy Gill on 05/11/2020 and 20/11/2020. The coupled model was validated and reviewed with input from SESW over a series of meetings in February 2021 (10/02/21 & 19/02/21), with sign off confirmed on 26/02/2021.

Technical Working Group Model review

No further comments provided at this stage