GARD response to Ofwat consultation on Gate 2 decisions

Volume 2 - Addendum to GARD response to Thames Water's consultation on draft WRMP24

Review of WRMP aspects related to Pywr model output

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Addendum to GARD response to TW draft WRMP24

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GARD's response to the consultation on Thames Water's draft WRMP24 was incomplete for various topics that were dependent on receipt of Thames Water's new Pywr model output, as requested through EIR-22-23-390 on 12th December 2022. The requested data were not received in full until 22nd March 2023, the day after the WRMP consultation closed. Therefore, this Addendum to GARD's WRMP response covers the following topics:

- Review of validation of Pywr and GARD modelling, using previous Thames Water's previous WARMS2 modelling as a benchmark
- Review of validity of stochastically generated river flow data
- Review of Abingdon reservoir deployable output (DO) and drought resilience
- Review of Severn to Thames Transfer (STT) deployable output

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1. Validity of modelling and stochastic data

Pywr model validation

When comparing Pywr modelling with WARMS2 modelling using the same historic river flow data, Thames Water's description of "a very close match" is not justified. There is a large difference in modelled London storage drawdown in the critical 1934 drought. 12

In critical droughts there is a very poor match between WARMS2 historic simulations and Thames Water's Pywr output when it uses different historic flows from the same hydrological model that generated the 19,200 years of stochastic river flow data. For example, the Pywr maximum London reservoir drawdowns in the droughts of 1933-34 and 1943-44 were about 25,000-30,000 Ml less than the WARMS2 modelled drawdowns, equivalent to over-estimating the London deployable output by about 50-60 Ml/d. 13

The main reason for the poor fit between Pywr and WARMS2 modelling is the large differences between the WARMS2 historic flows and the historic flows generated by the hydrological model that created the stochastic flow data. When simulating naturalised Teddington flows, the flows used in the Pywr model grossly overestimate winter flow recovery during the 2-year droughts of 1933-34 and 1943-44. The WARMS2 modelling of the naturalised flows is a much better fit to the naturalised gauged flows. 14

The Pywr model over-estimation of winter flow recovery after droughts has profound implications for assessing the deployable output of Abingdon reservoir and STT options:

- For Abingdon reservoir, the over-estimation of winter flow recovery disguises the reservoir's lack of resilience in long duration droughts. 18
- For the Severn to Thames transfer, over estimation of winter flow recovery in the Thames diminishes the benefit of the unsupported transfer

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Validity of stochastic river flow data

In addition to the over-estimation of winter flow recovery for stochastic flows, we have major concerns about the use of the 48 year period 1950 to 1997 as the basis for generating 19,200 years of stochastic river flows. 18 The use of historic climate data only for 1950-1997 means the exclusion of the three most severe droughts of the past 100 years (1921, 1933-34 and 1943-44), as well as the past 25 years of most rapid climate change.

Analysis of Pywr model output shows that about 75% of all severe droughts in the 19,200 year record occur in the calendar year 1976, which is the most severe drought in the historic record for 1950-1997. It appears that the method of generating the 19,200 years of flow data replicates the pattern of droughts in the historic record. The historic drought of 1975-76 was not particularly severe because it ended in September 1976, whereas the 21 droughts of 1921, 1934 and 1944 extended into the early winter. The historic drought of 1975-76 was not preceded or followed by dry years. Therefore, the Pywr modelling cannot generate the type of long drought that tests the resilience of Abingdon reservoir.

This problem was identified in WRSE's method statement on stochastic climate data in 2020. They advised that "*Companies may complement the stochastic dataset with drought artificial weather series to represent prolonged drought events (which the stochastic generator will not have been trained on)*". TW have not followed that advice 22 and the impact of long duration droughts on the deployable output of Abingdon reservoir has not been assessed in the WRMP or Gate 2 reports.

Analysis of naturalised flows in the Thames since the 1880s shows that that low flows have increased steadily and significantly over the past 140 years, which have also been the period of rapid global temperature increases. This suggests that selection of different 23 periods of historic climate data as the basis for generating the stochastic data could have a material effect on the stochastic flows generated by the hydrological modelling.

In our opinion, the base historic data should have included all available climate data since 1997, thereby covering the recent period of rapid climate change

Our conclusion from review of the validity of the stochastic data is that the stochastic river flow datasets used to determine deployable outputs for existing supplies and strategic 24 resource options in Thames Water's plan are not fit for purpose.

Validation of GARD's modelling

When using the same historic river flows as WARMS2, GARD's modelling almost exactly matches the WARMS modelling (a much better fit than the Pywr modelling of the 1934 25 drought).

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When using the same stochastic flows from the 19,200 year record, GARD's model is
generally quite a close match to the Pywr modelling. In view of the differences between
Pywr and WARMS modelling using historic flows, differences between the GARD
modelling and Pywr modelling seem likely to be due to flaws in the Pywr modelling. For 27
example, we have identified that the Pywr model simulates the West Berkshire
Groundwater Scheme incorrectly.

2. The deployable output (DO) of Abingdon reservoir

Thames Water's assessments of deployable output without climate change

Thames Water calculates deployable outputs for London by using the Pywr model to
simulate the frequency of London reservoir storage falling into the Level 4 emergency 29
storage zone. The London demand that causes only 38 failures in 19,200 years of
simulation is then the 1:500 year deployable output (19,200 ÷ 500 = 38.4). We agree that
this is the correct way of determining deployable output.

However, on some occasions droughts in which failures extend into two different years
have been counted as two failures instead of one. This error causes the deployable output
of the Abingdon reservoir (without climate change) to be over-estimated by 6 Ml/d for 30
the 150 Mm^3 reservoir and 4 Ml/d for the 100 Mm^3 reservoir.

There is another serious Pywr modelling error in assuming that, when refilling Abingdon
reservoir, the minimum required flow (MRF) in the River Thames at Culham is set at only
450 Ml/d instead of the true value of 1450 Ml/d. TW recognises this error and provides a
correction in an appendix to the modelling technical report, showing that it only reduces 31
deployable output by 2 Ml/d. Our modelling shows a similar DO reduction due to this
error, when simulating stochastic versions of the 1975-76 drought.

Although the Culham MRF error does not appear to have a big impact on Abingdon
reservoir deployable output, it can greatly affect the speed of reservoir refilling after
droughts. The main Gate 2 report for Abingdon reservoir claims that the reservoir refills in
5 months after extreme droughts, showing an example of recovery after a stochastic 32
version of the 1976 drought. However, the historic drought of 1976 was followed by a wet
winter, so that also tends to be the case with stochastic versions of the 1976 drought.

For some of the relatively few droughts in the stochastic record which are not versions of
the 1976 drought, GARD's modelling shows that Abingdon reservoir is less than half full at 32, 36
the start of the next summer and vulnerable to failure if another dry summer follows.

Thames Water's assessment of deployable output with climate change

In the main WRMP report, the widely quoted deployable outputs for Abingdon reservoir 33
are 271 Ml/d for the 150 Mm^3 reservoir and 185 Ml/d for the 100 Mm^3 reservoir. These

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are TW's assessments for the '<u>median'</u> climate change scenario. However, TW's preferred plan assumes the '<u>high'</u> climate change scenario, so the assessed DOs for Abingdon reservoir should also be for the 'high' climate change scenario.

Using TW's figures, the deployable output of the 150 Mm^3 reservoir with 'high' climate change allowance should have been 252 Ml/d, not 271 Ml/d. The equivalent deployable output of the 100 Mm^3 reservoir with 'high' climate change should have been 169 Ml/d, not 185 Ml/d. This is another serious flaw in Thames Water's deployable output assessment for Abingdon reservoir. 34

Reservoir resilience in long duration droughts

In GARD's response to TW's WRMP19, we showed that the stochastic flow records in use at that time (based on historic flows including the long droughts of 1921, 1934 and 1944) included a number of droughts in which the 150 Mm^3 Abingdon reservoir was only able to deliver deployable outputs of about 100 to 150 Ml/d. TW's method of assessing deployable outputs in WRMP19 was unable to take account of these droughts, so there was no recognition that Abingdon reservoir had poor resilience to long duration droughts. 34

The new Pywr modelling of the full 19,200 year stochastic record and TW's method of assessing deployable output has the capability of assessing the resilience in long droughts, but the method of generating the stochastic flows has excluded long droughts from the record, with most of the stochastic droughts being based on the relatively short drought of 1975-76. 35

However, a few of the droughts in the stochastic record, not based on 1976, do show some lack of resilience in long droughts, even though they were not severe or numerous enough to influence the DO assessment. 35

As already mentioned, TW have not followed WRSE's advice by generating artificial long droughts "*to represent prolonged drought events (which the stochastic generator will not have been trained on)".* We have provided an example of this, with the historic drought of 1933-34 being preceded by the flows of the moderately dry years 1996-97. This shows there would be catastrophic failure of London's supplies during such a drought and the deployable output of the 150 Mm^3 Abingdon reservoir, without climate change, would fall from 285 Ml/d to 163 Ml/d. 37

We conclude that, if proper consideration is given to the occurrence of long duration droughts, the deployable output of Abingdon reservoir would be far less than that claimed by Thames Water, perhaps in the region of only 50% of the claimed amounts. 38

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Allowances for dead and emergency storage

In our main response to the consultation on TW's WRMP24, we proposed that TW's proposed 6% emergency storage allowances for Abingdon reservoir should be increased to be in line with the emergency storage allowance in other major UK reservoirs. It is also 39
vital that all of the water in emergency storage should be of sufficiently good water quality to be useable, recognising the increased threat of algal blooms and poor reservoir water quality in severe droughts, especially with climate change.

Therefore, we propose that the allowances for dead and emergency storage should be:

- Dead water should be based on an average residual water depth of 5m, not an average depth of 2.5m as proposed by TW 40
- Emergency storage should be 15% of live storage to be in line with Llyn Brianne, Clywedog and the Welsh Dee regulating reservoirs

With these proposals for dead storage and emergency storage, GARD's modelling shows that the deployable outputs for the 150 Mm^3 and 100 Mm^3 reservoir would reduce by 44 42
Ml/d and 25 Ml/d respectively.

Conclusions from our review of Abingdon reservoir deployable output

In our opinion, the deployable output of Abingdon reservoir has been grossly over-estimated for WRMP24 and the Gate 2 reports. In addition to failure to properly consider 43
resilience to long duration drought, we have found the following flaws in Thames Water's deployable output assessments:

	150 Mm^3 reservoir	100 Mm^3 reservoir
DO with climate change as WRMP24	271 Ml/d	185 Ml/d
Less Double counting of droughts	-6 Ml/d	-4 Ml/d
Wrong value of Culham MRF	-2 Ml/d	-1 Ml/d
Wrong climate change scenario	-19 Ml/d	-16 Ml/d
Inadequate dead & emergency storage	-44 Ml/d	-25 Ml/d
Corrected Deployable Output	**200 Ml/d**	**139 Ml/d**

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GARD proposed changes to reservoir DO (excluding long drought resilience)

In addition, we consider that the deployable output of Abingdon reservoir will be a lot less than shown in the table above, perhaps only half these values, when proper consideration has been given to the likelihood of a sequence of dry years which prevent the reservoir 41
from being full at the start of a major drought or delay its refilling after a major drought.

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2. Deployable output of Severn to Thames transfer and support sources

Conclusions from our review of Severn Thames transfer deployable output

Thames Water's Pywr modelling has grossly under-estimated the deployable output of unsupported STT options. Our modelling shows that the 1:100 year DO of the unsupported 300 Ml/d transfer should be 129 Ml/d compared to Thames Water's figure of about 90 Ml/d. For the 500 Ml/d unsupported transfer, we estimate the 1:100 year DO to be 182 Ml/d compared with Thames Water's figure of about 130 Ml/d. 42

Thames Water's under-estimation of deployable outputs is highly significant because the unsupported transfer would be a viable first phase of the STT, not dependent on the Minworth or Vyrnwy support sources. The additional London deployable output from unsupported transfers would allow all the Chilterns chalk stream abstraction reductions to go ahead as soon as the Severn to Thames aqueduct is built, potentially in the early 2030s. 45

The reason for Thames Water's underestimation of deployable outputs appears to be inadequacies in the stochastic river flow data which over-estimate the speed of flow recovery in the River Thames after long droughts and under-estimate the frequency of occurrence of long droughts. These deficiencies negate the unsupported STT's ability to provide substantial refill of the London reservoirs during long droughts, due to differences in geology between the Thames and Severn catchments. 45

The under-estimation of deployable outputs for the unsupported transfer will also affect the DOs for options with modest amounts of support, but the amount of under-estimation will diminish as the amount of support increases. 46

The need for Vyrnwy replacement sources

Thames Water appear to have assumed that at least 80% of the nominal support from Vyrnwy reservoir will require replacement of deployable output through new United Utilities sources. GARD's modelling shows that only about 50% replacement deployable output is needed. This would mean that the costs of STT options with Vyrnwy support may have been inflated by the cost of up to about 70 Ml/d of unnecessary replacement sources. 46

1. Introduction

1.1 Scope of this Addendum

GARD's response to the consultation on Thames Water's draft WRMP24 was submitted on the deadline date of 21st March 2023. Due to late receipt of modelling information requested on 12th December 2022, ie just before the start of the consultation period, GARD's consultation response was incomplete for various topics that were dependent on Thames Water's model output, as explained in the introduction to GARD's consultation response[1]:

> *"We will make an Addendum to this response when we have received the requested data and had time to review them and use them in our own modelling. The Addendum can be expected to cover the deployable outputs and operating costs of the Abingdon reservoir and Severn to Thames transfer options."*

Therefore, this Addendum to GARD's WRMP response covers the following topics:

- Review of validation of Pywr and GARD modelling, using WARMS2 modelling as a benchmark
- Review of validity of stochastically generated river flow data
- Review of Abingdon reservoir deployable output (DO) and drought resilience
- Review Severn to Thames Transfer (STT) deployable output
- Review of STT operational use with regard to operating costs
- Proposed additions to scope of Gate 3 investigations

The requested data were not received in full until 22nd March 2023, the day after the WRMP consultation closed. The last received data were crucial from GARD's perspective because they were needed for validation of GARD's own modelling using stochastic data – the daily time series of all Pywr modelled output for the existing London supply system, comprising 132 separate daily time series each covering the full 19,200 years of simulation.

Thames Water initially offered an extension to the consultation deadline of 5 days for GARD to review the modelling and submit an Addendum, by 10.00am on 27th March. Following negotiations, it was agreed that GARD would submit the Addendum by 30th April, with an initial submission of key findings by 14th April. Copies of the relevant email correspondence are in Appendix A.

Even with the Addendum deadline of 30th April, there has been very little time available for GARD to review the model output and its effect on the WRMP.

[1] GARD WRMP response Section 1.2, page 18

1.2 Data requested and received

The need for Pywr model output to be transparently available in time for its detailed review was flagged by GARD in its response to WRSE's emerging regional plan in March 2022[2]. In the absence of information on deployable outputs in WRSE's plan, GARD made an information request for more detail including model output on 19th January 2022 (see copy of request in Appendix B). WRSE's response was received via Thames Water on 16th February 2022, but fell far short of what was requested.

The availability of modelling data was discussed at a meeting between GARD and Thames Water on 11th April 2022. At this meeting Thames Water explained that they did not store all the data generated by Pywr modelling, so some of the data requested by GARD was not retrievable. There were also constraints due to dependency on outside consultants. However, Thames Water recognised GARD's need to receive data well in advance of the draft WRMP24, as recorded below in the meeting note (full meeting note in Appendix B):

> *"Under EIR Thames Water is not required to provide any data it has not stored. As we understand John's need for the data requested to be provided at least a few months before draft WRMP24 submission during November 2022, we will look to test our, being consultants and water companies, ability to supply.*
>
> [And in the meeting actions]

G. Need to check with consultants regarding their availability to conduct modelling . TW will check with consultants etc and respond."

There was no follow-up response from Thames Water and the matter was not pursued by GARD until the information request EIR-22-23-390 on 12th December 2022. Nevertheless, this information request could not have come as a surprise to Thames Water and it is disappointing that none of the requested information was received until 9th February 2023 and the full information was not received until the consultation closed on 21st March, 14 weeks after request EIR-22-23-390 was submitted.

[2] GARD response to WRSE emerging regional plan, Section 1.4, page 7
https://www.abingdonreservoir.org.uk/downloads/GARD%20WRSE%20final%20response%2014.3.22.pdf

2. Validation of models and stochastic data

2.1 Validation of Pywr modelling

As explained in Thames Water's response to EIR-22-23-390, the Pywr model is validated in two separate and important steps[3]:

1. Validation of the model (historical time series) using flow inputs taken directly from WARMS2. The aim of this validation step was to ascertain whether the Pywr model replicates Thames Water's WARMS2 or Aquator modelling, if using the same river flow data.

2. Validation of the model (historical time series) using flow inputs making use of hydrological models which were then used for the stochastic modelling. The aim of this validation step was to ascertain the differences in model outputs caused by differences in river flows generated by the different hydrological models.

Appendix I of the draft WRMP24, Deployable Output, provides some plots of both steps of the Pywr model validation process. The first step, using WARMS2 flows to validate the simulation of the supply system, showed only a moderately good fit between Pywr and WARMS2 modelling of reservoir drawdowns, as shown by the plot below from Figure I-6 in Appendix I:

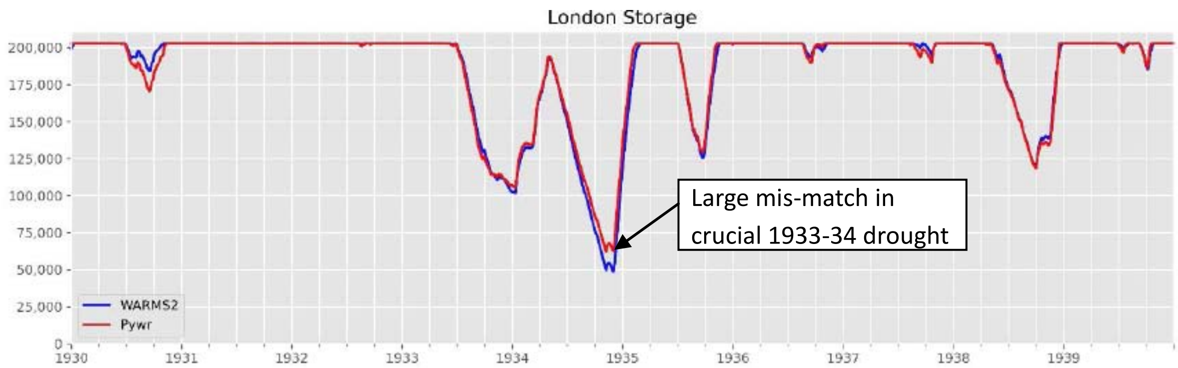


Figure 1 - TW Step 1 validation of Pywr, simulation of London storage using WARMS flows

Thames Water describes the model fit shown above as[4]:

> *"The results in Figure I - 6 for key drought periods show that the Pywr model provided a very close match to results seen in WARMS2 during this validation step."*

Thames Water's description of the modelled fits shown above as "a very close match" is not justified, bearing in mind that the two models used the same river flows as the main input data. There is a large difference in drawdown in the critical 18-month drought of 1933-34,

[3] Response to EIR-22-23-390, Item 5 (see full response in Appendix B to this Addendum)
[4] TW WRMP24 Appendix I, paragraph I.126

which casts doubts on model accuracy in other 18-month droughts

Step 2 of Thames Water’s Pywr validation used river flows from generated from historic weather using the hydrological model that generated the 19,200 years of stochastic river flow data. The Pywr modelling is then compared with the WARMS model output which used river flows generated using different rainfall data from the same historic period and the WARMS hydrological model. The resulting plots in Figure I-7 of Appendix I show large differences in modelled storages in droughts as below:

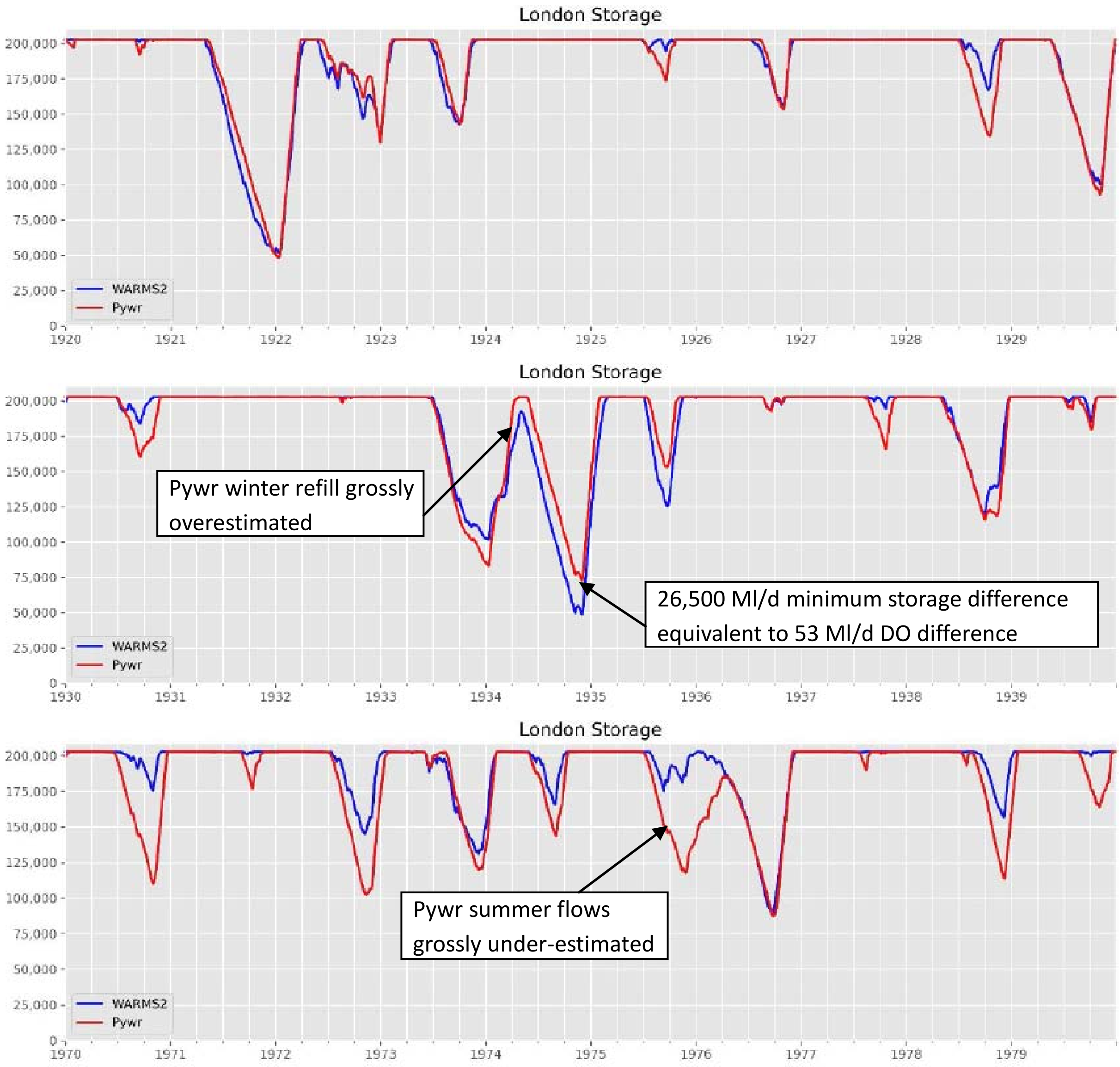


Figure I - 7: Step 2 Pywr Model Validation Plots

Figure 2 - TW Step 2 validation of Pywr, simulation of London storage using Pwyr flows

In Appendix I, Thames Water describes the validation fits above as follows[5]:

“Figure I - 7 shows validation plots for key drought periods for the fully updated

[5] TW WRMP24 Appendix I, paragraph I.126

hydrological and water resources model (run in the 'WRSE North' configuration). These plots show a close agreement between Pywr and WARMS2 outputs for key drought periods, with the revised hydrological modelling/rainfall datasets seeming to suggest greater drawdowns during some moderately dry periods. The DO calculated when the model was run was 2296 Ml/d (a figure comparable with the 2302 Ml/d WARMS2 DO). Considering the degree of change that had been undertaken and results from WRMP19 hydrological modelling, this was considered a good fit."

The fits in the maximum drought drawdowns, which Thames Water describe as "close", are mostly poor. The Pywr modelled drawdown in the severe single-year drought of 1921 was similar to the WARMS modelled drawdown, enabling Thames Water to say that there was little difference in the deployable outputs shown by each model.

However, the Pywr maximum drawdown in the severe two-year drought of 1933-34 was 26,600 Ml less than the WARMS2 modelled drawdown[6]. This is equivalent to over-estimating the London deployable output by about 53 Ml/d (in two-year droughts, the London reservoirs take about 500 days to fall to minimum storage, so the deployable output difference is roughly the storage difference in Ml divided by 500 days).

The cause of this major difference between the Pywr and WARMS modelling of droughts is the differences in modelled Teddington 'natural' flows, as shown below for the historic 1933-34 drought[7]:

[6] Pywr modelled data from Pywr output file 'New Flows Validation' and WARMS modelled data from file 'AR20-Q4-Sc1-London DO-2302', both provided to GARD under EIR-22-23-390

[7] Ibid

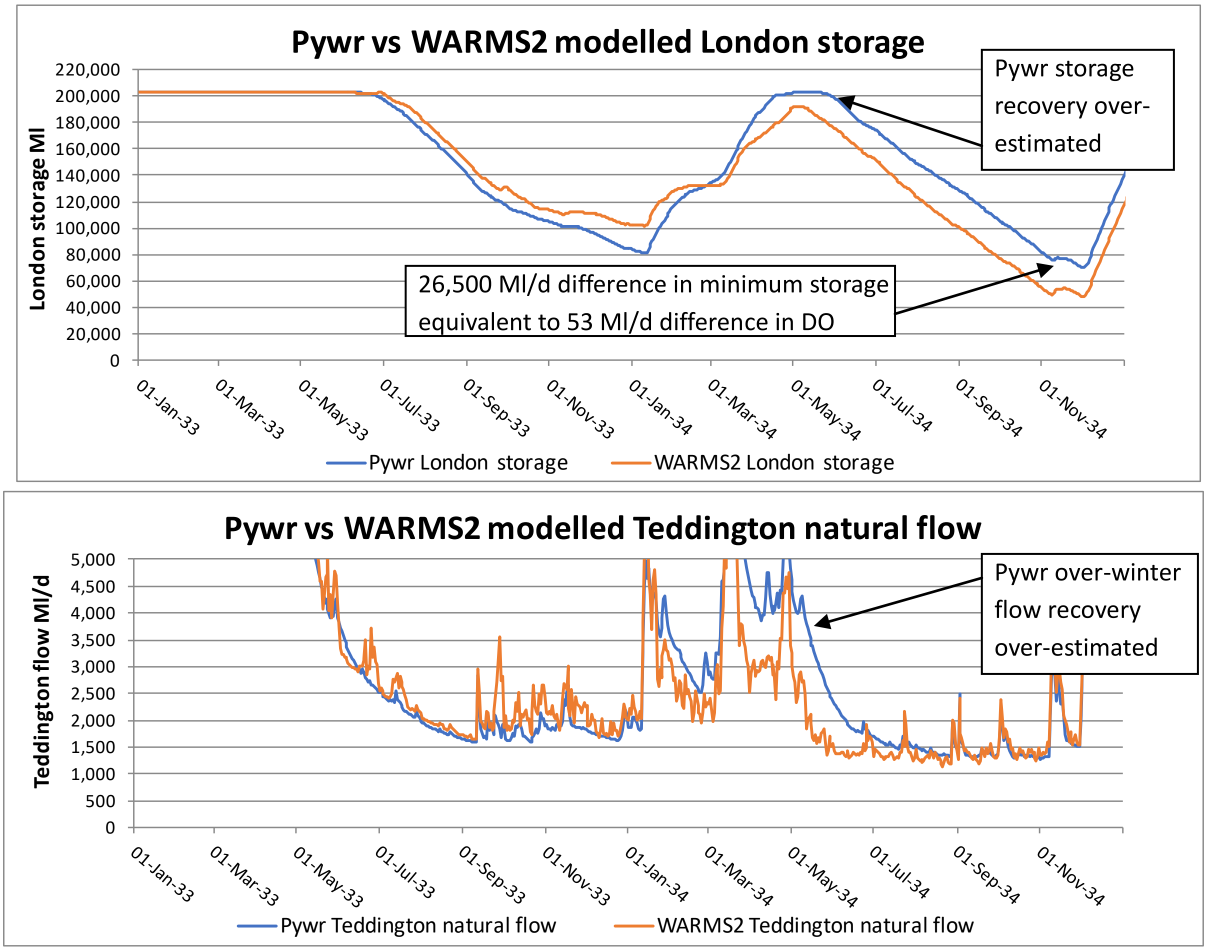


Figure 3 - Comparison of Pywr and WARMS2 modelling in 1933-34 drought

In the flows of the 2-year drought of 1933-34, Pywr over-estimates the over-winter river flow and London storage recovery, leading to a large over-estimation of residual storage and deployable output.

There is a similar picture in the major 2-year drought of 1943-44, which Thames Water did not show in Figure I-7 in Appendix I:

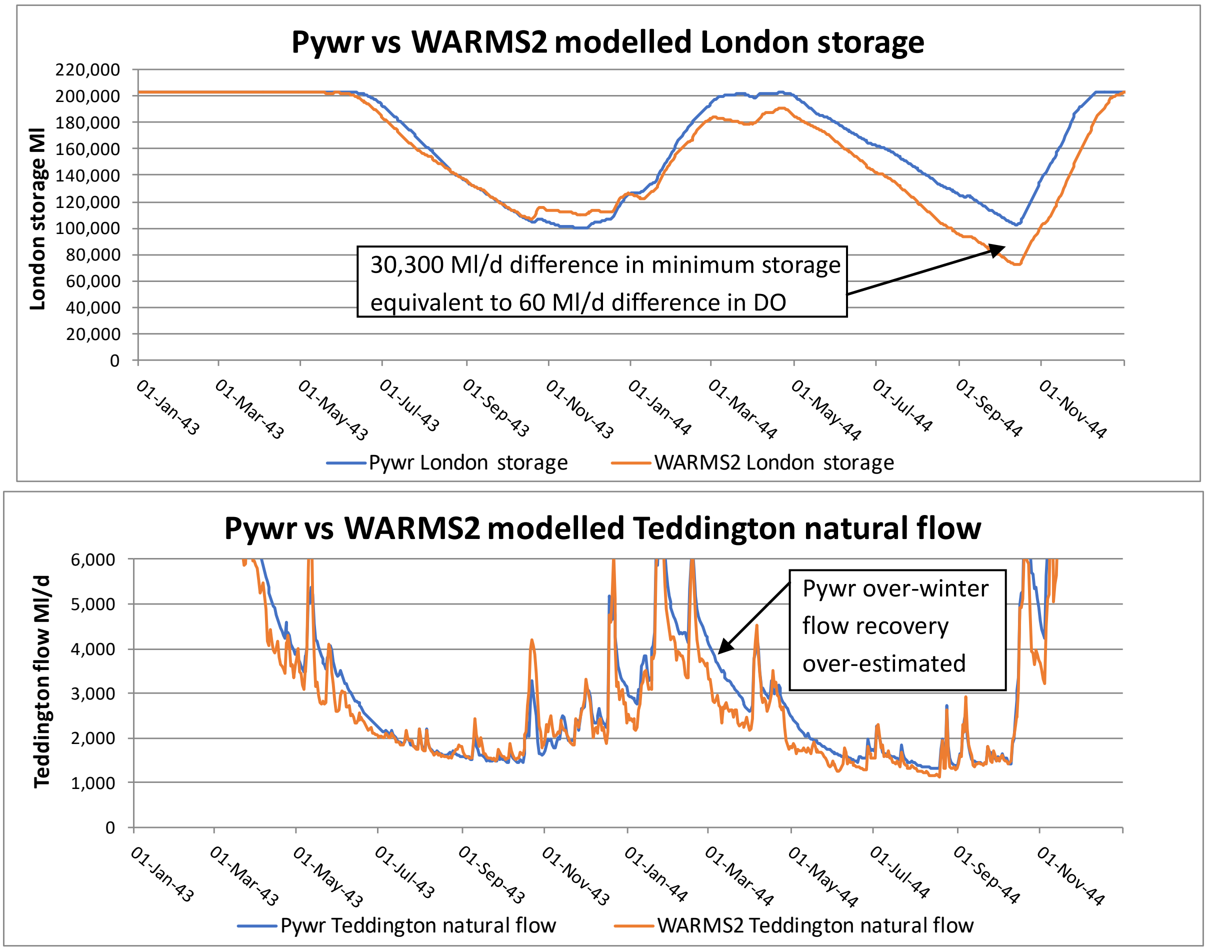
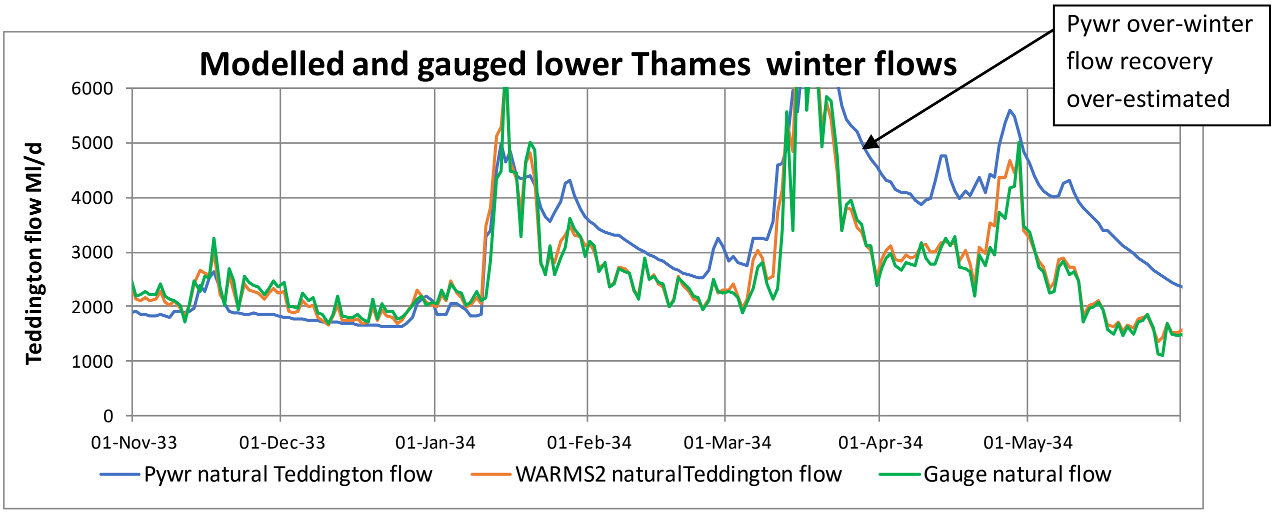


Figure 4 - Comparison of Pywr and WARMS2 modelling in 1943-44 drought

In the flows of 2-year drought of 1943-44, the Pywr model over-estimates the minimum storage by 30,300 Ml, equivalent to a deployable output difference of about 60 Ml/d. As for the modelling of the 1933-34 drought, the reason for the modelled storage differences is the differences in modelled natural flows during the winter between the two summer droughts.

The differences in modelled winter flows during 2-year droughts can be seen more clearly in Figure 5, which also shows the gauged naturalised Kingston flows, which the NRFA web-site explains are derived from the actual gauged flows by adding back all the lower Thames abstractions by Thames Water and Affinity Water[8]:

[8] NRFA naturalised daily flows at Kingston https://nrfa.ceh.ac.uk/data/station/info/39001



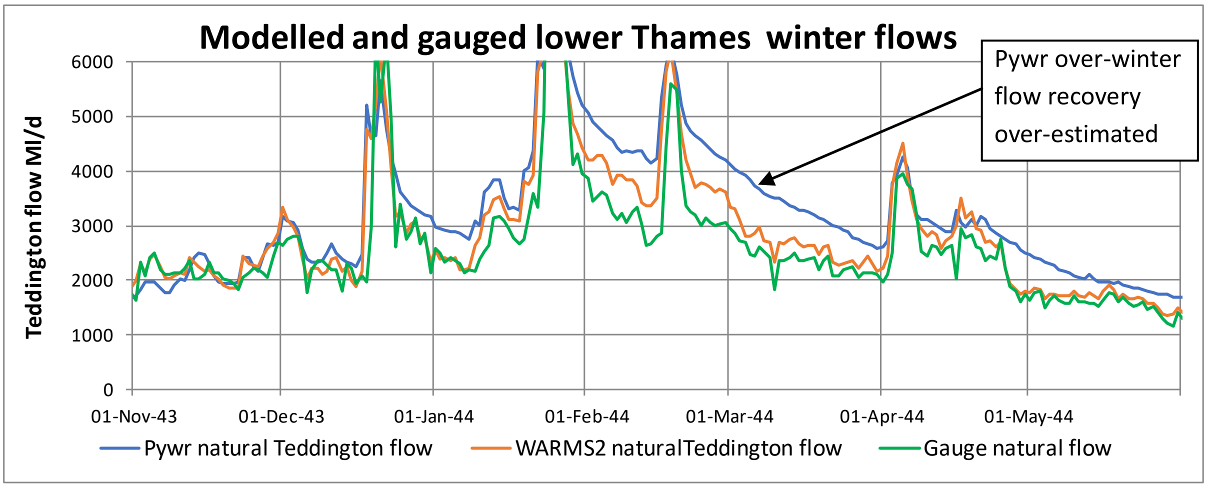


Figure 5 - Modelled and gauged natural winter flows in 2-year droughts

The Pywr model grossly overestimates the winter flow recovery during the 2-year droughts of 1933-34 and 1943-44. The WARMS2 modelling of the naturalised flows is a much better fit to the naturalised gauged flows, although there is some over-estimation of flow recovery in the winter of the 1943-44 drought.

Although the Pywr used a different version of historic rainfall data to that used in the WARMS model[9], this analysis suggests that the hydrological model used to generate river flows from climatic records provides a poor simulation of the Thames catchment response to winter rainfall occurring at the end of a long summer drought. It appears that the modelled flows used in the Pywr model may respond too quickly to the winter rainfall, not taking sufficient account of the need for groundwater level recovery before flows can recover in the chalk tributary catchments which dominate the pattern of flows in the Thames. This would have profound implications for assessing the deployable output of the Abingdon reservoir and STT options:

[9] TW WRMP24, Appendix I, paragraph I.128

- For Abingdon reservoir, the over-estimation of winter flow recovery would disguise the reservoir's lack of resilience in long duration droughts.
- For the Severn to Thames transfer, over estimation of winter flow recovery in the Thames would diminish the benefit of the unsupported transfer, when flows in the Severn recover faster than flows in the Thames, as is always the case when droughts end.

The implications of this on the deployable output and drought resilience of the Abingdon reservoir and STT options are further discussed in Sections 3 and 4 of this Addendum.

2.2 Validity of stochastically generated river flows

Overall concerns

In Section 2.1, we have demonstrated the flaws in the hydrological modelling used to generate river flows from historic climate records. In particular, the generated river flows greatly over-estimate the speed and amount of flow recovery in the intervening winters during the 2-year droughts in which London's supplies are most vulnerable. These flaws have led to the poor validation of Pywr modelling when compared to WARMS2 modelling using historic flows during the 2-year droughts of 1933-34 and 1943-44. This is shown by Thames Water's own analysis in Figures 1 and 2 and our analyses in Figures 3 to 5.

In addition, we continue to have major concerns about the use of the 48 year period 1950 to 1997 as the basis for generating 19,200 years of stochastic river flows, excluding the severe droughts of 1921, 1933-34 and 1943-44. We expressed these concerns in our response in October 2020 to WRSE's consultation on their Method Statements for preparing their regional plan, but we can see no evidence in Thames Water's WRMP that our concerns have been considered or acted upon.

In short, the use of historic climate data only for 1950-1997 means the exclusion of:

- the droughts of 1921, 1933-34 and 1943-44, the three most severe droughts of the past 100 years for London's supplies
- the past 25 years of most rapid climate change

Therefore, the period 1950-1997 is an unsatisfactory basis for generating the stochastic data, lacking both the period of extreme low flows pre-1950, with several long duration droughts, and the recent period of most rapid climate change.

Exclusion of droughts of 1921, 1934 and 1944

The exclusion of the droughts of 1921 and 1933-34 is of particular concern, because they both extended well into the winter and London reservoir storage would not have started to recover until 20th January 1922 or 5th December 1934 respectively. The most severe drought in Thames Water's selected history, 1950-1997, was 1975-76 in which reservoir levels started to recover on 23rd September 1976. The period 1950-1997 contained no severe droughts extending into late autumn/winter like 1921 and 1934, so this type of long drought is not adequately represented in the 19,200 year stochastic record. We also note that the drought of 2011-12 which extended to early 2012 is excluded from the historic base period.

The 19,200 years of stochastic river flows are generated by perturbing the weather patterns of the period 1950 to 1997. It is, therefore, inevitable that the droughts generated in the 19,200 year stochastic flow record have followed the pattern of droughts in the historic period 1950 to 1997. This is shown by the following plot taken from the report on the WRSE Regional System Simulator[10] and described *as "a heat map to more easily understand where failures occurred across the stochastic data set"*:

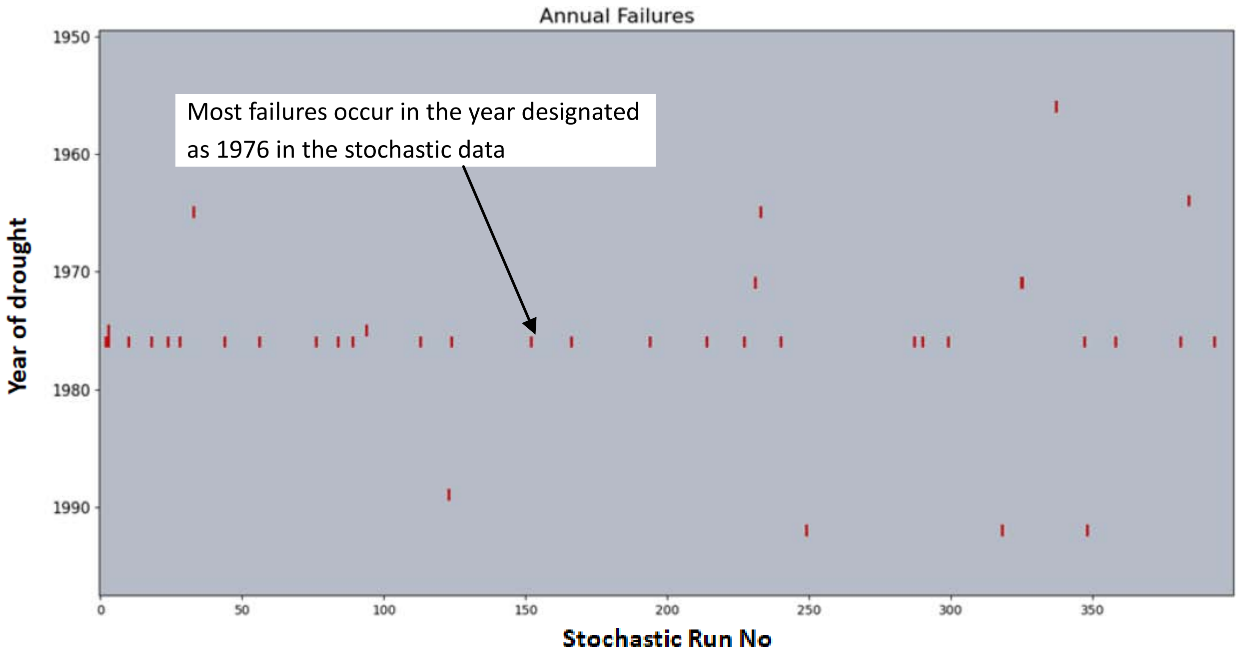


Figure 6 - 'Heat map' showing distribution of severe droughts in the 19,200 year record

This plot shows that 27 of the 37 droughts plotted on Figure 6 occurred in the modelled years 1975-76. The remaining 10 droughts occurred in lesser droughts in the historic record, like 1992. The Regional System Simulator report does not explain how the above plot was derived, but we have generated similar patterns by analysing the 19,200 years of Level 4 (ie supply failure) control line crossing data provided under EIR 22-23-390 for existing London supplies[11] and London supplies with the 150 Mm^3 Abingdon reservoir[12], as shown in Figure 7:

[10] WRSE Regional System Simulator, August 2021, Atkins, Figure 3-3
[11] Data from EIR-22-23-390 file *'tw-london-stochastic-baseline-v5 last day dy-failures.csv'*
[12] Data from EIR-22-23-390 file *'tw-sesro-150-london-stochastic-baseline-v8 last day dy-failures.csv'*

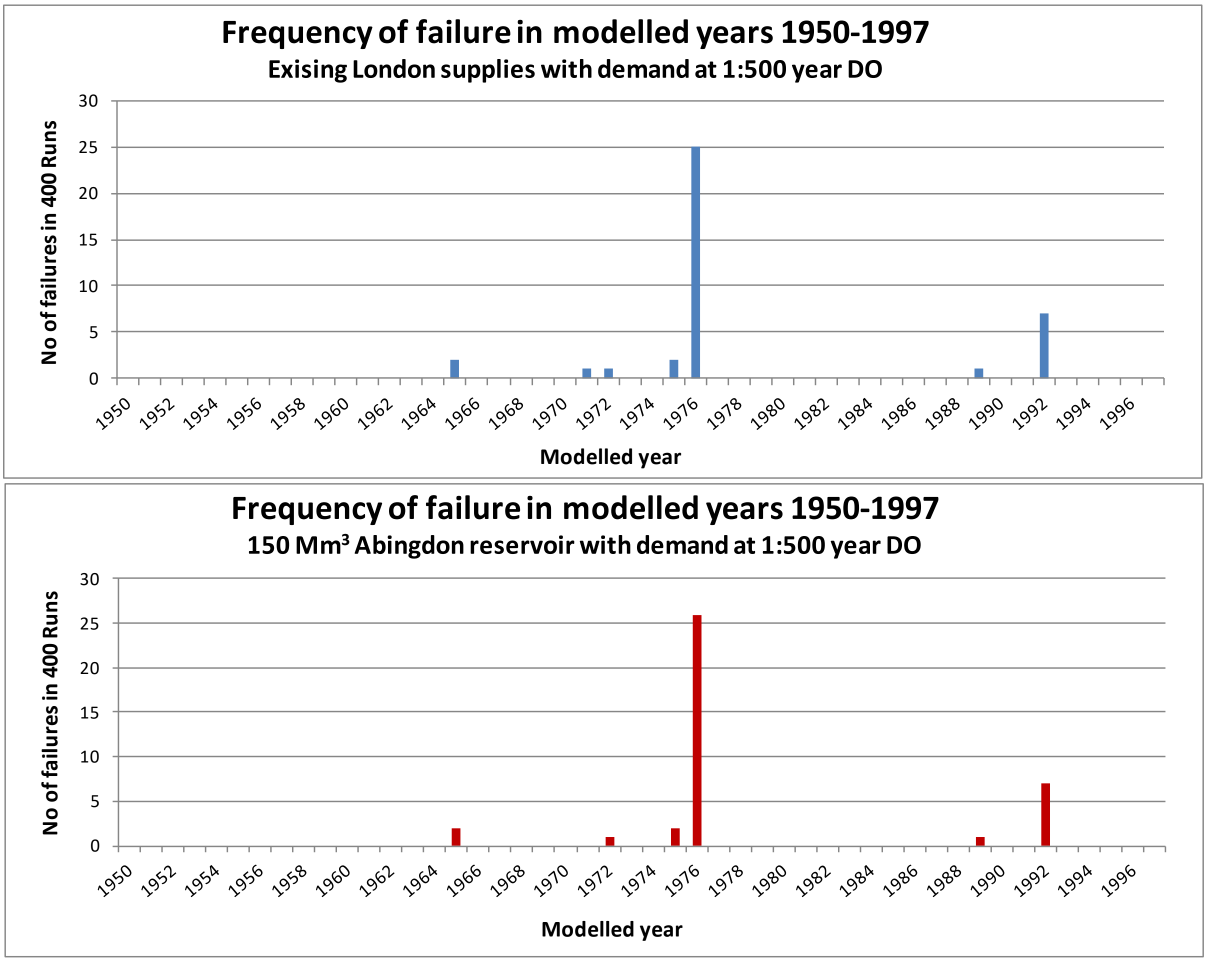


Figure 7 - Pywr modelled frequencies of supply failure in each year of stochastic data

The patterns of 'year of failure' are almost identical in the Pywr 19,200 year simulations of existing London supplies and existing supplies with Abingdon reservoir, in each case replicating the pattern of historic droughts in the period 1950-97 – much the most severe drought was 1975-76. There are also some modelled supply failures in stochastic flows for 1992, which was not a significant historic drought year, but followed three consecutive dry years in 1989 to 1991 – see later comments following Figure 9.

It is evident that the method of generating stochastic river flows has retained the general pattern of historic flows 1950 to 1997, varying the intensity of droughts whilst keeping their general shape and duration. The method will not generate droughts of different shapes, for example droughts of much longer duration. This danger was identified in WRSE's Method Statement for Stochastic Climate Datasets[13]:

> *"As with any dataset generated based on existing datasets using statistical methods, the stochastic weather sequences are only as good as the datasets on which they are trained. As stated above, the stochastic dataset is formed of 400 48-year sequences and*

[13] WRSE Method Statement on Stochastic Climate Datasets: Consultation Version, July 2020, paragraph 2.7

is trained on the 1950-1997 baseline period. There is a risk that extreme, extended droughts may not necessarily be well reflected in the dataset, although quantifying this risk is extremely difficult. Companies may complement the stochastic dataset with drought artificial weather series to represent prolonged drought events (which the stochastic generator will not have been trained on)."

The relative severity of actual droughts of the past 100 years, in terms of their impact on London's supplies, can be seen from the plot below of minimum modelled drawdown, derived from Thames Water's modelling of existing London supplies at a deployable output of 2302 Ml/d[14]:

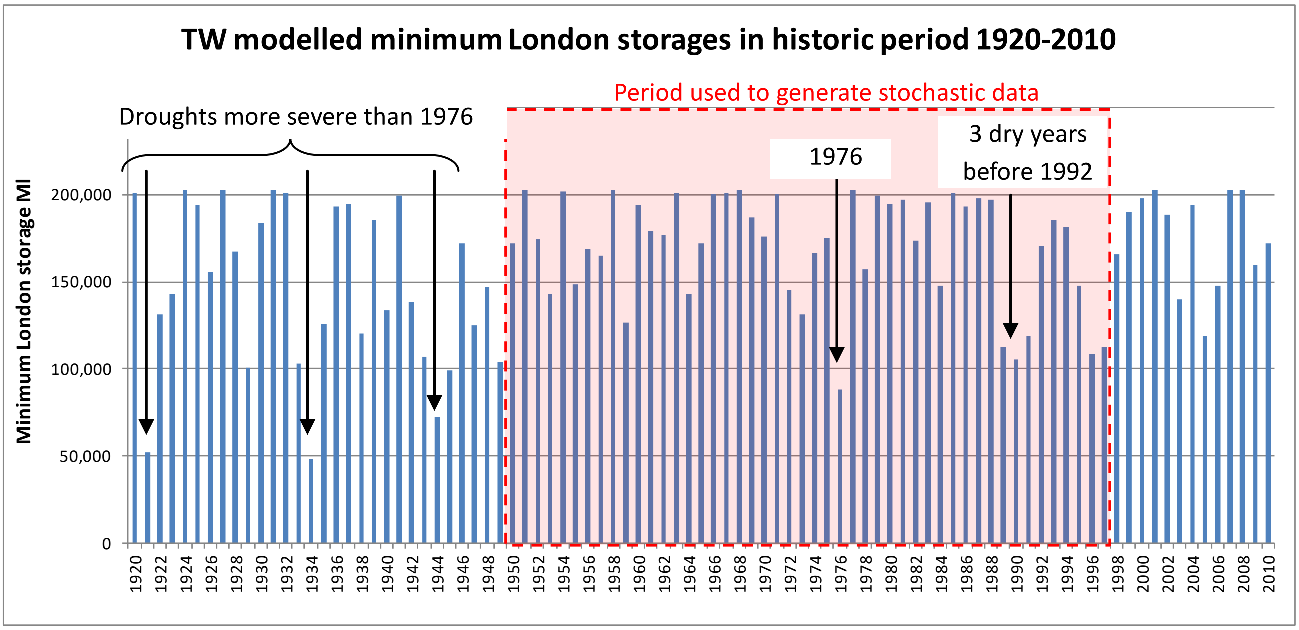


Figure 8 - Relative severity of droughts 1920-2010 as impact on minimum London storage

As can be seen in Figure 8, the droughts of 1921, 1934 and 1944 were all a lot more severe than the 1976 drought in terms of impact on London reservoir storage. The reason for the greater impact of the 1921, 1934 and 1944 droughts was the length of the droughts, with the longest droughts causing the greatest drawdown of London storage, as shown in Figure 9[15]:

[14] Data from EIR-22-23-390 file *"AR20 Q4 Sc1 - London DO – 2302.xlsx"*
[15] Ibid

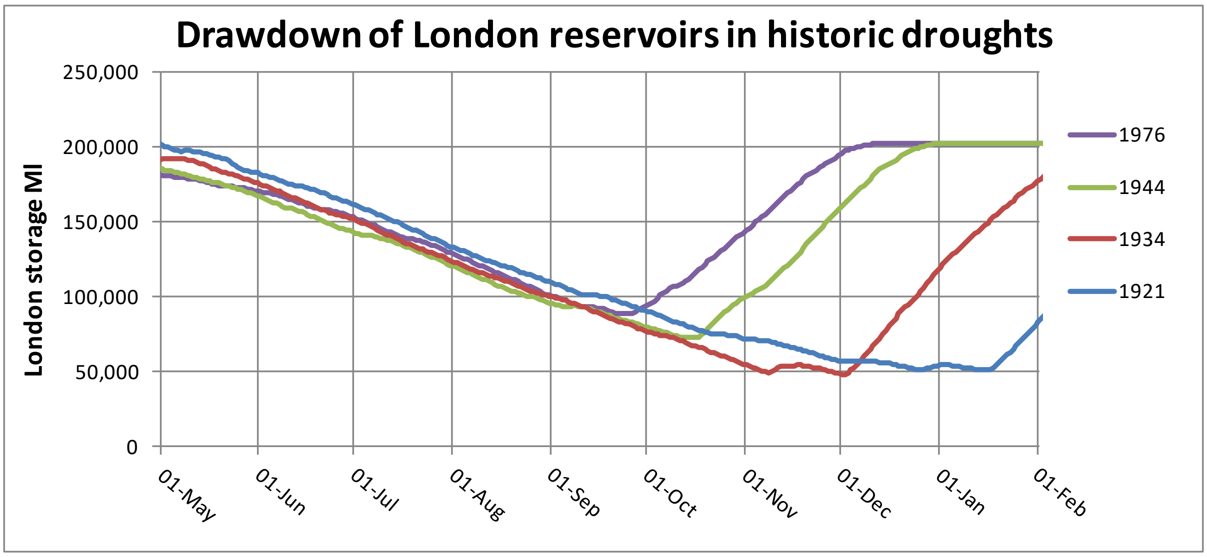


Figure 9 - TW modelled drawdown of London reservoirs in major historic droughts

It is evident from this plot that the 1976 drought was of much too short a duration to be a representative ‘training drought’ for all the stochastically generated droughts. The absence of any other significant droughts in the 1950 to 1997 period further limits the variability of the stochastically generated droughts.

The potential significance of much longer droughts, or sequences of dry years, is shown by number of supply failures generated by the stochastic modelling in 1992, as shown earlier in Figure 6. Historically, 1992 was not a particularly dry year, as can be seen from the modelled historic drawdowns in Figure 8. However, the presence of three moderately dry years in 1989 to 1991 has evidently been enough for the hydrological modelling to generate some very severe droughts in 1992.

As we will show later, the 1992 droughts in the stochastic record are much longer droughts than those occurring in 1976 and they test the resilience of Abingdon reservoir, typically emptying the reservoir well before the end of the drought. However, because the period 1989 to 1992 was not exceptionally dry, there are relatively few droughts of this type in the stochastic record. As we shall show in Section 2, there were more droughts of this type in the stochastic data for WRMP19, which were ‘trained’ on the period 1920 to 1997, ie including the 1921, 1933-34 and 1943-44 droughts. We suspect that there would have been still more of this type of long drought if weather data for the 1890s had been included in the ‘training period’.

Despite this problem being identified in WRSE’s 2020 Method Statement, it appears to have been ignored in Thames Water’s WRMP. We have found no evidence that Thames Water have followed WRSE’s suggestion of “*Companies may complement the stochastic dataset with drought artificial weather series to represent prolonged drought events (which the stochastic generator will not have been trained on)*”. For example, what would happen if a drought like 1976 was to follow a drought like 1921, 1934 or 1944?

Exclusion of climate records since 1997

Figure 9 shows the periods of climate data used for the WRMP19 and WRSE stochastic data generation, in the context of global temperature changes since 1880[16], highlighting the rapid changes since 1997:

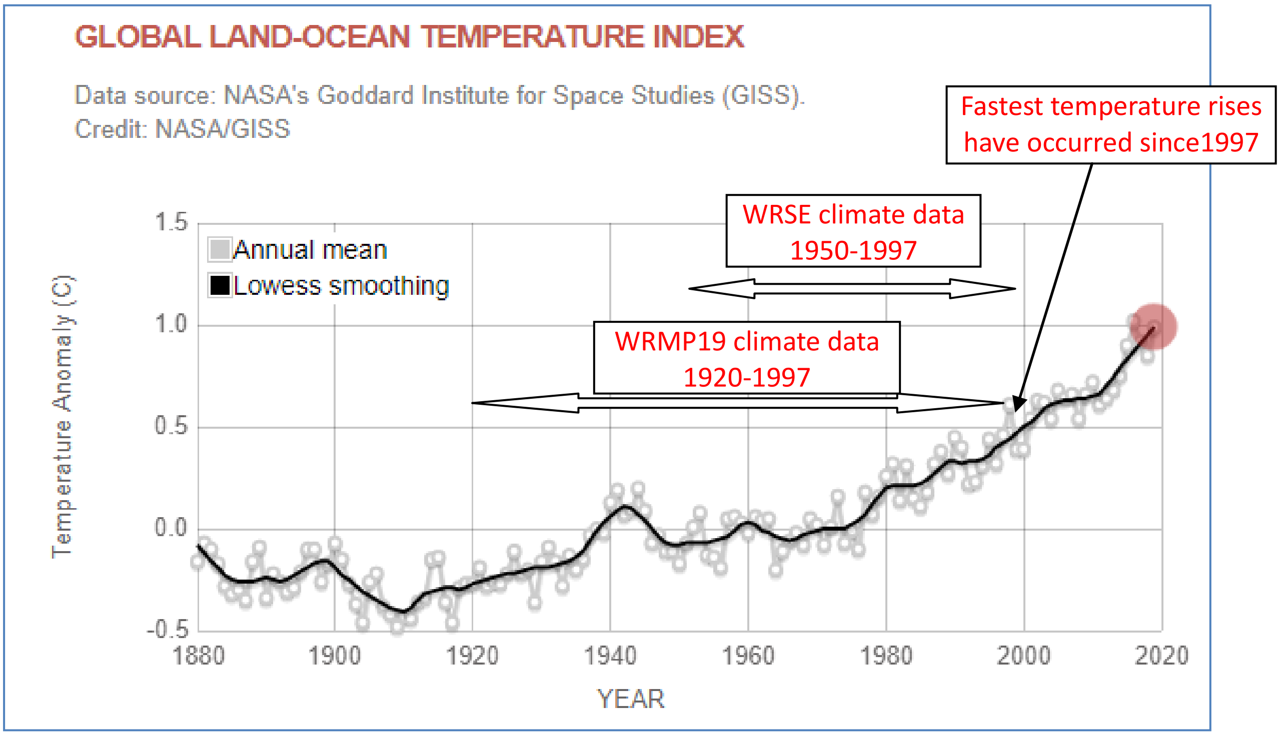
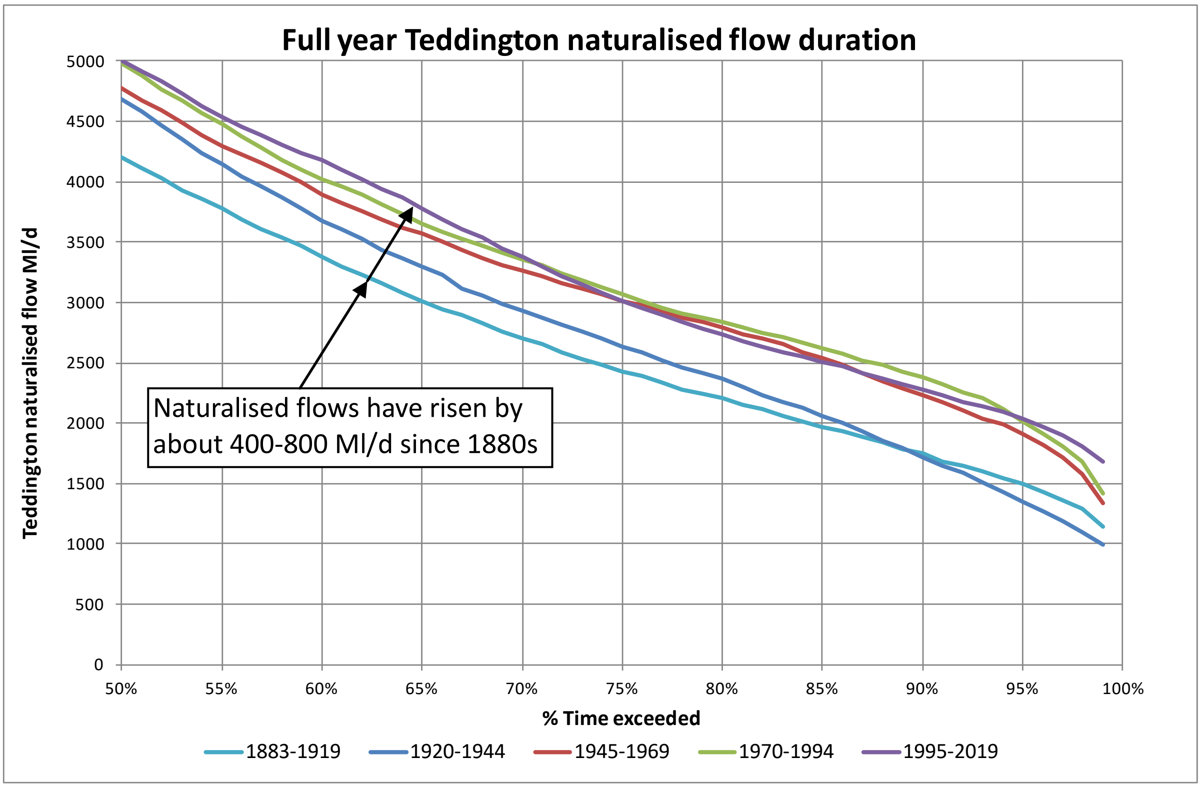


Figure 10 - Stochastic data 'training' periods vs global temperature changes since 1880

Figure 11 shows changes in the flow-duration characteristics of naturalised flows in the Thames at Teddington since 1885, ie the same period as Figure 10:

[16] https://climate.nasa.gov/vital-signs/global-temperature/



Note: data from naturalised Kingston flows on NRFA website, which allow for lower Thames abstractions, but not abstractions or effluent returns upstream of Windsor [17]

Figure 11 - Changes in Lower Thames naturalised flow durations since 1883

Over the past 140 years, the naturalised flow data show steady growth of about 400-800 Ml/d in water available in the lower Thames for London's reservoir-based supplies, although we recognise that there are some doubts over the reliability of the data from the early part of the record and the method of naturalisation does not take account of the abstractions and effluent returns above Windsor (relatively small as net values)[18].

From this, it appears that selection of different periods of historic climate data as the basis for generating the stochastic data could have a material effect on the stochastically generated climate data and, consequently, on the flows generated by the hydrological modelling.

In our opinion, the base historic data should have included all available climate data since 1997, thereby covering the recent period of rapid climate change.

Our conclusions on the validity of the stochastic data

Our conclusion from review of the validity of the stochastic data is that the stochastic river flow datasets used to determine deployable outputs for existing supplies and strategic resource options in Thames Water's plan are not fit for purpose because:

[17] NRFA web-site, Kingston naturalised data download https://nrfa.ceh.ac.uk/data/station/meanflow/39001
[18] As noted on the NRFA web-site

1. The hydrological modelling that converts stochastic weather data into 19,200 years of daily river flows gives a poor validation when its generated historic flows are compared with WARMS2 modelled flows and gauged flow data.

2. The only significant drought in the period in the period 1950-97 was the 1976 drought which was of a much shorter duration than the historic droughts of 1921, 1933-34 and 1943-44. Therefore, it is not a suitable drought for 'training' stochastic droughts, so there is insufficient variability in the shape and duration of the droughts in the 19,200 year stochastic flow records.

3. Thames Water has failed to follow the WRSE suggestion that the stochastic datasets should be complemented with artificial drought weather series to represent prolonged drought events, which the stochastic generator will not have been trained on.

4. The exclusion of the 25 years of weather since 1997, the period of most rapid climate change, means that the stochastically generated flows don't take proper account of demonstrable steady increases in lower Thames flows since the 1880s.

The implications of these conclusions will be considered in Sections 3 to 5 of this Addendum.

2.3 Validity of GARD's modelling of Thames Water's supply system

GARD's modelling of Thames Water's supply system has been validated in two steps:

- Step 1: by comparison of GARD's modelling using historic rivers with the Thames Water's Aquator modelling for AR20, as provided under EIR-22-23-390 in file *"AR20 Q4 Sc1 – London DO – 2302"*

- Step 2: by comparison of GARD's modelling using stochastic river flows with the Thames Water's Pywr modelling of existing supplies, as provided in EIR-22-23-390 in file *"New Flows Validation"*

Validation plots for Step 1, comparison with AR20 Aquator modelling, are shown in Figure 12:

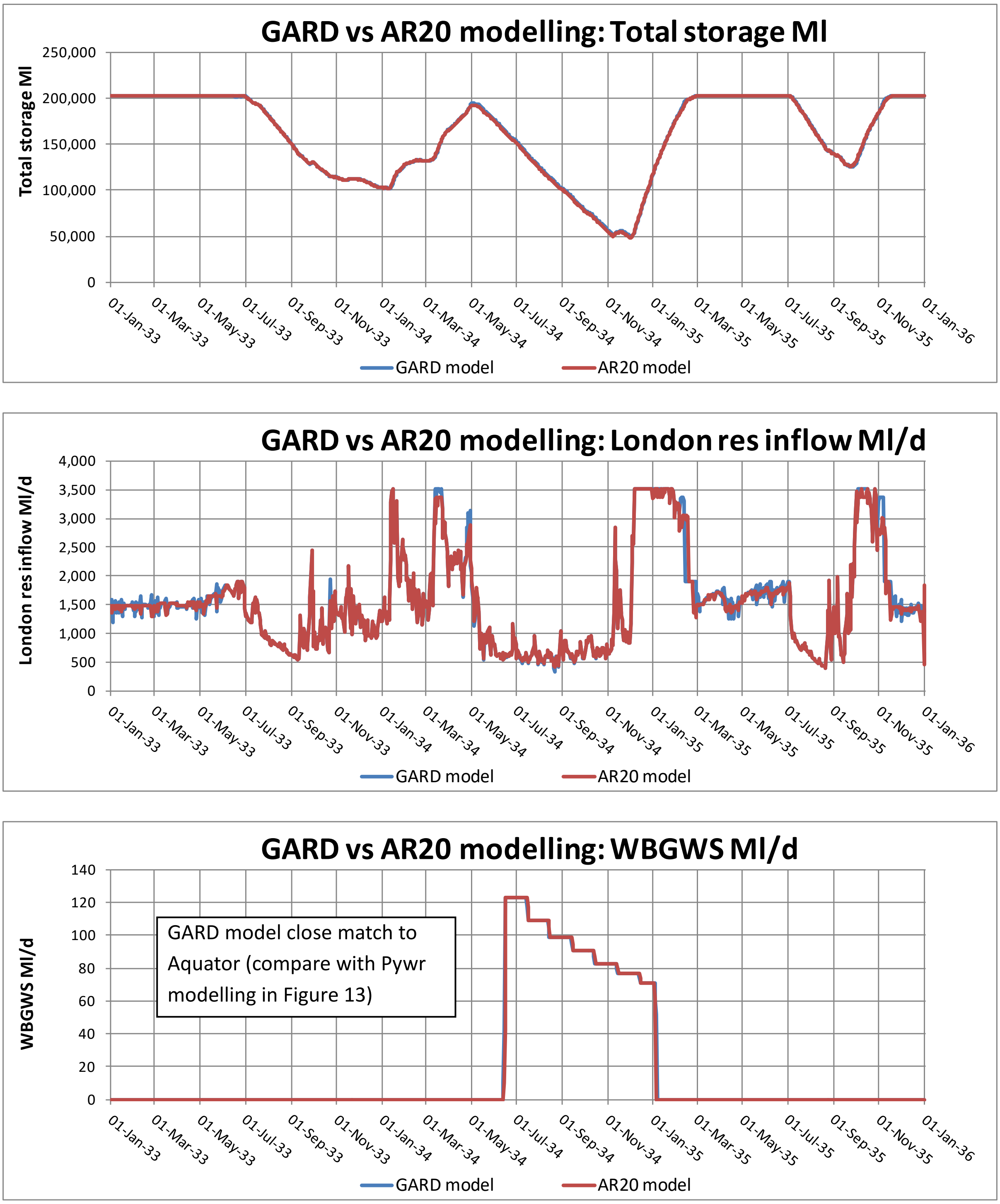


Figure 12 - Step 1 Validation of GARD model, comparison with Aquator modelling

The plots above show that GARD's modelling provides a virtually exact match to Thames Water's AR20 modelling of the London supply system with historic flows, exactly replicating the Annual Review 2020 London deployable output of 2302 Ml/d. The GARD model provides a much better fit to the WARMS output data than the equivalent Pywr modelling shown in Figure 1.

Step 2 for validation of GARD's model used the same stochastic river flow data as used in the

Pywr model for comparison with Pywr model output of existing London supplies[19]. The comparative model outputs are shown in Figure 13, simulating the drought of 1976 in Run 152 of the stochastic data, which the Pywr modelling shows to be just achieving a deployable output of 1971 Ml/d:

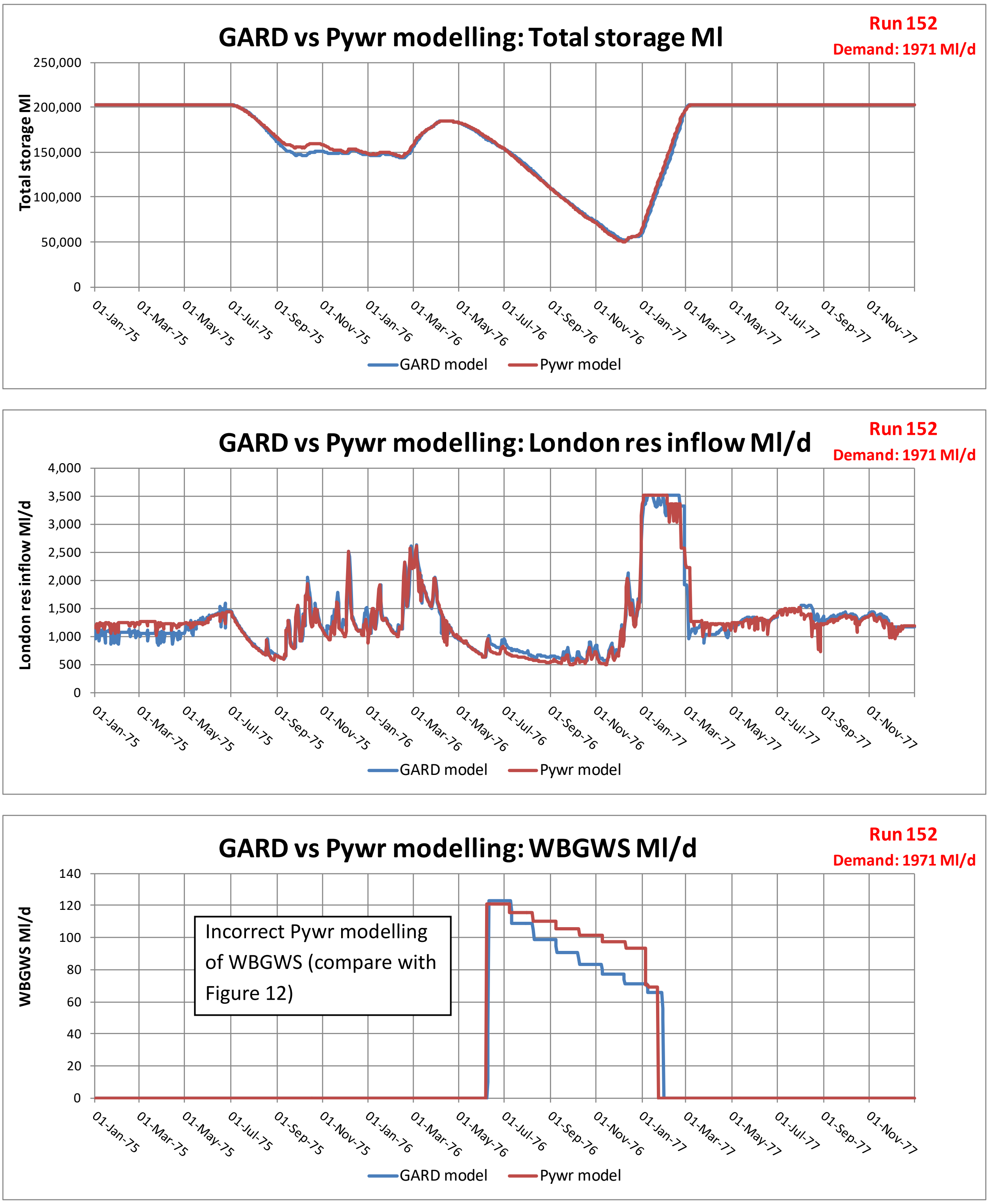


Figure 13 - Step 2 Validation of GARD model, comparison with Pywr modelling

[19] Pywr model output as supplied under EIR-22-23-390, Item 1

Figure 13 show that the GARD model output matches the Pywr model output quite well. Some of the small differences in model output are likely to be due to deficiencies in the Pywr modelling, bearing in mind that the GARD model provides a better fit to Aquator modelling (compare Figures 1 and 12).

The Pywr model simulates the WBGWS output incorrectly, making insufficient allowance for the monthly reduction in output from the scheme. The GARD modelling shown in Figure 12 exactly matches the Aquator output, so it appears to be the Pywr output which is at fault.

The plots in Figures 12 and 13 show that GARD's model reliably simulates existing London supplies. Detailed Pywr model output for Abingdon reservoir and STT options has not been made available to GARD, so we are not able to make a direct comparison of GARD and Pywr modelling of these options.

3. Deployable output of Abingdon reservoir

3.1 Thames Water's deployable output assessment

Thames Water's assessment of the deployable output of the Abingdon reservoir options is described in a technical note provided under EIR-22-23-390. The deployable output without climate change is summarised in Table 5-1 of the technical note[20] as:

	Previous analysis		Latest analysis	
SESRO option	DO	Scheme DO	DO	Scheme DO
None (baseline)	1965	n/a	1967	n/a
75 Mm^3	2119	155	2121	154
150 Mm^3	2258	293	2252	285

Table 1 - Thames Water assessment of DO of existing supplies and Abingdon reservoir

Thames Water calculates deployable outputs for London by using the Pywr model to simulate the frequency of London reservoir storage falling into the Level 4 emergency storage zone. The London demand that causes only 38 failures in 19,200 years of simulation is then the 1:500 year deployable output (19,200 ÷ 500 = 38.4). The Pywr model is run repeatedly with small stepped increases in demand to determine the frequency of failure at each demand level and hence deployable output.

Under EIR-22-23-390, Thames Water provided GARD with the Pywr 'Control Line Crossing Data' showing years of failure at each modelled demand level for the existing London supplies, the 150 Mm^3 Abingdon reservoir, the unsupported 500 Ml/d STT and the STT with 500 Ml/d of support sources[21]. Using these data, we have re-assessed the deployable output of existing London supplies and the 150 Mm^3 Abingdon reservoir in Figure 14:

[20] Technical Note Enhanced RSS Modelling of SESRO and Thames to Affinity Transfer Schemes, Table 5-1, Atkins, 30th May 2022

[21] EIR-22-23-390, Item 4

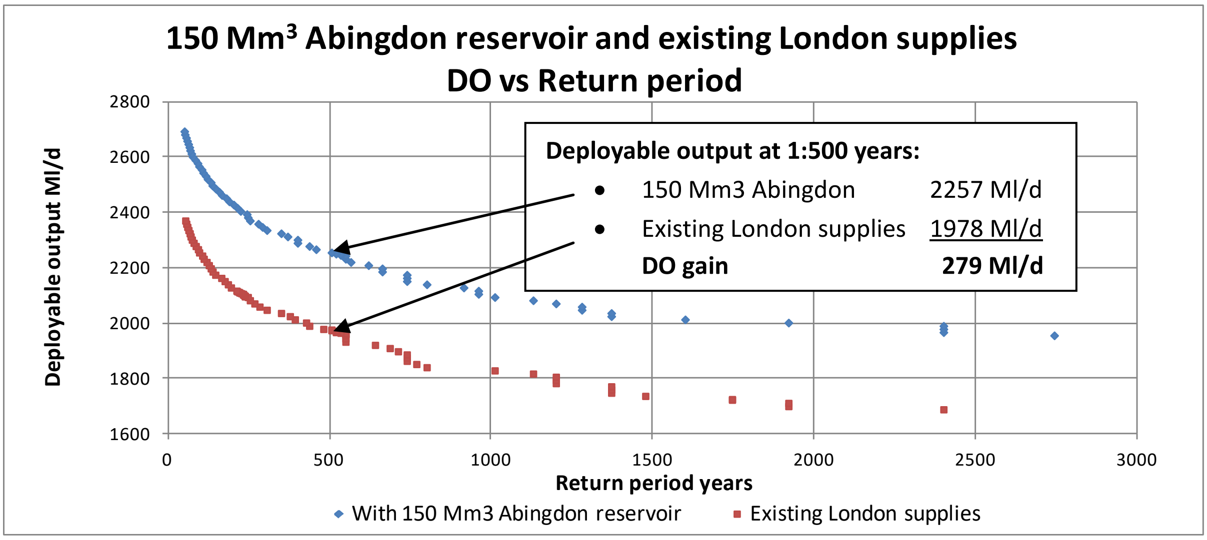


Figure 14 - GARD reassessment of Abingdon DO using Pywr model output

This shows the DO of the 150 Mm3 Abingdon reservoir to be 279 Ml/d as compared with TW's figure of 285 Ml/d. The reason for the difference is that in creating the plots in Figure 14, we have counted drought failure <u>events</u> rather than <u>years</u> of failure. Thames Water have attempted to count failure events by taking years as ending on 31st March, as explained in EIR 22-23-390[22]: *"A year is defined from Apr to Mar, in order not to count L4 events which extend into January."* Unfortunately, L4 failures in some droughts still extend beyond 31st March and some failures start before 1st April, as for the example shown below[23]:

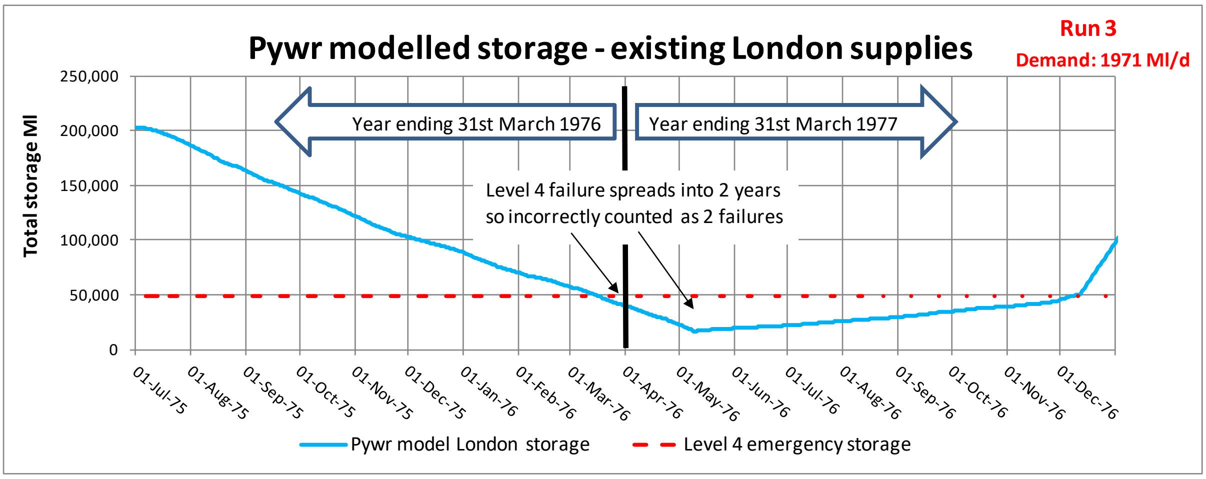


Figure 15 - Example of double counting of droughts in TW's DO analysis

The double counting of some drought events has caused Thames Water to over-estimate the deployable output of the 150 Mm^3 Abingdon reservoir by 6 Ml/d or 2%. The equivalent error for the 100 Mm^3 reservoir would be 4 Ml/d. Although not a large error, this could still be significant when comparing the reservoir with other options.

[22] EIR-22-23-390, Item 5, last paragraph
[23] Pywr model output for existing London supplies, as provided by EIR 22-23-390, Item 1

There is another serious Pywr modelling error in assuming the minimum required flow (MRF) at Culham to be only 450 Ml/d instead of 1450 Ml/d. This error is recognised by Thames Water in a footnote[24] to the technical note on deployable assessment supplied to GARD under EIR-22-23-390 (but not available as part of the on-line WRMP24 documentation):

> *"When the flow is above 1,450 Ml/d then [the Pywr model assumes that] the full abstraction is available, which means that the river flow downstream of the abstraction can fall to 450 Ml/d under an abstraction of 1,000 Ml/d. This modelling of the constraint as a simple threshold was identified as incorrect towards the end of the study, and a Minimum Residual Flow (MRF) of 1,450 Ml/d should have been applied instead (so that at a river flow of 1,500 Ml/d then only 50 Ml/d can be abstracted). The impact of the MRF constraint is described in Appendix B."*

Appendix B of the technical note shows that this Pywr modelling error has no modelled effect on the deployable output of the 150 Mm^3 reservoir using river flows without climate change and reduces the deployable output with climate change by 2 Ml/d (reducing the deployable output from 271 Ml/d to 269 Ml/d[25]). GARD's modelling using stochastic flows without climate change also shows the error does not affect deployable output. We do not have the climate change flow data to check the 2 Ml/d DO loss.

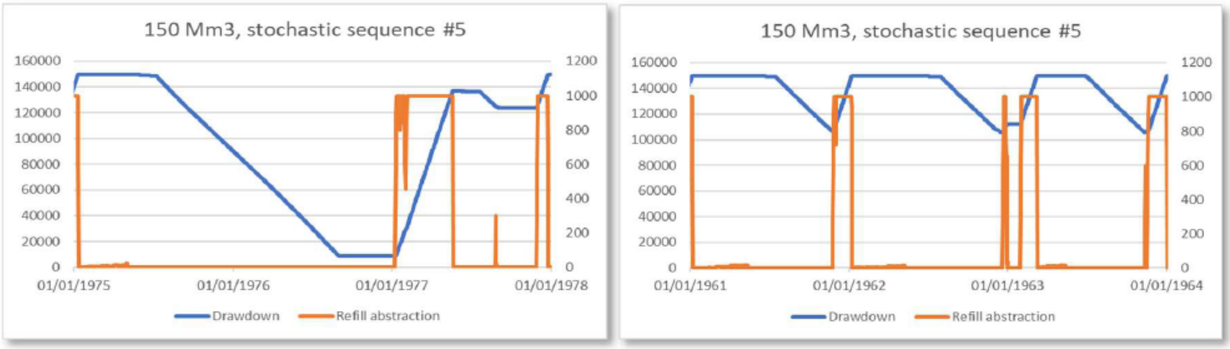
Although the Culham MRF error does not have a big impact on deployable output, it can greatly affect the speed of reservoir refilling after droughts. The main Gate 2 report for Abingdon reservoir claims that the reservoir refills in 5 months after droughts:

> *"Following drought periods, which result in longer periods of reservoir release to meet demands for water and hence a lower and deeper drawdown period, abstraction refill occurs for longer during the subsequent refill season as greater volumes are required to refill the reservoir. However, even after a long period of extreme drought and drawdown, refill is still achieved within 5 months. This is illustrated in Figure 4.1 below for one of the synthetic stochastic hydrological sequences. Refill would tend to be faster for the smaller reservoir sizes, due to the reduced volumes of storage."*

Thames Water's Figure 4.1 which is misleadingly said to illustrate 5-month refill after an extreme drought is copied below:

[24] Technical Note Enhanced RSS Modelling of SESRO and Thames to Affinity Transfer Schemes, footnote 2, page 3
[25] Ibid, Appendix B, Table 6-7

*Figure 4.1 SESRO drawdown and refill – extreme drought (left) compared to standard operation (right)**



** Note, primary y-axis is drawdown (Ml) and secondary y-axis is refill abstraction (Ml/d)*

Figure 16 - TW illustration of rapid Abingdon refill after "extreme" drought

The rapid refill shown in the Gate 2 report's Figure 4.1 will have been enhanced by the incorrect assumption of a 450 Ml/d MRF at Culham. It should also be noted that the historic drought of 1976 was followed by a wet winter, so the numerous stochastic droughts simulated by perturbation of historic 1976 weather also tend to be followed by wet winters and rapid Abingdon reservoir refill. When the stochastic droughts are based on the historic drought of 1992, which was followed by another quite dry year, Abingdon reservoir usually fails to refill in the next year, as for the example below generated by GARD modelling using Run 86 stochastic data and the correct 1450 Ml/d MRF at Culham:

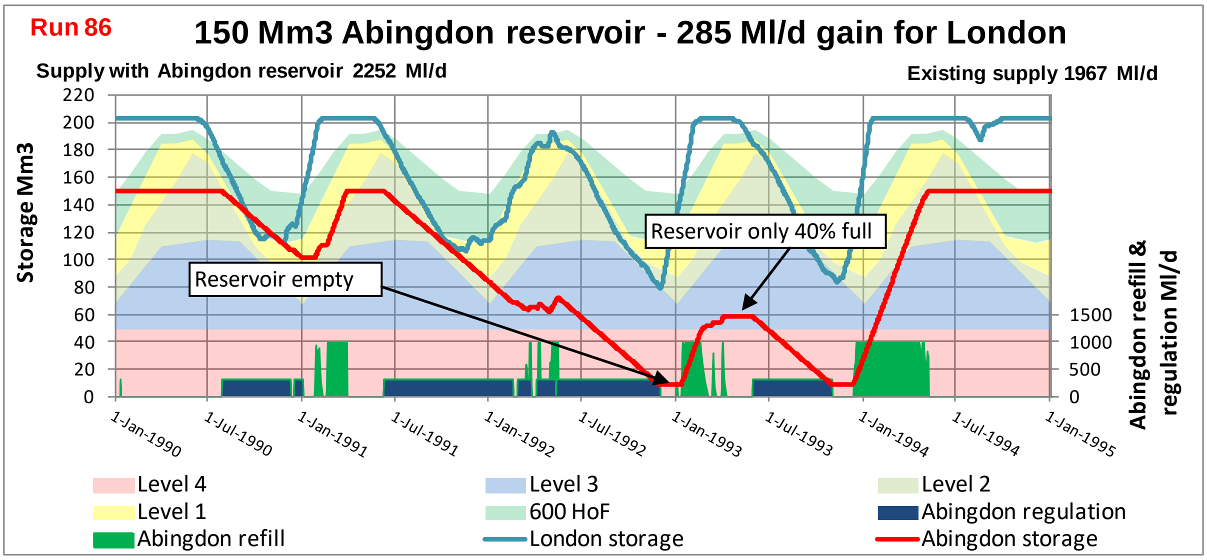


Figure 17 - Example of Abingdon reservoir failing to refill in the year following a drought

The 1991 drought in Run 86 was the 48th most severe drought in the 19,200 year stochastic record, so it has a return period of 1:400 years. Although London storage does not fall to Level 4 in this drought (because it is less severe than 1:500 years), Abingdon reservoir is still empty by the end of the drought and only 40% full at the start of the drought of 1993, quickly dropping again to empty. This is a good example of the reservoir's poor resilience in long droughts, which we will consider more in Section 3.3.

3.2 Effect of climate change on reservoir deployable output

The technical note on modelling of Abingdon reservoir shows the reduction in reservoir deployable output with median climate change as below[26]:

SESRO Size Mm^3	Previous DO (no CC) (Ml/d)[11]	Derived latest DO (no CC) (Ml/d)[12]	Derived CC impact (Ml/d)[13]	Derived latest DO with CC (Ml/d)
30	67.9	66.9	-1.4	65.5
75	155.0	154.2	-5.0	149.2
80	163.0	160.5	-5.4	155.1
100	195.0	192.0	-7.4	184.6
122	238.0	234.3	-10.3	224.0
125	243.9	240.2	-10.7	229.5
130	253.7	250.1	-11.4	238.6
150	292.9	285.4	-14.4	271.0

Table 2 - TW assessment of median climate change impact on reservoir DO

The median climate change deployable outputs of 271 Ml/d for the 150 Mm^3 reservoir and 185 Ml/d for the 100 Mm^3 reservoir are the figures used in Thames Water's main WRMP. The justification for assuming the median climate change impact is said to be[27]:

> *"Tier 1 DO calculation undertaken using WRSE Pywr model, involving a 'full stochastic' DO assessment, and incorporating the impact of climate change as per the WRSE standard approach to climate change assessment"*

However, Thames Water's preferred plan is based on 'pathway 4' which includes 'high' climate change[28]. Therefore, in developing the preferred plan, the deployable output for Abingdon reservoir should also allow for the high climate change scenario and not the median scenario. The effect of different climate change scenarios on reservoir deployable output is shown in the technical note as below[29]:

[26] Ibid, Table 6-4
[27] TW Main WRMP Report, Table 7-6 commentary
[28] TW Main WRMP Report, paragraphs 11.11 and 11.14
[29] Technical Note Enhanced RSS Modelling of SESRO and Thames to Affinity Transfer Schemes, Table 6-1

SESRO option 75 Mm^3		SESRO option 150Mm^3		Comment
Climate change scenario	Net DO impact (Ml/d)	Climate change scenario	Net DO impact (Ml/d)	
cc_01	-16.0	cc_01	-42.8	Worst-case
cc_03	-15.8	cc_03	-40.7	
cc_26	-14.0	cc_02	-36.5	
cc_02	-13.6	cc_06	-34.9	
cc_13	-12.8	cc_13	-34.6	
cc_11	-12.4	cc_10	-31.0	
cc_10	-11.5	cc_26	-30.5	
cc_06	-11.2	cc_11	-29.5	
cc_14	-9.0	cc_14	-26.4	
cc_05	-7.3	cc_05	-24.1	
cc_18	-6.9	cc_09	-20.7	
cc_24	-5.9	cc_04	-16.2	
cc_09	-5.3	cc_24	-16.0	
cc_04	-5.1	cc_17	-15.6	Median (lower of average)[10]

Table 3 - Effect of climate change scenarios on 1:500 year reservoir DO

Thames Water's WRMP appendix on climate change says that scenario cc_06 is used as the 'high' climate change scenario[30]. Table 3 shows that reduction in deployable output for the high scenario should have been 34.6 Ml/d for the 150 Mm^3 reservoir rather than 15.6 Ml/d reduction that was assumed for the median scenario.

In other words, the deployable output of the 150 Mm^3 reservoir with climate change allowance should have been 252 Ml/d, not 271 Ml/d. The equivalent deployable output of the 100 Mm^3 reservoir with climate change should have been 169 Ml/d, not 185 Ml/d.

Combined with the correction of the errors due to double counting of droughts, TW's assessed deployable outputs reduce to 246 Ml/d for the 150 Mm^3 reservoir and 165 Ml/d for the 100 Mm^3 reservoir. These figures are before consideration of the resilience of the reservoir to long duration droughts or the adequacy of the allowance for emergency storage.

3.3 Reservoir resilience in long duration droughts

In the run-up to WRMP19 and in our responses to the two consultations on WRMP19 GARD demonstrated the lack of resilience of Abingdon reservoir in multi-year droughts and the flaws in Thames Water's method of assessment of resilience in long droughts[31] [32]. The stochastic records used for assessment of schemes in WRMP19 included many droughts in which the 150 Mm^3 Abingdon reservoir would be unable to deliver its supposed deployable

[30] TW WRMP Appendix U Climate Change, paragraphs U.77 and U.101

[31] GARD response to first WRMP consultation, pages 134-141, April 2018

[32] GARD response to second WRMP consultation, pages 111 to 117, November 2018

output of about 290 Ml/d. An example of such a drought is shown below:

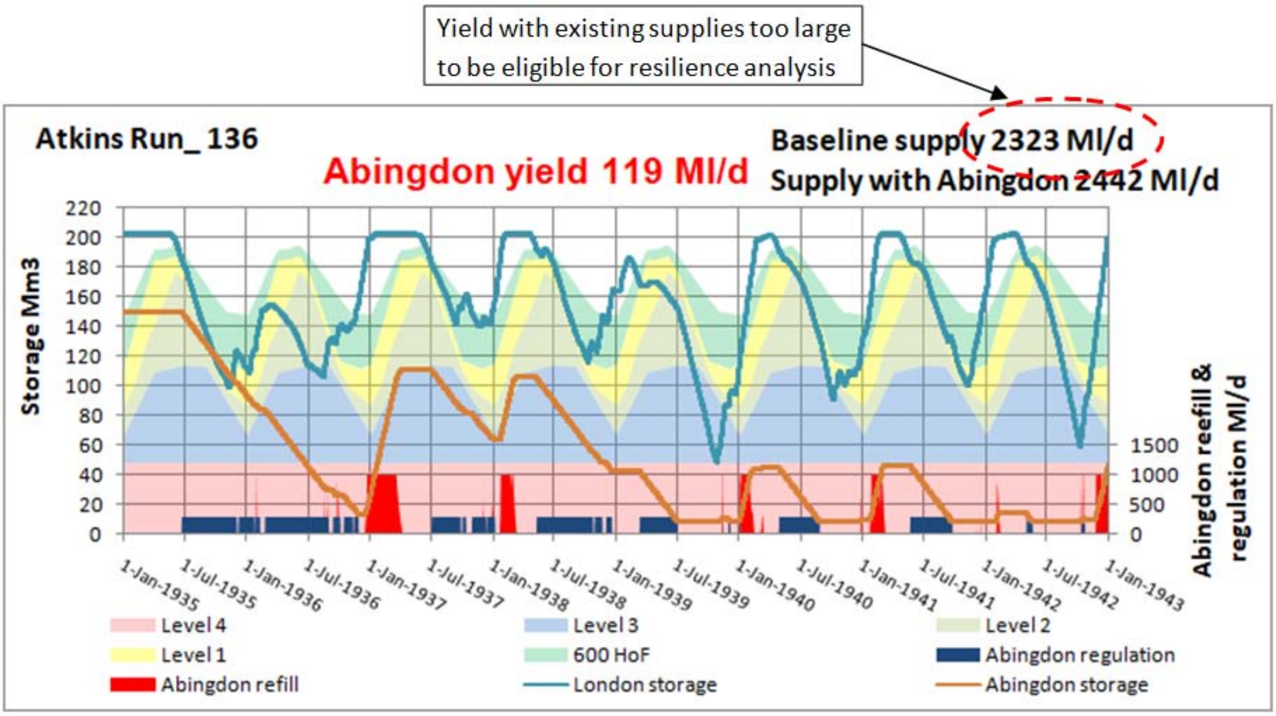


Figure 18 - Example of catastrophic drought not considered by TW in WRMP19

In our response to WRMP19, we commented[33] that, for the example above, the existing London supplies would be only moderately tested in the drought of 1939 (return period of less than 1:100 years for existing London supplies), so the drought was not sufficiently severe to be selected by TW for resilience checking. However, the succession of dry winters leading up to 1939 would leave Abingdon reservoir only about 30% full at the start of the 1939 drought. After catastrophic failure of London's supplies in 1939, Abingdon reservoir would remain virtually empty for several years, leaving London's supplies in a state of prolonged crisis. This type of event would be a major risk for London because of the severity of its consequences, but Thames Water's WRMP19 methodology failed to identify it or provide an estimate of its probability.

To some extent, the flaws in the WRMP19 method of assessment have been addressed by the Pywr modelling of the full 19,200 years of stochastic data, rather than the previous method which selected only a small proportion of droughts in the stochastic record, excluding many long duration droughts like the example shown in Figure 18.

However, as discussed in Section 3.1, the new method of generating stochastic data, excluding the long droughts of 1933/34 and 1943/44 from the base 'training' period, has introduced a new bias whereby most of the droughts in the 19,200 year record are based on

[33] GARD response to 2nd consultation on WRMP19, Figure 8-2 and last paragraph on page 115 https://www.abingdonreservoir.org.uk/downloads/GARD%20%20response%20to%202nd%20Consultation%20on%20TW%20draft%20WRMP%20Rev%2029.11.18.pdf

the shape and duration of the 1975/76 drought which was not particularly long and was not preceded or followed by dry years. The dominance of the 1975/76 drought in shaping the droughts in the new historic record is shown in Figure 7 of this Addendum.

Nevertheless, even using the new flawed stochastic data, with their lack of long droughts, the modelling raises doubts about the resilience of the reservoir in the relatively few long droughts in the stochastic record. Figure 18 shows GARD modelling of the performance of the reservoir delivering the expected 285 Ml/d deployable output (no climate change) in the 1954 drought of Run 218. This drought is the 38th most severe drought in the drought sequences shown in Figure 2, so it has a return period of 1 in 505 years:

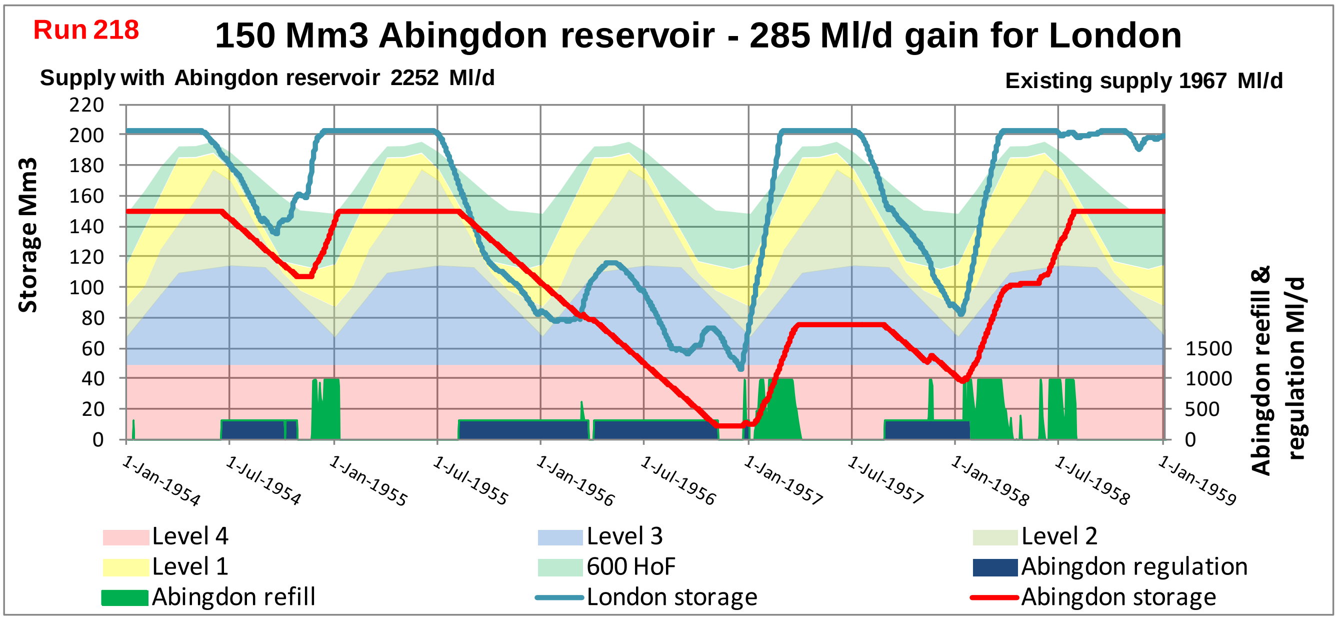


Figure 19 - Operation of 150 Mm3 Abingdon reservoir in a 1:505 year drought

This simulation illustrates some of the concerns over resilience of Abingdon reservoir in long droughts:

1. The simulated drought of 1955 was moderately severe and half the Abingdon storage had been used by the end of the summer. There would have been minimal refill during the winter of 1955-56, so Abingdon reservoir and the London reservoir would still be half full at the start summer 1956, with London already subject to Level 3 restrictions. These restrictions would remain in place for virtually the whole year. This would seem an unacceptable level of service for London.

2. Abingdon reservoir falls to the emergency storage level of 9,000 Ml on 5th November 1956, whereas the London storage continues to fall for about 6 weeks reaching its minimum level on 16th December. Thames Water have not said in their Gate 2 reports whether reaching the emergency storage level in Abingdon reservoir would trigger Level 4 emergency measures in London. Even if it doesn't, with London reservoirs nearing the emergency level and Abingdon reservoir effectively empty,

there would surely need to be restrictions in London demands beyond the Level 3 measures which have relatively little effect in the autumn months.

3. At the start of the following summer, Abingdon reservoir would still have been less than half full. If the drought in the late summer of the second year started earlier than July, there would have been a major problem with extended Level 4 failure of London's supplies.

The fundamental problem with the resilience of Abingdon reservoir in long droughts is that there is minimal water available to refill it in even moderately dry winters. Therefore, it is vulnerable to a succession of 3 or more dry years.

With the method that has been used to generate the 19,200 years of stochastic data, the pattern of drought occurrence and the shape of individual droughts is governed by the sequence of occurrence of droughts in the historic weather period used to "train" the generated stochastic data. The historic period used, 1950 to 1997, did not contain either a drought which severely tested London's supplies (the 1976 drought was too short) or any extended sequence of drought years. Therefore, the stochastic data generated could not include any multi-year drought sequences of the type that Abingdon reservoir is unable to deal with.

As previously mentioned in Section 2.2, this flaw in the stochastic data was identified in WRSE's method statement on the stochastic climate datasets[34]:

> *"There is a risk that extreme, extended droughts may not necessarily be well reflected in the dataset, although quantifying this risk is extremely difficult. Companies may complement the stochastic dataset with drought artificial weather series to represent prolonged drought events (which the stochastic generator will not have been trained on)."*

Despite this advice and the known concerns over long droughts, Thames Water has failed to consider any artificial weather series to represent prolonged drought events. By re-ordering the sequence of dry years in the historic record, it can be shown that Abingdon reservoir would fail to deliver its expected deployable output in a succession of dry years preceding a major drought.

For example, if the historic drought of July 1933 to November 1934 had been preceded by the historic river flows of July 1996 to June 1997, the effect on Abingdon reservoir trying to deliver its expected 285 Ml/d deployable output (without climate change) would be as shown by GARD's modelling in Figure 18:

[34] WRSE Method Statement on Stochastic Climate Datasets: Consultation Version, July 2020, paragraph 2.7

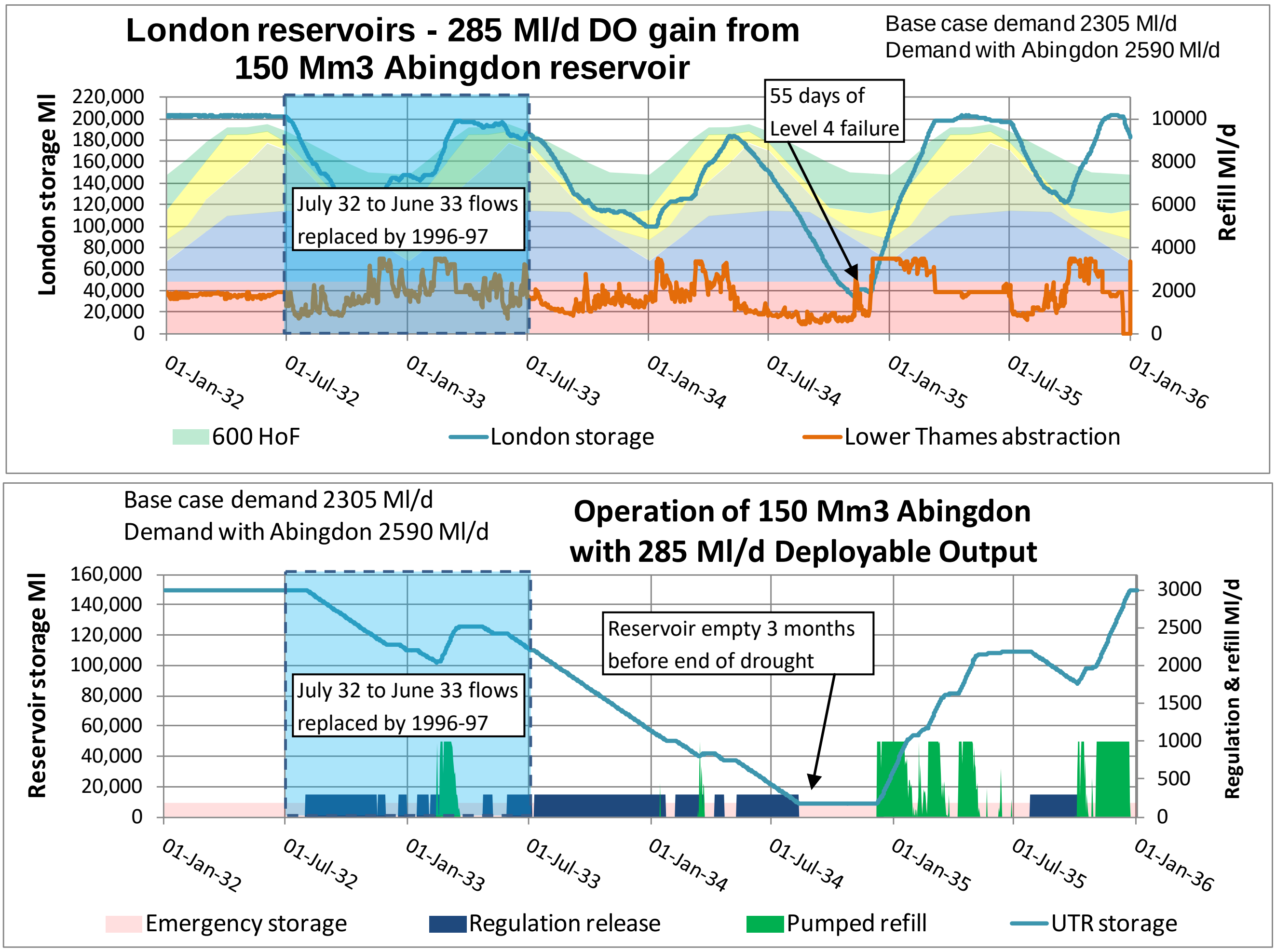


Figure 20 - Abingdon reservoir in artificially extended historic 1934 drought

In this scenario, replacing the historic flows of mid-1932 to mid-1933 with the historic flows of mid-1996 to mid-1997 would lead to 55 days of Level 4 failures for London's supplies, with Abingdon reservoir being empty 3 months before the end of the drought. This would be a catastrophic failure of London's supplies, with Level 4 restrictions starting in August 1934 at the peak of the tourism season. In this seemingly plausible scenario, the deployable output that can be sustained by Abingdon reservoir is only 163 Ml/d, not 285 Ml/d.

We conclude that, if proper consideration is given to the occurrence of long duration droughts, the deployable output of Abingdon reservoir would be far less than that claimed by Thames Water, perhaps in the region of only 50% of the claimed amounts. In the 5 years since WRMP19, Thames Water have failed to address the concerns previously raised by GARD, even after their validity had been acknowledged by WRSE in their method statement on generating stochastic climate datasets in 2020.

3.4 Allowances for dead and emergency storage

In our main response to the consultation on Thames Water's WRMP24, we proposed that TW's proposed 6% emergency storage allowances for Abingdon reservoir should be increased to be in line with the emergency storage allowance in other major UK reservoirs as below:

- Clywedog reservoir 13%
- Llyn Brianne reservoir 14%
- Bristol Water (Chew, Blagdon) 18%
- Welsh Dee system 20%
- TW London reservoirs 24%
- TW Farmoor reservoir 33%

Thames Water says that the allowance of 6% emergency storage, ie 9,000 Ml for the 150 Mm^3 reservoir, is equivalent to 30 days of supply from the regulation release of 300 Ml/d, which they claim is in line with UK normal practice. However, there appears to have been no consideration of the minimum average depth of water required for acceptable water quality. Thames Water's themselves agree that an average water depth of less than 5m will be likely to lead to water quality problems[35]:

> *"The 28m water depth noted in the [GARD's] comment is the depth of the live storage (51m AOD to 79m AOD), there is a further 5m depth of dead storage in the central trench underneath (46m AOD to 51m AOD). We agree that a water depth of less than 5m would likely lead to water quality issues, hence the definition of such water as dead storage."*

Therefore there should be a minimum average depth of 5m of water when the emergency storage is <u>empty</u>. Figure 21 shows a cross-section of the reservoir and borrow pit[36]:

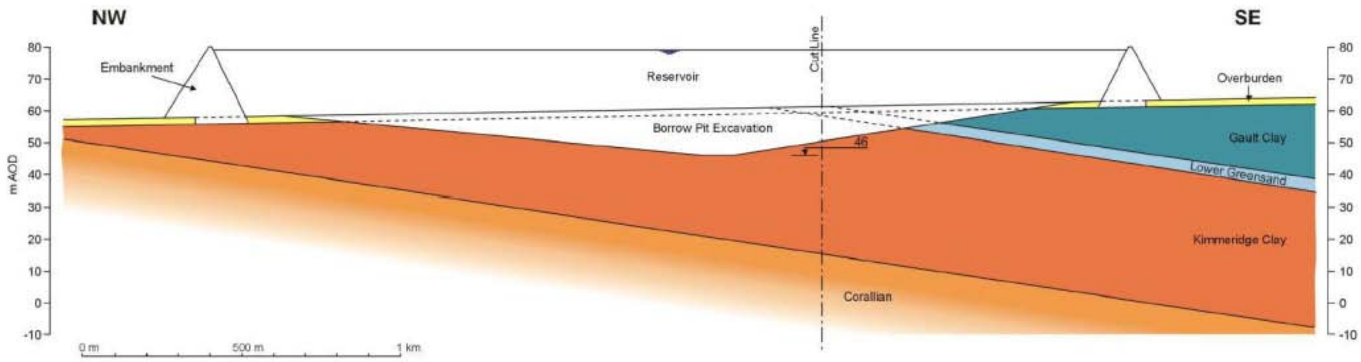


Figure 21 - Cross-section of reservoir showing borrow pit

This shows that the maximum depth of the borrow pit is about 5m so the average depth is only about 2.5m, not 5m. The average depths of water for the dead storage and Thames Water's proposed emergency storage are shown in Table 4:

[35] WRMP19 Reservoir Feasibility Report, page 435, Mott MacDonald, July 2017
[36] Gate 2 Concept Design Report Figure 2.1

Reservoir dimensions from 2017 reservoir feasibility report[37]	**150 Mm^3 reservoir**	**100 Mm^3 reservoir**
Gross storage	165,000 Ml	110,000 Ml
Live storage	150,000 Ml	100,000 Ml
Dead storage	15,000 Ml	10,000 Ml
TW emergency storage (6% of live storage)	9,000 Ml	6,000 Ml
Area at full supply	675 ha	404 ha
Embankment perimeter	10.3 km	7.9 km
Area at base of embankment	551 ha	309 ha
Average depth of dead storage	2.72 m	3.23 m
Maximum depth of TW emergency storage	1.63 m	1.94 m
Average depth, dead + maximum emergency	**4.35 m**	**5.17 m**

Table 4 - TW proposed water depths for dead and emergency storage

This shows that Thames Water's planned volumes of dead and emergency storage fail to meet their own criterion for a minimum average depth of 5m for useable water. None of Thames Water's proposed emergency storage for the 150 Mm^3 reservoir would be useable because it would all have to come from an average water depth of less than 5m. Only 0.17m depth of the proposed 6,000 Ml of emergency storage for the 100 Mm^3 reservoir would be useable, equivalent to just 525 Ml.

Thames Water's emergency storage proposals ignore their own concerns about future water quality as stated in the main WRMP24 report[38]:

> *"By looking at the resilience of our raw water storage and supply network we have found that the change in algal bloom severity and duration is dependent on individual reservoir characteristics, including their physical structure and management. For example, deeper reservoirs have better control measures to manage the raw water quality and therefore are more resilient to the impacts of climate change.*
>
> *Nevertheless, as well as future raw water resource availability, the water quality challenge and how this may change in future climates is an important factor to account for in planning. Evidence indicates that the impact of climate change is increasing the range of species of algae that can cause a bloom event in our reservoirs and also increasing the period of year for which our reservoirs are at risk of algal bloom."*

Recognising the increasing threat of algal blooms and poor reservoir water quality, we propose that the allowances for dead and emergency storage should be:

- Dead water should be based on an average residual water depth of 5m
- Emergency storage should be 15% of live storage to be in line with Llyn Brianne, Clywedog and the Welsh Dee regulating reservoirs

[37] WRMP19 Reservoir Feasibility Report, PDF pages 242-243 and 248-249
[38] TW WRMP24 main report, paragraphs 4.129 and 4.130

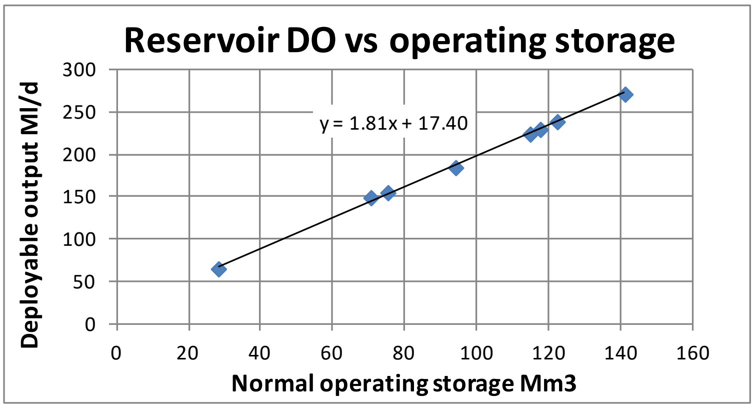
In our opinion, these would be reasonably cautious allowances to make, in line with the precautionary water quality measures being adopted for the STT, including the treatment of all transferred water at Deerhurst and high levels of treatment planned for Minworth and Netheridge effluent.

The reassessed dead and emergency storage volumes would then be as below:

	Nominal capacity		
GARD reassessment of dead and emergency storage	**150 Mm^3 reservoir**	**100 Mm^3 reservoir**	**Comment**
Gross storage	165,000 Ml	110,000 Ml	As per 2017 feasibility report
Dead storage with average 5m depth	27,570 Ml	15,460 Ml	Bottom area ha x 5m depth
Live storage, including emergency	137,430 Ml	94,540 Ml	Gross storage less dead
Emergency storage 15% of live storage	20,615 Ml	14,181 Ml	15% typical for regulating reservoirs
Storage available for normal operation	**116,816 Ml**	**80,359 Ml**	Live storage less emergency
Average depth of dead storage	5.0 m	5.0 m	TW stated minimum acceptable
Average depth of GARD emergency storage	3.7 m	4.6 m	Emergency storage ÷ bottom area
Average depth dead + emergency	**8.7 m**	**9.6 m**	Depth remaining at start of emergency

Table 5 - GARD reassessment of dead and emergency storage allowances

The relationship between normal operating storage and reservoir deployable output assuming median climate change is as below, using the same data from the SESRO modelling technical note as used in our Table 2 [39]:



Storage		
Nominal Mm3	**Normal operation Mm3**	**DO Ml/d**
30	28.2	65.5
75	70.5	149.2
80	75.2	155.1
100	94.0	184.6
122	114.7	224.0
125	117.5	229.5
130	122.2	238.6
150	141.0	271.0

Figure 22 - Abingdon reservoir deployable output vs normal operating storage

Combining the changes in normal operating storage shown in Table 5 with the trendline relationship between storage and DO shown in Figure 22, the impact on Abingdon reservoir DO of GARD's proposals for dead and emergency storage is shown in Table 6:

[39] Technical Note Enhanced RSS Modelling of SESRO and Thames to Affinity Transfer Schemes, Table 6-1

	Normal operating storage			
Option	TW	GARD	Difference	DO reduction
150 Mm^3 reservoir	141,000 Ml	116,816 Ml	24,185 Ml	43.8 Ml/d
100 Mm^3 reservoir	94,000 Ml	80,359 Ml	13,641 Ml	24.7 Ml/d

Table 6 - Reservoir DO reduction with GARD proposed dead and emergency storage

With GARD's proposals for dead storage and emergency storage, Table 6 shows that the deployable outputs for the 150 Mm^3 and 100 Mm^3 reservoir would reduce by 43.8 Ml/d and 24.7 Ml/d respectively.

3.5 Conclusions from review of reservoir deployable output

In our opinion, the deployable output of Abingdon reservoir has been grossly over-estimated for WRMP24 and the Gate 2 reports. In addition to failure to properly consider resilience to long duration droughts, we have found the following flaws in Thames Water's deployable output assessments:

	150 Mm^3	100 Mm^3
DO with climate change as WRMP24	271 Ml/d	185 Ml/d
Less Double counting of droughts	-6 Ml/d	-4 Ml/d
Wrong value of Culham MRF	-2 Ml/d	-1 Ml/d
Wrong climate change scenario	-19 Ml/d	-16 Ml/d
Inadequate dead & emergency storage	-44 Ml/d	-25 Ml/d
Corrected Deployable Output	**200 Ml/d**	**139 Ml/d**

Table 7 - GARD proposed changes to reservoir DO (excluding long drought resilience)

In addition, we consider that the deployable output of Abingdon reservoir will be a lot less than shown in Table 7, perhaps only half these values, when proper consideration has been given to the likelihood of a sequence of dry years which prevent the reservoir from being full at the start of a major drought or delay its refilling after a major drought. Thames Water have failed to recognise that their method of generating stochastic flows cannot create long drought sequences and have failed to consider artificial drought sequences as recommended in WRSE's method statement on stochastic climate datasets.

4. Severn-Thames transfer deployable output and operating costs

4.1 TW and GARD assessments of STT deployable output

Thames Water's assessment of the relationship between STT deployable output, transfer capacity and support sources is shown on Figure 2-1 in the Technical Note on Pywr modelling of the STT[40] as copied below:

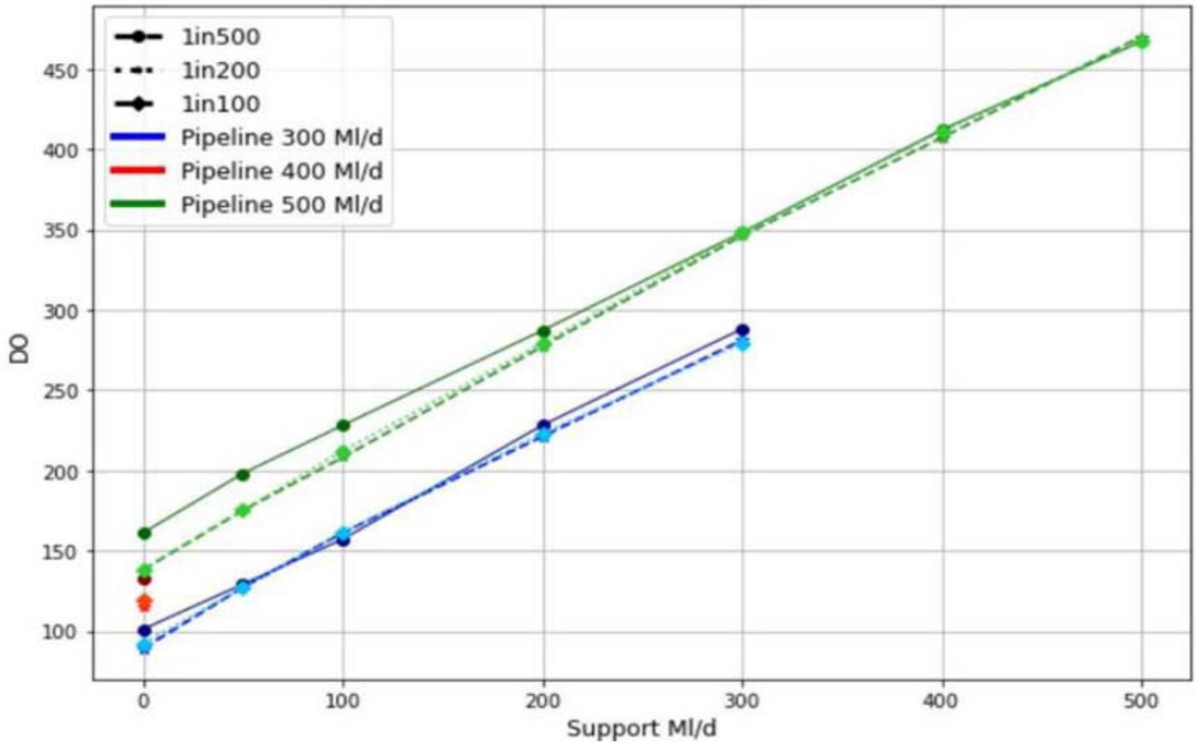


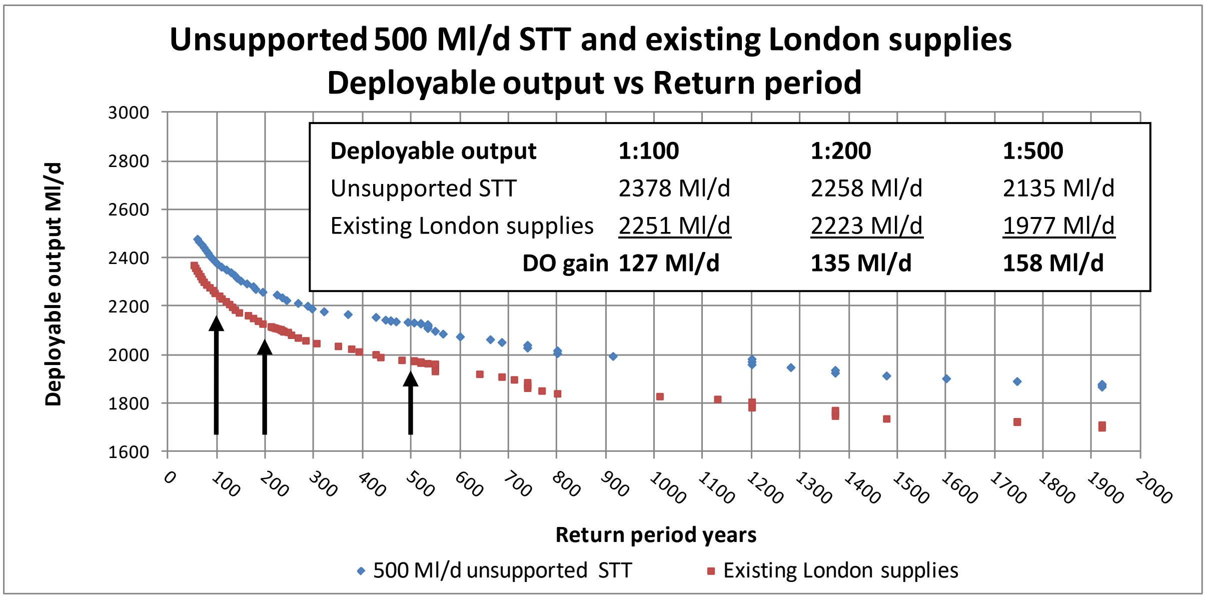
Figure 23 - TW assessment of deployable output of STT options (without climate change)

This plot appears to show that the DO of the unsupported transfer is higher for a 1:500 return period than for the 1:200 and 1: 100 return periods. We have used the Pywr 'Control Line Crossing Data' provided under EIR-22-23-390 [41] [42] to examine the DO gains for the unsupported and fully supported 500 Ml/d transfer options, as shown below:

[40] Technical note Severn-Thames Transfer: use of regional Pywr model to explore DO modelling results, Atkins, June 2022

[41] Excel file 'tw-stt-500-0-london-stochastic-baseline-v4 last day dy-failures'

[42] Excel file 'tw-stt-500-500-london-stochastic-baseline-v4 last day dy-failures'



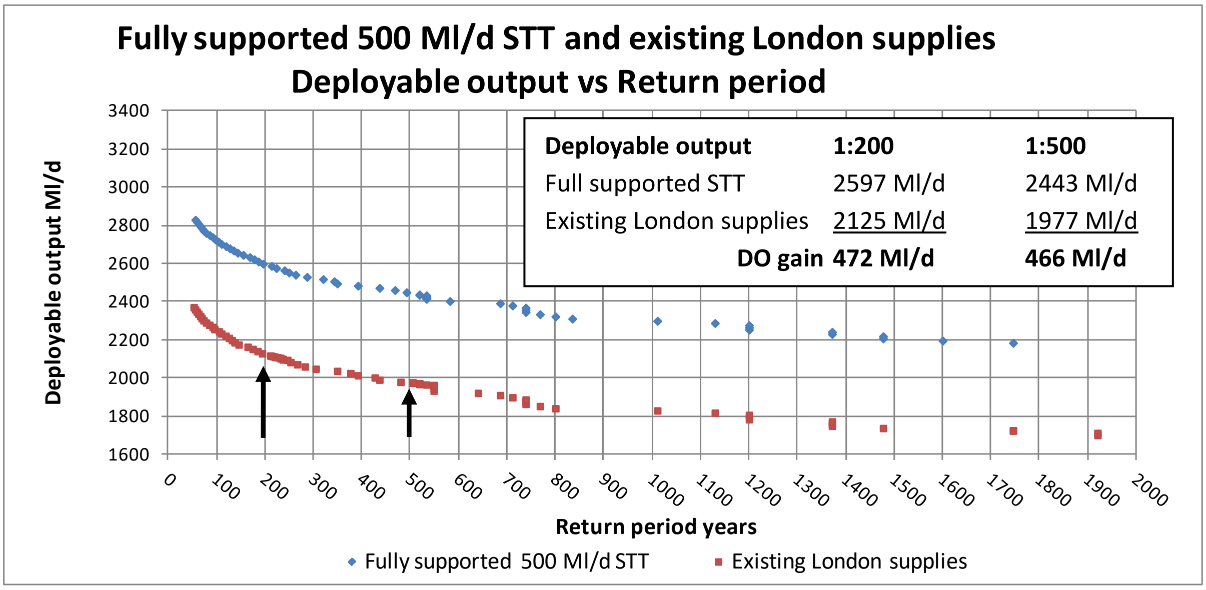
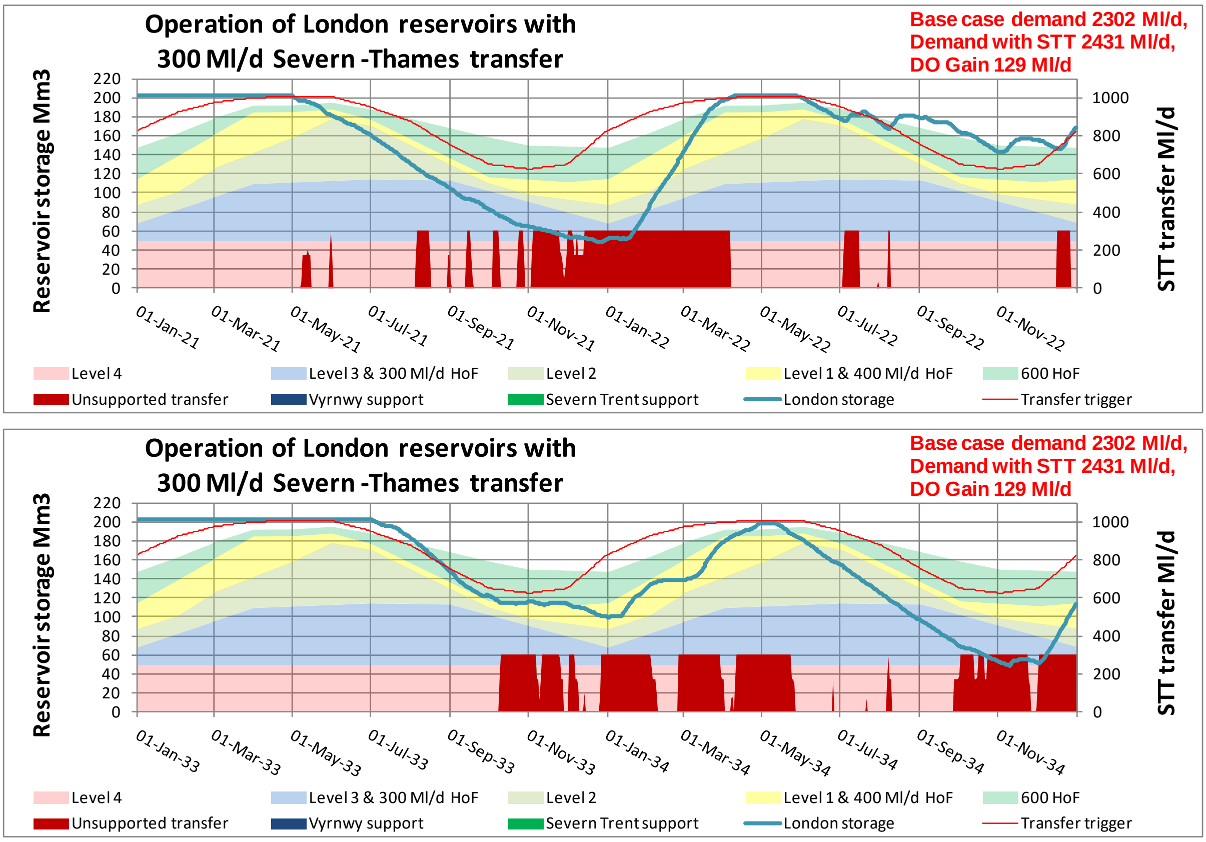


Figure 24 - GARD assessment of 500 Ml/d STT deployable output using Pywr modelling

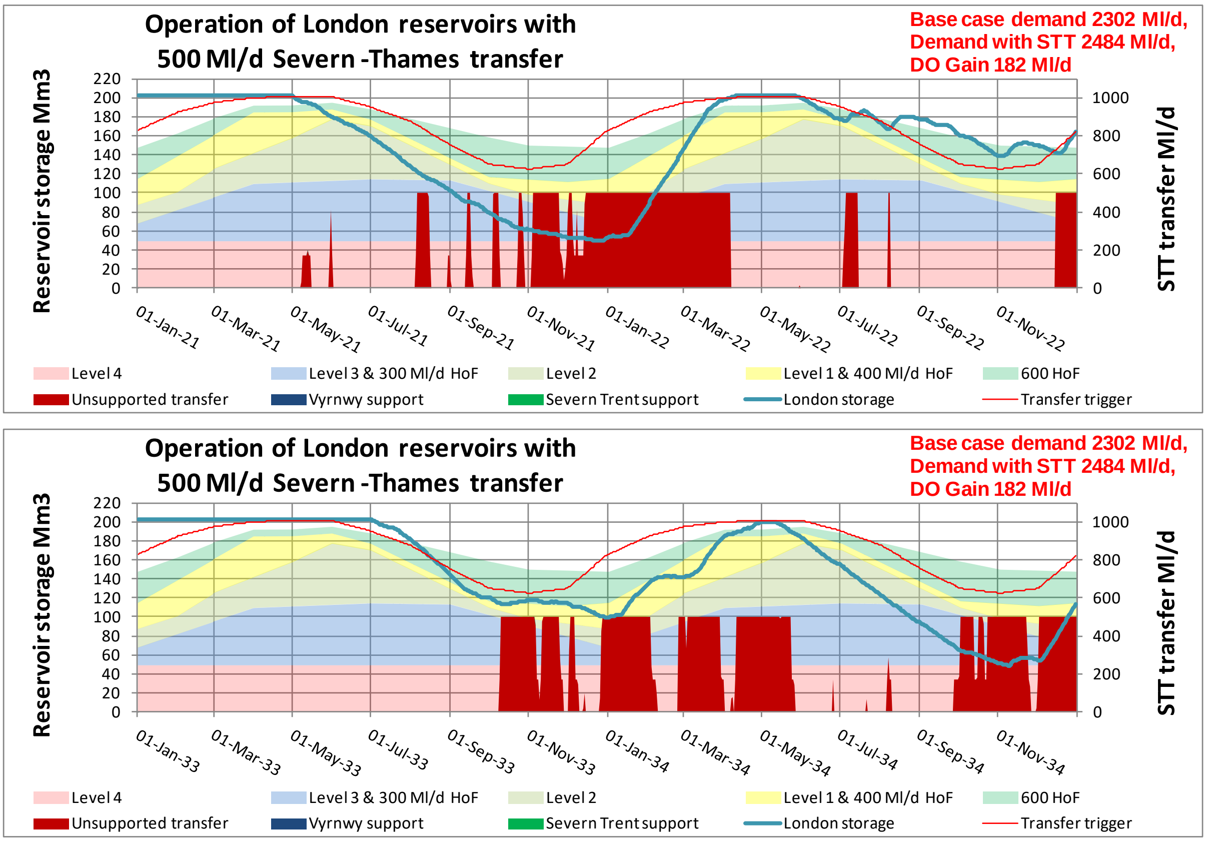
The deployable output gains for the 500 Ml/d STT shown in Figure 24 are a close match to the Thames Water's DO gains for the 500 Ml/d transfer shown on Figure 23, including the unsupported STT's deployable output increasing as droughts become more severe. The inference from this, if correct, is that the unsupported STT is more resilient against extreme droughts than London's existing supplies.

However, the deployable outputs for the unsupported STT shown in Figures 23 and 24 are a lot less than the DOs assessed by GARD's modelling using the historic flow data – the historic droughts of 1921 and 1934 being assumed to be around 1:100 year return period.

The plots below show GARD's modelling of the 300 Ml/d and 500 Ml/d unsupported transfer in the droughts of 1921 and 1934, in each case with London's supplies operating at their full deployable output. There is assumed to be a 20 Ml/d sweetening flow, but no other support.



a) Unsupported 300 Ml/d transfer



b) Unsupported 500 Ml/d transfer

Figure 25 - Operation of 300 Ml/d and 500 Ml/d USTT in droughts of 1921 and 1934

GARD's assessed deployable outputs for the unsupported STT are substantially more than Thames Water's assessments as shown below:

	GARD DO for historic flow records	Thames Water DO for 1:100 return period
300 Ml/d USTT	129 Ml/d	90 Ml/d
500 Ml/d USTT	182 Ml/d	130 Ml/d

Note: Thames Water DOs are estimated from the plot in Figure 23

Table 8 - Comparison of GARD and TW assessments of USTT deployable output

No detailed output from the Pywr modelling of the STT has been made available to GARD, so we are unable to identify the reason for the large deployable output differences shown in Table 8. However, we suspect that the reasons for the differences are deficiencies in the stochastic river flow data:

1. The stochastic river flow data over-estimate the speed of River Thames flow recovery after extended summer droughts, as shown by Figure 5 of this Addendum and the following text.

2. As described in Section 2.2 of this Addendum, the stochastic river flow data fail to generate long duration droughts.

3. These deficiencies in the stochastic data negate the unsupported STT's ability to provide substantial refill of the London reservoirs during long droughts, for example as shown for the drought of 1933-34 shown in Figure 25. This benefit of the unsupported STT is due to differences in geology of the Thames and Severn catchments – flows in the Severn recover much faster in the autumn, compared to flow recovery in the Thames which is delayed by the large amount of pervious limestone and chalk bedrock in the catchment.

The deployable output differences shown in Table 8 are highly significant because the unsupported transfer would be a viable first phase of the STT, not dependent on the Minworth or Vyrnwy support sources, and the additional London deployable output would allow all the Chilterns chalk stream abstraction reductions to go ahead as soon as the Severn to Thames aqueduct is built, potentially in the early 2030s.

GARD's assessed deployable outputs for the unsupported STT shown in Table 8 assumed no benefit from the 35 Ml/d Netheridge support source, apart from the provision of the 20 Ml/d sweetening flow[43]. If the full 35 Ml/d enhancement of Severn flows is included as a support source available at all times, the London deployable outputs for the unsupported transfer are increased to 139 Ml/d for the 300 Ml/d transfer and 193 Ml/d for the 500 Ml/d transfer. We note that, if the DO gain at 1:500 is higher than the DO gain at 1:100 as shown in Figure 23, the DOs for the unsupported transfer could be even higher.

[43] STT feasibility and concept design report, Section 3.1, page 5

The under-estimation of DOs for the unsupported transfer will also affect the DOs for options with modest amounts of support, although the amount of under-estimation will diminish as the amount of support increases.

4.2 Need for UU replacement sources for Vyrnwy support option

We have found no clear statement in the WRMP documentation or Gate 2 reports for the amount of United Utilities replacement sources needed if Vyrnwy reservoir is used to support the STT. The Gate 2 feasibility report on the North West transfer refers to the replacement sources as 'sub-options' and recognises that they will not be needed continuously[44]:

> *"Allowing this indirect type of trading support helped us to reduce the capacity of [sub-] options required for trading well below the total transfer amount (167 Ml/d versus 205 Ml/d)."*

However, this is still suggesting that about 80% of the nominal Vyrnwy support amount will need to be replaced by deployable output from the new sub-options. GARD's modelling shows that this is not the case, as illustrated below in plots of modelled operation of Vyrnwy reservoir in the droughts of 1933/34 and 1975/76:

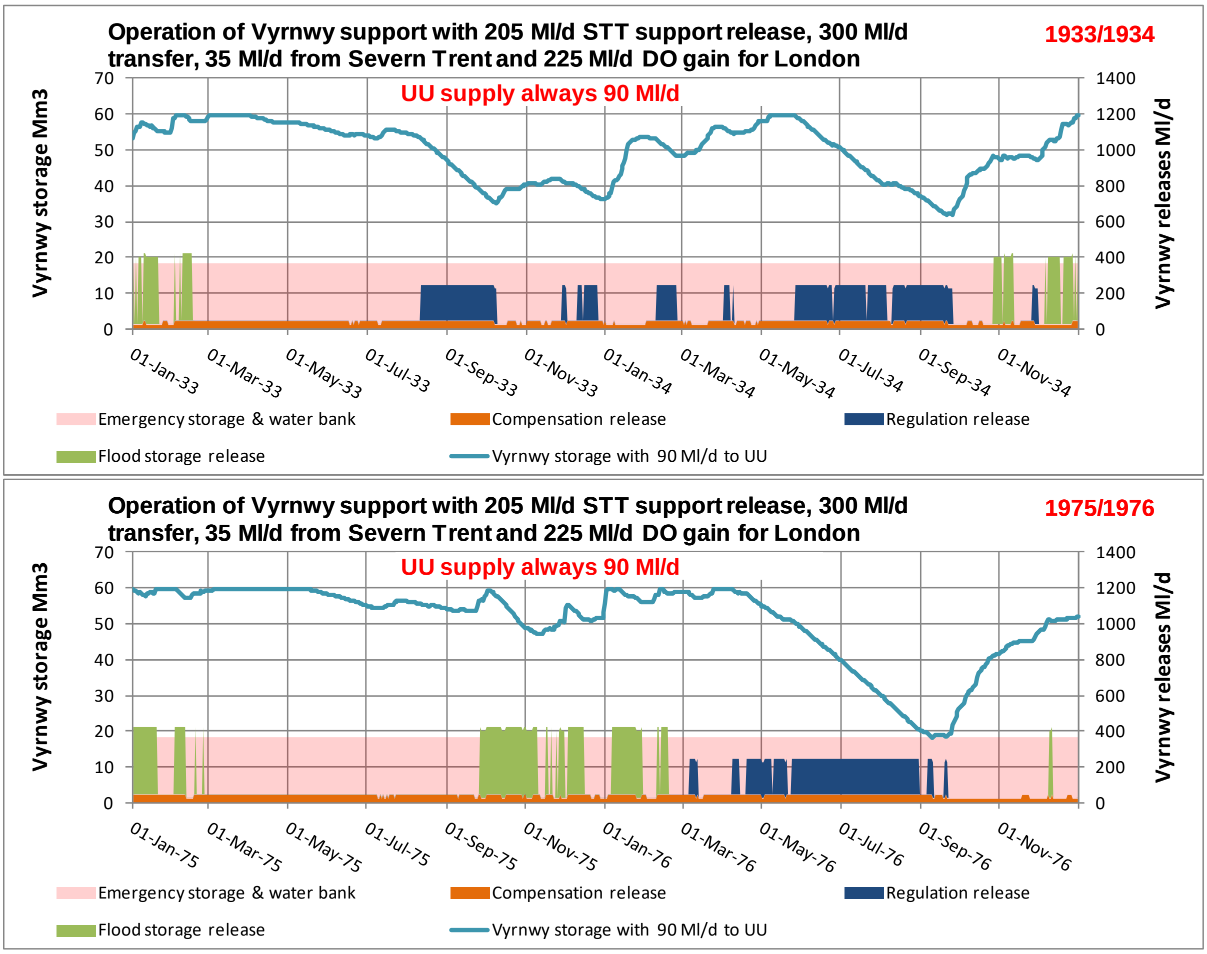


Figure 26 - Potential UU supplies from Vyrnwy while supporting STT

[44] NW Transfer Gate 2 feasibility report, paragraph 4.17

The upper plot shows that in the drought of 1933/34, usually the critical historic drought for the reservoir when supplying United Utilities, it can easily sustain a continuous supply to United Utilities of 90 Ml/d, as well as providing 205 Ml/d of support to the STT when needed. The lower plot in Figure 26 shows that 90 Ml/d is the deployable output to UU that can just be sustained in the 1975/76 drought, in addition to the 205Ml/d support to the STT – in this scenario, 1975/76 is the critical historic drought.

The deployable output of Vyrnwy reservoir when used for continuous direct supply to United Utilities is about 190 Ml/d (from GARD's modelling). Therefore, the sub-options needed to replace United Utilities deployable output lost when providing 205 Ml/d of support to the STT are only about 100 Ml/d (190 Ml/d less 90 Ml/d), not 167 Ml/d as stated in the NW Transfer feasibility report.

In the WRMP documentation and the Gate 2 reports we have founded no statement of the amount of sub-option replacement sources assumed when costing STT options with Vyrnwy support. If options with 205 Ml/d of Vyrnwy support have assumed 167Ml/d of sub-options are needed, rather than 90 Ml/d as shown by our modelling, the STT option cost will have been inflated by the capital and operating costs of an unnecessary 77 Ml/d of replacement sources. If the costing assumption has been 1:1 replacement sources for the nominal amount of Vyrnwy support, as we suspect has been the case, the inflation of the STT option costs will have been even higher. The lack of clarity of the assumed amount of replacement sources is a major failure of transparency in the WRMP and Gate 2 documents.

4.3 Modelling of STT use for operating costs

In the WRMP and Gate 2 documents we have found no statement of the assumed annual amounts of STT operation for assessing operating costs. No time series data have been supplied for Pywr modelling of operational use of the STT. This is another failure of transparency, particularly as the high pumping costs and energy use of the STT are frequently touted as factors against the scheme.

4.4 Conclusions on STT deployable outputs and operational use

Thames Water have grossly under-estimated the deployable output of unsupported STT options. Our modelling shows that the 1:100 year DO of the unsupported 300 Ml/d transfer should be 139 Ml/d compared to Thames Water's figure of about 90 Ml/d. For the 500 Ml/d unsupported transfer, we estimate the 1:100 year DO to be 182 Ml/d compared with Thames Water's figure of about 130 Ml/d.

Thames Water's under-estimation of deployable outputs is highly significant because the unsupported transfer would be a viable first phase of the STT, not dependent on the Minworth or Vyrnwy support sources. The additional London deployable output from unsupported transfers would allow all the Chilterns chalk stream abstraction reductions to go ahead as soon as the Severn to Thames aqueduct is built, potentially in the early 2030s.

The reason for Thames Water's underestimation of deployable outputs appears to be inadequacies in the stochastic river flow data which over-estimate the speed of flow recovery in the River Thames after long droughts and under-estimate the frequency of occurrence of long droughts. These deficiencies negate the unsupported STT's ability to provide substantial refill of the London reservoirs during long droughts, due to differences in geology between the Thames and Severn catchments.

Thames Water appear to have assumed that at least 80% of the nominal support from Vyrnwy reservoir will require replacement of deployable output through new United Utilities sources. GARD's modelling shows that only about 50% replacement deployable output is needed. This would mean that the cost of STT options with Vyrnwy support have been inflated by the cost of up to about 70 Ml/d of unnecessary replacement sources.

Appendix A - Correspondence regarding Addendum timing

From: John Lawson [mailto:johndlawson123@gmail.com]
Sent: 29 March 2023 13:38
To: 'Anthony Owen'
Cc: 'gard.chair'
Subject: RE: Timeline for review of datasets

Hi Tony

OK, I can send "draft key findings" as best I can by 14th April, aiming at least to identify where our concerns lie, with some supporting evidence.

I'm finding some things I don't understand in the Pywr data. Is it OK for me to contact Peter direct about these? They are probably things that he can answer immediately and easily, so if he can reply quickly that will help.

Regards

John

From: Anthony Owen [mailto:anthony.owen@thameswater.co.uk]
Sent: 29 March 2023 10:59
To: John Lawson
Cc: gard.chair
Subject: RE: Timeline for review of datasets

HI, John, thank you for the detail you have sent through. Best laid plans of the timing of holidays always seem to have a problem or two!!

We are obviously under some time pressure too with the other water companies linked to SESRO (Affinity and Southern) expected to send out their Statement of Response documents in mid-May, and also WRSE's at the same time. Any alignment will be key and the time they need for their governance processes too.

Can I suggest a compromise:

Can I ask you to send your draft key findings to Thames Water before your holiday, and then GARD sends your full write up as early as you can but no later than the end of April.

We will do all we can to take account of the GARD response addendum in our Statement of

Response.

Rgds
Tony Owen

From: John Lawson <johndlawson123@gmail.com>
Sent: 28 March 2023 14:55
To: Anthony Owen <anthony.owen@thameswater.co.uk>
Cc: gard.chair <gard.chair@gmail.com>
Subject: RE: Timeline for review of datasets

Dear Anthony

Thanks for the direct approach. I appreciate that you need time for your turn around, but I also need time to assess your Pywr data, align my modelling and use my analysis to provide evidence to back up whatever further comments GARD may have on deployable outputs and operating costs of the various options.

I got busy on this as soon as I eventually downloaded the outstanding Pywr data (I had already done what I could with the data I had been able to access). It is going well so far (my model replicates Pywr output quite well), but it is going to take time. Therefore, even working over the Easter break, I really need until the end of April to do what I need to do and then to work with GARD to turn it into an addendum to the initial consultation response. Matters are complicated by my being away from 14th April to 23rd April on a long booked and immoveable holiday.

Although it will take me quite a lot of time to do the analysis, I don't envisage GARD's addendum being very long (maybe 10-20 pages including lots of plots??), so I don't think Peter would need 2 weeks to review it.

So where does that leave us?

Regards

John

From: Anthony Owen [mailto:anthony.owen@thameswater.co.uk]
Sent: 28 March 2023 14:20
To: John Lawson
Subject: Timeline for review of datasets

Hi John,

I have been asked to provide a deadline to confirm when GARD need to complete their consultation response and thought it may be better to check with yourself as it comes down to the time you need to review these datasets that for various reasons have taken a while to land in your in-tray.

I hope this it is OK talking directly to you as I thought it may help us get to an date with less emails. If not please let me know…..

Currently I have suggested April 6th (Thurs before bank holiday) and Derek has requested end of April. Peter has suggested your review may take around 2 weeks to review. I am aware that the longer the timeline the more difficult it is for me to include in our findings, as the turn around required into Statement of Response and WRSE is quite quick.

So, it would be useful if you were able to provide me your view please, and I can work from there.

Thank you in advance……

Rgds
Tony

---------- Forwarded message ---------

From: Anthony Owen <anthony.owen@thameswater.co.uk>

Date: Fri, Mar 24, 2023 at 11:23 AM

Subject: GARD - Window to update of Section 4.2

To: gard.chair <gard.chair@gmail.com>, Lesley Tait <lesley.tait@thameswater.co.uk>

Cc: Peter Blair <Peter.Blair@thameswater.co.uk>, John Lawson <johndlawson123@gmail.com>, Lana Kraine <Lana.Kraine@thameswater.co.uk>

Hi Derek,

I believe John now has access to the datasets.

We have also received your consultation response. Thank you for that. And as you noted you have one section left to complete.

To allow yourselves more time to review I suggest you provide this by Noon on Thursday April 6th.

I ask that you only update the relevant section, being "Section 4.2 on the Abingdon Reservoir Deployable Output and Drought Resilience ", and do not change any others parts of the document.

Thank you Derek.

Rgds

Tony

From: Derek Stork <gard.chair@gmail.com>
Sent: 17 March 2023 09:50
To: Lesley Tait <lesley.tait@thameswater.co.uk>
Cc: Peter Blair <Peter.Blair@thameswater.co.uk>; Anthony Owen <anthony.owen@thameswater.co.uk>; John Lawson <johndlawson123@gmail.com>
Subject: Re: FW: Stochastic flow data used in Pywr modelling

Dear Lesley,

WIthout going into our version of the timescale vs yours, I think your suggestion is a sensible way forward, and GARD therefore accepts the proposal.

So, to be clear, we will submit our response on 21st March, and, irrespective of whether the data has arrived or not, the response will exclude the analysis of the Stochastic time series results.

We will then come to an agreement with you when we receive the data, on the timescale for our addendum response.

I hope this problem with the data will be solved as soon as possible.

with best regards,.

Derek
Dr D Stork CPhys FInstP,
Hon Chairman,
GARD

On Thu, Mar 16, 2023 at 4:41 PM Lesley Tait <lesley.tait@thameswater.co.uk> wrote:

Dear Derek,

Thank you for your reply.

My understanding is this:

09 February: TW provided access to a SharePoint (SP) site for John to download the time series data that had been requested alongside data that was shared by TW via a secure file transfer. TW EIR team notified John by email and asked John to contact TW if there were any access issues.

- 01 March: John raised technical queries in relation to the Pywr model output and accompanying note.
- 11 March: Peter Blair responded to John's technical queries. The nature of some of the queries signalled to Peter that John had not reviewed the time series data that had been provided to John via SP.
- 11 March: Following email dialogue between Peter and John, John identified the email sent by TW on 09 February giving access to TW's SP site was in his Spam, however when John tried to download the files from the SP site the time period of 30 days had been exceeded.
- 13 March: TW sent a new SP link to John, however this link is not working. There is currently an issue with Microsoft and external users accessing TW's SP site that TW is working to resolve with Microsoft and as a result John has not been able to access the SP site and obtain the requested data. We are working with TW IT department and Microsoft to resolve this issue and share the data with John as soon as is possible.

In terms of the extension to the consultation deadline, whilst we are content to consider an extension for this aspect of GARD's response in view of the difficulties John has had in accessing the data provided, my concern is that we need sufficient time to give due consideration to the addendum to GARD's response within the statutory timeline to produce the Statement of Response, which is 13 June 2023 for Thames Water and mid May for the other SE water companies, and as you know we are working collaboratively to ensure a regional approach to the long term planning of water resources.

My suggestion therefore is that GARD submit their response to TW's consultation by the deadline of 21 March 2023 and include a note that GARD want to complete further review of the deployable output assessment once it has access to the time series data, and we then revisit the timeline for the addendum when GARD has received the additional data requested.

With best regards

Lesley

From: GARDchair <gard.chair@gmail.com>
Sent: 16 March 2023 15:00
To: Lesley Tait <lesley.tait@thameswater.co.uk>
Cc: Peter Blair <Peter.Blair@thameswater.co.uk>; Anthony Owen

<anthony.owen@thameswater.co.uk>; John Lawson <johndlawson123@gmail.com>; Amanda Jones <Amanda.Jones1@thameswater.co.uk>
Subject: RE: Stochastic flow data used in Pywr modelling

Dear Lesley,

Thank you for your email, and I note your offer.

However, I note that, apart from the fact that the first request for this data was made on 20th December:

- We do not yet actually have the data; and
- It will probably take us 4 weeks to analyse it when it arrives. That makes it already too late to comply with your offer.

My view is that we should be given 4 weeks from receipt of the data. Alternatively, We could submit our response on this particular item on 11th May, the deadline date of our submission to RAPID's representation on their draft Determination for Gate 2.

I think the best course of action is to for you to continue to try and get us the data asap, and for us to note in our submission that the response on this topic has been held up by Database issues at TW (in a 'no-fault' statement of the facts) and that we will be submitting at a further date to be notified.

With best regards,

Derek
Dr D Stork CPhys FInstP,

Hon Chair

GARD

Sent from Mail for Windows

From: Lesley Tait
Sent: 16 March 2023 13:01
To: gard.chair
Cc: Peter Blair; Anthony Owen; John Lawson; Amanda Jones
Subject: FW: Stochastic flow data used in Pywr modelling

Dear Derek,

Thank you for your email.

Recognising the challenges in sharing the data with John, we'd be happy to extend the deadline for GARD's representation to Thames Water's consultation on the dWRMP in regard to feedback on the deployable output assessment until Monday 27th March 2023 @ 10am.

We are working to a statutory timetable to consider all the representations received to the consultation, changes to our draft plan in response and produce a formal response to the consultation, and we need to work closely with WRSE and the other SE water companies as we complete this work. We are required to publish our Statement of Response to the consultation on 13 June 2023, and WRSE and the other SE companies will publish their respective responses in mid-May, as such the timeline is tight and we want to ensure we have sufficient time to give all responses full consideration. I trust this provides sufficient additional time to enable GARD to complete its review and appraisal of the deployable output assessment. Please let me know if this is acceptable.

As per your email, we ask that GARD submit the rest of their representation by the closing date of the consultation on 21st March 2023.

Best regards

Lesley

Appendix B - information requests and correspondence

1. Original data request at time of WRSE's emerging regional plan

From: John Lawson <johndlawson123@gmail.com>
Sent: 19 January 2022 17:49
To: Admin at WRSE <wrsefiles@wrse.org.uk>
Cc: Trevor Bishop <trevor.bishop@wrse.org.uk>; Blackwell, Richard <Richard.Blackwell@uuplc.co.uk>; Lesley Tait <lesley.tait@thameswater.co.uk>; Thomas, Gareth/COT <gareth.thomas@jacobs.com>; 'Paul Hickey' <Paul.Hickey@ofwat.gov.uk>; 'DerekBT' <derek.stork@btinternet.com>; 'John Broadbent' <Johnrbroadbent@gmail.com>
Subject: GARD data request No DR3: Deployable output of existing and proposed London supplies

Dear WRSE contact

Figure 2.6 of Annex 4 shows 'utilisations' of the proposed strategic options for Thames Water. The quoted values of utilisation for the major resource options are 293 Ml/d for Abingdon reservoir and 292 Ml/d for the Seven to Thames Transfer (STT). The footnote to Figure 2.6 says that the STT value is made up of a number of schemes and that the quoted Ml/d figures are the maximum utilisation across the planning period. In this context, we assume that 'maximum utilisation' is synonymous with 'dry year annual average deployable output (DO)'.

We have seen WRSE's method statements for deployable output, stochastic data, hydrological modelling and regional simulation modelling, plus the scoping report for regional simulation modelling. From these reports, we assume that the 1:500 year DOs of existing supplies and strategic options have been determined by running the 19,200 years of daily stochastic data in the 'Pywr' regional system simulation model and determining the demand that can be satisfied in 499 years out of 500, ie 38 years of failure in 19,200 years.

We would like to see Pywr output for these three scenarios:

- Existing Thames Water supplies for London at the deployable output assumed as for the central estimate for WRSE's plan (is this 2305 Ml/d as for WRMP19?)
- Existing supplies with Abingdon reservoir operating with the quoted DO gain of 293 Ml/d
- Existing supplies with the STT operating with the quoted DO gain of 292 Ml/d

We would like to see the full 19,200 years of Pywr output for these three scenarios, but appreciate that at a daily time step this would be too much data for Excel. Therefore, please could we see the model output at a weekly time step which would fit on a normal Excel spreadsheet. We have not previously seen any Pywr output, so it is difficult for us to know what is available. However, for these three scenarios, please could the following weekly data, or something similar, be included on the spreadsheets for the full 19,200 years:

For existing London supplies:

- River flows upstream of Teddington and Feildes Weir
- Demand and supply (after restrictions as per service levels)
- River abstractions to fill the reservoirs, with the Thames and Lea reservoirs shown separately
- Outflows from reservoirs to supply
- Reservoir storages
- Transfers in the Thames Lee tunnel
- Reservoir evaporation
- Supply outputs from all other sources, with groundwater sources, desalination, NLARS, and WBGWS shown separately
- Bulk supplies in and out

In addition to these data at a weekly time step, please could we see the full Pywr output at a daily time step, in a format equivalent to WARMS2 output, for the critical drought at which the existing system is just able to meet the assumed existing DO.

For Abingdon reservoir (without the STT):

Please could we see the same model output for existing supplies that we have described above, plus the following for Abingdon reservoir delivering a DO gain of 293 Ml/d:

- River flows upstream of Culham
- Inflows and outflows from Abingdon reservoir
- Reservoir storage
- Reservoir evaporation
- Transmission losses between Culham and London
- Bulk transfers supported by Abingdon reservoir, eg to Affinity Water and Southern Water

In addition to these data at a weekly time step, please could we see the full Pywr output at a daily time step in the critical drought for the system with Abingdon reservoir.

For the Severn to Thames transfer (without Abingdon reservoir):

Please could we see the same model output for existing supplies that we have described above, plus the following for the STT delivering a DO gain of 292 Ml/d:

- Inflows to Vyrnwy reservoir
- Outflows from Vyrnwy reservoir, showing separately compensation flows, regulation for STT, supplies to UU, flood releases and environmental releases

- Vyrnwy reservoir storage
- Vyrnwy reservoir evaporation
- Other new Severn support releases, eg from Mythe
- Transmission losses in Severn
- Severn flow upstream of Deerhurst
- Transfer to STT including sweetening flows
- Transmission losses to London
- Bulk transfers supported by the STT, eg to Affinity Water and Southern Water

In addition to these data at a weekly time step, please could we see the full Pywr output at a daily time step for the STT option in the critical drought for the system with the STT.
Please could we also see a copy of the report or reports which describe the modelling used to generate the deployable outputs assumed in WRSE's plan. We would expect this report to include details of climate change assumptions and operating assumptions for service levels, reservoir control diagrams, abstraction constraints, etc

We note from Figure 2.6 of Annex 4 that from 2040 onwards WRSE's plan assumes that both Abingdon reservoir and the STT are in operation, with the STT introduced in several phases. WRSE's regional plan does not appear to say whether or not Abingdon reservoir and STT DOs can simply be added to give a combined DO. If the plan is assuming that the DO of Abingdon reservoir and the STT operating in conjunction is significantly more than the sum of the individual DOs, please could we see the model output that justifies this.

We appreciate that this data request might be onerous for you to provide and some of the information might not be readily available. Therefore, perhaps we should quickly arrange a Teams discussion to determine how you can meet GARD's needs with minimum work for yourselves.

Regards

John

2. Meeting to discuss availability of model output in April 2022

From: John Lawson [mailto:johndlawson123@gmail.com]
Sent: 11 April 2022 09:42
To: 'Anthony Owen'; 'EIR Requests'
Cc: 'Peter Blair'; 'gard.chair'; 'John Broadbent'
Subject: RE: GARD Meet RE: EIR-21-22-749 Mr Lawson

Dear Tony

Thanks very much for these notes, which I agree as a record of our discussion. It was good to have had an open and quite informal technical discussion.

I have some comments and queries on the Actions listed with I have marked with tracked changes on the attached version.

I look forward to soon receiving the promised data for the control curve crossing points for the existing supplies on their own, the SESRO option and the 300/200 STT option.

As a general comment, I am surprised that so little Pywr data is being recorded for each run. I understand the concern about the volume of data and storage requirement, but it seems to me that the minimal data that you record leaves Pywr operating as a "black box" with little ability to get a feel for what the output means or apply commonsense checks. For example, if the only London system output that is recorded is the data for the LTCD control line crossings, there is no means of checking the operation of the numerous drought sources (Gateway desal, NLARS, WBGWS, etc) or whether in the incoming Teddington and Feildes Weir flows look sensible.

Anyway, I am optimistic from the meeting notes that more data will be provided for the DO runs and look forward to hearing when I can expect them.

Regards

John

John Lawson and Thames Water Meet

31st March 2022

Held by Teams meeting

Attendees:

John Lawson: GARD
Peter Blair: Thames Water
Tony Owen: Thames Water
Subjects John Lawson asked to cover:

1. No model output provided for existing supplies for London's current DO, of c.1964Ml/d
2. Output for STT and SESRO model runs – did not include the storage for existing London reservoirs
3. No flows for Feildes Weir or Teddington Semi-Naturalised provided for any runs
4. Report on validation of Pywr via WARMS

During the session Peter Blair provided a summary of the hydrological and water resources simulation modelling undertaken. In summary:

- At WRMP19 TW used WARMS2 (Aquator model) alongside IRAS to undertake DO modelling

- WARMS2 involves inputs of rainfall, PET and naturalised flow at Teddington Weir and Days Weir
  - WARMS2 contains rainfall-runoff models (benefit of this is an ability to dynamically model river flows, disbenefit is a speed penalty)
  - WARMS2's geographical extent is the whole of the Thames catchment, including areas in which water is supplied by Affinity Water and others, meaning that abstractions such as Farmoor dynamically influence flows arriving in London
  - i.e., Semi-naturalised flow at Teddington and Feildes Weir are outputs from WARMS2 and cannot be obtained without running the model
  - IRAS's geographical extent is only London, meaning that abstractions in other zones do not influence flows arriving in London
  - IRAS requires river flows inputs directly and does not contain rainfall-runoff models
  - i.e., Semi-naturalised flow at Teddington and Feildes Weir are inputs to WARMS2
- For WRMP24 TW are using a pywr (pronounced 'pie-W-R', or 'pie-weir' or 'pie-whirr') model
  - WRSE pywr model's geographical extent for TW involves broadly the same extent as WARMS2. This includes, for example, SWOX WRZ, and so means that abstractions at are Farmoor dynamically included
  - Pywr model does not include rainfall-runoff models and so requires river flows as an input
  - As such, the pywr model has inputs of river flows and denaturalising influences associated with groundwater abstraction, but considers other denaturalising influences, such as surface water abstraction and effluent returns, dynamically
  - As such, semi-naturalised flow at Teddington and Feildes Weir are outputs from pywr
- This means that item 3 above is an output from the pywr model, rather than an input.

Peter also summarised the reasons for not having sent further data relating to items 1, 2, and 3 listed above – these reasons are: the only data needed to calculate DO is annual 'control curve crossing' (e.g. during each year of the stochastic record a non-zero/zero for the 'L4' control curve indicates whether the 'Level 4' control curve has/has not been crossed) – due to the other reasons listed below only this 'control curve crossing' data was saved during each DO run (i.e. the minimum amount of data needed to calculate DO was saved); a single daily 19,200-year timeseries requires approximately 80MB storage if using a csv format (e.g. Deerhurst flows file, as sent) – if we were to save, e.g., 30 timeseries at 50 demand levels from a given DO run, this would mean a total storage requirement of 120GB per DO run (John noted that it would be possible to re-run the model at a single level of demand after 'DO' has been found which is true but was not done, and would still entail a significant storage requirement, c.2GB per DO run if saving 25 timeseries per run, if carried out for all DO runs); application of ‘recorders’ (which are applied to ‘tell’ the pywr model to save a particular dataset) slows the model down – one of the reasons for pywr’s speed is its default setting of saving no outputs; applying recorders is not as trivial as in Aquator as it requires script writing/editing . We have sent all data that was requested which is available to us (noting that additional data was discussed during the meeting, e.g. yearly ‘control curve crossing’ data, and John requested that these be made available), but unfortunately this has meant that the further data (items 1, 2, 3 above) that John has requested has not been stored.

Under EIR Thames Water is not required to provide any data it has not stored. As we understand John’s need for the data requested to be provided at least a few months before draft WRMP24 submission during November 2022, we will look to test our, being consultants and water companies, ability to supply. Please note that provision of this data requires:

- Thames Water resource and consultant resource time, and note it is the consultants at this time who manage the pywr model on behalf of a number of water companies.
- Non-trivial time input to add ‘recorders’ and conduct specific re-runs
- In some cases, other water companies to also allow release.

Note: during the meeting we reviewed the EIR letter 21 22 749 covering DR03 sent to John describing data sent/not sent on February 19 and replied to with comments by John on 3 March.

Actions recorded:

H. Output data needed to calculate DO is recorded on a yearly basis (as described above) where reservoir storage crosses various control curves. Data with consultants. Send for Baseline London DO, 150Mm3 SESRO DO run, and two STT runs (500Ml/d unsupported and 500Ml/d with 200Ml/d support available at Deerhurst) at their respective DO figures. Please could you provide the control curve crossing data to match the STT output data you have already supplied ie 300 Ml/d capacity transfer with 200 Ml/d of support. Please could you also tell me what the London deployable output gain was for the 300/200 output you have already supplied.
I. Reports on Pywr model.
    a. Report available covering development of model. TW to check if on WRSE website and if not, and signed off by WRSE, to send. I can’t find this on WRSE’s web-site, so please could you send it.
    b. Pywr validation model. Not available at this time. Will be sent and/or placed on WRSE website once produced and signed off at a later date.

J. Plots of reservoir storage are available from historical pywr model validation runs. TW to send.

K. River flows at Teddington Weir and Feildes from DO runs (Base, STT, SESRO), along with all other requested pywr model outputs. At present we do not have these (as noted above). TW to review ability to send and timing – see point G. I presume you mean point F.

L. Reference to WRPG in letter sent to John Lawson 16th February. Section 5.3 of WRPG: *Your deployable output should not include the contributions from any demand or supply drought measures such as drought permits or orders.* I continue to be unsure of this point, so please could you clarify:
   - Does your modelling allow for the demand savings for NEUBs etc as was the case in WARMS2 modelling, or do some of these measures require a DP or DO?
   - Does your modelling allow for the progressive reduction of the Teddington HoF in droughts to 600, 400, 300 Ml/d, or does some of this require a DP or DO?
   - Do any of your 'drought schemes' require DPs or DOs thereby excluding them from your DO assessments – Gateway desal, NLARS, WBGWS, etc?
   - Please could you send me a PDF copy of the WRPG guidelines – I can't find a downloadable PDF on the web.

M. Need to check with consultants regarding their availability to conduct modelling . TW will check with consultants etc and respond.

3. GARD information request on 12th December 2022 and TW response

Thames Water Utilities Limited
EIR Requests
Clearwater Court
Vastern Road
Reading
Berkshire
RG1 8DB

Email: EIR.Requests@thameswater.co.uk

26 January 2023

Our Ref: EIR-22-23-390

Environmental Information Regulation (EIR) Request

Dear Mr Lawson

Thank you for your e-mail dated 12 December 2022. Please see our response below to your request as set out in your e-mail.

Your Request

Now that the Thames Water WRMP24 is imminent, I would like to re-open our request for modelling information. Our last exchange on this subject was as per the email below dated 11th April, including the attached note of our last meeting with my comments at that time. Although you said in the meeting notes that you would undertake various follow-up actions, I don't think that I received anything more from you.

Please could you provide up-dated versions of all the stochastic data and modelling files that you previously supplied in February 2022, as listed in the attached Word document. In the case of the STT utilisation file, please could this be for the full 500 Ml/d transfer version, with support from Vyrnwy, Minworth, Shrewsbury, Netheridge and Mythe.

Please could you also provide the following, including responses to the matters raised in my comments on the attached meeting note, namely:

1. Pywr model output provided for existing supplies for London's current DO, previously quoted as c.1964Ml/d.

2. An explanation of why the Pywr DO for London's existing supplies doesn't match the DO of 2296 Ml/d quoted in paragraph 403 of the June 2022 Annual Review of the WRMP:

   "403. Implementing the new Aquator XV software has resulted in the London WRZ DO increasing from 2291 Ml/d to 2296 Ml/d".

3. Please could you provide Aquator XV output for the existing 2296 Ml/d DO in the same format as previously supplied WARMS2 output of the existing London DO (previously 2305 Ml/d for WRMP19).

4. Please could you provide the Pywr London reservoir control curve crossing data to match the STT output data you supply, ie the full 500 Ml/d version as above. Please could you also tell me what the London deployable output gain is for this STT version.

5. Please could you provide the full report or reports on the Pywr modelling, including its validation details and description of how it was used to assess deployable outputs for your main SROs including SESRO, STT, Teddington DRA T2AT and T2S. In the case of the Thames to Southern (T2S) Pwyr output, please could this include the full Pwyr output of the amounts transferred.

6. Please could the stochastic data include the flows upstream of the main lower Itchen and Test abstraction locations.

7. Please could you provide the latest version of the LTCD and clarify which monthly demand reductions and Teddington HoFs are triggered by the various control lines.

8. Please could you clarify which Drought Permits and Drought Orders are now assumed to apply in your London DO assessments.

9. Please advise any changes in the operating rules for the 'strategic schemes' since the WRMP19 DO modelling, i.e. the operating rules for Gateway desalination, NLARS, WBGWS, etc.

Our Response

Note: For a number of the items requested below we have sent you datasets of varying sizes. Although these datasets have been checked there may be remaining anomalies or errors. If anything is found, please inform us at your earliest opportunity.

Before itemised requests, you requested updated versions of data previously provided.

Regarding the data sent previously:

- DR1 (Environmental Destination) – we believe you have requested (and have been sent) this data through WRSE, is this correct?
- DR2 – flow data for the River Severn and River Thames – no updates
- DR3 – Timeseries outputs from STT and SESRO runs – no updates
- DR7 – Effluent returns - no updates

Item 1 – Pywr Model Output for London DO

'Control Curve Crossing' and timeseries outputs from a run of the London model have been sent. The 'control curve crossing' data includes detail of the resultant DO calculation (1 in 500-year L4 DO being the key output). The timeseries outputs provided are for a demand level of 1971 Ml/d.

Notes:

• As discussed in our meeting last year, we were previously unable to provide time series outputs from the Pywr model without asking consultants to undertake model runs on our behalf.

• We have now received a copy of the Thames Water element of the WRSE pywr model, and so are able to undertake model runs using TW sub-models.

• The WRSE pywr model is a model made up of many sub-models. In the 'full' version of the model, i.e., the one used to undertake our DO modelling, the Affinity Water supply area model is run at the same time as the TW models.

• We have been provided with only the TW sub-models (due to data confidentiality), and so the runs which we can undertake involve the application of boundary conditions for abstractions made from the Lower Thames by Affinity Water.

- As such, we are now able to undertake runs using the TW sub-models in-house. It must, however, be borne in mind that these runs are not using exactly the same model setup as the 'full' model, and so the results are slightly different.

Item 2 – Difference Between dWRMP24 and AR22 DO

This was not a request for data, so no data has been sent.

The EA Annual Review 2022 states that London's DO is 2311 Ml/d (rather than 2296 Ml/d). Yearly DO updates are undertaken in steps (in order to understand the significance of each change) and the step referenced in paragraph 403 was not the final step. Paragraph 406 of the Annual Review 2022 states that London's DO for AR22 was 2311 Ml/d.

There are several factors which explain the difference between Annual Review 2022 and dWRMP24 figures. Differences between WRMP19 DO values and those in dWRMP24 are discussed in Appendix I of our dWRMP. The main reasons relate to the fact that the AR22 values are calculated to provide comparison with WRMP19 values, and so have been calculated using methods and assumptions aligned with our WRMP19 DO calculation and the WRMP19 Water Resources Planning Guideline (WRPG); the dWRMP24 values, on the other hand, use methods and assumptions aligned with the WRMP24 WRPG. The two main differences are:

- The AR22 DO stated is a DO subject to the Level of Service condition of "No failures subject to the historical climate record". The dWRMP24 DO is calculated subject to the WRMP24 WRPG requirement of Level 4 restrictions not being implemented more often than once every 500 years. The gap between a "worst historical" (c.1 in 100-year) and "1 in 500-year" DO for the London WRZ is around 260 Ml/d.

- The AR22 DO stated, being aligned with the methods used to calculate our WRMP19 Deployable Output, is taken from a DO run in which demand restrictions according to our current Levels of Service are turned on. The dWRMP24 DO figure, aligned with the amended requirements of the WRMP24 WRPG, is taken from a DO run with the benefits of demand restrictions turned off. The gap between a 1 in 500-year DO calculated with demand restrictions turned on and one with demand restrictions turned off is around 100-110 Ml/d.

    - The benefits associated with the implementation of demand restrictions, as per our current Levels of Service, are considered as an 'option' and benefits can be seen in line 7.02FP for each WRZ in the WRMP Tables. Benefits from the implementation of demand restrictions during droughts are allocated zero cost in our investment modelling, and so are generally the first options selected.

Other reasons for differences between these figures are:

• Our dWRMP24 DO modelling was carried out using source DO figures from AR20 (except where there were known, material changes between AR20 and the time at which modelling was undertaken, around March 2021). Source DO changes between AR20 and present have been incorporated as post-modelling amendments. The supply forecast was finalised before our AR22 submission, and so not all sources have DOs aligned with AR22.

• Our dWRMP24 DO modelling includes a more dynamic approach to DOs from groundwater sources, whereas our AR22 DO modelling uses the WRMP19 'static DO' approach. Further detail can be found in Appendix I of the dWRMP.

• Changes in datasets and models – our AR22 DO uses WARMS2 (and so incorporates integrated hydrological modelling, and uses the historical weather dataset), whereas our dWRMP24 DO uses the Pywr model, the stochastic weather dataset, and a different hydrological model, as discussed in Appendix I of the WRMP.

Item 3 – Aquator Output from AR22 DO Run

Output from our AR22 DO run has been provided. Please note that the data is presented in a similar but not identical format to data from WARMS2.

Item 4 – Control Curve Crossing Data

'Control curve crossing' data has been provided for four runs:

- Baseline stochastic DO – DO = 1967
- Stochastic DO for the 150 Mm3 SESRO DO benefit – DO = 2252, DO benefit = 285
- Stochastic DO for the 500 Ml/d pipeline uSTT DO benefit – DO = 2128, DO benefit = 161
- Stochastic DO for the 500 Ml/d pipeline, supported by 500 Ml/d – DO = 2434, DO benefit = 467

Note that these DO runs carried out by Atkins using the 'full' (i.e., not treating Affinity as a boundary condition) version of the model. Please note also that the DO benefits seen here will not align with those seen in our WRMP tables, as the DO benefits stated for each option in our WRMP Tables incorporate the impact of climate change at 2070.

We do not have available a 'control curve crossing' output for the exact setup in your request.

Please note that 'control curve crossing' data involves a yearly determination of whether a particular curve has been crossed. In the outputs provided, I believe the value presented is the last day in the year that the curve had been crossed (rather than the duration of control curve crossing). A year is defined from Apr to Mar, in order not to count L4 events which extend into January.

Item 5

Please see the link below for the report written on the WRSE Pywr model:

https://www.wrse.org.uk/media/axlktoyx/wrse-regional-system-simulator-report.pdf

In the data sent across, two Pywr outputs and an additional WARMS2 output have been included to provide more detail regarding the validation of the TW/London Pywr model. These are spreadsheet outputs from pywr model runs using historical timeseries. They demonstrate the water balance of the model (shown in individual tabs, e.g., showing the River Thames, River Lee, New River and individual WTW water balance), show that inputs to the model (in this validation case) are aligned with the AR20 DO run (against which the model was validated), and show that resultant reservoir storage outputs from the model are aligned with WARMS2. The reason for being able to send these now is as referred to in Item 1 (i.e., we have access to the TW elements of the model). The pywr model validation involved a staged validation in order to identify the causes of changes (e.g., is a DO change due to a model topology change, or a change in the hydrology?) and the outputs from two validation stages have been included:

- Validation of the model (historical timeseries) using flow inputs taken directly from WARMS2. The aim of this validation step was to ascertain whether the structure of the Pywr model gave an acceptable validation
- Validation of the model (historical timeseries) using flow inputs making use of hydrological models which were then used for the stochastic modelling. The aim of this validation step was to ascertain the differences in model outputs caused by using this different hydrological model.

Please see the end of this note for a glossary of the timeseries provided in the validation outputs (and timeseries provided in answer to the first item in your queries).

We have included several reports on modelling carried out to determine benefits of different supply options. Reports that we have sent are:

- SESRO Task 1 – modelling to establish the impact of climate change on the DO of the SESRO option.
- SESRO Task 5 – modelling to establish the sensitivity of the SESRO option's DO to release volumes.
- SESRO Task 3 & 4 – modelling to establish the conjunctive use benefit associated with T2AT (procured alongside work on SESRO).
- STT – modelling to establish the reasons for change in STT DO between WRMP19 and dWRMP24.
- T2ST – modelling to establish the conjunctive use benefit associated with T2ST. Note that the conjunctive use benefit of T2ST has not been included in

the WRSE investment modelling, as the modelling carried out did not fully consider the conjunctive use interactions between Havant Thicket and T2ST, with Havant Thicket expected to materially alter the conjunctive use behaviour of the system.

- SESRO-STT-T2ST – modelling to establish how SESRO, STT and T2ST would work together

Alongside the T2ST report, we have included the timeseries as requested.

Item 6

NA – Southern Water

Item 7

The Lower Thames Control Diagram is mostly unchanged from WRMP19. A copy has been provided.

The Teddington Target Flow figures used are:

- Blue Band: 800 Ml/d
- Green Band: 600 Ml/d Jan-Feb; 700 Ml/d Mar-Oct; 600 Ml/d Nov-Dec
- Yellow Band: 400 Ml/d Jan-Feb; 300 Ml/d Mar-Oct; 400 Ml/d Nov-Dec
- Red Band: 300 Ml/d

When determining the DO benefit associated with demand restrictions according to our current level of service, we undertake a DO run with demand savings measured turned off and then a DO run with them turned on and find the difference. A change to the LTCD if incorporating demand restrictions into DO modelling is that TUBs have been moved to Level 2 (from Level 3 at WRMP19) in order to align with other WRSE member companies. Monthly reductions to demand in these runs are as set out in the table below:

London Demand Savings Percentages (cumulative)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
L1	1.1	1.2	1.2	1.3	1.5	2.2	2.2	2.1	1.3	1.2	1.2	1.2
L2 (inc TUB)	4	4.1	4.2	5.6	6.7	12.5	13.1	11.9	5.6	4.7	4.4	4.3
L3	5.4	5.5	5.6	7	8.1	13.9	14.5	13.3	7	6.1	5.8	5.7
L4	23.4	23.5	23.6	25	26.1	31.9	32.5	31.3	25	24.1	23.8	23.7

Item 8

As is required by the WRPG (Section 5.3), in our baseline DO modelling no drought permits or orders are included (neither supply-side nor demand-side).

Item 9

Changes to operating rules for strategic schemes are as follows:

- Gateway desalination plant – output when triggered changed to 100 Ml/d (from 150 Ml/d). Output during non-drought periods changed to 0 Ml/d (from Apr-Jun 25 Ml/d, 0 Ml/d other times). Please see section 4 for further details on the Gateway desalination plant.
- Hoddesdon Transfer scheme – unavailable (0 Ml/d output), compared to 12.5 Ml/d output in WRMP19
- NLARS – no change
- CHARS – no change
- Stratford Box – no change
- ELReD – no change
- WBGWS – no change

Additional Note – Table of Pywr time series provided

[6-page listing of Pywr time series was received, but not reproduced here]

If you are dissatisfied with the outcome of the internal review, you can apply, without charge, to the Information Commissioner, who will consider whether Thames Water has complied with its obligations under the EIR and can require Thames Water to remedy any problems. You can find out more about how to do this, and about the EIR in general, on the Information Commissioner's website at: www.ico.org.uk.

Yours sincerely

Paul

Paul Bridgens
Data Protection Advisor
Data Protection Investigations

Attachment(s):

- OneDrive_2023-01-13 Item 1
- OneDrive_2023-01-13 Item 3
- OneDrive_2023-01-13 Item 4
- OneDrive_2023-01-26 Item 5
- OneDrive_2023-01-13 Item 7