



GARD response to

Water Resources South East's

Consultation on

Securing Resilient Water Resources for

South East England

3rd July 2020

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Drought resilience of existing London supplies and Abingdon reservoir

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Summary

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The overall conclusion of this report is that Thames Water has grossly over-estimated the yield gain from the 150,000 MI Abingdon reservoir, quoting a yield of 294 MI/d in their Final WRMP. We believe the true yield gain to be in the region of 180 to 220 MI/d.

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Thames Water's analysis of drought resilience of Abingdon reservoir

The lack of resilience of Abingdon reservoir to long duration drought was first identified by GARD in October 2016. Since then, Thames Water and Atkins have produced a succession of reports, including the draft WRMPs, in which they have claimed that their analysis proves that the reservoir provides a yield of at least 275 MI/d. They say the reservoir is resilient to all plausible droughts, despite their latest analysis showing that the yield of Abingdon reservoir would be reduced to less than 150 MI/d in some long droughts. However, they say such events are extremely unlikely so they can be ignored.

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In our opinion, Thames Water used a flawed methodology, which only looked at 25% of the droughts in the available 15,600 years of stochastic data, and used inappropriate methods of drought selection and yield analysis. These flaws were compounded by averaging the yields assessed for individual droughts, so the very low yields in long duration droughts were disguised by higher yields in some other droughts.

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We consider that assessment of yield gain from Abingdon reservoir in individual droughts is the wrong way of assessing the yield benefit of the reservoir. This should be done by looking at the gross yield-probability relationship of London's supplies, with and without the reservoir, using the full 15,600 years of record. The yield benefit from Abingdon reservoir at a given return period is then the difference in the gross yield, with and without the reservoir, at that return period. This is the methodology that Atkins used for assessing yield of Severn-Thames transfer options and it should also be used for Abingdon reservoir.

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The drought resilience of London's existing supplies

Our evaluation of the yield-probability relationship for London's existing supplies is similar to Atkins' using IRAS river flows, if we assume, as Atkins have done, that the stochastic data represent 20,000 years of climate. However, evidence from long-term Oxford rainfall records shows the 15,600 years of river flows should not be assumed to represent 20,000 years of climate. If the stochastic data are only assumed to be representative of 15,600 years, our conclusions are:

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- Thames Water's current yield of 2305 MI/d for London's supplies can be maintained in droughts of up to 1:108 year return period, ie in all but 144 years out of 15,600.
- If the existing supplies are required to be resilient to a return period of 1:200 years, the yield is reduced to 2182 MI/d, a loss of 123 MI/d from the current 2305 MI/d.
- For a 1:500 year resilience, the yield of existing supplies falls to 2070 MI/d, a loss of 235 MI/d from the current 2305 MI/d.

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The allowance of 48,500 MI of emergency storage in the London reservoirs (24% of gross storage) can sustain supplies with Level 4 cuts for at least 60 days, rather than the 30 days which Thames Water say is their policy. 36

London's reservoirs are not adversely affected by sequences of moderately dry years, so they refill completely in most winters. The critical period of droughts for existing supplies is 18 months. 21

Yield gain from Abingdon reservoir

The yield-probability relationship for London's supplies augmented by the Abingdon reservoir has been assessed by modelling the gross yield of the supplies in each of the 200 most severe droughts in the 15,600 year record of IRAS river flows. When compared with the yield-probability relationship for existing supplies, the yield gain from Abingdon reservoir is assessed as: 22

- 253 MI/d at a return period of 1:500 years using the IRAS river flows
- 215 MI/d when the IRAS yields are converted to WARMS equivalents using Atkins' equation – 60 MI/d less than Atkins' 275 MI/d value in their May 2018 Technical Note. 23

The 215 MI/d yield gain is consistent across the full range of return periods. However, it assumes only 6% of emergency storage provision as proposed by Thames Water. If the emergency storage is increased to 20%, in line with other UK reservoirs, the yield gain from Abingdon reservoir would be reduced by a further 30-40 MI/d to about 180-220 MI/d. 37

Although there are doubts about the validity of the IRAS flow record and the conversion to WARMS equivalent yields using Atkins' equation, it seems likely that, when properly assessed using 15,600 years of reliably derived river flows and with a realistic allowance for emergency storage, the yield gain will be much less than the 275 MI/d concluded by Atkins. The 294 MI/d yield gain assumed by Thames Water in their WRMP appears to be a gross over-estimate. 38

Resilience in long duration droughts

There are 25 long duration droughts in the IRAS generated river flows in which the yield gain from Abingdon reservoir, with the 6% emergency storage assumption, is less than 240 MI/d. All but 6 of these droughts have return periods of between 100 years and 500 years for Abingdon reservoir's gross yield – they are not especially rare events in the context of a resilience design standard of 1:500 years. In all of these droughts, if a yield gain of 294 MI/d is needed (as assumed in Thames Water's WRMP), the Level 4 supply cuts with Abingdon reservoir would be much longer than they would be with the existing supplies at current levels of demand. This is a major failing in Abingdon reservoir's drought resilience. 29

Low Abingdon reservoir storage in the spring is a common feature of all the long duration droughts in which the Abingdon reservoir yield is much reduced. Our analysis shows that there is a 1: 50 year probability that Abingdon reservoir will be less than half full at the start of summer and a 1:100 year probability that it would be less than 1/3rd full. Although, a 32

severe drought will not necessarily then occur, there will still be a big threat of Level 4 supply cuts later in the year.

The above highlights the essential problem in relying on a 'supplementary' water resource which itself shares the climatic problems of the water resource zones being supplied. An equivalent situation would simply not arise with a 'climate proof' back-up such as desalination. It is easy to imagine the sense of panic, and the potential waste of administrative and technical effort in arranging back-ups, that would prevail when Abingdon reservoir is nearly empty at the start of summer, and the consequent economic damage, even if Level 4 supply cuts are not eventually needed because of a wet summer. This needs to be fully assessed and costed in WRSE's resilience analysis.

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Our analysis shows that Abingdon reservoir would have some excessively long periods of being drawn down: over 3 years between refills, at about 1:100 year return period, over 5 years at about 1:600 years, and sometimes up to 8 years between refills. It is unusual for major reservoirs for public water supplies to be designed to remain drawn down for periods of over 2 years. In the context of London's supplies being required to have a resilience of 1:500 years, the acceptability of the frequencies of draw-downs in excess of 3 years seems highly questionable.

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Emergency storage in Abingdon reservoir

Thames Water justify the 9,000 MI (6%) emergency storage allowance by saying it complies with their policy of 30 days' emergency storage, as for the London reservoirs. However, analysis of rates of depletion of London's reservoirs in severe droughts shows that the 24% emergency storage provision would maintain supplies for at least 60 days, not 30 days.

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In our opinion, in view of the high degree of resilience expected from London's supplies and the vulnerability to long duration droughts, an allowance of 20% emergency storage in Abingdon reservoir, ie 30,000 MI would be a pragmatic risk management measure and in line with other UK reservoirs. If the emergency storage is increased to 30,000 MI (20%), we estimate that the yield gain would be reduced by about 15%, ie by about 30-40 MI/d.

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Recommendations for WRSE's further resilience analysis

Much of the weakness of Thames Water's resilience analysis to date stems from failure to convert the 15,600 years of stochastic climate data into reliable flow records for the River Thames. Generation of 15,600 years of reliable river flow records, with and without climate change, should be a top priority in WRSE's further work on resilience. Even better, the historic climate data used to generate the river flows should include the most up-to-date records in the 21st century, thereby covering the recent period of rapid climate change, and giving a true 20,000-year dataset.

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The slow running of Thames Water's WARMS model has been a major constraint in assessing the resilience of London's supplies. A model capable of simulating operation of the supplies in individual droughts in a few seconds, rather than the hours currently needed by WARMS,

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should be a priority in WRSE's programme of model development.

The increased frequency, duration and economic cost of Level 4 supply restrictions with Abingdon reservoir in long duration droughts should be properly analysed and taken into account when comparing the economic benefits of Abingdon reservoir with other water resource options.

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WRSE's continuing resilience investigations should also address:

1. The operational control rules for Abingdon reservoir in conjunction with the London reservoirs. This should include revisions to the Lower Thames Operating Agreement that take into account the amount of storage remaining in Abingdon reservoir.
2. The acceptability of multi-year periods of draw-down of Abingdon reservoir. The investigation should take account of international best practice for water supplies for major cities and the acceptability of the long periods of Level 3 supply restrictions that might be needed during periods of extended draw down of Abingdon reservoir.

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GARD will take a keen interest in WRSE's investigations of the resilience of Abingdon reservoir. We would hope that there can be some collaboration between GARD and WRSE in these investigations, rather than GARD being held at arms' length and only engaged superficially at brief stakeholder meetings with too many participants to allow a detailed technical discussion of the matters we have raised in this report.

1. Introduction

1.1 Purpose of this report

This report has been prepared to support GARD's response to consultation on WRSE's report "Securing resilient water resources for South East England". The report focuses on resilience of London's water supplies in droughts and covers:

- A summary of GARD's previous involvement in the resilience analysis
- Comment on Atkins' Technical Note of 18th May 2018¹
- Analysis and comments on the drought resilience of existing London supplies
- The drought resilience of Abingdon reservoir
- Recommendations for further resilience analysis

A copy of GARD's response to WRSE's five consultation questions is in Appendix B.

1.2 GARD involvement in drought resilience analysis to date

GARD's involvement in the analysis of drought resilience has focused on Abingdon reservoir and the sequence of events has been:

1. In responding to Thames Water's draft and final Fine Screening reports in October 2016² and May 2017³, GARD pointed out that the yield of Abingdon reservoir would be much reduced if an 18 month drought is followed by another dry winter extending into a third dry year.
2. In August 2017, we produced a report "GARD review of UTR resilience", which used Atkins' 15,600 years of stochastic data to identify a number of droughts in which the yield of Abingdon reservoir was only 100-200 MI/d and showed the consequent extent of Level 4 supply restrictions in London. We concluded that Atkins had failed to provide a credible estimate of the probability of such events, nor given proper consideration to their disastrous consequences.
3. In January 2018, TW held a technical stakeholder meeting at which Atkins presented their proposal for more investigation of the resilience of Abingdon reservoir, and GARD presented the findings of our August 2017 report⁴ and commented on Atkins' investigation proposal. We criticised their method of drought selection and the averaging of drought yields, which effectively ignored severe long droughts.
4. In April 2018, our response to the first TW WRMP19 consultation repeated our concerns of the lack of resilience to long droughts and flaws in Atkins' methodology.

¹ Technical Note, Abingdon Reservoir Resilience Assessment Method. Doug Hunt, Atkins, 1 May 2018.

² GARD response to TW's draft option Fine Screening Report, pages 31-34, October 2016

³ GARD response to TW's updated option Fine Screening Report, pages 11-12, March 2017

⁴ <http://www.gard-oxon.org.uk/downloads/GARD%20review%20of%20UTR%20resilience%20final-21-08-17.pdf>

5. In November 2018, our response to the second TW WRMP consultation considered Atkins' Technical Note on their further investigation, dated May 2018 but not given to GARD until October 2018. We requested output from the WARMS modelling used in the Technical Note, but this was not received until 9th November – too late to be assessed by the consultation submission date of 28th November. Our WRMP response repeated our earlier criticisms pointing out again the flaws in Atkins' methodology.
6. In June 2019, Thames Water's Statement of Response to the second WRMP consultation addressed GARD's criticism as follows:

“The Abingdon reservoir scheme has been subjected to rigorous analysis using best practice for long term water resource planning, including the use of stochastically generated extreme events to supplement the historical record and all 20 UKCP09 2080s scenarios. This is consistent with the deployable output modelling undertaken for other options, such as the Severn Thames transfer, and has shown that the Abingdon reservoir scheme is resilient to plausible droughts up to a severity of 0.5% annual average risk of occurrence, the EA's reference level of service for company drought resilience, across the full range of associated drought profiles (intensities and durations) and climate change impacts in the 2080s.”

In Section 2 of this report, we review Atkins' Technical Note of May 2018, referring to the WARMS modelling used in the technical note and output from our own modelling.

1.3 GARD's simulation model of the Thames supply system

To facilitate the modelling of drought resilience using the 15,600 years of stochastically generated river flow data, GARD's daily simulation model of the London and Thames valley water supplies has been refined as follows:

- The model version that uses Atkins' 15,600 years of stochastic data – 200 “Runs”, each with 78 years of daily data – has been “slimmed down” to make it run faster. This has involved deleting rarely used parts of the model and has reduced the Excel file size from 148 Mb to 107 Mb. It now runs faster and can simulate 78 years of daily data in about 90 seconds.
- A further cut down model version runs single droughts from Atkins' drought library, each drought comprising 10 years of daily data. A 10 year simulation takes about 15 seconds, allowing rapid determination of system yield which requires multiple simulations to find the demand level which just avoids Level 4 drought restrictions.
- The model has been validated by comparing its output with some output from the IRAS modelling of the 15,600 years of data, and with WARMS modelling of one of the severe droughts, as described in Appendix A.

The conclusions of the model validation detailed in Appendix A are:

1. GARD's modelling using WARMS river flows closely matches WARMS modelling.
2. GARD's modelling using IRAS river flows is a reasonable match with IRAS modelling.
3. GARD's modelling of droughts using IRAS river flows shows significant differences to WARMS modelling using WARMS river flows. Figure 1 shows an example of storages and inflows to the London reservoirs in the severe drought in IRAS Run 114 (drought 3-8 in the Atkins' drought library):

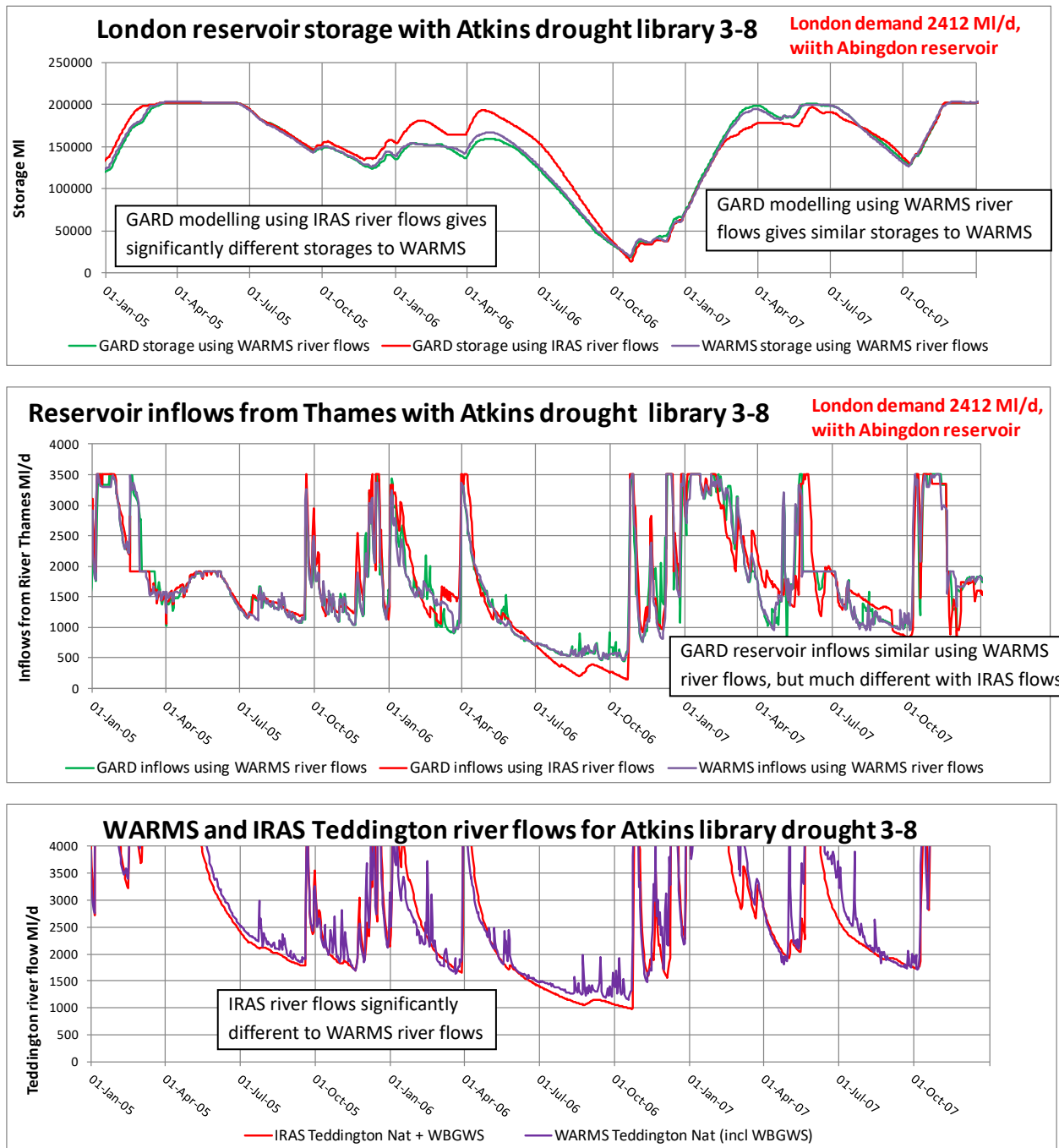
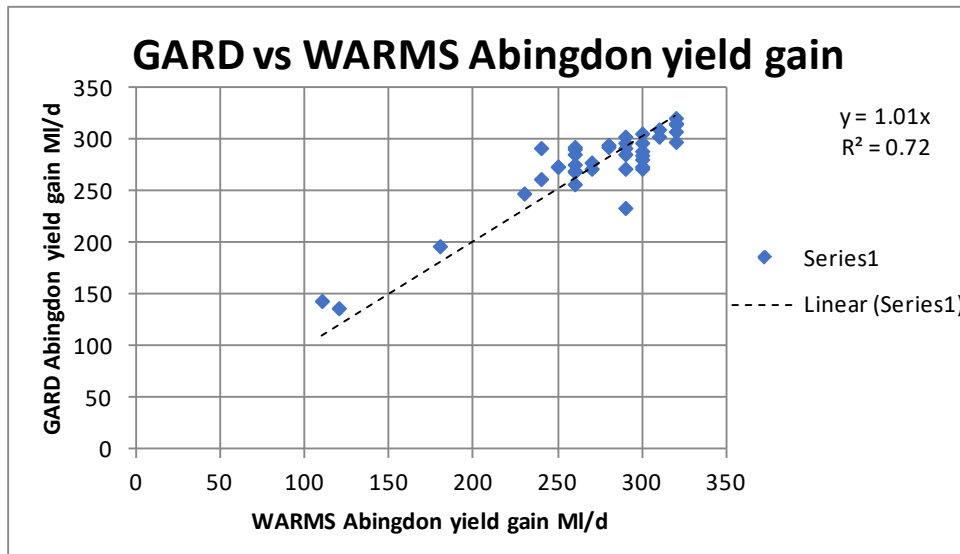


Figure 1- Validation of GARD model using IRAS and WARMS river flows

4. GARD's modelling using IRAS river flows gives gross yield of the existing London supplies about 30-50 MI/d more than the IRAS modelling. WARMS modelling of existing London supplies gives gross yields about 120-200 MI/d more than IRAS modelling. Therefore, GARD's modelling using IRAS flows gives gross yields about 100-150 MI/d less than the WARMS modelling
5. GARD's modelling using IRAS river flows shows similar supply system behaviour to the WARMS modelling in droughts, but with differences of up to about +/- 30% in the Abingdon reservoir yield gain in long duration droughts, as shown in Figure 2:



Note: WARMS yields from Table 4-1 of Atkins Technical Note, May 2018

Figure 2 - GARD vs WARMS assessments of yield gain of Abingdon reservoir

The hydrographs in Figure 1 show that GARD's modelling with WARMS river flows gives a close match with WARMS modelling using the same river flows. This suggests that the differences in Abingdon reservoir yield gain assessment in Figure 2 are primarily due to differences between WARMS and IRAS river flows generated from the same stochastic weather data. The inaccuracies from Atkins' yield assessment methodology may also contribute to the differences – due to the slow running of the WARMS model, Atkins were unable to assess the 'just-not-failing' demand for each drought with and without the reservoir.

An overall conclusion from validation of the GARD, WARMS and IRAS models is that the differences are mainly due to differences in the river flows generated by the WARMS and IRAS models, using the same stochastic weather data.

In our opinion, it should not be assumed that the WARMS generated river flows are "correct", so GARD's modelling of droughts using IRAS generated river flows must be "wrong". River Thames flows in droughts are dependent on the flows from the numerous chalk valley tributaries, which are difficult to estimate accurately even using full regional groundwater models. The rainfall/run-off models used to generate the WARMS and IRAS river flows from the stochastic weather data are inherently less accurate than regional groundwater models.

2. Atkins' Technical Note of May 2018

Atkins' investigation methodology, as used in the Technical Note can be summarised as:

- Use of IRAS modelling of the existing London supplies with 15,600 years of stochastic data to identify 240 droughts with a return period of between 1 in 75 years and 1 in 750 years, as ranked by the drought yield in each drought.
- Randomly select 25% of these droughts, ie 60 droughts.
- Use the WARMS model to assess the London yield gain from Abingdon reservoir for each of the 60 droughts.

At Thames Water's technical stakeholder meeting on 29th January 2018 to discuss the resilience of Abingdon reservoir, GARD raised a number of objections to Atkins' proposed methodology:

- It would not assess the probability of occurrence of the long duration droughts in which the yield from Abingdon reservoir is much reduced.
- It would not consider the consequences of Abingdon reservoir being able to provide only a fraction of its expected c.290 MI/d yield gain in a long drought (for example, the extended duration of Level 4 supply cuts).
- It would not consider the adequacy of the emergency storage provision in Abingdon reservoir, noting that Abingdon reservoir would be nearly empty for several years in long droughts, with likely poor water quality in the shallow residual storage.
- Only 25% of droughts in the stochastic record would be examined, so critical droughts are likely to be missed.
- The method of drought selection would miss droughts that are very severe with Abingdon reservoir, but less severe for existing supplies.
- The method of yield assessment was crude and likely to be inaccurate.

Many of the weaknesses in Atkins' methodology are the consequence of the slow running of Thames Water's WARMS model, which was said to make it impossible to examine all the droughts in the 15,600 year record or to undertake a proper yield analysis, even for the selected 60 droughts. A simulation of a 100 year "drought library" with 10 droughts is understood to take several hours, so it was not feasible for the WARMS model to identify the maximum demand without Level 4 failure for each of the 60 droughts, let alone all 240 of the identified droughts.

At the stakeholder meeting in January 2018, GARD made various suggestions for improvements in Atkins' methodology. These were not correctly recorded in the meeting minutes. Following GARD's written complaint, Thames Water produced a revised meeting

note incorporating some of GARD's proposed changes, but these notes were not widely issued and the original draft meeting notes are still on Thames Water's web-site⁵.

The result of the yield assessments was shown in Atkins' Table 4-1 which is re-produced below, with the addition of GARD's estimate of the drought return period with Abingdon reservoir added to London's supplies (see later for details of GARD's methodology):

Atkins Drought Library	Drought no.	IRAS Run and Year	Base case IRAS DO	Atkins UTR yield gain	GARD UTR yield return period
1	0	187_1976	1810	260	473 yrs
	1	166_1941	1830	300	363 yrs
	2	186_1979	1830	260	400 yrs
	3	34_1980	1850	300	411 yrs
	4	176_1931	1850	300	422 yrs
	5	73_1977	1870	290	390 yrs
	6	25_1959	1890	320	223 yrs
	7	126_1978	1890	290	339 yrs
	8	44_1936	1910	310	318 yrs
9	78_1994	1910	300	233 yrs	
2	0	147_1931	1910	280	233 yrs
	1	6_1936	1950	290	200 yrs
	2	32_1924	1970	250	161 yrs
	3	103_1993	1970	280	164 yrs
	4	184_1966	1970	300	214 yrs
	5	57_1972	1990	310	171 yrs
	6	157_1935	1990	240	190 yrs
	7	0_1943	2010	180	240 yrs
	8	100_1985	2010	260	151 yrs
9	184_1947	2010	290	113 yrs	
3	0	24_1955	2030	290	127 yrs
	1	168_1922	2030	290	119 yrs
	2	193_1927	2030	270	142 yrs
	3	21_1980	2050	260	96 yrs
	4	186_1996	2050	260	125 yrs
	5	33_1981	2070	260	116 yrs
	6	1_1986	2090	320	105 yrs
	7	58_1984	2090	240	104 yrs
	8	114_1975	2090	110	200 yrs
9	193_1955	2090	300	95 yrs	
4	0	25_1940	2110	320	103 yrs
	1	23_1924	2110	270	95 yrs
	2	130_1968	2110	230	92 yrs
	3	143_1969	2110	250	122 yrs
	4	7_1972	2130	260	< 99 yrs
	5	59_1958	2130	320	90 yrs
	6	109_1930	2130	120	156 yrs
	7	155_1959	2130	300	150 yrs
	8	183_1933	2130	320	98 yrs
9	54_1993	2150	260	< 99 yrs	
5	0	111_1936	2150	280	< 99 yrs
	1	6_1968	2170	300	88 yrs
	2	48_1992	2170	290	< 99 yrs
	3	144_1940	2170	310	< 99 yrs
	4	21_1977	2190	260	< 99 yrs
	5	61_1945	2190	320	< 99 yrs
	6	102_1968	2190	300	< 99 yrs
	7	16_1976	2210	290	< 99 yrs
	8	146_1940	2210	270	< 99 yrs
9	2_1953	2230	320	< 99 yrs	
6	0	17_1952	2230	120	126 yrs
	1	81_1969	2230	300	< 99 yrs
	2	97_1975	2230	270	< 99 yrs
	3	132_1929	2230	200	88 yrs
	4	171_1985	2230	330	< 99 yrs
	5	19_1922	2250	#N/A	< 99 yrs
	6	55_1989	2250	340	< 99 yrs
	7	78_1934	2250	300	< 99 yrs
	8	96_1979	2250	#N/A	< 99 yrs
9	179_1978	2250	310	< 99 yrs	

Table 1 - Atkins assessment of Abingdon reservoir yield gains

From GARD's estimate of the return periods of the droughts, only 33 of the 60 droughts analysed had return periods of over 100 years. None of the droughts had a return period of more than 500 years. Thus, Atkins' analysis sampled 25% of the 15,600 years – 3900 years – and nearly half of the droughts they then selected had return periods of less than 100 years.

Despite Atkins only looking at a small part of the 15,600 year stochastic record, they still identified four droughts with Abingdon yields of less than 200 MI/d, three of which were

⁵ Draft note of Technical Stakeholder meeting on 29.1.2018, Thames Water
<https://corporate.thameswater.co.uk/-/media/Site-Content/Thames-Water/Corporate/AboutUs/Our-strategies-and-plans/Water-resources/Document-library/Past-meetings/29-January-2018/draft-meeting-minutes-290118.pdf>

only 110-120 MI/d. However, Atkins then averaged all their Table 4-1 yields as 275 MI/d and concluded that this is the drought resilient yield from Abingdon reservoir. The very low yield in some droughts was considered inconsequential (Technical Note Conclusions, page 10):

“It is acknowledged that some lower yields do occur as a result of longer duration droughts that are severe enough to test the conjunctive capability of the London-Abingdon system, but these are rare, at less than 10% of major drought events. The 275MI/d expected yield accounts for the influence of such events.”

In our opinion, looking at the yield gain from Abingdon reservoir in individual droughts is the wrong way of assessing the yield benefit of the reservoir. This should be done by looking at the gross yield return period relationship of London’s supplies, with and without the reservoir, using the full 15,600 years of record. The yield benefit from Abingdon reservoir is then the difference in the gross yield, with and without the reservoir, at that return period. This is the method that Atkins used in assessing yields for Severn-Thames transfer options⁶ and the method GARD has used later in this report.

Atkins’ Technical Note of May 2018 concluded that:

“This analysis is in line with the previous resilience analysis presented to the TSF and demonstrates that a simple analysis of the expected yield of the Abingdon reservoir across a range of major droughts is appropriate for estimating its resilience across the full range of drought severities. It is therefore recommended that no further work is undertaken, as additional work would simply result in the same general findings.”

We do not agree with this statement. In our opinion, Atkins’ methodology was inappropriate. They should have made use of the full 15,600 years of record to determine the yield-probability relationship, with and without the reservoir. They should have examined the consequences of supply failure in the long droughts where Abingdon reservoir would fail to deliver its expected gross yield, as we have done in the next sections of this report.

3. Drought resilience of existing London supplies

3.1 Initial ranking of droughts

To identify the most severe droughts for detailed analysis, we ran the 15,600 years of IRAS river flow data in GARD’s model and ranked the drought severity for London’s existing supplies, with and without Abingdon reservoir, for each of the 15,600 years, as follows:

1. Determine the minimum annual storage in London’s reservoirs with the existing supply system with the base case London demand of 2140 MI/d for each of the 15,600 years – ie all of IRAS’s 200 “Runs”, each comprising 78 years of daily data. The base case demand of 2140 MI/d, when modelled using IRAS river flows, is equivalent to the present base case demand of 2305 MI/d using WARMS river flows, as shown in

⁶ Severn Thames Transfer Options. Note on Option Yield, page 6 and Figures 3-1 to 3-3. July 2018. Atkins

the plot below taken from Atkins' Report "Thames Water Stochastic Resource Modelling: Stage 2&3 Report, Figure 5-2".

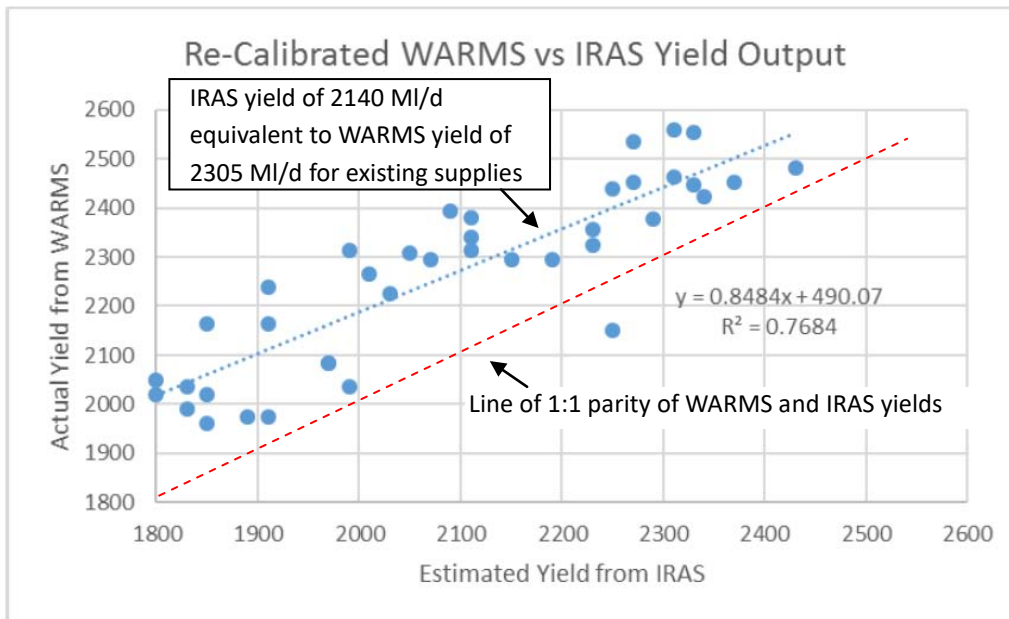


Figure 3 - Comparison of WARMS and IRAS yield of existing London supply system

2. Determine the minimum annual storage in London's reservoirs for the supply system with Abingdon reservoir and a demand of 2434 MI/d for each of the 15,600 years. The demand of 2434 MI/d is an increase of 294 MI/d for Abingdon reservoir, which is the yield shown for Abingdon reservoir used for programme appraisal in Thames Water's final WRMP19, Section 10, Table 10-29.
3. Rank the minimum storages for each year, with and without Abingdon reservoir.
4. By inspection of the ranked data, remove the years adjacent to the years of maximum drawdown for each drought, to avoid double counting of consecutive years within the same drought.

The supply simulations to determine drought ranking, assumed no demand reductions more severe than Level 3 (ie no Level 4 supply cuts) and calculated negative storage where the reservoirs emptied in severe droughts. This artifice was only used to identify all the droughts down to about 1:100 year return period, with and without the reservoir, for more detailed analysis of yield and return period.

As an illustration of the identification of droughts for further analysis, extracts from the table of ranked droughts are shown in Table 2 below. It should be noted that the return periods (RP) for each drought year in Table 1 are calculated on the basis of Atkins' assumption that the 15,600 years of stochastic river flows are equivalent to 20,000 years of data. The validity of Atkins' assumption is considered later in this report.

Ranking with repeat drought years excluded						
IRAS Run_year	Min London storage with base case MI	Min London storage with UTR MI	Drought rank for existing supplies	Drought rank with UTR	No repeat RP for existing supplies 1 in yrs	No repeat RP with UTR 1 in yrs
122_1962	-263538	-370066	1	1	20000 yrs	20000 yrs
159_1975	-217245	-336024	2	2	10000 yrs	10000 yrs
97_1986	-162581	-298033	3	3	6667 yrs	6667 yrs
149_1941	-157075	-212810	4	4	5000 yrs	5000 yrs
62_1943	-132607	-125059	5	12	4000 yrs	1667 yrs
72_1997	-131556	-152215	6	9	3333 yrs	2222 yrs

Droughts around 1:500 year return period:

151_1945	-32246	-64040	34	22	588 yrs	909 yrs
183_1956	-31890	-24100	35	47	571 yrs	426 yrs
192_1957	-31570	-26505	36	45	556 yrs	444 yrs
166_1941	-29033	-42606	37	34	541 yrs	588 yrs
176_1931	-25279	-17923	38	52	526 yrs	385 yrs
87_1987	-24967	-50000	39	27	513 yrs	741 yrs
29_1941	-23858	-13877	40	56	500 yrs	357 yrs

Droughts around 1:200 year return period:

0_1943	26132	-12864	96	58	208 yrs	345 yrs
24_1955	26851	28690	97	111	206 yrs	180 yrs
189_1926	27226	31086	98	116	204 yrs	172 yrs
56_1996	27493	26538	99	107	202 yrs	187 yrs
155_1959	28864	30105	100	114	200 yrs	175 yrs
161_1957	28890	33289	101	121	198 yrs	165 yrs

Droughts around 1:100 year return period:

91_1965	68018	69989	198	233	101 yrs	86 yrs
92_1922	68029	70710	199	238	101 yrs	84 yrs
55_1996	68579	69450	200	229	100 yrs	87 yrs
160_1928	68659	70070	201	235	100 yrs	85 yrs
2_1953	68697	70973	202	240	99 yrs	83 yrs
92_1962	68717	70495	203	237	99 yrs	84 yrs

Droughts less than 100 year RP for existing supplies, but severe loss of Abingdon reservoir yield:

158_1989	71285	71500	214	242	93 yrs	83 yrs
136_1942	71451	31846	215	118	93 yrs	169 yrs
169_1966	71478	73101	216	258	93 yrs	78 yrs
198_1927	77328	80462	246	306	81 yrs	65 yrs
109_1930	77586	6597	247	84	81 yrs	238 yrs
176_1988	77612	79056	248	296	81 yrs	68 yrs

Level 4 supply cuts only needed with Abingdon reservoir

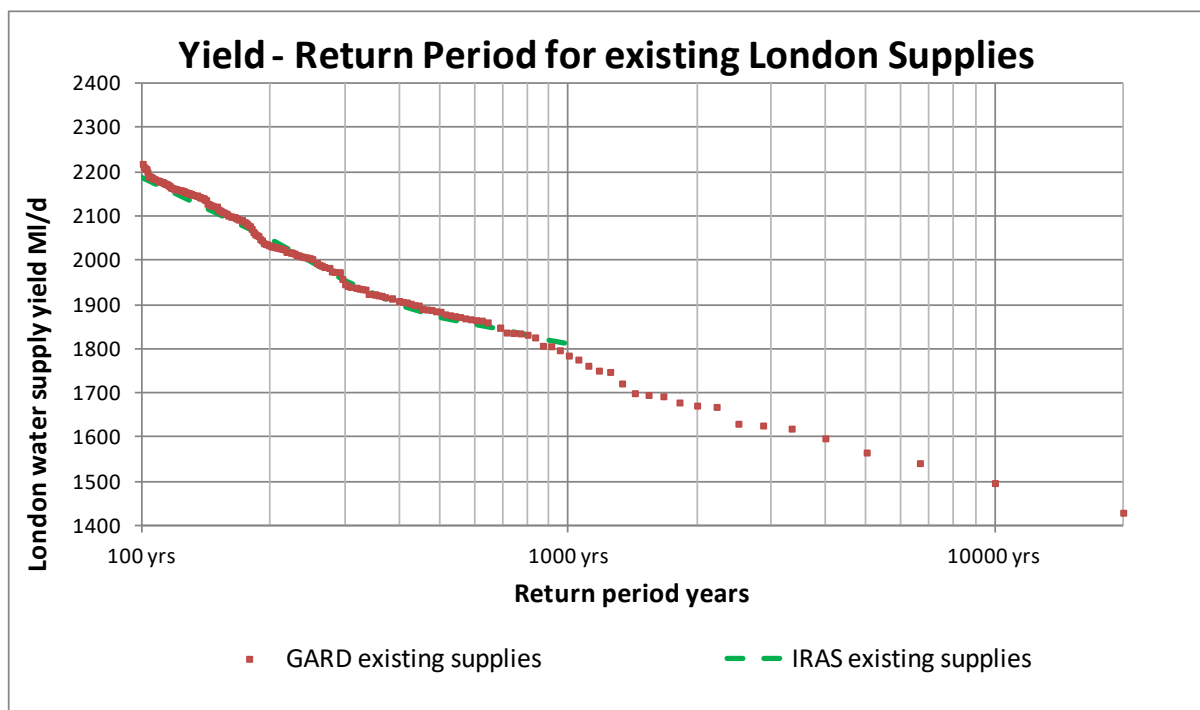
- Notes: 1. Minimum storages at demands of 2140 MI/d for existing supplies and 2434 MI/d with Abingdon reservoir
2. Yields of 2140/2434 MI/d using IRAS flow data equate to 2305/2599 MI/d using WARMS flow data

Table 2 - Extracts from GARD's table of initial drought identification

This methodology ensured identification of all droughts of return period more than 100 years, with and with Abingdon reservoir. Table 2 shows that in some droughts there is much more draw-down of London’s reservoirs when Abingdon reservoir is added to the existing supply system. The bottom part of Table 2 shows examples of droughts where Level 4 supply cuts would only be needed when Abingdon reservoir is added to the existing London supplies.

3.2 GARD’s assessment of yield-probability of existing supplies

The 10-year version of GARD’s model has been used to determine the yield-probability of the existing London supply system, for all drought years in the 15,600-year records with return period greater than 100 years, as shown in Figure 4:



- Notes: 1. GARD assessment if assuming that the 15,600 years of stochastic data represent 20,000 years of climate
 2. IRAS assessment copied from Figure 5-4 of Atkins’ Stage 2&3 Report

Figure 4 - Yield-probability for existing London supplies (assuming 20,000 years of record)

GARD’s assessment shows an almost identical yield-probability relationship to the IRAS relationship shown in Atkins’ Stage 2&3 report⁷, providing some further validation of GARD’s modelling. On Figure 4, GARD’s calculation of the drought probabilities from the ranking of gross supply yield assumes that the 15,600 years of stochastic data are representative of 20,000 years of actual climate – the same assumption as made in Atkins’ reports.

Atkins’ justification of their assumption that the 15,600 years of stochastic data are equivalent to 20,000 years of climate data is given below⁸:

⁷ Thames Water Stochastic Modelling Stage 2&3 Report, Figure 5-4, Atkins, July 2018

⁸ Ibid page 34

“A count of the number of failures within the record was taken at each level of demand and then divided by 20,000 to generate a return period for that yield. [The value 20,000 was taken rather than the 15,400 years of generated data, as the anomaly fitting was designed to make the weather generator reflective of the 20th Century climate overall. The literature review confirmed that there were no ‘level 4’ type droughts in the first 20 years of the 20th Century for the Thames basin, so the full period was taken as the denominator to avoid biasing the yield results]. The return period/yield relationship was then plotted for IRAS based on this data.”

The critical droughts for London’s existing supplies are mostly of about 18 months’ duration, but the stochastic data include some droughts of about 30 duration that are critical for the existing supplies (three summers and two winters). With the addition of Abingdon reservoir, London’s supplies become more vulnerable to 30-month droughts because of the limited availability of water for refilling the additional reservoir.

Figure 5 shows the Met Office 18-month and 30-month rainfall totals for Oxford for each year since 1853⁹:

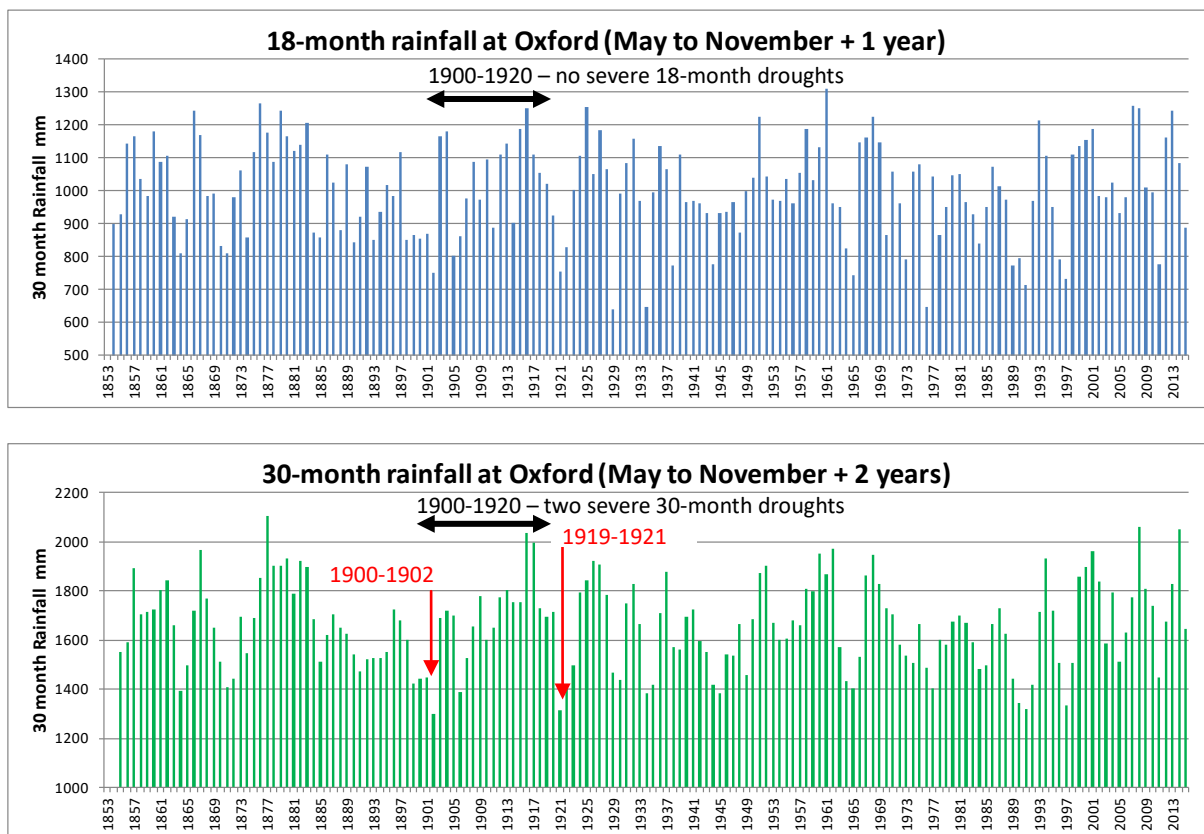


Figure 5 - 18-month and 30 month rainfall totals for Oxford since 1853

The upper plot in Figure 5 supports the assumption that there probably were no ‘Level 4’ 18-month droughts in the first 20 years of the last century. However, the lower plot suggests this is not the case for 30-month droughts. The most severe 30-month drought since 1853

⁹ <https://www.metoffice.gov.uk/pub/data/weather/uk/climate/stationdata/oxforddata.txt>

was from May 1900 to November 1902. The second most severe 30-month drought was May 1919 to November 1921. It thus appears that there were probably at least one and possibly two 'Level 4' 30-month droughts in the first 20 years of the last century.

Therefore, in our opinion, the return period for droughts should be calculated by dividing the drought rank by 15,600, not by 20,000. The yield-probability relationship for existing supplies shown in Figure 4 then re-plots as in Figure 6:

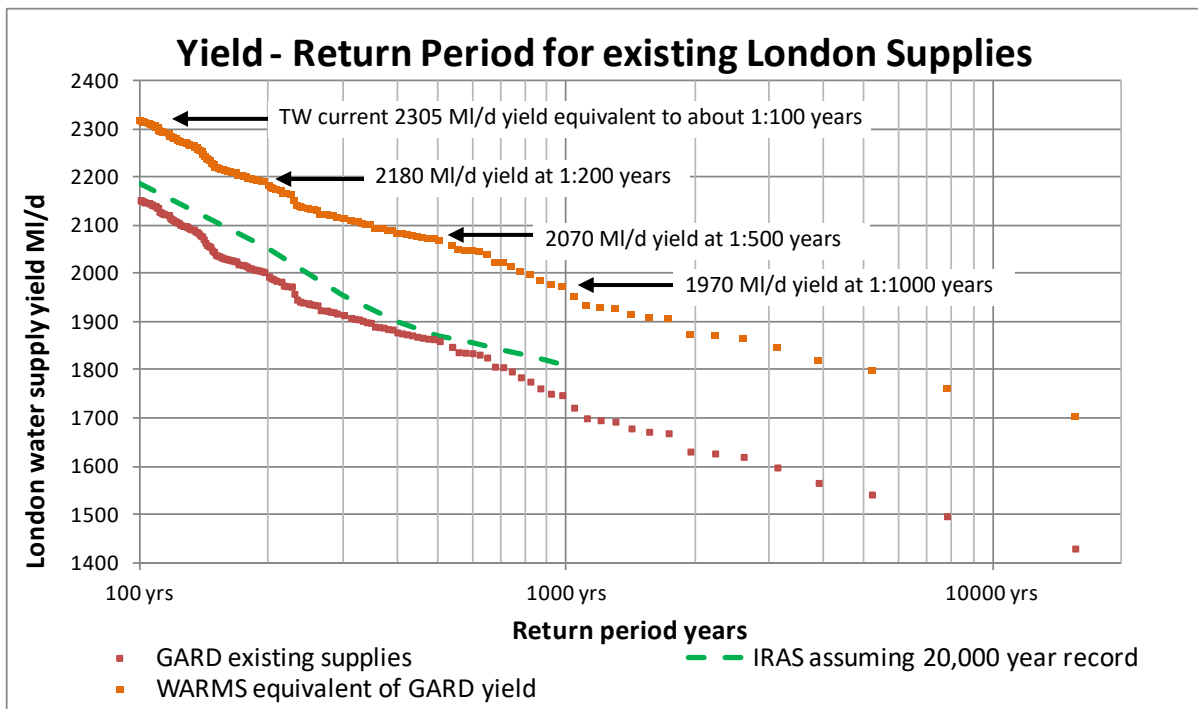


Figure 6 - Yield-probability for existing London supplies (assuming 15,600 years of record)

Calculation of the yield return periods assuming 15,600 years of record reduces the yields by about 30-50 MI/d. In our opinion, this is a better way of calculating return periods and yields than Atkins' assumption of a 20,000 year record.

Figure 6 also shows the WARMS equivalent of GARD's yields, calculated using the Atkins equation shown on Figure 3:

$$y = 0.8464x + 490.07 (R^2 = 0.7684)$$

Figure 3 shows a large scatter of x-y values about the yield calculated using this equation – errors of about +/- 100-150 MI/d for individual droughts. This is indicative of a major weakness in Atkins' methodology – the failure to generate WARMS flows for all 15,600 droughts in the stochastic weather record, and using IRAS flows instead. Nevertheless, the IRAS flows are the only flows at present available for all the droughts, so the 'WARMS equivalent' yields are the only ones available that make use of the full stochastic data.

The yields of the existing London supplies at various return periods are as follows, when calculated assuming 15,600 years of record:

- TW's currently assumed 2305 MI/d yield has a return period of about 1:100 years, matching Thames Water's expected 1:100 year frequency of Level 4 supply cuts in their published service levels¹⁰. If calculated assuming 20,000 years of record, the return period is about 1:140 years. As well as exceeding TW's expected frequency of Level 4 supply cuts, 1:140 years does not feel right, bearing in mind that there have been two droughts in the past 100 years in which the yield is about 2305 MI/d – 1920/21 and 1933/34.
- A yield of 2182 MI/d at 1:200 years – a loss of 123 MI/d from the current 2305 MI/d.
- A yield of 2070 MI/d at 1:500 years – a loss of 235 MI/d from the current 2305 MI/d.

The loss of yield of 123 MI/d at 1:200 years and 235 MI/d at 1:500 years compare with Thames Water's WRMP figures of '130-150 MI/d' and 'around 250 MI/d' respectively.¹¹

The new requirement for supplies to assure yield in 1:500 year droughts implies a loss of London yield of 235 MI/d. The capital cost of replacement sources could be at least £1billion. In justifying the need for this, it is important to understand how the existing London supply system would behave in the event of droughts in the range 100 to 500 year return period.

3.3 Behaviour of existing supplies in droughts of 100 to 500 year return period

Atkins' published reports to date show no detail of how the London supply system would behave in severe droughts. There appears to have been no consideration of different types of drought or the performance of the supplies in droughts more severe than the nominal design standard. For example, there appears to have no consideration of the adequacy of emergency storage or the duration of Level 4 supply cuts in the event of a drought more severe than the design standard. In GARD's view, this failure to examine more details of typical 'severe' cases is a major failing of their exercise. As we will show below, there are numerous examples of counter-intuitive results of adding a *climate-dependent* water resource to a complex baseline system. These would essentially not arise in the case of a supplementary water resource which was climate-independent.

In doing the analysis for this report, we have looked at plots of reservoir storage and refill in all the droughts of more than 100-year return period in the 15,600 year record. We have analysed minimum storages and durations of Level 4 supply cuts for about 200 droughts in the record.

We have shown below illustrations of the behaviour of the existing London supplies in some typical droughts with return periods between 100 and 500 years:

¹⁰ Thames Water Final WRMP 19, Table 1-1, April 2020

¹¹ Thames Water Final WRMP, Section

- The drought in IRAS Run_34 1980, which is a typical single year drought (like the historic drought of 1921) with a return period of 1:488 years for the existing London supply system
- The drought in IRAS Run_25 1959, which is a typical 18-month drought (like the historic droughts of 1933/34 and 1975/66) with a return period of 1:289 years for the existing London supply system
- The drought in IRAS Run_162 1933, a typical 18-month drought with a return period of 1:217 years for the existing London supply system
- The drought in IRAS Run_185 1947, which is an 18-month drought preceded by a dry year (return period 1:179 years) – the type of long drought in which Abingdon reservoir yield is reduced

Drought of IRAS Run_34, 1928 - Single year drought with 1:488 year return period

Figure 7 shows the storage and refill of London’s reservoirs operating at the WARMS equivalent present day demand of 2305 MI/d. The lower plot shows the detail at the peak of the drought, including the storage occurring if the Level 4 supply cuts were not made.

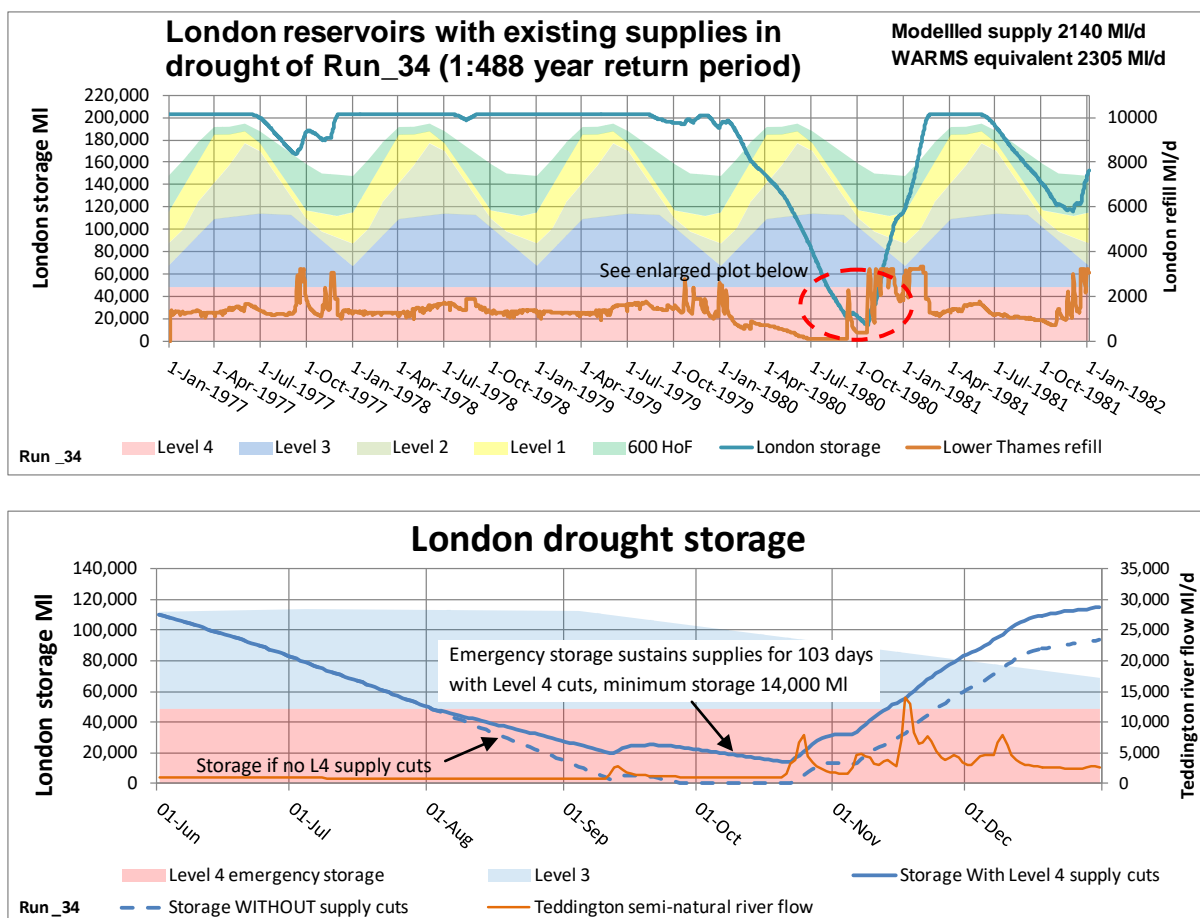


Figure 7 - Operation of existing supplies in typical single year drought (1:488 year RP)

The 48,500 MI of emergency storage and Level 4 supply cuts would be more than sufficient to maintain the reduced supplies for 103 days until Thames river flows increased in the late autumn. This is well in excess of Thames Water’s 30-day emergency storage criterion. The minimum storage would be about 14,000 MI.

Without the Level 4 supply cuts, the emergency storage would maintain supplies for 56 days until the reservoirs were completely empty, but they would remain empty for 25 days before supplies without Level 4 cuts could resume.

Drought of IRAS Run25, 1959 – 18-month drought with 1:289 year return period

Figure 8 shows the operation of the existing supplies in a typical 18-month drought with a return period of 1:289 years:

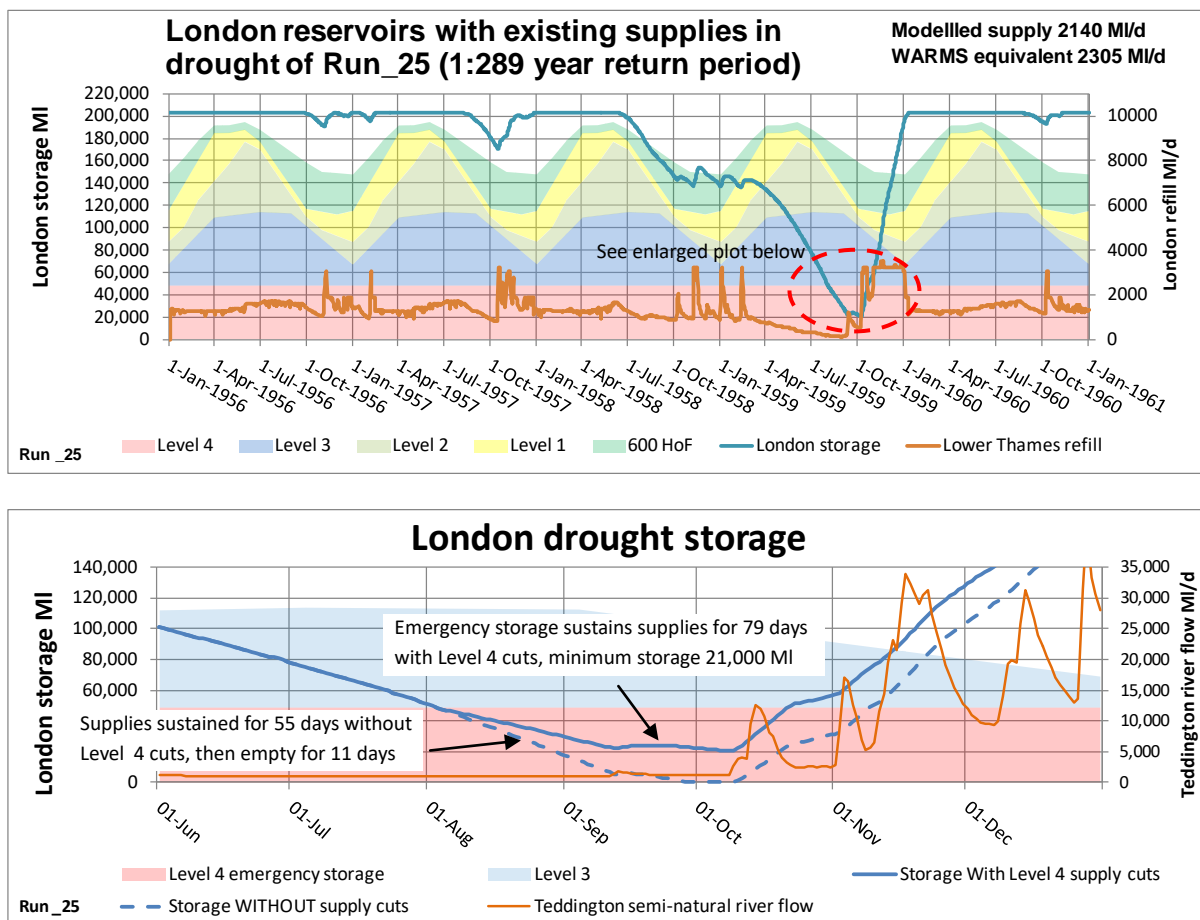


Figure 8 - Operation of existing supplies in typical 18-month drought (1:233 year RP)

With Level 4 supply cuts, the emergency storage would maintain supplies for 79 days, with a minimum storage of 21,000 MI. This is well in excess of Thames Water’s criterion of 30 days and suggests that the Level 4 emergency storage control line could be set lower.

Without the Level 4 supply cuts, supplies could be sustained for 55 days, but the reservoirs would then be empty for 11 days before starting to refill in the autumn.

Drought of IRAS Run162, 1933 – 18-month drought with 1:217 year return period

Figure 9 shows the operation of the existing supplies in a typical 18-month drought with a return period of 1:217 years:

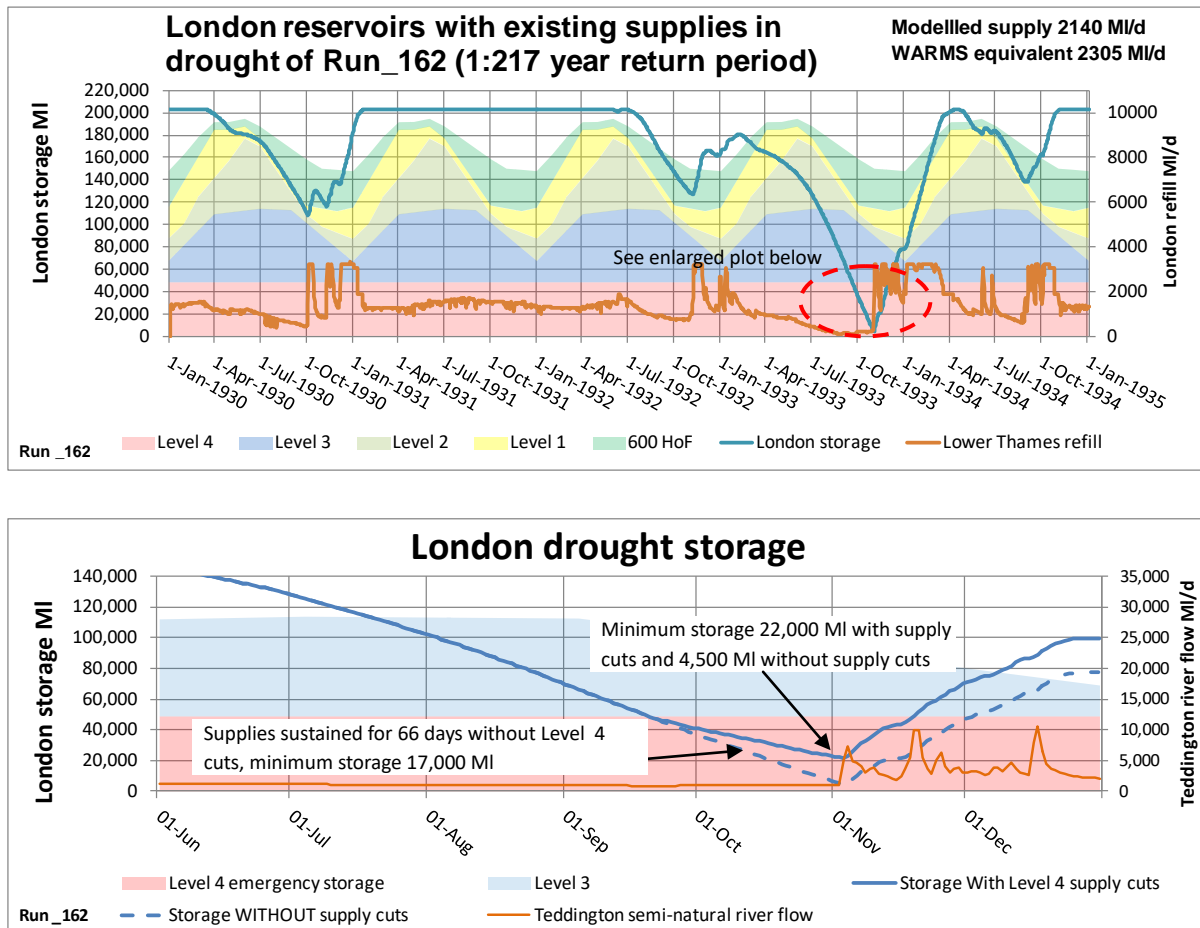


Figure 9 - Operation of existing supplies in typical 18-month drought (1:217 year RP)

With Level 4 supply cuts, the emergency storage would be in use for 59 days and the minimum storage would be about 22,000 MI.

If there were no Level 4 supply cuts, supplies could still be maintained throughout the 1:217 year drought and there would still be a minimum remaining storage of about 4,500 MI.

GARD’s modelling shows that the 48,500 MI of emergency storage would be sufficient to maintain supplies without Level 4 cuts in all droughts up to return periods of 200 years. If the return periods are assessed assuming a 20,000 year climate record, the existing supplies could be maintained without Level 4 supply cuts in droughts up to 1:250 years return period.

Drought of IRAS Run 185, 1947 – 18-month drought with 1:179 year return period, preceded by two moderately dry years

Figure 10 shows the operation of the existing supplies in the 1: 179 year drought and the moderately dry years which preceded it:

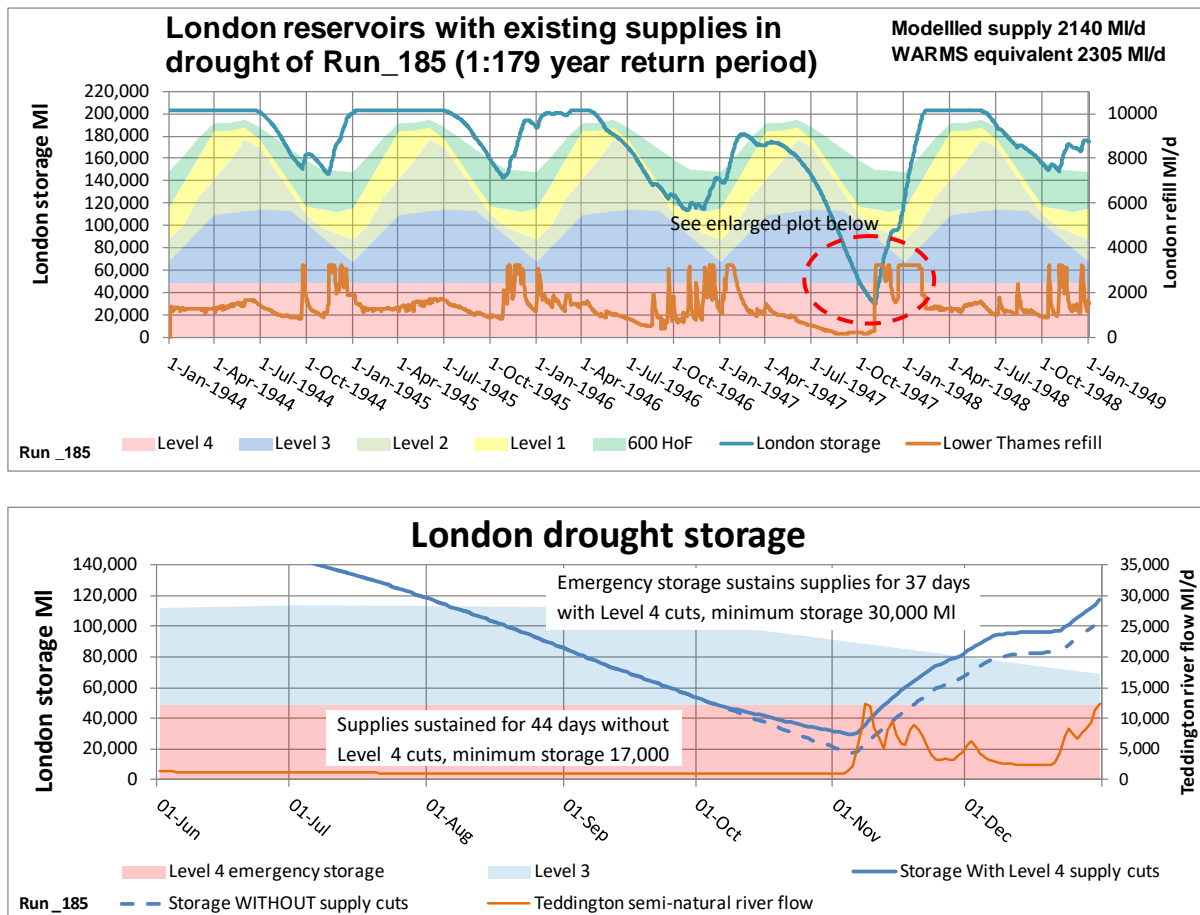


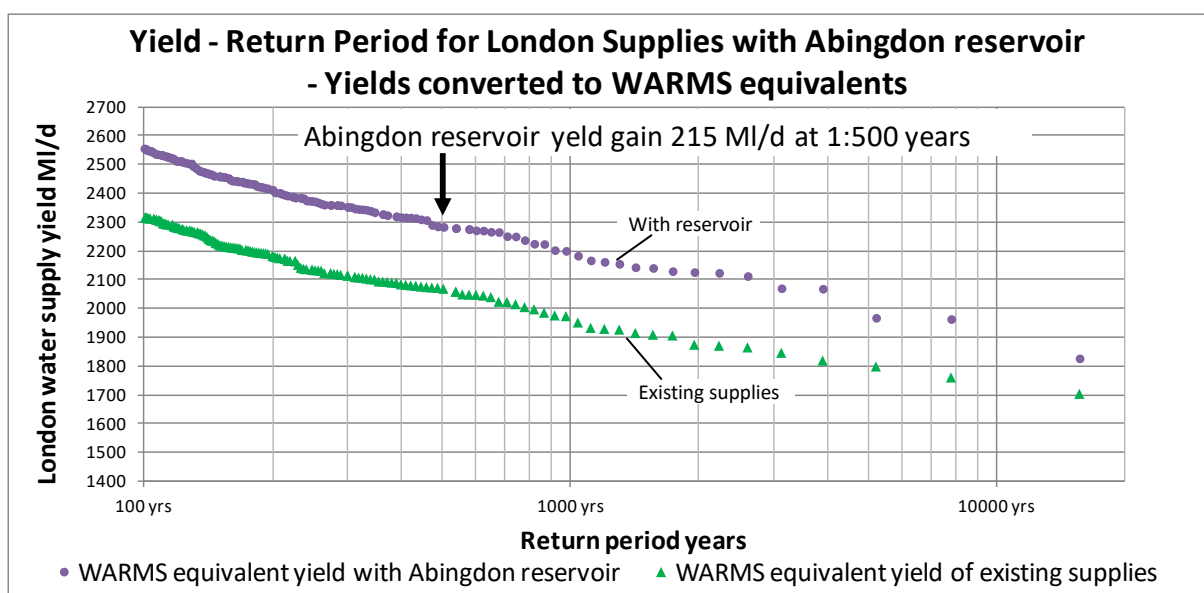
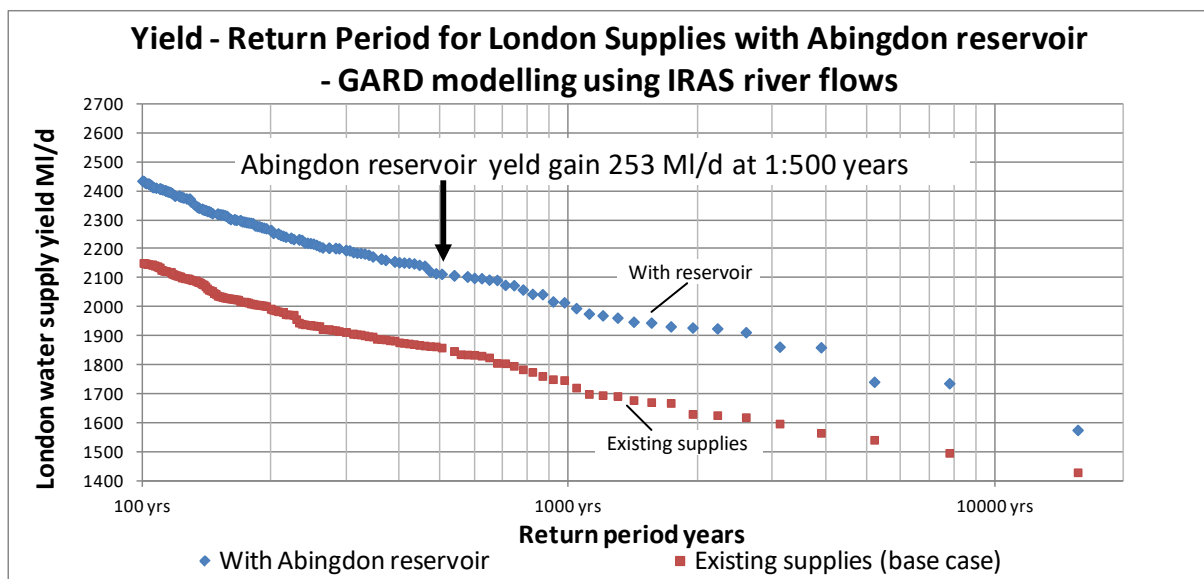
Figure 10 - Operation of existing supplies in 18-month drought following a dry year

Even without any Level 4 supply cuts, the supplies can be maintained throughout the drought with a minimum storage of about 17,000 MI. The London reservoirs easily refill after each of the moderately dry years, 1944 and 1945 shown in Figure 10. Even in 30-month droughts like the one shown later in Figure 15, the London reservoirs are virtually full at the start of the last 18 months of the drought. The critical droughts for London’s existing supplies are of about 18 months’ duration.

4. The drought resilience of London's supplies with Abingdon reservoir

4.1 GARD's assessment of yield gain from Abingdon reservoir

Using GARD's model and IRAS river flows, we have assessed the gross yields of London's supplies with the addition of Abingdon reservoir for the 200 most severe droughts in the 15,600-year IRAS flow records. The 200 most severe droughts with Abingdon reservoir were identified using the methodology described in Section 3.1. The yields derived using IRAS flows were then converted to WARMS equivalent yields using the Atkins equation shown on Figure 3. The gross yields for each drought were ranked and their return periods calculated assuming 15,600 years of record. The results are shown on Figure 11:



In lower plot, yields using IRAS flows are converted to WARMS equivalent using Atkins' equation: $y = 0.8464x + 490.07$

Figure 11 - GARD assessment of 1:500 year yield gain from Abingdon reservoir

Figure 11 shows that the yield gain from Abingdon reservoir is 253 MI/d when assessed

using IRAS river flows. The yield drops to 215 MI/d when the IRAS yields are converted to WARMS equivalents using Atkins' equation – a 15% drop and 60 MI/d less than the 275 MI/d yield estimated by Atkins.¹²

The return periods shown on Figure 11 are calculated assuming a 15,600 year record, rather than Atkins' assumption of equivalence to a 20,000 year record. The justification for this is given in Section 3.2, supported by the records of 30-month Oxford rainfall droughts shown on Figure 5. However, even if Figure 11 is re-plotted using the 20,000 year record assumption, the 1:500 year yield gain for Abingdon reservoir is still about 215 MI/d.

The 15% drop in yield gain when converting GARD's IRAS yield gains using IRAS flows to WARMS equivalents is not consistent with Figure 2 of this report which shows a 1:1 equivalence, albeit with a relatively small number of comparisons and only a moderate correlation on the plot. This uncertainty needs to be resolved.

4.2 Resolution of differences between GARD and Atkins' yield assessments

GARD's Abingdon reservoir yield of 215 MI/d is much less than the 294 MI/d quoted in Thames Water's final WRMP or the 275 MI/d quoted in Atkins' Technical Note. In our opinion, the differences between GARD and Thames Water's reservoir yield gains are probably the consequence of the flaws in Atkins' methodology that we highlighted in Section 2 of this report:

- The use of only 25% of the available 15,600 years of data
- The method of drought selection which excludes long duration droughts which are severe with the reservoir in place but less severe for existing supplies
- The high proportion of assessed droughts with return periods less than 100 years
- The crude method of yield assessment for each drought
- The "averaging" of assessed drought yields for a small proportion of droughts instead of the ranking of gross yields for all droughts, as used to generate Figure 10.

We accept that the methodology that we used to derive the Abingdon reservoir yield gain of 215 MI/d also has potential flaws:

- our use of IRAS river flow data, which differ significantly from the river flows generated by WARMS using the same stochastic weather data and which, according to Atkins, "gives around 150MI/d lower yield, with a +- 150MI/d range"¹³
- the conversion of yields to WARMS equivalents using Atkins' formula, derived from the scatter plot on Figure 3, which shows quite a weak correlation between yields

¹² Atkins Technical Note, page 10, May 2018

¹³ Atkins Technical Note, page 1, May 2018

derived from IRAS and WARMS flows ($R^2 = 0.77$), and which may not be applicable when Abingdon reservoir is added to the existing supplies.

However, the weaknesses in both Atkins' and GARD's methodologies could and should be addressed by using the rainfall/run-off component of the WARMS model to generate river flows for the full 15,600 years of stochastic weather data. The yields for each drought should then be assessed using a model that will run fast enough to allow a proper yield assessment. This suggestion was made by GARD at the technical stakeholder meeting on 29th January 2018, using the slide shown in Figure 12:


Solution to modelling problem?

Problem with modelling 15,600 years of flows:

- River flows from IRAS/Catchmod are unreliable
- Running WARMS2/Hysim is too slow

So, why not:

- Generate stochastic river flows in Hysim alone?
- Run stochastic flows in a faster simulator like IRAS or GARD's model? Check with WARMS2?



Copied from Slide 43 of GARD's presentation to the technical stakeholder meeting of 29th January 2018

Figure 12 - GARD proposal for improved generation of stochastic river flows

Atkins' written response to this proposal was included in Thames Water's unpublished final note of the 29th January 2018 stakeholder meeting as follows:

*"In response to GARD's 'solution to modelling problem' on **Slide 43**, it is not feasible to run extended stochastically generated sequences of rainfall and PET through WARMS2 given the computation burdens involved. Although the IRAS model can be used to run the full 15,400 year stochastic time series, this relies on outputs from the Catchmod lumped parameter hydrological model of the River Thames, which produces different results to the more accurate, catchment distributed model contained within WARMS2 (Catchmod gives around 150MI/d lower yield, with a +/- 150MI/d range). However, the WARMS2 DOs can be mapped to the IRAS results enabling DO vs. return period plots to be generated.*

Furthermore, GARD incorrectly state on this slide that WARMS2 uses HYSIM, this is not the case as WARMS2 uses inbuilt rainfall runoff models. In fact, the flows in Aquator not only include the 'natural' catchments, whichever rainfall-runoff model they use, but also include the impacts of return flows, abstractions etc., and so in order to get flows that end up being in Aquator, you have to run Aquator – there's no quick way round it."

In our opinion, in view of the large differences in GARD and Thames Water yield assessments, it is essential that the resilience work now being undertaken by WRSE makes use of the full 15,600 years of river flows, derived from the stochastic weather data using a reliable rainfall/run-off model. We do not believe that it is necessary to run Aquator, in its slow-running full optimisation mode, to get sufficiently reliable estimates of “*the impacts of return flows, abstractions, etc*”, as stated above by Atkins. These can be simply approximated, as has been done in GARD’s model. The validity of the approximations can be spot-checked using the WARMS model.

The yield for all droughts should be assessed, with and without Abingdon reservoir. The yield assessments for each drought should be done properly by finding the demand that can just be sustained without Level 4 supply cuts, instead of the crude approximation used by Atkins. If the existing methodology using the WARMS model is unable to do this, it should be modified or replaced by a model that is fit-for-purpose, with WARMS only used for spot checks.

4.3 Behaviour of supplies with Abingdon reservoir in droughts of 1:100-500 year RP

To illustrate the drought behaviour of London’s supply supported by Abingdon reservoir we have shown below operation of supplies in the following droughts:

- The drought in IRAS Run_ 25 1959, which is a typical 18-month drought with a return period of 1:289 years for the existing London supply system and 1:223 years with the addition of Abingdon reservoir – the same drought that is shown for existing supplies on Figure 8. For this drought, our assessed yield gain from Abingdon reservoir is **321 MI/d**.
- The drought in IRAS Run_185 1943, which is an 18-month drought preceded by two moderately dry years, 1:179 years RP for existing supplies and 1:236 years RP with Abingdon reservoir – the type of long drought in which Abingdon reservoir yield is reduced and which is shown for existing supplies on Figure 10. For this drought, our assessed yield gain from Abingdon reservoir is **219 MI/d**.
- The drought in IRAS Run_ 39,1958 – a 30-month drought with 1:101 year RP for existing supplies and 1:208 year RP with Abingdon reservoir. For this drought, our assessed yield gain from Abingdon reservoir is **101 MI/d**.

For each of these droughts, we have analysed the operation of London’s supplies with the modelled demand of 2434 MI/d (WARMS equivalent 2555 MI/d), ie with the system requiring 294 MI/d yield gain from Abingdon reservoir, as assumed in Thames Water’s WRMP¹⁴. In the last two longer droughts, in which the yield gain from the reservoir is much less than 294 MI/d, the assessed drought return period with the reservoir is a lot more than the return period for

¹⁴ Thames Water final WRMP19, Section 10, Table 10-29

existing supplies. The addition of the reservoir makes the drought become more severe for London's supply. This would not happen with a climate independent source like desalination.

Drought of IRAS Run25, 1959 – 18-month drought with 1:289 year return period for existing supplies and 1:223 year return period with Abingdon reservoir

Figure 13 shows the conjunctive operation of the London and Abingdon reservoirs, with an additional Abingdon reservoir supply of 294 MI/d (as per TW's WRMP), in the same typical 18-month drought as shown for the existing supplies on Figure 8:

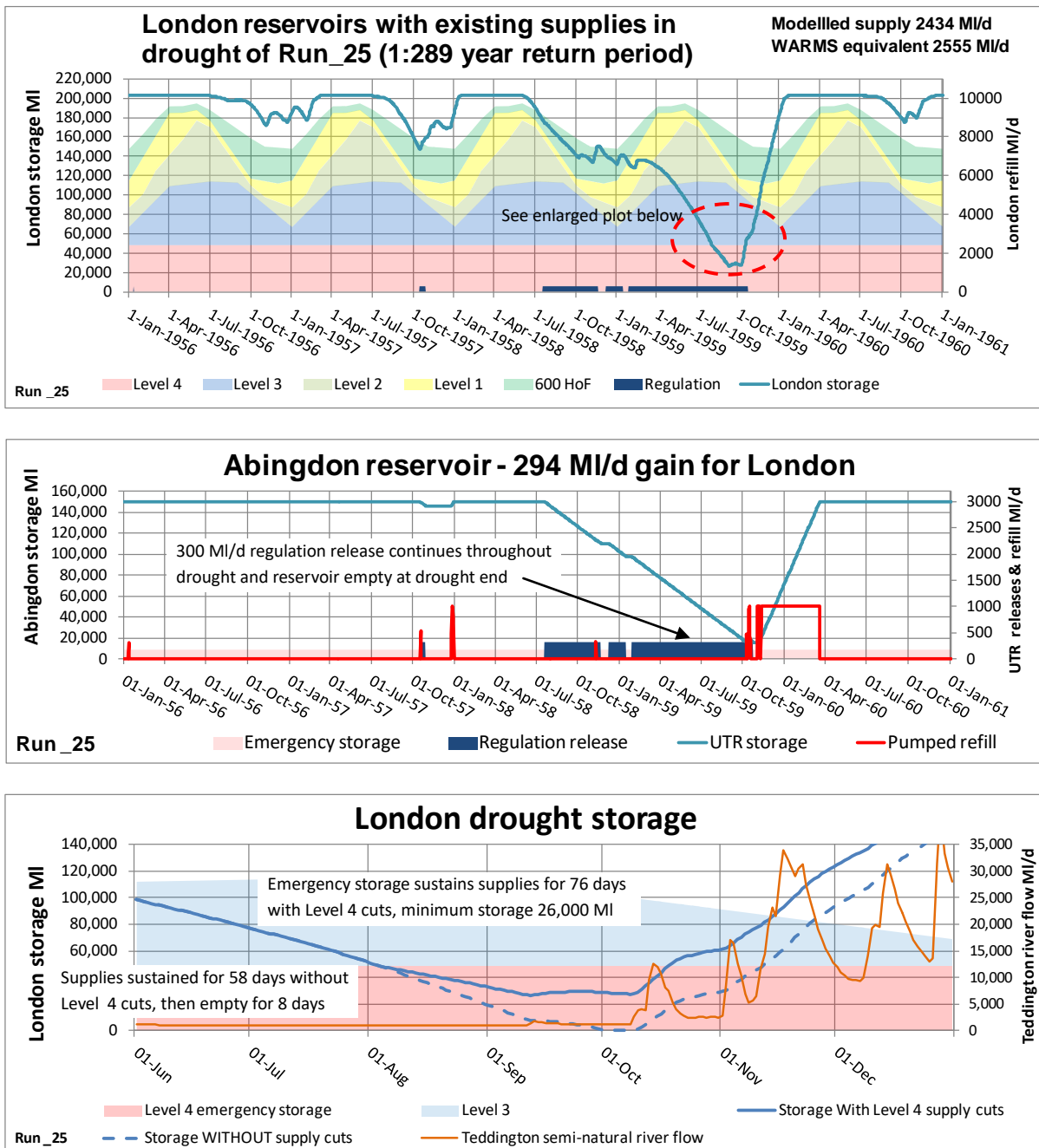


Figure 13 - Operation of London and Abingdon reservoirs in typical 18-month drought

The Abingdon reservoir operation shown in Figure 13 is typical for droughts of up to 18 months duration, like the historic drought of 1933/34. The 300 MI/d release continues throughout the drought and Abingdon reservoir just empties at the end of the drought. The duration of Level 4 restrictions and the minimum London reservoir storages are similar to those that would occur with the existing London supplies in this drought (see Figure 8).

Drought of IRAS Run 185, 1947 – 18-month drought with 1:179 year RP for existing supplies and 1:236 year RP with Abingdon reservoir, after two other quite dry years

Figure 14 shows the conjunctive operation of the London and Abingdon reservoirs, with an additional Abingdon reservoir supply of 294 MI/d, in the same 18-month drought as shown for the existing supplies on Figure 10:

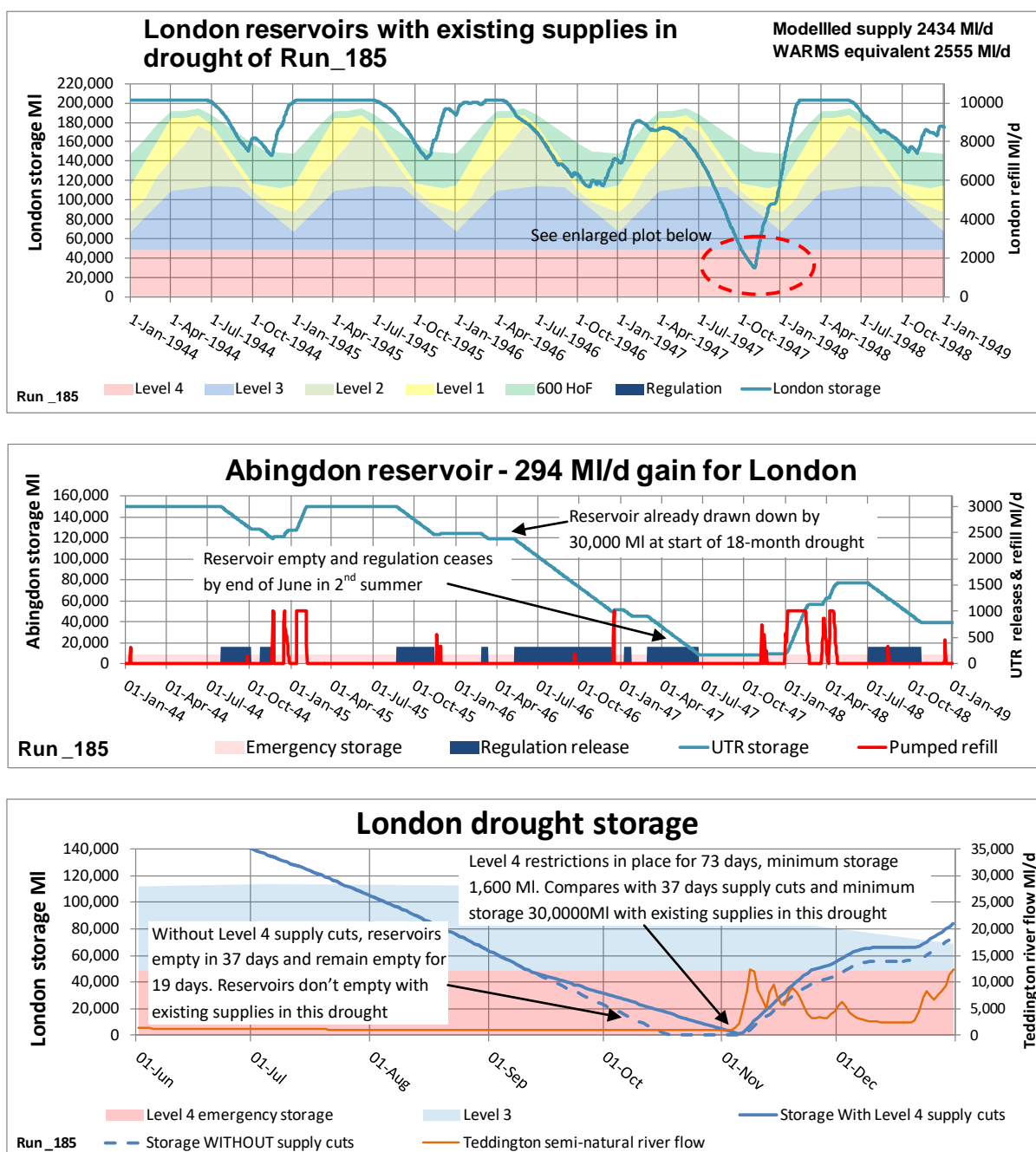


Figure 14 - Operation with Abingdon reservoirs in 18-month drought after two dry years

Due to the previous dry year, Abingdon reservoir is drawn down by 30,000 MI/d at the start of the 18-month drought, so the yield gain that can be sustained by Abingdon reservoir is only 219 MI/d. Therefore, if required to supply an additional 294 MI/d as per TW's WRMP, the duration of Level 4 cuts would be 73 days instead of only 37 days with the existing supplies in this drought. Without the Level 4 cuts, the London reservoirs would empty.

Drought of IRAS Run 39, 1958 – typical 30-month drought with 1:101 year RP for existing supplies and 1:208 year RP with Abingdon reservoir

The upper plot in Figure 15 below shows the existing London reservoirs could sustain the demand of 2140 MI/d (WARMS equivalent 2305 MI/d) without Level 4 supply cuts. The lower two plots show the supply failures that would occur if Abingdon reservoir is required to supply an additional 294 MI/d.

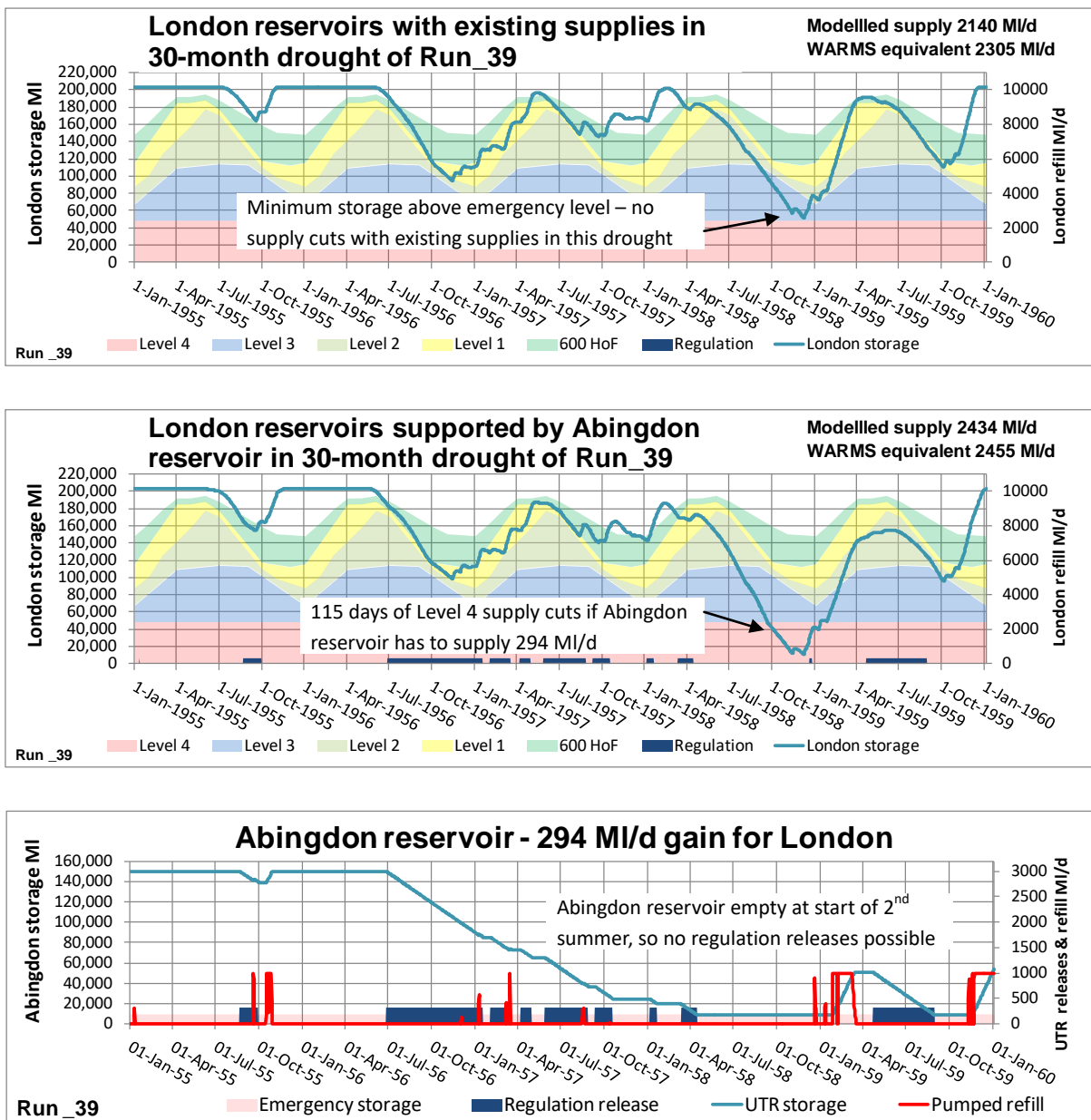


Figure 15 - Operation with Abingdon reservoirs in typical 30-month drought

The yield gain that can be sustained by Abingdon reservoir in this drought is only 101 MI/d, because Abingdon reservoir would be empty at the start of the second summer of the drought. Therefore, if expected to yield 294 MI/d, as per Thames Water’s WRMP, there would be 3½ months of Level 4 supply restrictions in the second summer of the drought.

In Table 3 below, we have listed all the droughts in excess of 1:100 year return period for Abingdon reservoir’s gross yield, in which the reservoir would deliver less than 240 MI/d yield gain:

Droughts in which Abingdon reservoir yield gain is less than 240 MI/d							
Yields of existing supplies and with Abingdon reservoir (UTR) in droughts						WARMS equivalent gross yields	
IRAS Run_year	Existing supplies gross yield MI/d	UTR gross yield MI/d	UTR yield GAIN MI/d (<200)	Base case gross yield return period 1 in yrs	UTR gross yield return period 1 in yrs	Base case MI/d	With UTR MI/d
98_1958	2007	2076	69	188 yrs	709 yrs	2193	2251
159_1975	1497	1576	79	7800 yrs	15600 yrs	1760	1827
39_1958	2152	2253	101	101 yrs	208 yrs	2316	2402
17_1952	2272	2376	104	75 yrs	126 yrs	2418	2506
48_1940	2140	2255	115	108 yrs	203 yrs	2306	2403
136_1942	2285	2412	127	75 yrs	107 yrs	2429	2536
109_1930	2179	2316	137	86 yrs	156 yrs	2339	2455
17_1968	2220	2362	142	77 yrs	131 yrs	2374	2494
114_1975	2121	2265	144	116 yrs	200 yrs	2290	2412
104_1959	2137	2299	162	109 yrs	170 yrs	2303	2441
175_1928	1940	2105	165	240 yrs	578 yrs	2136	2276
128_1938	2115	2291	176	117 yrs	177 yrs	2284	2434
149_1941	1542	1737	195	5200 yrs	7800 yrs	1798	1964
0_1943	2025	2222	197	168 yrs	240 yrs	2208	2375
180_1981	2209	2408	199	79 yrs	110 yrs	2364	2533
50_1988	1994	2203	209	200 yrs	284 yrs	2182	2359
185_1947	2012	2231	219	179 yrs	236 yrs	2197	2383
85_1948	1722	1949	227	1040 yrs	1418 yrs	1951	2144
176_1989	1876	2109	233	411 yrs	538 yrs	2082	2279
165_1957	2146	2379	233	105 yrs	124 yrs	2311	2508
73_1977	1923	2157	234	274 yrs	390 yrs	2122	2320
151_1945	1938	2174	236	248 yrs	347 yrs	2134	2334
142_1956	2177	2413	236	88 yrs	106 yrs	2337	2537
115_1951	1906	2145	239	318 yrs	446 yrs	2107	2310
147_1955	2096	2335	239	129 yrs	139 yrs	2268	2471

See Figure 15

See Figure 14

Table 3 - Long droughts in which Abingdon reservoir gives less than 240 MI/d yield gain

In all of these droughts, if a 294 MI/d yield was expected from the reservoir as per TW’s WRMP, London’s supplies would experience substantially longer supply failures than would have occurred with the existing supplies at the existing demand levels (2140 MI/d with IRAS and 2305 MI/d WARMS equivalent). Examples of two of these droughts are shown on Figures 14 and 15.

There are 25 droughts listed on Table 3, of which all but 6 have return periods of less than 1:500 years and more than 100 years for Abingdon reservoir's gross yield. In our opinion, the frequency of these long droughts, in which Level 4 supply cuts with Abingdon reservoir are much longer than they would be with existing supplies, is a major failing in Abingdon reservoir's drought resilience.

In their Technical Note of May 2018, Atkins recognised the existence of long duration droughts, but dismissed them as insignificant:

"It is acknowledged that some lower yields do occur as a result of longer duration droughts that are severe enough to test the conjunctive capability of the London-Abingdon system, but these are rare, at less than 10% of major drought events. The 275MI/d expected yield accounts for the influence of such events.

There is no indication that the expected resilience of the reservoir or the variability in yield changes significantly with drought severity, and longer duration events are rare as a proportion of all droughts across all of the severity bands that were tested."

The list of droughts in Table 3 shows that Atkins' downplaying of the significance of long duration droughts is not justified. In the 15,600 years of record there are 125 droughts with return periods between 100 years and 500 years. Of these, Table 3 shows there were 19 droughts in which the yield gain is less than 240 MI/d – about 1 drought in 6:

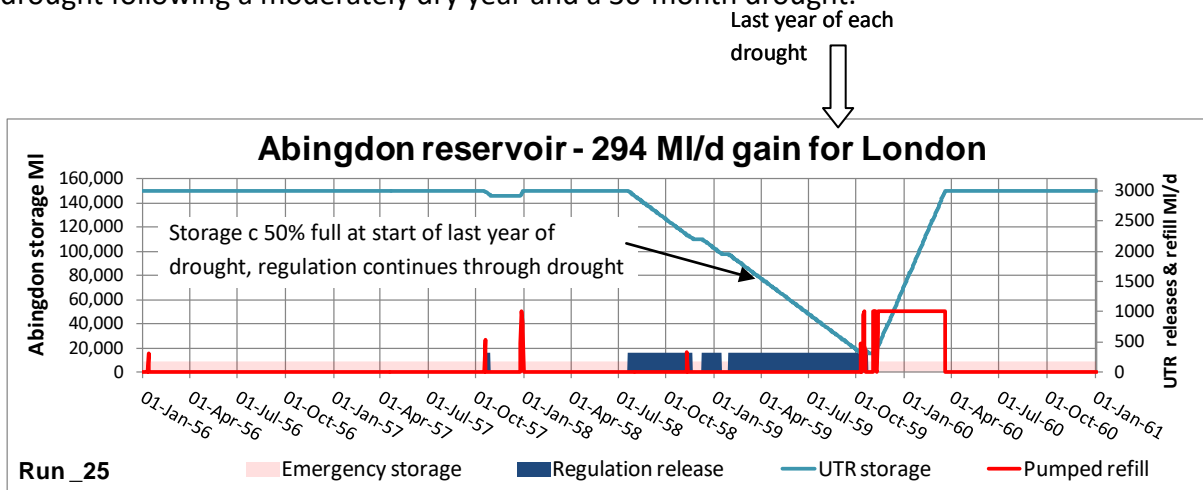
- Even in a relatively 'minor' long duration drought like that shown on Figure 14, with an Abingdon yield gain of 219 MI/d, the duration of Level 4 supply cuts would be 73 days compared to only 37 days for the existing supply system.
- In the major long duration drought shown on Figure 15, in which the Abingdon reservoir yield is only 101 MI/d, there would be no Level 4 restrictions if the existing supplies were required to meet present day demands, but 3½ months of Level 4 supply cuts if Abingdon reservoir is required to supply an additional 294 MI/d.

The increased frequency and duration of Level 4 supply restrictions with Abingdon reservoir in long duration droughts should be properly analysed and taken into account when comparing the economic benefits of Abingdon reservoir with other water resource options. The huge economic cost of Level 4 supply restriction in London has been the driver to justify the increase in the resilience standard from about 1:100 years (worst historic) to 1:500 years. Therefore, the economic damage from increased frequency and duration of Level 4 restrictions should be properly costed when comparing Abingdon reservoir with other options.

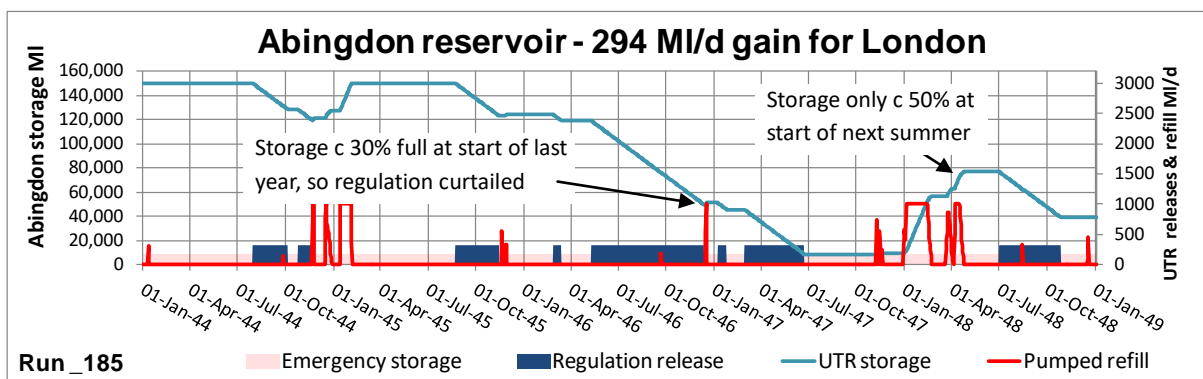
4.4 Operational management of low Abingdon reservoir storage

The analysis of typical droughts described in Section 4.3 and illustrated in Figures 13-15 has shown that the security of London's supplies with Abingdon reservoir is dependent on the

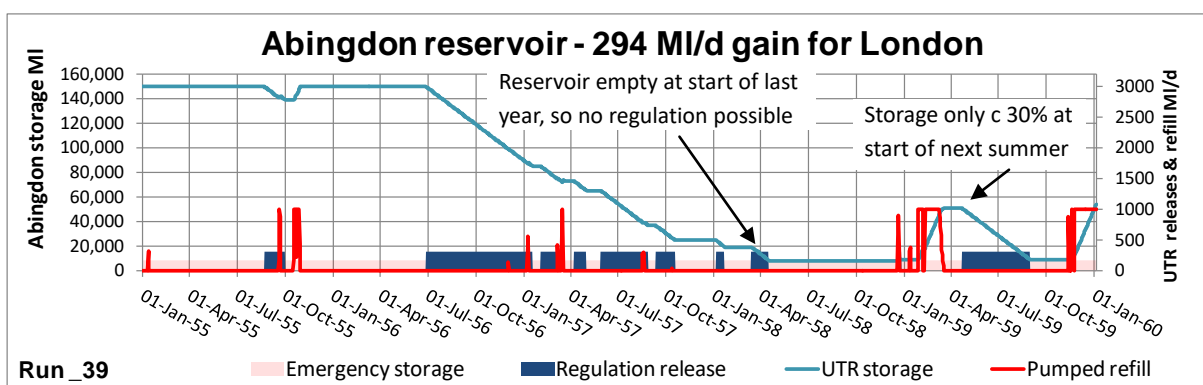
amount of water available in Abingdon reservoir at the start of the last year of the drought. In Figure 16 below, we have compared the trajectory of Abingdon reservoir storage in the three droughts analysed in Figures 13-15 – a typical 18-month drought, an 18-month drought following a moderately dry year and a 30-month drought.



Typical 18-month drought



18-month drought following a moderately dry year



Typical 30-month drought

Figure 16 - Abingdon reservoir draw-down trajectory in different types of drought

With a typical 18-month drought like that of IRAS Run 25, Abingdon reservoir starts to draw down with the commencement of regulation in the first summer. Regulation is then needed almost continuously until the end of the drought in the second summer, by which time

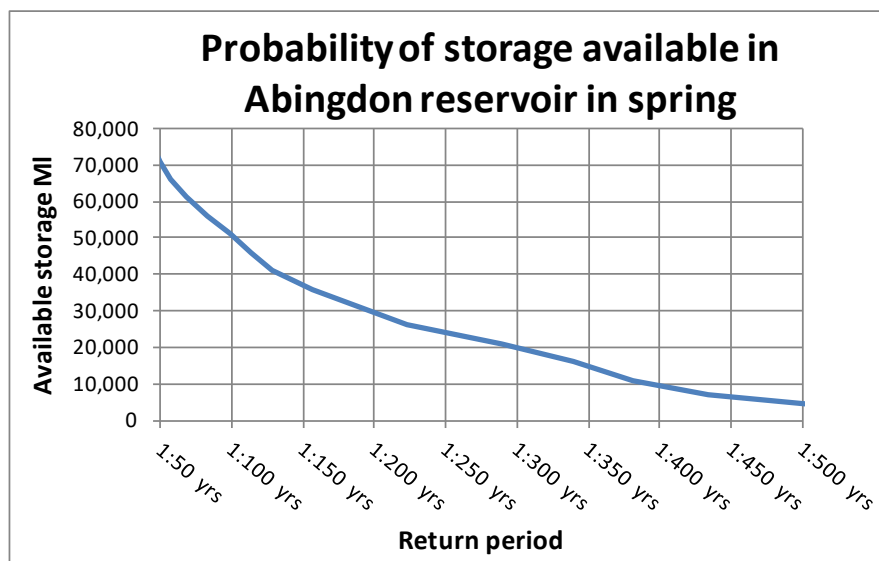
Abingdon reservoir is just empty. Typically, there is minimal refilling of Abingdon reservoir in the winter of the 18-month drought.

At the start of the second summer of the 18-month drought, Abingdon reservoir is typically about 50% full. Provided Abingdon reservoir is at least 50% full in the spring of a drought year, London’s supplies are almost certain to be secure.

For the 18-month drought following a moderately dry year as for IRAS Run 185, Abingdon reservoir is only about 30% full at the start of the second year, so Abingdon reservoir is unable to prevent Level 4 supply cuts later in the year.

For the typical 30-month drought as for IRAS Run 39, Abingdon reservoir is almost empty in the spring of the second year, so extensive Level 4 supply cuts later in the year are inevitable.

From this it follows that the security of London’s supplies with Abingdon reservoir depends on whether the reservoir is at least 50% full in the spring, ie a storage of at least 70,000 MI in excess of the emergency storage. Figure 17 shows the spring storage-probability relationship for Abingdon reservoir, determined by modelling the full 15,600 years of IRAS data with a London demand of 2434 MI/d, ie assuming an additional yield of 294 MI/d from Abingdon reservoir, as per Thames Water’s WRMP.



Note: the available spring storage is the modelled maximum available each year up to the end of April

Figure 17 - Probability of spring storage available in Abingdon reservoir

Figure 17 shows that there is a 1: 50 year probability that Abingdon reservoir will be less than half full at the start of summer. Although, a severe drought will probably not then occur, there will still be a very real threat of Level 4 supply cuts later in the year. There would be a 1:100 year probability that Abingdon reservoir would be less than 1/3rd full at the start of summer, in which case the threat of Level 4 supply cuts would be severe.

The plots of typical droughts shown on Figure 16 shows that in two of the three droughts, Abingdon reservoir would be less than half full in the spring of the following year. Although, in these cases another severe drought did not follow, it is easy to imagine the sense of panic that would prevail and the consequent economic damage. As the risk that another dry summer would follow and Abingdon reservoir would quickly empty would have been flagged as a high-risk event, the London authorities and the government, would need to have contingency plans in place, and this might involve setting in motion a wide range of possibly environmentally- and economically-damaging measures. The risk of failure of London’s supplies due to Abingdon reservoir’s inability to deal with long duration droughts should be formally assessed using Government’s Risk Management procedures¹⁵, as should be applied to risk assessment for all the major resource options.

As a general observation of the pattern of droughts in the IRAS flow records, low winter flows and low reservoir levels in the spring often occur after severe droughts, probably because of the chalk groundwater deficits that have built up during the drought.

The pattern of droughts in the IRAS flow records often results in prolonged periods of Abingdon reservoir draw-down. The frequency of long periods of Abingdon reservoir draw-down when operating to provide a yield gain of 294 MI/d is shown in Table 4:

Abingdon reservoir draw-down exceeding	No of occurrences in 15,600 year record	Return period
3 years	151	1:103 years
4 years	56	1:279 years
5 years	28	1:557 years
6 years	9	1:1733 years
7 years	4	1:3900 years
8 years	1	1:15600 years

Table 4 - Frequency of periods of long draw-down of Abingdon reservoir

Figure 18 shows an example of the threat posed by long draw-down of Abingdon reservoir, which would probably invoke emergency measures in London, even though the onset of wet weather in September would have prevented emergency storage being reached:

15

https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/583297/170110_Framework_for_Management_of_Risk_in_Govt_final_1_.pdf Note that the risk posed by the UTR being less than 1/2 full in the Spring is 2% per annum, and 20% in a decade (a typical construction time for another reserve supply). The impact of the risk is at least very high/major, and so even though the likelihood is relatively low, the risk would have to be regarded as 'red' or 'intolerable'.

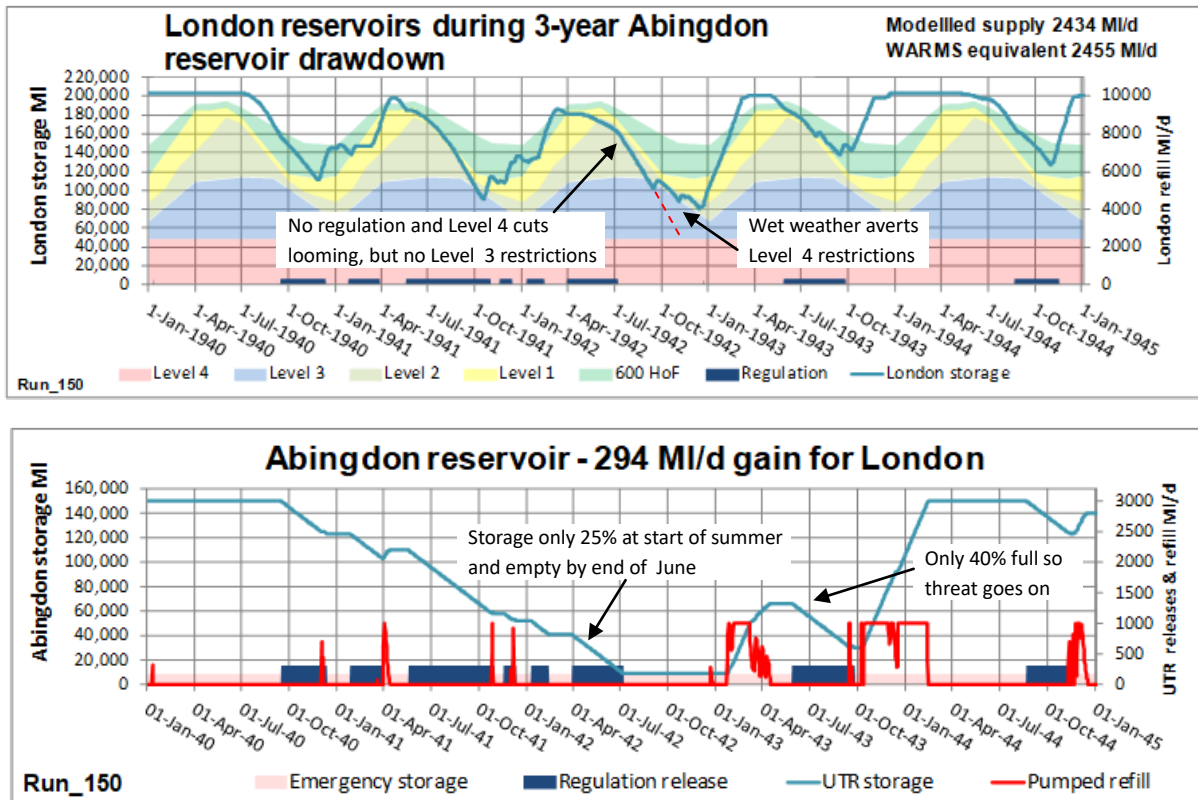


Figure 18 - Example of threat of supply cuts in long Abingdon reservoir draw-down

In this example, despite Abingdon reservoir being only 25% full in April 1942, with the present Lower Thames control rules there would be no Level 3 demand restrictions until September. With Abingdon reservoir empty and no regulation possible after the end of June, London reservoirs would drop rapidly and Level 4 supply cuts would only be averted by early onset of wet weather in September.

As far as we are aware, no consideration has yet been given to changes to the Lower Thames Operating Agreement that would be needed if Abingdon reservoir was added to the London supply system. In our opinion, revised control rules should take into account the draw-down of Abingdon reservoir. In the example shown in Figure 18, the control rules would require Level 3 supply restrictions in the conditions that prevailed in the summer of 1942. In order to comply with the Thames Water's service levels for frequency of Level 3 restrictions, it is likely that the yield gain from Abingdon reservoir would be reduced.

In our experience, it is unusual for major reservoirs for public water supplies to be designed to have draw-down periods of over 2 years. In the context of London's supplies being required to have a resilience of 1:500 years, the acceptability of the frequencies in Table 4 of draw-downs in excess of 3 years and possibly exceeding 8 years seems highly questionable. This does not appear to have been a consideration in Thames Water and Atkins' assessments of the resilience of Abingdon reservoir.

In our opinion, the investigations of resilience being undertaken by WRSE should address:

1. The operational control rules for Abingdon reservoir in conjunction with the London reservoirs. This should include revisions to the Lower Thames Operating Agreement that take into account the amount of storage remaining in Abingdon reservoir, whilst complying with Thames Water’s existing Levels of Service and providing acceptable durations of reduction of the Teddington hands-off flows.
2. The acceptability of multi-year periods of draw-down of Abingdon reservoir. The investigation should take account of international best practice for water supplies for major cities and the acceptability of the long periods of Level 3 supply restrictions that might be needed.

4.5 Emergency storage provision in Abingdon reservoir

The emergency storage provision currently planned for Abingdon reservoir is 9,000 MI, ie only 6% of reservoir storage. Thames Water justify this as being 30 days of regulation releases at 300 MI/d, thereby complying with their policy of having 30 days of emergency storage.

In our response to the consultation on Thames Water’s first draft WRMP, we challenged this¹⁶ on the grounds that raw water storage reservoirs are usually designed to have an emergency storage allowance of 12-25% of live storage, for example:

- Clywedog reservoir 13%¹⁷
- Llyn Brienne reservoir 14%¹⁸
- Bristol Water (Chew, Blagdon) 18%¹⁹
- Welsh Dee system 20% (of gross storage)²⁰
- TW London reservoirs 24%²¹
- TW Farmoor reservoir 33%

Yorkshire Water’s policy is for *“30 days supply at the reservoir or group yield, or 12.5 per cent of reservoir stocks, whichever is greater”*.²²

Thames Water’s Statement of Response to the consultation did not address this criticism, merely re-stating that 9,000 MI *“equates to 30 days demand”*.²³

In our earlier Table 3, we listed 25 long duration droughts out of 15,600 years of records when Abingdon reservoir would be able to supply less than 240 MI/d rather than the 294 MI/d assumed in Thames Water’s WRMP. With Abingdon reservoir the duration of Level 4

¹⁶ GARD response to Thames Water’s first consultation on draft WRMP, page 120, April 2018 <http://www.gard-oxon.org.uk/downloads/GARD%20response%2029.04.2018.pdf>

¹⁷ South Staffs Water Draft Drought plan, Figure 2, August 2017.

¹⁸ DCWW Welsh Water Drought Plan, Figure 20, July 2015.

¹⁹ Bristol Water Draft Final Drought Plan, Figure 2, July 2017.

²⁰ United Utilities Revised Draft Drought Plan, Figure A6.11, January 2017.

²¹ TW WARMS2 modelling of London and Farmoor systems, as provided to GARD.

²² Yorkshire Water Draft Drought Plan, Section 2.1, January 2018.

²³ Thames Water Statement of Response, Appendix F, page 395, October 2018

supply cuts would be a lot longer than it would be for existing supplies in the same drought.

It should also be noted that the emergency storage provision of 24% (48,500 MI) in the London reservoirs is equivalent to a lot more than 30 days' storage. Figure 19 shows examples of the use of London's emergency storage in extreme droughts:

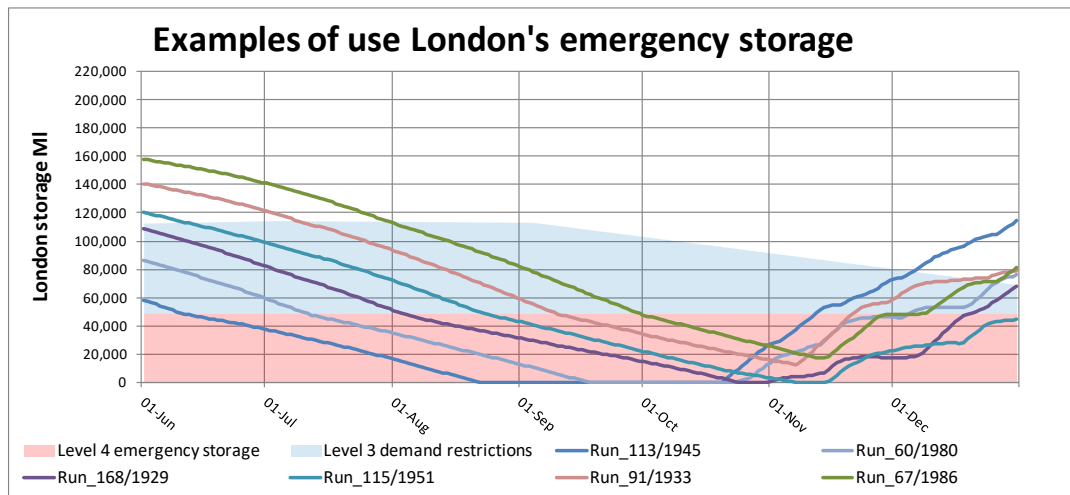


Figure 19 - Examples of use of London's emergency storage in severe droughts
 Table 5 shows the rate of use of the emergency storage as the London reservoir levels continue to fall in the droughts shown on Figure 19:

Drought	Return period for existing supplies	Average rate of storage loss
Run_113/1945	1:1300 years	664 MI per day
Run_60/1980	1:918 years	713 MI per day
Run_168/1929	1:578 years	527 MI per day
Run_115/1951	1:318 years	622 MI per day
Run_91/1933	1:264 years	617 MI per day
Run_67/1986	1:279 years	713 MI per day

Table 5 - Rate of use of emergency storage in London reservoirs in extreme droughts

The maximum rate of fall of the storage in London's reservoirs at present day demand with Level 4 restrictions is less than 800 MI per day. This shows that the 48,503 MI provision of emergency storage in London's reservoirs is enough to maintain supplies for at least 60 days, not 30 days.

To provide an equivalent supply security to the existing London reservoirs, the emergency storage in Abingdon reservoir should be a lot more than 6% of gross storage. For example, an allowance of 60 days of regulation release at 300 MI/d would amount to 18,000 MI of emergency storage, double Thames Water's proposed 9,000 MI allowance and 12% of the gross storage of 150,000 MI. An allowance of 12% would still be at the bottom end of the range of emergency storage in other reservoirs in the UK, as listed above.

In our opinion, in view of the high degree of resilience expected from London's supplies and

the vulnerability to long duration droughts, an allowance of 20% emergency storage in Abingdon reservoir, ie 30,000 MI would be a pragmatic risk management measure. This would be in line with other UK reservoirs, as listed above.

If the emergency storage in Abingdon reservoir is increased to 30,000 MI (20%), we estimate that the yield gain would be reduced by about 15%, ie by about 30-40 MI/d. In Section 4.1, we estimate the yield gain from Abingdon reservoir to be 253 MI/d using IRAS river flows, converting to a WARMS equivalent of 215 MI/d. With a 20% provision for emergency storage, the yield from Abingdon reservoir reduces to in the region of 180 to 220 MI/d.

5. Conclusions

5.1 Atkins' Technical Note of May 2018

In our opinion, Atkins used a flawed methodology in their Technical Note of May 2018:

- Use of only 25% of the available 15,600 years of stochastic data.
- Selection of droughts which were not representative of the type of long duration which reduce the yield of Abingdon reservoir.
- Nearly half the selected droughts had return periods of less than 100 years, so were not appropriate when considering a 1:500 year resilience standard.
- The evidence in Oxford rainfall records of at least one and possibly two severe 30-month droughts in the first 20 years of the 20th century, shows that 15,600 years of stochastic data should not be taken as equivalent to 20,000 years of climate, as assumed by Atkins.
- The method of assessing yield gains in individual droughts was crude and prone to error.
- The “averaging” of yield gains from Abingdon reservoir in the poorly selected individual droughts gives a much higher yield than shown by the yield-probability relationship for all the droughts.

In our opinion, looking at the yield gain from Abingdon reservoir in individual droughts is the wrong way of assessing the yield benefit of the reservoir. This should be done by looking at the gross yield return period relationship of London's supplies, with and without the reservoir, using the full 15,600 years of record. The yield benefit from Abingdon reservoir is then the difference in the gross yield, with and without the reservoir, at that return period. This is the method used by Atkins in assessing the yield of Severn-Thames transfer options and it should be used in assessing the yield of Abingdon reservoir.

Our overall conclusion on Atkins' Technical Note is that their estimated yield of 275 MI/d for Abingdon reservoir is invalid.

5.2 The drought resilience of London's existing supplies

Our evaluation of the yield-probability relationship for London's existing supplies is almost identical to Atkins' evaluation using IRAS river flows, if the 15,600 years of river flows are assumed to represent 20,000 years of climate. However, if the stochastic data are only assumed to be representative of 15,600 years, our conclusions are:

- Thames Water's currently assumed yield of 2305 MI/d for London's supplies can be maintained in droughts of up to 1:108 year return period, ie in all but 144 years out of 15,600.
- If the existing supplies are required to be resilient to a return period of 1:200 years, the yield is reduced to 2182 MI/d, a loss of 123 MI/d from the current 2305 MI/d.
- For a 1:500 year resilience, the yield of existing supplies falls to 2070 MI/d, a loss of 235 MI/d from the current 2305 MI/d.

The losses of yield of 123 MI/d at 1:200 years and 235 MI/d at 1:500 years compare with Thames Water's WRMP figures of '130-150 MI/d' and 'around 250 MI/d' respectively.

The allowance of 48,500 MI of emergency storage in the London reservoirs can sustain supplies with Level 4 cuts for at least 60 days, rather than the 30 days which Thames Water say is their policy. GARD's modelling shows that the 48,500 MI of emergency storage would be sufficient to maintain supplies without Level 4 cuts in all droughts up to return periods of 200 years.

London's reservoirs are not adversely affected by sequences of moderately dry years, refilling completely in most winters. The critical period of drought is 18 months.

5.3 The drought resilience of Abingdon reservoir

Yield gain from Abingdon reservoir

The yield-probability relationship for London's supplies augmented by the Abingdon reservoir has been assessed by modelling the gross yield of the supplies in each of the 200 most severe droughts in the 15,600 year record of IRAS river flows. When compared with the yield-probability relationship for existing supplies, the yield gain from Abingdon reservoir is assessed as:

- 253 MI/d at a return period of 1:500 years using the IRAS river flows
- 215 MI/d when the IRAS yields are converted to WARMS equivalents using Atkins' equation – 60 MI/d less than Atkins' estimate of 275 MI/d in their May 2018 Technical Note .

This yield gain is consistent across the full range of return periods. However, it assumes only 6% of emergency storage provision. If the emergency storage is increased to 20%, in line

with other UK reservoirs, the yield gain would be reduced by a further 30-40 MI/d to in the region of 180-220 MI/d.

Although there are doubts about the validity of the IRAS flow record and the conversion to WARMS equivalent yield using Atkins' equation, it seems likely that, when properly assessed using 15,600 years of reliably derived river flows, the yield gain will be much less than the 275 MI/d concluded by Atkins. The 294 MI/d yield gain assumed by Thames Water in their WRMP appears to be a gross over-estimate.

Resilience in long duration droughts

There are 25 droughts in the IRAS generated river flows in which the yield gain from Abingdon reservoir is less than 240 MI/d, with the 6% emergency storage assumption. All but 6 of these droughts have return periods of between 100 years and 500 years for Abingdon reservoir's gross yield – they are not especially rare events in the context of a resilience design standard of 1:500 years. In all of these droughts, if a yield gain of 294 MI/d is needed (as assumed in Thames Water's WRMP), the Level 4 supply cuts with Abingdon reservoir would be much longer than they would be with the existing supplies at current levels of demand. This is a major failing in Abingdon reservoir's drought resilience.

Low Abingdon reservoir storage in the spring is a common feature of all the long duration droughts in which the Abingdon reservoir yield is much reduced. Our analysis shows that there is a 1: 50 year probability that Abingdon reservoir will be less than half full at the start of summer and a 1:100 year probability that it would be less than 1/3rd full. Although, a severe drought will usually not then occur, there will still be a big threat of Level 4 supply cuts later in the year.

The above highlights the essential problem in relying on a 'supplementary' water resource which itself shares the climatic problems of the water resource zones being supplied. An equivalent situation would simply not arise with a 'climate proof' back-up such as Desalination. It is easy to imagine the sense of panic, and the potential waste of administrative and technical effort in arranging back-ups, that would prevail when Abingdon reservoir is nearly empty at the start of summer, and the consequent economic damage, even if Level 4 supply cuts are not eventually needed because of a wet summer. This needs to be assessed in WRSE's resilience analysis.

Extended draw-down of Abingdon reservoir

Our analysis shows that Abingdon reservoir would have some excessively long periods of draw down:

- over 3 years between refills, about 1:100 year return period
- over 4 years about 1:300 year return period
- over 5 years about 1:600 years, and sometimes up to 8 years

It is unusual for major reservoirs for public water supplies to be designed to be drawn down for periods of over 2 years. In the context of London's supplies being required to have a resilience of 1:500 years, the acceptability of the frequencies of draw-downs in excess of 3 years and possibly exceeding 8 years seems highly questionable.

Emergency storage in Abingdon reservoir

The 9,000 MI emergency storage allowance in Abingdon reservoir is only 6% of the gross storage. This is much lower than the emergency storage in other major UK reservoirs, which is in the range 12%-30% of live storage. Thames Water justify the low emergency storage allowance by saying it complies with their policy of 30 days emergency storage, as for the London reservoirs. However, analysis of rates of depletion of London's reservoirs in severe droughts shows that the 24% emergency storage provision would maintain supplies for at least 60 days, not 30 days.

In our opinion, in view of the high degree of resilience expected from London's supplies and the vulnerability to long duration droughts, an allowance of 20% emergency storage in Abingdon reservoir, ie 30,000 MI would be a pragmatic risk management measure and in line with other UK reservoirs. If the emergency storage is increased to 30,000 MI (20%), we estimate that the yield gain would be reduced by about 15%, ie by about 30-40 MI/d.

5.4 Recommendations for WRSE's further resilience analysis

Generation of 15,600 years of reliable river flow records for the River Thames, with and without climate change, should be a top priority in WRSE's further work on resilience. Much of the weakness of Thames Water's resilience analysis to date stems from failure to convert the 15,600 years of stochastic climate data into reliable flow records. Without a full 15,600 years of reliable flow records for the River Thames, it is not possible to undertake reliable yield analysis or detailed analysis of behaviour of the supplies in drought conditions.

We also propose that a full century of climate data is used to generate the stochastic climate data and river flows, ie including the actual climate of 2000-2019. This would ensure inclusion of data from the period when climate change has been most significant.

The slow running of Thames Water's WARMS model has been a major constraint in assessing the resilience of London's supplies. A model is needed that can simulate operation of the supplies in individual droughts in a few seconds rather than the hours currently needed for a single simulation. If the existing WARMS model is not able to do this, it should be replaced by a model that is fit for purpose. This should be a priority in WRSE's programme of model development.

The increased frequency and duration of Level 4 supply restrictions with Abingdon reservoir in long duration droughts should be properly analysed and taken into account when comparing the economic benefits of Abingdon reservoir with other water resource options.

The huge economic cost of Level 4 supply restriction in London has been the driver to justify the increase in the resilience standard from about 1:100 years (worst historic) to 1:500 years. Therefore, the economic damage from increased frequency and duration of Level 4 restrictions should be properly costed when comparing Abingdon reservoir with other options.

In our opinion, the investigations of resilience now being undertaken by WRSE should address:












1. The operational control rules for Abingdon reservoir in conjunction with the London reservoirs. This should include revisions to the Lower Thames Operating Agreement that take into account the amount of storage remaining in Abingdon reservoir, whilst complying with Thames Water's existing Levels of Service and providing acceptable durations of reduction of the Teddington hands-off flows.
2. The acceptability of multi-year periods of draw-down of Abingdon reservoir. The investigation should take account of international best practice for water supplies for major cities and the acceptability of the long periods of Level 3 supply restrictions that might be needed.

GARD will take a keen interest in WRSE's investigations of the resilience of the resilience of Abingdon reservoir. We would hope that there can be some collaboration between GARD and WRSE in these investigations, rather than GARD being held at arms' length and only engaged superficially at brief stakeholder meetings.

John Lawson, FREng, FICE
3rd July 2020

Appendix A – Validation of GARD model using Atkins’ stochastic river flow data

A version of GARD’s model uses Atkins’ stochastically generated river flow data as supplied by Thames Water in 2017:

Name	Type	Comprese...	Password pr...	Size	Ratio	Date modified
 FeildesWeir_stochastic_flows_all.csv	Microsoft ...	62,615 KB	No	62,615 KB	0%	29/05/2017 08:04
 FeildesWeir_climate_change_run_3_all.csv	Microsoft ...	61,971 KB	No	61,971 KB	0%	29/05/2017 08:04
 Teddington_stochastic_flows_all.csv	Microsoft ...	56,003 KB	No	56,003 KB	0%	29/05/2017 08:04
 Teddington_climate_change_run_3_all.csv	Microsoft ...	55,881 KB	No	55,881 KB	0%	29/05/2017 08:04
 Deerhurst_DO_denaturalised_flows_m3_s_CC_Run_3.csv	Microsoft ...	55,677 KB	No	55,677 KB	0%	29/05/2017 08:04
 Vyrnwy_natural_flows_m3_s.csv	Microsoft ...	51,347 KB	No	51,347 KB	0%	29/05/2017 08:04
 Bewdley_natural_flows_m3_s.csv	Microsoft ...	46,172 KB	No	46,172 KB	0%	29/05/2017 08:04
 Deerhurst_natural_flows_m3_s.csv	Microsoft ...	45,297 KB	No	45,297 KB	0%	29/05/2017 08:04
 Clywedog_natural_flows_m3_s.csv	Microsoft ...	42,740 KB	No	42,740 KB	0%	29/05/2017 08:04
 Days_Weir_stochastic_flows_all	Microsoft ...	15,127 KB	No	36,842 KB	59%	08/08/2017 18:32
 DaysWeir_climate_change_run_3_baseline_stochastic_flows_all.csv	Microsoft ...	14,793 KB	No	36,223 KB	60%	08/08/2017 18:41

It is understood that these river flow data were used in Atkins’ resilience reports of December 2016²⁴ and May 2018²⁵.

GARD’s model using these flow data has been validated in three ways:

1. **Comparison of IRAS and GARD modelling of the London supply system using the same flow data:** comparing IRAS modelling of the unsupported Severn-Thames transfer, using stochastic river flows Run_0, with GARD’s modelling of the USTT.
2. **Comparison of IRAS and GARD assessments of the deployable output of existing London supplies:** DOs from GARD modelling using IRAS flows with IRAS deployable outputs for selected droughts in Appendix 1 of Atkins Technical Note, May 2018
3. **Comparison of GARD and WARMS modelling of Abingdon reservoir in Drought 8 of Library 3, both using the WARMS generated river flow data:** This allows like-for-like comparison of GARD and WARMS modelling of Abingdon reservoir using the same river flow data derived from the stochastic weather data used to generate flows for Run_114.
4. **Comparison of GARD modelling of Abingdon reservoir in Drought 8 of Library 3, using IRAS flow data from Run_114, with the WARMS modelling of this drought.** This allows comparison of GARD modelling using IRAS generated river flows with WARMS modelling using WARMS generated river flows, both derived from the same stochastic weather data.
5. **Comparison of GARD DO gains for Abingdon reservoir using IRAS flows with WARMS DO gains for Abingdon reservoir using WARMS flows.** This provides validation of GARD’s primary tool for the resilience analysis, which uses all the 15,600 years of IRAS generated river flows.

²⁴ Thames Water Stochastic Resource Modelling, Stage 2&3 Report, 16 December 2016

²⁵ Technical Note, Abingdon Reservoir resilience assessment method, Atkins, 1 May 2018

A1. Comparison of IRAS and GARD modelling using the same IRAS flow data

The only IRAS supply system model output made available to GARD was for the unsupported Severn-Thames transfer, using Run_0 river flows. Figure 1 shows a comparison of GARD and IRAS modelling of the most severe drought in the Run_0 flow records:

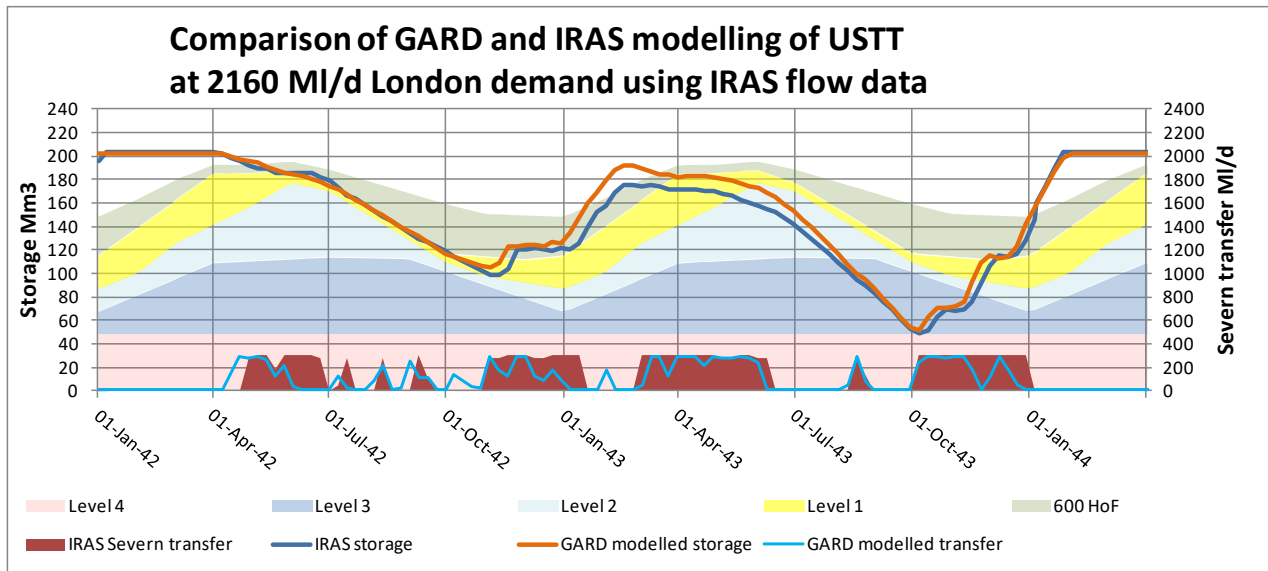


Figure A1 - Validation of GARD modelling with IRAS modelling, both with IRAS flows

Figure A1 shows a reasonably good match between the GARD and IRAS modelling. The differences are likely to be due to:

- The IRAS model runs on a 7-day time step, whereas the GARD model runs on a daily time step (Figure 1 shows 7-day averages of GARD output to match the IRAS time steps).
- Differences in the amounts and timing of the unsupported transfer. These may be due to different assumptions about the transfer trigger or the Deerhurst hands-off flow, possibly aggravated by IRAS operating on a 7-day time step.
- Possibly IRAS simplifications of the London supply system operating rules, aggravated by the 7-day time step.

Overall, the relatively small differences in the models seem unlikely to have a material effect on conclusions drawn from the use of the models.

A2. Comparison of IRAS and GARD assessments of the yields of London supplies

Figure A2 compares the IRAS assessments of the deployable output of existing London supplies in selected droughts in Appendix 1 of Atkins Technical Note of May 2018 with GARD's assessment using IRAS river flows in GARD's model:

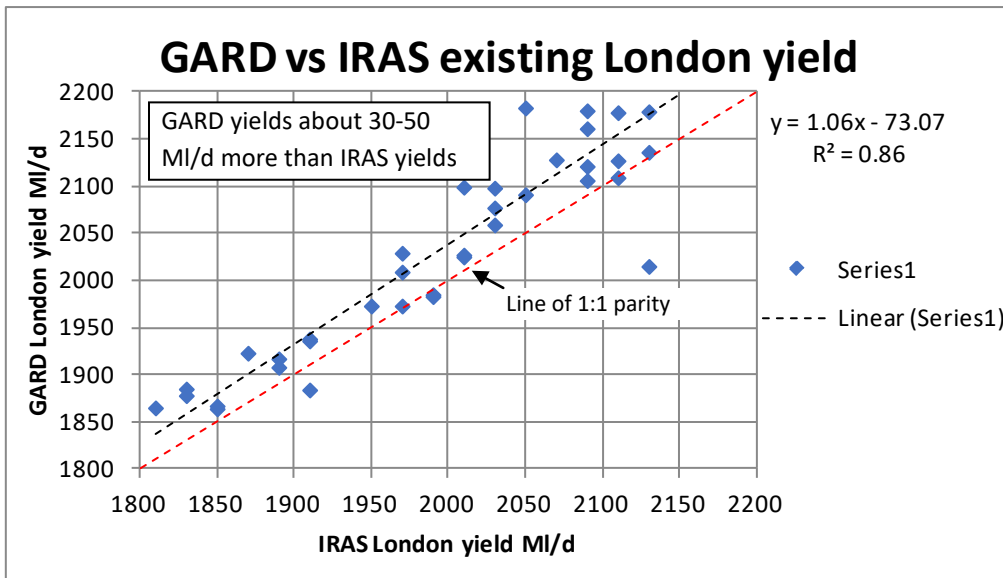
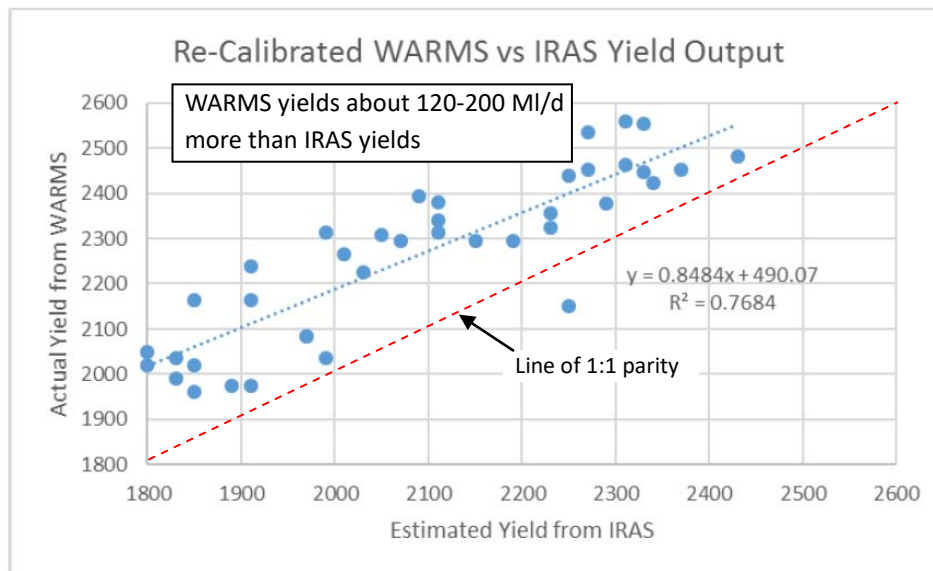


Figure A2: GARD vs IRAS assessment of yields of existing London supplies in the selected droughts in Atkins Technical Note, Appendix 1

GARD assessments of deployable output of London’s supplies are about 30-50 MI/d more than the IRAS assessments using the same river flow data.

Atkins found that their assessment of the yield of existing London’s supplies using the WARMS river flow data in the WARMS model was about 120-200 MI/d more than the IRAS model using IRAS river flows



Copied from Atkins’ Report “Thames Water Stochastic Resource Modelling: Stage 2&3 Report, Figure 5-2”

Figure A3: WARMS vs IRAS assessment of yields of existing London supplies

It can be concluded that GARD’s model using IRAS flows gives yields for the London supplies about 100-150 MI/d less than the yield assessed by WARMS using WARMS river flows.

A3. Comparison of GARD and WARMS modelling of Abingdon reservoir in Drought 8 of Library 3, both using WARMS generated river flow data

Drought 8 of Library 3, as defined in Atkins' Technical note of May 2018, uses river flows generated by the stochastic data used for flow series Run_114. From WARMS modelling, this drought was the most severe of the 60 droughts in Atkins' drought library, giving an Abingdon reservoir yield gain of only 110 MI/d. It was one of three droughts in the 60-drought library for which the Abingdon reservoir yield gain was less than 150 MI/d.

A comparison of GARD and WARMS modelling of Abingdon reservoir in this drought at a London supply output of 2412 MI/d is shown on Figure A4:

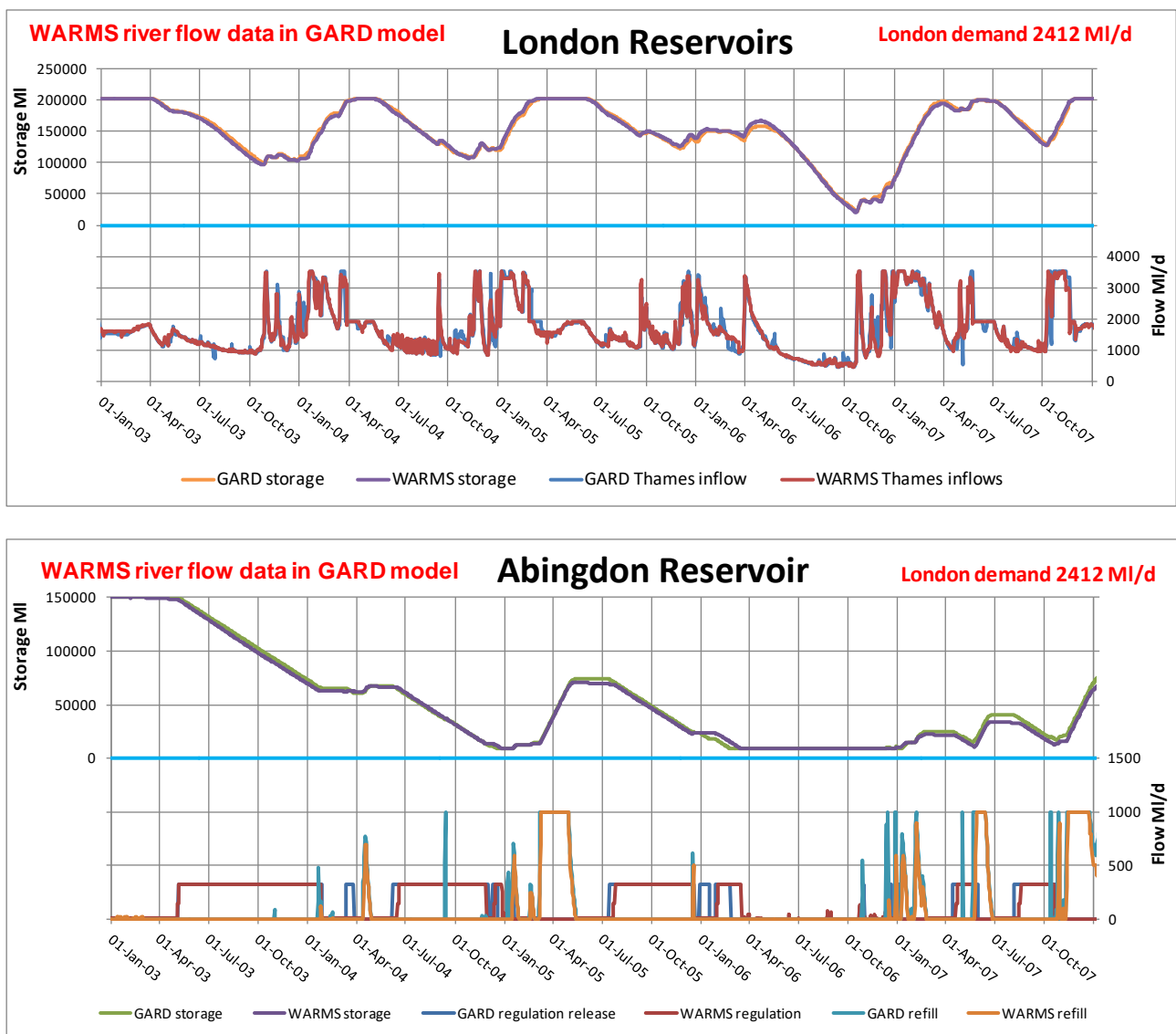


Figure A4 - Validation of GARD modelling with WARMS modelling, both using WARMS flows

The GARD modelling of London and Abingdon reservoir storages is a close match with the WARMS storages. There is also a good match of the various reservoir inflows and outflows.

A4. Comparison of GARD and WARMS modelling of Abingdon reservoir in Drought 8 of Library 3, with GARD model using IRAS generated river flow data

When the GARD model uses the IRAS generated river flow data from Run_114, there is a less good match with the WARMS model data using WARMS generated river flow data, as shown on Figure A5:

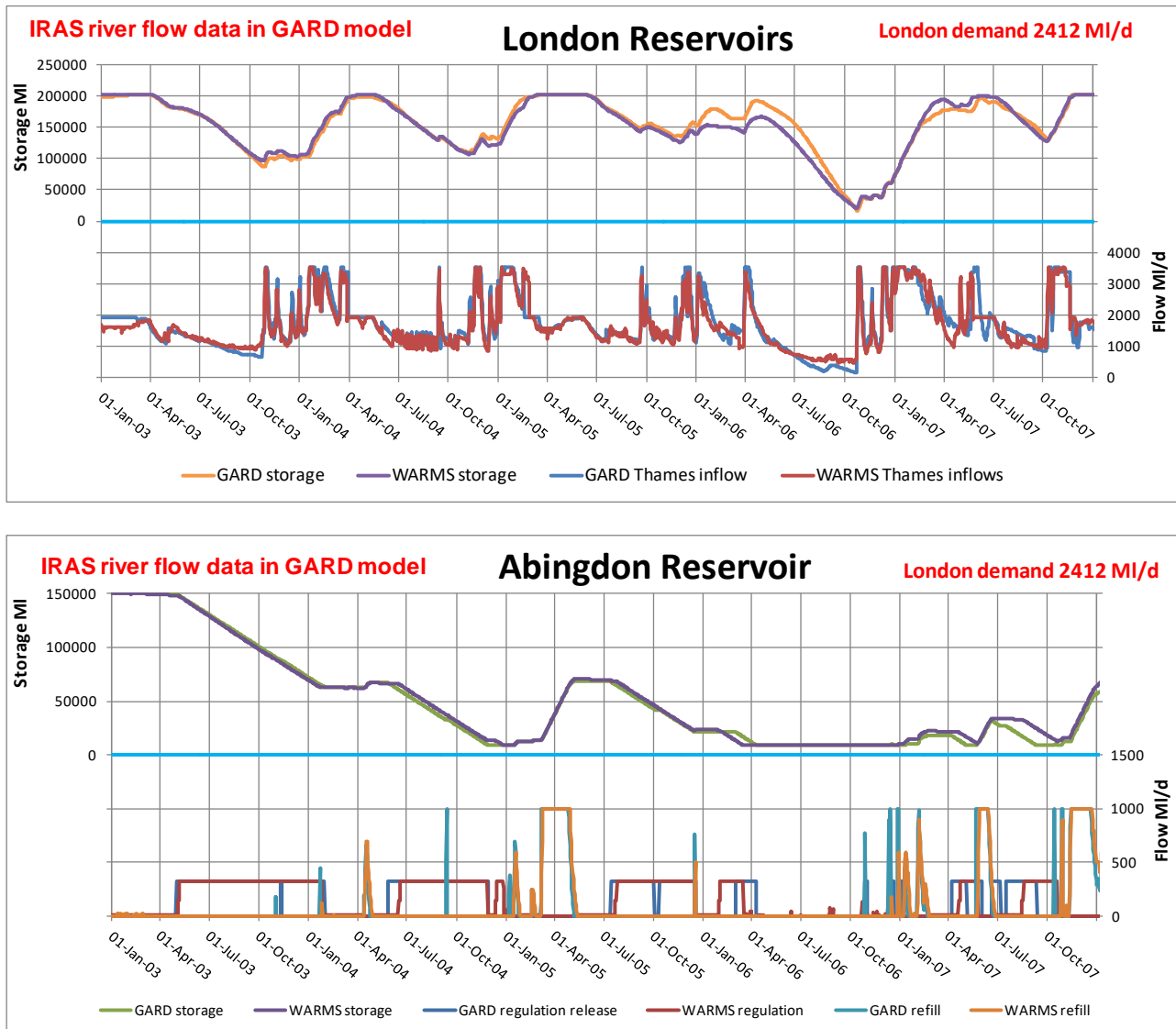


Figure A5 - Validation of GARD modelling with WARMS modelling, GARD using IRAS flows

The differences between the GARD and WARMS modelling of London reservoir storages appear to be mainly due differences in reservoir inflows from the Thames, as a consequence of differences in the River Thames at Teddington flow data generated by the WARMS and IRAS models, both using Run_114 stochastic data.

Figure A5 shows there are only minor differences between the GARD and WARMS modelling of the storages, inflows and outflows from Abingdon reservoir.

Using GARD's model, the yield gain from Abingdon reservoir for London's supplies in

Drought 8 of Library 3 was 144 MI/d as compared with 110 MI/d determined by Atkins. GARD’s yield gain is determined by the difference between the London supply yield with and without Abingdon reservoir at which Level 4 storage is just avoided. This is the correct method, as normally used by Thames Water.

However, this method requires multiple simulation runs, for every drought – typically for each drought, 10 runs for the base case and 10 runs with Abingdon reservoir, so about 20 runs in total. GARD’s model runs a simulation in about 15 seconds, so multiple runs can be quickly achieved.

The WARMS model takes about 2 hours for each simulation, so it was not feasible for Atkins and Thames Water to make a proper assessment of the yield gain for a large number of droughts. Instead they used the contorted methodology described on pages 3 and 4 of Atkins’ Technical Note of May 2018. The technical note includes no evidence of validation of their yield assessment methodology by comparing yields obtained by their methodology with yields obtained using the normal methodology requiring multiple WARMS runs.

A5. Comparison of GARD yield gains for Abingdon reservoir using IRAS flows with WARMS yield gains for Abingdon reservoir using WARMS flows.

This provides validation of GARD’s primary tool for the resilience analysis, which uses all the 15,600 years of IRAS generated river flows. Figure A6 shows a comparison of GARD and Atkins’ assessments of the yield of Abingdon reservoir in droughts with Abingdon reservoir yields in Atkins’ Technical Note Table 4-1:

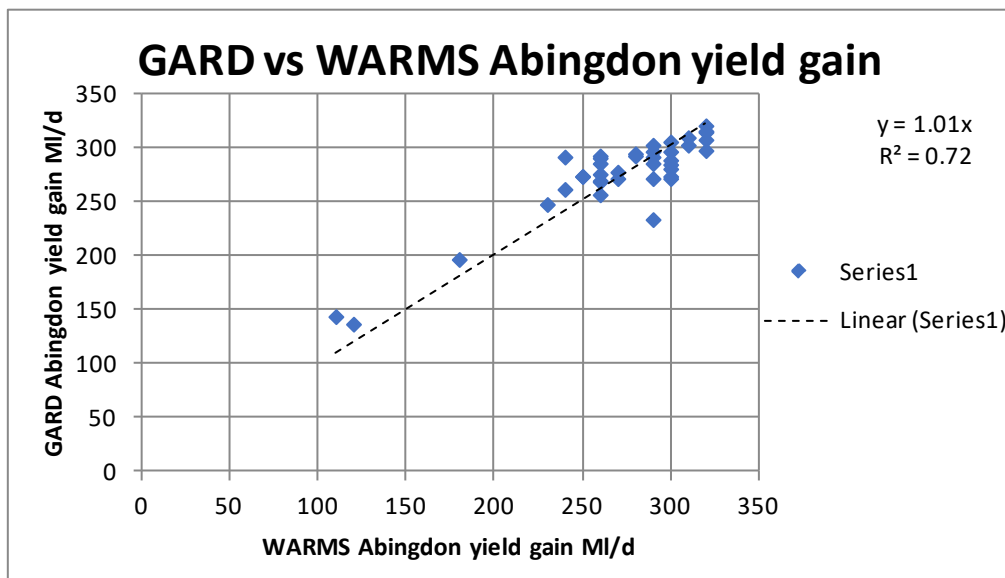


Figure A6 – Comparison of GARD and Atkins yield assessments for long duration droughts

GARD’s modelling using IRAS river flow data gives similar low yields in some droughts to the WARMS modelling, but with differences of up to +/- 30%. GARD’s modelling with WARMS river flows shows close agreement with WARMS modelling using the same river flows as

shown in Figure A2 above. This suggests that the differences in Abingdon reservoir yield assessment in Figure A6 are primarily due to differences between WARMS and IRAS river flows generated from the same stochastic data. The inaccuracies from Atkins yield assessment methodology may also contribute to the differences.

Appendix B – GARD response to questions in WRSE’s consultation

GARD Response to WRSE’s Consultation on their Framework for Securing Resilient Water Resources for South East England

Introduction

Group Against Reservoir Development (GARD) is a community based organisation representing the interests of local residents and businesses, mainly in the South Oxfordshire villages of Steventon, Drayton, East and West Hanney and Marcham, who would be affected by Thames Water’s plans to build a major new reservoir near Abingdon. Details of our organisation and activities can be seen here <http://www.gard-oxon.org.uk/>.

To support this consultation response, we have prepared a separate report “Drought resilience of existing London supplies and Abingdon reservoir”. The footnotes to our response to WRSE’s five consultation questions make frequent reference to this report, which should be taken as part of our response to the consultation.

Note: the footnote references to GARD’s separate report may not be visible in the question responses posted on WRSE’s web-site, but they can be seen on the version included as Appendix B to the separate report.

Q1. Are the four systems we’ve suggested the right core systems for a regional multi-sector resilience plan? If not, which systems should we consider?

We agree that the four ‘core systems’ all need to be considered: public water supplies, non-public water supplies, environment (rivers and aquifers) and the wider South East. However, the resilience assessment should recognise that, in the dry and heavily populated South East, provision of reliable public water supplies is of paramount importance and the others are secondary considerations. We fear that concern to be seen to be considering all four aspects could lead to lack of focus on the yield and reliability of public water supplies.

That said, we recognise the need for “trade-offs between resilience, the environment and keeping bills affordable”¹ as referred to by WRSE. In that context, we query the statement on page 7 of the consultation document:

“Our multi-sector regional resilience plan is being developed as one of a number of regional plans in England and in line with the Environment Agency’s National Framework for Water Resources 2020 – which sets an ambition to improve resilience to drought by reducing the need for rota cuts and standpipes to a probability of 1 in 500 (a 5% chance every 25 years).”

Although we agree that limiting supply cuts to 1:500 years is a reasonable ambition, we think WRSE should look in detail at what is really needed to “reduce the need for rota cuts and standpipes to a probability of 1:500”. In our response to WRSE’s consultation on Future

¹ WRSE consultation document, page 4

Needs, we pointed out that the supply-demand balances in Water Resource Management Plans build in a number of mainly hidden safety factors that reduce the likelihood of demands exceeding available supplies in extreme circumstances²:

- Target headroom
- Climate change headroom
- Outage allowances
- Generous allowances for population growth
- Loss of supply due to climate change
- Supply loss due sustainability reductions, with no allowance for chalk stream returns
- Emergency storage retained in reservoirs
- Drought plans to provide more water if needed in emergency

These safety factors are built into the water resource planning guidelines and justified as such by the water companies. There is a further hidden safety factor in the fact that demands generally rise steadily with population growth, whereas new water resources are only introduced in quite large increments, so at most times there is an over-supply while demands rise towards the available supply.

Therefore, if water supplies are planned to give a positive supply/demand balance with all these safety factors in a 1:500 year drought, rota cuts and standpipes will only be needed if the 1:500 year drought coincides with a major outage at a time when a new increment in water supplies is almost needed but not quite available and population growth, climate change, sustainability reductions, etc have been under-estimated in the WRMPs by an amount that exceeds the headroom allowances, which are substantial.

In our opinion, if water supplies continue to be planned in this way to a 1:500 year drought standard, the probability of rota cuts and standpipes actually being triggered is far more extreme than 1:500 years.

Even when supply cuts are triggered, for example in London by the Level 4 control line in the Lower Thames Operating Agreement, there is generous emergency reservoir storage available, which could continue to maintain supplies without cuts for much longer than the “30 days supply” quoted by Thames Water – see examples in GARD’s separate report, showing supplies maintained without Level 4 cuts for 2-3 months whilst London reservoir storage is in the emergency zone³.

We have estimated that the shift in resilience design standard from worst historic (roughly 1:100 years) to 1:500 years entails a loss of yield for London’s supplies of 235 MI/d⁴. The capital cost of replacement sources could be at least £1 billion. If the replacement source is Abingdon reservoir, in addition to the cost, there would be irreversible damage to the local

² GARD response to WRSE consultation on Future Needs, page 40, April 2020

³ See GARD supporting report, Figures 7, 8, 9 and 10 and pages 17-21

⁴ See GARD supporting report, page 17

environment and major disruption to the local community.

WRSE should look in detail at the probability of supply cuts being actually needed, taking into account all the hidden safety factors in the WRMP supply/demand balances that we have referred to earlier. With a good understanding of the real probability of supply cuts, it will then be possible to make a well informed “trade-off between resilience, the environment and keeping bills affordable”

Q2. Do the three characteristics of our framework – Reliability, Adaptability and Evolvability – cover the key elements of resilience? If not, what other characteristics should we consider?

We agree that reliability, adaptability and evolvability cover the range of characteristics needed for resilient water supplies. These characteristics are well described on page 9 of WRSE’s consultation document.

However, we are alarmed by the example of reliability quoted on page 9:

“The simpler a resource is the more reliable and less vulnerable it is. Groundwater in the South East tends to be more reliable than surface water (rivers) during a drought and a reservoir might be more reliable than a complex desalination plant.”

Whereas a reservoir is obviously less prone to mechanical break-down than a desalination plant, it is equally obviously more prone to drought than a desalination plant. This is particularly relevant for a reservoir situated in an area in which droughts have historically had a high coherence with the droughts experienced by the highly-populated zones around London. There are no significant natural features to suggest that there will be a future significant separation of the climate of Oxfordshire and that of the London region. This choice of an example of reliability suggests a worrying bias in favour of Abingdon reservoir and a lack of awareness of its poor re-fill characteristics and vulnerability to long duration droughts. We will say more about this in our response to Questions 3 and 4.

Q3. Do you think looking at testing the resilience of options and systems in this way will help deliver a more comprehensive plan?

As stated in our response to Question 2, we agree that reliability, adaptability and evolvability cover the main characteristics required for resilient water supplies. We also agree that these terms are rather general and there is a need to consider systematically the 20 secondary factors that are shown on page 11 of the consultation document and labelled R1-6, A1-8 and E1-6. This seems to us to be a sensible and clear sub-division.

However, we are concerned that WRSE’s methodology puts too much emphasis on metrics.

There is insufficient attention to the importance of understanding and explaining how each resource option performs in relation to these metrics. The comparison between reservoirs and desalination referred to in Question 2 illustrates the potential danger and difficulty of using metrics. How will the reliability of Abingdon reservoir's yield be assessed and scored as a metric, if the reliability of the yield is separated from the yield assessment itself? This appears to be the intention stated on page 10 of WRSE's consultation document:

“Interaction with ‘Best Value’ decision making and environmental assessment frameworks

It's important to note there are a number of key aspects of resilience, relating to drought severity, the uncertainty of future supply and demand conditions and the environmental impact of proposed investments, which are not specifically covered by the framework described in this report. This is because they are already covered elsewhere within the ‘Best Value’ decision-making and environmental frameworks. This potential overlap has been mapped out as part of the creation of the resilience framework and the assessment metrics described here have been deliberately designed to ensure there are no gaps between the frameworks, while also avoiding ‘double counting’ of benefits.”

Whereas we can understand the desire to avoid over-lap and double counting of benefits, the separation of yield assessment and assessment of its uncertainty creates a big danger that the evaluation of ‘uncertainty of performance’ (R1) will suffer from lack of understanding how yields have been assessed.

For example, how will WRSE be able to apply metrics to the uncertainty of meeting the Environment Agency's ambition of 1:500 year probability of supply cuts, if they have not been closely involved with the yield and supply/demand balance assessments?

GARD's separate report supporting this consultation response looks in detail at the resilience of the Abingdon reservoir option and provides a case study of what needs to be addressed by WRSE's resilience framework. The findings of our report can be summarised as:

Abingdon reservoir yield

1. GARD's assessment of the yield gain from Abingdon reservoir is about 180-220 MI/d. This compares with 294 MI/d assumed in Thames Water's WRMP and 275 MI/d in Atkins' Technical Note, May 2018.⁵
2. Thames Water's yield assessment is unreliable because it only looked at 25% of the droughts in the available 15,600 years of stochastic data, and used inappropriate methods of drought selection and yield analysis. These flaws were compounded by averaging the yields assessed for individual droughts, so the very low yields in long duration droughts were disguised by higher yields in some other droughts.⁶

⁵ See GARD supporting report, pages 22 and 39

⁶ See GARD supporting report, page 9

3. GARD's yield assessment modelling used IRAS river flow records generated from Atkins' stochastic weather data. The IRAS river flow records are considered by Thames Water to be less reliable than river flows generated by WARMS, so the IRAS yields for Abingdon reservoir were converted into WARMS equivalent yields using Atkins' correlation formula, which is also likely to be unreliable.⁷

Emergency storage provision

4. Thames Water's yield assessment only allowed for 9,000 MI (6%) emergency storage in Abingdon reservoir. This was justified by saying it complies with their policy of 30 days emergency storage, as for the London reservoirs. However, analysis of rates of depletion of London's reservoirs in severe droughts shows that the 24% emergency storage provision would maintain supplies for at least 60 days, not 30 days.⁸
5. In view of the high degree of resilience expected from London's supplies and the vulnerability of Abingdon reservoir to long duration droughts, GARD's 180-220 MI/d yield estimates allow for 20% emergency storage in Abingdon reservoir, ie 30,000 MI. This would be a pragmatic risk management measure and in line with other UK reservoirs. If the emergency storage is increased to 30,000 MI (20%), the yield gain is reduced by about 15%, ie by about 30-40 MI/d.⁹

Resilience in long duration droughts

6. There are 25 long duration droughts in the IRAS generated river flows in which the yield gain from Abingdon reservoir is less than 240 MI/d (with Thames Water's assumption of only 6% of emergency storage). All but 6 of these droughts have return periods of between 100 years and 500 years for Abingdon reservoir's gross yield – they are not especially rare events in the context of a resilience design standard of 1:500 years. In all of these droughts, if a yield gain of 294 MI/d is needed (as assumed in Thames Water's WRMP), the Level 4 supply cuts with Abingdon reservoir would be much longer than they would be with the existing supplies at current levels of demand. This is a major failing in Abingdon reservoir's drought resilience.¹⁰
7. Low Abingdon reservoir storage in the spring is a common feature of all the long duration droughts in which the Abingdon reservoir yield is much reduced. Our analysis shows that there is a 1: 50 year probability that Abingdon reservoir will be less than half full at the start of summer and a 1:100 year probability that it would be less than 1/3rd full. Although, a severe drought will not necessarily then occur, there

⁷ See GARD supporting report, page 22

⁸ See GARD supporting report, page 34

⁹ See GARD supporting report, page 36

¹⁰ See GARD supporting report, page 25

will still be a big threat of Level 4 supply cuts later in the year.¹¹

8. The above highlights the essential problem in relying on a 'supplementary' water resource which itself shares the climatic problems of the water resource zones being supplied. An equivalent situation would simply not arise with a 'climate proof' back-up such as desalination. It is easy to imagine the sense of panic, and the potential waste of administrative and technical effort in arranging back-ups, that would prevail when Abingdon reservoir is nearly empty at the start of summer, and the consequent economic damage, even if Level 4 supply cuts are not eventually needed because of a wet summer. This needs to be assessed in WRSE's resilience analysis.¹²
9. Our analysis shows that Abingdon reservoir would have some excessively long periods of being drawn down: over 3 years between refills, at about 1:100 year return period, over 5 years at about 1:600 years, and sometimes up to 8 years between refills. It is unusual for major reservoirs for public water supplies to be designed to have draw-down periods of over 2 years. In the context of London's supplies being required to have a resilience of 1:500 years, the acceptability of the frequencies of draw-downs in excess of 3 years seems highly questionable.¹³

Recommendations for WRSE's further resilience analysis in GARD's separate report¹⁴

10. Much of the weakness of Thames Water's resilience analysis to date stems from failure to convert the 15,600 years of stochastic climate data into reliable flow records for the River Thames. Generation of 15,600 years of reliable river flow records, with and without climate change, should be a top priority in WRSE's further work on resilience.
11. We also propose that a full century of climate data is used to generate the stochastic climate data and river flows, ie including the actual climate of 2000-2019 (up to the most recent available data). This would ensure inclusion of data from the period when climate change has been most significant.
12. The slow running of Thames Water's WARMS model has been a major constraint in assessing the resilience of London's supplies. A model capable of simulating operation of the supplies in individual droughts in a few seconds, rather than the hours currently needed by WARMS, should be a priority in WRSE's programme of model development.
13. The increased frequency, duration and economic cost of Level 4 supply restrictions with Abingdon reservoir in long duration droughts should be properly analysed and

¹¹ See GARD supporting report, page 32

¹² See GARD supporting report, page 32

¹³ See GARD supporting report, page 33

¹⁴ See GARD supporting report, pages 39-40

taken into account when comparing the economic benefits of Abingdon reservoir with other water resource options.

14. WRSE's continuing resilience investigations should also address:

- The operational control rules for Abingdon reservoir in conjunction with the London reservoirs. This should include revisions to the Lower Thames Operating Agreement that take into account the amount of storage remaining in Abingdon reservoir.
- The acceptability of multi-year periods of draw-down of Abingdon reservoir. The investigation should take account of international best practice for water supplies for major cities and the acceptability of the long periods of Level 3 supply restrictions that might be needed during periods of extended draw-down of Abingdon reservoir.

In responding to Question 4, we will consider how the matters raised in GARD's report can be covered by WRSE's proposed 20 'sub-metrics'.

Q4. Are the sub-metrics we've chosen appropriate and, if not, which others should we consider? Do you think we should include metrics which can't be fully objective?

Although we think the resilience characteristics covered by the 20 sub-metrics are appropriate, we think they will be difficult or impossible to score objectively. On page 11 of the consultation document, it says that the scores for each metric will be placed into one of five categories. We presume this means excellent, good ..., etc. In our opinion, even for the 13 metrics which WRSE say can be objectively modelled, there will inevitably be subjectivity in the underlying modelling, creation of the scoring system and placement of scores into categories.

In our opinion, although the metrics and scoring system could be a useful tool for comparing options, it should not be a substitute for well documented technical evidence used to make carefully explained and transparent judgements.

The findings of GARD's report on the resilience of Abingdon reservoir illustrate the difficulty of using metrics to quantify resilience and make comparisons between options. For example, referring to the comments on the resilience of Abingdon reservoir in our response to Question 3:

- How can all the complexities and uncertainties of the assessment of the yield of Abingdon reservoir be objectively converted into a single score for 'Uncertainty of Performance' in sub-metric R1? Any attempt to do this is certain to be highly

subjective and open to challenge.

- Into which sub-metric would the vulnerability of Abingdon reservoir to long duration droughts be placed? Would it be lumped in with yield assessment and considered under 'Uncertainty of Performance (R1)'? Or would it be considered as part of 'Ability to Persist and Recover' under the sub-metric 'Frequency and extent of drought order/permits (R4)'? It could be considered under 'Timing and Warning of events' and scored under 'Duration of enhanced drought restrictions (A2)'? Arguably, it could result in low scores in all these sub-metrics, but this could be deemed double or treble counting. Whatever choice is made, it will be highly subjective, even though WRSE say that all these sub-metrics can be fully objectively modelled.

We believe that WRSE's approach is putting far too much emphasis on the metrics and not enough on technical evidence and well reasoned arguments.

Going back to our Question 1 comments on the reliability of reservoirs and desalination plants, the reliability of Abingdon reservoir can and should be covered by technical evidence of the type we have shown in our supporting report. Equally, the reliability of desalination plants can be described in terms of the types of breakdown that might occur, the difficulties of operating occasionally, with supporting evidence.

We note that WRSE's technical report describes the reliability of desalination on PDF page 34 as follows:

"For example, theoretically a desalination plant is 'reliable' under drought events as it is not hydrologically vulnerable. However, they tend to be complex to operate, are difficult to turn off and re-start and tend to be inflexible as far as the distribution system is concerned, as their water quality needs to be carefully managed to prevent taste and issues such as iron/manganese mobilisation in the pipe network. It is therefore likely that desalination plants will score poorly in the 'vulnerability to asset failure and other hazards', 'complexity of operation' and even 'PWS system connectivity' categories as a result of this."

The adverse comments on the reliability of desalination may well be valid, but if so, they will need to be backed up by detailed technical evidence, including case studies from other countries where use of desalination for public water supplies is more common. The statement about desalination plants quoted above makes no reference to any supporting technical documents or reports. It also makes no allowance for improving technology, essential in an exercise which is supposed to set the ground rules for the water supply in the south-east for the next 80 years. The supporting technical evidence will be essential to prevent the scoring of the sub-metrics referred to by WRSE's paragraph above from being wildly subjective.

In concluding our response to Question 4, we feel that WRSE should recognise that scoring all of their 20 sub-metrics will be subjective and will need to be backed up by detailed and transparent technical evidence.

Q5. Do you believe changing our planning approach to a regional multi-sector resilience plan will help us plan better for future shocks and stresses

Whereas we agree that WRSE's approach will give a good coverage of the matters that affect the resilience of water supplies, we fear that there is too much emphasis on metric scoring and not enough on provision of transparent technical evidence. Although we appreciate that the metrics are intended to make the resilience assessments and comparison of options as objective as possible, we fear that the opposite will be achieved unless there is more emphasis on technical evidence and well-reasoned arguments.

We propose that in WRSE's reporting of the scoring of the sub-metrics, every score should be cross-referenced to the technical evidence which justifies that score.

We note that WRSE's consultation document makes no mention of the weighting of scored metrics for use in overall option comparisons. This is referred to in WRSE's technical report as follows:

"Where these sub-metrics are combined to an overall score for each of the three resilience indices (reliability, adaptability and evolvability) within the methodology, this inevitably involves a degree of weighting and subjectivity. The main use of these overall index scores is therefore limited to the option optimisation tool used in the 'Best Value' modelling,. Their key purpose is to provide a framework that allows us to demonstrate that an appropriate range of trade-offs have been considered when examining the portfolios that could be used to 'solve' the regional need."

We are pleased to see that WRSE recognise the inevitable subjectivity of the weighting. We suggest that the use of the metrics should include transparent sensitivity testing to find out how outcomes would change with different weightings.

GARD
3rd July 2020