Technical Stakeholder Meeting, 29 January 2018

Draft note of meeting

1. Welcome and Introductions

Richard Aylard welcomed everyone to the meeting. Richard explained that the objectives of the meeting were to:

- review and agree a methodology for further work to assess the resilience of the proposed Abingdon reservoir to drought following concerns raised by the Group Against Reservoir Development (GARD); and
- to agree the timeline for the further work and milestones to share the output.

Doug Hunt of Atkins provided an overview of the work completed to date to assess the resilience risk of the reservoir to drought. Doug also set out the main issues raised by GARD, TW/Atkins responses to these, and the proposal for additional analysis to address these issues. The slide pack and a technical note titled “Abingdon reservoir resilience assessment method, 17 October 2017” were circulated to all confirmed meeting attendees on 22 January 2018. The slide pack and technical paper will be published on Thames Water’s website www.thameswater.co.uk/wrmp.

John Lawson, on behalf of GARD, presented GARD’s main issues with respect to the resilience assessment of the reservoir. The slide pack was not shared with stakeholders in advance of the meeting and therefore Thames Water was not given opportunity to correct a number of factual errors and comments contained in the slides. GARD’s slide pack and Thames Water’s response to it are attached to the minutes (Appendices 1&2). These will be published on Thames Water’s website www.thameswater.co.uk/wrmp.

The main discussion points from the meeting are noted below, followed by the agreed methodological points.

2. Main discussion points

- The purpose of the assessment is to test the resilience of the system to drought to understand how long before the system fails under drought conditions, and how this affects the reservoir in comparison to other options.
- The approach used a large, artificially generated, stochastic data set, consisting of rainfall and evaporation data. Two simulation modelling tools were used to evaluate yield and benefit ie IRAS and WARMS2. A random sample of 30 droughts, of 1:100 or worse return period, were chosen and the yield of the reservoir assessed.
- The findings of the assessment showed that if a drought that is severe enough to test the existing London system, and long enough to prevent refill for 2 years, then the benefit from the Abingdon reservoir to the combined system could potentially drop significantly. However, it was noted that all options have some resilience risk (e.g. very poor yields for

shorter duration severe droughts from the unsupported Severn-Thames transfer). The critical question to understand in terms of resilience is the likely frequency of occurrence of such events and the net impact this has on expected DO.

- The results showed that 10% of the droughts resulted in a reservoir yield that was lower than expected, but the average yield across all drought risk/return periods was within 5 Ml/d of the expected yield.

- These findings were similar to the findings of GARD, based on their own modelling, but Atkins and GARD had adopted different interpretations of the findings. GARD highlighted, from its own analysis, that Abingdon is resilient to droughts < 17 months, but there were examples of the reservoir showing poor resilience to long duration droughts. The likely frequency of occurrence of such events and thereby an assessment of the associated risk of supply failure in London was not assessed.

- Atkins stated that from a technical perspective it considered the work it had completed for Thames Water to be unbiased and robust. The approach adopted is in line with the approach used in the WaterUK long-term planning framework, the UKWIR guidance and the approach that is being used by other water companies – United Utilities, Severn Trent Water and Anglian Water. However to address GARD's concerns Atkins had proposed further work; the proposal had been shared with stakeholders in advance of the meeting.

- Overall GARD's main concerns focused on the following points 1) sampling methods and 2) yield assessment techniques and the use of average yield as an appropriate metric.

1. **Sampling methods -** The assessment used droughts in the range 1:100 to 1:500 return period. The need for a higher standard for return period in London was discussed. GARD proposed that a wider range of droughts extending to a return period of 1:2000 should be analysed, particularly in view of the economic and social consequences of supply failure in London. Atkins explained that Defra has not specified the level of drought that water companies should plan to. The Water Resources Planning Guideline (WRPG) includes a requirement for companies to consider planning to a 1:200 year drought. TW confirmed that customers had indicated support to a 1:200 year drought but not beyond. GARD stated that its analysis indicated that Abingdon reservoir could maintain its yield in a short duration drought but in longer duration droughts there would be insufficient water to refill the reservoir. GARD focussed its presentation on the Abingdon reservoir and did not present findings for the resilience of the London supply system as a whole which is supported by a wide variety of strategic schemes, in addition to storage reservoirs. CCG suggested that there is insufficient time to complete this work for this round of investment plans – this work should be part of a longer term work programme. GARD proposed that a resilience design standard should be a key part of the next round of investment plans.

- **Randomised sample -** Atkins clearly explained that the selection of droughts needed to be on a randomised basis, if not, the sample will be biased; to shoehorn in a long duration drought will result in sample bias. Atkins reassured GARD that long duration droughts have been considered in its analysis as these occur (with a frequency of around 10% of events) through the range of drought return periods. WWF suggested that a sample of long duration droughts should be considered but not to deliberately select them, as to do so would undermine the statistical validity of the analysis. Atkins proposed that a larger sample of 40 droughts between 1:100 and 1:500 return period ie 25% of the population should be considered, and that this was statistically adequate. Following further discussion it was agreed to increase the number to 60 to alleviate ongoing concerns and to extend the range of drought events to 1 in 75 year – 1 in 750 year occurrence. It was also agreed that every third drought from the stochastic dataset will be selected to form the sample for detailed analysis in WARMS2 – this will provide a statistically unbiased sample.

2. **Yield assessment - IRAS/WARMS2:** Atkins used the IRAS model as a pre-screening tool to enable the random selection of 30 droughts and then the more detailed WARMS2 model to calculate the yield benefit of the individual droughts. TW/Atkins recognises that WARMS2 is a more accurate model but it is not able to process the vast quantities of stochastic data quickly and the combination approach adopted was used as a pragmatic solution due to time constraints; the uncertainty was assessed to be +/- 5-10%.

   There was challenge from GARD and CPRE that the long run time for WARMS2 is not a sufficient reason for not using WARMS2 for the entire analysis and that this should be looked at for the next round of WRMP planning in 2024. It was recognised that resilience is a new area for the water industry and there was a general consensus that further work should be completed to improve the use of the models for future investment plans. CPRE agreed that there is a limit to the analysis that can be completed for WRMP19 but suggested that this is a key area for further work on resilience.

   For the purposes of the assessment, Atkins confirmed that 'average expected' Deployable Output (DO) during severe droughts is used as the indicator of resilience of the system to drought. The results are presented in a histogram of yield versus number of droughts, the shape of the histogram is important as the analysis is working out the number and risk of the droughts that are in the tail i.e. low yield and the associated probability of occurrence.

   There was a discussion around the yield range for each return period. Atkins confirmed that based on the analysis completed to date there was no evidence that the expected yield reduced as drought return period increased (i.e. no decreasing trend with drought risk). It was agreed that Atkins will produce the yield range (in the form of a 'box-whisker plot') for each of the 6 'drought libraries' that are produced, as each of these covers a discrete range of return periods and hence any trend of decreasing yield with risk should be apparent if it exists.

3. Other issues

GARD raised other points around operating rules, the need to change the Lower Thames Control Diagram (LTCD) and model the output under these revised conditions, the extent of emergency storage and comparison between option types. These were not covered in detail in this meeting and will need to be covered in separate discussions.

GARD requested to have stochastic river flows generated by WARMS2 and WARMS2 output of confirming the yield of the Abingdon reservoir. TW agreed to provide the WARMS2 output for the Abingdon reservoir and explained that the enhanced resilience analysis that Atkins would undertake would generate river flows which would be made available to stakeholders. **Action TW.**

The majority of stakeholders attending the meeting supported the revised proposal agreed with Atkins during the discussion as a practical solution for conducting a resilience analysis of the Abingdon reservoir. Circulated with these draft minutes is a revised proposal "UTRD Sampling and Analysis Proposal v4".

Attendees

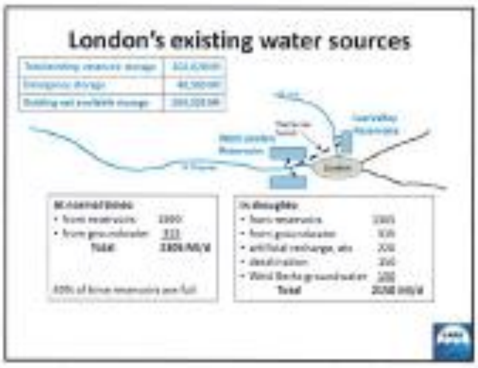
Ken Burgin	CCT
Colin Fenn	WWF
Dave Cook	Wilts and Berks Canal Trust
Dave Wardle	ICE
Derek Stork	GARD
Doug Hunt	Atkins
Harry Hodgson	CCG/Small Business Federation
John Lawson	GARD
Kane Horton	Canal and Rivers Trust
Katya Manamsa	Environment Agency
Kay Lacey	CCG/Pang Valley Flood Forum
Michael Sumbler	Bristol Water
Neil Edwards	RWE Npower
Nick Honeyball	Affinity Water
Peter Spillett	Thames Rivers Trust
Richard Harding	CPRE
Sarah Wardell	Environment Agency
Sophie Temple	Natural England
Stuart Homann	Environment Agency

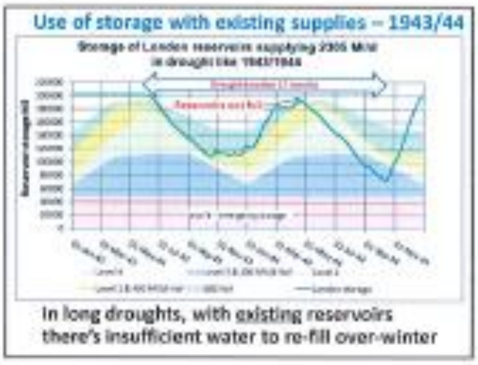
Apologies

Trevor Cramphorn	Cotswold Rivers Trust.

Thames Water:
Richard Aylard (Chair)
Chris Lambert
Tony Owen
Lesley Tait
Katie Woollard

Appendix 1 – GARD presentation slides





Availability of WARMS2 modelling

TW have supplied GARD WARMS2 output for:

- Existing supplies with the old LTCD (DO 2268 Ml/d)
- Existing supplies with latest LTCD (DO 2305 Ml/d)
- Existing supplies for SWOX, including Farmoor
- Unsupported Severn-Thames transfer

TW have refused to supply GARD with any output for WARMS2 modelling of Abingdon reservoir operation

Therefore, we have used our own model

GARD's model of operation of TW's supplies

Mimics WARMS2 for:

- Daily simulation of London and SWOX supplies
- Includes detailed operating rules for all sources – reservoirs, desal, ARS, WBGWS, etc – all as per WARMS2
- 165 Mb Excel spreadsheet
- Simulates 90 years of daily operation in 90 seconds
- Extensive graph plotting facility for outputs

Virtually perfect match to WARMS2 output for all scenarios supplied by TW

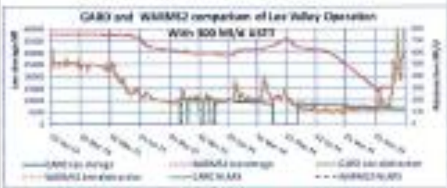
Validation of GARD model v WARMS2

Lines indistinguishable - perfect match For London storage and Thames refill

Validation of GARD model v WARMS2

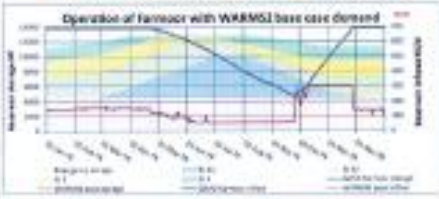
Perfect match for existing supplies and latest LTCD

Validation of GARD model v WARMS2



Lines indistinguishable - perfect match For Lee Valley reservoirs and NLARS schemes

Validation of GARD model v WARMS2



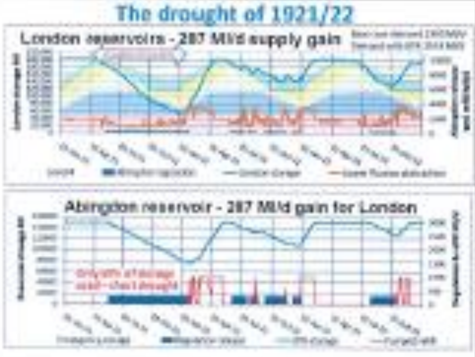
Lines indistinguishable - perfect match For Farmoor Reservoir in Upper Thames

How would London's supplies with Abingdon reservoir behave in 20th Century droughts?

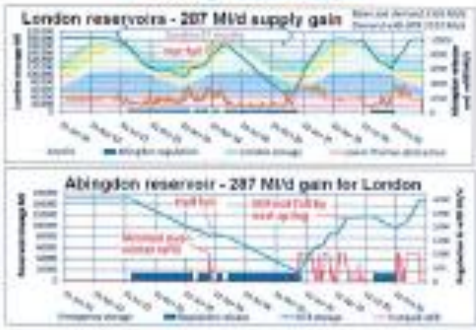
Four significant droughts in the 20th Century – 1921/22, 1933/34, 1943/44 and 1975/76

We have modelled them assuming TW's 287 Ml/d gain in deployable output

The drought of 1921/22



The drought of 1933/34



The need to change the LTCD

- As far as we know TW's modelling assumes no changes to existing LTCD
- 287 Ml/d DO gain ignores Level 1 Service Level failures (1 in 4 years, instead of 1 in 5 years)
- If the 1 in 5 year standard is maintained, DO gain drops well below 287 Ml/d
- Revised LTCD should include Abingdon storage to restrict supplies if Abingdon is well drawn down at start of summer

Lessons from 20th Century Droughts

- London supplies gain 287 Ml/d (TW figure), but with substantial Service Level 1 failure
- LTCD needs to include Abingdon storage
- Shortage of over-winter refill
- London supply with Abingdon is always resilient to droughts of less than 17 months

(provided Abingdon is full at start of drought)

Resilience to droughts of less than 17 months

- If drought < 17 months Abingdon reservoir's London yield gain is always at least 280 Ml/d

Net storage – 141,000 Ml

Drought duration – 500 days (17 months)

Yield gain 141,000 ÷ 500 days = 282 Ml/d

The resilience analysis should focus on droughts of over 500 days (17 months)

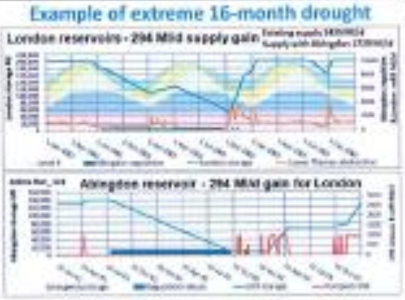
GARD's analysis of long duration droughts

- Has used 15,600 years of Atkins river flow data
- Searched for examples of long droughts
- Simulated in GARD's model
- Determined yield for existing London supplies with Abingdon reservoir to find yield gain
- Has observed operational performance

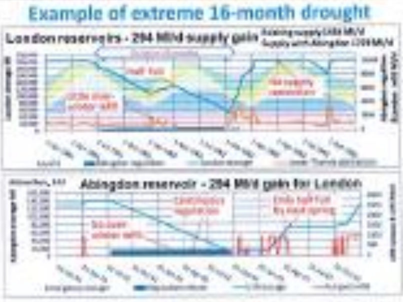
The use of Atkins' river flow data

- We are aware of Atkins' data flaws, but
- It's been used by TW for identifying droughts for their resilience analysis
- It's been used by TW for assessing resilience of Severn-Thames transfer options
- It's been used by Water UK and other water companies for their resilience assessments
- TW have refused to supply GARD with stochastic river flows generated by WARMS2

Example of extreme 16-month drought



Example of extreme 16-month drought



Example of a 19-month drought

Impact of Level 4 restrictions

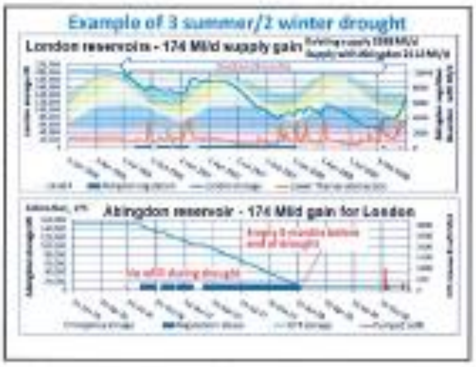
EA 2015 Report on Water Supply Resilience:

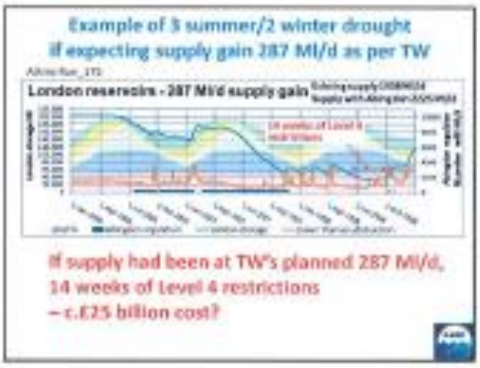
"emergency water restrictions has the potential for severe economic, societal, reputational and environmental impacts – particularly in large conurbations"

"one study estimated the monthly cost for London alone at £7 – 10 billion"

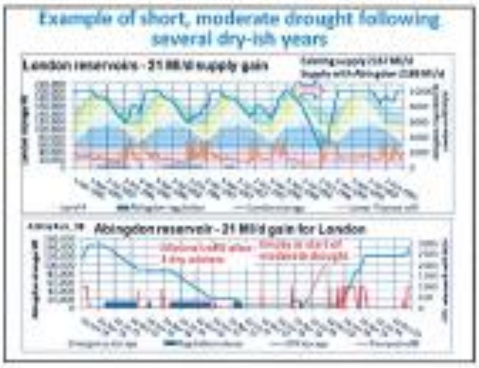
"societal impacts of such restrictions could include break-down of social cohesion and serious impacts on public health"


19-month drought, expecting TW's 287 Ml/d
London reservoirs - 287 Ml/d supply gain
If supply had been at TW's planned 287 Ml/d,
43 days of Level 4 restrictions
– c.£10 billion cost?


Example of 3 summer/2 winter drought
London reservoirs - 174 Ml/d supply gain
Abingdon reservoir - 174 Ml/d gain for London


Example of 3 summer/2 winter drought
if expecting supply gain 287 Ml/d as per TW
London reservoirs - 287 Ml/d supply gain
If supply had been at TW's planned 287 Ml/d,
14 weeks of Level 4 restrictions
– c.£25 billion cost?


Example of 3 summer/2 winter drought
if 287 Ml/d supply as per TW and no Level 4 cuts
London reservoirs - 287 Ml/d supply gain
If supply had been at TW's planned 287 Ml/d
and Level 4 restrictions not implemented
– all reservoirs empty, total supply failure


Example of short, moderate drought following several dry-ish years
London reservoirs - 21 Ml/d supply gain
Abingdon reservoir - 21 Ml/d gain for London


Example of short, moderate drought following three dry-ish years, if expecting TW's 287 Ml/d gain
London reservoirs - 287 Ml/d supply gain
If supply had been at TW's planned 287 Ml/d,
11 weeks of Level 4 restrictions
– c.£20 billion cost?

Conclusions from GARD's analysis of long duration droughts

1. London's supplies with Abingdon reservoir are **not resilient** to droughts lasting longer than 17 months
2. London's supplies would not be resilient if several dry-ish years precede moderate droughts, even if relatively short
3. If such events occur when still expecting TW's 287 Ml/d gain, Level 4 failures could last 3 months at up to c. £25 billion cost
4. With the Abingdon reservoir option, major changes are needed for the LTCD

The need for more investigation

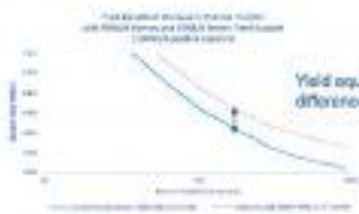
Primary questions to be answered:

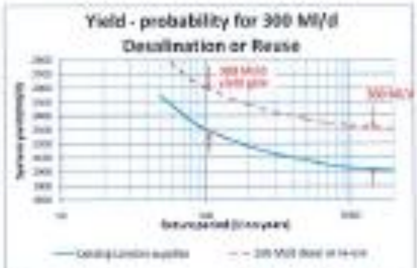
1. How likely are droughts identified by GARD?
2. Consequences if they occur whilst still expecting a 287 Ml/d yield gain: - how long would Level 4 failure last? - cost of Level 4 restrictions? - What if Level 4 cuts not implemented?
3. Design standard for resilience and DO?

Secondary questions to be answered:

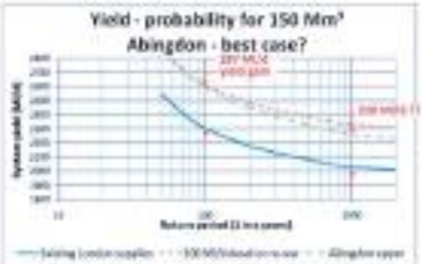
4. Operating rules and changes to LTCD?
5. Need for emergency storage & its usability?
6. Comparison with other option types?

This type of analysis should be undertaken for all options

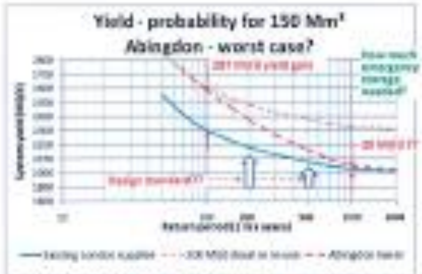




Desalination or reuse yield gain always the same regardless of drought



TW hope that yield falls only slightly in very severe droughts



GARD fear that yield gain drops to near zero in very severe droughts

Does Atkins' methodology answer these questions?

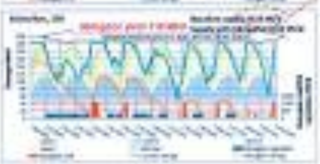
	In Atkins scope?
1. How likely are droughts identified by GARD?	No
2. Consequences if they occur whilst still expecting a 287 Ml/d yield gain: - how long would Level 4 failure last? - cost of Level 4 restrictions? - What if Level 4 cuts not implemented?	No
3. Design standard for resilience and DO?	No
4. Operating rules and changes to LTCD?	No
5. Need for emergency storage & its usability?	No
6. Comparison with other option types?	Yes?

The likelihood of long duration droughts

Flaws in Atkins proposed methodology

1. Drought selection based on IRAS modelling of existing supplies, 1 in 100 to 1 in 1000, instead of with Abingdon
2. Consequently, misses long duration droughts

Examples of severe droughts missed by Atkins methodology



Existing supply yields are more than 2140 Ml/d said by Atkins to be 1 in 100 years yield for existing supplies

Not rare enough, so not eligible for selection!

More flaws in Atkins' methodology

3. Assessing droughts of less than 17 months duration is pointless – DO always > 282 Ml/d, provided Abingdon starts full
4. Averaging of severe droughts is meaningless
5. Need to look at consequences of more rare droughts to select the resilience standard – consider up to 1 in 2000 years?
6. Inadequate yield assessment using WARMS2

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?

Resilience design standard

Frequency of Level 4 restrictions, ie supply cuts

- Other companies vary from 1 in 100 years to "never"
- What is appropriate for London's supplies?
- Thames Barrier protects up to 1 in 1000 years
- Need to evaluate consequences and costs
- Needed for transparency in consulting with Government, GLA and customers

Operating Rules, Service Levels and the LTCD

- The LTCD needs to be changed to include Abingdon storage and maintain existing Levels of Service
- Should operating rules ensure Abingdon and London reservoirs draw down in parallel (like Thames valley and Lee valley reservoirs)?
- Effect on resilience and Deployable Output is not known at present

Emergency storage

- Traditionally, c. 25% emergency storage is the safeguard against major supply cuts in droughts worse than historic
- The proposed Abingdon reservoir emergency storage is only 6% - 9 Mm^3 in 150 Mm^3
- Is this enough bearing in mind the huge costs of Level 4 supply cuts?
- At 9 Mm^3 emergency storage, average water depth will be about 1.5 m over a 6 km^2 lake – will the water be usable (Algal blooms, WQ)?

Summary

1. The Abingdon reservoir is always resilient to droughts of less than 17 months duration
2. It is not resilient to longer droughts
3. It is particularly vulnerable to droughts following several dry-ish years
4. The resilience standard needs to take account of the huge costs of Level 4 supply cuts
5. More attention should be given to operating rules and emergency storage
6. The scope of TW's proposed further work is inadequate for addressing these matters

Appendix 2 – Thames Water response to GARD's presentation 'The Resilience of the proposed Abingdon Reservoir to Long Duration Droughts'

Introduction

Thames Water (TW) has complied with the requirements set out in the Water Resources Planning Guideline (WRPG, 2017), the guidance that water companies must comply with when preparing their 2019 Water Resource Management Plans (WRMP19), in respect of assessment of Deployable Output (DO) and undertaking options appraisal, including that of the Abingdon Reservoir. TW has also applied innovative approaches, utilising stochastic methods to better understand supply system vulnerability to drought, facilitating a step change in the form of increased drought resilience of the London Water Resource Zone (WRZ).

The analysis presented by GARD does not comply with the requirements of the WRPG, and the associated methodologies and approaches. Two key errors are:

- The duration of a drought is not defined by the drawdown duration of the combined London reservoirs as defined by GARD (**Slide 4).** A drought usually starts well in advance of reservoir drawdown commencing.
- TW's preferred plan for WRMP19 increases drought resilience from a 1 in 125 year drought event to a 1 in 200 year drought event to align with the WRPG reference level of service for drought resilience. GARD suggests (S**lide 42)** that TW should 'consider up to 1 in 2000 years', a level of drought resilience far in excess of the prescribed reference within the WRPG.

TW's DO modelling has been carried out using the independently audited WARMS2 model[1] which shows that performance is maintained throughout analysis. An independent review[2] concluded that the simulation model used by GARD has a number of limitations. The report from the review states '*From an intrinsic modelling capability perspective GARD2 is inferior to WARMS2*', '*the two models cannot be relied upon to deliver the same outcomes under all operating conditions'* and there is '*significant residual concern as to GARD2's reliability for use as an intervention analysis tool*.' The results from the GARD model presented (**Slides 8 – 12)** should therefore be viewed in this context.

To clarify understanding of the approaches that TW is following to assess the supply forecast and to appraise options for the London WRZ within its WRMP19, and to further address technical questions GARD has posed to TW within the presentation, TW has provided responses relating to:

1. Baseline DO forecast with existing sources: Historic droughts
2. Baseline DO forecast with existing sources plus Abingdon reservoir: Historic droughts
3. Baseline DO forecast with existing sources plus Abingdon reservoir: Stochastic droughts

[1] WRMP 2019 WARMS2 Independent Review, HRW, September 2017
[2] The reliability and fitness for purpose of the GARD2 spreadsheet model of Thames Water's water supply system model, WARMS2, Hydro-Logic Services, December 2016

1. London baseline DO with existing sources: Historic Droughts

On **Slide 3**, GARD presents a misunderstanding of the approach to assess London's supply forecast, of which DO (DO) is a key component. There is no reference to the WRPG definition of DO '*the output of a commissioned source or group of sources or of a bulk supply for a given level of service as constrained by, hydrological yield; licensed quantities; environment (through licence constraints); pumping plant and/or well/aquifer properties; raw water mains and/or aquifers, transfer and/or output main; treatment and water quality*'. Furthermore, GARD suggests that individual 'normal' and 'dry' years within the entire period (historical record) of assessment are looked at in isolation when assessing water available from existing sources within the London WRZ. This is not correct. It is the Dry Year Annual Average (DYAA) DO, the average rate of supply that can be maintained from the London WRZ throughout the entire period of assessment (historical record) with restrictions on customer demand applied in line with TW's Levels of Service which forms the basis of the assessment.

TW has assessed the DYAA DO of London to be 2305 Ml/d with a DO benefit of 126 Ml/d achieved across the historic period of assessment by implementing progressively more enhanced customer water use restrictions to manage demand as combined London reservoir storage and Lower Thames Flow at Teddington weir declines. These demand management measures, and the resultant DO benefit, forms part of the Lower Thames Operating Agreement between TW and the Environment Agency (EA), with defined storage/flow level drought action triggers monitored using the optimised Lower Thames Control Diagram (LTCD). A further yield benefit to London is derived from various strategic schemes progressively 'switched on' at storage/flow level drought action triggers in line with Levels of Service on the LTCD. The yield from these schemes forms an integral part of London's DYAA DO.

Using the historical record, failure of the London WRZ, is described in terms of breaching the Level 4 emergency storage volume of the combined London reservoirs on the LTCD. Failure does not occur as DYAA DO is the average rate of supply that can be maintained from the London WRZ throughout the entire period of historical record without breaching Level 4 storage. Strategic schemes and restrictions on customer demand, applied in combination in line with Levels of Service and the LTCD, support the London reservoir storage and Lower Thames Flow at Teddington weir and so buffer the water supply system against Level 4 failures.

2. London baseline DO with existing sources plus Abingdon: Historic Droughts

The Abingdon Reservoir, also known as the Upper Thames Reservoir (UTR), is a proposed regulating reservoir, into which water is abstracted from the River Thames at Culham when available, releasing the stored water back to the River Thames and so augmenting flows for re-abstraction in London. The Abingdon Reservoir usable capacity provides support to London reservoir storage and Lower Thames Flow at Teddington weir during drought, buffering the downward progression of London storage through the LTCD and Level 4 failures.

The Abingdon Reservoir usable capacity would provide support, in combination with strategic schemes and restrictions of customer demand applied in line with Levels of Service and the LTCD, until the emergency storage level is reached. At this point strategic schemes and restrictions of customer demand applied in line with Levels of Service and the LTCD continue to support combined

London reservoir storage and Lower Thames Flow at Teddington weir and Abingdon Reservoir emergency storage is maintained.

Abingdon Reservoir usable capacity is not acting in isolation to support the combined London reservoir storage and Lower Thames Flow at Teddington weir to buffer Level 4 failures. Rather, Abingdon Reservoir is used in combination with other strategic schemes and restrictions of customer demand applied in line with Levels of Service and the LTCD.

The Abingdon Reservoir, if selected as an option, would provide a DO benefit during the historical record, increasing the London WRZ DYAA DO from 2305 Ml/d by +288Ml/d to 2593 Ml/d. This is due to the fact that the Abingdon Reservoir usable capacity provides support, in combination with strategic schemes and restrictions on customer demand, until Abingdon Reservoir emergency storage is reached. At this point strategic schemes and restrictions of customer demand, applied in line with Levels of Service and the LTCD, continue to support London reservoir storage and Lower Thames Flow at Teddington weir, buffering against Level 4 failures while Abingdon Reservoir emergency storage is maintained.

This DO of 2593 Ml/d is the baseline DO of the London WRZ including Abingdon reservoir and accounts for all 'types' of droughts (durations and intensities) which have occurred during the historic record up to a severity of 1 in 125 years. Operated to a DO of +288Ml/d Abingdon reservoir is resilient to droughts of this type into the future, including droughts such as the 1933/34 and 1943/44 when there was not complete refill over the winter months as referenced by GARD on **Slides 4, 5 and 17.**

With regard to GARD's specific criticisms relating to how the DO benefit of Abingdon has been modelled within WARMS2 (**Slide 16):**

- GARD states that the DO gain ignores Level 1 Service failures (1 in 4 years, instead of 1 in 5 years) and that if the 1 in 5 year standard is maintained DO gain drops. Level 1 failures refer to the frequency of media campaigns and a pragmatic risk based approach has been applied in assessing DO whereby, if the Level 1 curve is crossed for ≤1 week in certain instances the failure is disregarded. As an example, to achieve the London WRZ DYAA DO of 2593 Ml/d including the Abingdon Reservoir, the Level 1 curve is crossed 26 times as opposed to 20 times (100 year historic record / 5 = 20), however in the 6 instances which exceed Levels of Service these failures are for durations ≤1 week.
- GARD further states that TW's modelling assumes no changes to the existing LTCD. This is true: the operating strategy for the Abingdon Reservoir is aligned with the LTCD already optimised based on existing resources as agreed with the EA and in line with the appraisal of all other water resource options within WRMP19. Abingdon Reservoir would operate as a strategic scheme, which releases water during drought periods when storage/flow level drought action triggers, in line with Levels of Service on the LTCD, are crossed. The operating strategy for switching on the Abingdon Reservoir releases to deliver yield benefit are:
    - Naturalised Teddington flow remains at or below 3000 Ml/d for 10 or more days <u>AND</u> Combined London reservoir storage drops below the Teddington Target Flow (TTF) line of 800 / 600-700 Ml/d on the LTCD.

- It is also suggested that a revised LTCD should include Abingdon storage to restrict supplies if Abingdon is well drawn down at start of summer, however the key point here is that Abingdon is a proposed regulating reservoir which provides support to London reservoir storage and Lower Thames Flow at Teddington weir during drought, buffering the downward progression of London storage through the LTCD and Level 4 failures. It is the DO of the London WRZ, the system as a whole, which is considered and not just the Abingdon Reservoir in isolation when assessing the DO.

3. Baseline DO forecast with existing sources plus Abingdon reservoir: Stochastic droughts

GARD states that 500 days / 17 months is the critical threshold for the drought duration to which Abingdon is resilient (**Slide 17).** TW agrees that Abingdon is resilient to droughts of 17 months, however it is also resilient to longer duration droughts as during the assessment of baseline DYAA DO including the Abingdon Reservoir [2593 Ml/d] there are opportunities to preserve Abingdon Reservoir storage by stopping augmentation releases from the reservoir to the River Thames when river flows allow, i.e. when both Teddington flow and LTCD storage/flow triggers are not satisfied. Under these conditions augmentation release ceases and Abingdon Reservoir storage plateaus. This means that for the baseline DYAA DO run including the Abingdon Reservoir, drawdown of the Abingdon Reservoir to emergency storage takes >500 days and there are < 500 days when augmentation releases are made.

Abingdon Reservoir usable capacity (141,000 Ml) is a sufficient volume to provide support to London reservoir storage and Lower Thames Flow at Teddington weir when combined with other strategic schemes and restrictions on customer demand in line with Levels of Service and the LTCD. This applies for 550 days or 18 months of drought conditions, before Abingdon Reservoir emergency storage (9000 Ml) is reached, after which Abingdon Reservoir augmentation release ceases and its support for London reservoir storage and Lower Thames Flow at Teddington ceases. For extended, more severe droughts, emergency storage (9000 Ml) within the Abingdon Reservoir is preserved, with support for London reservoir storage and Lower Thames Flow provided from a combination of alternative strategic schemes and restrictions of customer demand in line with Levels of Service and the LTCD.

It is the drought vulnerability of the London WRZ, the system as a whole, which should be considered and not just the Abingdon Reservoir in isolation when determining which droughts should be the focus of the resilience analysis.

Failure of the London WRZ, which is described in terms of breaching Level 4 emergency storage of the combined London reservoirs on the LTCD, will occur after Abingdon Reservoir emergency storage is reached. That is, LTCD Level 4 failure to maintain emergency storage in the combined London reservoirs will be triggered by an extreme extended duration drought, and for droughts of extended duration Abingdon Reservoir emergency storage is preserved.

Using more extreme droughts from the stochastic data of extended drought duration, failure will occur only once the combined yield benefit from the Abingdon Reservoir, strategic schemes and restrictions of customer demand, applied in line with Levels of Service, is exhausted.

Resilience analysis for TW's WRMP19 carried out by Atkins to date has involved using more extreme droughts derived from a stochastic analysis of historical conditions.

The drought sample has included different 'types' of droughts than those contained within the historic record, droughts both with longer durations and intensities (as referenced by GARD on **Slide 6, 17 and 18**) and more severe droughts > 1 in 125 year drought return period. Such droughts result in a reduction in water available for abstraction, reductions in winter refill (as referenced by GARD on **Slides 4, 5 and 17**) and changes to London WRZ system performance including reductions in yield.

On **Slide 19** GARD describes how they have selected specific droughts 'searched for examples of long droughts' from the stochastic data record. These samples are therefore biased to a particular drought type and there has been no assessment of the risk with which such events might occur and how this risk compares to the EA's reference standard of 1 in 200 year resilience; **slides 21 to 23 and 25 to 30** then present the impact on London WRZ system performance of this biased sample. Atkins's (Doug Hunt's) method[3] avoids sample bias when selecting droughts as it enables the full 15,400 years of stochastic drought DOs, modelled and ranked using IRAS (the simplified lumped water resources model) to be sampled randomly within a prescribed range of return periods to produce drought libraries to be run through WARMS2 (Note: It is too resource intensive to run the full 15, 400 years of stochastic data through the fully distributed WARMS2 model). Mapping the WARMS2 DOs to the results to the IRAS results enables DO vs. return period plots to be generated.

Droughts of a similar type (duration and severity) to those selected by GARD will be included in Atkins' randomly selected sample of droughts which will include a total of 60 droughts. These droughts will lie within a range of severity just below the worst historic drought (1 in 75 years) and a 1 in 750 year event and will include a range of drought durations[3]

By simply selecting specific droughts GARD is conducting resilience analysis which is not appropriate. The way TW has carried out resilience analysis for WRMP19 is to look at the impact of stochastic droughts on yield, not on Level 4 failure days. As a worked example, on **Slide 25** GARD's model output shows London WRZ failing the Level 4 constraint under a 19 month drought for 43 days; this has occurred due to the fact that GARD has applied the baseline DO benefit of the proposed Abingdon reservoir assessed by TW using WARMS2 under the worst historic 1 in 125 year drought. The resilience analysis carried out by Atkins involves using more extreme droughts sampled from the stochastic data which includes 19 months drought of this 'type'. Level 4 on the LTCD remains the constraint on demand, and as a result the yield / the DYAA DO 2593 Ml/d as constrained by yield is reduced and the level of demand applied to the system ensures Level 4 is not breached throughout the period of assessment.

Response to GARD's Conclusions

In response to GARD's conclusions (**Slide 31),** the London WRZ system as a whole is currently resilient to droughts up to a return period of 1 in 125 years (0.8% annual probability of occurrence).

Preferred options which TW includes within WRMP19 will increase drought resilience to a 1 in 200 year event (0.5% annual probability of occurrence). This will be a step change in resilience during the 80 year planning horizon in line with EA's reference level of service, such that Level 4 events will

[3] Proposal Abingdon Reservoir Resilience Assessment Method, Atkins, February 2018

not occur within the London WRZ up to a drought return period of at least 1 in 200 years. The Abingdon Reservoir is one option which would enable this step increase in drought resilience within the Thames WRZ to meet the EA's reference level of service for drought resilience.

TW's WRMP19 will also examine the impact of a 1 in 500 year drought event (0.2% annual probability of occurrence) on the London WRZ in terms of a reduction in DO.

The DO vs. return period plots to be generated from the stochastic data by Atkins as part of their Abingdon Reservoir resilience work [3] will include long duration droughts. The results from this work will enable GARD to characterise the droughts presented in their presentation in terms of return period (and annual probability of occurrence) and so contextualise the droughts within the EA's reference level of service for drought resilience, as well as TW's WRMP19.

DO vs. return period plots to be generated from the stochastic data by Atkins as part of their Abingdon Reservoir resilience work [3] will include long duration droughts and show the DO reduction under a range of drought durations and severities.

TW response to GARD Outstanding Questions

In response to GARD's outstanding questions **(Slides 32-34 and 39)**

1. DO vs. return period plots to be generated by Atkins as part of their Abingdon Reservoir resilience methodology[3] show the likelihood of London WRZ DOs (supported by Abingdon Reservoir in combination with other strategic schemes and restrictions of customer demand) under a range of different types of drought events (a range of durations) within prescribed return periods (severities) from within the stochastic data set.
2. See Response to GARD's conclusions on slide 31 above.
3. The EA's prescribed reference level of service for drought resilience is 1 in 200 years, i.e. Level 4 events will not occur up to a drought return period of 1 in 200 years, however may occur under droughts >1 in 200 years (this response also covers **slide 44**).
4. The operating strategy for the Abingdon Reservoir is aligned with the LTCD optimised on existing sources as agreed with the EA; this is a consistent approach with all other WRMP19 options (this response also covers **slide 45**).
5. Abingdon Reservoir emergency storage allowance has been taken off the total capacity of the reservoir, which equates to 30 days demand and includes a normal allowance for 'dead storage', water that it would be unadvisable to discharge back to the river due to water quality concerns. Abingdon Reservoir provides support to London reservoir storage and Lower Thames Flow at Teddington weir in combination with strategic schemes and restrictions of customer demand applied in line with Levels of Service and the LTCD. As a result, therefore, the drawdown of Abingdon Reservoir and the combined London reservoirs does not occur in parallel. The emergency storage at Abingdon reservoir would add to that of the London reservoirs which have storage equivalent to 30 days demand.
6. The Abingdon Reservoir is compared with other option types as part of the draft WRMP19 options appraisal.

TW response to GARD Comments on Atkins Proposal

DO vs. return period plots to be generated from the stochastic data by Atkins, sampled as part of the Abingdon Reservoir resilience work will include long duration droughts and show the DO reduction under a range of drought durations and severities. Atkins analysis will include a total of 60 droughts that lie within a range of severity just below the worst historic drought (1 in 75 years) and a 1 in 750 year event and will include the types of drought events, long duration droughts, consistent with those on **Slide 41** ; GARD's statement on this slide that there are 'examples of severe droughts missed by Atkins methodology' is not correct as droughts of this 'type' will be included in the resilience analysis. The results from this work will enable GARD to characterise the droughts presented in this presentation in terms of return period (and annual probability of occurrence) and then to contextualise the droughts within the EA's reference level of service for drought resilience and TW's WRMP19 which has been prepared in line with the latest WRPG.

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 150Ml/d lower yield, with a +/- 150Ml/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.

TW, 23/02/18