Drought Plan 2022

Appendix 4

Drought management for Anglian Water reservoirs

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1. Introduction

Anglian Water operates eight reservoirs, five of which (Rutland Water, Grafham Water, Pitsford, Ravensthorpe and Hollowell) form a partially integrated supply system known as Ruthamford.

The remaining three reservoirs are Covenham, Alton Water and Ardleigh. Ardleigh Reservoir is jointly owned with Affinity East and operated under the provisions of the Ardleigh Reservoir Order under guidance of the Ardleigh Reservoir Committee.

Key details of the reservoirs are summarised in Table 1.1. Those with the suffix 'R' form part of the Ruthamford supply system.

Table 1.1: Anglian Water reservoir source details

Reservoir	Gross storage capacity (Ml)	Surface area (km²)	Construction date	Water Resource Zone
Alton	9,720	1.56	1976	East Suffolk
Ardleigh	2,285	0.48	1971	South Essex
Covenham	10,717	0.87	1968	East Lincolnshire
Grafham^{R}	57,306	6.27	1966	Ruthamford South
Hollowell^{R}	2,028	0.51	1938	Ruthamford North
Pitsford^{R}	16,000	2.75	1956	Ruthamford North
Ravensthorpe^{R}	1,774	0.45	1891	Ruthamford North
Rutland^{R}	120,825	11.01	1977	Ruthamford North

2. Yield assessment

Historically, we have assessed reservoir yields using OSAY (Operating Strategy for Assessing Yield), an in-house reservoir assessment model.

For supply forecast assessments in the Water Resources Management Plan (WRMP) 2019, we have moved to a system model, AQUATOR. This can be used to provide deployable output for Water Resource Zones (WRZs), using input rainfall, river flows and groundwater yield data. The AQUATOR models were also used to assess the yield of individual reservoirs.

AQUATOR does not use the OSAY yield figures, but instead uses river flows directly to model dynamic reservoir and direct intake yields. Flows require denaturalisation to account for wider catchment abstractions and discharges not specifically included in AQUATOR. An open-water PET series has also been used directly in the model, to represent reservoir evaporation.

River flow data has been simulated using our rainfall-runoff models.

SIMFLOW, which is based on the Stanford Watershed Model, is used for the catchments contributing to the following reservoirs: Alton, Ardleigh, Grafham, Rutland, Pitsford, Ravensthorpe and Hollowell. The model is used for reproducing river flows at the reservoir intake points. The Stanford Watershed Model is a lumped parameter model that considers the catchment as a single unit upstream of a defined outflow point (e.g. a gauging station). The model outputs include daily streamflow, groundwater recharge, evapotranspiration and soil moisture storage.

For these existing models, major catchments have been subdivided into smaller, reasonably homogeneous sub-catchments, in which surface geology, topography and land-use were assumed consistent.

It is worth noting that new rainfall-runoff models have been produced for our WRMP 2024 for all river flows, however, these are currently relatively ‘untested’ and we are still within a consultation and feedback period with respect to changes these updated flows may have on the historical river flows. The reservoir yields are therefore results of model runs with the SIMFLOW flows described previously.

Using AQUATOR to assess the yields produces slightly different results for many reasons and have been fully detailed in a technical note[1]. The key advantages of AQUATOR over OSAY can be summarised as follows:

- The use of a realistic refill control curve;
- Better representation of reservoir evaporation; and
- Checking of abstraction against seasonal and annual licence limits

The methodology for calculating the yield in AQUATOR follows a custom model update and methodology produced by Oxford Scientific Software / Hydro-logic Services[2]. Yield is assessed without demand restrictions imposed (“No Restrictions” (NR)), as a ‘Levels of Service’ impact would be quantified on a system-wide basis. A summary of the yield updates is provided in Table 2.1.

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[1] *Mott MacDonald (2018) Comparison of OSAY and Aquator yield estimates 2018*

[2] *Hydro-logic Services (2020) Aquator XV “Post-Migration” Further model update/development and reservoirs yield assessment (v2 Model)*

Table 2.1: Reservoir yield updates

Reservoir	Drought Plan 2019 and WRMP 2019 yield[3] (Ml/d)	Drought Plan 2022 yield[4] (Ml/d)	Change from previous yield assessment
Alton	34.5	29.5	Application of 5 year abstraction licence was not possible in OSAY
Ardleigh*	27.5	26.0	Application of 5 year abstraction licence was not possible in OSAY
Covenham	57.0	63.0	Application of annual licence was not possible in OSAY
Grafham	225	219	Change to the assumptions of upstream abstraction have led to the reliable yield at Grafham being less than WRMP 2019
Pitsford	38.5	38.5	
Ravensthorpe and Hollowell	6.4	6.4	
Rutland	323	324	Application of annual licence was not possible in OSAY

* Includes Balkerne river support. Total yield before Affinity Water take

2.1 Critical period

When analysing a reservoir, not all drought durations have the same potential to threaten the water supply. Thus, short dry periods, during which time the reservoir can sustain a constant supply by using the previous storage, are not critical. However, longer periods (up to several consecutive months or even years) with a continuous deficit can deplete the existing reserves, but their probability of occurrence is lower.

Given a certain infrastructure (i.e. a particular storage capacity and a certain number of water sources with fixed capacity) the historical record can be used to infer the most problematic drought duration. This can be modelled by accumulating the monthly deficits (the difference between outflows and inflows) for different durations within the existing record and identifying the maximum deficit in each case. This defines the critical period.

The return period of the critical drought has been evaluated by obtaining the series of accumulated flows during the critical period starting in the same month of each year, and fitting a statistical distribution for analysing their frequency. Although this implies that parts of the record are counted more than once when the critical period is greater than one year, it avoids the need for correction due to autocorrelation. The fit of the different statistical distributions has been evaluated by means of the Kolmogorov and X2 tests. Overall, this approach is considered to give a good approximation of the likelihood of a certain critical drought.

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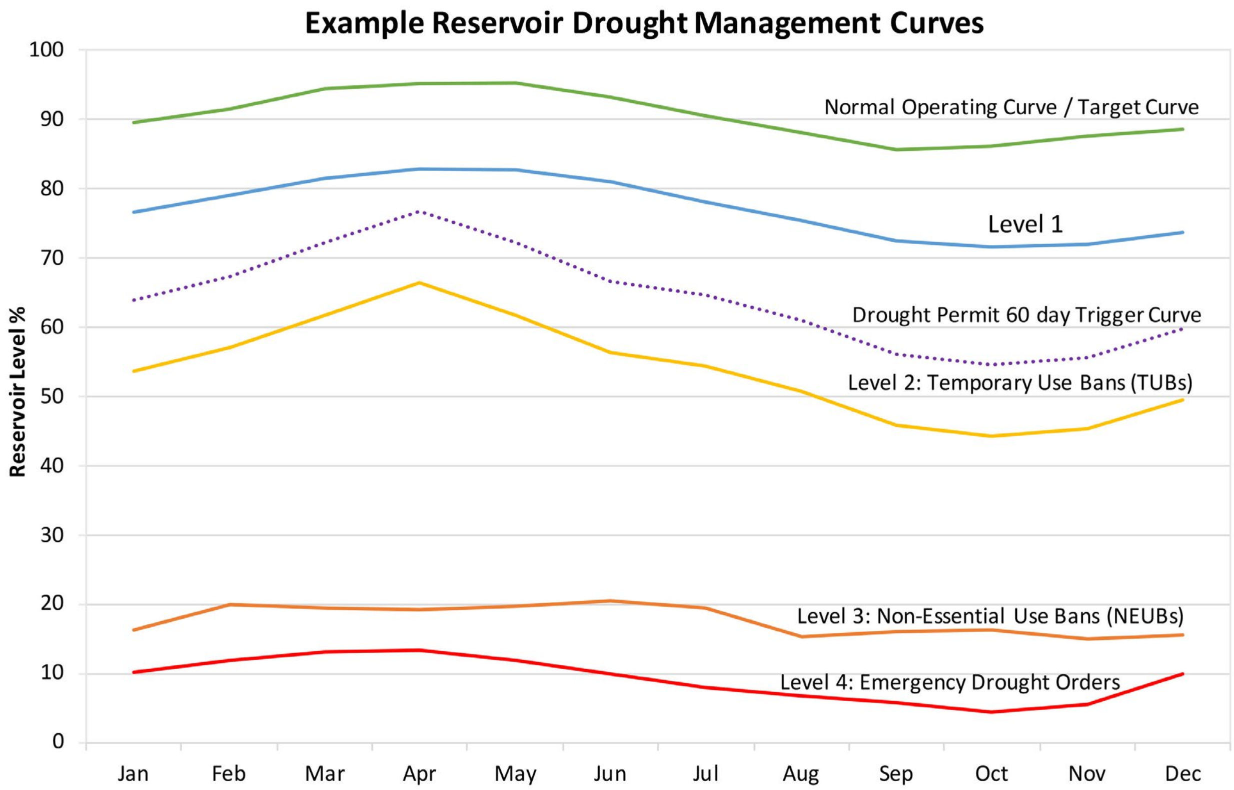
[3] *Mott MacDonald (2016) Surface Water Yield Assessment Update 2016*
[4] *Anglian Water (2021) Surface Water Yield Update 2021*

3. Reservoir drought management control curves

We have defined drought management control curves for each of our reservoirs, which act as a reference against which we can track changes in reservoir storage levels. These define the refill target and response to drought and are demonstrated in Figure 3.1.

Continuous monitoring records the storage levels at each of our operational reservoirs and the data are collated to provide a continuous profile of historical storage levels. Understanding the potential onset of a drought is achieved by assessing the current storage relative to the target level expected for that time of year. Where reservoir storage sees a continued decline due to low rainfall and river flows, this is evidence that our supplies may be affected by drought.

Figure 3.1: Example of reservoir control and trigger curves



3.1 Normal operating curve or target curve

The normal operating curve is an optimum storage 'target' or 'control' to ensure security of water supply should the reservoir experience a drought equivalent to its reference drought.

We do not expect our reservoirs to always be on target, various factors can affect the ability for the reservoir to be at this level. Maintenance on our abstraction systems, raw water quality and supply network changes are the key operational influences which affect the level in our reservoirs. These are planned in when possible with the aim to reduce the overall affect on the reservoir from these changes.

3.2 Drought permit trigger curve

We have created a 'drought permit trigger curve' to provide an indication of when we would think about applying for a drought permit. The trigger curve provides sufficient time for us to complete the necessary permit application requirements so that we could have a drought permit in place before we crossed Level 3, if required during the winter, or after implementing TUBs triggered by crossing Level 2, during the summer. However, the actual decision to apply will be made by the Drought Management Team, on review of the time of year, and wider resource and environmental situation.

3.3 Drought management curves

We have four drought management curves for our pumped storage reservoirs which have been developed to enable effective and timely responses to the onset of drought conditions. When storage reaches any of our drought management curves further actions may be taken to reduce demand (and hence the reduction in storage) and prolong the security of supply. The natural inflow reservoirs (Hollowell & Ravensthorpe) have three drought management curves; Level 2, 3 and 4. A Level 1 curve was not derived for these reservoirs due to the nature of these reservoirs and their relatively small contribution to the Ruthamford system.

The actions are:

- Level 1: Initial demand-side actions (e.g. increased water efficiency communications) and supply-side actions with minor environmental impact (e.g. optimising sources and winter drought permits)
- Level 2: Temporary Use Bans (TUBs) followed by possible implementation of a drought permit
- Level 3: Non-Essential Use Bans (NEUBs)
- Level 4: Emergency Drought Orders

The three drought management curves now aligned with our WRMP 2019 Levels of Service restrictions are Level 2, Level 3 and Level 4. Operating with these drought management curves also has the effect of increasing reservoir yield and deployable output, i.e. demand reduction conserves storage and maintains supply at a higher average rate than would have been possible if trigger curves had not been employed. The Drought Alert Curve (DAC) from Drought Plan 2019 was replaced as it no longer reflected the actions which would already be taking place before reaching this point. The new Level 1 curve is a reflection of these actions.

Table 3.1: Reservoir drought response framework (the full framework is presented in the Drought Plan)

Drought status	Normal (non-drought) conditions	Prolonged dry weather		Drought approaching 2nd dry winter	Drought approaching 3rd dry summer and onwards			
		Dry weather	Potential drought					
Drought scenario	Normal / wet	Dry summer, looking to dry winter	1st dry winter looking to 2nd dry summer	2nd dry summer looking to 2nd dry winter	2nd dry winter looking to 3rd dry summer onwards			
Reservoir response	Reservoir storage above or at Target curve	Reservoir storage starting to show declining trend from Level 1	Reservoir storage sees continued decline from Level 1 towards Level 2	Reservoir storage crossed winter drought permit trigger	Reservoir storage crossed summer drought permit trigger	Reservoir storage crossed Level 2	Reservoir storage crossed Level 3	Reservoir storage crossed Level 4
Indicative response / actions	Manage river support, comply with Section 20 agreements	Activate river support if required	Determine likely need for winter drought permits and prepare application	Apply for and then implement winter drought permits	Prepare summer drought permits	Implement TUBs, followed by drought permits	Impose NEUBs	Impose rota cuts

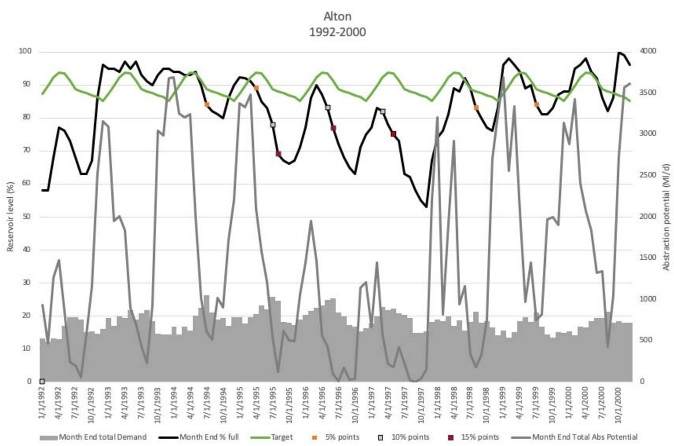
3.4 Derivation of control curves

Level 1

Level 1 curves have been derived using historic reservoir levels, reservoir demand and abstraction potential data. Reservoir levels are daily telemetered values on the most part from the year 2006 onwards; older data is from monthly or weekly dips. Reservoir demand is telemetered from the point the water exits the draw off tower. Abstraction potential is a measure of the amount of water available for abstraction at the associated abstraction point. It considers current pump capacities, associated MRFs or HOFs and operational details for the site.

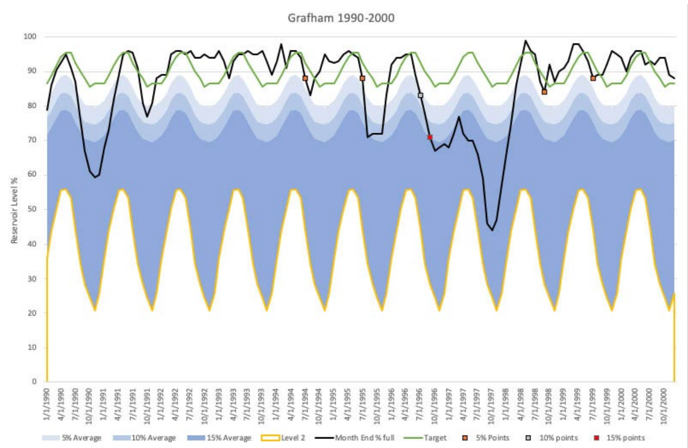
An initial review was completed to look at the number of times the reservoir saw a decline from target due to demand being greater than abstraction potential. Where a decline occurred that was 5%, 10% or 15% from target this was plotted. Figure 3.2 shows this review on Alton Water looking at data from 1992-2000. Abstraction potential generally drops during the summer months. During this time the reservoir dropped: 5% below target due to demand 5 times, 10% below target due to demand 4 times and 15% below target due to demand 3 times. This review was completed on all reservoirs.

Figure 3.2: Review of abstraction potential and demand for Alton Reservoir 1992-2000



The historic reservoir levels were analysed and averaged to create an average reservoir level curve. The 5%, 10% and 15% values were then reviewed against this (Figure 3.3). After a review of the data it was decided that we would remove the 5% line, as in most cases this was crossed every summer and was therefore deemed normal for a summer period.

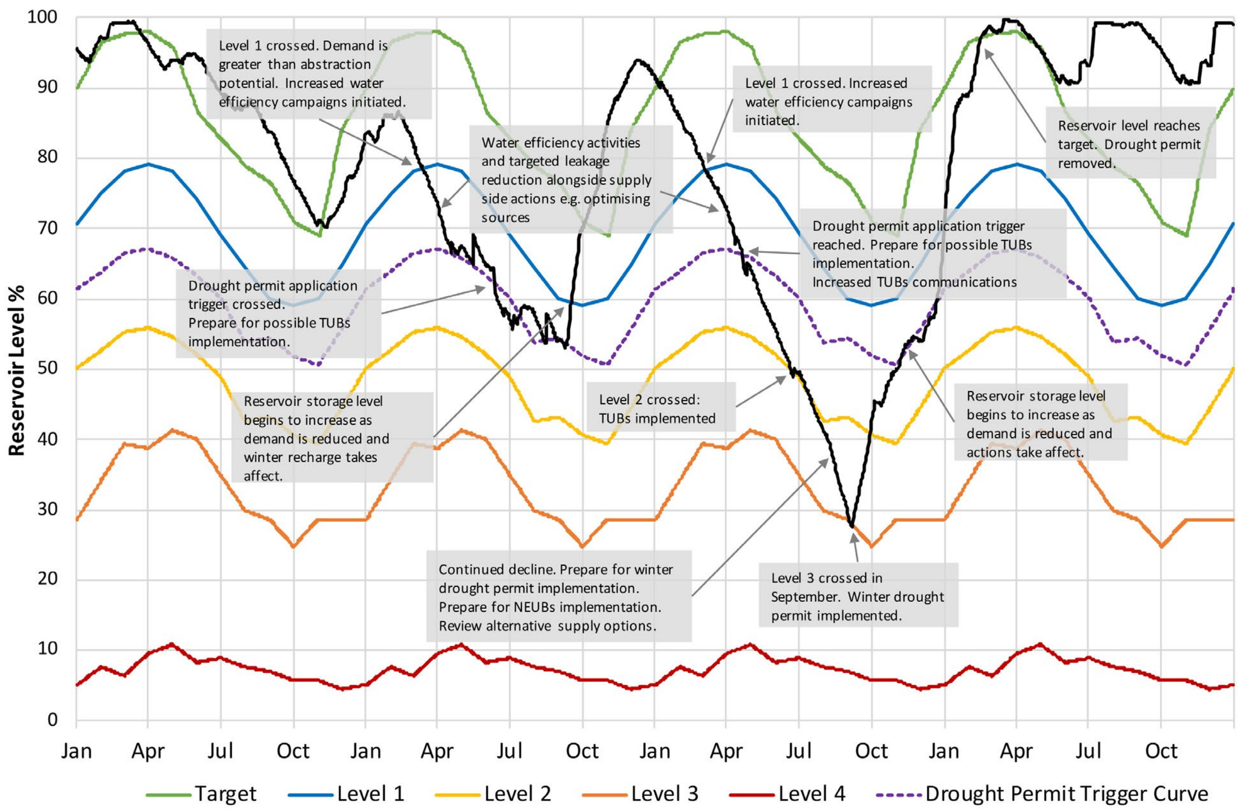
Figure 3.3: Review of 5, 10 and 15% values for Grafham Reservoir



The Level 1 curve was agreed to be set at 10% below target. Analysis was completed on how often we would cross this level for each reservoir.

Level 1 actions have been agreed and further detailed in **Sections 3.1 and 3.2**, **Main Plan**, all actions are dependent on the % below target.

Figure 3.4: Shows the actions which would be taken when crossing the drought management curves



Drought permit trigger curve

We have carried out analysis on historic drought scenarios to develop an indicative drought permit trigger specific for each reservoir which has a drought permit. These are demonstrated in **Section 3.6**.

This trigger is based on the median storage a specified number of days (n) before Level 2 was crossed in the historic series. Crossings were only counted where the crossing lasted for at least 90 consecutive days, to avoid double counting the same drought where storage may have oscillated around Level 2. Descriptive statistics were calculated for the data, in which the median storage was found to be most representative.

Comparisons were made between the median storage and the storage value for the reservoir reference drought, n days before Level 2 is crossed. In all cases, the selected median value was higher than that for the reservoir reference drought, thus representing a more conservative trigger point.

The number of days used to develop the trigger curve has been considered for each reservoir, to reflect the reservoir and catchment characteristics. We have also reviewed the application process for the two permits we applied for on the River Nene, for Rutland Water and Pitsford Water during the 2011 drought. Both had a two-month (60 day) preparation period. We consider this to remain an appropriate length of time for permits at these reservoirs, as we have learned lessons from these permit applications and have a better understanding of the issues we may face, which allow us to be more prepared for any future applications. We have also invested to make our Ruthamford system more conjunctive following the 2011-12 drought, increasing our options to support Grafham and Pitsford demand from Rutland and therefore helping to reduce the need for a drought permit.

We also consider this period of time to be a good approximation for permit applications at our other reservoirs, as both the Nene permits have complex downstream navigational and environmental considerations. In line with the guidance, we are working to ensure we are ‘application ready’ in advance of any permit application, with the aim of speeding up the application process. This is detailed for each permit in **Appendix 9**.

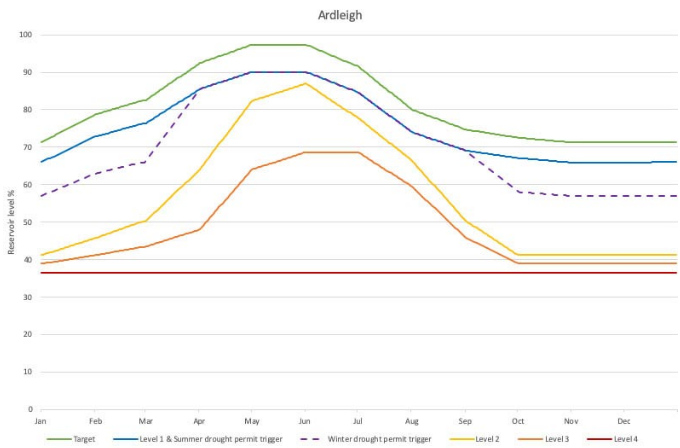
As a result, we have developed a 60-day trigger for all reservoirs with drought permits.

Ardleigh

A slightly different approach has been followed for Ardleigh. Due to its small size and single season criticality the drought management curves are very high in the summer and low in the winter. The drought permit is also an extension of a licenced groundwater support option that can be used during dry periods, both factors have resulted in a different approach to developing the Level 1 and drought permit trigger for drought management.

Level 1 is calculated as 7.5% below the target curve. The drought permit trigger is calculated as 7.5% below the target curve in the summer and 20% below the target curve in the winter, to account for the variable shape of the curve. Cross checking the curve against recent years’ reservoir levels indicates it is reasonably aligned with the 1 in 5 years crossing frequency, which is what we generally assume for Level 1. This is demonstrated in Figure 3.5. Due to Ardleigh’s responsive nature, before implementing any Level 1 actions we will consider the time that the reservoir level has spent below the curve as well as our other monitoring indicators.

Figure 3.5: Ardleigh Reservoir drought management curves



Drought management curves

OSAY, an in-house reservoir model, has been used to derive Level 2, Level 3 and Level 4 drought management curves for all reservoirs. These are being reviewed as part of the WRMP 2024 in order to optimise the control curves to maximise yield.

For modelling purposes we have assumed demand-savings for each of the customer restrictions that we can apply under each of our defined drought management curves, based on the standard approach as preferred by the Environment Agency for water resource planning purposes. The associated demand reductions and the frequency at which we would expect to impose the restrictions are detailed in Table 3.2. In line with WRMP guidelines, we have not applied any supply-side benefits such as drought permits to the baseline yield assessments. These have been looked at separately.

Table 3.2: Summary of drought management curves as modelled in OSAY

Drought management curves	Action	Demand reduction %	Frequency (years)
Level 2	Temporary Use Bans	5	1:10
Level 3	Non-Essential Use Bans	10	1:40
Level 4 (until 2025)	Emergency Drought Orders	34-52	1:100
Level 4 (from 2025)			>1:200

3.5 Future control curve development

The control curves originally developed in OSAY, have been transferred over to AQUATOR. These curves are used in an operational context which also reflect operational constraints such as maximum fill level.

We are currently developing system curves for our reservoir zones, using the new AQUATOR model we have built for supply forecasting in the WRMP. This is investigating whether the current operational curves can be refined considering WRZ system conjunctive use. For example, both Alton and Ardleigh are operated within wider, groundwater- dominated supply zones and, as such, opportunities exist for resource sharing which control curves may help to optimise. The AQUATOR model is still considered to be a 'young' model and curve development is part of the wider model refinement.

We have considered it appropriate to maintain these curves for the WRMP 2019 and Drought Plan 2022 at this stage.

In addition the WRMP 2019 includes a strategic grid to increase connectivity across the Anglian region. This requires sub-regional to regional conjunctive use and may require a full system review of the curves.

3.6 Reservoir control curve graphs

Figures 3.6-3.13 demonstrate the control curves, including drought permit trigger curve where applicable, for each reservoir.

Note: Alton, Covenham, Hollowell and Ravensthorpe do not have drought permit trigger curves because they do not have associated drought permits.

Figure 3.6: Alton Water drought management curves

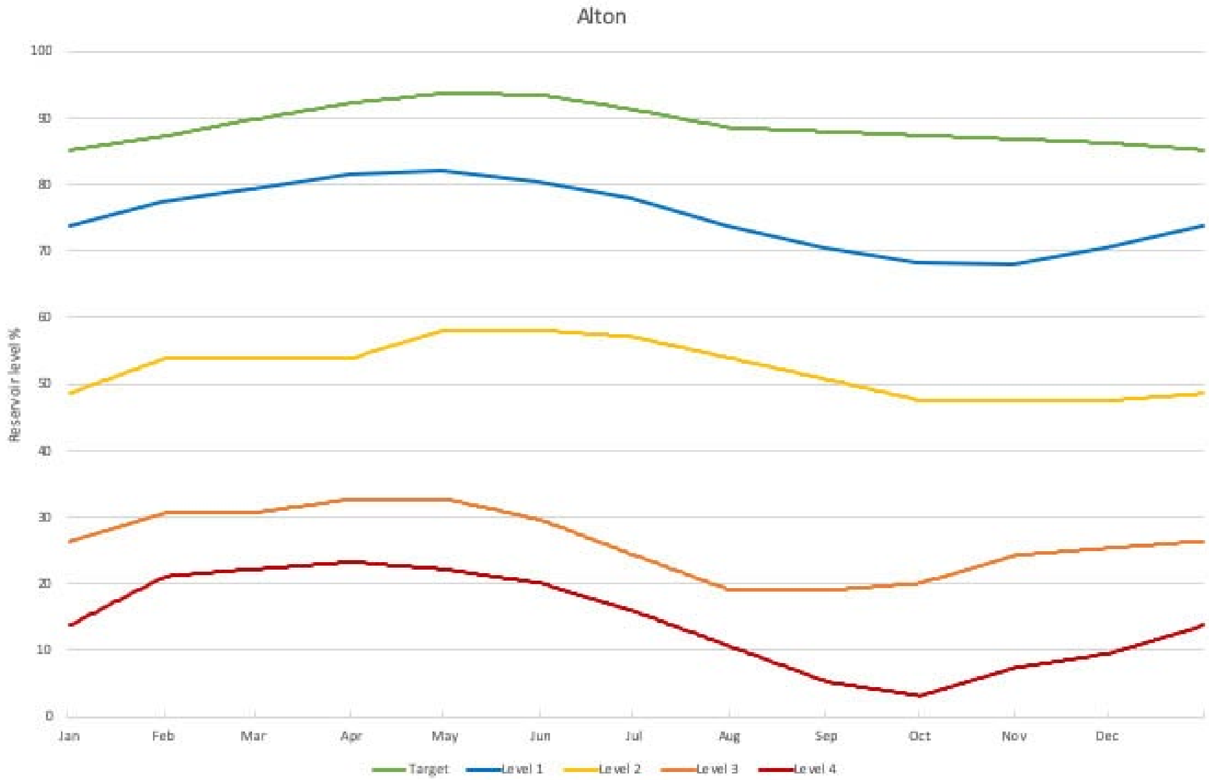


Figure 3.7: Ardleigh reservoir drought management curves

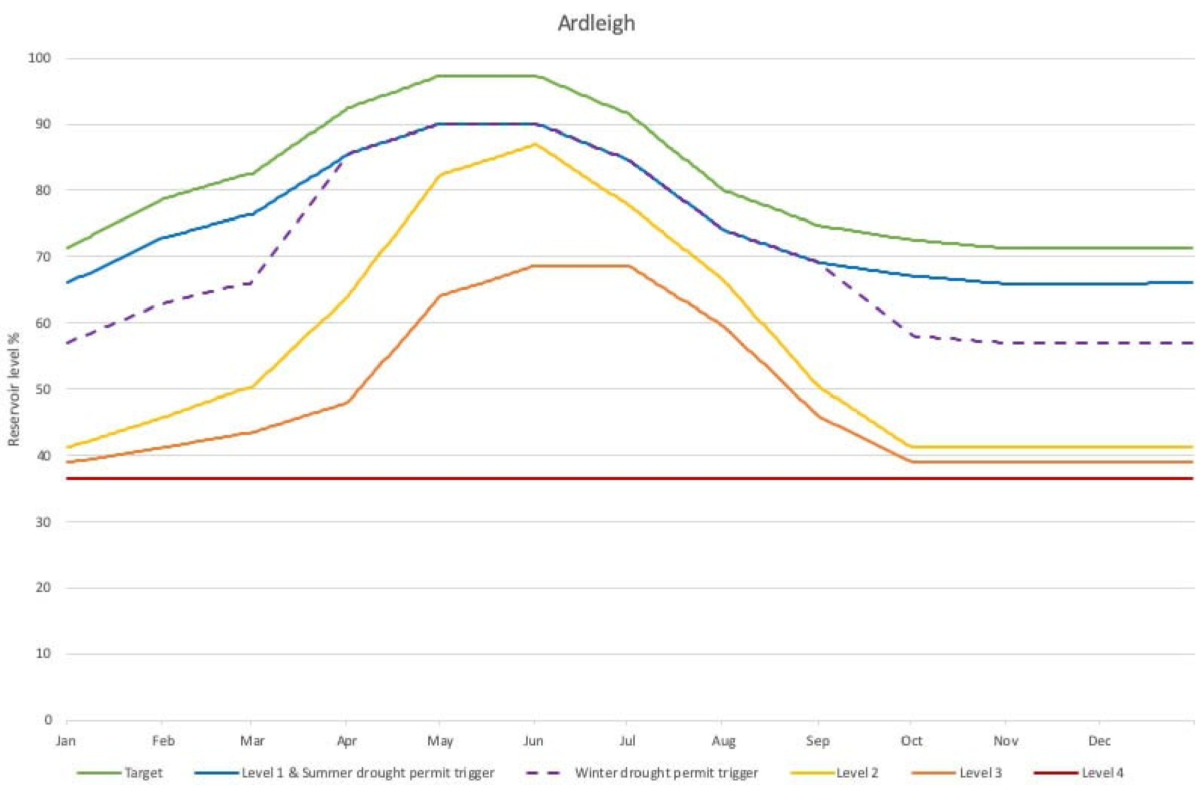


Figure 3.8: Covenham drought management curves

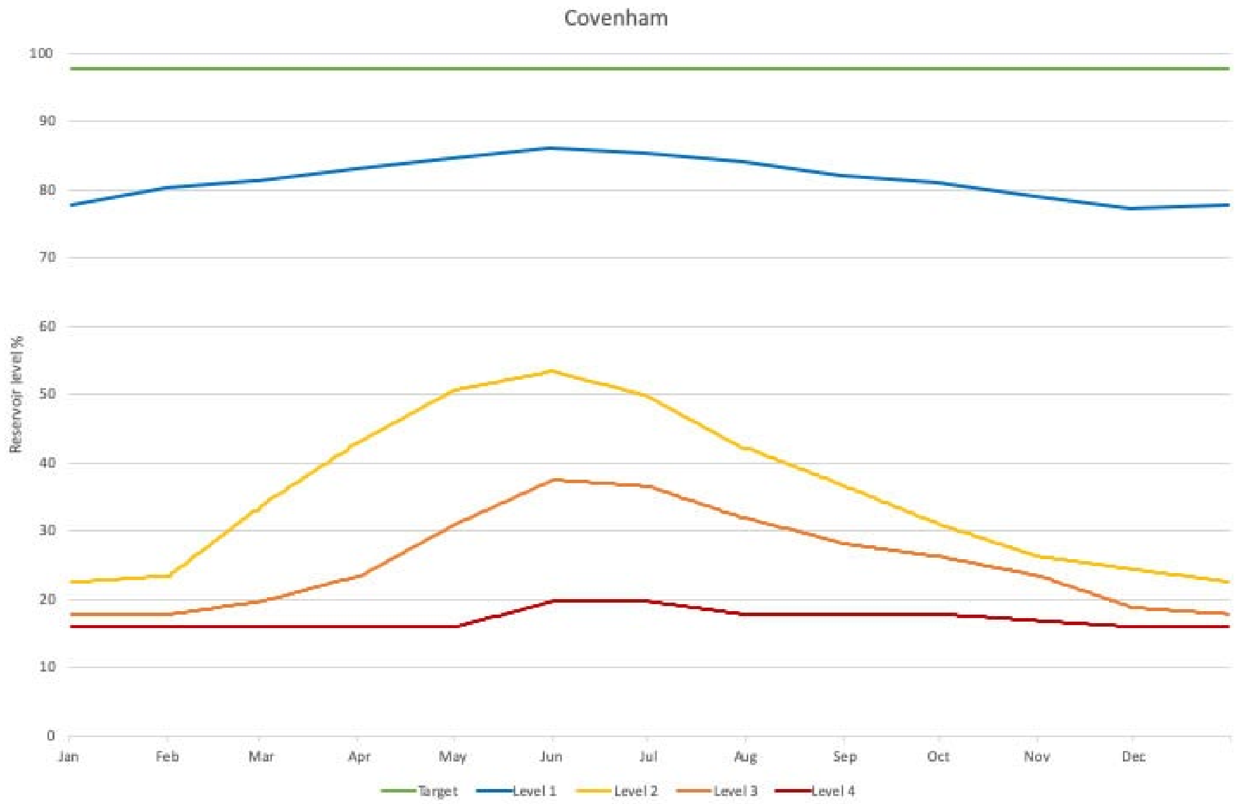


Figure 3.9: Grafham drought management curves

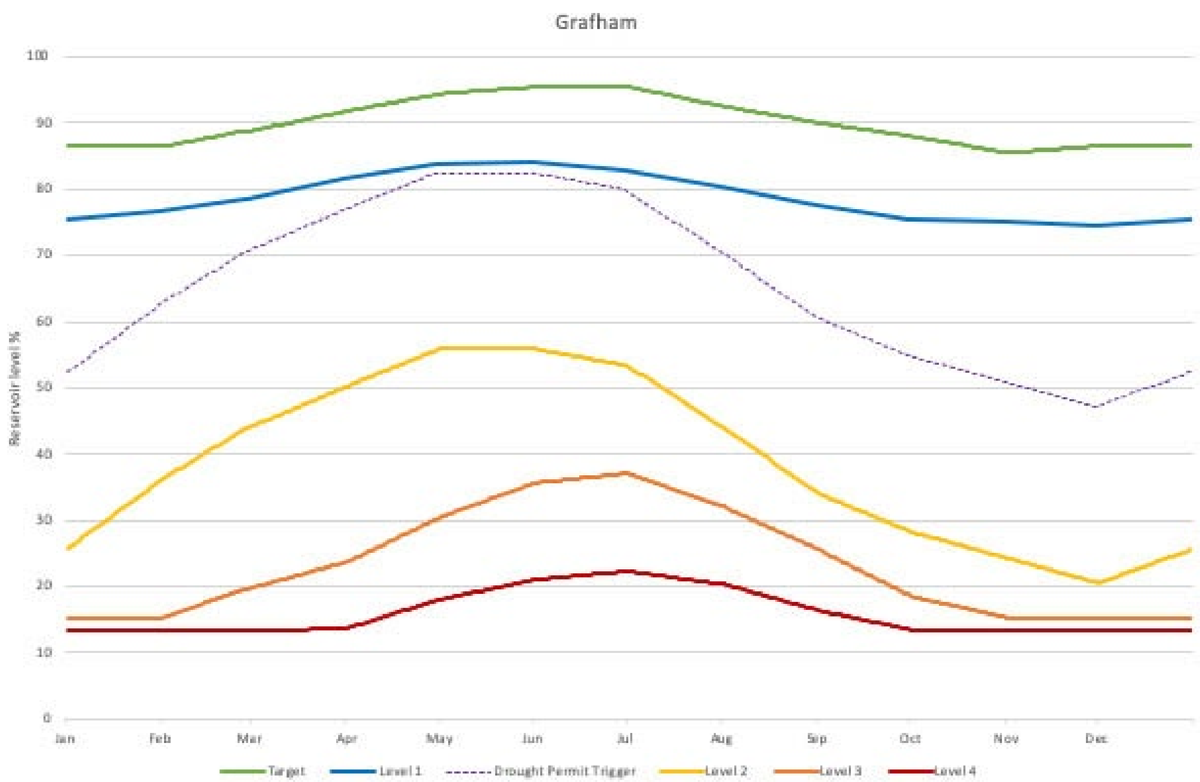


Figure 3.10: Hollowell drought management curves

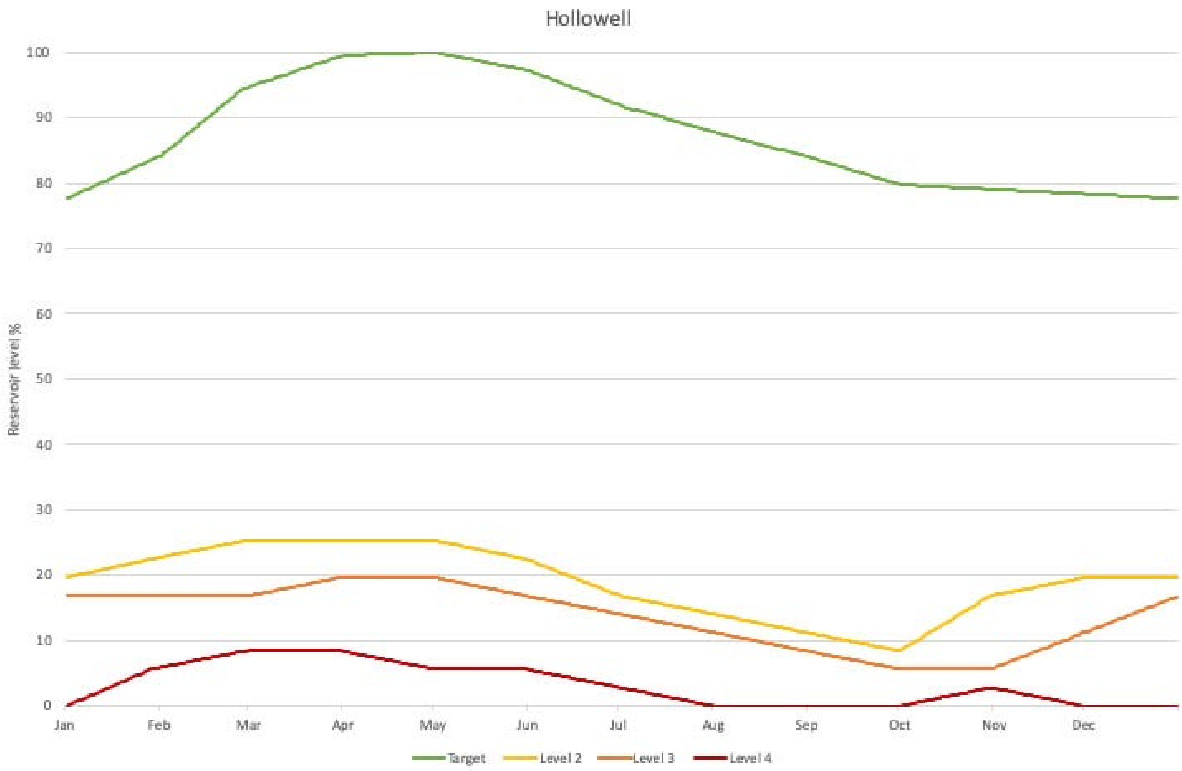


Figure 3.11: Ravensthorpe drought management curves

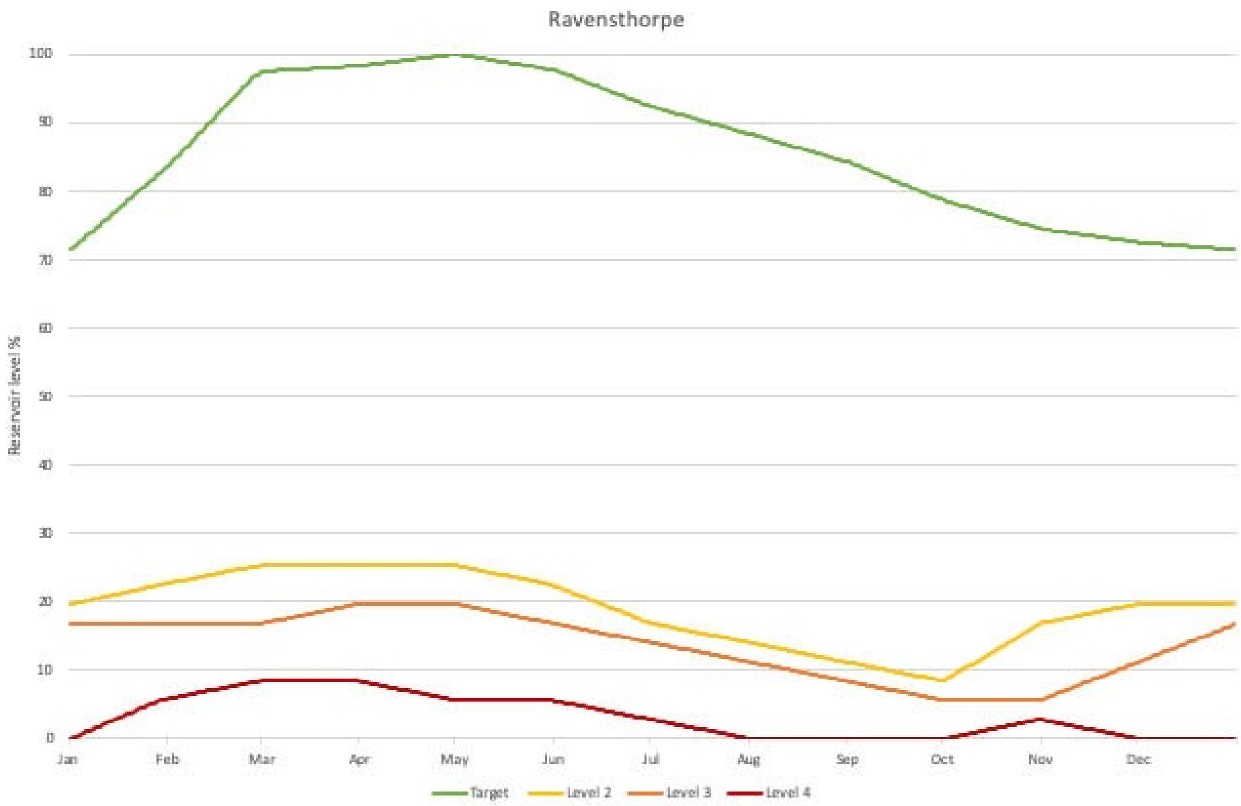


Figure 3.12: Pitsford drought management curves

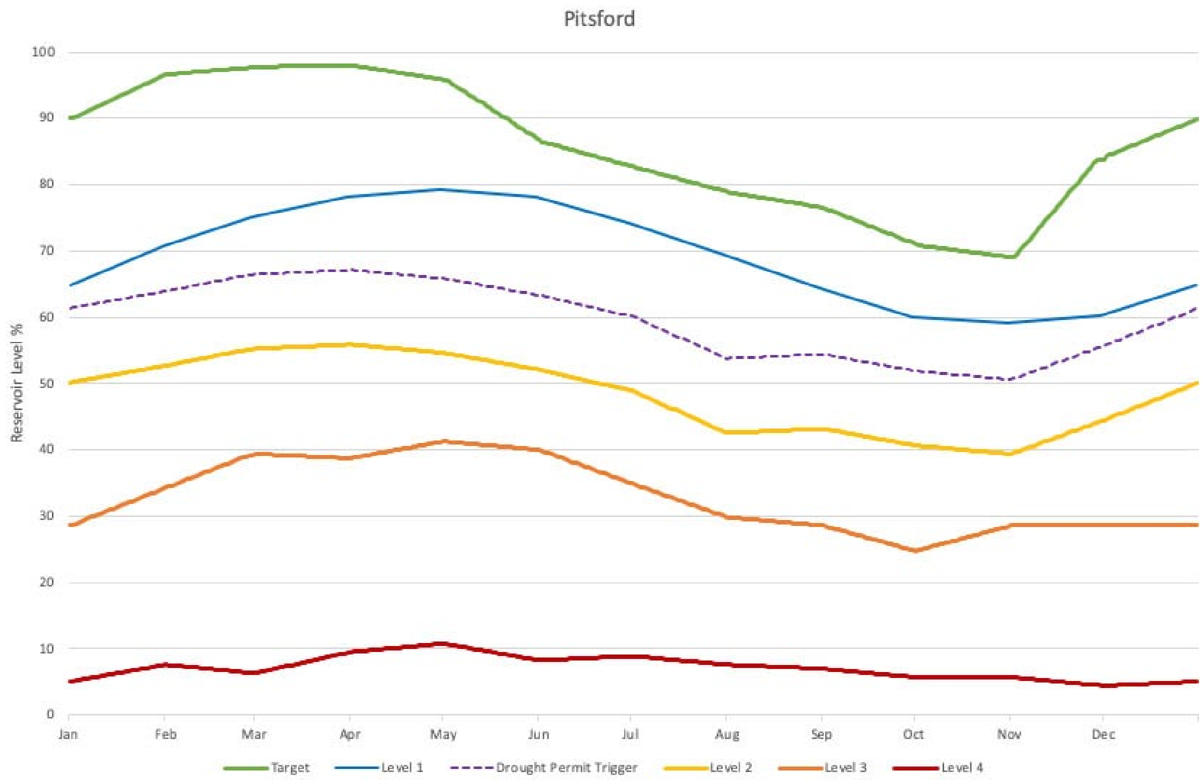
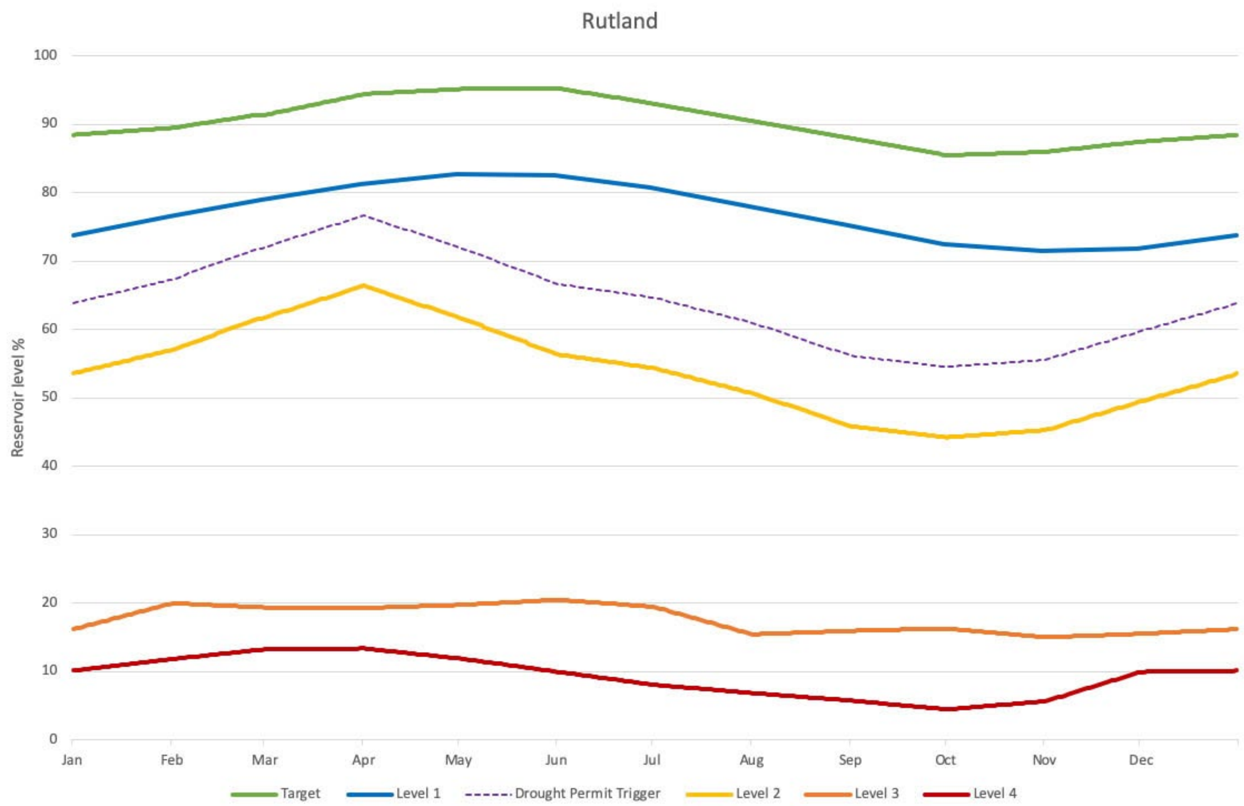


Figure 3.13: Rutland drought management curves



4. Drought management curves - historic droughts

4.1 Testing the reservoir curves and actions

The worst simulated historical drought (reference drought) has been used to demonstrate how our drought management actions for surface water reservoirs would be implemented.

The reference droughts for our reservoir sources are detailed in Tables 4.1 and 4.2 below.

Table 4.1: Reservoir reference drought year and associated drought vulnerability

Reservoir	Reference drought	Drought vulnerability
Alton Water	1997	Medium
Ardleigh	1934	Short*
Covenham	1989-92	Long
Grafham Water	1934	Long
Rutland Water	1934	Long
Pitsford Reservoir	1934	Medium
Ravensthorpe & Hollowell	1934	Short

* This is a reflection of Ardleigh's small size, but due to its large catchment it recovers quickly.

Table 4.2: Drought vulnerability

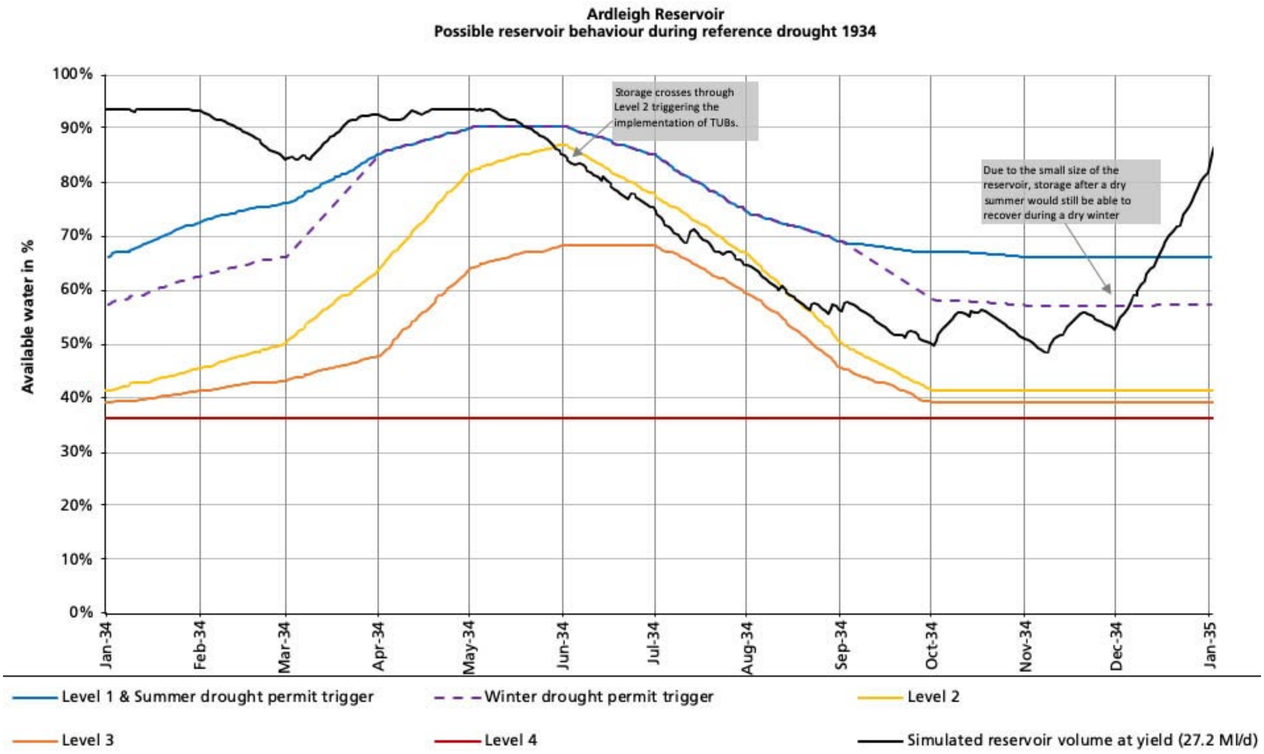
Drought vulnerability	Drought type
Short	Single-season drought (typically 6 to 12 months)
Medium	Multi-season drought (1-2 years, typically 2 dry summers and an intervening dry winter)
Long	Multi-season drought (typically lasting over two years)

We have included annotated examples of our reservoirs with modelled historic reservoir storage for the reference droughts. They show the benefit of the drought permit and drought management demand interventions being applied.

Ardleigh Reservoir

An annotated example for Ardleigh Reservoir with a winter drought permit is presented below in Figure 4.1. This uses modelled historic reservoir levels for the reference drought (1934). This shows the benefit of the groundwater drought permit and the drought management actions being applied.

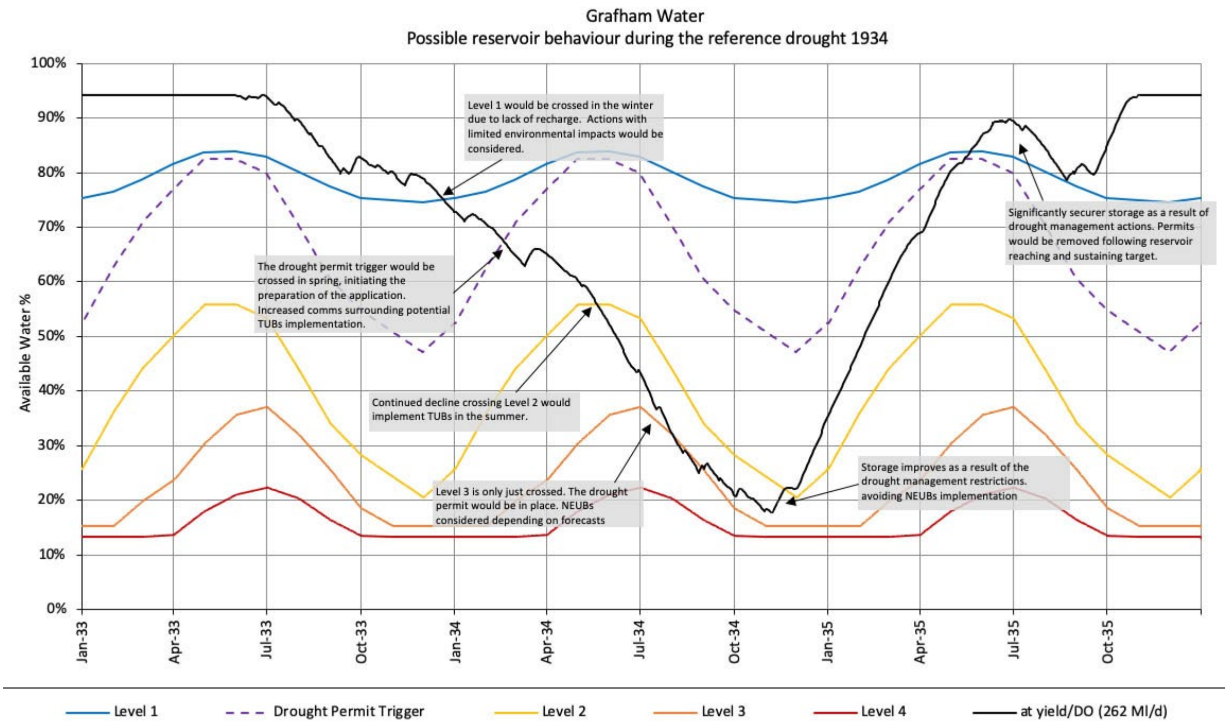
Figure 4.1: Worked example for Ardleigh Reservoir showing drought permit trigger, permit activation and demand intervention



Grafham Water

An annotated example for Grafham Water with a winter drought permit is presented below in Figure 4.2. This uses modelled historic reservoir levels for the reference drought (1934). This shows the benefit of the drought permit and drought demand interventions being applied.

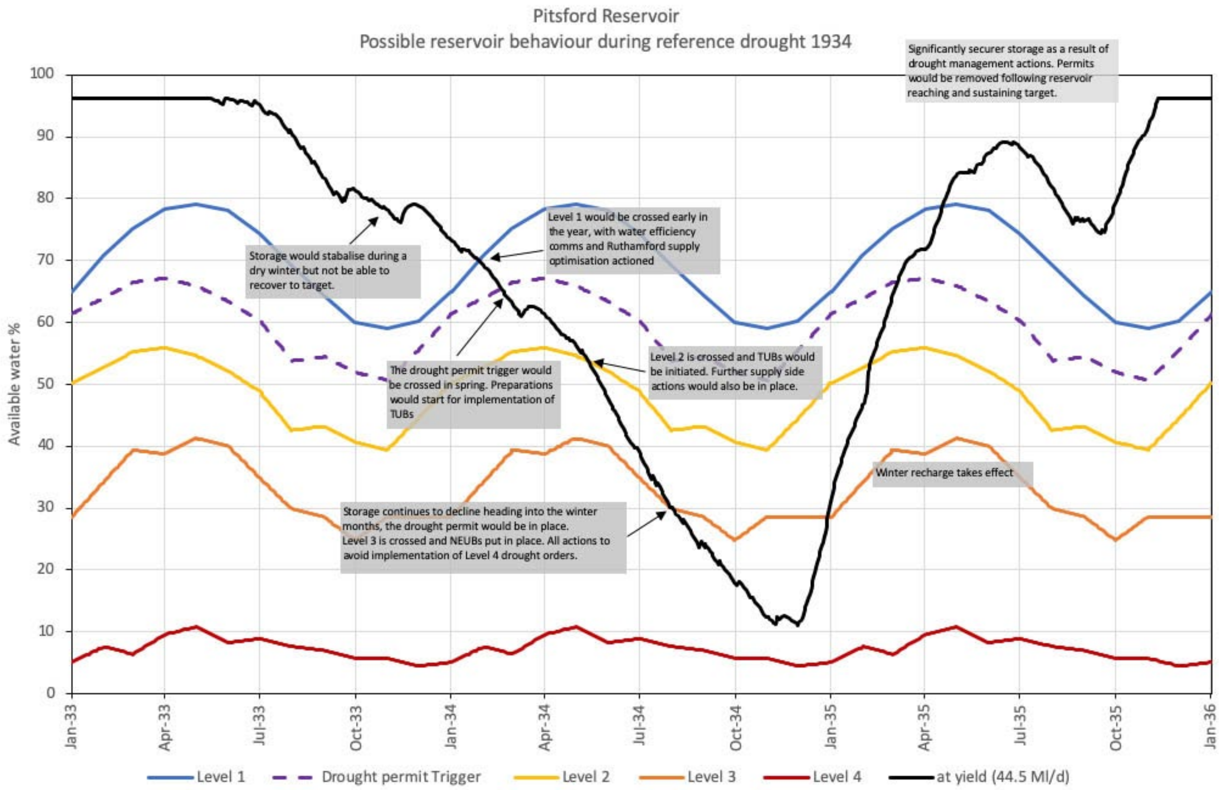
Figure 4.2: Worked example for Grafham showing drought permit trigger, permit activation and demand intervention benefits



Pitsford Water

An annotated example for Pitsford Water with a winter drought permit is presented below in Figure 4.3 this uses modelled historic levels for the reference drought (1934). This shows the benefit of the drought permit and drought management interventions being applied.

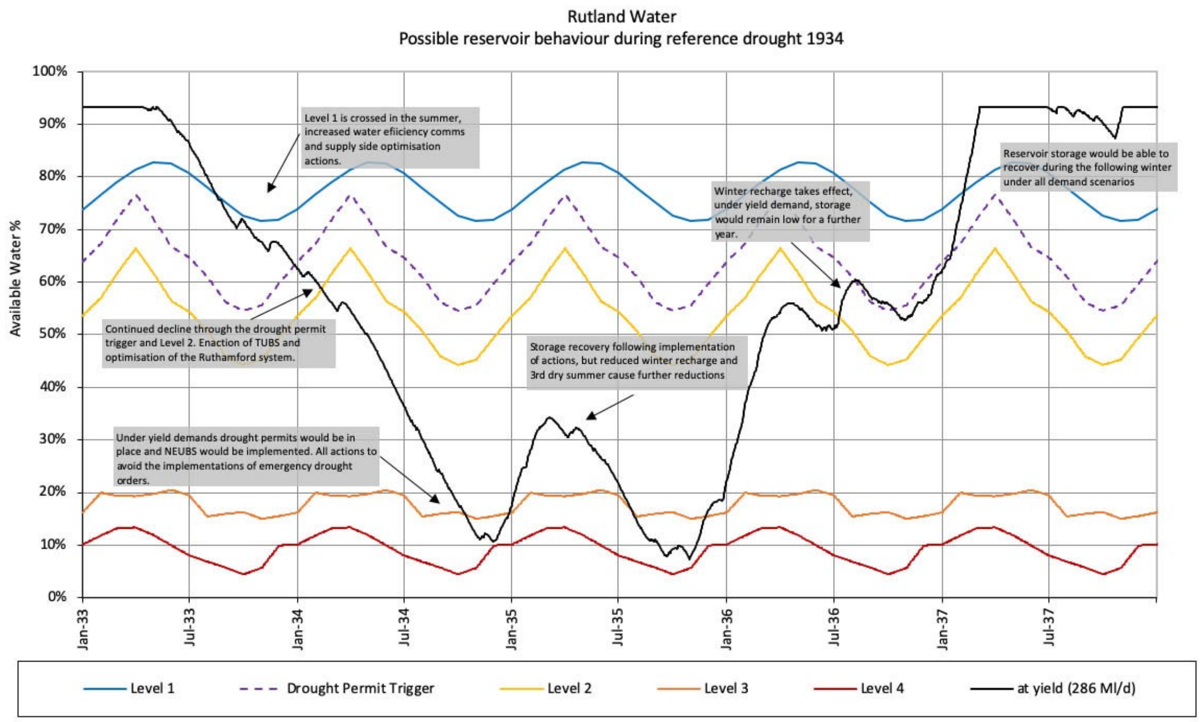
Figure 4.3: Worked example for Pitsford reservoir showing drought permit trigger, permit activation and permit benefits



Rutland Water

An annotated example for Rutland Water with a winter drought permit is presented below in Figure 4.4. This uses modelled historic reservoir levels for the reference drought (1934). This shows the benefit of the drought permit and drought demand interventions being applied.

Figure 4.4: Worked example for Rutland reservoir showing drought permit trigger, permit activation and demand intervention benefits



5. Drought management curves - scenario testing

In addition to testing the reference drought against the drought management curves (**Section 4**), a sample of representative droughts have been selected from the simulated historic flow series to illustrate the impacts that could be experienced at all the operational reservoirs. A simulated reservoir series has been used to illustrate how the drought management actions could be initiated and implemented over a range of drought scenarios. The model has been run with three demand scenarios (listed in order of most to least yield):

- reservoir hydrological yield demand
- water treatment works deployable output (accounting for current water resource infrastructure and operational assumptions) demand.
- indicative 'drought demands' using demand data from 2005-2006,

Drought management simulations have been compared to the baseline with no restrictions imposed to illustrate the impacts and value of drought management curve restrictions to each reservoir during drought. Note that "no restrictions" is represented as NR in the charts below.

Drought scenario modelling demonstrates the operational actions and decisions that could be taken during a drought. Each reservoir responds differently to drought, as a result of differing demand pressures relative to yield, hydrological characteristics of the contributing catchments and the demand management options available at that source. The figures below illustrate the range and variation between drought events and their impact on storage and the challenges faced when managing resources. Drought management actions identified in these scenarios offer guidance but cannot be prescriptive and a full, holistic assessment of factors particular to the specific situation is required to enable informed and effective decision-making and management.

5.1 Scenarios

Past droughts have been used to demonstrate current drought management for three differing drought scenarios, as described below:

- Short duration, single season droughts (typically 6 to 12 months).
- Medium duration, multi-seasonal droughts (1 to 2 years, typically consisting of two dry summers and an intervening dry winter).
- Long-term drought (typically lasting over 2 years.)

Droughts were selected via assessment of local river flow deficits compared to the historical average. Monthly mean cumulative flow deficits were compared to historic monthly means for each particular intake. A simulated flow series was utilised in order to consider a full range of historical drought periods.

A 'short' drought was selected by assessment of the greatest 12-month flow deficit in the relevant composite river flow series that resulted in reservoir storage drawdown. A 'medium' drought was selected from 18-month flow deficits, starting in April or May; and 'long' droughts from the greatest 36-month flow deficit in the series that would cause significant and prolonged resource pressures.

For some reservoirs, e.g. Covenham and Rutland Water, the 'long' drought was seen to last for longer than 36 months and this is shown in the relevant graph below. Where a single year was found to re-occur in more than one scenario, an alternative was selected based on holistic assessment of flow deficits and simulated reservoir model output.

Table 5.1 shows the drought scenarios, drought year and approximate return periods assessed, alongside the reference drought year and approximate return period and the drought scenario the reservoir is considered vulnerable to. Return periods are calculated using analysis completed for the WRMP 2019 by the Met Office[4] and Atkins[5] and are based on analysis of rainfall accumulations at a sub-regional level (Lincolnshire, Trent, Norfolk, Suffolk and Ruthamford).

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[4] *Met Office (2017) Technical Note: Extreme Value Analysis of long duration droughts using Bayesian methods*
[5] *Atkins (2017) Drought Selection Process and Criteria - Anglian Water Services*

Table 5.1: Reservoir drought scenarios

Reservoir	Drought scenario						Reference drought		Drought vulnerability
	Short		Medium		Long				
	Year	Approx RP	Year	Approx RP	Year	Approx RP	Year	Approx RP	
Alton Water	1976	1 in 50	1996 -98	1 in 200	1972 -75	1 in 50	1997	1 in 200 year	Medium
Ardleigh	1976	1 in 50	1973 -74	1 in 100	1995 -97	1 in 50	1934	1 in 50 to 1 in 150 year	Short
Covenham	1957	not assessed	1934 -35	1 in 100	1921 -28	1 in 200 over 24 mths (drought event is only 2 season)	1991	> 1 in 200 year	Long
Grafham Water	1929	1 in 100	1933 -35	1 in 200	1942 -46	1 in 200	1934	~ 1 in 200 year	Long
Rutland Water	1976	1 in 200	1996-98	1 in 200	1933-37	1 in 200	1934	~ 1 in 200 year	Long
Pitsford Reservoir	1929	1 in 100	1975 -76	1 in 50	1943 -45	1 in 200	1934	~ 1 in 200 year	Medium
Ravensthorpe & Hollowell	1929	1 in 100	1975-76	1 in 50	1943-45	1 in 200	1934	~ 1 in 200 year	Short

5.2 Reservoir graphs

The following section presents graphs showing possible reservoir behaviour during historic droughts in relation to drought management actions.

Alton Water

Alton Water is currently operated below its hydrological yield, being constrained by a 5-year reservoir abstraction licence. Consequently, the scenario graphs show the reservoir's ability to recover storage during dry winters. Figure 5.3 illustrates the benefit to storage of drought management curve restrictions during long droughts. The drought in this scenario does not appear to have a particularly severe return period, but this may be a result of the sub-regional analysis not fully reflecting more localised droughts. The option of the Mill River source for additional pumped refill during times of drought offers further resilience.

Figure 5.1: Alton Water possible reservoir behaviour during a "short" drought

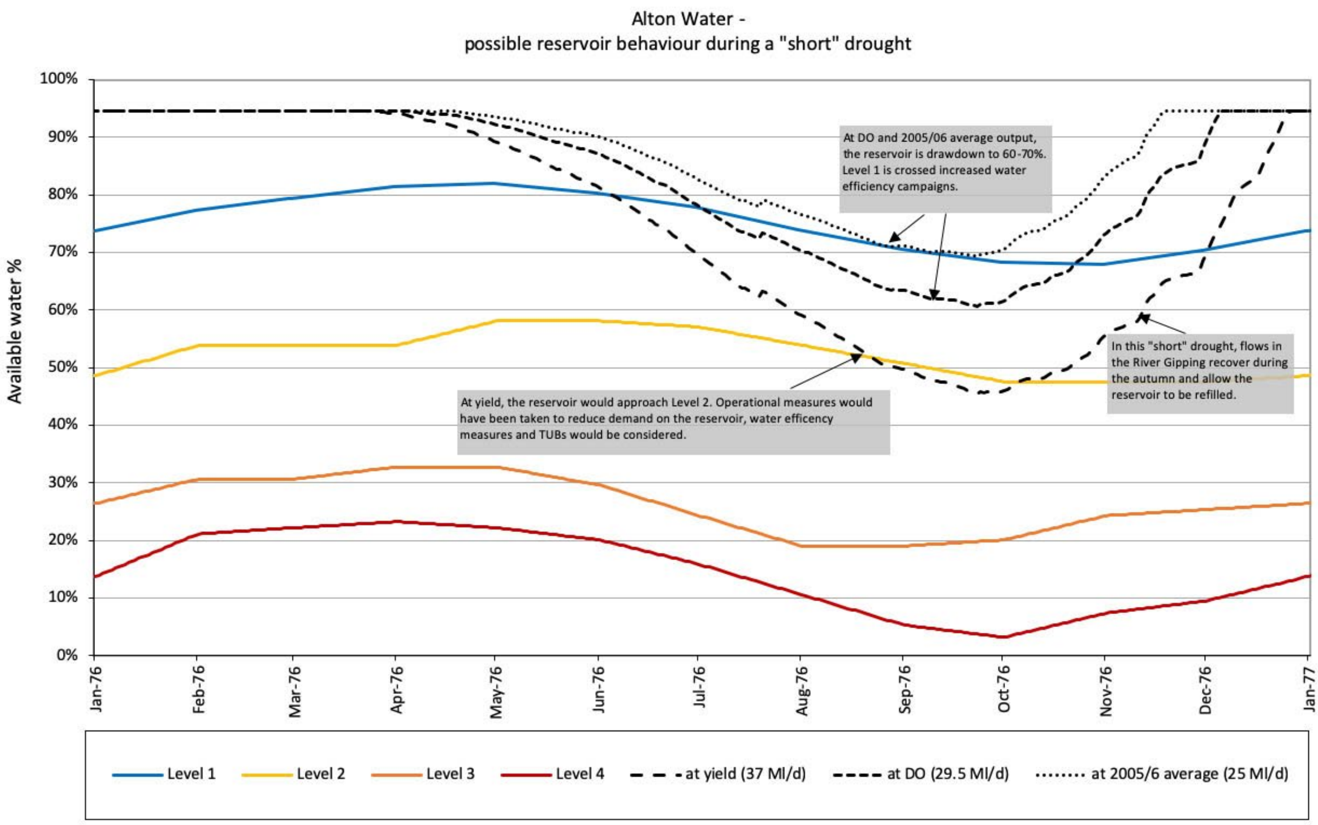


Figure 5.2: Alton Water possible reservoir behaviour during a “medium” drought

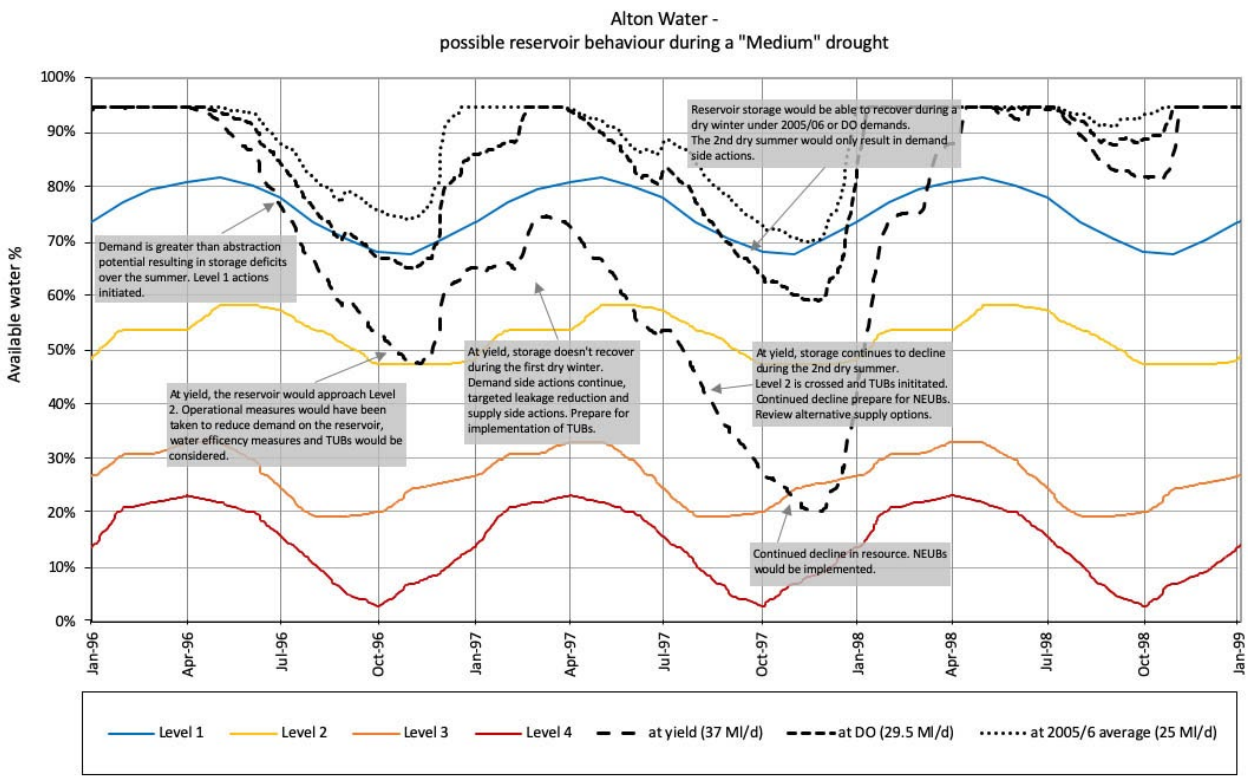
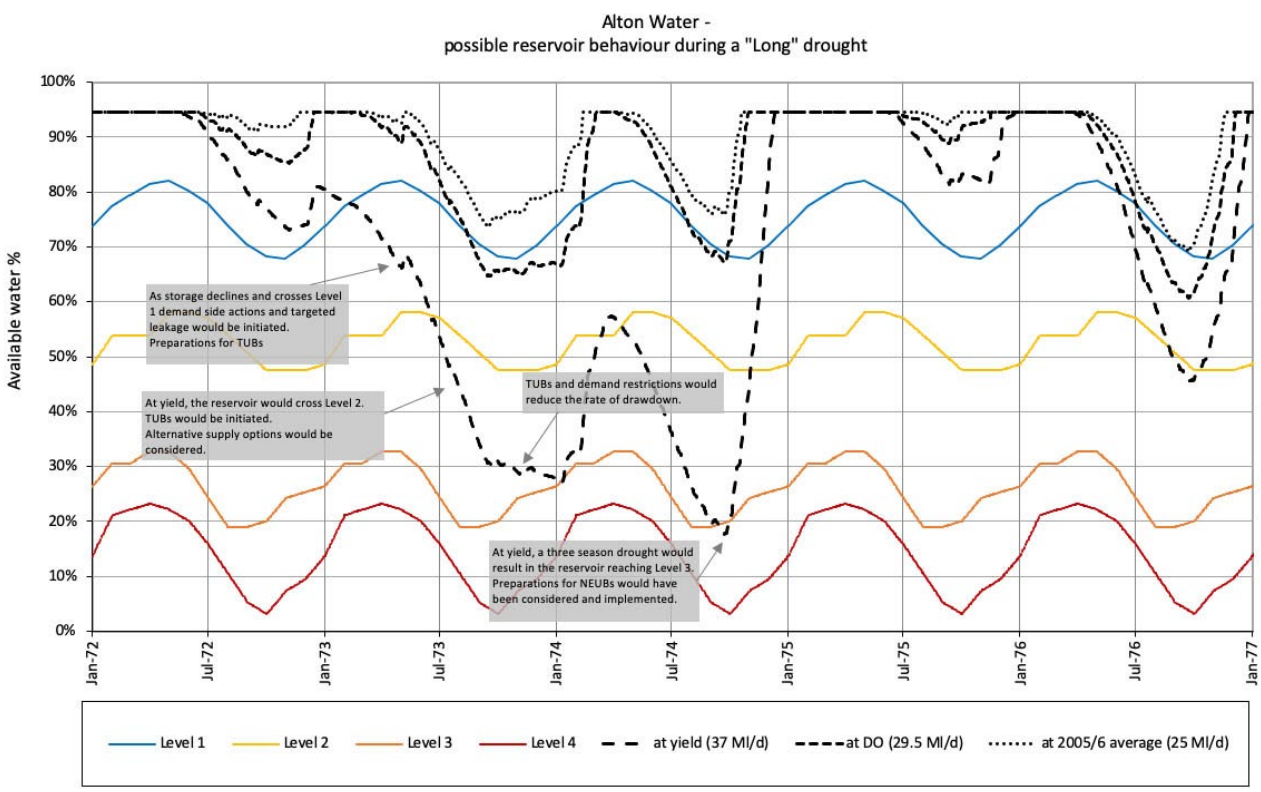


Figure 5.3: Alton Water possible reservoir behaviour during a “long” drought



Ardleigh Reservoir

Ardleigh Reservoir's small size can result in both rapid drawdown and refill, resulting in it being short / single season vulnerable. However its large catchment means refill tends to be reliable. The drought scenarios in Figures 5.4 to 5.6 show how the reservoir is susceptible to short periods of drought but able to refill even during dry winters. Augmentation of the River Colne from a groundwater source offers additional water for abstraction at times of low flow, demonstrated in Figure 5.6. We also have a drought permit option to temporarily increase abstraction for the augmentation boreholes.

Figure 5.4: Ardleigh Reservoir possible reservoir behaviour during a "short" drought

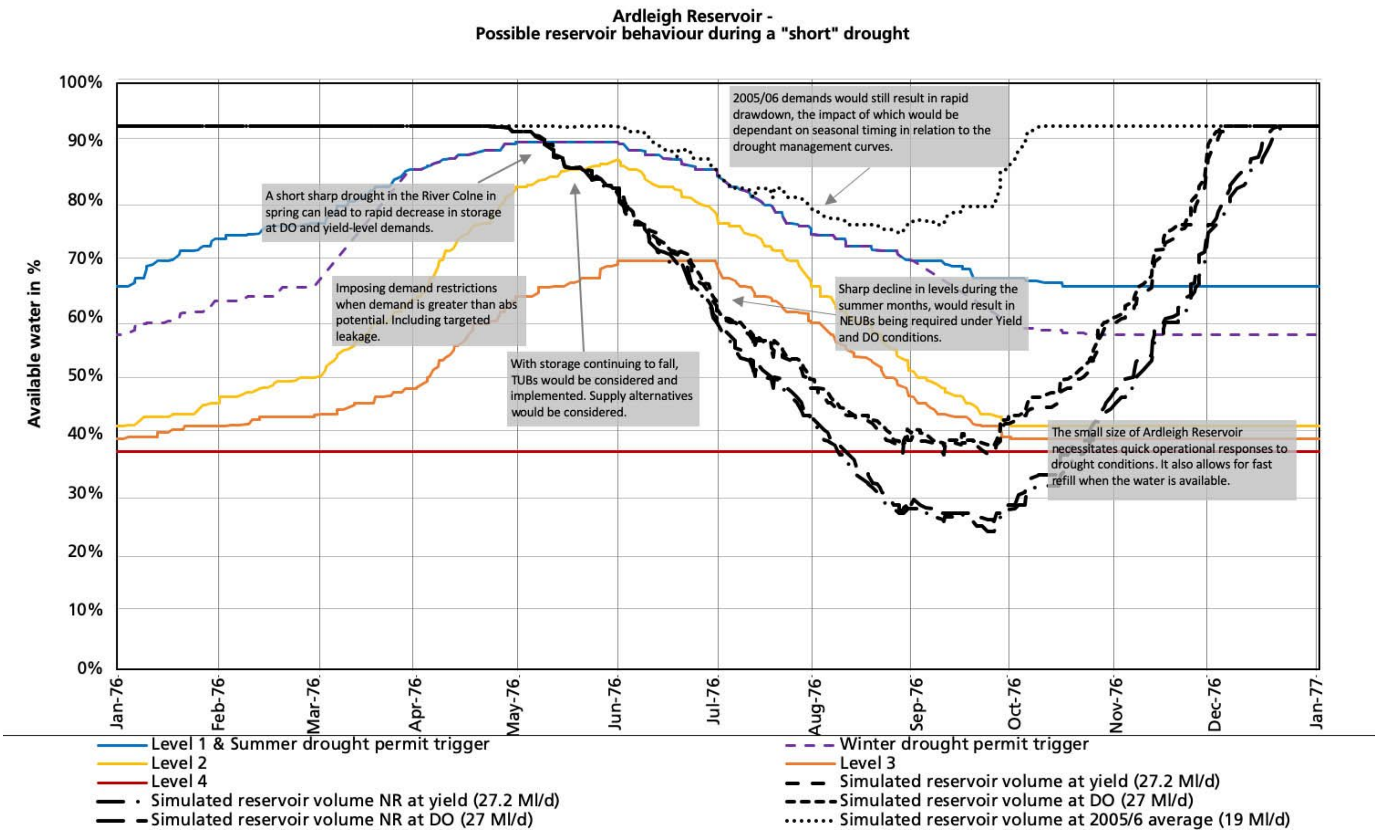


Figure 5.5: Ardleigh Reservoir possible reservoir behaviour during a “medium” drought

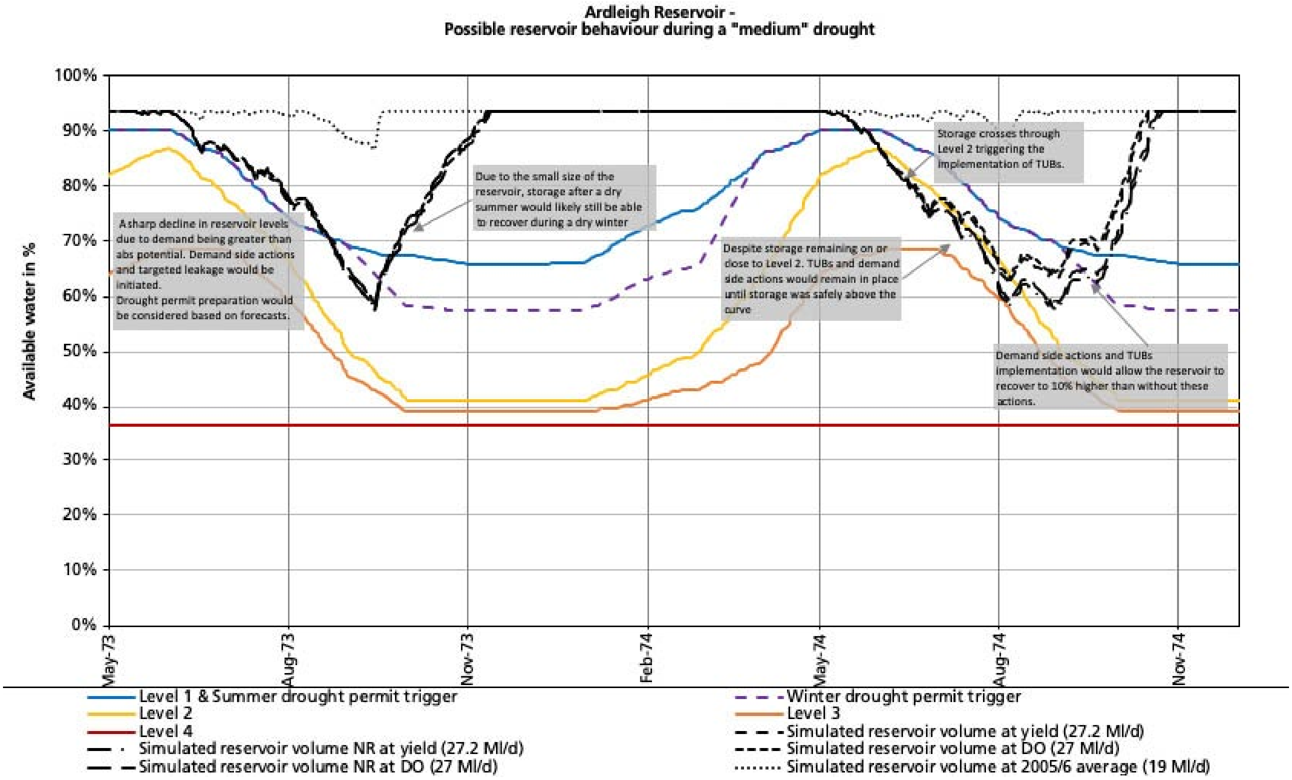
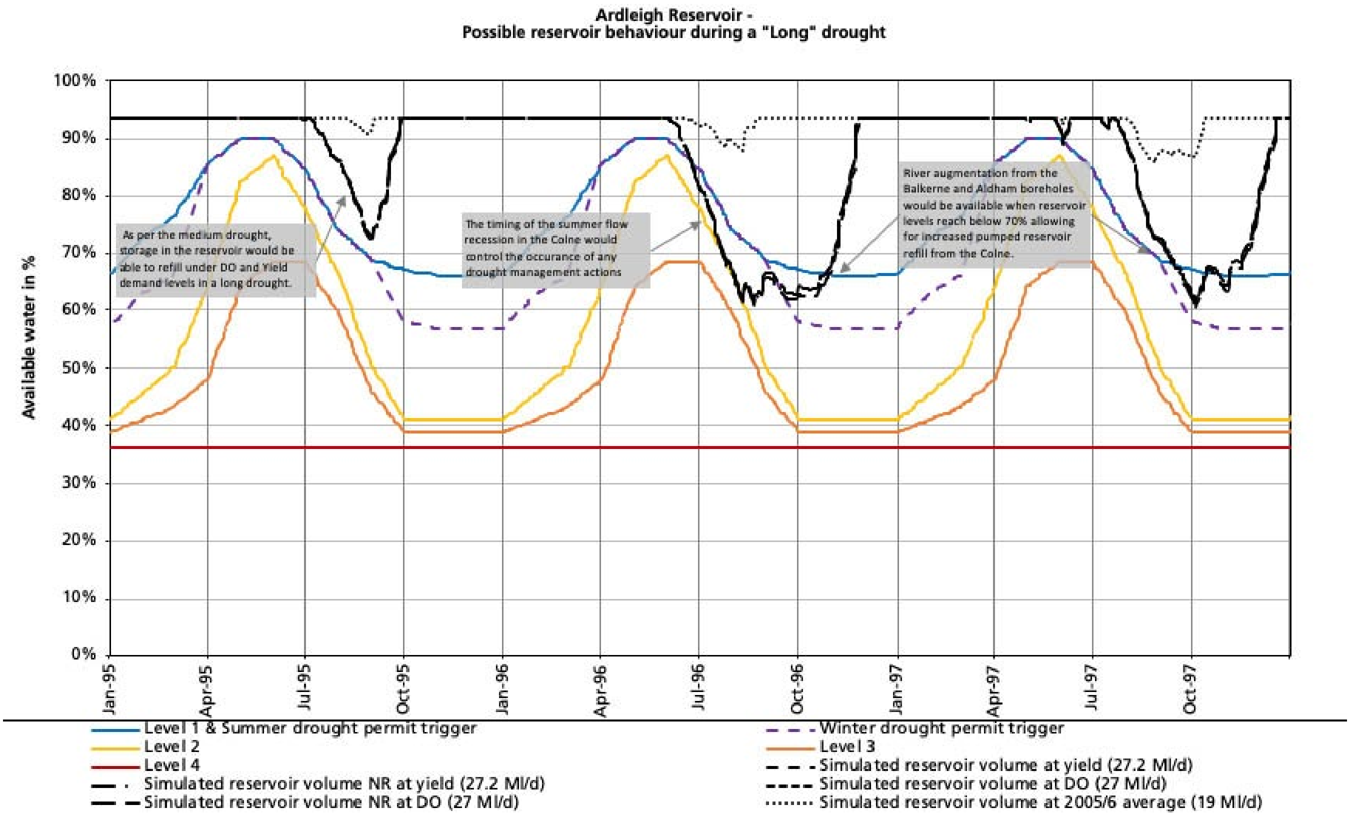


Figure 5.6: Ardleigh reservoir possible reservoir behaviour during a “long” drought



Covenham Reservoir

Covenham is an impounding reservoir entirely dependent on pumped refill. It does not respond quickly to changes in rainfall and is only considered vulnerable to long duration droughts mainly due to the current difference between demand and yield.

Figures 5.7 to 5.9 illustrate the long drawdown and recovery periods for an extended multi-season drought at Covenham Reservoir. The storage behaviour can be attributed to the high Chalk baseflow component of the catchments from which Covenham is filled and their hydrological responses to drought.

Figure 5.7: Covenham Reservoir possible reservoir behaviour during a "short" drought

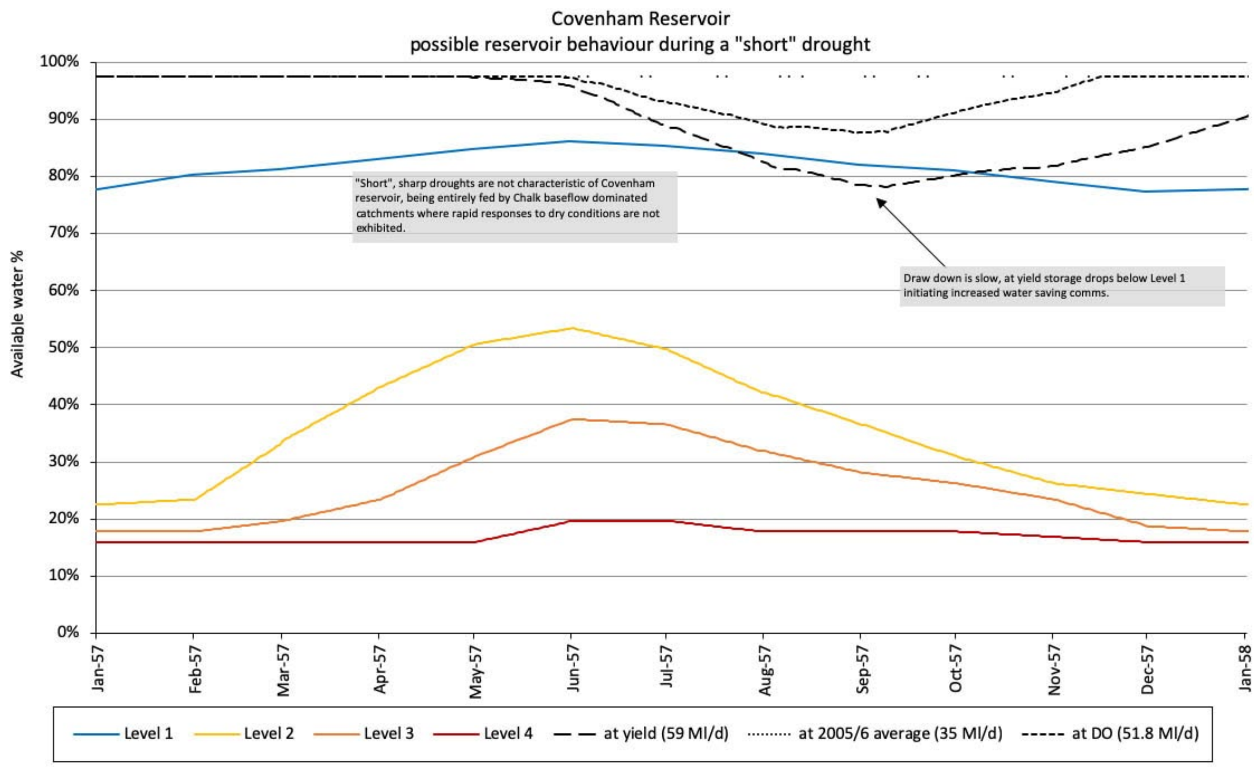


Figure 5.8: Covenham Reservoir possible reservoir behaviour during a "medium" drought

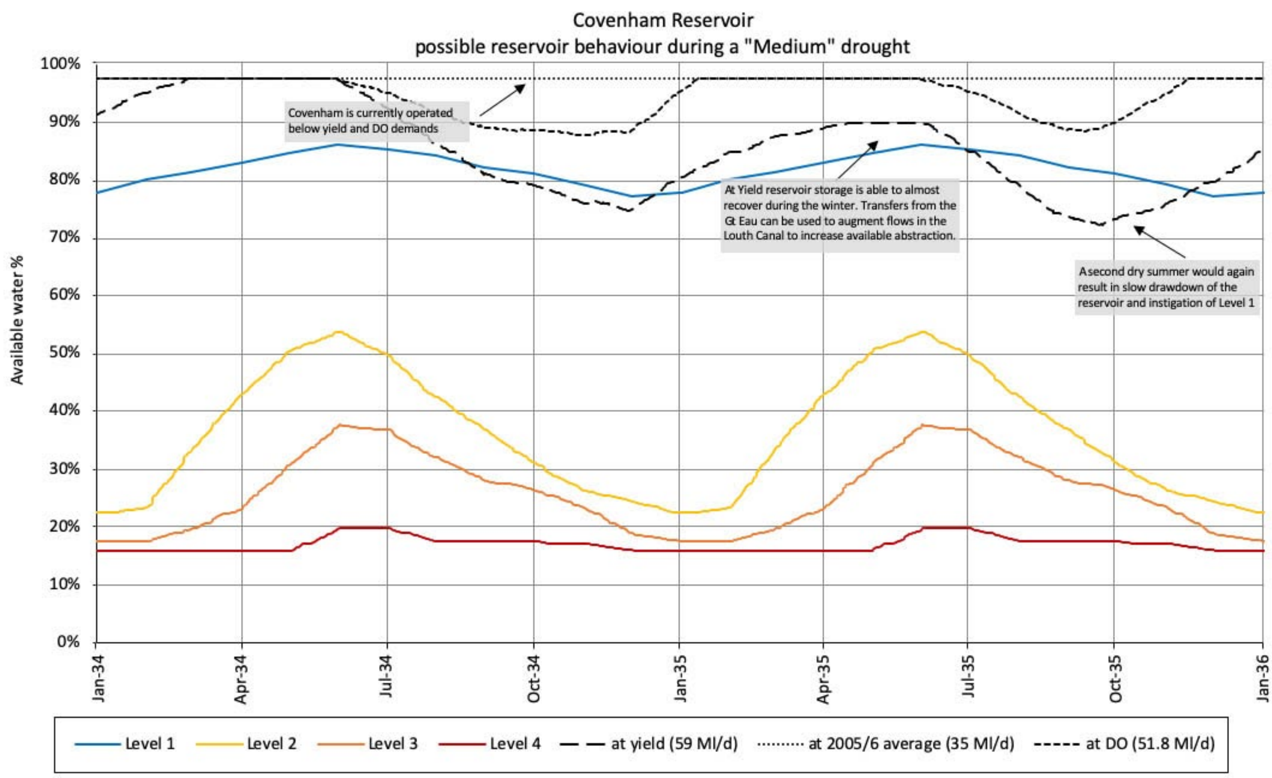
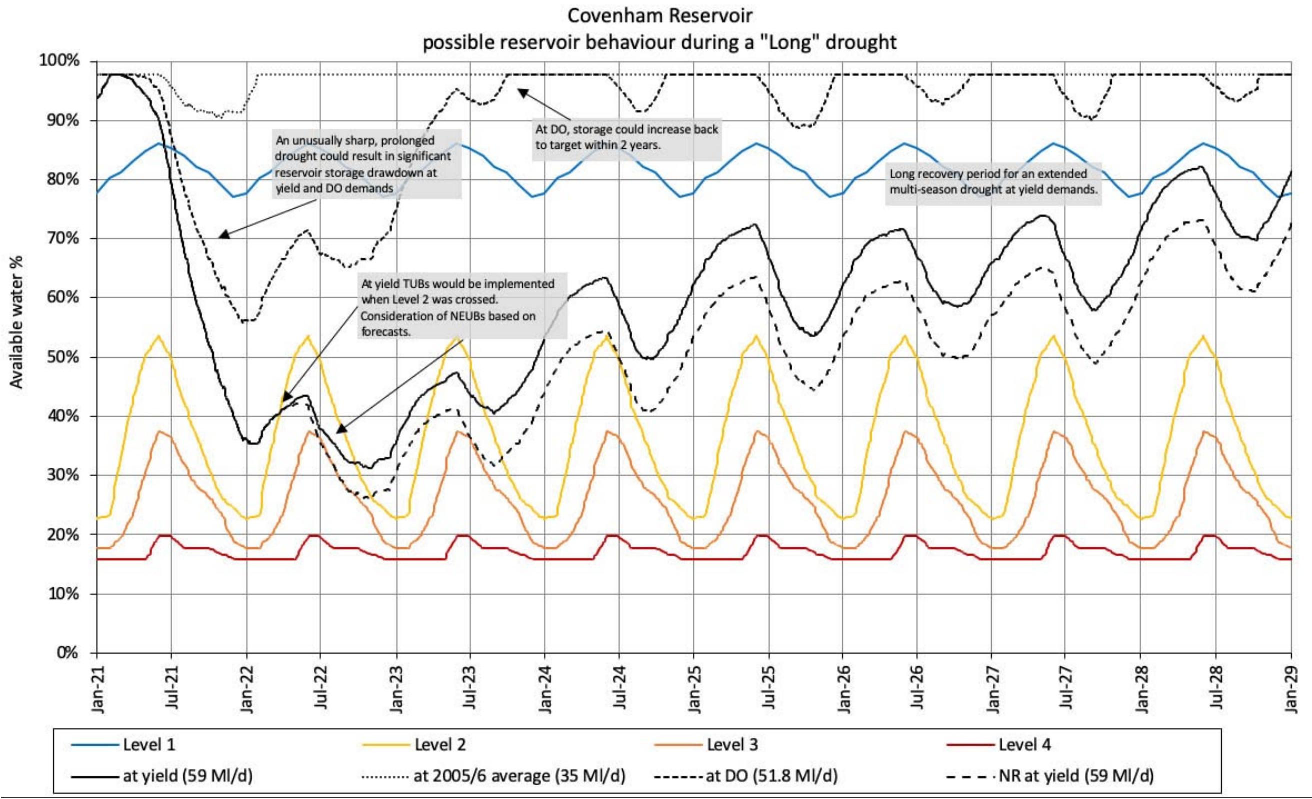


Figure 5.9: Covenham Reservoir possible reservoir behaviour during a “long” drought



Grafham Water

Figure 5.10 shows how a short single-season drought in Grafham Water's pumped refill river catchment would result in depletion of storage but no requirement for drought management curve demand restrictions. Figures 5.11-5.12 show the relative impact of a 'medium' and 'long'-term drought. They also illustrates the influence that Level 2 and Level 3 could have on reservoir storage drawdown and prolonging the security of supply to customers. The reservoir simulation model includes the assumed consent of a drought permit to reduce the minimum residual flow on the River Great Ouse at Level 3, further aiding storage stabilisation and recovery.

Figure 5.10: Grafham Water possible reservoir behaviour during a "short" drought

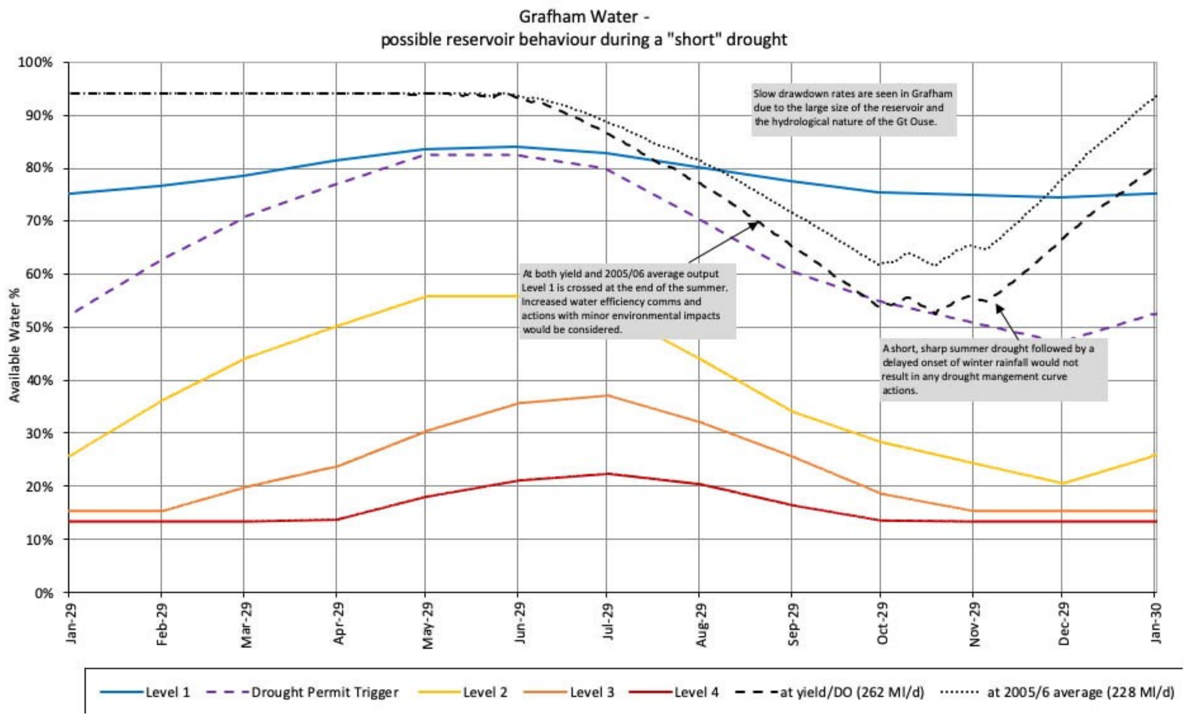


Figure 5.11: Grafham Water possible reservoir behaviour during a "medium" drought

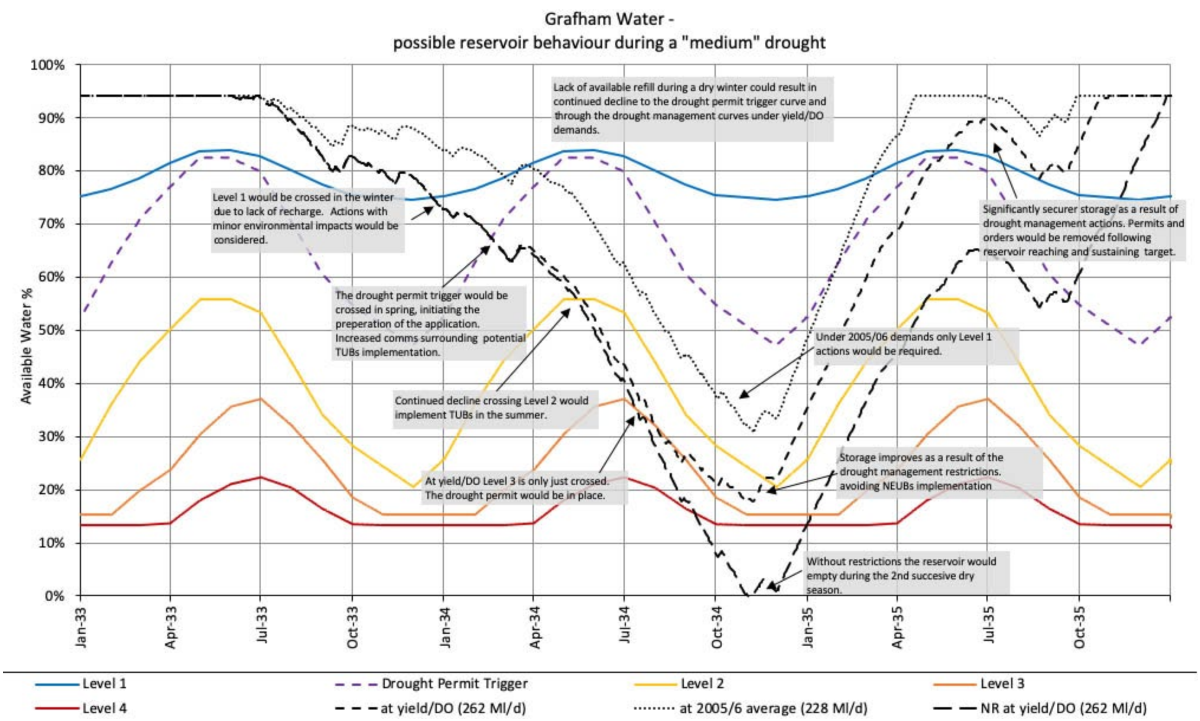
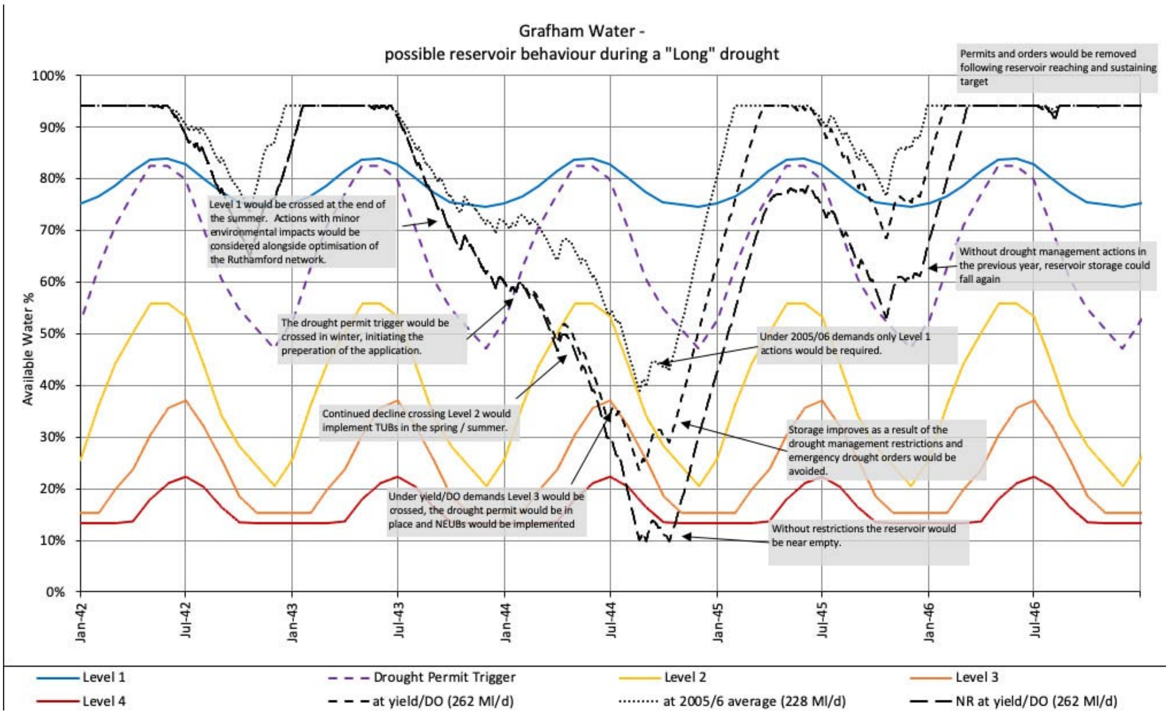


Figure 5.12: Grafham Water possible reservoir behaviour during a “long” drought



Rutland Water

Due to its large size, Rutland Water exhibits slow drawdown rates during a drought. In the scenarios modelled, storage could be maintained above drought management curves during a 'short' drought, with potential drought management curve restrictions during a three-season drought, as shown in Figure 5.15. This illustrates the impact of a 3-year drought, with storage struggling to recover over the winter periods and an extended period of recovery. The improved connectivity of the Ruthamford supply system following actions from the 2011/12 drought, allows for re-distribution of demand across the other reservoirs in that system - Grafham and Pitsford. Depending on the situation this could either increase demand from Rutland to support other areas or reduce reservoir drawdown and further aid recovery. A drought permit option to reduce the minimum residual flow at the intake on the River Nene is included in the model at Level 3.

Figure 5.13: Rutland Water possible reservoir behaviour during a "short" drought

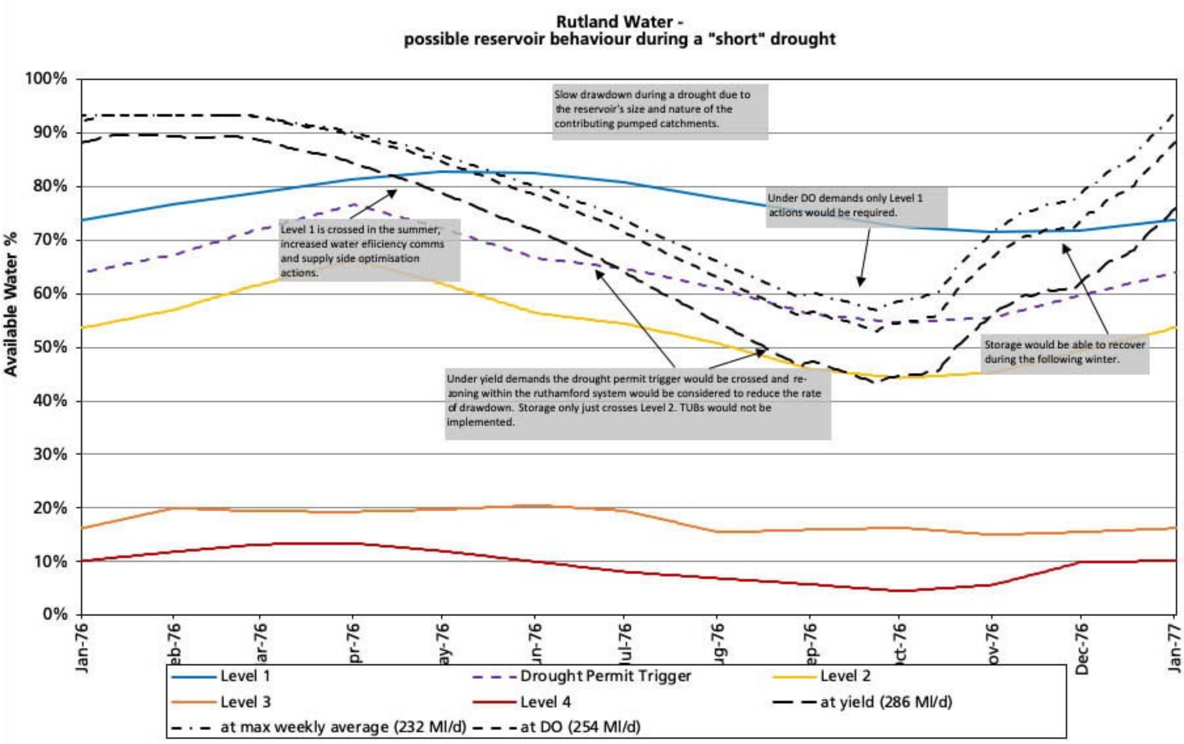


Figure 5.14: Rutland Water possible reservoir behaviour during a “medium” drought

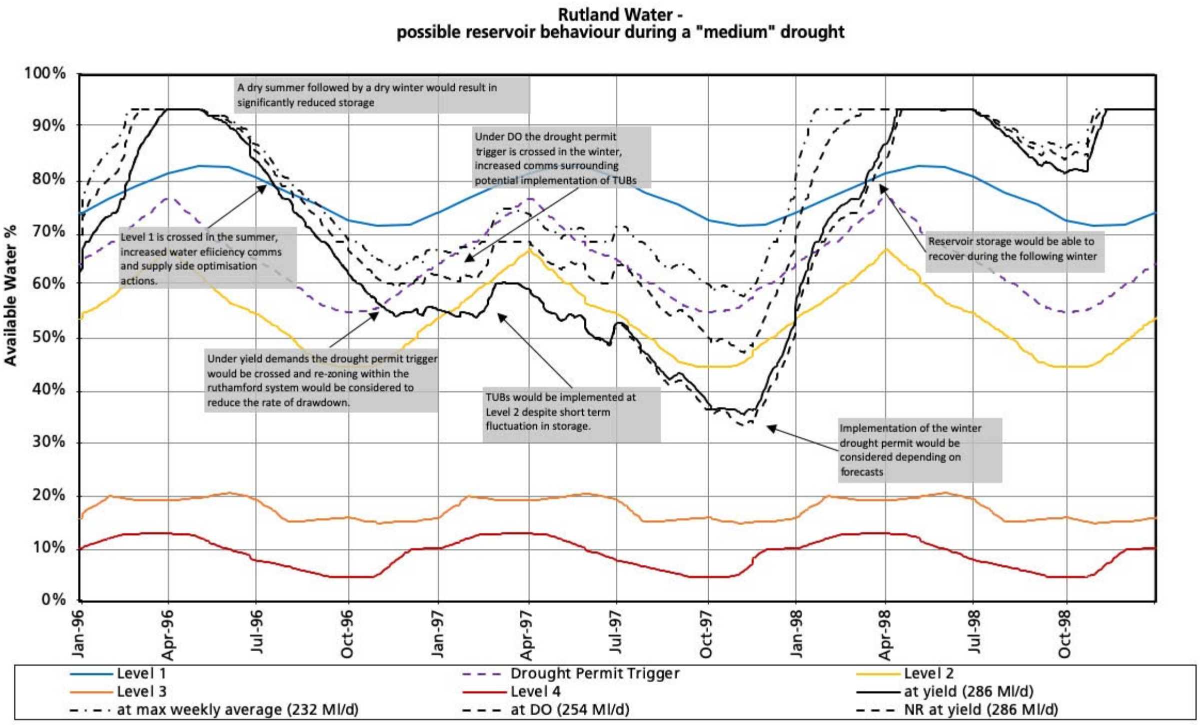
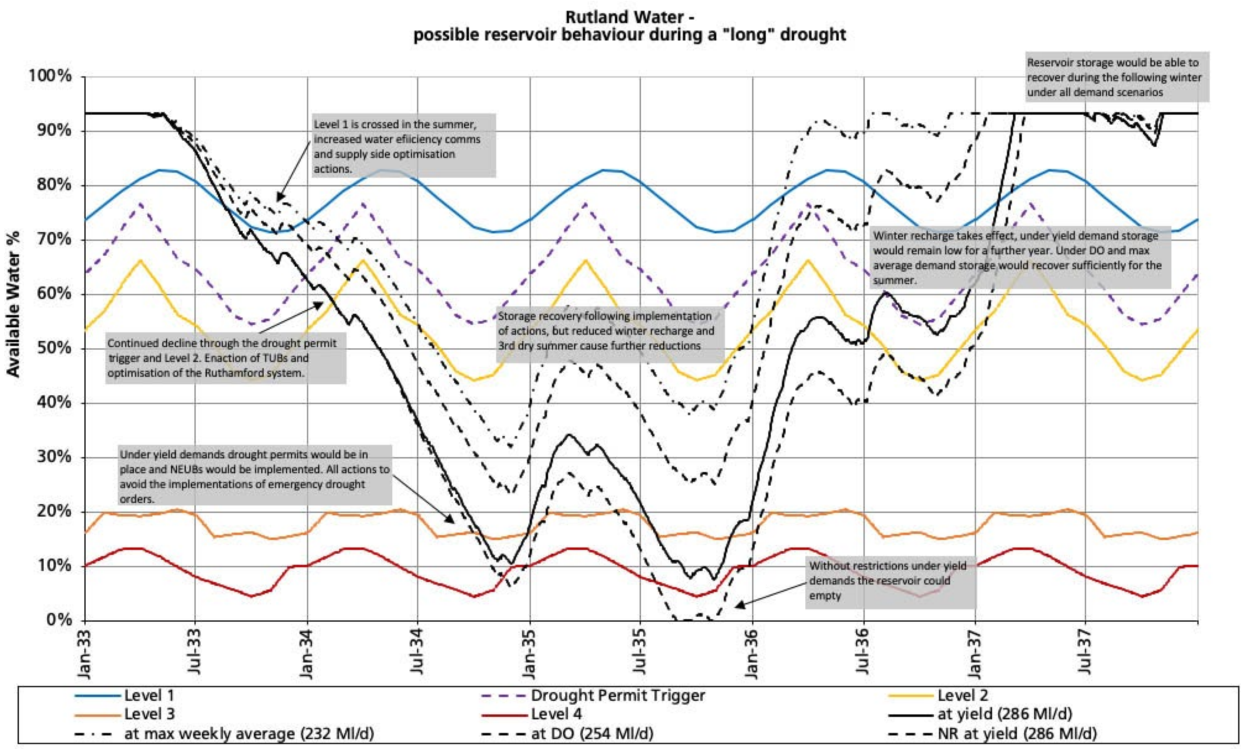


Figure 5.15: Rutland Water possible reservoir behaviour during a “long” drought



Pitsford Reservoir

Pitsford is part of the Ruthamford supply system, with Grafham and Rutland being able to support this area if required. Pitsford is currently operated close to its DO and yield demands.

A 'short' or 'medium' duration drought (as shown in Figures 5.16 and 5.17) would result in depletion of storage but no drought management curve actions would be required. The additional demand at yield would, however, trigger Level 2 restrictions during a 'medium' duration drought.

A 3-year 'long'- term drought, such as that shown in Figure 5.18, would lead to a prolonged period of below-target storage and restrictions would be required under all demand scenarios. Figure 5.18 illustrates the benefit to storage that could be achieved under drought management restrictions. A drought permit option to reduce the minimum residual flow at the intake on the River Nene for Pitsford is included in the modelling, initiated before Level 3.

Figure 5.16: Pitsford Reservoir possible reservoir behaviour during a “short” drought

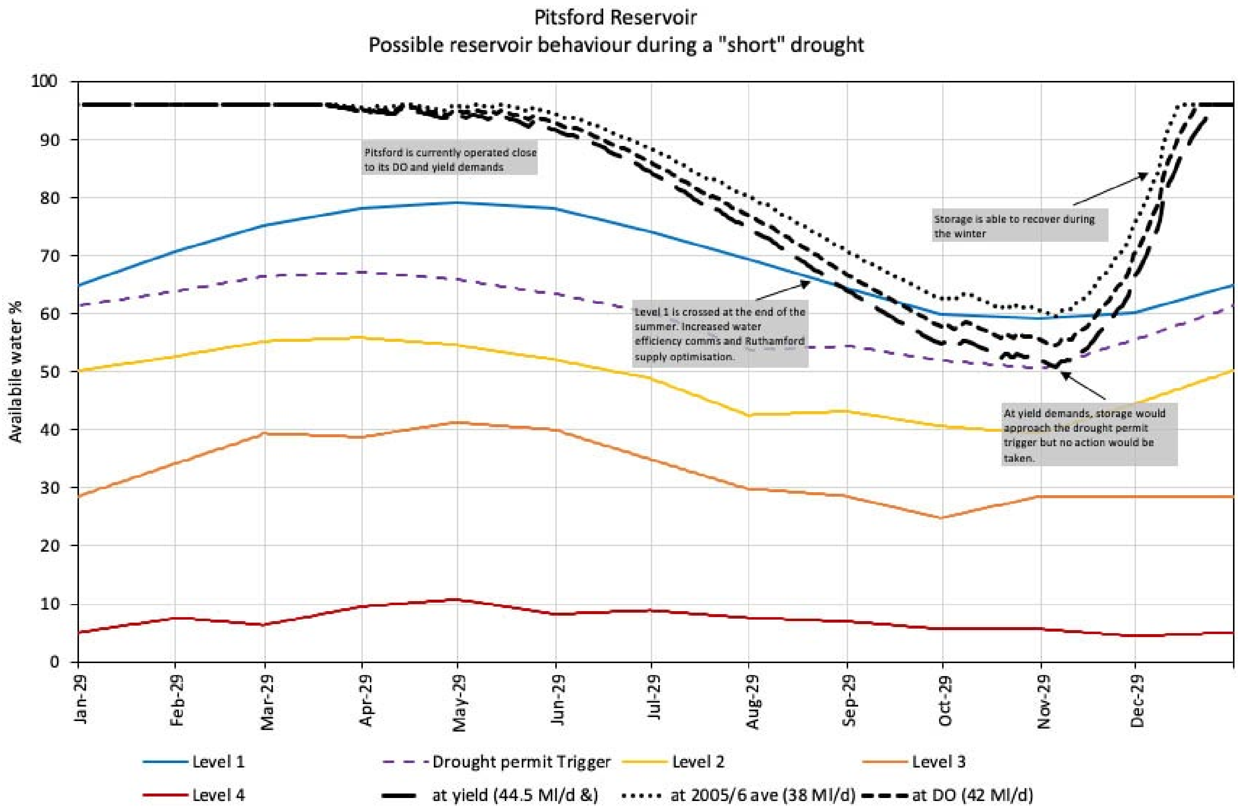


Figure 5.17: Pitsford Reservoir possible reservoir behaviour during a “medium” drought

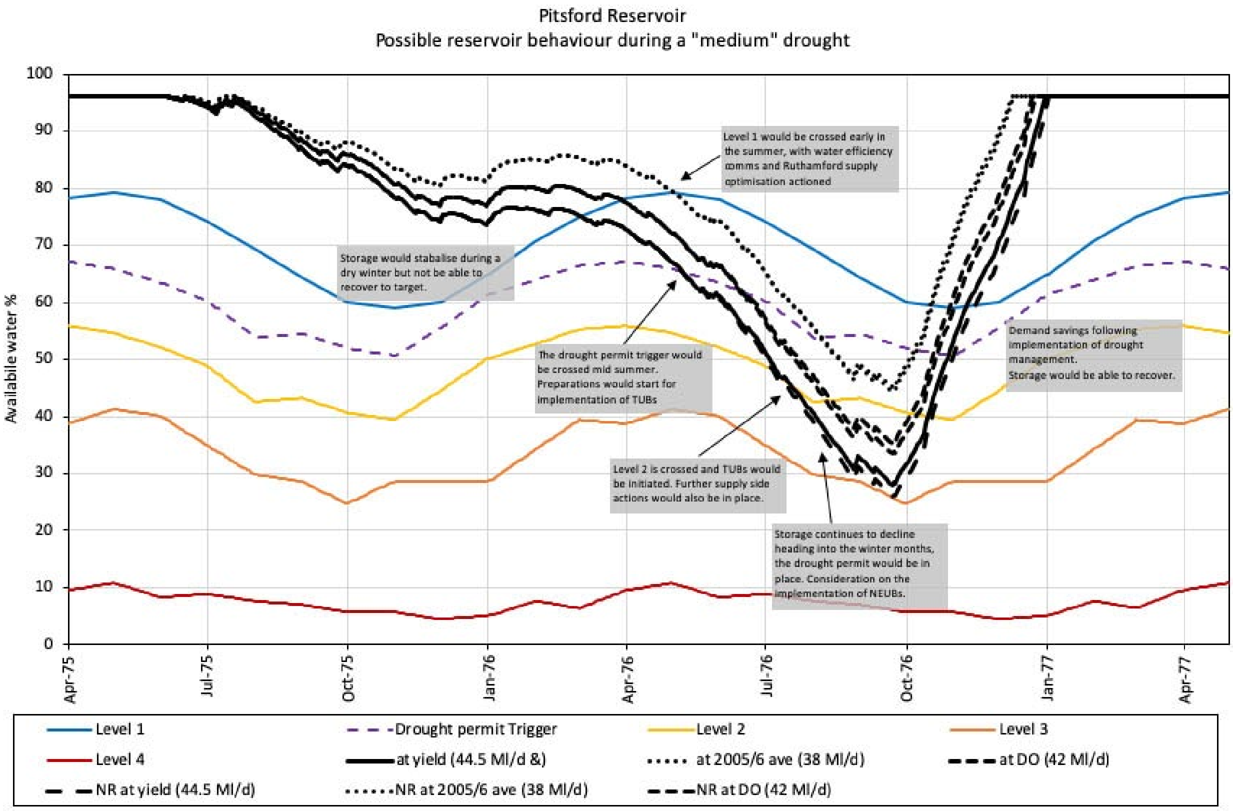
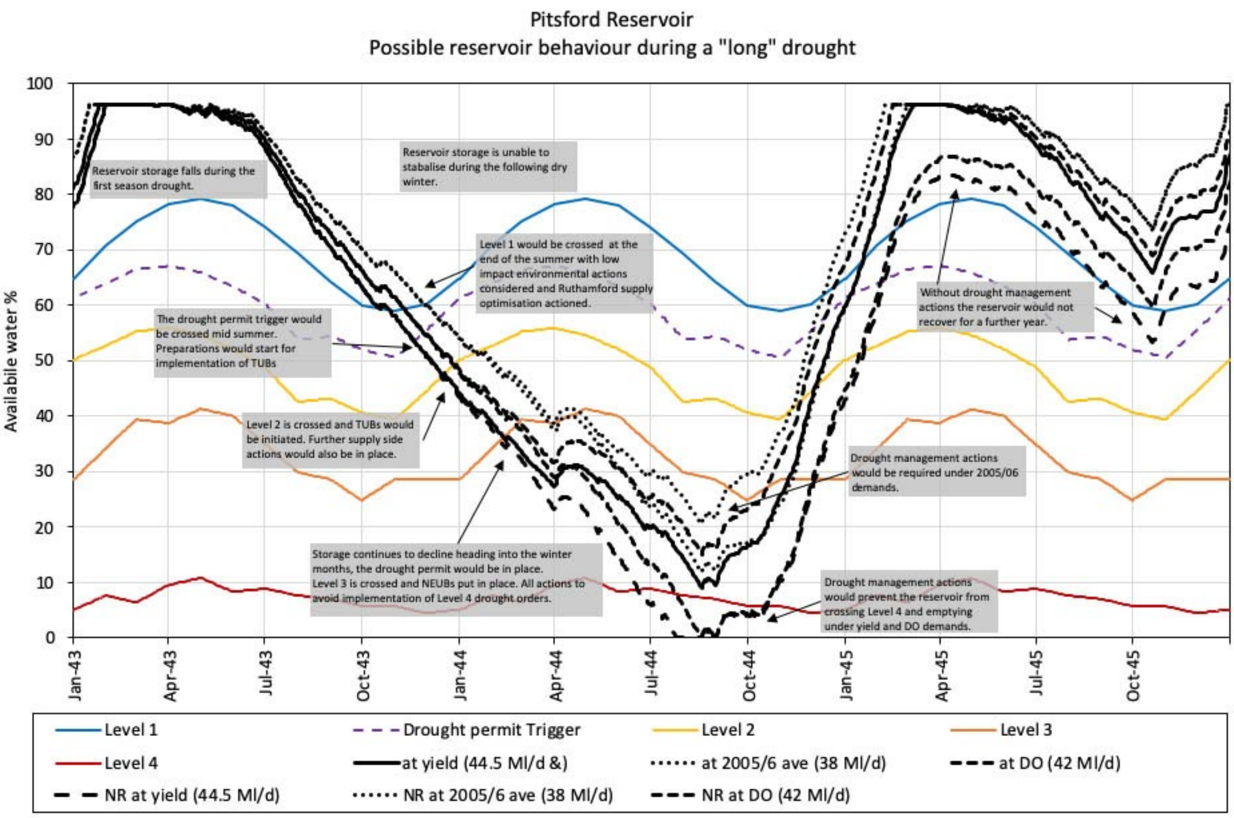


Figure 5.18: Pitsford Reservoir possible reservoir behaviour during a “long” drought



Hollowell and Ravensthorpe Reservoirs

Hollowell and Ravensthorpe are fully connected with both reservoirs feeding the same supply area, they are also part of the Ruthamford supply system. With Pitsford being able to support this supply area if required. Hollowell and Ravensthorpe have been considered in combination for the scenario testing. As explained in **Section 3.3** Hollowell and Ravensthorpe do not have Level 1 curves, however due to their connectivity with Pitsford, if Level 1 actions were initiated at Pitsford these actions would also occur in the Hollowell and Ravensthorpe supply zone.

A ‘short’ duration drought (as shown in Figure 5.19) would result in depletion of storage but no drought management curve actions would be required.

Under a “medium” drought (as shown in Figure 5.20) demand actions and supply optimisation of the Ruthamford system would take place when levels dropped below 60%.

A greater than 3-year ‘long’- term drought, such as that shown in Figure 5.21, due to lack of recharge during the winter months would lead to a prolonged period of below-target storage and Level 1 actions including Ruthamford optimisation would be in place until the reservoirs recovered.

Figure 5.19: Hollowell & Ravensthorpe possible reservoir behaviour during a “short” drought

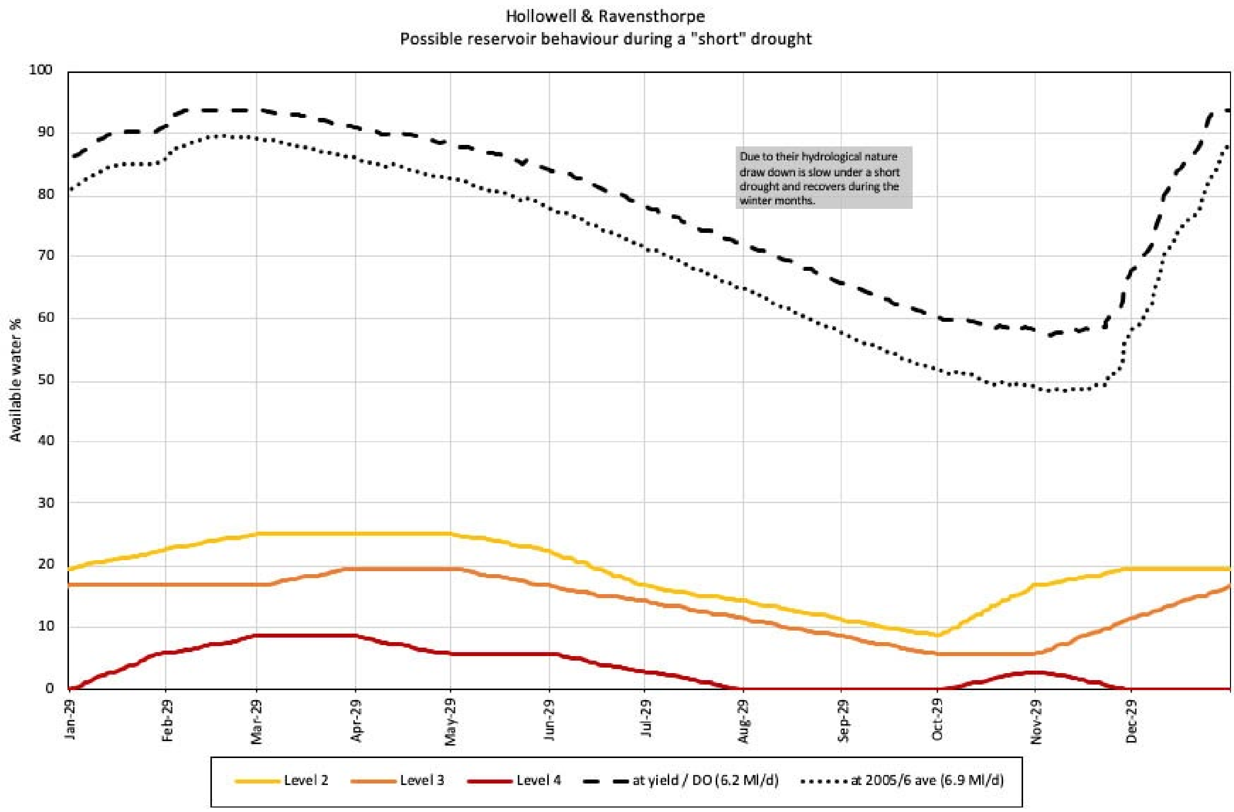


Figure 5.20: Hollowell & Ravensthorpe possible reservoir behaviour during a “medium” drought

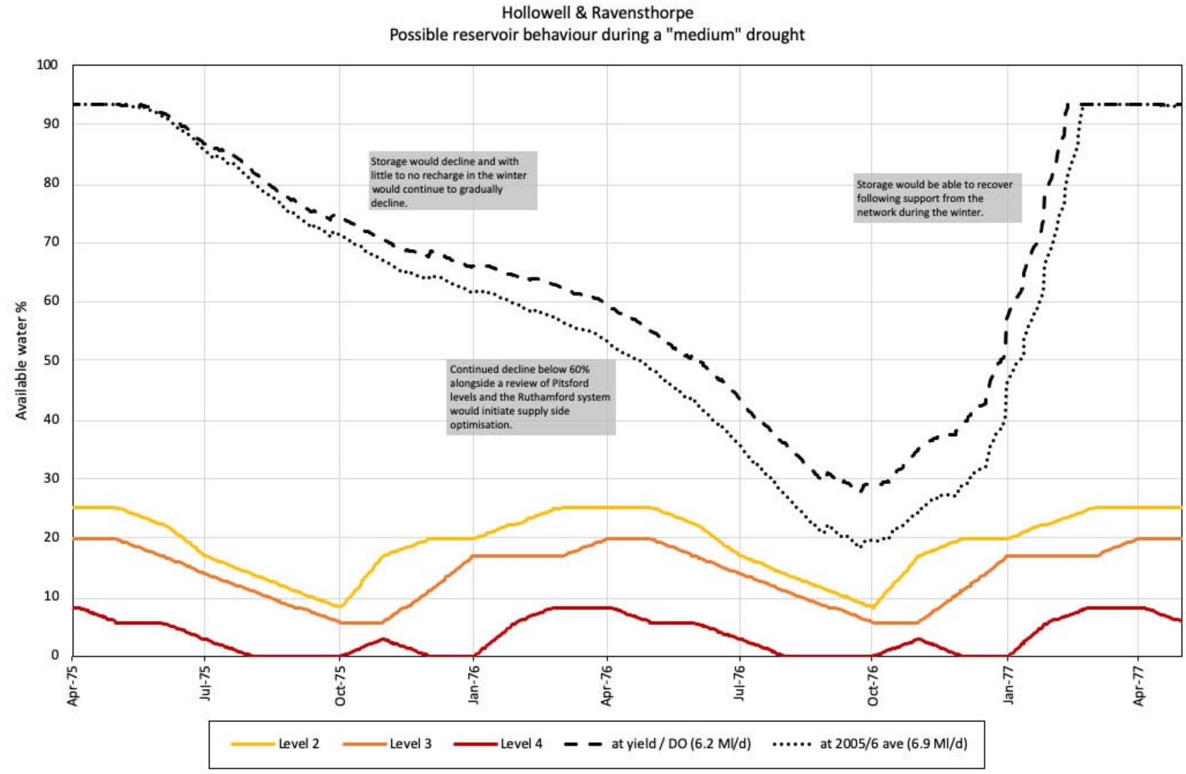
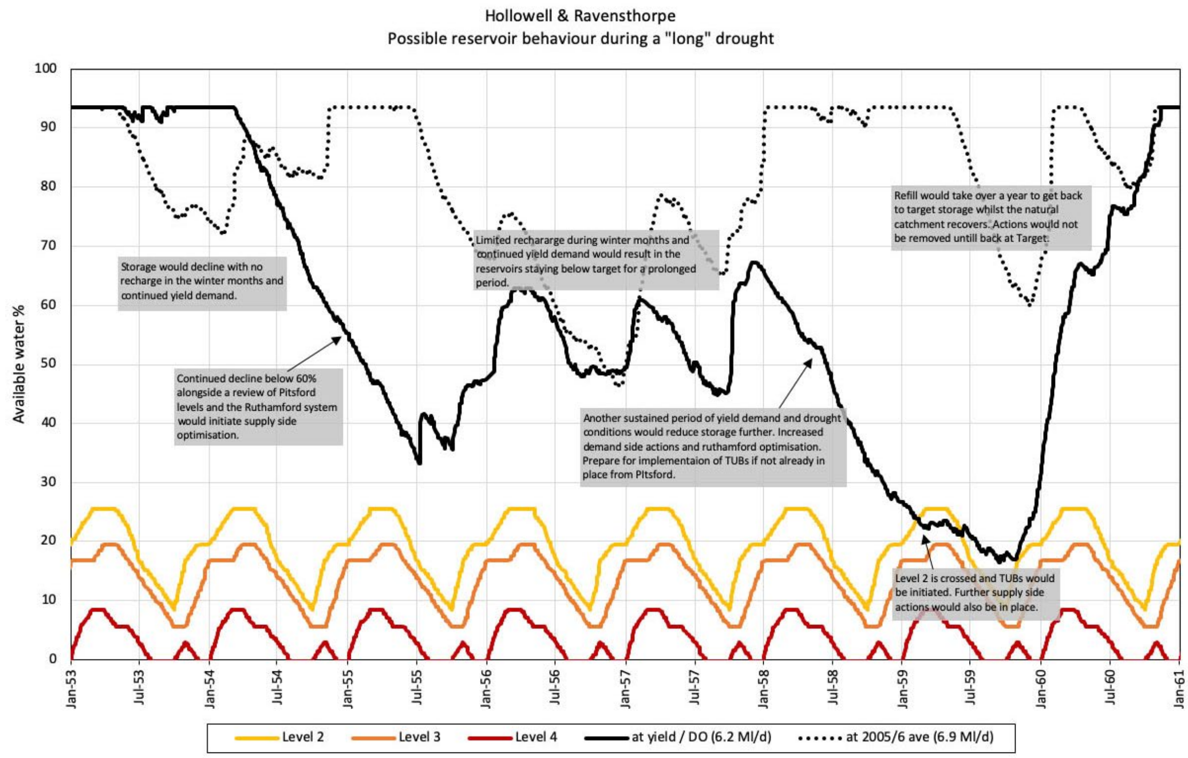


Figure 5.21: Hollowell & Ravensthorpe possible reservoir behaviour during a “long” drought



Cover photo - Anglian Water's Rutland Water reservoir, a 1,555-hectare biological Site of Special Scientific Interest (SSSI), east of Oakham in Rutland. It was designated a SSSI in 1984.