Water Supply – Deployable Output and Climate Change Impact Assessment Report

SES Water's draft Water Resource Management Plan 2019

SES Water

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Executive summary

SES Water operates thirty-two groundwater sources that take water directly from the local Chalk and Lower Greensand aquifers via boreholes and wells; groundwater is also captured as it emerges from the Chalk aquifer via springs in the Fetcham area. There is also a surface water abstraction on the River Eden, a little to the east of the supply area, which feeds into the Bough Beech reservoir.

As part of their draft 2019 Water Resources Management Plan (dWRMP19) submission, SES Water is required to calculate the total amount of water it can reliably supply to customers over the course of a 'design drought', expressed as an average daily rate of supply in the drought year. It may also draw attention to the amount it can supply during specific parts of the design drought, known as 'critical periods'. In the SES Water supply area the key critical period is during the summer, when the customer demand for water is significantly higher than during other parts of the year.

AECOM has undertaken the supply calculations described above on behalf of SES Water. These calculations are referred to as a Deployable Output (DO) assessment; the reliable supply available during the period of peak strain i.e. when demand is highest, is known as Peak DO (PDO), while the reliable supply available during the period of lowest resource availability is known as Minimum DO (MDO). Both PDO and MDO are presented in the units of 'millions of litres per day' (or 'Ml/d').

In order to reassess the SES Water DO, a review of constraints information has been undertaken. Lumped parameter models have been developed for key observation boreholes using historic climate data and catchment parameters, in order to predict groundwater levels during the worst drought on historic record. Using existing scaling factors, these modelled groundwater levels were then used to provide an approximation of the water level condition at each groundwater source during this drought event. The operational drought curve for each groundwater source was "curve shifted" to this water level condition and the critical constraints were examined, thereby providing an estimate of DO for this event.

An existing rainfall-runoff model (CatchMOD) for the River Eden has been refined using historic climate data in order to predict river flows during this event. The modelled river flows were used to provide an approximation of the water available for abstraction from the River Eden during this drought event, and to provide an estimate of DO.

The Environment Agency has requested that water companies test a 'reference' drought within the WRMP that might occur once every 200 years (i.e. a severe drought) in addition to the 'design drought' selected by the water company. The lumped parameters models and rainfall-runoff model were extended to include stochastically generated climate data in order to predict the groundwater levels/ river flows and reliable supplies that might be available in plausible droughts that are more severe than those experienced in the past (i.e. more severe than those experienced in the 1970s and 1990s).

The baseline DO values that are recommended for the Economics of Balancing Supply and Demand (ESBD) modelling within the dWRMP19 are as follows:

Drought event	PDO (Ml/d)	MDO (Ml/d)
Worst drought on historic record	300.7	215.7
1:200 year event	287.0	206.5

The worst drought on historic record is estimated to represent a severe two dry winter scenario with a return period of about 1 in 100 years with respect to reservoir storage and 1 in 35 year with respect to groundwater level. However, given the overall sensitivity of surface water to drought it is likely that the combined DO is more representative of a 1 in 100 year condition than a 1 in 35 year. The 1 in 200 year event represents a plausible three dry winter scenario that is more severe than previous droughts in the 98 year long historic record.

Water companies are also required to account for the impacts of climate change on DO. To that end, climate change factors have been generated by HR Wallingford using the Future Flows climate scenarios. These factors were then used to perturb the historic climate record for the worst drought on historic record and the stochastic climate record for the 1:200 year drought event for input into the lumped parameter models and rainfall-runoff model. From the resulting groundwater level and river flows series, a central estimate or average scenario was selected, providing groundwater levels and river flows from which to provide an estimate of DO for these events with climate change.

The DO values with climate change that are recommended for ESBD modelling are as follows:

Drought event	PDO (Ml/d)	MDO (Ml/d)
Worst drought on historic record	290.6	207.3
1:200 year event	287.7	209.8

1. Introduction

1.1 The SES Water resource zone

The SES Water resource zone includes parts of East Surrey, West Sussex, west Kent and south London and within it the company operates 32 groundwater sources, the Fetcham springs source and the Bough Beech (River Eden) surface water source (Figure 1). Bough Beech reservoir is SESW's only surface water resource, fed by an abstraction from the River Eden that operates during the winter. The reservoir supplies approximately 15% of the company, with various groundwater sources supplying the remaining 85%. Further details are provided in Table 1-1.

Table 1-1 SES Water sources

Source Name	Source Type	Licence	Licence type/ name	Source Name
Leatherhead	Groundwater	28/39/32/32	Group Licence	Mole Valley Chalk
Elmer & Young Street				
Fetcham Boreholes		28/39/32/31	Fetcham Group Licence	
Fetcham Springs		28/39/32/30		
Dorking		28/39/32/33		Lower Greensand
Buckland		28/39/32/29	Group Licence	
Clifton's Lane				
Warwick Wold		28/39/32/28	Group Licence	
Brewer Street				
Bletchingley		9/40/3/62GR	Godstone Group Licence	
North Park				
Godstone				
Flower Lane				
South Green		9/40/3/61GR	Westwood Group Licence	
Water Lane				
Westwood		9/40/1/35GR		
Kenley		28/39/41/37	Kenley/ Purley Group Licence	North Downs Chalk
Purley				
Woodmansterne		28/39/41/68	Woodmansterne Group Licence	
Holly Lane				
Chipstead				
Smitham		28/39/41/36		
Oaks		28/39/41/69	Oaks/ Woodcote Group Licence	
Woodcote				
Hackbridge & Goatbridge		TH/039/0041/014	Hackbridge Group Licence	
Nonsuch		28/39/40/08	Cheam Group Licence	
Cheam				
Cheam Park				
Springclose Lane				
Secombe Centre				
Sutton				
Sutton Court Road				
Langley Park				
Bough Beech River	Surface water	9/40/3/386/S	Bough Beech Licence	River Eden

Source Name	Source Type	Licence	Licence type/ name	Source Name
Bough Beech Reservoir				Reservoir

1.2 Background

SES Water is required to calculate deployable output (DO) values every five years as part of its WRMP submission. DO is defined by UKWIR's *Handbook of source yield methodologies* (2014) as:

> ***"the output of a commissioned source or group of sources or of bulk supply as constrained licence (if applicable), pumping plant and/or well/aquifer properties, raw water mains and/or aqueducts, transfer and/or output main, treatment and water quality, for specified conditions and appropriate demand profiles to capture variations in demand over the year".***

Previous assessments of DO were undertaken in 2013, 2008, 2002 and 1996. Details of these assessments are as follows:

- The 2013 assessment presented individual source DO values for the 1 in 50 year drought event, a return period suggested to be appropriate for water resources investigations by the UKWIR *Critical Period Groundwater Yield* publication (UKWIR, 2001). The assessment included a review of changes in DO resulting from licence updates and assessed the impact of droughts since 1920 on DO as required by the Environment Agency's *Water Resource Planning Guideline* (October 2012) (Atkins, 2013a). It did not include DO values for the worst drought on historic record, a review of infrastructural constraints or a Levels of Service (LoS) analysis. The Bough Beech surface water source was considered in isolation to groundwater sources.
- The 2008 assessment also presented DO values for the 1 in 50 year drought event, but considered the impact of the worst drought on record by applying calculated reductions to the overall DO values. The assessment also included a review of constraints on individual source DO values and included operational data for up to and including the drought experience within the SES Water area in 2006 (Atkins, 2008). It did not include a LoS analysis and considered the Bough Beech surface water source in isolation to groundwater sources.
- Additionally SES Water undertook some work in November 2015, in conjunction with the Water Resources in the South East (WRSE) Group, to estimate DO values under extreme drought conditions, i.e. 1 in 100 year and 1 in 200 year drought events. This was done by curve shifting the operational drought curve for each source through the application of scaling factors and based on the analysis of critical period observation borehole records.

1.3 The current report

AECOM has been commissioned to undertake the reassessment of SES Water's DO for the dWRMP19 submission. This study draws on the work previously done during WRMP14 but has also further developed the assessment in order to adhere to the current guidance. Additionally recommendations have been made for work on developing a Water Resource Zone (WRZ) model for the next WRMP.

This reassessment has been completed taking account of the following guidance:

- Environment Agency, June 2016. *Estimating impacts of climate change on water supply*;
- Environment Agency, April 2017. *Water Resources Planning Guideline: Interim update* (WRPG);
- Environment Agency, June 2016. *Drought Plan and WRMP Links*;
- Environment Agency, 2013. *Climate change approaches in water resources planning – overview of new methods*;
- UKWIR, 2000. *Unified Methodology for the Determination of Deployable Output*;
- UKWIR, 2016. *WRMP 2019 Methods – risk based planning*;
- UKWIR, 2016. *WRMP 2019 Methods - decision making process guidance*;
- UKWIR, 2014. *Handbook of source yield methodologies*;
- UKWIR, 2012. *WR27 DO report*; and
- UKWIR, 2000. *Unified Methodology for the Determination of Deployable Output*.

This report outlines the procedures followed for the reassessment of DO for dWRMP19 and summarises the results from each step in the process. Chapter 2 outlines the groundwater source DO assessment work; Chapter 3 outlines the work done using CatchMOD and Aquator to estimate DO values for the Bough Beech surface water source; and Chapter 4 outlines the work done to account for the impact of climate change on DO.

1.4 Planning scenarios and DO assessment

1.4.1 Selection of design droughts

The Environment Agency's WRPG (April 2017) indicates that the data in the WRMP should be based on the 'dry year annual average' (for demand) and a 'design drought' (for supply). The guidance indicates that the design drought can be the worst on record, or a more challenging but plausible drought.

The current deployable output assessment explores the worst drought on historic record and the 1 in 200 year drought event. The impact of this severe (but plausible) drought is examined through the consideration of 15,600 years of stochastic climate data.

1.4.2 Planning scenarios

The Environment Agency's WRPG (April 2017) also indicates that the water company may choose to explain how it will deal with a period of peak strain, known as the 'critical period' scenario. SES Water's WRMP14 demonstrated that it has a critical period associated with peak summer demand. For this reason a critical period (peak summer demand) scenario is addressed within the current deployable output assessment, in addition to the dry year annual average scenario.

The links between planning scenarios and DO are as follows:

- The Environment Agency's WRPG (April 2017) states that water companies *"may also choose to explain how you will deal with a period of peak strain known as the critical period".* The assessment of PDO is associated with the 'dry year critical period' (DYCP) planning scenario and also the design drought, where the resource zone supply-demand balance is sensitive to peak demand. The UKWIR *Handbook of Source Yield Methodologies* (2014) defines PDO as the "*deployable output for the period in which there is highest demand"*.
- The assessment of Average demand Deployable Output (ADO) is linked to the dry year annual average scenario. The UKWIR WR27 DO report (2012) defines the ADO as *"the deployable output of a source for the average annual period"* and goes on to state that *"the average demand is literally the average over the year computed as average over a normal year or average over a dry year"*. ADO is typically assessed within a WRZ model that includes demand profiles. At a project start-up meeting in December 2016, the Agency were satisfied for dWRMP19 to provide pointers towards a more sophisticated approach for WRMP24, with use of a WRZ model that includes all surface water and groundwater sources. A recommendation has been made for work to develop a WRZ model and to undertake a LoS analysis towards the next WRMP.
- The assessment of Minimum Deployable Output (MDO) is linked to the critical period (minimum groundwater level and river flow) scenario. Under the UKWIR unified methodology guidance published in 2000, groundwater source 'ADO' assessments (improved methodology) were based on monthly operational data for those months when groundwater levels were at or near their annual minima for the worst drought to have affected the area of the source. However, the use of data associated with minimum groundwater levels means that the assessments now fall under the category of MDO. The UKWIR *Handbook of Source Yield Methodologies* (2014) defines MDO as the *"DO for the period in which groundwater levels are at their lowest, usually late autumn".* In the absence of a WRZ model with which to assess ADO, the assessment of MDO for this study is used as a proxy for the 'dry year annual average' (DYAA) planning scenario, as per previous assessments.

1.5 Acknowledgement

Members of staff at SES Water and the Environment Agency have assisted with the provision of data and the investigation of queries on various source issues. They have been mentioned where appropriate in the assessment audit trails. The Consultant gratefully acknowledges this assistance.

2. Groundwater source deployable output assessment

2.1 Introduction

The key purpose of undertaking individual groundwater source DO assessments is to define how each source works, the critical constraints to DO, and to define the relationship between source water levels and groundwater levels at appropriate critical period observation boreholes for use in the curve shifting process. The process of source DO assessment also provides an opportunity to:

- Select appropriate 'critical period' records and gauging station records (i.e. good drought indicators);
- Identify and rank drought years using historic groundwater level and flow records;
- Refine the source constraints information;
- Review the source operational data; and
- Estimate individual source DO values for the worst drought on historic record (WDHR) and for the 1:200 year drought event.

2.2 Selection of drought indicator sites

Source operational data often does not contain non-pumping source water levels for periods of interest, i.e. drought years. No groundwater level telemetry or manual dip data, beyond a small amount of data collected in the late 1990's, was available to this study. The identification of a critical period observation borehole which best represents the source aquifer and supply area, and the generation of a relationship between this borehole and the source, allows for the non-pumping source water level to be estimated for these periods of interest.

For each source, the general shape of the drought curve is based on available operational data or the extrapolation of analytical data. The drought curve can then be "shifted" to a different starting point (the non-pumping water level) depending on the drought condition and water levels in the critical period observation borehole.

The locations of the SES Water public water supply sources are provided in Figures 1 and 2. The figures show that the sources are distributed across the 835 km^2 resource zone within different groundwater and surface water catchments and different aquifers. Subsequently, more than one critical period (drought) indicator was previously examined for the SES Water area. However there are few observation boreholes which have a long and continuous water level record, that are still being monitored and that do not dry out during certain droughts. Table 2-1 below lists the critical period boreholes used in this study.

Table 2-1 Critical period observation boreholes

EA Reference	Observation borehole name	Length of record	Aquifer resource unit	Comments
TQ25/013	Well House Inn	1942-2016	North Downs Chalk	Relatively unaffected by abstraction and does not dry out.
TQ55/1	Riverhead	1965-2016	Lower Greensand	Longest local record within the Lower Greensand but not within SES Water supply area.

The Well House Inn borehole is located up groundwater gradient of any major groundwater abstractions and therefore groundwater levels here are considered to be reasonably representative of natural recharge to the Chalk aquifer. The Riverhead borehole is located in close proximity to two major groundwater abstractions and the Darent River; therefore groundwater levels here are considered to be influenced by abstraction within the Folkestone Formation (Figure 1).

2.3 Lumped parameter models

A lumped parameter model is a rainfall-recharge model which can be used to generate series of groundwater levels at a given location using climate data and catchment parameters. The model can be calibrated to an observed groundwater level record and then used to extend the groundwater level series or to predict groundwater levels using different rainfall and potential evapotranspiration (PET) inputs.

2.3.1 Well House Inn

A lumped parameter model was developed for the Well House Inn borehole. This contains rainfall and PET for the South London area, as provided by the Environment Agency. This model was used to calibrate the historic observed groundwater level to the period of complete rainfall and PET record, 1998 to 2016, and to identify the lowest annual minima groundwater level in the historic record (Figure 2).

Following calibration, the model was used to run 15,600 years' (200 series of 78 years') worth of stochastically generated rainfall and PET data for the South London area, as provided by WRSE. This model was then used to estimate the annual minima groundwater levels at the Well House Inn borehole for return periods longer than the historic observed groundwater level record and with greater certainty.

2.3.2 Riverhead

Additionally a lumped parameter model was developed for the Riverhead borehole. This contains rainfall and PET for the South London area, as provided by the Environment Agency. This model was used to calibrate the historic observed groundwater level to the period of complete rainfall and PET record, 1998 to 2016, and to identify the annual minima groundwater level in the historic record (Figure 3).

Following calibration, the model was used to run 15,600 years' (200 series of 78 years') worth of stochastically generated rainfall and PET data for the South London area, as provided by WRSE. This model was then used to estimate the annual minima groundwater levels at the Riverhead borehole for return periods longer than the historic observed groundwater level record and with greater certainty.

For a summary of rainfall and PET inputs to these lumped parameter models, see Appendix A.

2.3.3 Limitations

The lumped parameter models were developed to provide a simple approach to the estimation of groundwater levels at the Well House Inn and Riverhead boreholes during key drought events. The limitations of the lumped parameter models are as follows:

- The models are calibrated to a short time period, 1998 to 2016. This is due to the length of PET record available;
- The models are therefore calibrated to the limited range in groundwater levels within this short time period; and
- The groundwater levels generated within models can only provide an approximation of available aquifer resources.

2.4 Ranking of drought years

The observed groundwater level record for both the Well House Inn and Riverhead observation boreholes was used to identify the lowest annual minima groundwater levels on historic record. The historic observed groundwater level record is considered the most appropriate metric with which to identify the worst drought on historic record, as this is a representation of how the aquifer and therefore resources respond to climate.

The two lowest annual minima groundwater levels in the complete historic record for Well House Inn occur in 1944 and 1950; however the recession shape of the observed groundwater level suggests that the Well House Inn is being influenced by abstraction during this period. The exclusion of 1944 data has been supported by the Agency. The next lowest annual minima groundwater level occurs in both 2006 and 2012. On examination of the hydrograph of Well House Inn for 2012, it is apparent that there is an unusual pattern of recharge across the year. The pattern of recharge for 2006 appears to be more typical; therefore this year has been selected as the worst on historic record.

The six lowest annual minima groundwater levels in the complete historic record for Riverhead borehole occur within the 1990s; however the observed groundwater level record suggests that the Riverhead borehole is being influenced by abstraction throughout this period. The next lowest annual minima groundwater level occurs in 2006, corresponding with the worst on historic record at the Well House Inn.

Therefore 2006 is the lowest ranking year in terms of annual minima groundwater levels at both the Well House Inn and Riverhead observation boreholes that is useful to this study.

2.5 Frequency analysis

The purpose of the hydrological frequency analysis undertaken was to provide a ranking of severe droughts. This analysis was undertaken on the stochastically generated groundwater level data to provide both a statistical return period for the selected historic groundwater levels, i.e. the annual minima groundwater levels for 2006, and modelled groundwater levels for the 1:200 year event.

The results of the hydrological frequency analysis are shown in Table 2-2 below. The Well House Inn borehole monitors the Chalk and has a very different response to rainfall compared to the Riverhead Lower Greensand borehole; this is a key reason why the return periods are so different.

Table 2-2 Severe droughts (observed groundwater level data)

Critical period observation station	Location relative to SES Water WRZ	Worst drought on historic (observed) record	Approximate return period of most severe drought (based on annual minima)
Well House Inn	Within the old Sutton WRZ	2006	1 in 35 year
Riverhead	East	2006	1 in 175 year

The return periods should be treated with caution as the frequency analysis is sensitive to the period of record and the fit of the normal distribution. This is particularly the case for the Riverhead borehole, where the lumped parameter model is calibrated to a short period only due to the apparent influence of abstraction on groundwater levels prior to 1998. The frequency analysis suggests that the WDHR (2006) represents around a 1 in 35 year drought at the Well House Inn borehole and around a 1 in 175 year drought at the Riverhead borehole (Figures 4 and 5 respectively).

2.6 Drought condition groundwater levels

Table 2-3 below summarises the annual minima groundwater levels and peak week groundwater levels at Well House Inn and Riverhead for the WDHR and for the 1:200 year event (severe drought).

Within the SES Water area, the dry year peak in demand appears to occur in July more often that other summer months; therefore this has been selected as the peak month and peak week groundwater levels have been selected from late July.

Table 2-3 Drought period groundwater levels at critical period boreholes

		Well House Inn		Riverhead	
Return period	**Source**	**Annual minima groundwater level (maOD)**	**Peak groundwater level (maOD)**	**Annual minima groundwater level (maOD)**	**Peak groundwater level (maOD)**
Worst drought on historic record	Observed levels	**86.66** (15 Mar. 2006)	**88.34** (23 Jul. 2006)	**74.54** (19 Sep. 2006)	**74.70** (17 Jul. 2006)
	Modelled levels	**86.81** (15 Feb. 2006)	**88.84** (23 Jul. 2006)	**74.69** (1 Oct. 2006)	**75.05** (17 Jul. 2006)
1 in 200 year event	Modelled levels	**85.46** (Stochastic scenario 194, year 71)	**86.47** (Stochastic scenario 109, year 12)	**74.62** (Stochastic scenario 159, year 11)	**75.12** (Stochastic scenario 46, year 39)

2.6.1 MDO drought condition groundwater levels

For the calculation of MDO at sources associated with the Well House Inn observation borehole, the annual minima groundwater level for the WDHR event, i.e. 2006, was selected from actual water level data within the historic lumped parameter model. For the 1:200 year event, a frequency analysis was undertaken on the annual minima for 15,600 years of modelled groundwater level data generated using stochastic climate data within the lumped parameter model. This identified the annual minima for a 1:200 year event.

As the lumped parameter model for the Riverhead borehole is calibrated to a short period only, the observed annual minima groundwater level for the WDHR is lower than the modelled annual minima for the 1:200 year event. Therefore the annual minima groundwater level for the WDHR has been selected from lumped parameter modelled data rather than observed.

2.6.2 PDO drought condition groundwater levels

For the calculation of PDO at all sources, the peak week groundwater levels for the WDHR were selected from actual water level data within the historic lumped parameter model. Within the SES Water area, the dry year peak in demand appears to occur in July more often that other summer months; therefore this has been selected as the peak month and peak week groundwater levels have been selected from late July. For the 1:200 year event, a frequency analysis was undertaken on the mean monthly values for 15,600 years of modelled groundwater level data generated using stochastic climate data within the lumped parameter model. This identified the mean monthly value for July for a 1:200 year event.

2.7 Scaling factors

The existing DO assessment diagrams for SES Water groundwater sources typically contain test data and some operational data dating from the 1990's. No additional operational data is available to this study; therefore there is no source operational data for the worst drought year on record.

Therefore in order to estimate the DO values for the worst drought year on record and for the 1 in 200 year event, curve shifting of the operational drought curve to the minima water level condition in 2006 has been undertaken. The degree of shift in rest water level is calculated from analysis of the Well House Inn and Riverhead critical period records and the application of scaling factors to describe the relationship between water level fluctuations at the appropriate critical period observation borehole and those at the source borehole (see Table 2-4). These scaling factors were defined in WRMP14 and described in the report, *Review of Groundwater Source Deployable Outputs for 2014*, and are considered appropriate to use for this study. The methodology is described below:

> ***'Comparing either a hydrograph of rest water levels of the source being analysed or the hydrograph of a nearby observation borehole with the hydrograph of the signature observation borehole for the ARU (Aquifer Resource Unit). Where a good correlation exists between the groundwater level fluctuation recorded at the signature observation borehole and non-pumping water levels at a particular source, the linear regression equation has been used to directly calculate a 1 in 50 year return period annual minimum no-pumping water level for the source.***
>
> ***Where there are insufficient recorded non-pumping water levels for the source or where there is not as good a correlation between signature borehole water levels and source non-pumping water levels, the 1 in 50 year non-pumping water level for the source has been estimated by scaling the response observed at the signature borehole using a local observation borehole. This scaling operation comprises a simple comparison of the mean annual water level fluctuation of the nearest appropriate observation borehole to a source with the mean annual fluctuation of the signature borehole for the ARU' (Atkins, 2013a).***

The inputs to this process are as follows:

- A source rest water level and date - taken from the existing source DO assessment diagrams;
- A critical period borehole groundwater level for the same date – taken from the observed groundwater level record;

- A critical period borehole groundwater level under average and peak conditions for the WDHR event and the 1:200 year event - taken from the Well House Inn and Riverhead lumped parameter models and summarised in Table 2-3;
- Scaling factors as defined in the *Review of Groundwater Source Deployable Outputs for 2014* and summarised in Table 2-4 below.

Table 2-4 Scaling factors (taken from WRMP14)

Source name	Scaling factor
Cheam Cheam Park Springclose Lane Nonsuch	0.627
Langley Park Secombe Centre Sutton Sutton Court Road	0.48
Chipstead	1.6879*(Well House Inn GWL)-71.0941
Holly Lane Woodmansterne	1
Hackbridge & Goatbridge	0.28
Oaks Woodcote	0.4
Kenley	1.6879*(Well House Inn GWL)-71.0941
Purley	0.5
Smitham Fetcham Boreholes Elmer & Young Street Leatherhead Dorking Clifton's Lane Warwick Wold Brewer Street Bletchingley North Park Godstone Flower Lane	1
Fetcham Springs	n/a
Buckland	0.57
Water Lane South Green Westwood	1.071

The output of this process is a set of non-pumping water levels for each source under the WDHR and the 1:200 year event conditions. The drought curve for each source can then be shifted to this different starting point depending on the drought condition and the DO can be read from where the shifted drought curves meet the critical source constraint, i.e. licence, pump capacity, pump cut-out or Deepest Advisable Pumping Water Level (DAPWL). These constraints are further described in Section 2.9.

2.8 Calculation of peak demand deployable output

Source assessment diagrams have been used to estimate the DO that can be obtained during the worst drought year on record during the peak demand period. For the peak demand condition, the improved UKWIR method requires that data for the resource zone peak week and two weeks either side should be considered for the worst drought year experienced by the source. However in order to delineate a drought curve, the existing diagrams refer to peak periods for several drought years and where there is limited data, to all the available data. The existing diagrams also contain output data which has been plotted as means of the preceding 7 days and the water levels represent the lowest water level measurement during those 7 days.

2.9 Calculation of minimum resource deployable output

Source assessment diagrams have been used to estimate the DO that can be obtained during the worst drought year on record when water levels are at their lowest (MDO). Where there is sufficient reliable data the minimum recorded rest and pumping water levels during the month of lowest groundwater levels in drought years, as identified from the ARU observation borehole, are plotted against the corresponding mean monthly output. Where there is a lack of reliable data minimum rest and pumping water levels have been included for any dry months during drought years if available. If these are not available, all available water level data has been plotted against the mean monthly output for the corresponding month in which the water level were recorded.

2.10 Source constraints

2.10.1 Licence constraints

For SES Water's groundwater sources, the individual source daily licence quantity has been used to constrain the source PDO, while the individual source average annual licence quantity has been used to constrain the source MDO.

The groundwater sources are subject to a number of group licences. These are not incorporated within the source DO assessment, but applied to the resource zone DO assessment. Where the sum of individual site DO's in a group is greater than the total group licence, the licence has been apportioned. It should be noted that although the individual site DO's may change depending on how the licence is apportioned, the DO of the overall group will not change. Group licence details are as follows:

- Leatherhead, Young St. & Elmer are together licensed to abstract 42.17 Ml/d at the annual average rate and 57.96 Ml/d at the peak rate;
- Buckland, Clears and Clifton's Lane are together licensed to abstract 2.27 Ml/d at the annual average rate and 4.55 Ml/d at the peak rate;
- Warwick Wold and Brewer Street are together licensed to abstract 6.85 Ml/d at the annual average rate and 7.27 Ml/d at the peak rate;
- Kenley and Purley are together licensed to abstract 22.79 Ml/d at the annual average rate and 44.39 Ml/d at the peak rate;
- Fetcham Group (Fetcham borehole and Fetcham Springs) has an annual average and peak license rate of 13.64 Ml/d;
- The Woodmansterne Group (Woodmansterne, Holly Lane, Chipstead, Smitham) has an annual average licence rate of 29.455 Ml/d.
- Oaks and Woodcote are together licensed to abstract 9.1 Ml/d at the annual average rate. There is no group peak rate however Oaks has a peak license rate of 13.64 Ml/d and Woodcote has a peak license rate of 6 Ml/d.
- Hackbridge Group (Hackbridge and Goatbridge boreholes) has an annual average licence rate of 10.74 Ml/d and a peak licence rate of 19 Ml/d. The peak is also constrained by a condition which limits abstraction over a 30 day period to no more than 150 Ml, i.e. average of 5 Ml/d at Goatbridge and 240 Ml, i.e. average of 8 Ml/d at Hackbridge. There is an additional condition whereby no more than 84Ml can be abstracted in 7 consecutive days i.e. average of 12 Ml/d.
- The Cheam Group licence (Nonsuch, Cheam, Cheam Park, Springclose Lane, Secombe Centre, Sutton, Sutton Court Road and Langley Park) has an annual average and peak licence rate of 32.96 Ml/d. The peak at Nonsuch is constrained by a condition whereby no more than 510Ml can be abstracted in 60 consecutive days (i.e. 8.5 Ml/d). Additionally, Cheam, Cheam Park and Springclose Lane are together licensed to abstract 18.81 Ml/d at the annual average and peak rate, and Sutton and Sutton Court Road are together licensed to abstract 22.73 Ml/d at the annual average and peak rate;

- Godstone Group license (Bletchingley, North Park, Godstone, Flower Lane and Duckpit Wood) has an annual average license rate of 7.98 Ml/d.
- Westwood Group license (South Green, Water Lane and Westwood) has an annual average license rate of 6.85 Ml/d with no group peak license rate. The individual sites do however have peak license rates of 2.18 Ml/d, 5.98 Ml/d and 5.61 Ml/d respectively. It should be noted that this Group comprises of two licenses, one for Westwood and one for South Green and Water Lane, which are run in conjunction with each other.

2.10.2 Environmental constraints

There are two environmental conditions incorporated within the abstraction licences which are as follows:

- A minimum flow of 0.5 Ml/d is required at Bourne Hall ponds before abstraction can take place at Nonsuch, Holly Lane and Chipstead. It should be noted that flows are augmented from other sources therefore it is not necessary to provide equivalent output constraint at these sites; and
- A minimum flow of 4.55 Ml/d is required at Carshalton Ponds before abstraction can take place at any Cheam Group boreholes, Hackbridge Group boreholes, Oaks, Woodcote, Holly Lane and Chipstead boreholes. It should be noted that flows are augmented from other sources therefore it is not necessary to provide equivalent output constraint at these sites.

2.10.3 Source works constraints

For each of the groundwater sources, updated pump capacities and pump cut-out levels were provided by SES water and appropriate changes were made where these differed from the 2014 DO assessment diagrams. Pump capacity is shown as a vertical line on the source DO diagrams while pump depth and pump cut-out levels are shown as horizontal lines. Pump cut-out levels are currently estimated to be 2 m above the pump depth unless an alternative cut-out level has been provided. A sensitivity analysis was undertaken on this assumed level for those sources where this is the critical constraint – Sutton Court Road, Brewer Street and Bletchingley. Reducing or increasing these cut-out levels by 0.5m would only result in an up to 0.2% combined increase or decrease in overall WRZ DO values.

2.10.4 Water quality constraints

Updated information on treatment works constraints was provided by SES Water. The treatment works capacity has not been apportioned between individual sources where there are multiple sources of supply, instead the total treatment works capacity has been used.

The 2014 DO assessment noted that the Buckland source is constrained by ammonia break through and the Secombe Centre source is not operational due to raw water bacterial issues. These constraints are still applicable as treatment for these water quality issues have not been introduced.

2.10.5 Water level constraints

For each of the groundwater sources, a Deepest Advisable Pumping Water Level (DAPWL) was defined in the *Review of Groundwater Source Deployable Outputs for 2014*, and are considered appropriate to use for this study. The methodology is described below:

"Where possible, the Deepest Advisable Pumping Water Level (DAPWL) has been defined on the basis of critical flow horizons. However, these are often not well known. Although fissure locations may be known, the relative contributions from fissures at different levels are often not. Therefore, in many cases it has been necessary to set the DAPWL according to a 'reasonable' operational level above the base of the well. In accordance with the original assessment methodology (UKWIR, 1995) the criteria used are:

- ***for an intergranular, uniform aquifer, allow 70% of the drought saturated aquifer penetrated by the well to be dewatered;***
- ***for a fissured or non-uniform aquifer, or one whose character is not known, allow 50% of the drought saturated aquifer penetrated by the well to be dewatered.***

Therefore, in the absence of specific knowledge of the major flow horizons in Chalk boreholes, a DAPWL given by 50% of the drought saturated aquifer penetrated by the well has been used. Where the known operational usage of a borehole conflicts with the calculated DAPWL, a DAPWL conforming to the operational data has been used. In some instances, a DAPWL given by 70% dewatering conforms to the operational data.

For confined Lower Greensand sources, the DAPWL has generally been taken as the base of the confining layer, usually the Gault Clay, as pumping below this level could potentially result in water quality problems by the introduction of air into the aquifer. Where the aquifer is unconfined, and specific flow horizons are not known, the DAPWL has been taken as 50% of the drought saturated aquifer penetrated by the well, in order to be conservative, as the aquifer may contain fissures or less permeable horizons. However, in some unconfined Lower Greensand sources, normal operational pumped water levels are below this elevation, in which case, 70% dewatering has been used" (Atkins, 2013a).

For each of the groundwater sources, the DAPWLs used in the 2014 DO assessment were verified using borehole data and reports provided by SES Water and adjustments were made where necessary.

DAPWLs are used to calculate the potential yield of the groundwater sources. The potential yield is the hydrological yield of the source adjusted for all constraints other than those related to licence, demands and levels of service. The potential yield of a source is reached when groundwater levels are drawn down to a DAPWL. The results of this work have been incorporated into the DO assessments (see Appendix B).

2.10.6 Critical constraints

The critical source constraint is that which limits source DO. Details of the current and previous (2014) critical constraint type for each of the thirty three (no. 33) SES Water groundwater sources are provided in Table 2-5. The key changes in critical source constraints since the 2014 study are listed below:

- Updated information at the Sutton Court Road, Bletchingley and Brewer Street sources indicates that the pump low level cut-out is higher than previously thought. For Sutton Court Road, this has resulted in a reduction in PDO and MDO; for Bletchingley, this resulted in a reduction in MDO only; and for Brewer Street, this has resulted in a reduction in PDO and MDO.
- Updated information at the Cheam source indicates that the operational pump capacity at minimum water levels is the critical constraint on PDO, rather than the DAPWL. This has not resulted in a change in PDO; rather the plotting of the drought curve for the worst drought on historic record has led to an increase in PDO.
- Updated information at Purley indicates that the pump low level cut-out is lower than previously thought. This has resulted in a significant increase in the PDO.
- Updated information at Fetcham Boreholes indicates that the installation of new pumps has increased pumping capacity. This has resulted in an increase in MDO.

Table 2-5 DO critical constraint type

Groundwater source	WRMP14 MDO critical constraint	dWRMP19 MDO critical constraint	WRMP14 PDO critical constraint	dWRMP19 PDO critical constraint
Cheam	DAPWL	DAPWL	DAPWL	Pump capacity
Cheam Park	DAPWL	DAPWL	DAPWL	DAPWL
Springclose Lane	Pump capacity	Pump capacity	Pump capacity	Pump capacity
Langley Park	Pump capacity	Pump capacity	Pump capacity	Pump capacity
Nonsuch Park	Licence	Licence	Licence	Licence
Sutton	Pump cut-out	DAPWL	Pump cut-out	DAPWL
Sutton Ct Rd	Pump cut-out	Pump cut-out	Pump capacity	Pump cut-out
Chipstead	Pump capacity	Pump capacity	Pump capacity	Pump capacity

Groundwater source	WRMP14 MDO critical constraint	dWRMP19 MDO critical constraint	WRMP14 PDO critical constraint	dWRMP19 PDO critical constraint
Holly Lane	Licence	Pump capacity	Pump capacity	Pump capacity
Woodmansterne	DAPWL	DAPWL	DAPWL	DAPWL
Smitham	Licence	Licence	Licence	Licence
Hackbridge & Goatbridge	Licence	Licence	Licence	Licence
Oaks	Licence	DAPWL	DAPWL	Pump capacity
Woodcote	Pump capacity	Pump capacity	Pump capacity	Pump capacity
Kenley	Licence	Pump capacity	Pump capacity	Pump capacity
Purley	Licence	Pump capacity	Pump cut-off	Pump capacity
Fetcham Boreholes	Pump capacity	DAPWL	Pump capacity	Pump capacity
Elmer & Young St	Licence	Licence	Licence	Licence
Leatherhead	Licence	Licence	Licence	Pump capacity
Dorking	Licence	Licence	Licence	Licence
Buckland	Water quality	Water quality	Water quality	Water quality
Clifton's Lane	DAPWL	DAPWL	DAPWL	DAPWL
Warwick Wold	DAPWL	DAPWL	DAPWL	DAPWL
Brewer Street	Pump capacity	Pump cut-off	Pump capacity	Pump cut-off
Bletchingley	Licence	Pump cut-off	Licence	Licence
North Park	Licence	Licence	Pump capacity	Licence
Godstone	Licence	Licence	Licence	Licence
Flower Lane	Licence	DAPWL	Pump cut-off	DAPWL
Water Lane	Pump cut-off	Pump capacity	Pump cut-off	Pump capacity
South Green	Licence	Licence	Licence	Licence
Westwood	DAPWL	DAPWL	DAPWL	DAPWL

2.11 Fetcham Springs

The source DO assessment for Fetcham Springs relies on source output data, available for 1989 to 2016. This data suggests that the source output does not equate to the total spring flow, as previously considered in WRMP14 and that the source output is influenced by demand. For the WDHR, the PDO is taken as the mean total source output for the peak week of abstraction during 2006 and two weeks either side (13th May to 16th June), minus the 0.5Ml/d allowance for return to Fetcham Pond, as required by the licence. The MDO is taken as the average total source output from the minimum average monthly total in 2006 (September), minus the 0.5Ml/d allowance.

While abstraction data has been gathered at the Fetcham Springs source since at least 1989, there is minimal available total springflow data available with which to estimate source DO. SES Water carried out clearance pumping at the springs in 2005/2006 and gathered information on total springflow then, for inclusion within the assessment of DO for WRMP09. There is insufficient data to relate total spring flows to groundwater levels thereby making it impossible to quantify the DO in other drought years, or an appropriate adjustment for the 1 in 200 year event. As the estimation of DO at the Fetcham Springs is not related to climate data or to groundwater levels at a critical period borehole, but rather the source output which is influenced by demand, an assumption has been made that the PDO and MDO values will not change for the 1:200 year event.

2.12 Groundwater source DO assessment results

The source DO assessment calculates the PDO and MDO for the WDHR and for the 1:200 year drought events. The results are presented in Table 2-7. It is noted that the source DO values presented do not take into account the group licence constraints or combined groundwater / surface water resource availability.

2.12.1 Assumptions taken

The source-specific assumptions are detailed on the DO assessment forms, provided in Appendix B. The general assumptions taken as part of the current study are as follows:

- Curve shifting of the operational drought curve, through the application of scaling factors and based on the analysis of critical period observation borehole records for the Well House Inn and Riverhead, provides a useful approximation of the water level condition in the peak period of 2006;
- The operational drought curves previously defined are appropriate to use and provide a useful estimate of DO values;
- Booster pump capacities and the distribution network are adequate to allow abstractions to be redistributed around the resource zone; and
- The DO values for the Fetcham Springs will not change between the WDHR and the 1:200 year event.

2.13 Comparison with previous assessments

Figures 6 and 7 provide a graphical comparison of the 2013 and 2017 calculated source PDO and MDO values. These are not directly comparable as the 2013 values relate to the 1:50 year drought event, while the 2017 values related to the worst drought on historic record. However they do provide an overview of the significant changes to PDO and MDO. Table 2-6 also summarises the overall difference in PDO and MDO between assessments.

Table 2-6 Comparison of groundwater DO assessment results - WRMP14 and dWRMP19

AMP	Design drought	PDO (Ml/d)	MDO (Ml/d)
WRMP14	1 in 50 year event	237.9	186.7
dWRMP19	Worst drought on historic record	269.1	189.6
Difference (+/-)		**+31.1**	**+2.9**

The overall change to MDO equates to only 1.5% of total groundwater MDO. The most significant changes are to MDO values at Sutton, Sutton Court Road, Holly Lane, Kenley, Purley, Elmer & Young Street, Leatherhead and Bletchingley and are primarily due to improved critical constraints knowledge.

The overall change to PDO equates to 11.6% of total groundwater PDO. The most significant changes are to PDO values at Woodmansterne, Kenley, Purley, Fetcham Springs, Elmer & Young Street, Leatherhead and Westwood. A sensitivity analysis was undertaken on the DO assessments for these sources to assess the impact of reverting to using the 1 in 50 year drought condition groundwater level at Idsworth Well to derive DO values:

- There is no difference between the 1 in 50 year and the WDHR PDO values at Kenley, Purley, Elmer & Young Street and Leatherhead; this is because the critical constraint updates are the key driver for DO changes at these sources.
- The difference between the 1 in 50 year and the WDHR PDO values at Woodmansterne and Westwood equates to 4.7Ml/d, or 1.7% of the total groundwater PDO.
- There is no difference between the 1 in 50 year and the WDHR PDO values at Fetcham Springs; this is because the WRMP14 and dWRMP19 assessments used the same methodology to derive PDO at this source based on the mean total source output for May 2006 to June 2007.

2.14 Summary

The outputs of the individual source DO assessment are:

- A defined relationship between source water levels and groundwater levels at ARU and signature observation boreholes;
- Identified and ranked drought years for the water resource zone;
- Refined source constraints information; and
- An estimate of individual groundwater source DO values for the worst drought on historic record and the 1 in 200 year drought event.

Table 2-7 Groundwater source DO assessment results

Source name	WDHR MDO (Ml/d)	WDHR PDO (Ml/d)	1:200 year MDO (Ml/d)	1:200 year PDO (Ml/d)
Cheam	8.90	12.00	8.90	12.00
Cheam Park	1.19	1.30	1.16	1.27
Springclose Lane	2.00	2.00	2.00	2.00
Langley Park	1.90	1.90	1.90	1.90
Nonsuch Park	5.00	12.00	5.00	12.00
Sutton	9.50	17.20	9.20	15.00
Sutton Ct Rd	0.80	1.45	0.75	1.30
Chipstead	5.00	5.00	5.00	5.00
Holly Lane	6.13	6.50	6.13	6.50
Woodmansterne	15.00	16.50	14.50	15.80
Smitham	5.68	5.68	5.68	5.68
Hackbridge & Goatbridge	8.47	17.20	8.47	17.20
Oaks	4.50	9.92	4.50	9.92
Woodcote	4.60	4.60	4.60	4.60
Kenley	17.74	22.08	17.74	22.08
Purley	5.05	19.20	5.05	19.20
Fetcham Boreholes	0.94	0.98	0.92	0.95
Fetcham Springs	8.33	10.98	8.33	10.98
Elmer & Young St	17.09	20.46	17.09	20.46
Leatherhead	25.07	37.50	25.07	37.50
Dorking	11.82	11.82	11.82	11.82
Buckland	1.40	1.40	1.40	1.40
Clifton's Lane	0.87	1.30	0.87	1.30
Warwick Wold	3.25	3.90	3.25	3.90
Brewer Street	2.45	2.55	2.45	2.55
Bletchingley	2.05	3.50	2.05	3.50
North Park	3.50	4.46	3.50	4.46
Godstone	2.48	2.60	2.48	2.60
Flower Lane	2.00	3.37	2.00	3.37
Water Lane	2.00	2.00	2.00	2.00
South Green	2.18	2.18	2.18	2.18
Westwood	2.70	5.61	2.70	5.10
Total for groundwater sources	**189.6**	**269.1**	**188.7**	**265.5**

3. Bough Beech source deployable output assessment

3.1 Introduction

The key purpose of undertaking a source DO assessment for Bough Beech is to define how the source works, and what source constraints are critical to DO. The process of source DO assessment also provides an opportunity to:

- Refine the source constraints information;
- Review the source operational data; and
- Estimate individual source DO values for the worst drought on historic record (WDHR) and for the 1:200 year drought event.

3.2 River Eden abstraction

Currently SES Water operate one river abstraction, at Chiddingstone on the River Eden, which is used to fill Bough Beech Reservoir during autumn/ winter months only (September to April inclusive). The constraint on DO for the Bough Beech Reservoir is the availability of water from the river abstraction during drought years. This is applicable for the DYAA scenario. Generally DYCP scenario is not applicable to a surface water source with significant storage as any seasonal variation in demand is met from the available storage. However a PDO value can be derived by multiplying the DO for the DYAA scenario by the peak (July) monthly demand factor from the dry year seasonal demand profile (see Section 3.5.5).

3.3 River Eden rainfall-runoff model (CatchMOD)

The volume available for abstraction from the River Eden for SES Water's Bough Beech reservoir is constrained by the river flow. In order to model river flow for drought periods, a CatchMOD rainfall-runoff model for the River Eden at Chiddingstone is required. CatchMOD models have been developed for this location in 2007 and an updated version in 2013, for this purpose.

In order to model river flow for more recent drought periods, the WRMP14 model has been updated to include historic rainfall and PET data from 01/10/2005 to 31/01/2017. The simulated abstraction at Chiddingstone, which fills the Bough Beech reservoir, is taken account of within the Aquator model and it is assumed that any upstream influences are already taken account of in the flow here.

3.3.1 Historic rainfall data

The areal rainfall data referred to in WRMP14 was a collation of historic daily rainfall data from the Environment Agency, recorded at 4 rain gauges with long records. These records were used to hindcast rainfall back to 01/01/1888. Areal rainfall was then calculated for 6 rain gauges that geographically best represented the Eden catchment at Chiddingstone.

To overcome the issue of missing data in the record for the 6 rain gauges used in WRMP14, the Medway areal rainfall series was obtained from the Environment Agency and compared to the previous areal rainfall data. While there is some difference between the two time series, it is not considered to be significant. The Environment Agency's Medway areal time series was the more conservative of the two and resulted in a better modelled fit with the observed flow data at low flows.

Therefore the historic rainfall time series used in the CatchMOD model consists of the areal rainfall for the period 01/01/1888 to 30/09/2005, and the Environment Agency's Medway areal rainfall for the period 01/10/2005 to 31/01/2017.

3.3.2 Historic PET data

The PET data used for WRMP14 was a collation of the following:

- Pre-1918 PET data was calculated using monthly maximum temperature records for Southampton, provided by the Met Office, and total monthly PET from the Environment Agency's PENSE dataset; and
- Data from 1918 to 2005 was obtained from the Environment Agency's PENSE dataset.

In order to improve the hindcasting of areal PET from 01/01/1888 to 31/12/1917, PET data derived by HR Wallingford in 2010 for the Reliability of Southern Region Public Water Supplies Project has been used for dWRMP19.

Therefore the historic PET time series used in the CatchMOD model consists of areal PET data from the Reliability of Southern Region Public Water Supplies Project for the period 01/01/1888 to 30/09/2005, and the Environment Agency's Medway areal PET for the period 01/10/2005 to 31/01/2017.

3.3.3 Stochastic climate data

The extended CatchMOD model was calibrated to the historic climate data and compared to the WRMP14 model. Comparison of the outputs proved visually almost identical and was reflected in the overall and low flow goodness-of-fit functions presented in CatchMOD.

The model was then used to generate river flows at Chiddingstone using 15,600 years (200 series of 78 years') worth of stochastically generated rainfall and PET data for the South London area, as provided by WRSE. Modelled river flows for return periods longer than the historic observed record were extracted with greater certainty than the previously used method of statistical analysis allowed.

For a summary of rainfall and PET inputs to CatchMOD, see Appendix A.

3.3.4 Drought years

In the 2013 drought plan, SES Water looked at a single season drought scenario (2005/2006), which predominantly impacted the Bough Beech reservoir. The worst drought on historic record for groundwater sources was identified as 2006 (see Section 2.3.3). The frequency analysis on stochastically generated groundwater level data suggests that this event represents around a 1 in 35 year drought at the Well House Inn borehole.

While surface and groundwater drought events rarely correspond; the CatchMOD-simulated river flow for the Chiddingstone gauging station in 2005 ranked as 3rd lowest, suggesting that 2005/2006 was a significant drought event for the River Eden. In order to assign a statistical return period to summed flows in this year, a frequency analysis was undertaken on these simulated river flows. This suggests that 2005 represents around a 1 in 48 year drought at the Chiddingstone gauging station. The return period should be treated with caution as the frequency analysis is sensitive to the period of record and the fit of the normal distribution. Additionally, the return period relates specifically to flows at Chiddingstone and does not reflect the return period of the DO of Bough Beech, which will be additionally influenced by reservoir storage, demand and how the source is used by SES Water.

The annual minima reservoir storage for Bough Beech was also examined and in 2005 and 2006 ranked as 6th and 13th lowest respectively. This ranking is based on simulated data from Aquator (1920 to 2017) as the historic observed record is only available for 2010-2017. The worst historic drought with respect to annual minima reservoir storage was 1948. No frequency analysis was undertaken on this data, as reservoir storage data can only reflect the storage used and measures and operational practices taken, rather than how rainfall and PET conditions affect river flows. Appendix F presents ranking of rainfall data; this highlights that with respect to a two dry winter scenario, 1948/49 was the most severe and 2005/06 was the 6th most severe within the 98 year long record.

The drought of 1948 is used as the worst historic drought (WDHR) for surface water and, based on the length of record, it is estimated to represent a 1 in 100 year event with respect to annual minima reservoir storage.

The 1:200 year event or 'severe' drought scenario has been identified by frequency analysis on the groundwater levels in the Well House Inn lumped parameter model using the WRSE stochastic rainfall-PET series. The stochastic rainfall and PET scenario data containing this year was then inputted into the CatchMOD model to derive a flow series for the River Eden for the 1:200 year event.

The 1:200 event had a two dry winter average rainfall of 277 mm, which is comparable to the 1948/49 worst historic drought, although it had a three dry winter average rainfall of 276 mm, which is more severe than 1948/49 (361 mm) and the worst three dry winter event in the 98 year long historic record (310 mm in 1922)

3.3.5 Comparison of historic flow record and CatchMOD simulation

Figure 12 presents a comparison of the actual historic flow record at Chiddingstone and the CatchMOD simulated flows. The actual historic flow record is truncated as the river goes out of bank at 4.73 m^3/s. However this is not an operational issue as the gauge was installed and is used for low flow purposes.

To overcome this, the CatchMOD model was calibrated with an 'adjusted' flow series at Chiddingstone, whereby flows above 4.73 m^3/s were generated using the Environment Agency's Penshurst/ Vexour Bridge flow series (located at approximately 7km downstream). This was carried out during PR14 but has not been repeated because only low flows are being considered when reviewing the calibration and model 'goodness-of-fit'. The 'goodness-of-fit' was considered between actual and simulated flows below the 4.73 m^3/s threshold and the match was considered to be reasonable.

3.4 Mill Stream rainfall-runoff model (CatchMOD)

A CatchMOD rainfall-runoff model was also developed for this study for the Mill Stream. The Mill Stream flows directly into the reservoir and represents the flows naturally contributing to the reservoir directly from its surrounding catchment. The amount of water derived from this source is very minor in comparison with the abstraction from the River Eden. The same historic and stochastic climate data was used in this model, as in the model for the River Eden at Chiddingstone.

3.5 Water resources model (Aquator)

In order to calculate the reliable yield of the Bough Beech reservoir for drought periods, a water resources model for the Bough Beech reservoir is required. An Aquator water resources model of the surface water system (River Eden abstraction and Bough Beech storage reservoir and supply) was initially developed in 2005. This model was further developed and refined in 2007, and again in 2013 for the company's WRMP14 submission.

Aquator is a component based modelling software, which allows for the representation of a water supply network together with the rivers, reservoirs and groundwater sources which may be used to supply the network. It allows source constraints to be applied to individual components within the model and for the inclusion of daily flow time series.

For the current study, a review of the available data relating to the SES Water resources system was undertaken, which included sources, demands and seasonal demand profiles, network constraints including water treatment works capacities, reservoir control curves demand saving from temporary water use restrictions and company Levels of Service. This data was used to identify a suitable set of Aquator model components, parameters and key assumptions for the 'Bough Beech Standalone' model development and DO analysis. Figure 9 provides a schematic of the connectivity's of SES Water's system as used within Aquator.

Within this parameter set, all demands and WTW capacities were set to zero, except for Bough Beech WTW which was set to 55 Ml/d maximum capacity, and Edenbridge demand zone which was set to 25 Ml/d average demand initially but varied to test the DO of the reservoir. The constraint on the Bough Beech to Edenbridge link was also relaxed in this simulation, by setting the maximum flow to be equal to the WTW capacity of 55 Ml/d (see Figure 9 for network connections).

3.5.1 Historic climate data

Although the historic rainfall and PET time series used in the CatchMOD model is referred to and was used in the early flow simulations, the earliest data (1/1/1888-31/12/1919) is quite uncertain and has been disregarded in subsequent Aquator modelling. Therefore the historic climate record used in the Aquator modelling extends from 1920 to 2017. This time series was not used to generate the climate change factors; the climate change factors were applied to it.

3.5.2 Stochastic climate data

The 1:200 year event or 'severe' drought scenario has been identified by frequency analysis on the groundwater levels in the Well house Inn lumped parameter model using the WRSE stochastic rainfall-PET series. The same stochastic rainfall and PET scenario data was also used in the Aquator modelling, in order to derive a flow series for the River Eden for the 1:200 year event.

3.5.3 Simulated flow data

Additionally, the model was updated to include the extended CatchMOD simulated flow series for the River Eden at Chiddingstone and the Mill Stream, as described in Section 3.2, and the 2013 dry year seasonal demand profile. Table 3-1 summarises the flow inputs to each of the Aquator model runs undertaken as part of this study.

Table 3-1 Flow inputs to baseline and stochastic Aquator model runs

Model run	Drought event	Flow series	Period of record
Baseline scenario	WDHR	CatchMOD simulated flows for River Eden and Mill Stream using historic rainfall and PET data	1920-2017
Stochastic scenario	1:200 year	CatchMOD simulated flows using a selected sequence of 78 years of stochastically generated rainfall and PET data which includes a 1 in 200 year event	78 years

3.5.4 Reservoir trigger curves

The Bough Beech Reservoir Aquator model contains reservoir parameters including drought trigger curves. These trigger levels or curves have been identified that when breached help SES Water to identify actions that need to be taken to ensure it can maintain its stated Levels of Service. The triggers also assist the Company to identify when it is in a drought and when a drought is over (SES Water, 2017).

As part of this study, the drought trigger curves, derived for the WRMP14, were tested to ensure that they are appropriate for use in the draft Drought Plan 2017. Reservoir levels were simulated for an extended period of 99 years of daily flow data (1928 to 2016). This confirmed that, despite upgrades to the capacity of the Bough Beech WTW in 2011 and 2012, the triggers were set to ensure the Company continued to meet its Levels of Service and were incorporated into the AECOM Bough Beech Reservoir Aquator model.

3.5.5 Demand

Monthly distribution input data is available for 31 Service Reservoir demand zones, and the SES WRZ: the available data covers the period 2014-2017. As using the single SES demand zone would be unlikely to show sufficient detail to consider constraints within the supply network, and 31 demand zones would make the model unwieldy, the Aquator model is based on 11 demand zones served by one or more Service Reservoir demand zones.

Appropriate seasonal demand profiles were determined by analysing total distribution input data, covering the period 1996-2016. Four years were identified with high peak monthly to annual average ratios: 1999, 2003, 2010 and 2013. The 2013 monthly profile was selected to represent typical recent dry year demand, and this profile was then applied to all 11 model demand zones. The 2003 dry year profile was also considered for use in the Aquator model, as this exhibited high summer peak to average ratios: however, it was felt that a more recent dry year would be more representative of current demand patterns, for example reflecting recent efforts to reduce peak demands through demand management measures. The peak monthly demand factor for July 2013 is 1.21.

3.5.6 Model runs

The DO assessment model runs undertaken within the updated Aquator model were based on zero breaches of emergency storage and meeting company target Levels of Service, using the English and Welsh method. This method involves setting a minimum and maximum overall demand in a resource zone and increasing the demand incrementally until failure is encountered. The DO of the system is defined as the overall demand that is one increment below the demand causing a failure (Oxford Scientific Software Limited, 2014). No return periods were assigned to these model runs, but rather the runs provide the DO at which the Levels of Service can be met within the period of record, i.e. historic or stochastic sequence.

The model runs also include the application of demand savings when the drought triggers are crossed but do not include any drought orders to abstract additional water in summer.

3.6 Bough Beech source DO assessment results

The updated Aquator model was used to calculate the average DO for the design drought (i.e. the WDHR) and for the 1:200 year drought event. The PDO was derived by multiplying the average DO by the monthly demand factor of 1.21 for July in the dry year demand profile. The results are summarised in the following table.

Figures 6 and 7 provide a graphical comparison of the 2013 and 2017 calculated source DO values. These are not directly comparable as the 2013 values relate to the 1:50 year drought event, while the 2017 values related to the worst drought on historic record. However the values do provide an overview of the changes to DO.

It should be noted that the model simulations do not fully reflect the way the reservoir operates in practice, as part of a wider conjunctive use system. The WDHR is believed to represent a severe two dry winter scenario with a return period of about 1 in 100 years with respect to reservoir storage and 1 in 35 year with respect to groundwater level. However, given the overall sensitivity of surface water to drought it is likely that the combined DO is more representative of a 1 in 100 year condition than a 1 in 35 year.

As previously stated, at a project start-up meeting in December 2016 the Environment Agency was satisfied for the dWRMP19 to sign-post the use of a more sophisticated approach for WRMP24, with use of a WRZ model that includes all surface water and groundwater sources. A recommendation has been made for work to develop a WRZ model and to undertake a LoS analysis towards the next WRMP.

Table 3-2 Bough Beech Reservoir DO assessment results

	WDHR (1948)		1:200 year event	
Source name	MDO (Ml/d)	PDO (Ml/d)	MDO (Ml/d)	PDO (Ml/d)
Bough Beech Reservoir	26.1	31.6	17.8	21.5

4. Climate change

4.1 Introduction

Water companies are required to account for the impacts of climate change on DO in their WRMP, which cover a minimum 25 year planning period from present day to the 2040s (Environment Agency, 2012). For WRMP14, the Environment Agency recommended that water companies adopt the 2030s time-horizon for assessing climate change impacts. For dWRMP19 submission, the Environment Agency is now recommending that water companies adopt the 2080s time-horizon for assessing climate change impacts, with the impacts then scaled back through the planning period (Environment Agency, 2017). AECOM commissioned HR Wallingford to undertake a Basic Vulnerability Assessment and climate change modelling for this study (for more detail, see Appendices C and D).

4.2 Initial climate change vulnerability

A Basic Vulnerability Assessment was undertaken to understand the vulnerability of SES Water's water supply system to climate change (Appendix C). The assessment made use of current knowledge of system vulnerabilities and included reference to the latest WRMP14 and Drought Plan 2013. This approach is consistent with the Water Resources Planning Guidelines and related guidance (Environment Agency, 2013). The Basic Vulnerability Assessment shows that SES Water's single WRZ should be classified as low vulnerability. This level of vulnerability was also exhibited by both WRZs in the WRMP14.

The vulnerability of SES Water's water supply system to climate change was re-examined following the calculation of the impacts of climate change on DO. The results are set out in Section 4.8.

4.3 Climate change modelling

Where a WRZ is classified as Low Vulnerability and rainfall-runoff models are available, the guidance specifies that "Tier 2" analysis should be undertaken as a minimum. Tier 2 methods have been used in the climate change modelling analysis undertaken by HR Wallingford.

The climate change modelling analysis was undertaken using the Future Flows Climate scenarios under a medium emissions scenario for the 2080s for the River Eden (Kent) catchment (Appendix D). This dataset consists of 11 equally likely scenarios of climate to 2098. Monthly climate change factors for rainfall and PET were calculated for the 2080s. These climate factors were then used to perturb the historical climate record and were input into an existing CatchMOD rainfall-runoff model of the River Eden. From this, 11 climate change river flow series were produced (one for each Future Flows scenario), from which 11 sets of monthly flow factors were generated.

The results demonstrate a tendency, due to climate change, towards reduced flows in the summer, autumn and early winter. There is a large variation in flows in the late winter and early spring although many of the scenarios indicate reduced flows between September and April. Therefore there is the potential to adversely impact the winter refill of the reservoir and correspondingly the water resource availability and drought resilience of this part of the system.

4.4 Future Flows

In order to generate climate change factors with which to perturb historic and stochastic climate data, HR Wallingford compared future flow projections for the River Eden at Penshurst/ Vexour Bridge, generated by the Future Flows project, to baseline flows for the River Eden at Chiddingstone. These two locations are in close proximity (Figure 1). This approach is considered appropriate considering the significant variability in climate change over the planning period and to take a more conservative approach to climate change, with a lower uplift in winter flows, to which SES Water are more sensitive, than future flow projections for other locations such as on the Medway. Monthly climate change factors for rainfall and PET were then calculated for the 2080s from these future flow projections.

4.5 Groundwater

4.5.1 Climate change groundwater levels

The climate change factors generated using the Future Flows climate scenarios were used to perturb the historic climate record (areal rainfall and PET for South London) for input into the lumped parameter models for the Well House Inn and Riverhead observation boreholes (Figures 10 & 11). It is a recognised issue in climate change impact studies that lengthy historic climate records, such as used in this Aquator modelling which extends from 1920 to 2017, already include a climate change signal; however the benefit of the increased record length, and the capture of more natural variability, is considered to outweigh this.

Additionally the factors were used to perturb the stochastic climate record (stochastic rainfall and PET for South London) for the 1:200 year event, as identified by frequency analysis. From this, 11 climate change groundwater level series were produced (one for each Future Flows scenario), from which the average scenario or central estimate was extracted for use in the DO assessment. The minimum and the maximum scenarios or estimates of uncertainty were extracted for use in the headroom assessment.

Table 4-1 below summarises the groundwater levels at Well House Inn and Riverhead selected for use in the climate change source DO assessments. These levels were used to provide an approximation of the water level condition at each of the groundwater sources within the WDHR and the 1:200 year drought event, taking account of climate change.

Table 4-1 Groundwater levels at critical period boreholes taking account of climate change

			Well House Inn		Riverhead	
Climate change estimate	Future Flows scenario	Return period	Annual minimum groundwater level (maOD)	Peak groundwater level (maOD)	Annual minimum groundwater level (maOD)	Peak groundwater level (maOD)
Average	afixq	WDHR (2006)	**85.53** (13 Feb)	**87.82** (23 July)	**74.40** (Dec)	**74.89** (July)
Minimum	afixm		83.61 (28 Dec)	83.96 (23 July)	74.36 (Dec)	74.83 (July)
Maximum	afixi		86.51 (13 Feb)	89.59 (23 July)	74.85 (Oct)	75.27 (July)
Average	afixq	1 in 200 year event	**85.17**	**85.27**	**74.51**	**74.88**
			Stochastic scenario 194, year 71	Stochastic scenario 109, year 12	Stochastic scenario 159, year 11	Stochastic scenario 46, year 39
Minimum	afixm		84.69	84.76	73.72	74.31
			Stochastic scenario 194, year 71	Stochastic scenario 109, year 12	Stochastic scenario 159, year 11	Stochastic scenario 46, year 39
Maximum	afixi		85.44	85.76	75.08	75.44
			Stochastic scenario 194, year 71	Stochastic scenario 109, year 12	Stochastic scenario 159, year 11	Stochastic scenario 46, year 39

4.5.2 Fetcham Springs

As outlined in Section 2.10, the source DO assessment for Fetcham Springs relies on source output data, which appears to be influenced by demand. Additionally there is insufficient data to relate total spring flows to groundwater levels thereby making it impossible to quantify an appropriate adjustment for the 1 in 200 year event. As the estimation of DO at the Fetcham Springs is not related to climate data or to groundwater levels at a critical period borehole, but rather the source output which is influenced by demand, an assumption has been made that the PDO and MDO values will not change for the central estimate of climate change.

4.5.3 Climate change groundwater DO results

The groundwater levels at Well House Inn and Riverhead selected for use in the climate change source DO assessments were then used to curve shift the operational drought curve for each source, thereby providing an estimate of DO for these events. The following table summarises the groundwater source DO results taking account of the average scenario or central estimate of climate change for the midpoint of the 2080s (i.e. 2085).

Table 4-2 Groundwater source DO results taking account of climate change for 2080s

Source name	WDHR PDO with climate change (Ml/d)	WDHR MDO with climate change (Ml/d)	1:200 year PDO with climate change (Ml/d)	1:200 year MDO with climate change (Ml/d)
Cheam	12.00	8.90	11.00	8.90
Cheam Park	1.30	1.16	1.25	1.16
Springclose Lane	2.00	2.00	2.00	2.00
Langley Park	1.90	1.90	1.90	1.90
Nonsuch Park	12.00	5.00	12.00	5.00
Sutton	16.90	9.20	13.50	9.00
Sutton Ct Rd	1.45	0.75	1.20	0.70
Chipstead	5.00	5.00	5.00	5.00
Holly Lane	6.50	6.13	6.50	6.13
Woodmansterne	16.50	14.70	15.20	14.30
Smitham	5.68	5.68	5.68	5.68
Hackbridge & Goatbridge	17.20	8.47	17.20	8.47
Oaks	9.92	4.50	9.92	4.50
Woodcote	4.60	4.60	4.60	4.60
Kenley	22.08	17.74	22.08	17.74
Purley	19.20	5.05	19.20	5.05
Fetcham Boreholes	0.96	0.92	0.92	0.92
Fetcham Springs	10.98	8.33	10.98	8.33
Elmer & Young St	17.05	14.25	17.05	14.25
Leatherhead	40.91	27.92	40.91	27.92
Dorking	11.82	11.82	11.82	11.82
Buckland	1.40	1.40	1.40	1.40
Clifton's Lane	1.30	0.87	1.30	0.87
Warwick Wold	3.90	3.25	3.90	3.25
Brewer Street	2.55	2.45	2.55	2.45
Bletchingley	3.50	2.05	3.50	2.05
North Park	4.46	3.50	4.46	3.50
Godstone	2.60	2.48	2.60	2.48
Flower Lane	3.37	2.00	3.37	2.00
Water Lane	2.00	2.00	2.00	2.00
South Green	2.18	2.18	2.18	2.18

Source name	WDHR PDO with climate change (Ml/d)	WDHR MDO with climate change (Ml/d)	1:200 year PDO with climate change (Ml/d)	1:200 year MDO with climate change (Ml/d)
Westwood	5.10	2.70	4.40	2.70
Total for all groundwater sources	**268.3**	**188.9**	**261.6**	**188.2**
Impact of climate change on total baseline DO for all groundwater sources +/- (Ml/d)	-0.75	-0.66	-3.69	-0.43

4.6 Bough Beech

The monthly climate change factors for rainfall and PET, calculated for the 2080s from these future flow projections for the River Eden at Penshurst/ Vexour Bridge, were used to perturb the historic climate record and input into the CatchMOD model for the Eden at Chiddingstone. From this, 11 climate change river flow series were produced, one for each Future Flows scenario, from which the average scenario or central estimate was extracted for use in the DO assessment. The minimum and the maximum scenarios or estimates of uncertainty were extracted for use in the headroom assessment.

Table 4-3 summarises the flow inputs to each of the Aquator model runs undertaken as part of this climate change assessment.

Table 4-3 Flow inputs to climate change Aquator model runs

Model run	Drought event	Flow series	Period of record
Average climate change scenario	WDHR	CatchMOD simulated flows using the central estimate of climate change on the historic climate record	1920-2017
Minimum climate change scenario	WDHR	CatchMOD simulated flows using the minimum estimate of climate change on the historic climate record	1920-2017
Maximum climate change scenario	WDHR	CatchMOD simulated flows using the maximum estimate of climate change on the historic climate record	1920-2017
Average climate change scenario	1:200 year	CatchMOD simulated flows using the central estimate of climate change on the selected sequence of stochastically generated rainfall and PET data	78 years
Minimum climate change scenario	1:200 year	CatchMOD simulated flows using the minimum estimate of climate change on the selected sequence of stochastically generated rainfall and PET data	78 years
Maximum climate change scenario	1:200 year	CatchMOD simulated flows using the maximum estimate of climate change on the selected sequence of stochastically generated rainfall and PET data	78 years

4.6.1 Climate change Bough Beech DO results

The central estimate climate change river flow series was ran through the Aquator model to provide an estimate of MDO for the WDHR and 1:200 year events. The PDO values were then derived by multiplying the DO for the DYAA scenario by the peak (July) monthly demand factor from the dry year seasonal demand profile. Table 4-4 summarises the Bough Beech DO results taking account of the average scenario or central estimate of climate change for the midpoint in the 2080s (i.e. 2085).

Table 4-4 Bough Beech Reservoir DO results taking account of climate change for 2080s

	WDHR		1:200 year event	
Source name	**MDO (Ml/d)**	**PDO (Ml/d)**	**MDO (Ml/d)**	**PDO (Ml/d)**
Bough Beech Reservoir	**18.4**	**22.3**	**21.6**	**26.1**
Impact of climate change on total baseline DO +/- (Ml/d)	-7.28	-8.83	+3.59	+4.35

Perhaps surprisingly, the impact of climate change leads to an increase in DO values for the 1 in 200 year event. This can be explained by the seasonal nature of the climate change perturbation factors and surface water abstraction. The impact of climate change factors during the period of May to August, when no abstraction is permitted, will be of lower significance; whilst climate change factors during the period of September to April, when abstraction is permitted, will have more influence on the results. For the Future Flows scenario 'afixq', the rainfall factors for November to March are greater than 1. The presentations in Appendix F demonstrate that whilst cumulative rainfall is similar with or without climate change, the rainfall for the period September to April is significantly greater under the climate change scenario.

4.7 Scaling and uncertainty

In line with the Environment Agency's WRPG (2012), the change in DO has been scaled for each year of the planning period. The scaled change to base year DO was calculated using the following equation to extrapolating from 2085 backwards.

$$\text{Scale factor} = \frac{\text{Year} - 1975}{2085 - 1975}$$

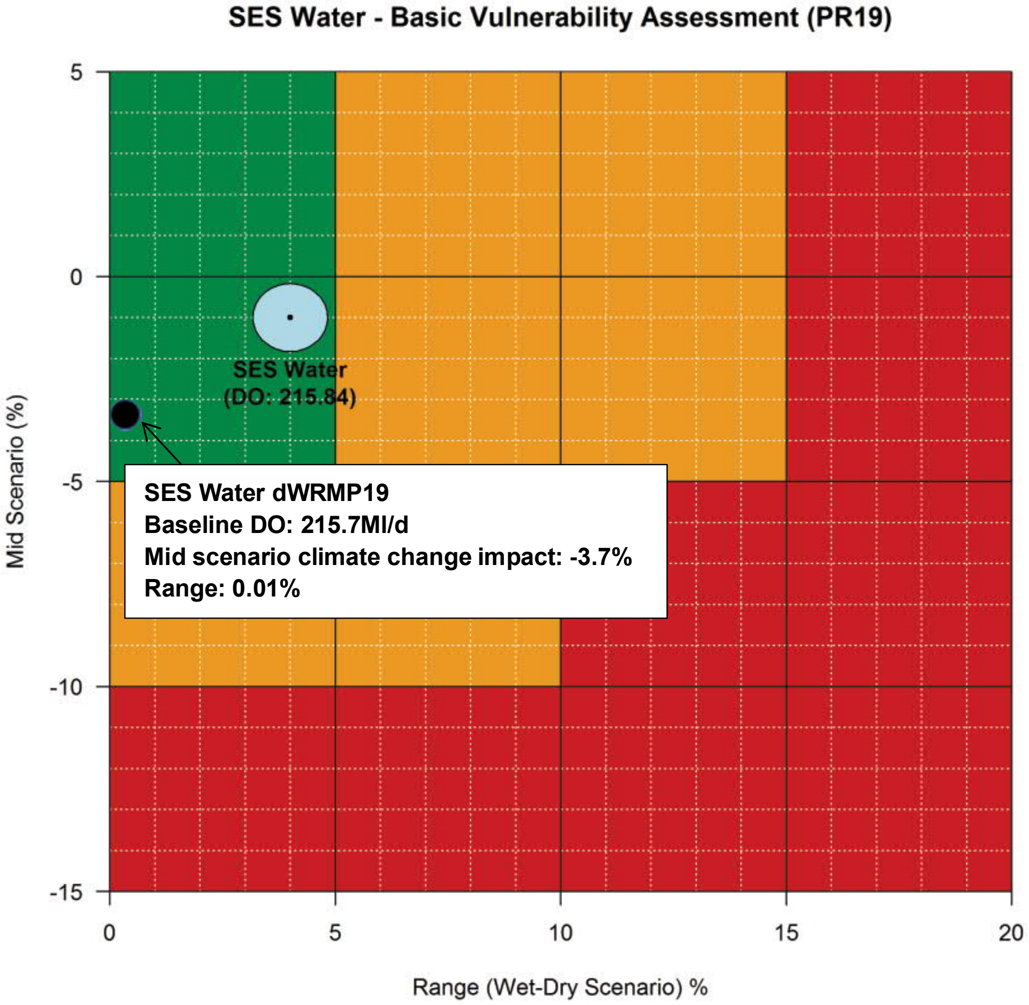
The scaled change in DO across the planning period as a result of best estimate of climate change impacts has been presented in Figures 13 and 14 and recorded in Appendix E.

4.8 Reassessment of climate change vulnerability

The vulnerability of SES Water's water supply system to climate change was re-examined following the calculation of the impacts of climate change on DO. The initial basic vulnerability classification was based on the climate change impact assessment carried out for the WRMP14. The classification was re-examined by plotting the change in DO for the average climate change scenario against the uncertainty range based on the DO and climate change impact assessment carried out for dWRMP19.

A magnitude versus sensitivity plot was prepared for the initial basic vulnerability assessment and is presented in Drawing 4-1. The red squares refer to high vulnerability; amber to medium vulnerability; and green to low vulnerability. The blue circle represents the results of the initial basic vulnerability assessment and the black circle represents the results of the re-examination, showing that the classification of SES Water's water supply system remains unchanged following the assessment of climate change impact on DO for the dWRMP19.

Drawing 4-1 SES Water – Basic Vulnerability Assessment



5. Conclusions and recommendations

5.1 Deployable output assessment

A reassessment of DO has been completed to support SES Water's next WRMP. This involved updating source models (operational data and constraints) and the assessment of DO using both historic and stochastic climate sequences. The baseline DO values that are recommended for the Economics of Balancing Supply and Demand (ESBD) modelling within the dWRMP19 are as follows:

Table 5-1 Summary of baseline WRMP19 DO values

Drought event	PDO (Ml/d)	MDO (Ml/d)
Worst drought on historic record (2006 for groundwater and 1948 for surface water)	300.7	215.7
1:200 year event	287.0	206.5

The WDHR is believed to represent a severe two dry winter scenario with a return period of about 1 in 100 years with respect to reservoir storage and 1 in 35 year with respect to groundwater level. However, given the overall sensitivity of surface water to drought it is likely that the combined DO is more representative of a 1 in 100 year condition than a 1 in 35 year.

The reassessment of DO has resulted in an overall increase in PDO values of 31Ml/d and in MDO values of 3Ml/d. These increases are primarily due to improved critical constraints knowledge.

5.2 Climate change impact assessment

An initial basic vulnerability assessment for the SES Water area was undertaken based on outputs from WRMP14 and Drought Plan 2013, and was completed in March 2017. The assessment concluded that SES Water's single WRZ has a 'Low Vulnerability' to climate change. This level of vulnerability was also exhibited by both WRZs in the WRMP14.

The climate change modelling analysis was undertaken using the Future Flows Climate scenarios under a medium emissions scenario for the 2080s for the River Eden (Kent) catchment. Monthly climate change factors for rainfall and PET were calculated for the 2080s and were used to perturb the historical and stochastic climate sequences. The perturbed climate sequences were then input into lumped parameter models for the Well House Inn and Riverhead observation boreholes, and the existing CatchMOD rainfall-runoff model of the River Eden.

The results provide 'lower range' and 'upper range' estimates of climate change impacts, which are to be used within the dWRMP19 headroom assessment. The 'most likely' climate change impact is to be used within SES Water's decision making tool for testing of the supply and demand balance. The 2080s impacts have been scaled back to the 2020s (resulting in a set of profiles) using the revised equation presented within the Environment Agency's *Climate change river flows supplementary information revised April 2017* and also the equations used at WRMP14.

The DO values with climate change that are recommended for ESBD modelling are as follows:

Table 5-2 Summary of WRMP19 DO values with climate change

Drought event	PDO (Ml/d)	MDO (Ml/d)
Worst drought on historic record	290.6	207.7
1:200 year event	287.7	209.8

The classification of SES Water's water supply system to climate change vulnerability was re-examined by plotting the change in DO for the average climate change scenario against the uncertainty range based on the DO and climate change impact assessment carried out for dWRMP19. The assessment concluded that SES Water's single WRZ remains at a low vulnerability to climate change.

5.3 Recommendations

5.3.1 Record source groundwater levels

It is recommended that a telemetry system is installed to measure groundwater levels at all sources. It is also recommended that well/ borehole manual dip datums are levelled where unknown, and that manual dipping is undertaken at least once every six months, and whenever pumps are moved, both at rest, and under pumped conditions, to validate the groundwater level telemetry.

This action would provide an understanding of how the source boreholes function and allow for the refinement of the relationship between the source and the critical observation boreholes.

5.3.2 Maintain 'source files'

It is recommended that 'source files' be maintained and updated if, or when, new constraint information is obtained (including DAPWL related information). These files should contain, where available, borehole logs, CCTV investigations and the results of geophysical surveying.

Information on source outages as a result of turbidity, metaldehyde, algal blooms, Cryptosporidium etc should be also added to the 'source files' as a review of operational water level data and outage data could help to identify water quality DAPWLs. Additionally all sources should be on a rolling programme with respect to CCTV surveys (and perhaps other surveys) so that the status of boreholes and wells can be updated. This might involve investigations every 10 to 20 years.

5.3.3 Record actual spring flow data

It is recommended that actual spring flow is recorded at all spring sources. This action would provide an understanding of how the spring functions and would allow for the development of a lumped parameter model for this source, the Fetcham Springs. Additionally this would allow for the perturbation of historic and stochastic climate data and subsequent prediction of the 1 in 200 year flows and the flows under climate change scenarios.

5.3.4 Develop a WRZ water resources model

It is recommended that a WRZ water resources model be developed for both the groundwater and surface water sources within the SES Water's area in preparation for WRMP24. At a project start-up meeting in December 2016, the Agency were satisfied for dWRMP19 to provide pointers towards a more sophisticated approach for WRMP24, including the use of a WRZ model (containing both the groundwater and surface water sources).

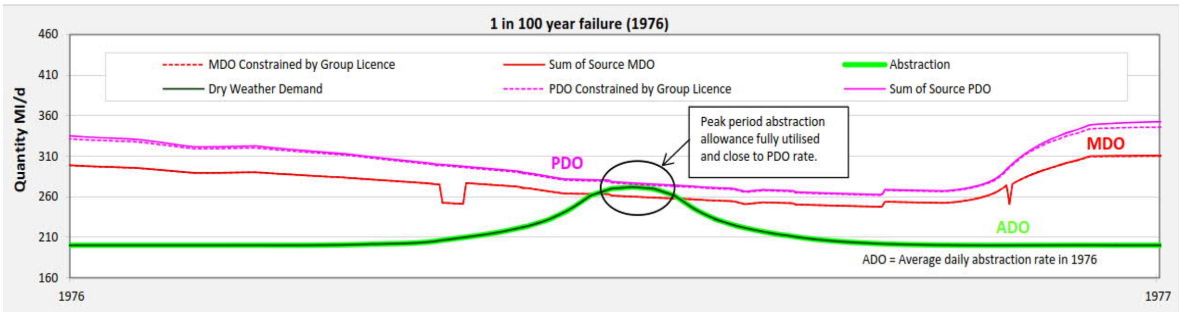
This action would provide a resource zone model with which to calculate resource zone DOs for a range of demand profiles and drought years and allow an improved Levels of Service analysis to be undertaken. The resource zone model would include a time series of available ADO and PDO abstraction rates for each source; sum these time series, apply group licence restrictions, and give an available ADO and PDO abstraction rate for the resource zone at any time step within the model. It would also provide a combined groundwater/ surface water availability for the WRZ/s.

The resource zone model would also calculate MDO. In the UKWIR *A Unified Methodology for the Determination of Deployable Output from Water Sources* (2000), groundwater source 'ADO' assessments were based on monthly operational data for those months when groundwater levels were at or near their annual minima for the worst drought to have affected the area of the source. However, the use of data associated with minimum groundwater levels means that the assessments now fall under the category of MDO. The UKWIR *Handbook of Source Yield Methodologies* (2014) defines MDO as the *"DO for the period in which groundwater levels are at their lowest, usually late autumn".*

ADO is associated with the 'dry year annual average' (DYAA) planning scenario and represents the average supply over the year computed as an average over a dry year. The UKWIR *WR27 (DO Report) Water Resources Planning Tools* (2012) defines the ADO as "*the deployable output of a source for the "average annual period*" and goes on to state that *"the average demand is literally the average over the year computed as average over a normal year or average over a dry year".*

Therefore ADO and MDO differ in that MDO represents the critical period of the year in terms of supply i.e. when groundwater levels are at their lowest, while ADO represents the average demand across the year and is constrained during the critical period either by PDO or MDO. This will depend on the water company's hydrogeological setting and demand profile.

The figure below illustrates how ADO and MDO could differ. In this example, the critical period for the supply-demand balance is when demand peaks in the summer and the average daily abstraction is constrained by the PDO abstraction rate. If demand was more evenly spread across the year, the critical period for the supply-demand balance could occur when supply drops along with groundwater levels in the late autumn. The average daily abstraction would then be constrained by the MDO abstraction rate.



Extract: AECOM (incorporating URS) (2013), *Portsmouth Water WRMP 2014 Studies - 2012 Deployable Output Assessment*

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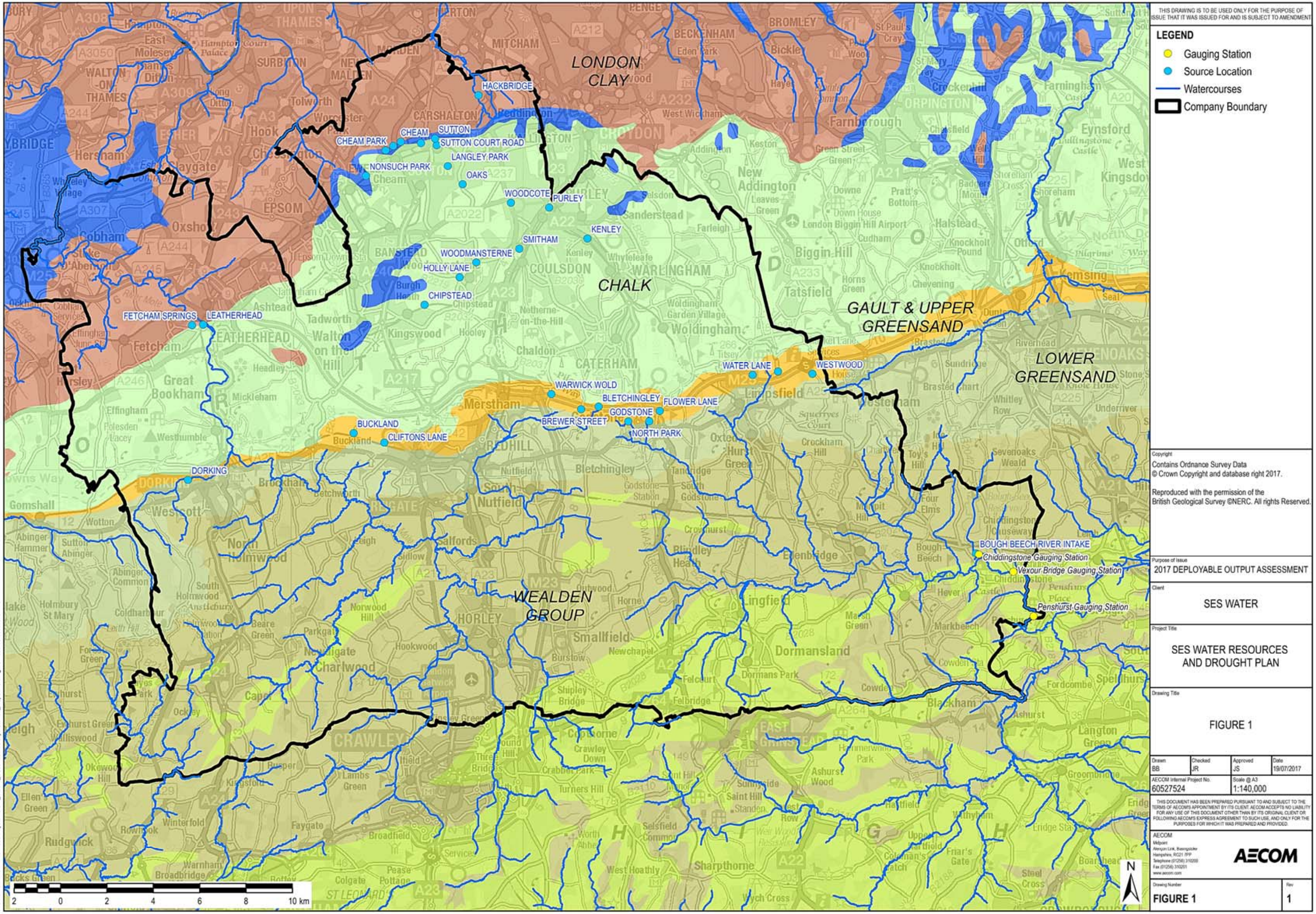

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WEALDEN GROUP
HACKBRIDGE
CHEAM PARK
CHEAM
SUTTON
SUTTON COURT ROAD
NONSUCH PARK
LANGLEY PARK
OAKS
WOODCOTE
PURLEY
KENLEY
SMITHAM
WOODMANSTERNE
HOLLY LANE
CHIPSTEAD
FETCHAM SPRINGS
LEATHERHEAD
WATER LANE
WESTWOOD
WARWICK WOLD
BLETCHINGLEY
FLOWER LANE
GODSTONE
BREWER STREET
NORTH PARK
BUCKLAND
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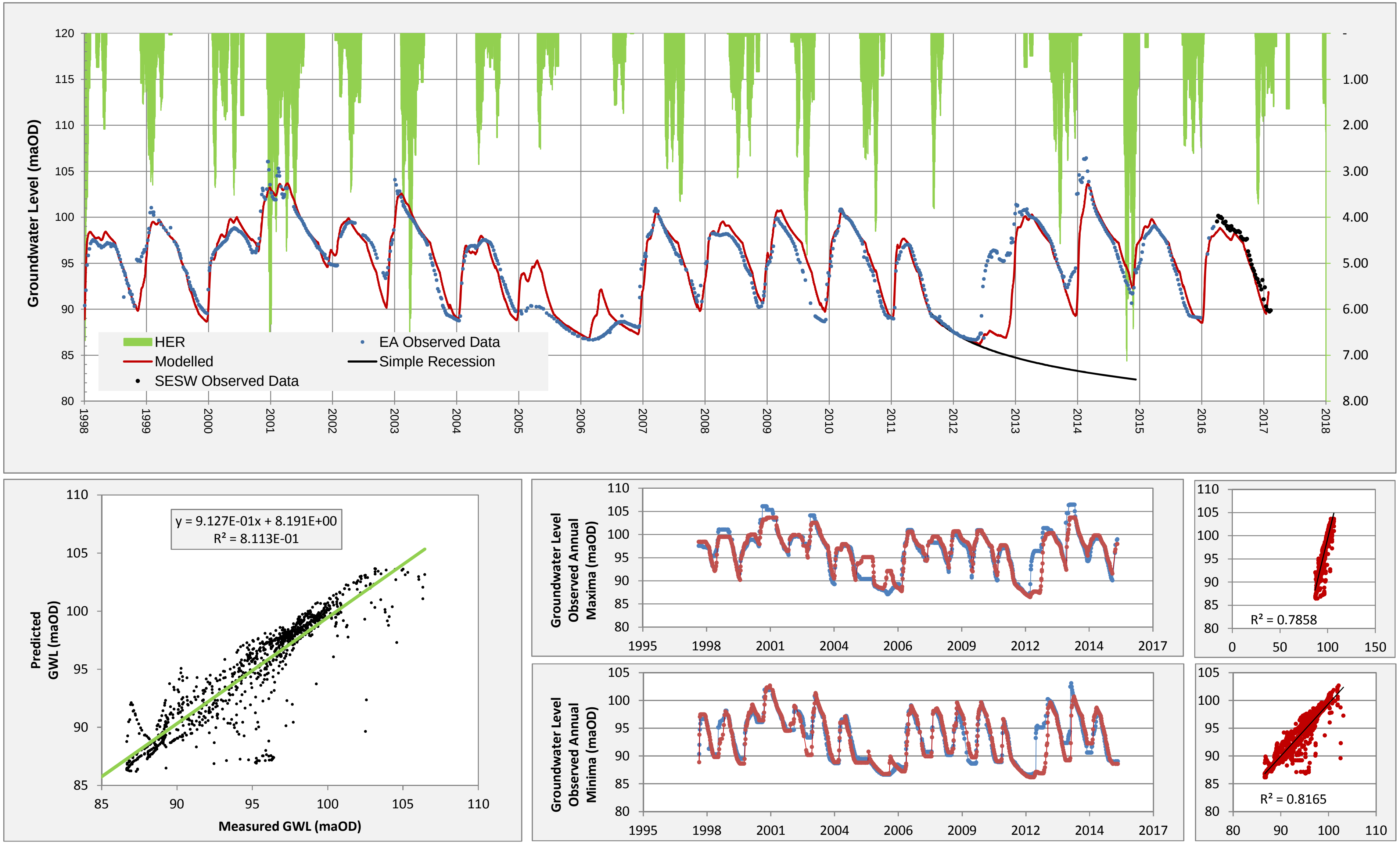
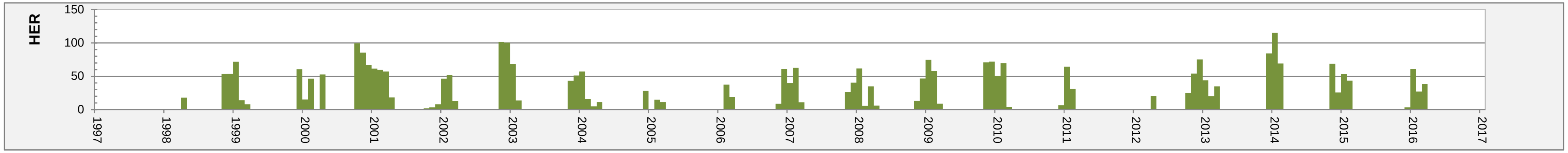
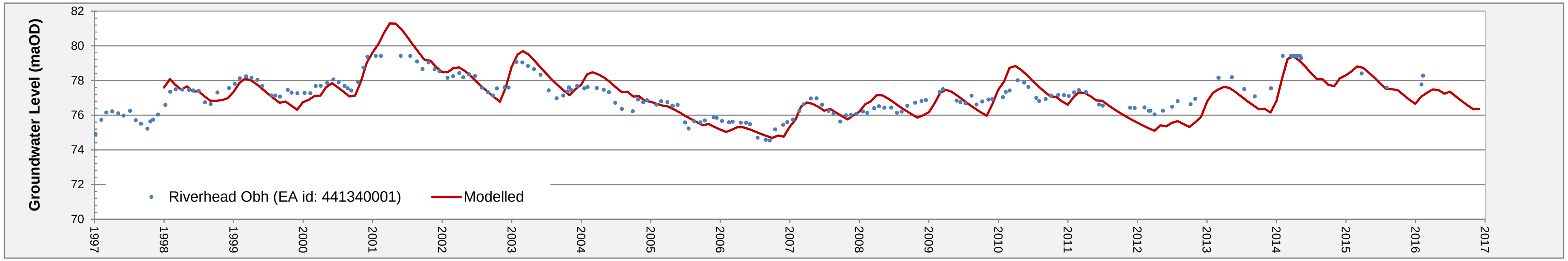
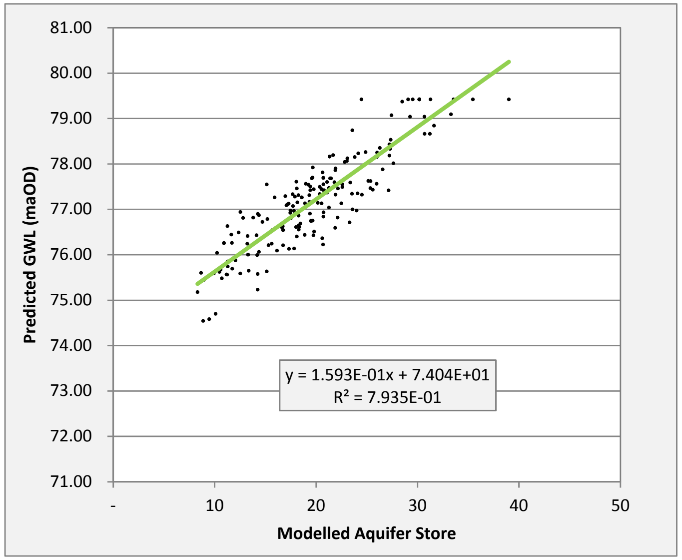
Lumped parameter model for Well House Inn observation borehole

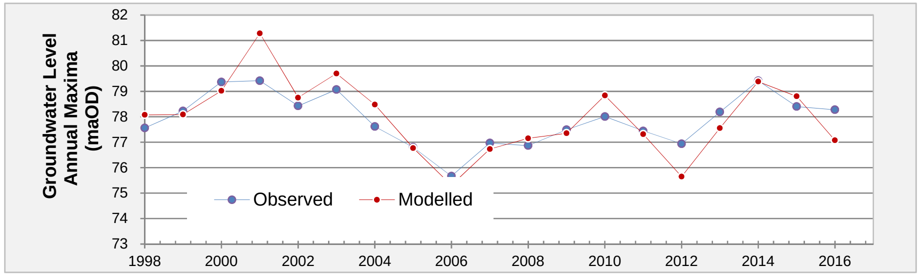


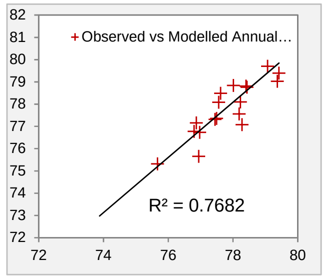
Lumped parameter model for Riverhead observation borehole

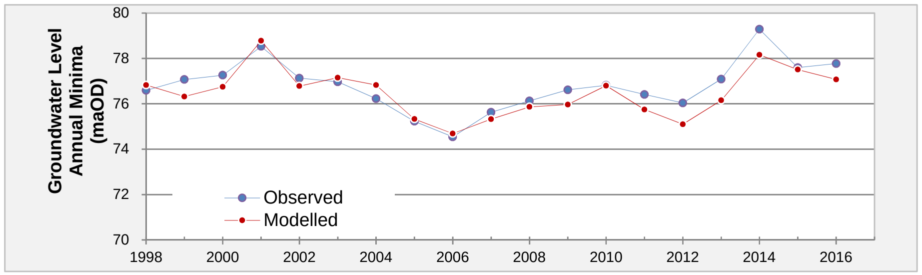


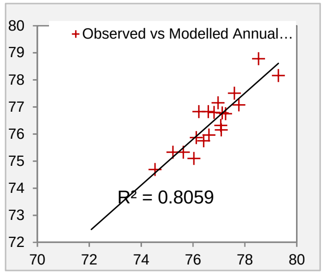




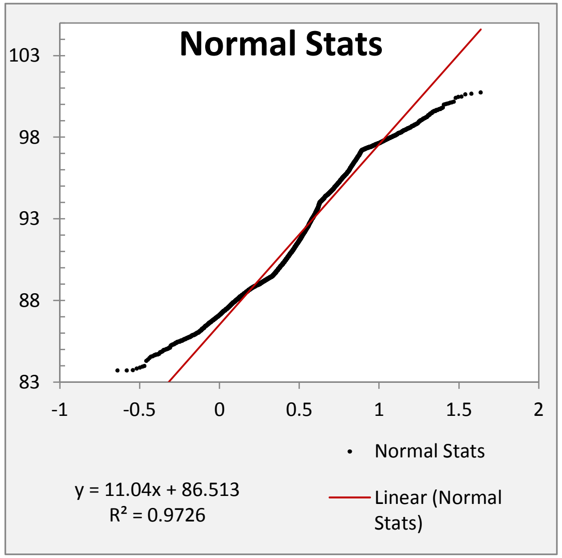


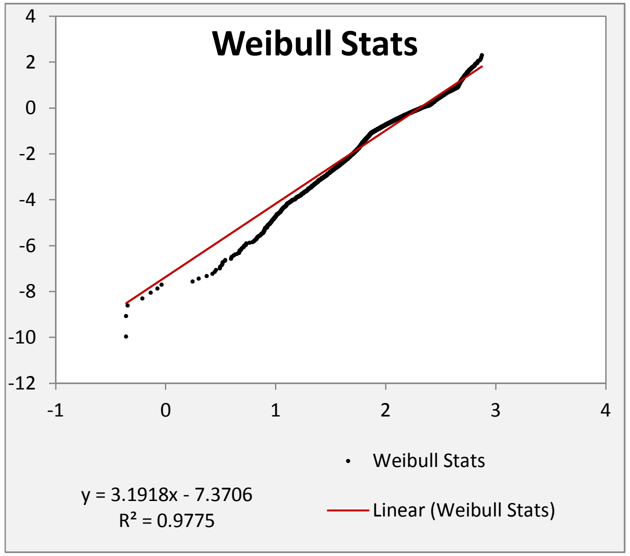


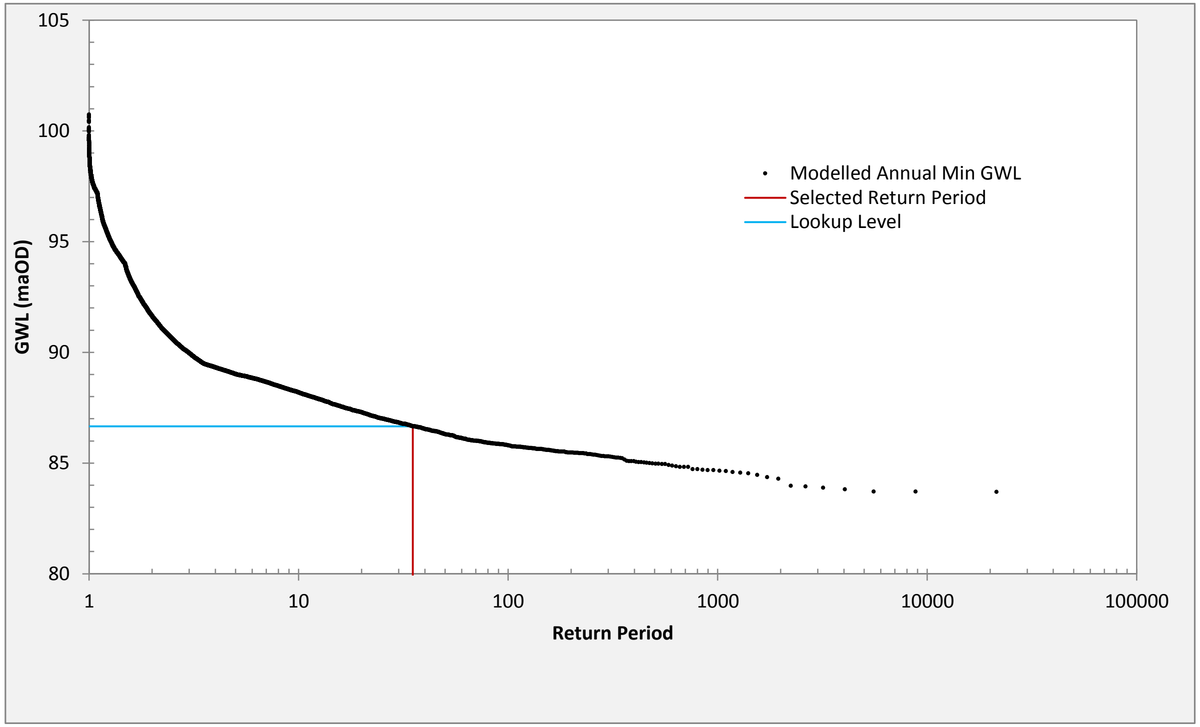




Frequency analysis plots showing the statistical return period for the observed annual minima groundwater level in 2006 at the Well House Inn observation borehole

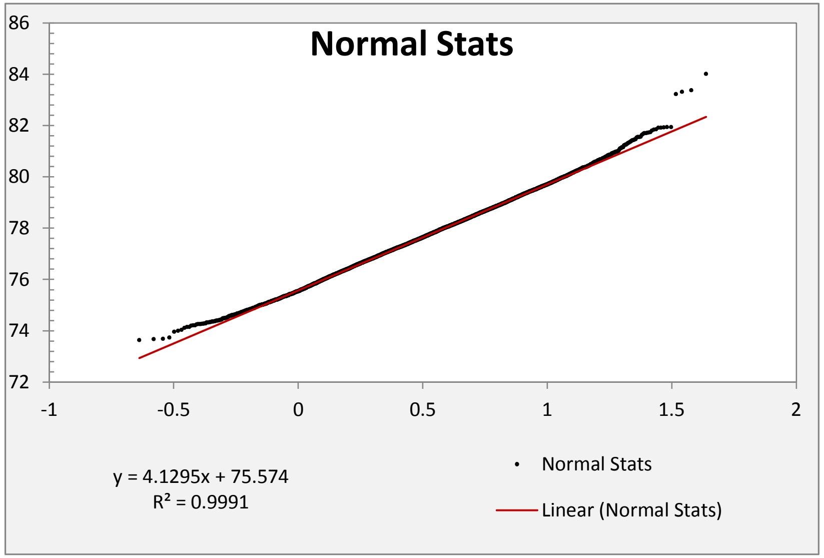


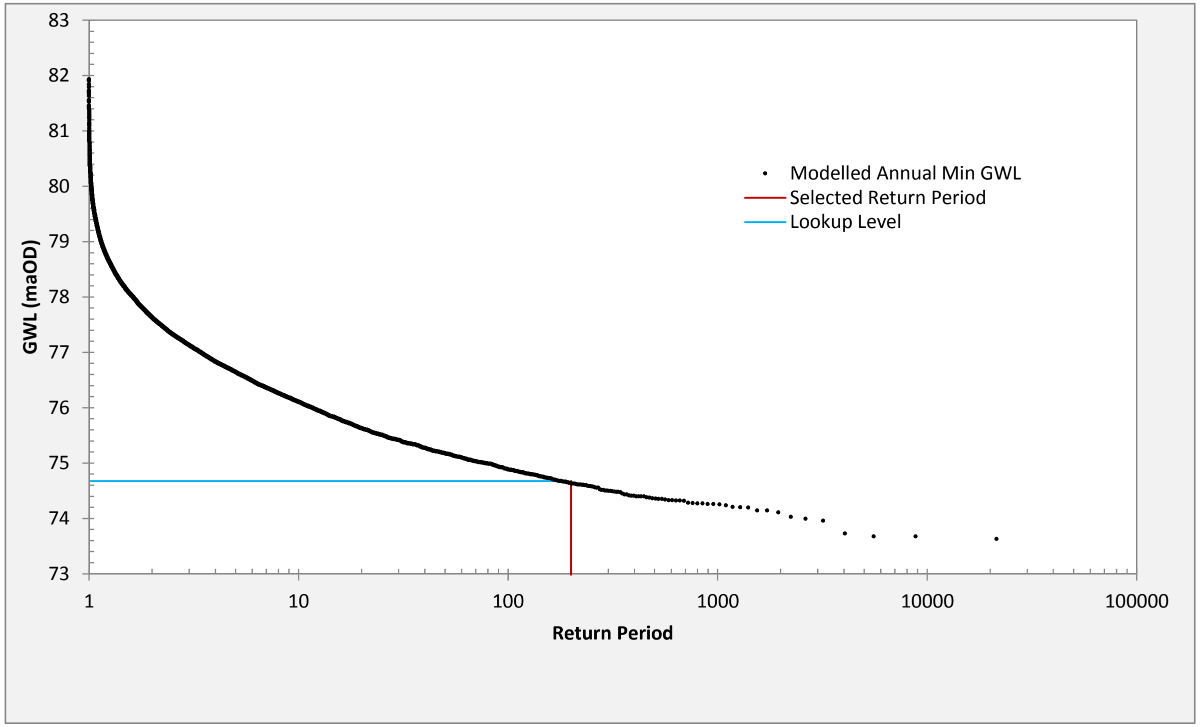




AECOM

Frequency analysis plots showing statistical return period for modelled annual minima groundwater level in 2006 at Riverhead observation borehole

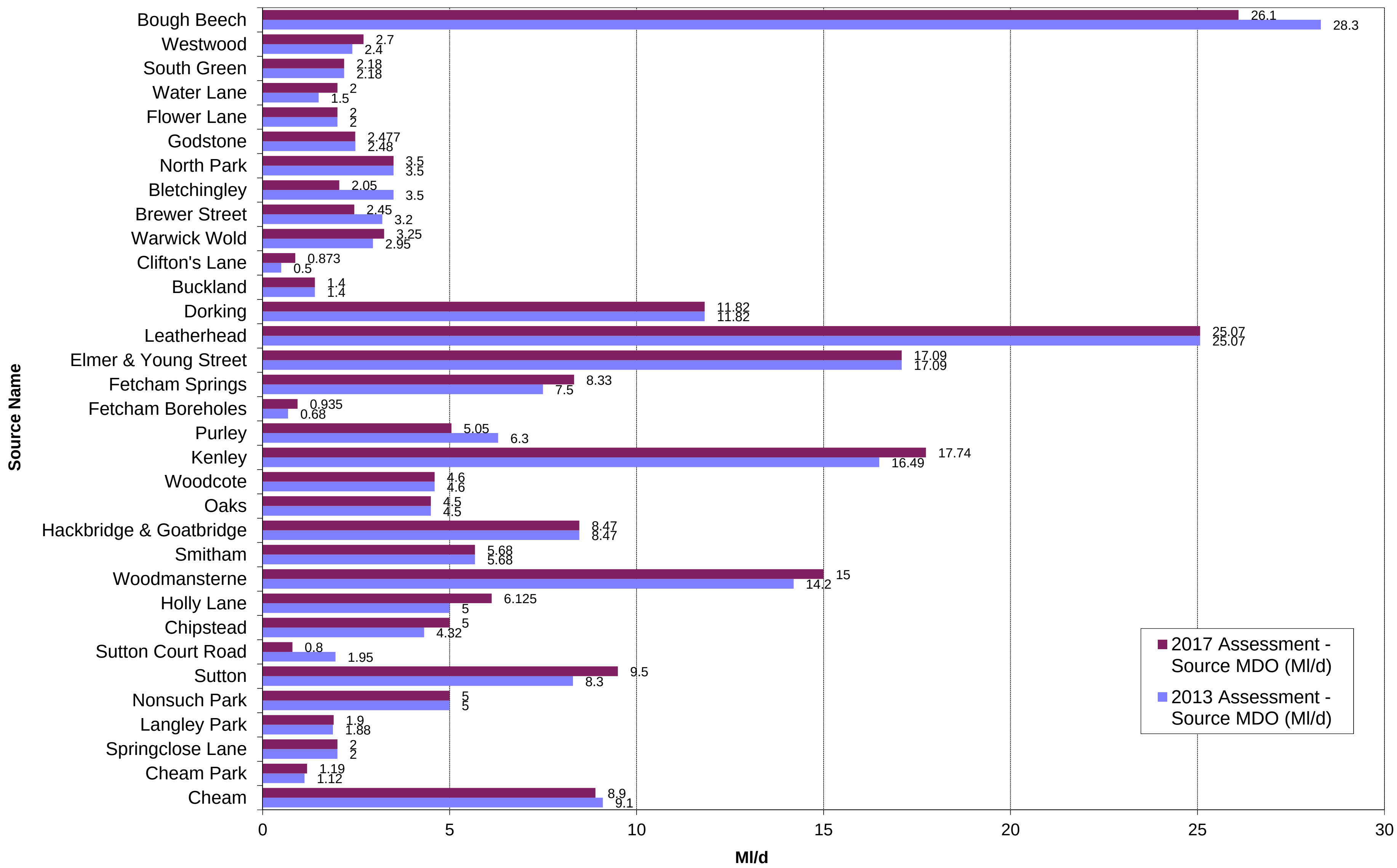




2017 Deployable Output Assessment

Comparison of groundwater source MDO values for dWRMP19 (worst drought on historic record) and for WRMP14 (1 in 50 year event)

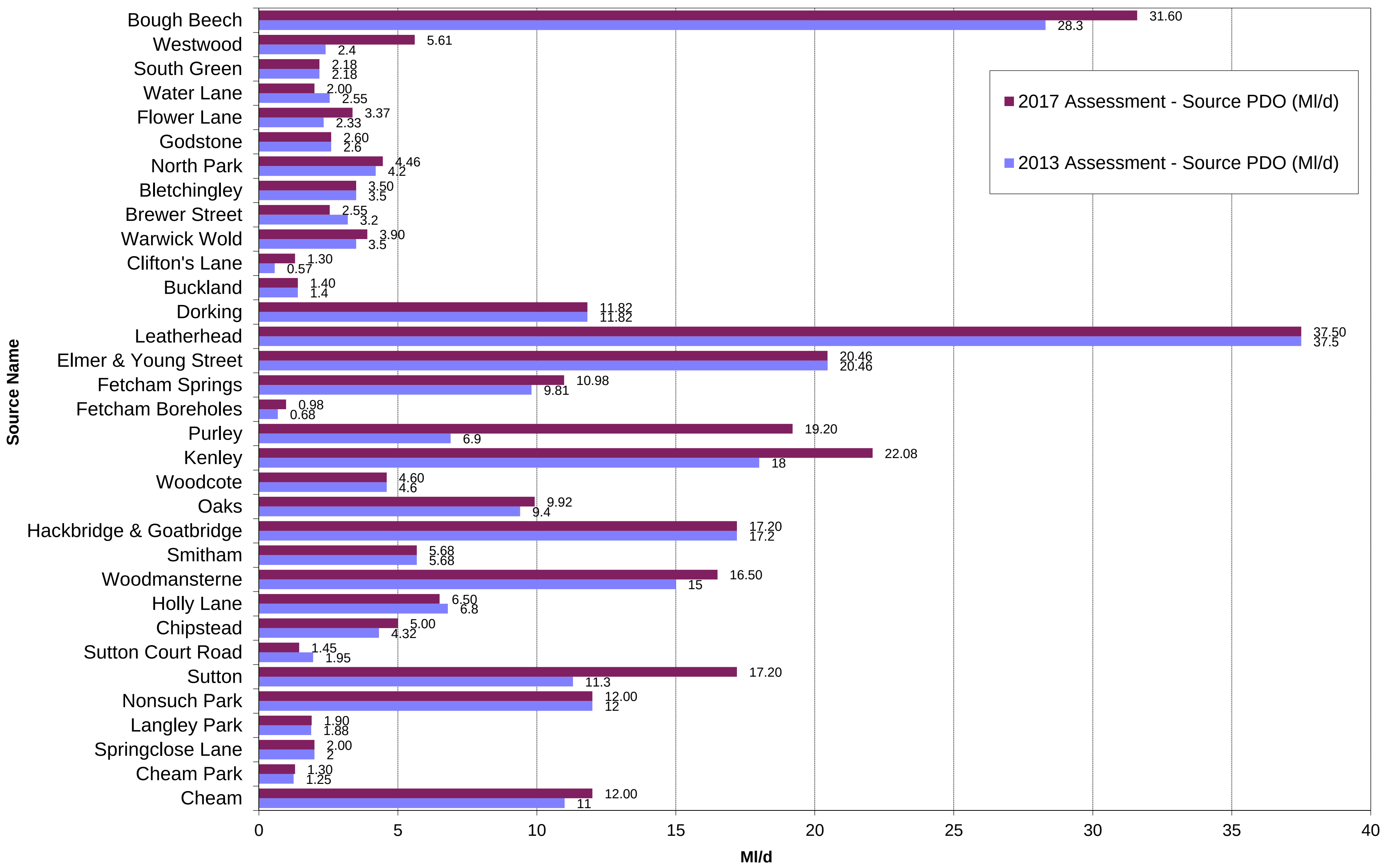
Figure 6



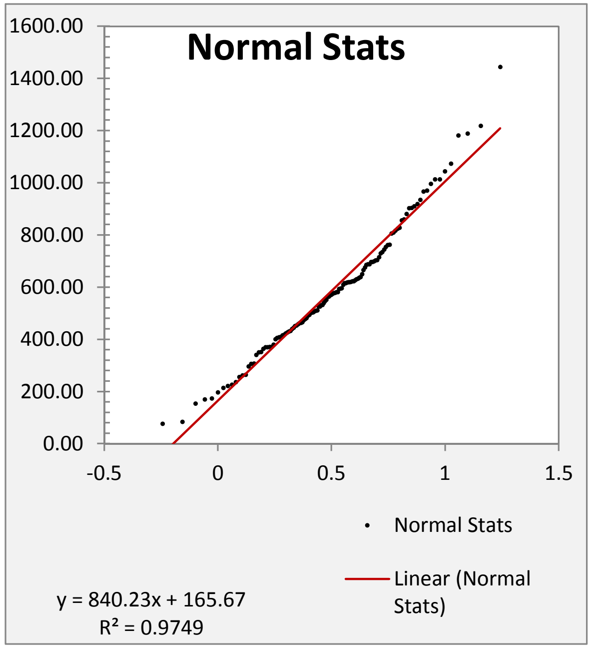
K:\jobs\60527524 SESW Water Resources and Drought Plan\400_TECH\420_SUPPLY\08 Summary of DO\
Summary DO plots 2017.xlsMinimum DO Chart
05/07/2017 15:54

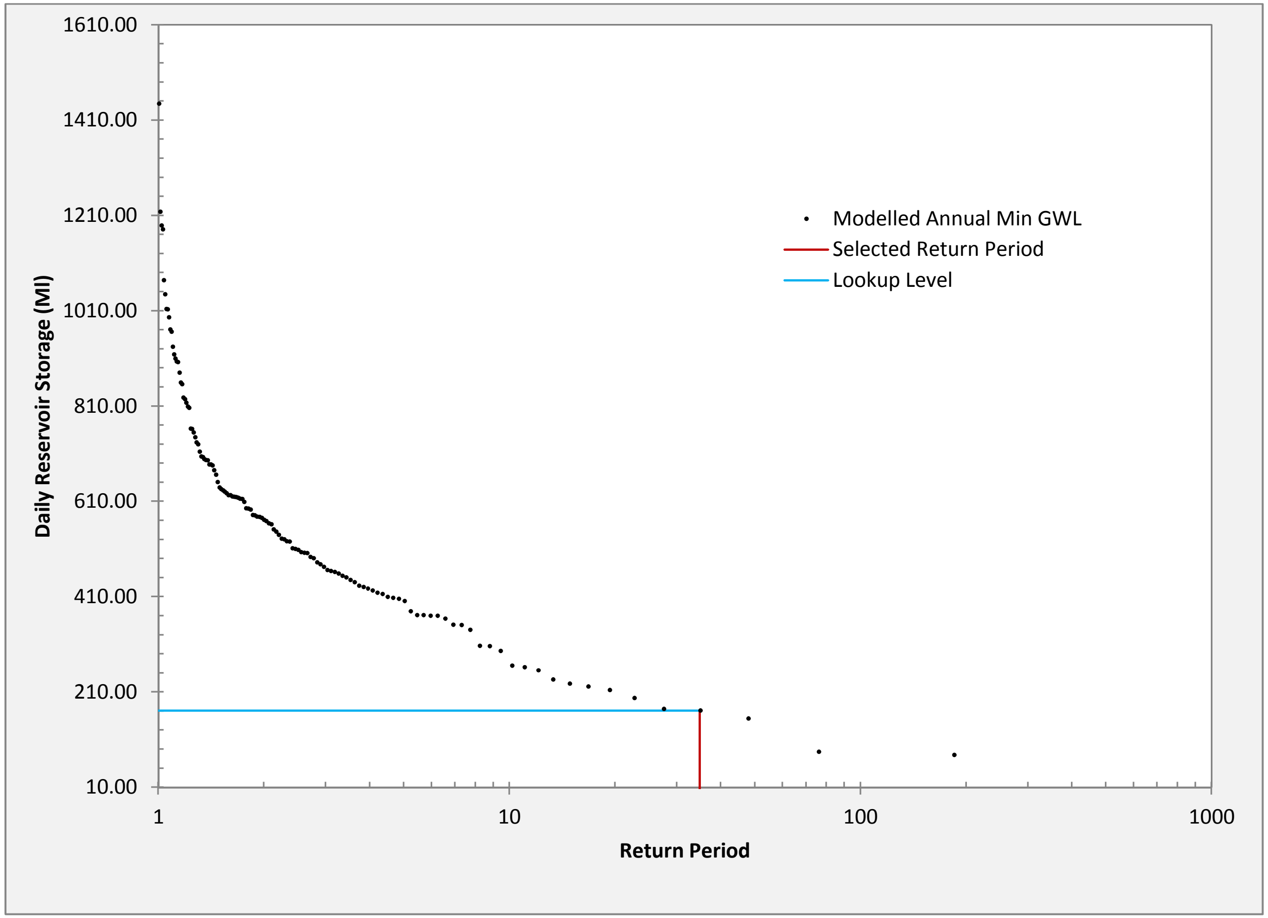
AECOM

Groundwater source deployable outputs for worst drought on historic record and 1:50 year event

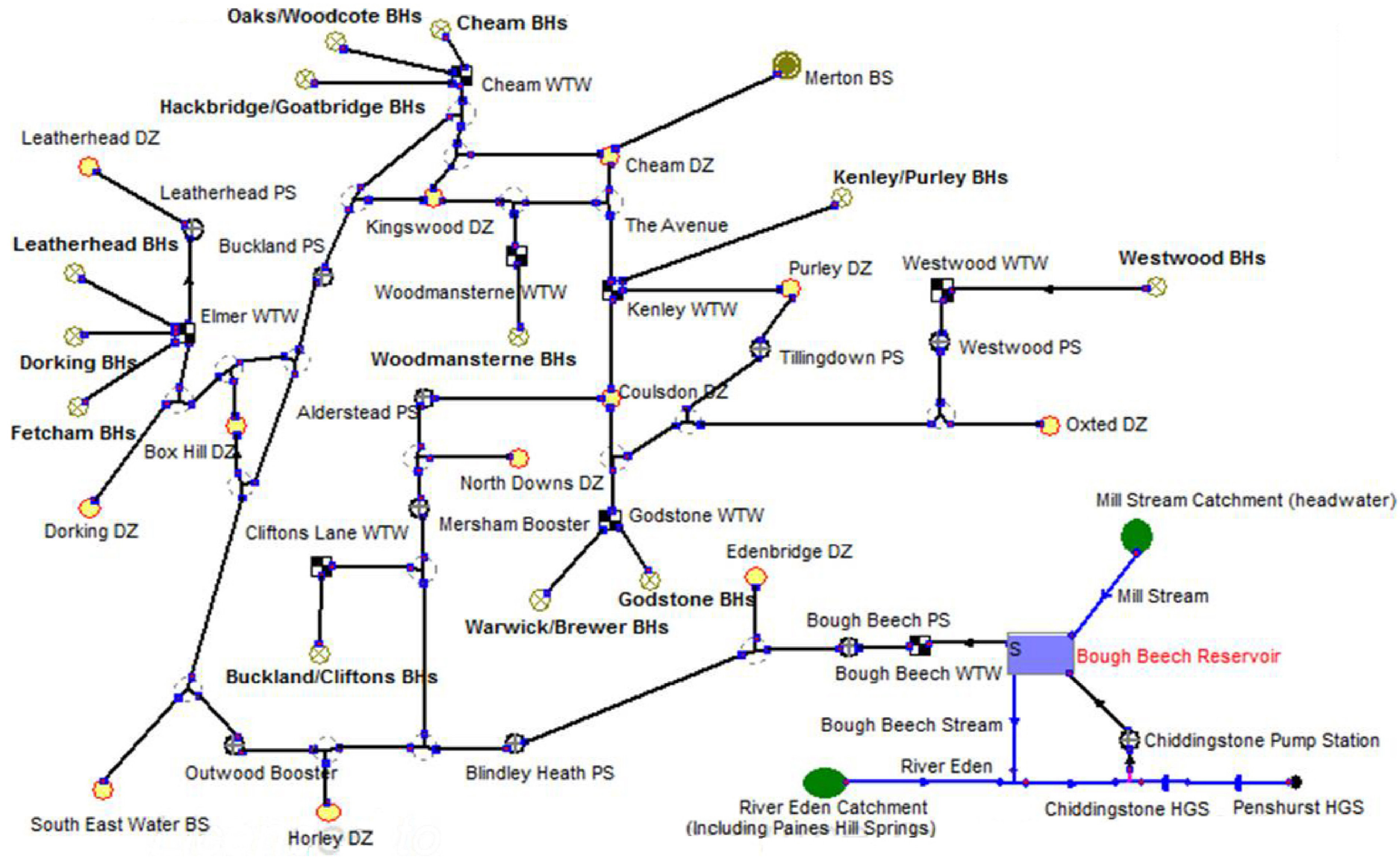


Frequency analysis plots showing the statistical return period for the annual simulated river flows in 2005 at the Chiddingstone gauging station





AECOM



File Name:I:\5004 - Information Systems\6xx_SESW_SuttonEastSurreyWater\02_Maps\Figure 6 - Aquator Schematic.mxd

THIS DRAWING IS TO BE USED ONLY FOR THE PURPOSE OF ISSUE THAT IT WAS ISSUED FOR AND IS SUBJECT TO AMENDMENT

LEGEND

Purpose of Issue
DO ASSESSMENT

Client
SES WATER

Project Title
SES WATER
DWRMP19

Drawing Title
AQUATOR SCHEMATIC

Drawn	Checked	Approved	Date
BB	JR	JS	13/09/2017

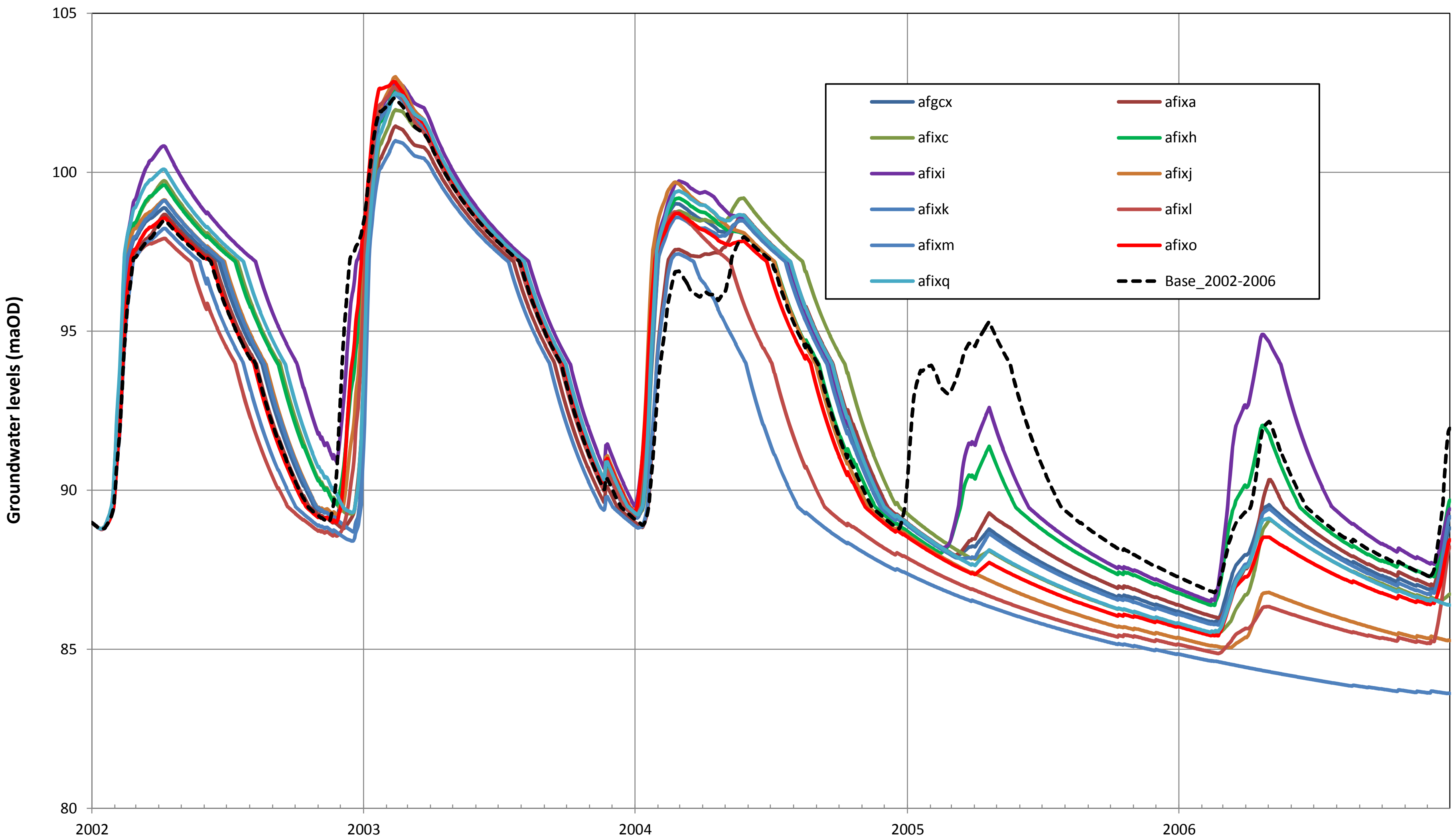
AECOM Internal Project No.	Scale @ A3
60527524	NOT TO SCALE

AECOM
Scott House
Alençon Link, Basingstoke
Hampshire, RG21 7PP
Telephone (01256) 310200
Fax (01256) 310201
www.aecom.com

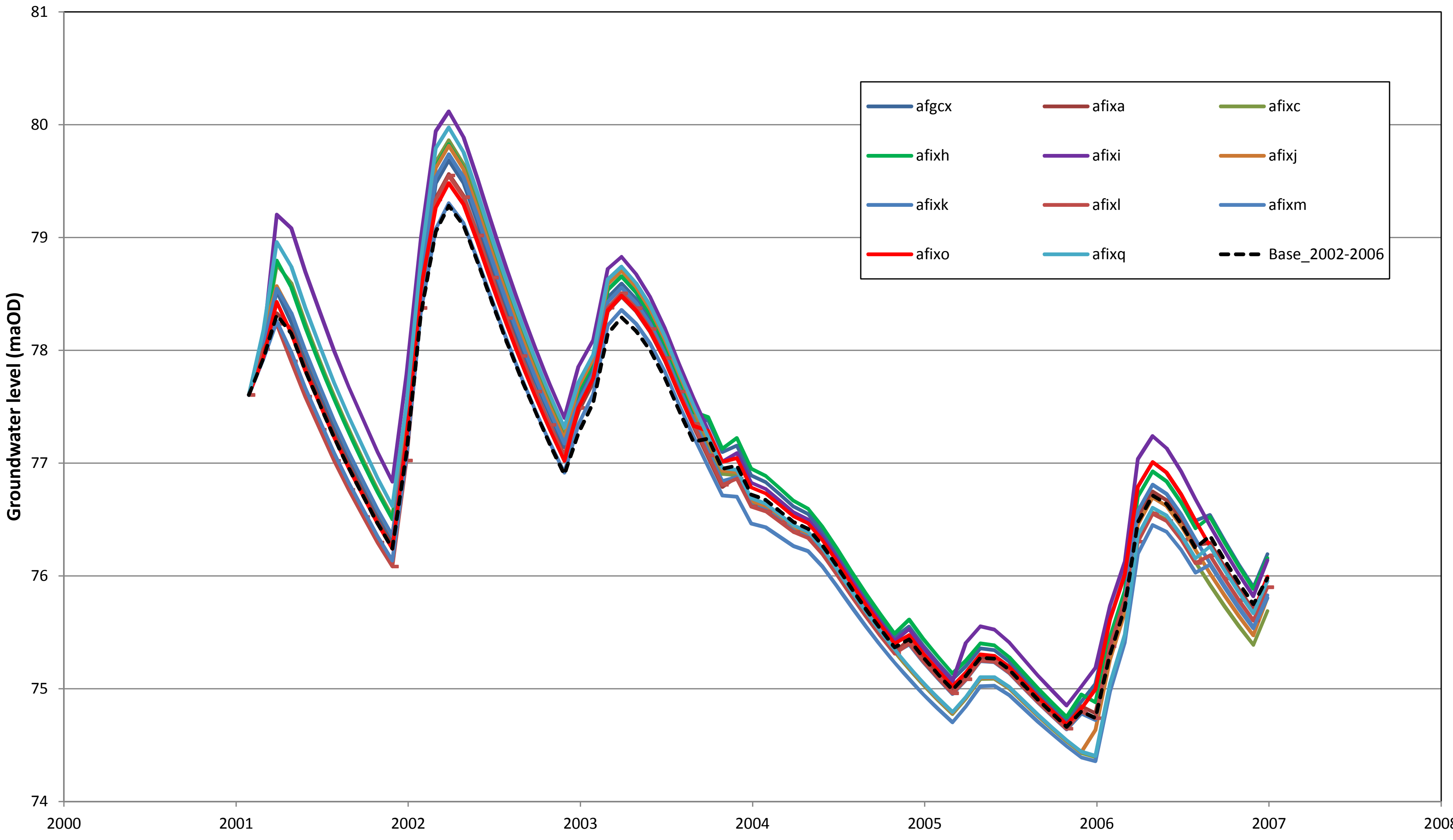
Drawing Number
FIGURE 9

Rev
0

Modelled groundwater levels at Well House Inn borehole using historic climate data perturbed with 11 Future Flow climate scenarios

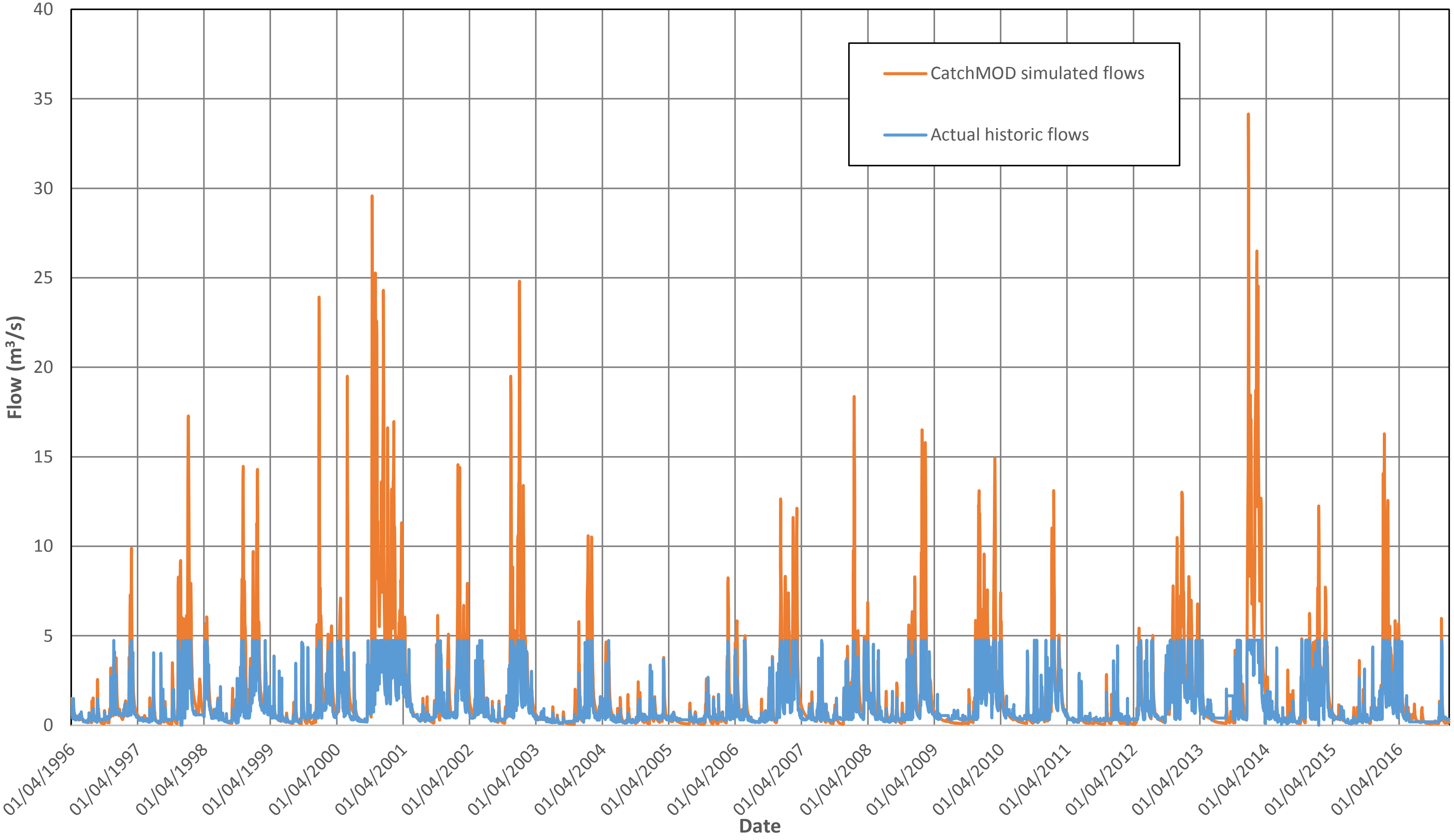


Modelled groundwater levels at Riverhead borehole using historic climate data perturbed with 11 Future Flow climate scenarios

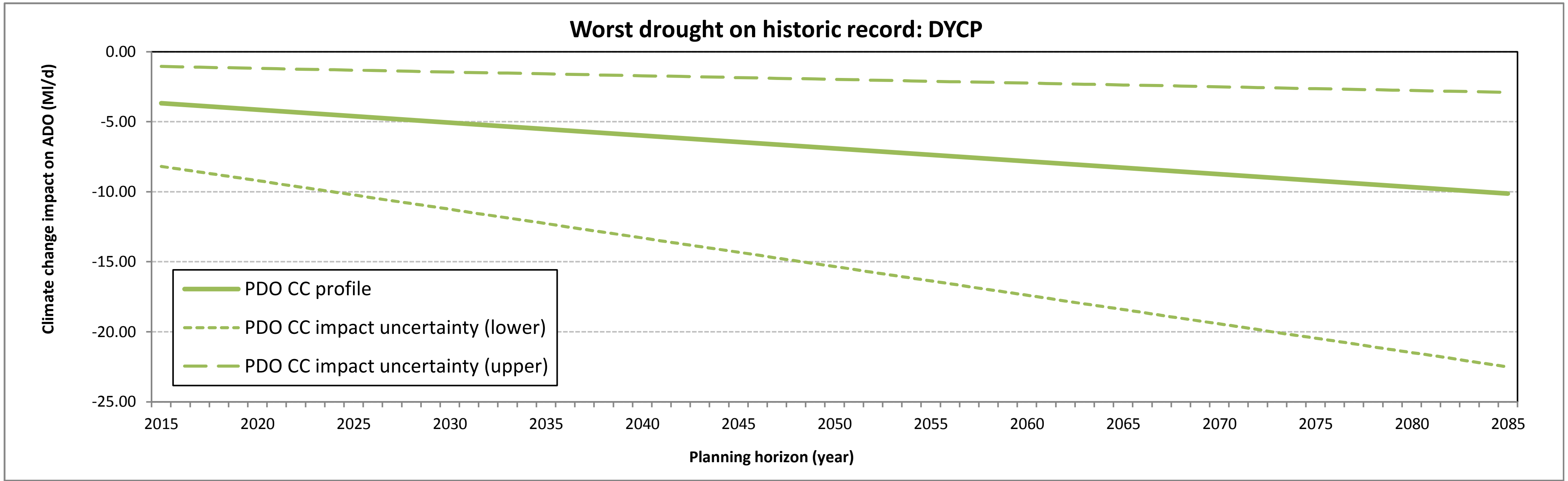


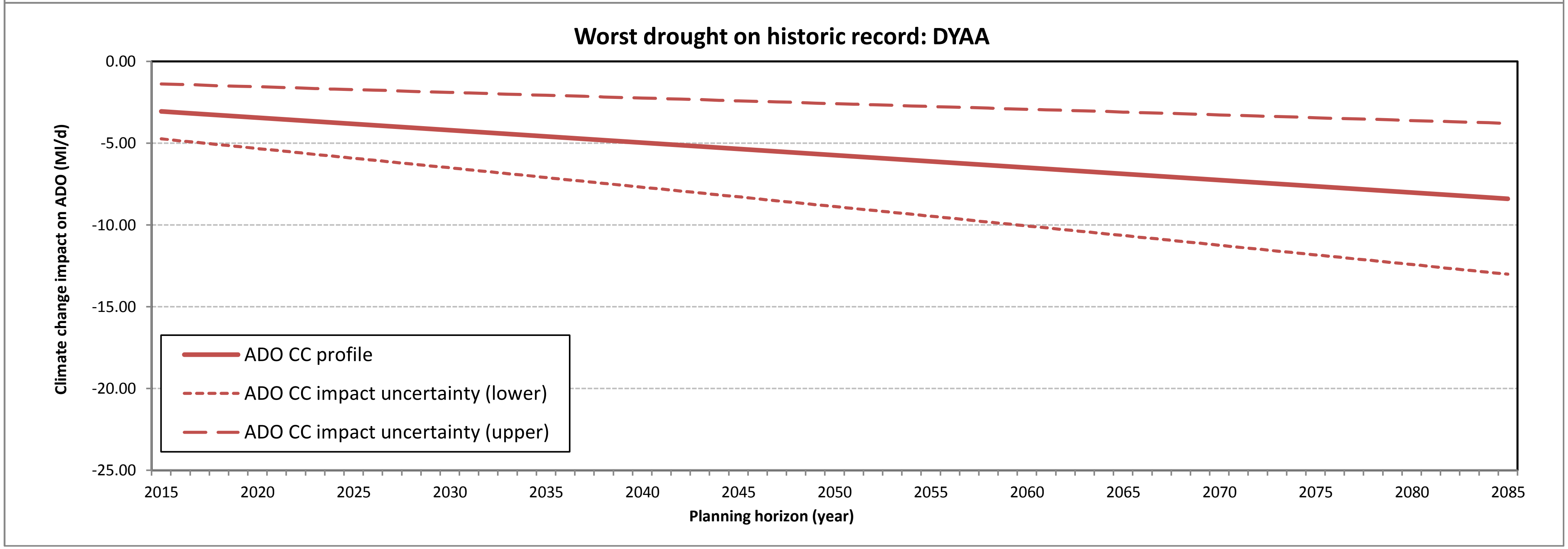
AECOM

Comparison of historic flow record and CatchMOD simulated flows at Chiddingstone

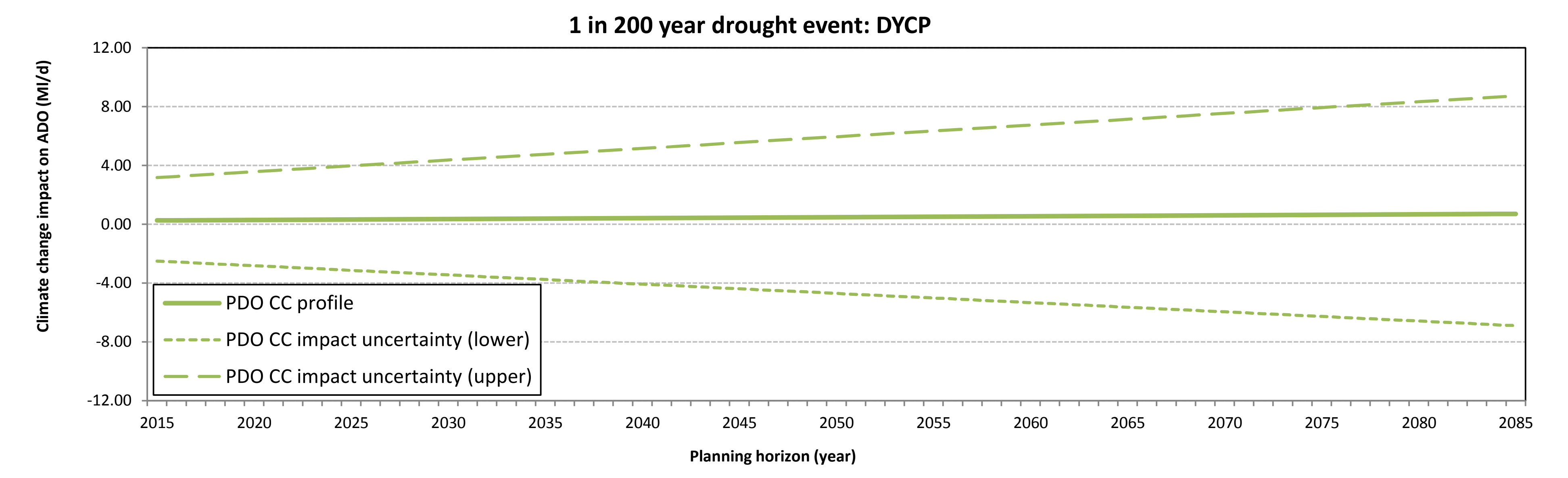


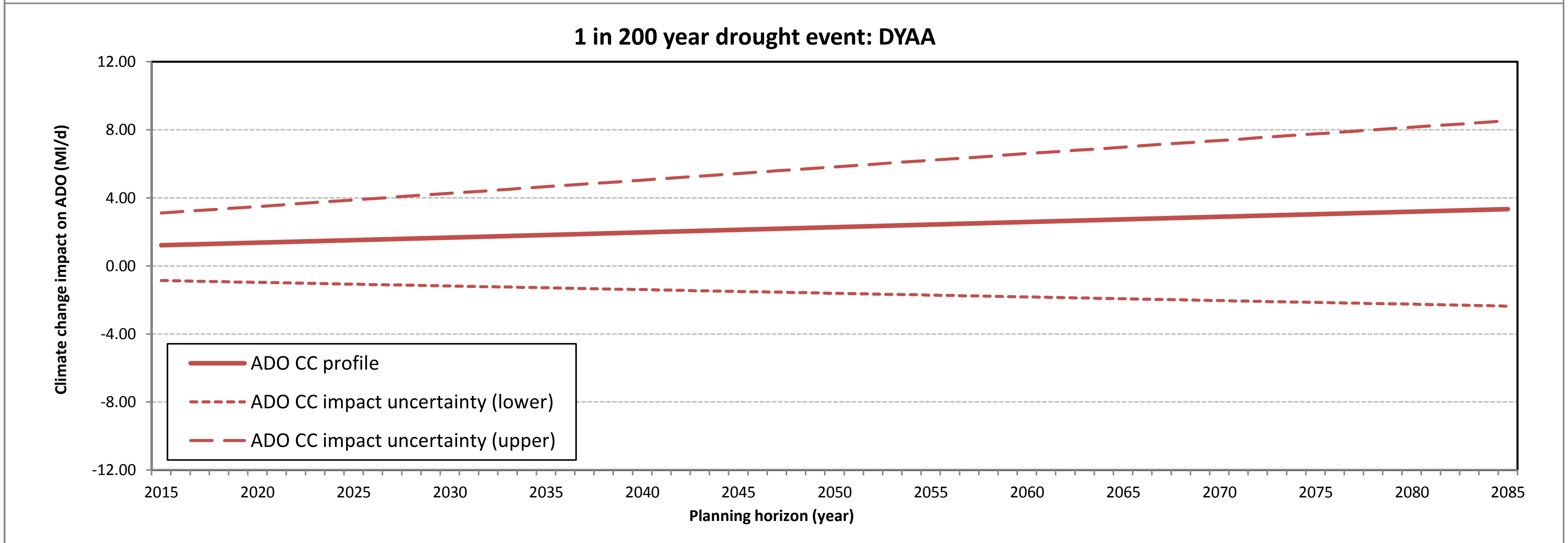
Scaling of climate change impact on DO for the planning horizon





Scaling of climate change impact on DO for the planning horizon





Appendix A Model rainfall and PET inputs

Lumped parameter model rainfall and PET inputs - groundwater

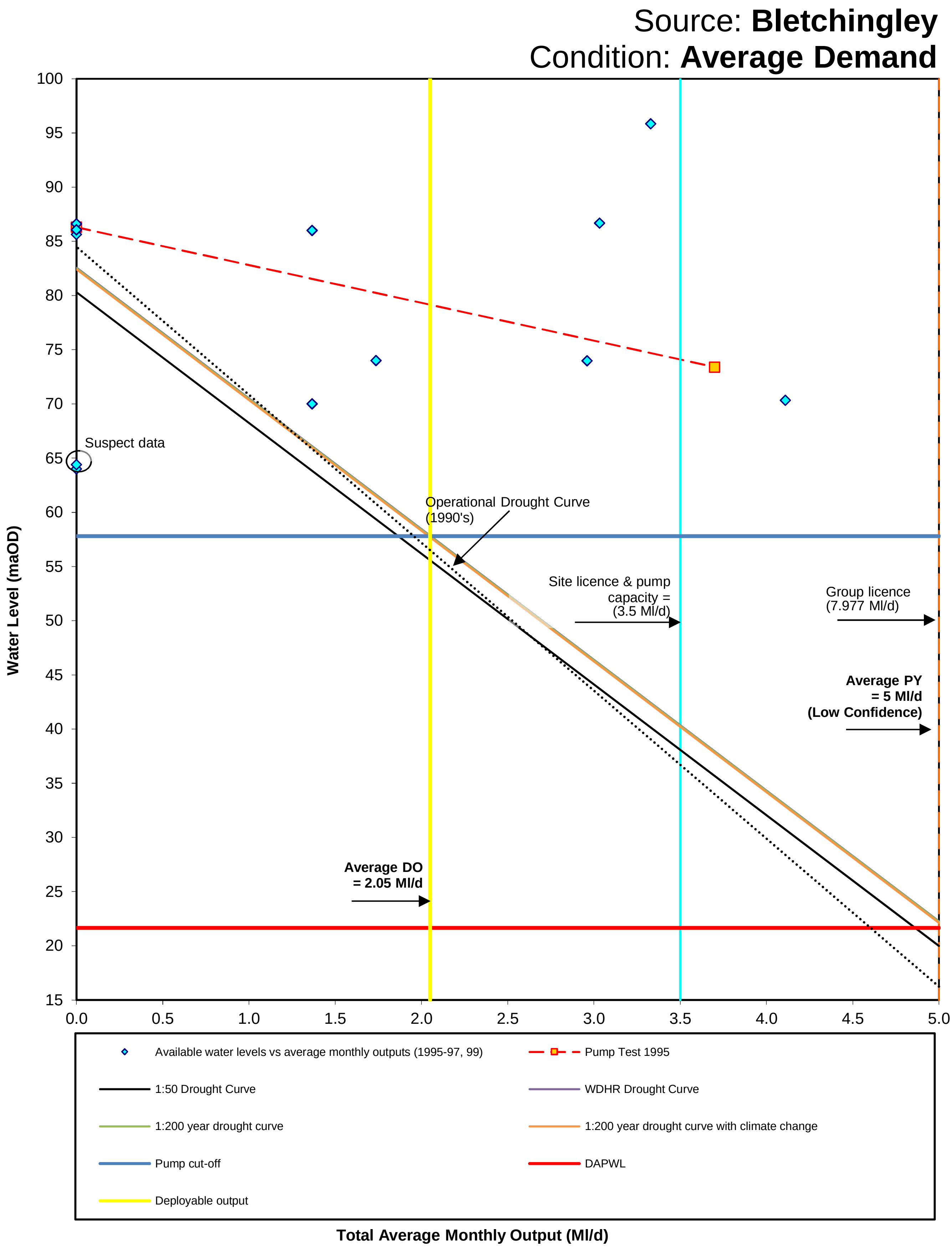
Parameter	WDHR	WDHR with climate change	1:200 year event	1:200 year event with climate change
Rainfall	South London areal rainfall (1962-2017)	South London areal rainfall perturbed by climate change factors generated using Future Flows	Stochastically generated rainfall for South London area (78 years)	Stochastically generated rainfall for South London area perturbed by climate change factors generated using Future Flows
PET	South London areal PET (1998-2017)	South London areal PET perturbed by climate change factors generated using Future Flows	Stochastically generated PET for South London area (78 years)	Stochastically generated PET for South London area perturbed by climate change factors generated using Future Flows
Origin	Environment Agency	HR Wallingford	WRSE	HR Wallingford

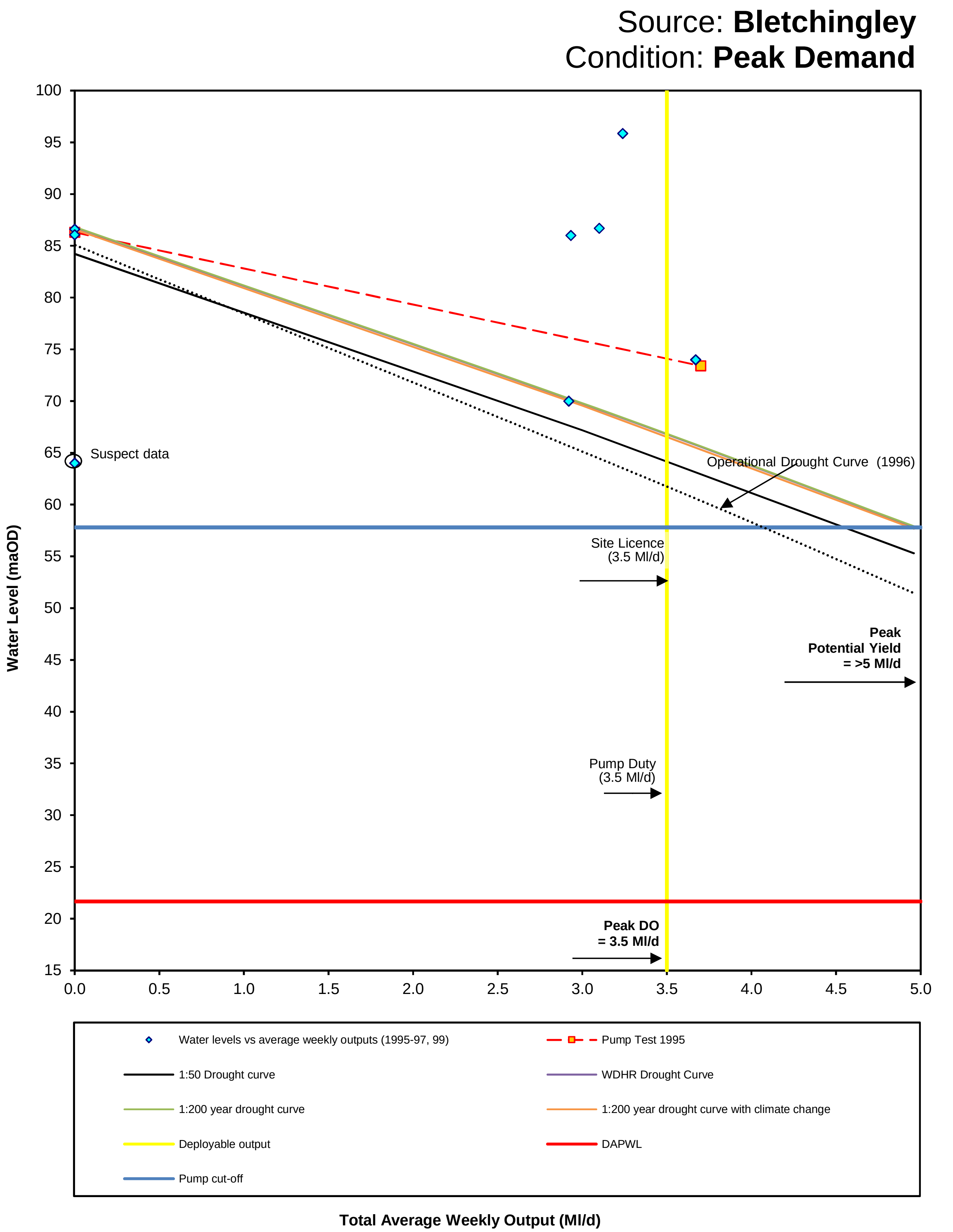
CatchMOD rainfall and PET inputs - River Eden & Mill Stream

Parameter	WDHR	WDHR with climate change	1:200 year event	1:200 year event with climate change
Rainfall	Collation of: Atkins areal rainfall (1888-2005*) Medway areal rainfall (2005-2017)	Collation of areal rainfall perturbed by climate change factors generated using Future Flows	Stochastically generated rainfall for South London area (78 years)	Stochastically generated rainfall for South London area perturbed by climate change factors generated using Future Flows
PET	Collation of: Areal PET from Reliability of Southern Region Public Water Supplies Project (1888-2005) Medway areal PET (2005-2017)	Collation of areal PET perturbed by climate change factors generated using Future Flows	Stochastically generated PET for South London area (78 years)	Stochastically generated PET for South London area perturbed by climate change factors generated using Future Flows
Origin	Atkins (2013) Environment Agency	HR Wallingford	WRSE	HR Wallingford

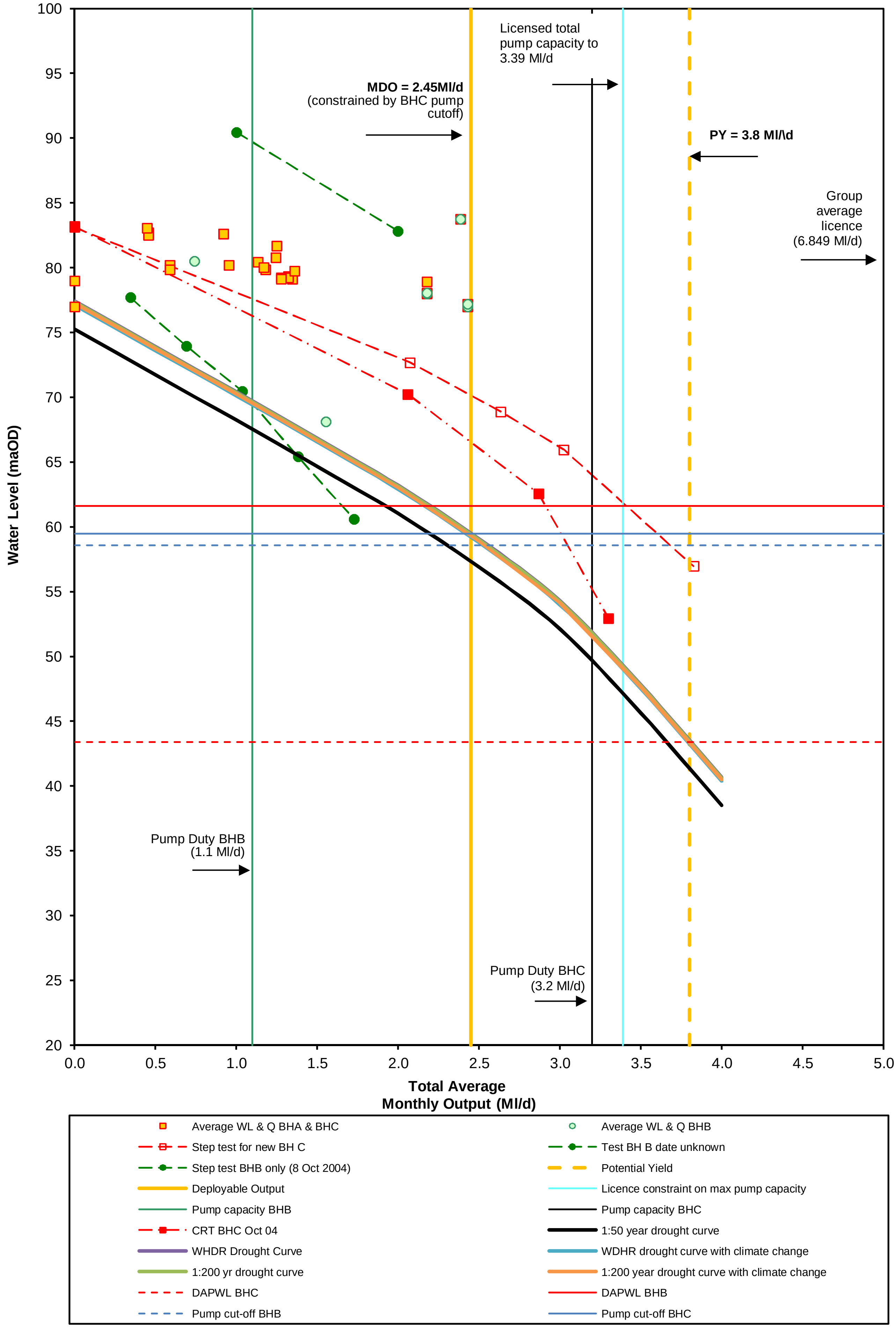
*The data from 1888 to 1919 was quite uncertain and was disregarded in subsequent Aquator modelling.

Appendix B DO assessment diagrams

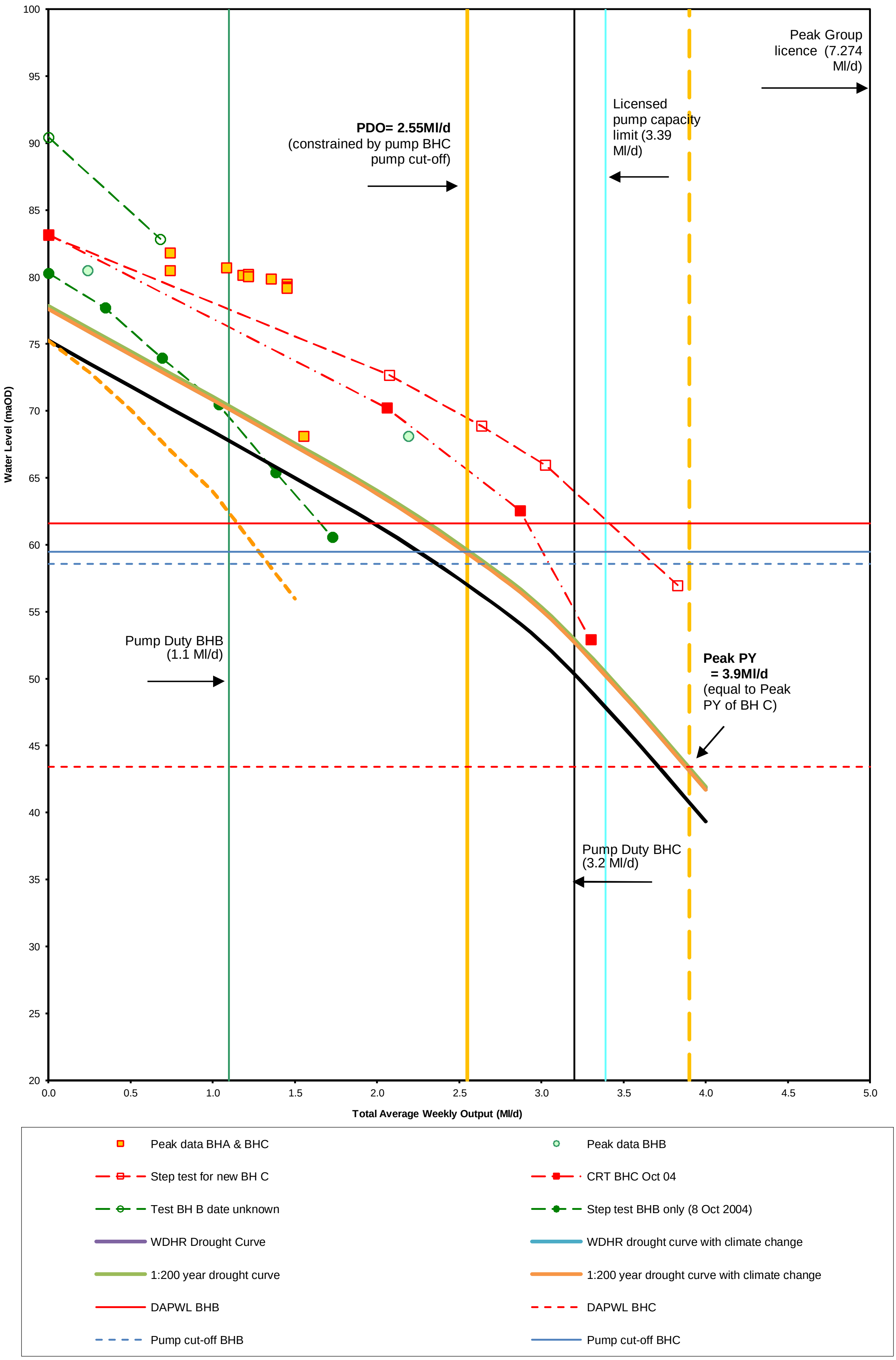

Source: Bletchingley
Condition: Average Demand
Water Level (maOD)
Total Average Monthly Output (Ml/d)
Suspect data
Operational Drought Curve (1990's)
Site licence & pump capacity = (3.5 Ml/d)
Group licence (7.977 Ml/d)
Average PY = 5 Ml/d (Low Confidence)
Average DO = 2.05 Ml/d
Available water levels vs average monthly outputs (1995-97, 99)
Pump Test 1995
1:50 Drought Curve
WDHR Drought Curve
1:200 year drought curve
1:200 year drought curve with climate change
Pump cut-off
DAPWL
Deployable output

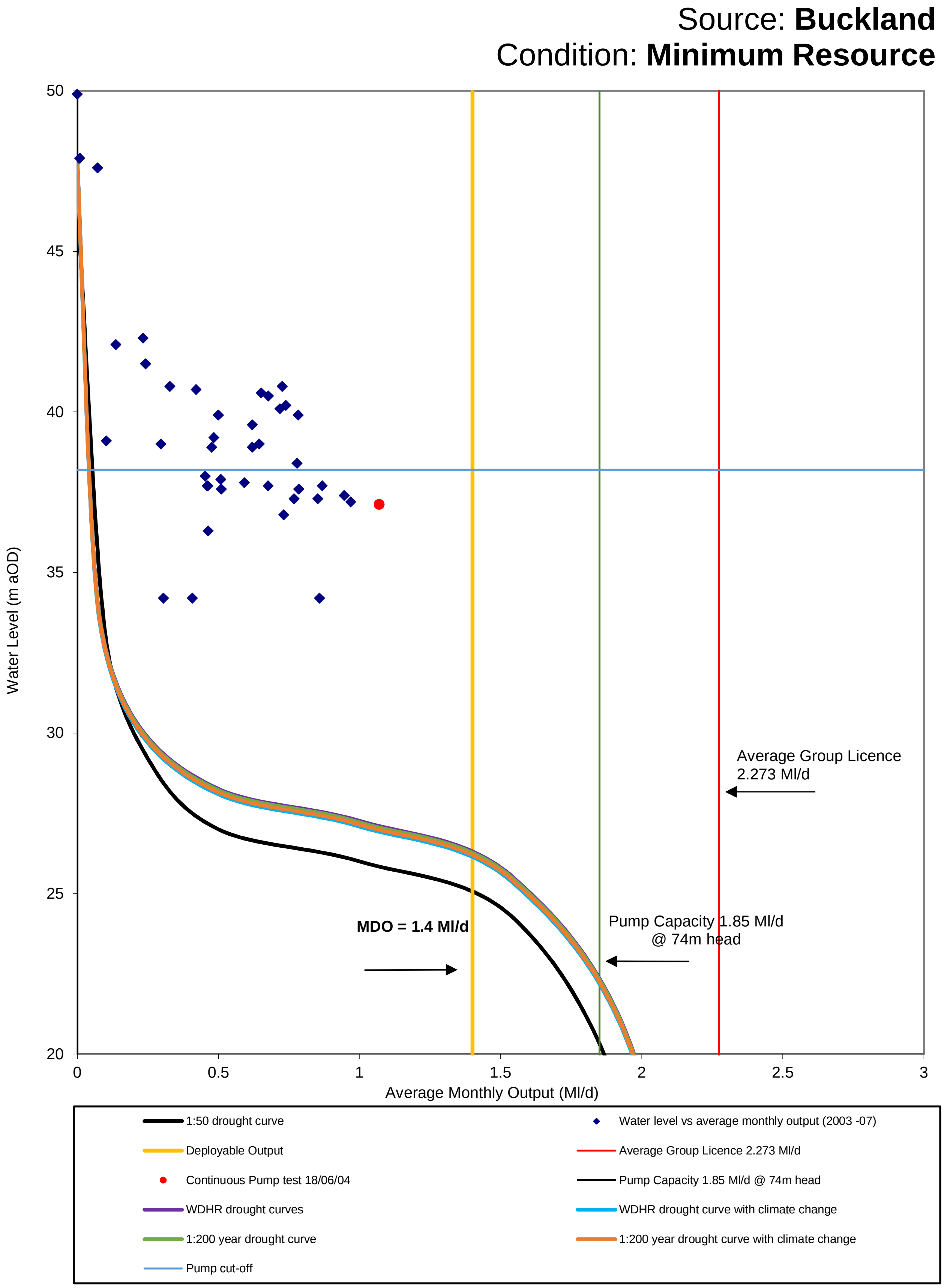

Source: **Bletchingley**
Condition: **Peak Demand**
Water Level (maOD)
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Suspect data
Operational Drought Curve (1996)
Site Licence
(3.5 Ml/d)
Peak
Potential Yield
= >5 Ml/d
Pump Duty
(3.5 Ml/d)
Peak DO
= 3.5 Ml/d
Water levels vs average weekly outputs (1995-97, 99)
Pump Test 1995
1:50 Drought curve
WDHR Drought Curve
1:200 year drought curve
1:200 year drought curve with climate change
Deployable output
DAPWL
Pump cut-off
Total Average Weekly Output (Ml/d)

Source: **Brewer Street**
Condition: **Minimum Resource**

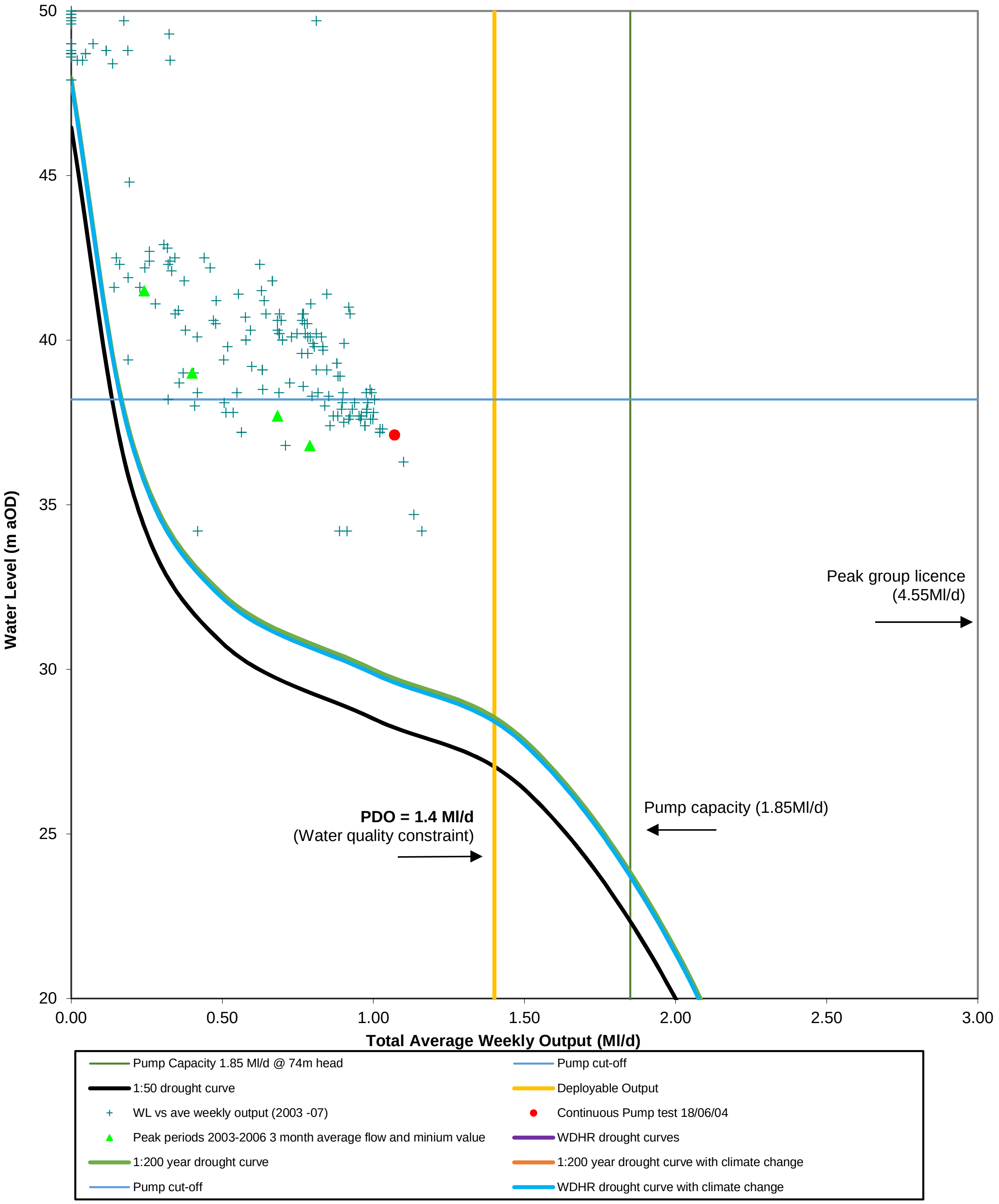


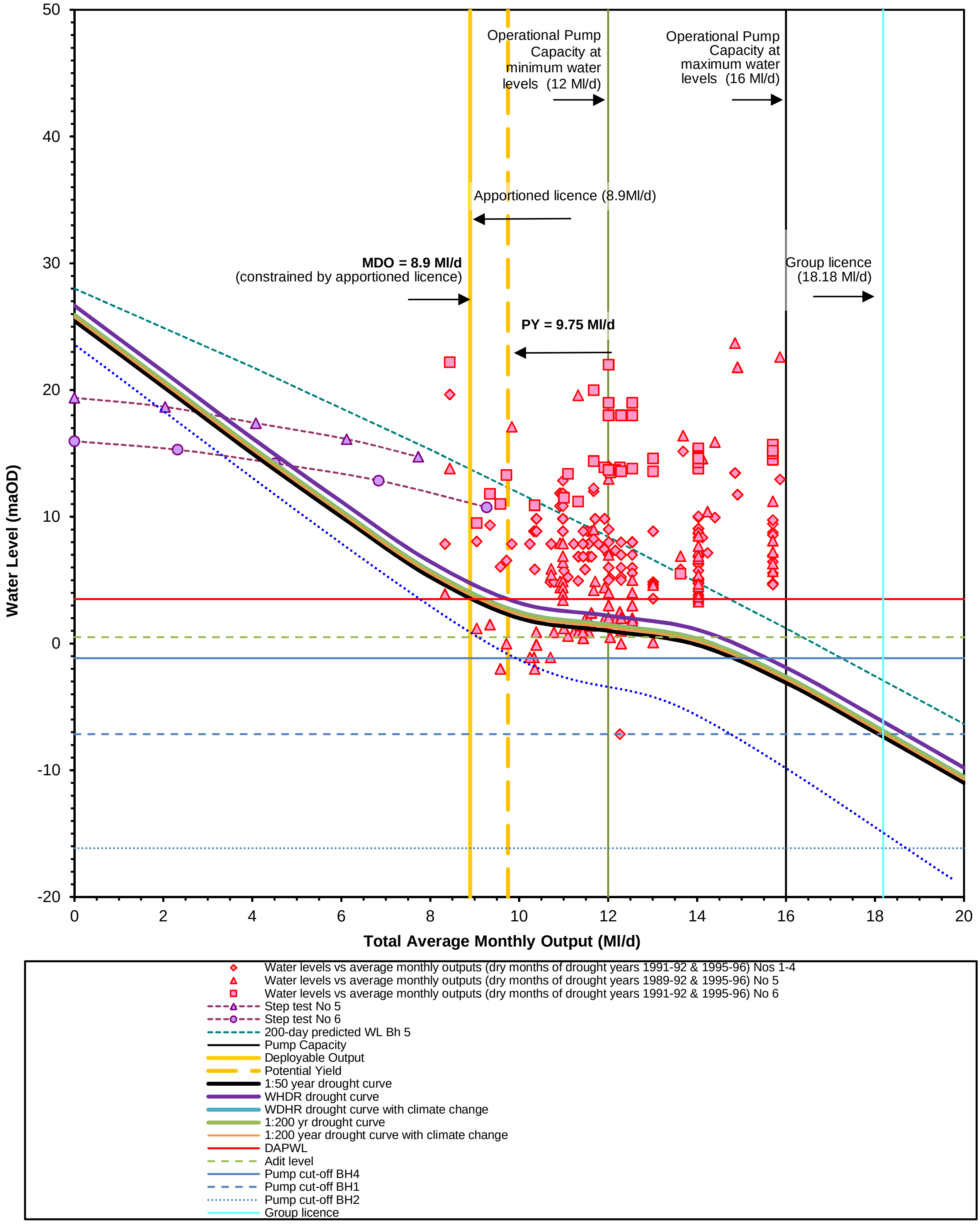
Source: **Brewer Street**
Condition: **Peak Demand**

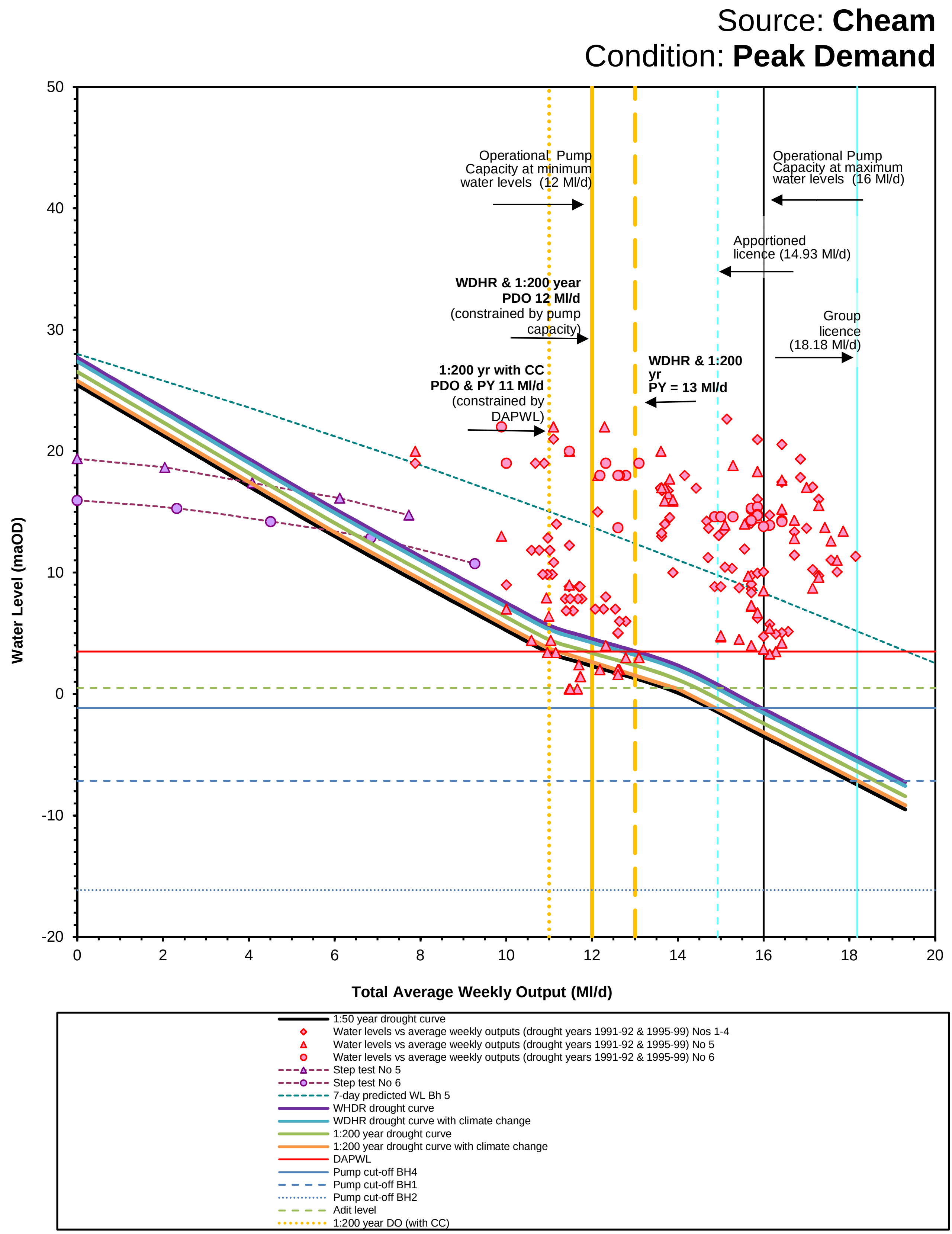



Source: **Buckland**
Condition: **Minimum Resource**
Water Level (m aOD)
50
45
40
35
30
25
20
0
0.5
1
1.5
2
2.5
3
Average Monthly Output (Ml/d)
Average Group Licence
2.273 Ml/d
MDO = 1.4 Ml/d
Pump Capacity 1.85 Ml/d
@ 74m head
1:50 drought curve
Deployable Output
Continuous Pump test 18/06/04
WDHR drought curves
1:200 year drought curve
Pump cut-off
Water level vs average monthly output (2003 -07)
Average Group Licence 2.273 Ml/d
Pump Capacity 1.85 Ml/d @ 74m head
WDHR drought curve with climate change
1:200 year drought curve with climate change

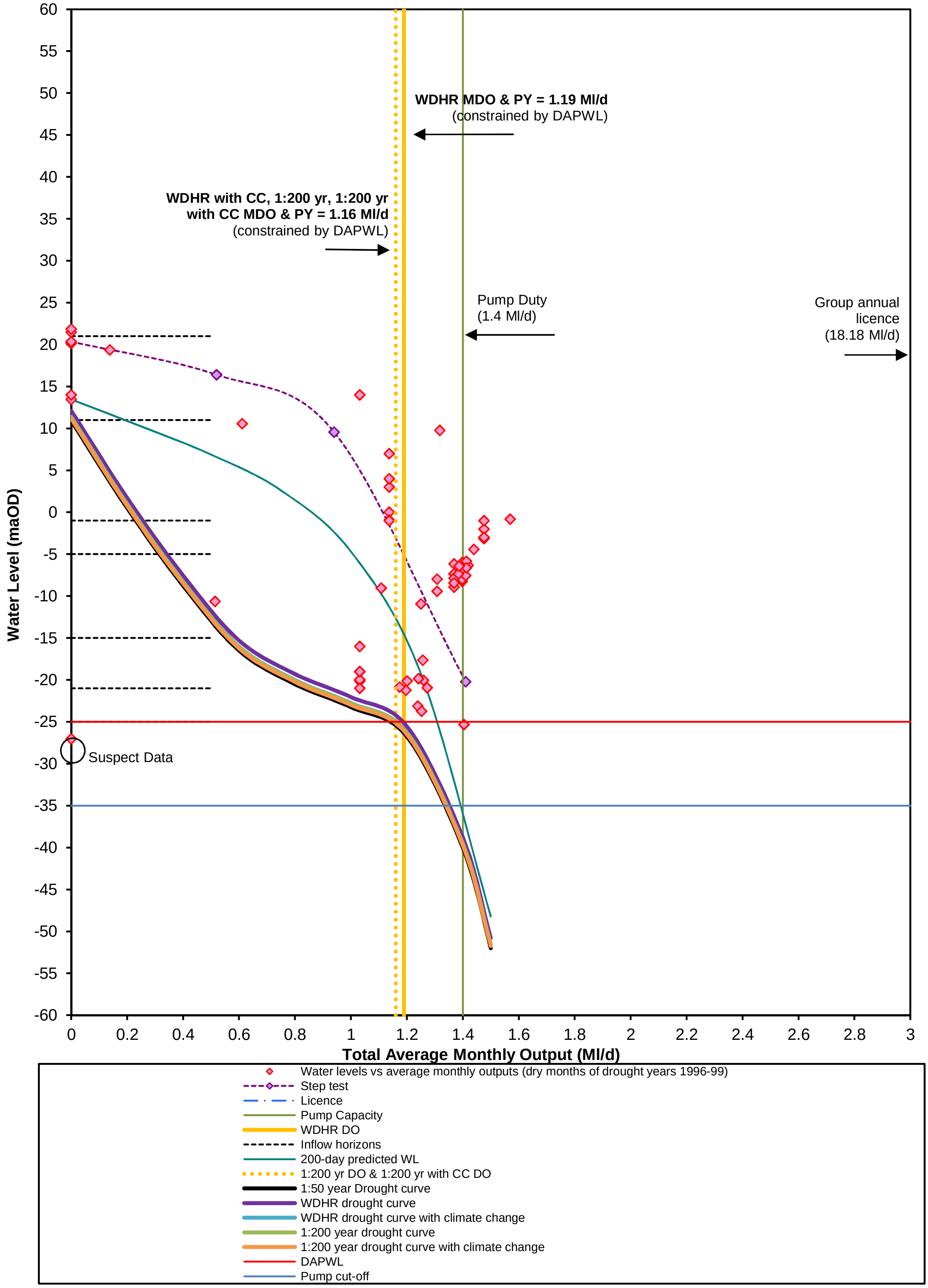
Source: **Buckland**
Condition: **Peak Demand**



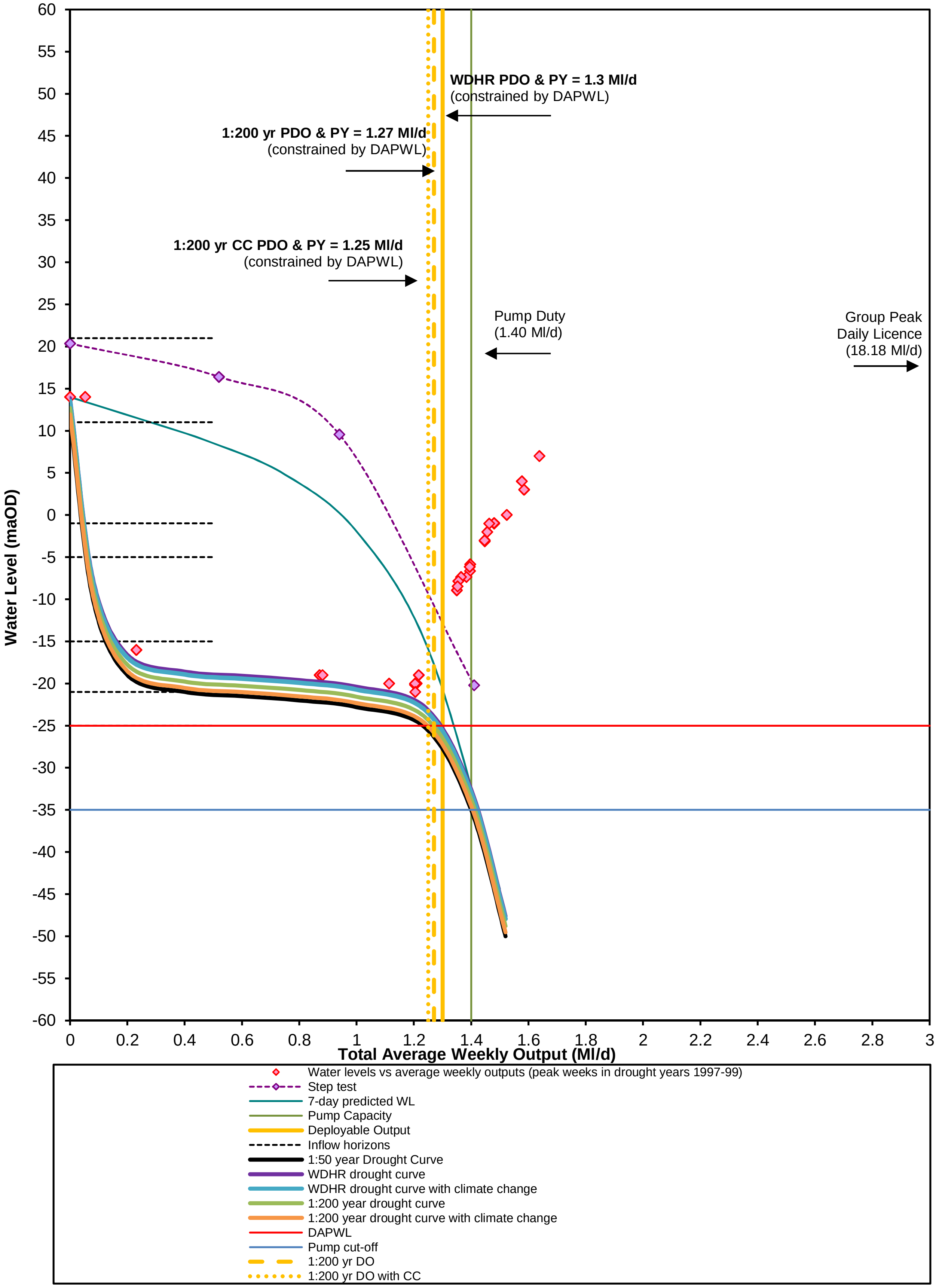

Operational Pump Capacity at minimum water levels (12 Ml/d)
Operational Pump Capacity at maximum water levels (16 Ml/d)
Apportioned licence (8.9Ml/d)
MDO = 8.9 Ml/d
(constrained by apportioned licence)
Group licence (18.18 Ml/d)
PY = 9.75 Ml/d
Water Level (maOD)
Total Average Monthly Output (Ml/d)
50
40
30
20
10
0
-10
-20
0
2
4
6
8
10
12
14
16
18
20
Water levels vs average monthly outputs (dry months of drought years 1991-92 & 1995-96) Nos 1-4
Water levels vs average monthly outputs (dry months of drought years 1989-92 & 1995-96) No 5
Water levels vs average monthly outputs (dry months of drought years 1991-92 & 1995-96) No 6
Step test No 5
Step test No 6
200-day predicted WL Bh 5
Pump Capacity
Deployable Output
Potential Yield
1:50 year drought curve
WHDR drought curve
WDHR drought curve with climate change
1:200 yr drought curve
1:200 year drought curve with climate change
DAPWL
Adit level
Pump cut-off BH4
Pump cut-off BH1
Pump cut-off BH2
Group licence


Source: Cheam
Condition: Peak Demand
Operational Pump Capacity at minimum water levels (12 Ml/d)
Operational Pump Capacity at maximum water levels (16 Ml/d)
Apportioned licence (14.93 Ml/d)
WDHR & 1:200 year PDO 12 Ml/d (constrained by pump capacity)
Group licence (18.18 Ml/d)
1:200 yr with CC PDO & PY 11 Ml/d (constrained by DAPWL)
WDHR & 1:200 yr PY = 13 Ml/d
Water Level (maOD)
Total Average Weekly Output (Ml/d)
50
40
30
20
10
0
-10
-20
0
2
4
6
8
10
12
14
16
18
20
1:50 year drought curve
Water levels vs average weekly outputs (drought years 1991-92 & 1995-99) Nos 1-4
Water levels vs average weekly outputs (drought years 1991-92 & 1995-99) No 5
Water levels vs average weekly outputs (drought years 1991-92 & 1995-99) No 6
Step test No 5
Step test No 6
7-day predicted WL Bh 5
WHDR drought curve
WDHR drought curve with climate change
1:200 year drought curve
1:200 year drought curve with climate change
DAPWL
Pump cut-off BH4
Pump cut-off BH1
Pump cut-off BH2
Adit level
1:200 year DO (with CC)

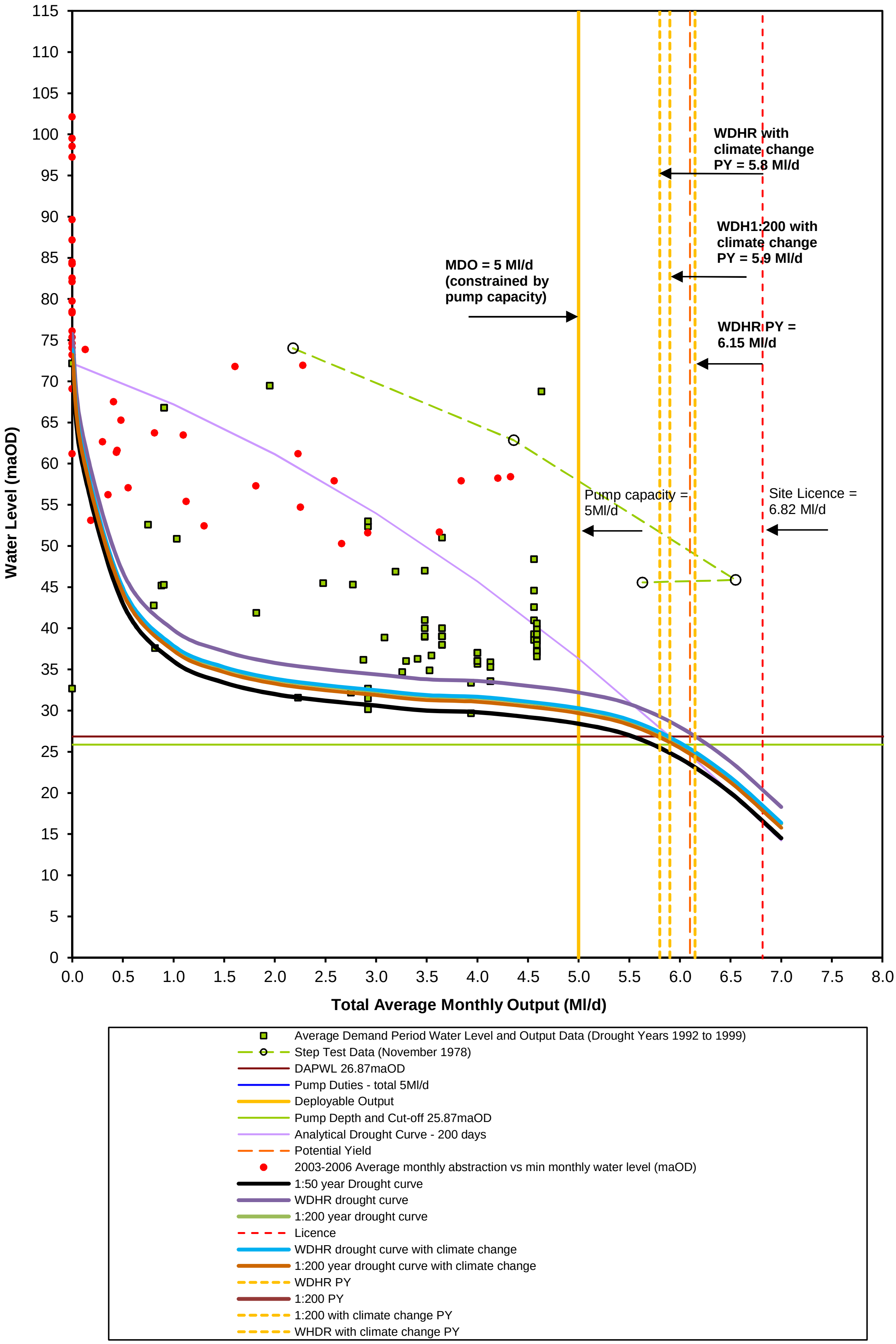
Source: **Cheam Park**
Condition: **Minimum Resource**

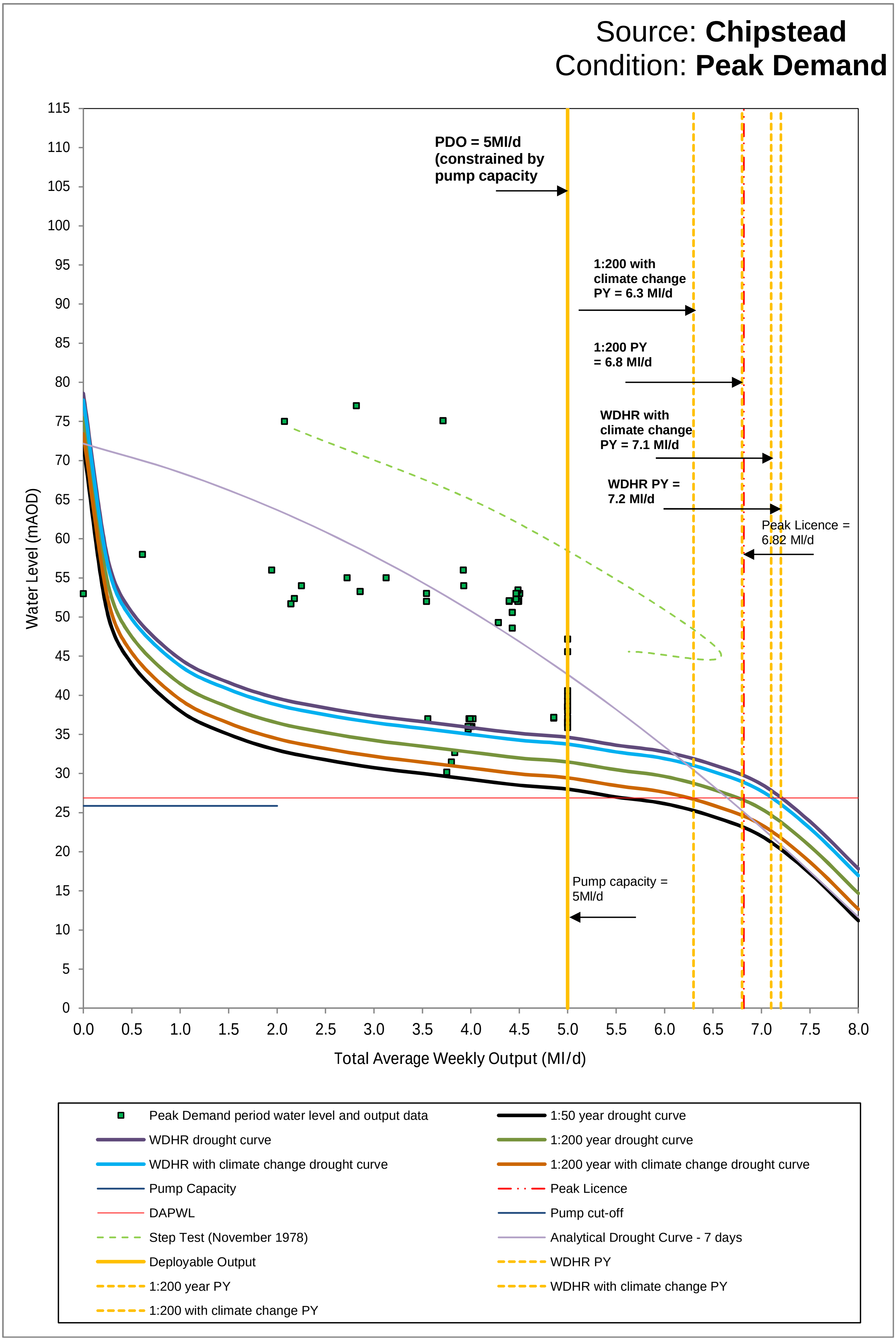


Source: **Cheam Park**
Condition: **Peak Demand**

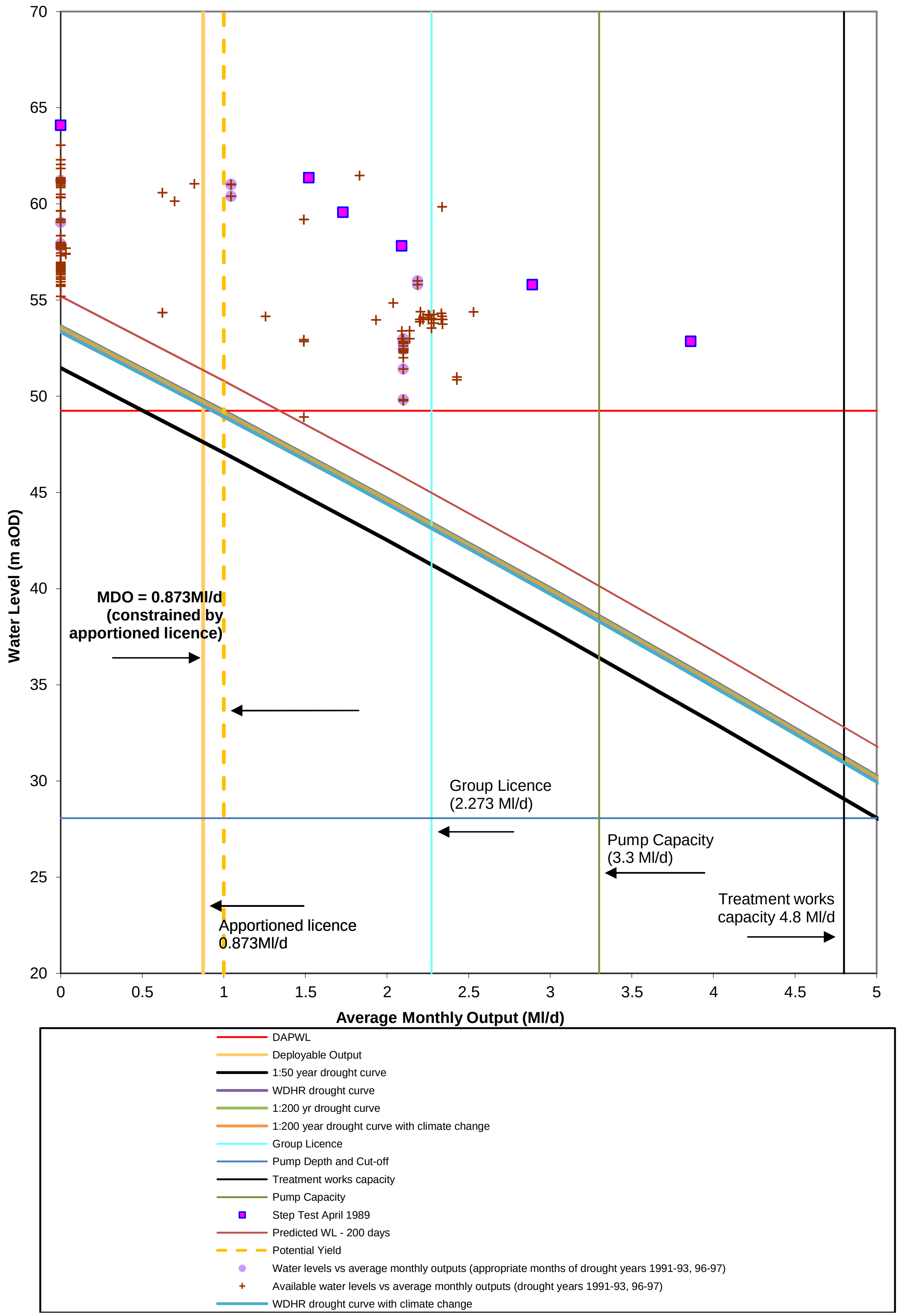


Source: **Chipstead**
Condition: **Minimum Resource**

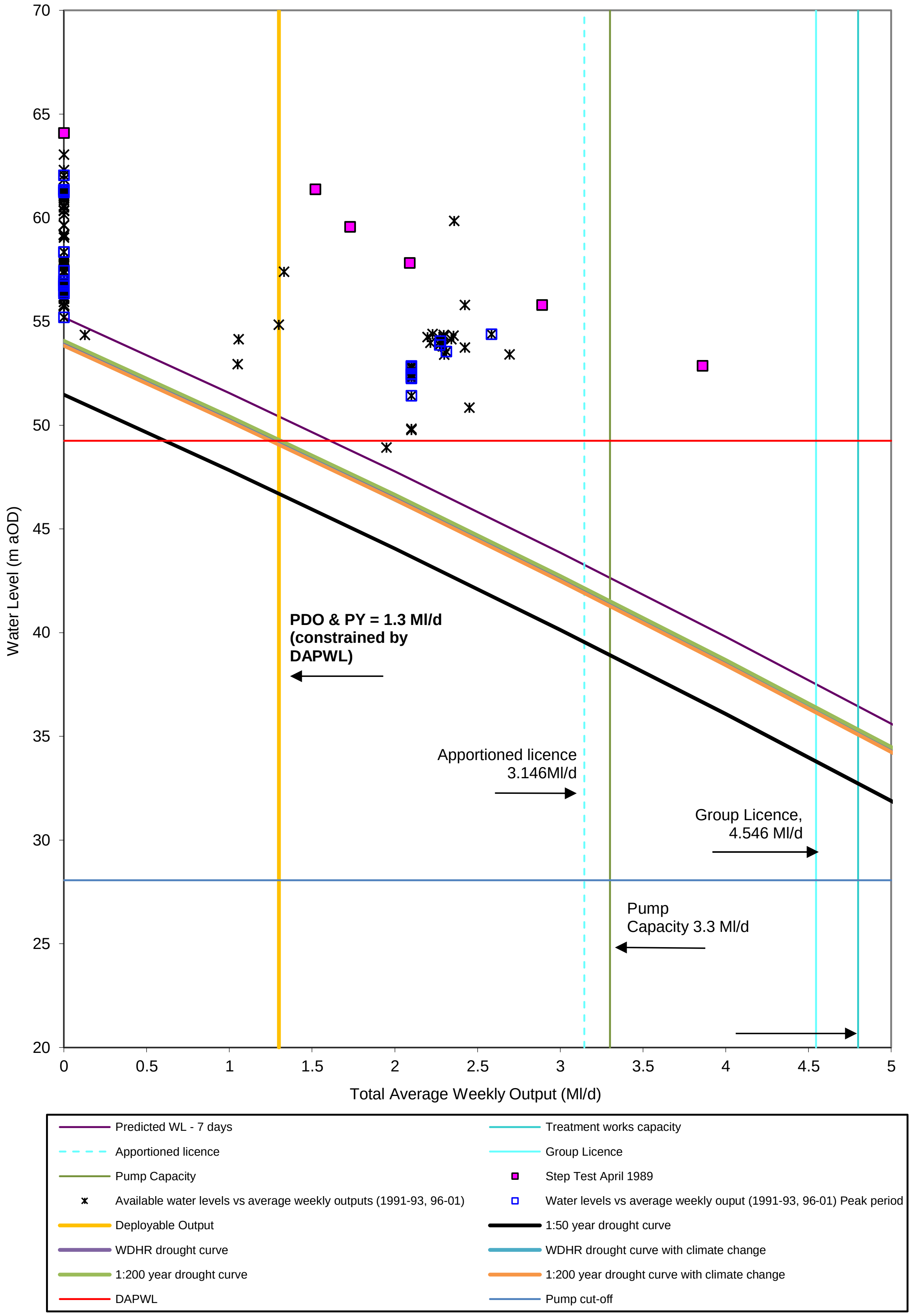


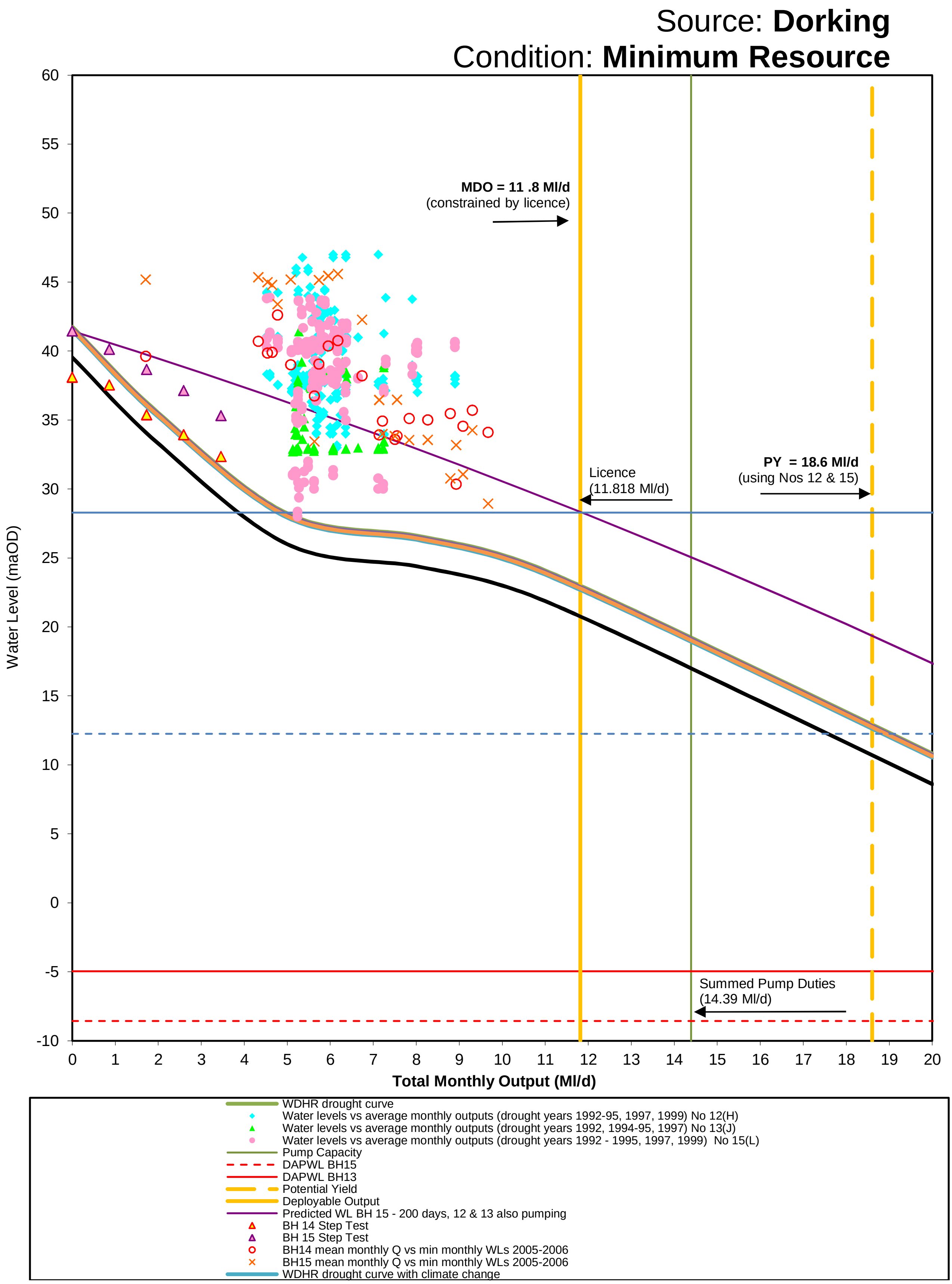

Source: **Chipstead**
Condition: **Peak Demand**
PDO = 5Ml/d (constrained by pump capacity
1:200 with climate change PY = 6.3 Ml/d
1:200 PY = 6.8 Ml/d
WDHR with climate change PY = 7.1 Ml/d
WDHR PY = 7.2 Ml/d
Peak Licence = 6.82 Ml/d
Pump capacity = 5Ml/d
Water Level (mAOD)
Total Average Weekly Output (Ml/d)
Peak Demand period water level and output data
1:50 year drought curve
WDHR drought curve
1:200 year drought curve
WDHR with climate change drought curve
1:200 year with climate change drought curve
Pump Capacity
Peak Licence
DAPWL
Pump cut-off
Step Test (November 1978)
Analytical Drought Curve - 7 days
Deployable Output
WDHR PY
1:200 year PY
WDHR with climate change PY
1:200 with climate change PY

Source: **Clifton's Lane**
Condition: **Minimum Resource**

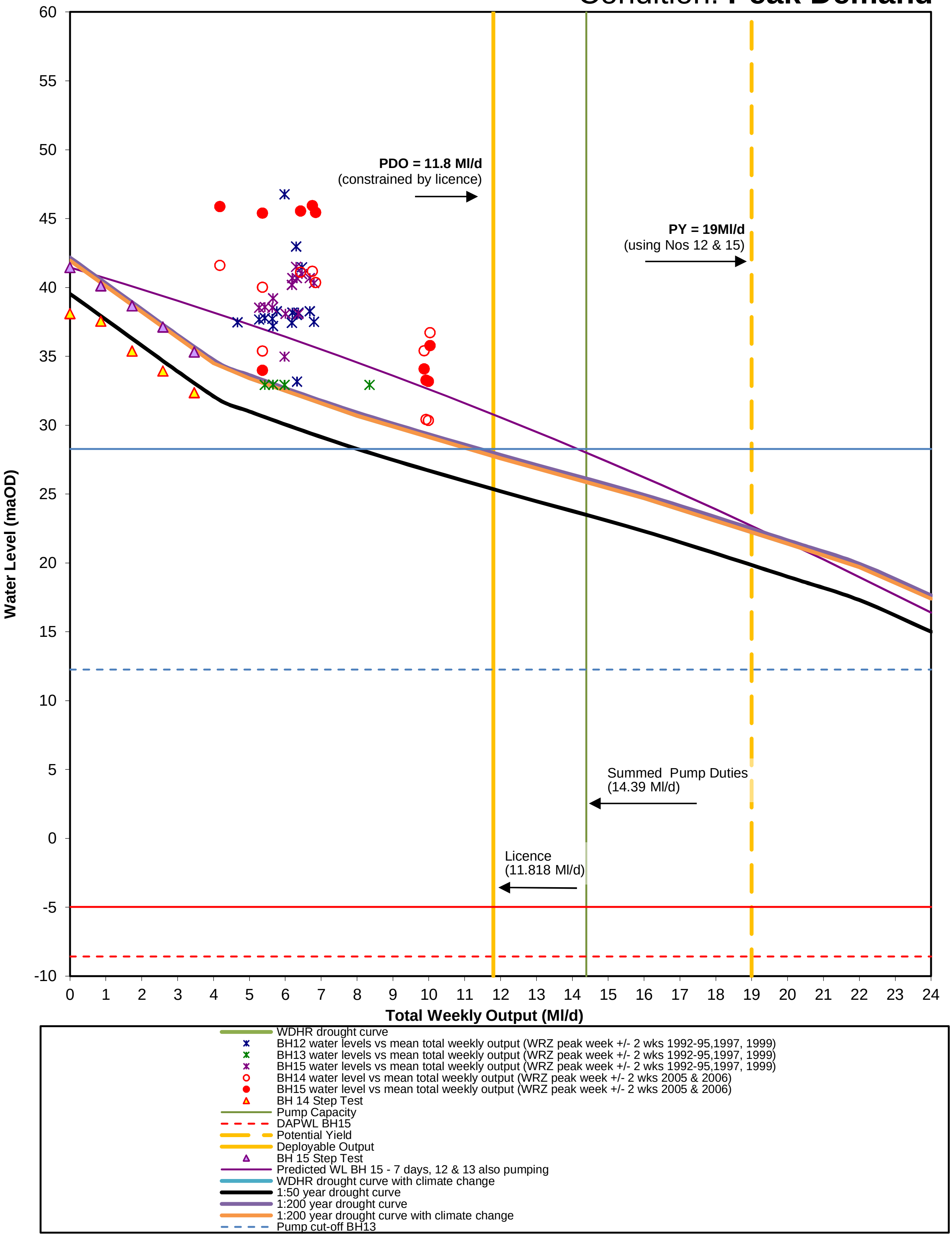


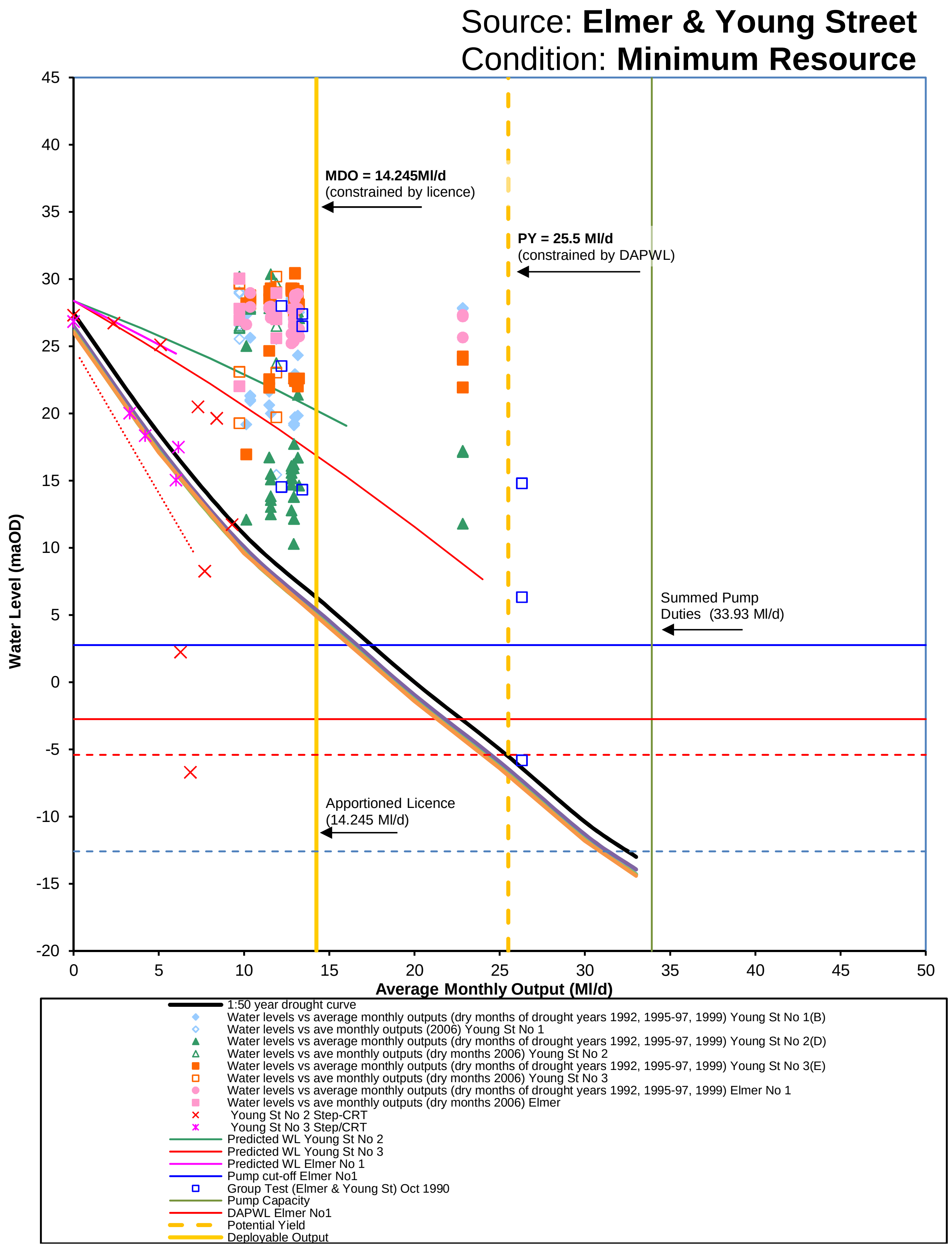
Source: **Clifton's Lane**
Condition: **Peak Demand**



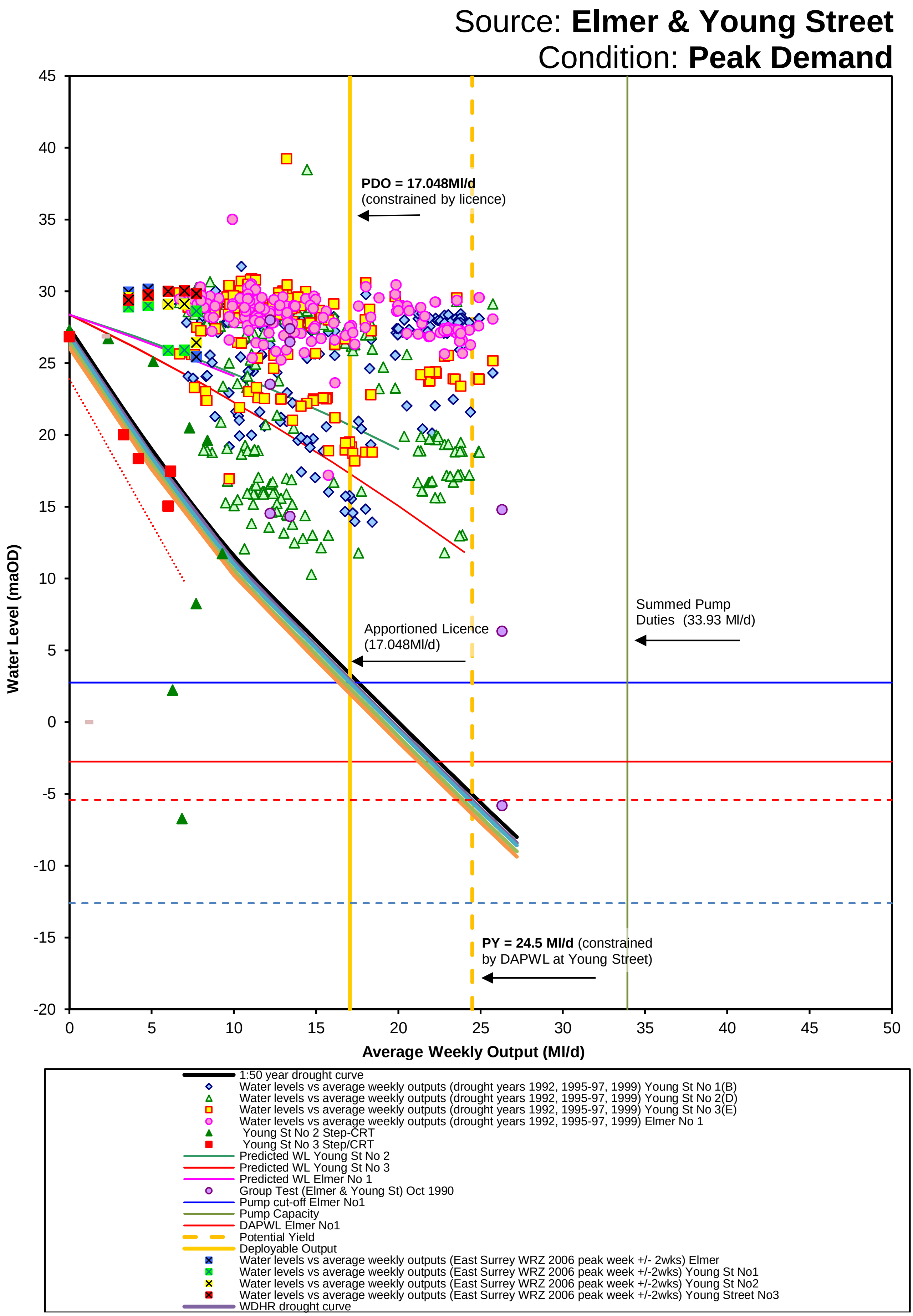

Source: **Dorking**
Condition: **Minimum Resource**
MDO = 11 .8 Ml/d
(constrained by licence)
Licence
(11.818 Ml/d)
PY = 18.6 Ml/d
(using Nos 12 & 15)
Summed Pump Duties
(14.39 Ml/d)
Water Level (maOD)
Total Monthly Output (Ml/d)
WDHR drought curve
Water levels vs average monthly outputs (drought years 1992-95, 1997, 1999) No 12(H)
Water levels vs average monthly outputs (drought years 1992, 1994-95, 1997) No 13(J)
Water levels vs average monthly outputs (drought years 1992 - 1995, 1997, 1999) No 15(L)
Pump Capacity
DAPWL BH15
DAPWL BH13
Potential Yield
Deployable Output
Predicted WL BH 15 - 200 days, 12 & 13 also pumping
BH 14 Step Test
BH 15 Step Test
BH14 mean monthly Q vs min monthly WLs 2005-2006
BH15 mean monthly Q vs min monthly WLs 2005-2006
WDHR drought curve with climate change

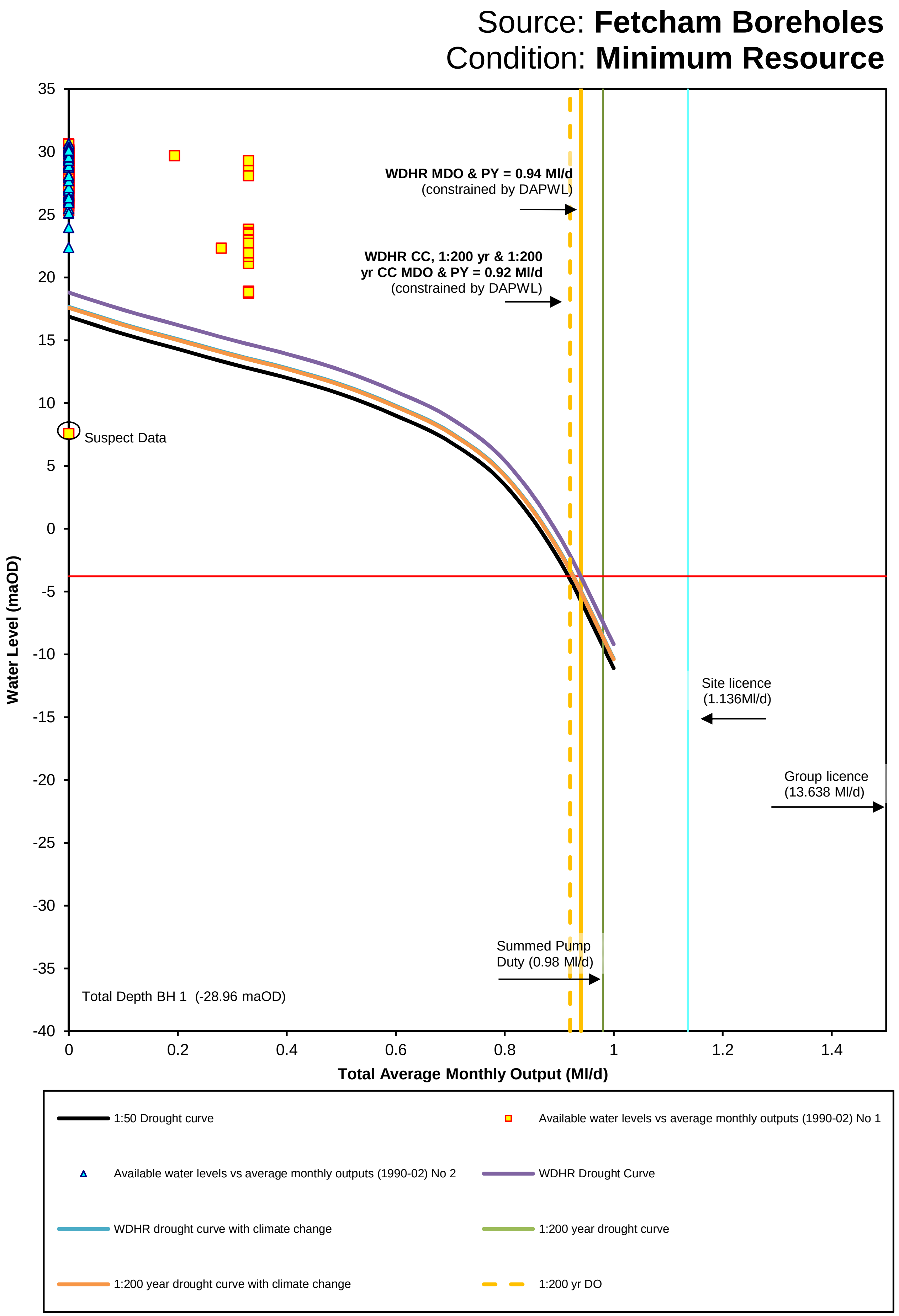
Source: **Dorking**
Condition: **Peak Demand**



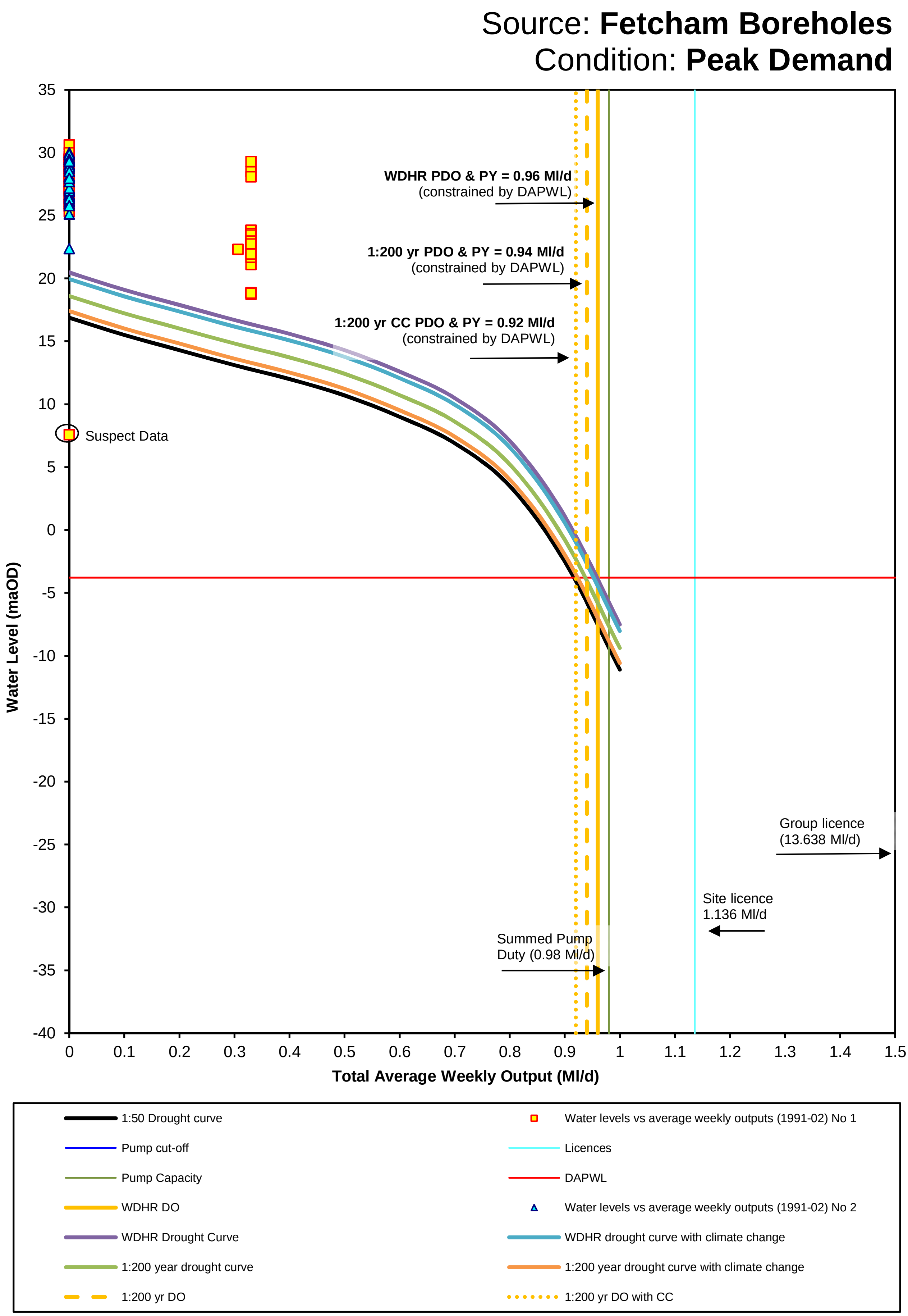


Source: **Elmer & Young Street**
Condition: **Minimum Resource**
MDO = 14.245Ml/d
(constrained by licence)
PY = 25.5 Ml/d
(constrained by DAPWL)
Summed Pump
Duties (33.93 Ml/d)
Apportioned Licence
(14.245 Ml/d)
Water Level (maOD)
Average Monthly Output (Ml/d)
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0
5
10
15
20
25
30
35
40
45
50
1:50 year drought curve
Water levels vs average monthly outputs (dry months of drought years 1992, 1995-97, 1999) Young St No 1(B)
Water levels vs ave monthly outputs (2006) Young St No 1
Water levels vs average monthly outputs (dry months of drought years 1992, 1995-97, 1999) Young St No 2(D)
Water levels vs ave monthly outputs (dry months 2006) Young St No 2
Water levels vs average monthly outputs (dry months of drought years 1992, 1995-97, 1999) Young St No 3(E)
Water levels vs ave monthly outputs (dry months 2006) Young St No 3
Water levels vs average monthly outputs (dry months of drought years 1992, 1995-97, 1999) Elmer No 1
Water levels vs ave monthly outputs (dry months 2006) Elmer
Young St No 2 Step-CRT
Young St No 3 Step/CRT
Predicted WL Young St No 2
Predicted WL Young St No 3
Predicted WL Elmer No 1
Pump cut-off Elmer No1
Group Test (Elmer & Young St) Oct 1990
Pump Capacity
DAPWL Elmer No1
Potential Yield
Deployable Output

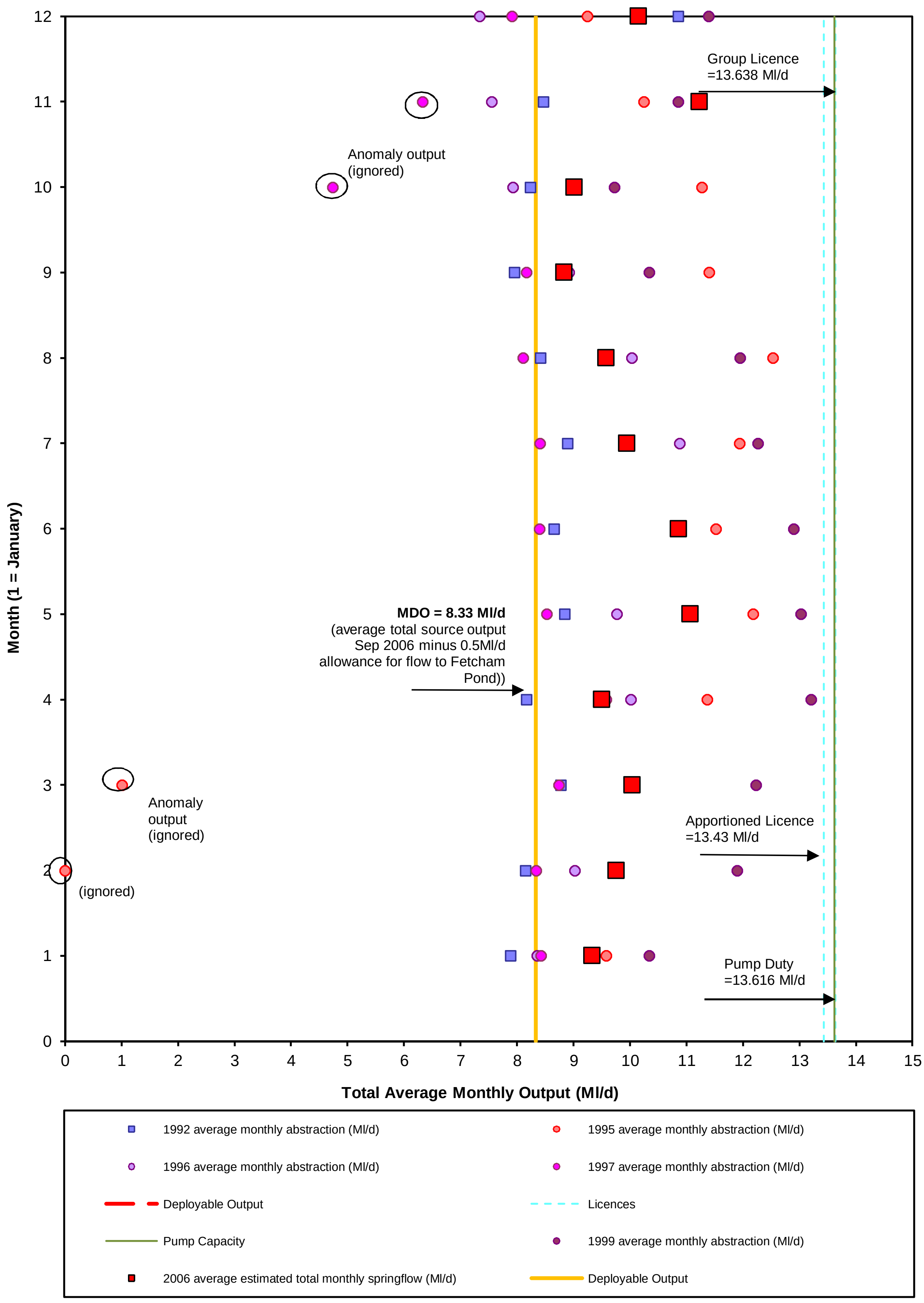

Source: **Elmer & Young Street**
Condition: **Peak Demand**
PDO = 17.048Ml/d
(constrained by licence)
Apportioned Licence
(17.048Ml/d)
Summed Pump
Duties (33.93 Ml/d)
PY = 24.5 Ml/d (constrained
by DAPWL at Young Street)
Water Level (maOD)
Average Weekly Output (Ml/d)
1:50 year drought curve
Water levels vs average weekly outputs (drought years 1992, 1995-97, 1999) Young St No 1(B)
Water levels vs average weekly outputs (drought years 1992, 1995-97, 1999) Young St No 2(D)
Water levels vs average weekly outputs (drought years 1992, 1995-97, 1999) Young St No 3(E)
Water levels vs average weekly outputs (drought years 1992, 1995-97, 1999) Elmer No 1
Young St No 2 Step-CRT
Young St No 3 Step/CRT
Predicted WL Young St No 2
Predicted WL Young St No 3
Predicted WL Elmer No 1
Group Test (Elmer & Young St) Oct 1990
Pump cut-off Elmer No1
Pump Capacity
DAPWL Elmer No1
Potential Yield
Deployable Output
Water levels vs average weekly outputs (East Surrey WRZ 2006 peak week +/- 2wks) Elmer
Water levels vs average weekly outputs (East Surrey WRZ 2006 peak week +/-2wks) Young St No1
Water levels vs average weekly outputs (East Surrey WRZ 2006 peak week +/-2wks) Young St No2
Water levels vs average weekly outputs (East Surrey WRZ 2006 peak week +/-2wks) Young Street No3
WDHR drought curve



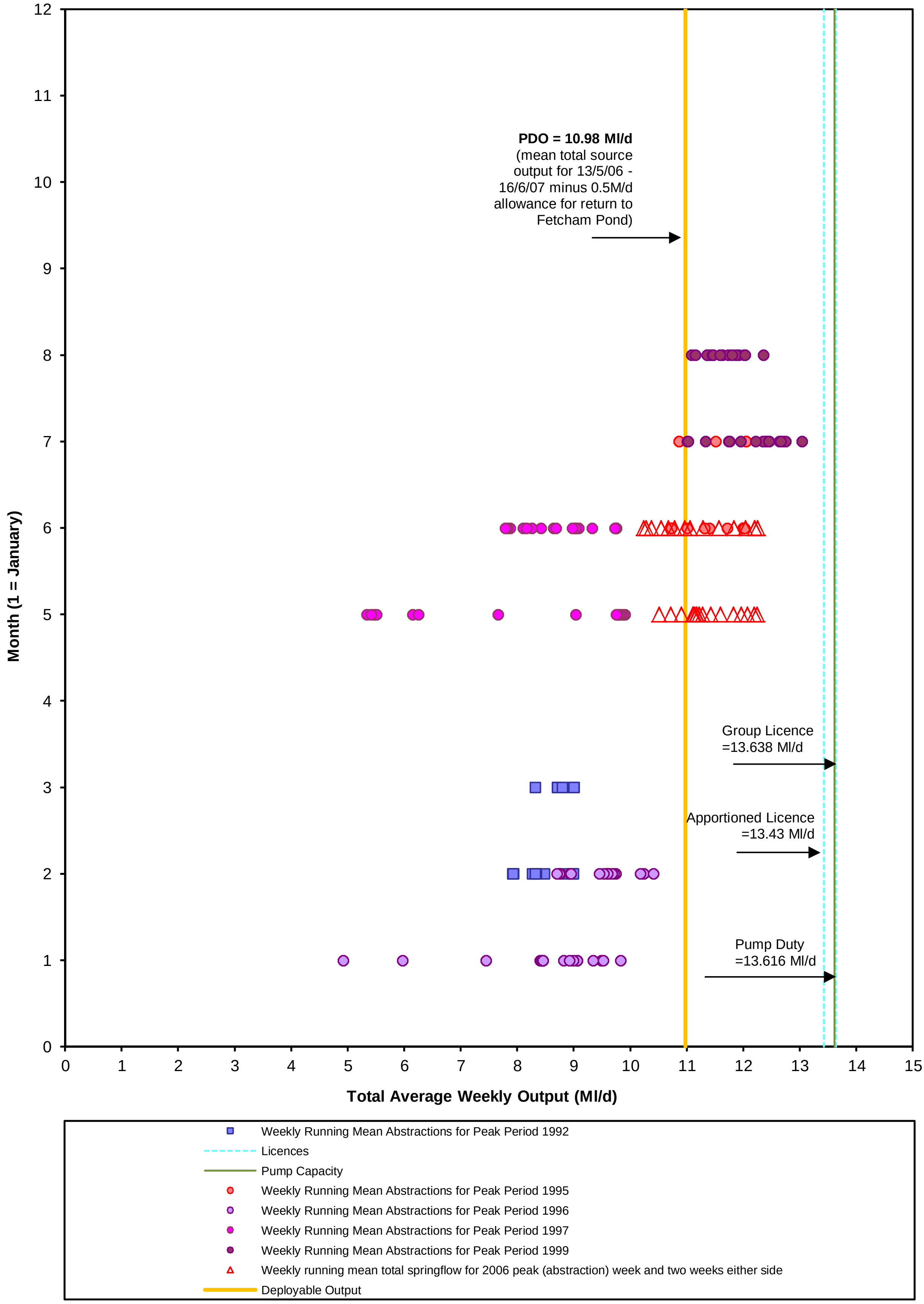
Source: Fetcham Boreholes
Condition: Minimum Resource
WDHR MDO & PY = 0.94 Ml/d
(constrained by DAPWL)
WDHR CC, 1:200 yr & 1:200 yr CC MDO & PY = 0.92 Ml/d
(constrained by DAPWL)
Suspect Data
Site licence
(1.136Ml/d)
Group licence
(13.638 Ml/d)
Summed Pump Duty (0.98 Ml/d)
Total Depth BH 1 (-28.96 maOD)
Water Level (maOD)
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0
0.2
0.4
0.6
0.8
1
1.2
1.4
Total Average Monthly Output (Ml/d)
1:50 Drought curve
Available water levels vs average monthly outputs (1990-02) No 1
Available water levels vs average monthly outputs (1990-02) No 2
WDHR Drought Curve
WDHR drought curve with climate change
1:200 year drought curve
1:200 year drought curve with climate change
1:200 yr DO

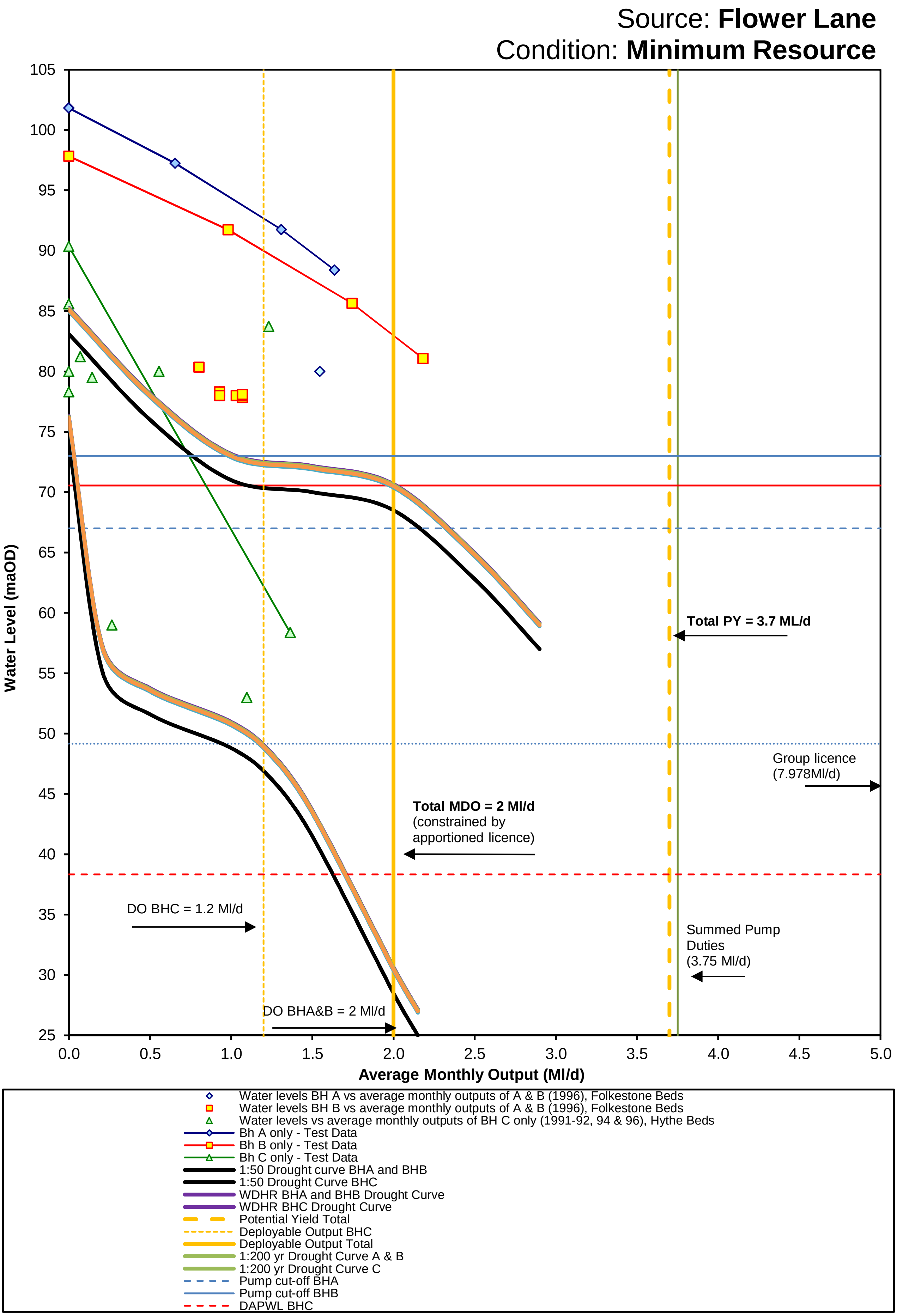

Source: Fetcham Boreholes
Condition: Peak Demand
WDHR PDO & PY = 0.96 Ml/d
(constrained by DAPWL)
1:200 yr PDO & PY = 0.94 Ml/d
(constrained by DAPWL)
1:200 yr CC PDO & PY = 0.92 Ml/d
(constrained by DAPWL)
Suspect Data
Group licence
(13.638 Ml/d)
Site licence
1.136 Ml/d
Summed Pump
Duty (0.98 Ml/d)
Water Level (maOD)
Total Average Weekly Output (Ml/d)
1:50 Drought curve
Pump cut-off
Pump Capacity
WDHR DO
WDHR Drought Curve
1:200 year drought curve
1:200 yr DO
Water levels vs average weekly outputs (1991-02) No 1
Licences
DAPWL
Water levels vs average weekly outputs (1991-02) No 2
WDHR drought curve with climate change
1:200 year drought curve with climate change
1:200 yr DO with CC

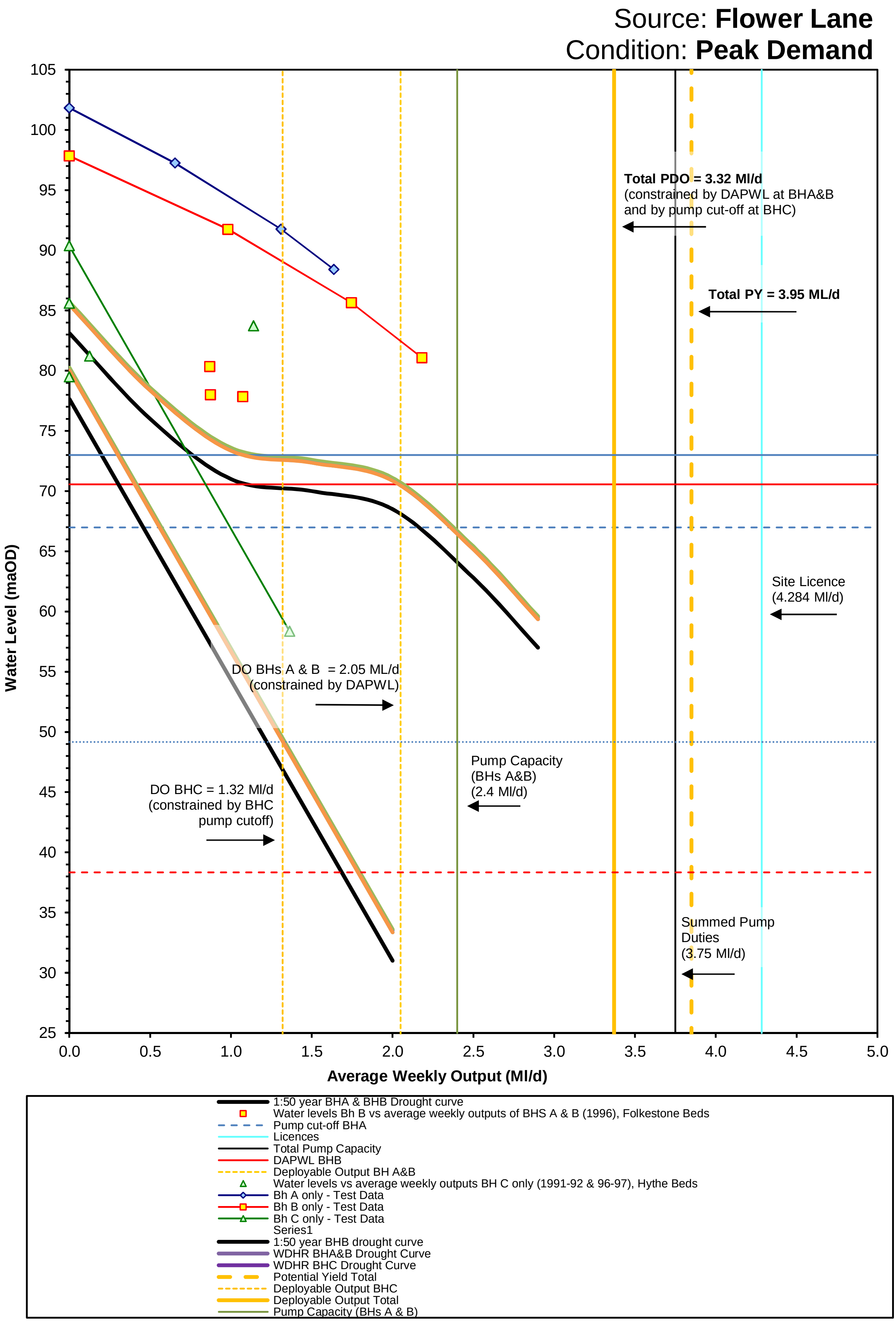
Source: **Fetcham Springs**
Condition: **Minimum Resource**



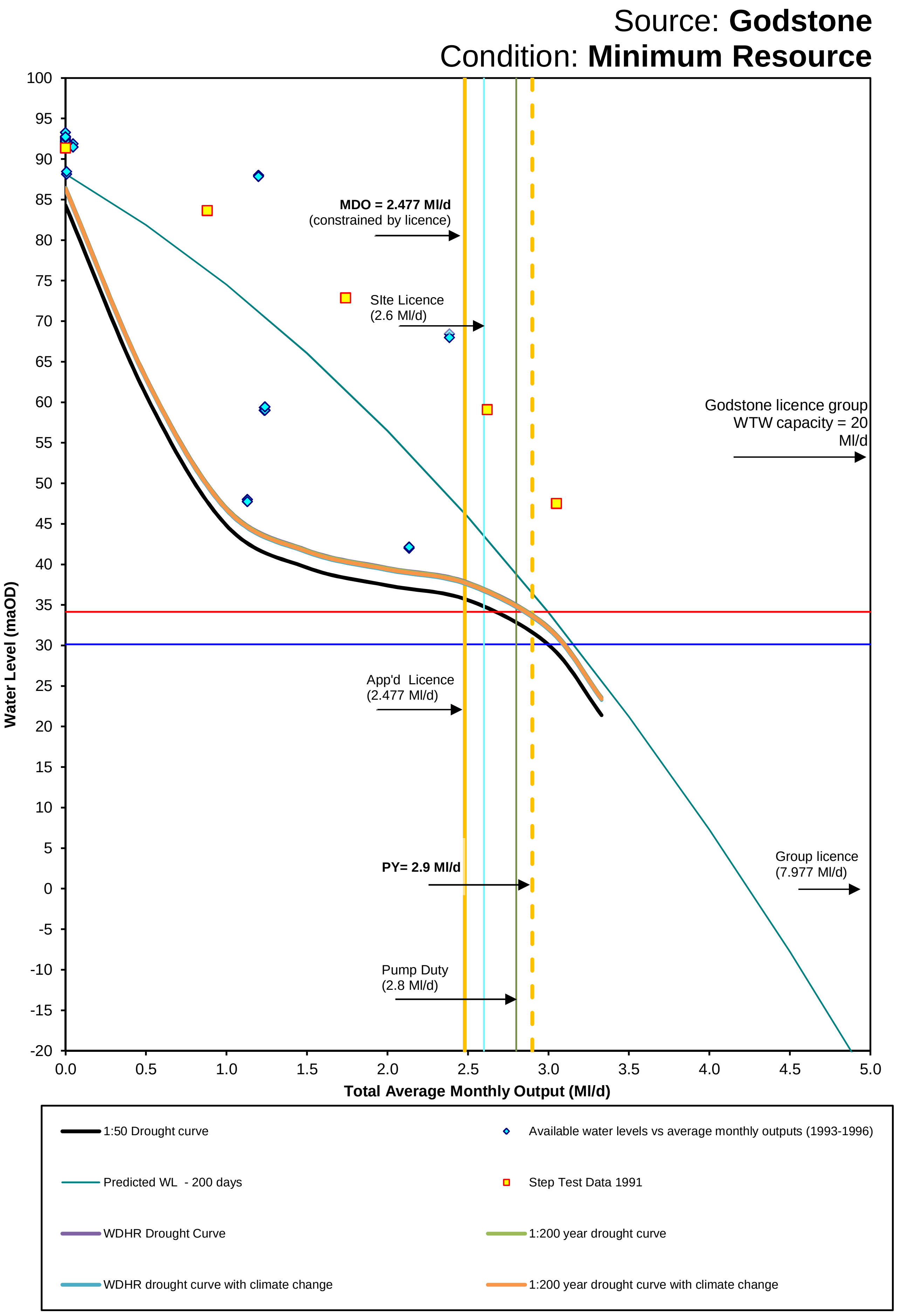
Source: **Fetcham Springs**
Condition: **Peak Demand**

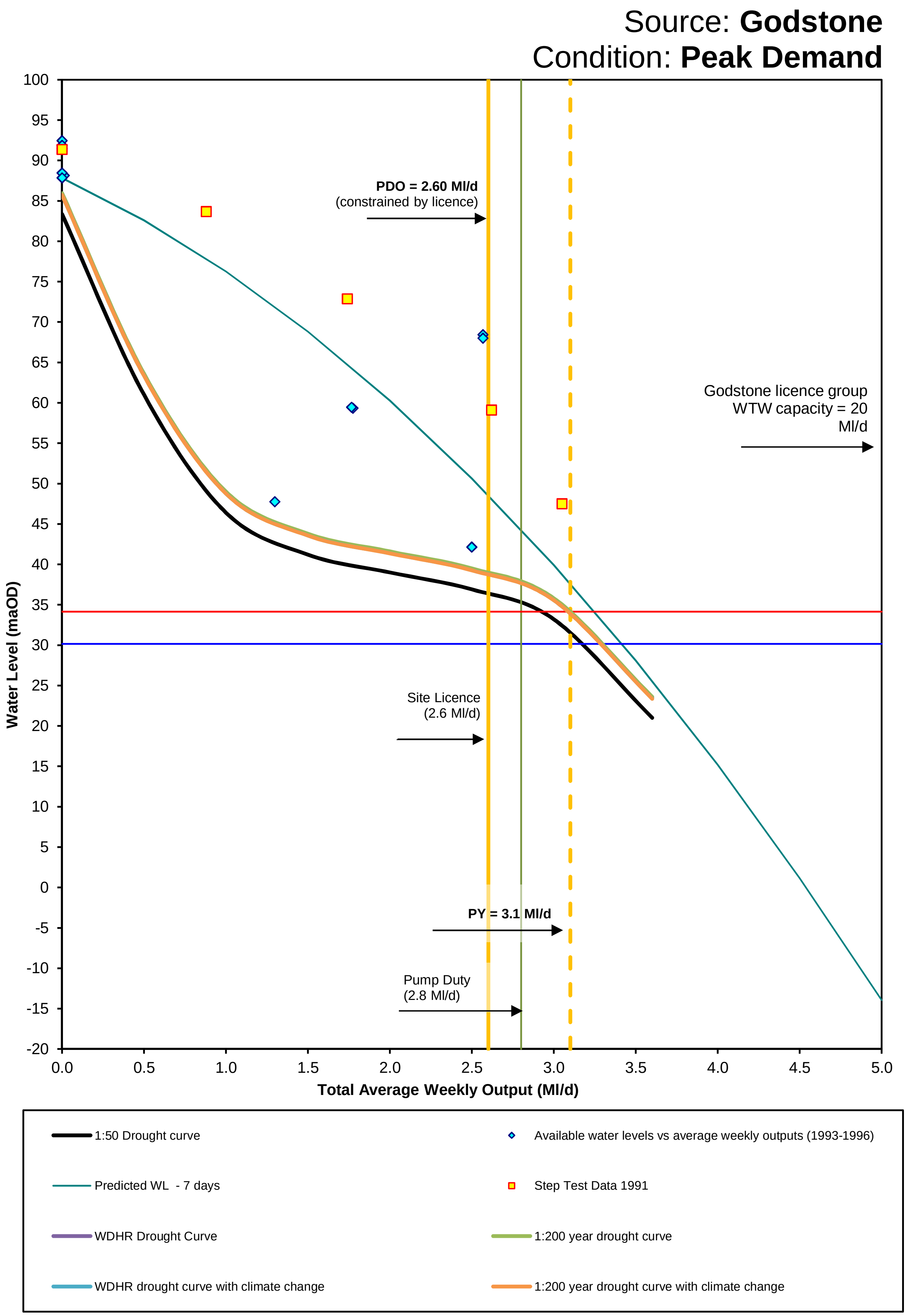



Source: **Flower Lane**
Condition: **Minimum Resource**
Water Level (maOD)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Average Monthly Output (Ml/d)
Total PY = 3.7 ML/d
Group licence (7.978Ml/d)
Total MDO = 2 Ml/d (constrained by apportioned licence)
DO BHC = 1.2 Ml/d
Summed Pump Duties (3.75 Ml/d)
DO BHA&B = 2 Ml/d
Water levels BH A vs average monthly outputs of A & B (1996), Folkestone Beds
Water levels BH B vs average monthly outputs of A & B (1996), Folkestone Beds
Water levels vs average monthly outputs of BH C only (1991-92, 94 & 96), Hythe Beds
Bh A only - Test Data
Bh B only - Test Data
Bh C only - Test Data
1:50 Drought curve BHA and BHB
1:50 Drought Curve BHC
WDHR BHA and BHB Drought Curve
WDHR BHC Drought Curve
Potential Yield Total
Deployable Output BHC
Deployable Output Total
1:200 yr Drought Curve A & B
1:200 yr Drought Curve C
Pump cut-off BHA
Pump cut-off BHB
DAPWL BHC

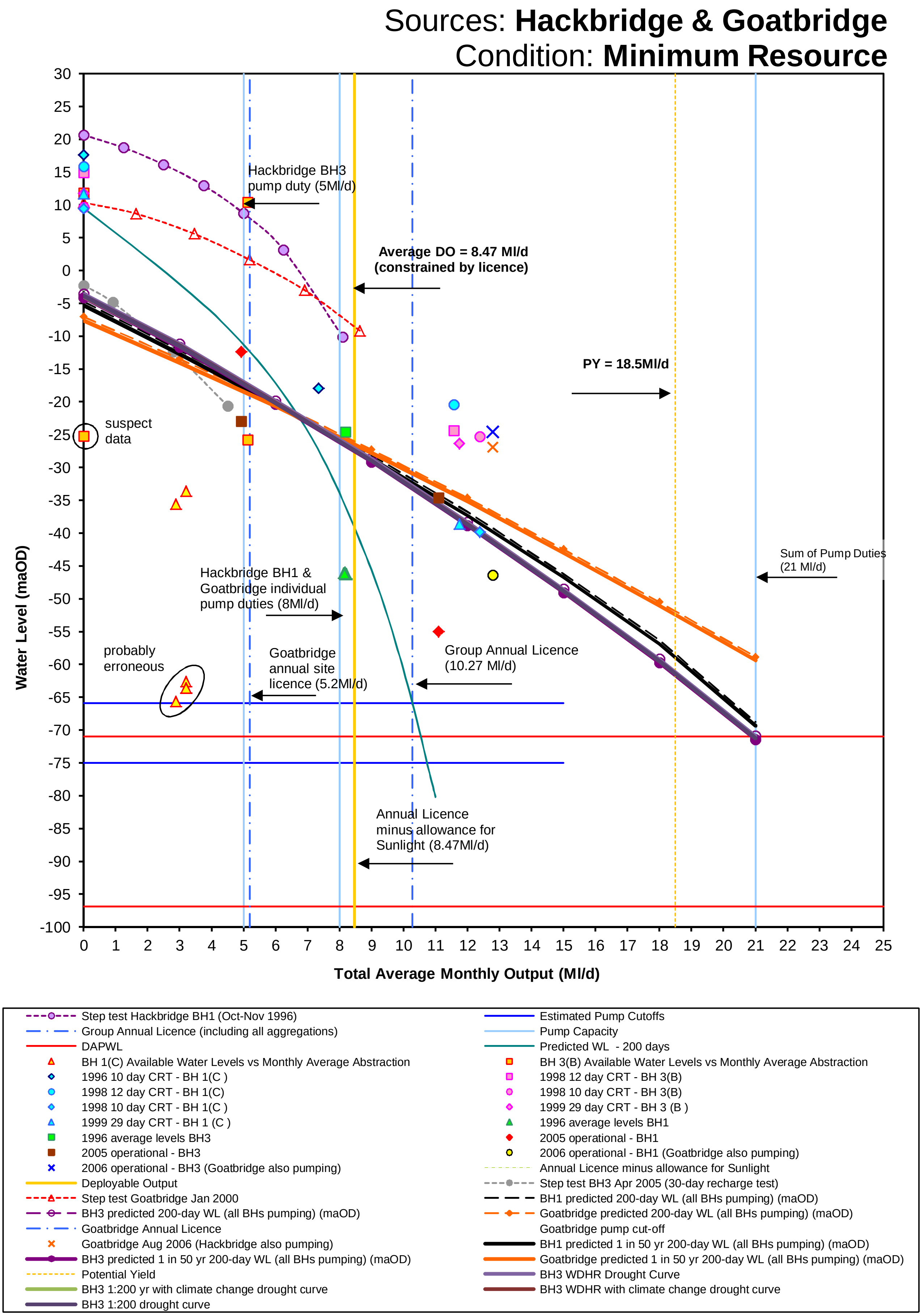


Source: Flower Lane
Condition: Peak Demand
Water Level (maOD)
Average Weekly Output (Ml/d)
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Total PDO = 3.32 Ml/d
(constrained by DAPWL at BHA&B
and by pump cut-off at BHC)
Total PY = 3.95 ML/d
Site Licence
(4.284 Ml/d)
DO BHs A & B = 2.05 ML/d
(constrained by DAPWL)
Pump Capacity
(BHs A&B)
(2.4 Ml/d)
DO BHC = 1.32 Ml/d
(constrained by BHC
pump cutoff)
Summed Pump
Duties
(3.75 Ml/d)
1:50 year BHA & BHB Drought curve
Water levels Bh B vs average weekly outputs of BHS A & B (1996), Folkestone Beds
Pump cut-off BHA
Licences
Total Pump Capacity
DAPWL BHB
Deployable Output BH A&B
Water levels vs average weekly outputs BH C only (1991-92 & 96-97), Hythe Beds
Bh A only - Test Data
Bh B only - Test Data
Bh C only - Test Data
Series1
1:50 year BHB drought curve
WDHR BHA&B Drought Curve
WDHR BHC Drought Curve
Potential Yield Total
Deployable Output BHC
Deployable Output Total
Pump Capacity (BHs A & B)

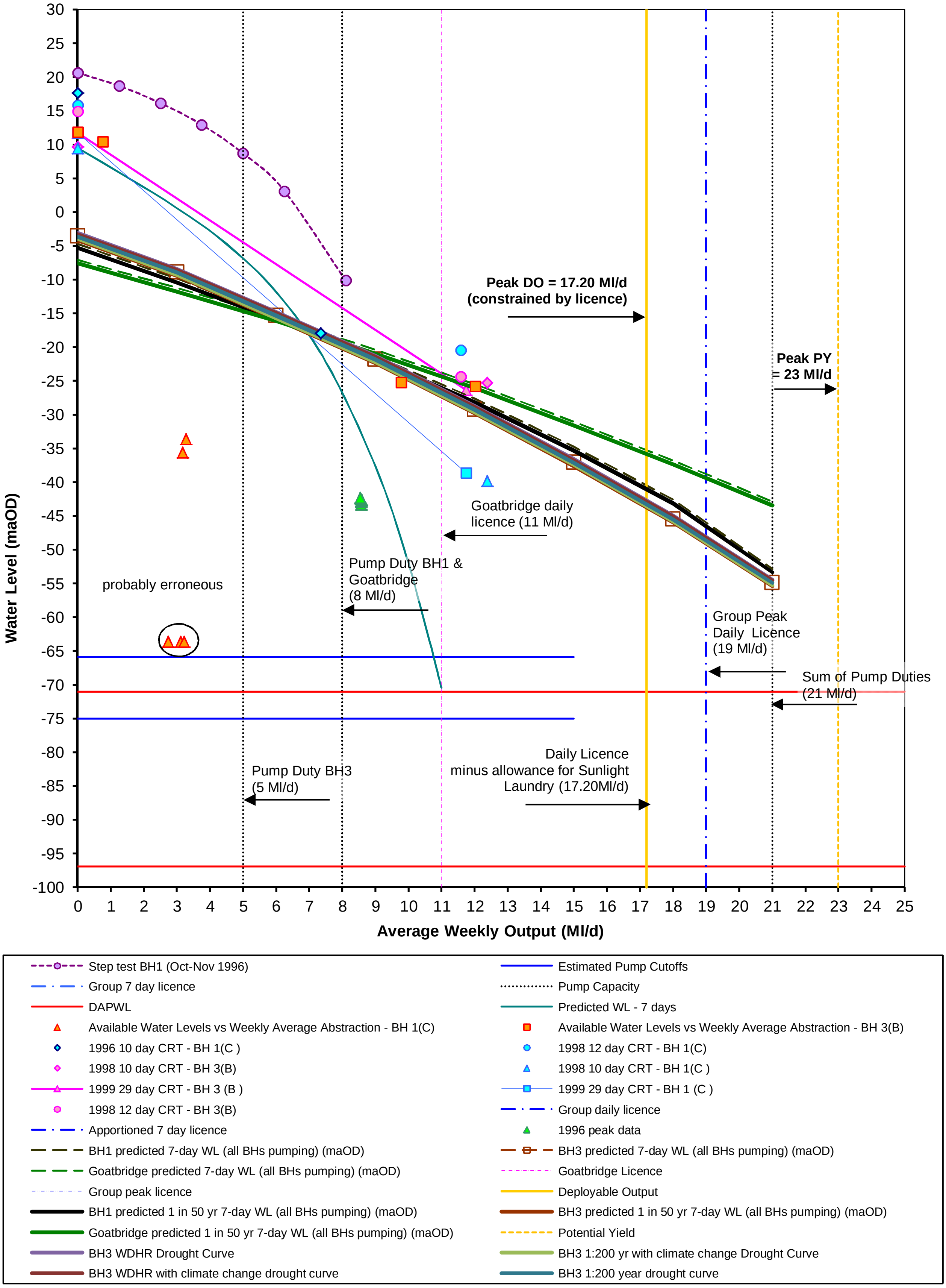

Source: Godstone
Condition: Minimum Resource
MDO = 2.477 Ml/d
(constrained by licence)
SIte Licence
(2.6 Ml/d)
Godstone licence group
WTW capacity = 20
Ml/d
App'd Licence
(2.477 Ml/d)
PY= 2.9 Ml/d
Pump Duty
(2.8 Ml/d)
Group licence
(7.977 Ml/d)
Water Level (maOD)
Total Average Monthly Output (Ml/d)
1:50 Drought curve
Predicted WL - 200 days
WDHR Drought Curve
WDHR drought curve with climate change
Available water levels vs average monthly outputs (1993-1996)
Step Test Data 1991
1:200 year drought curve
1:200 year drought curve with climate change



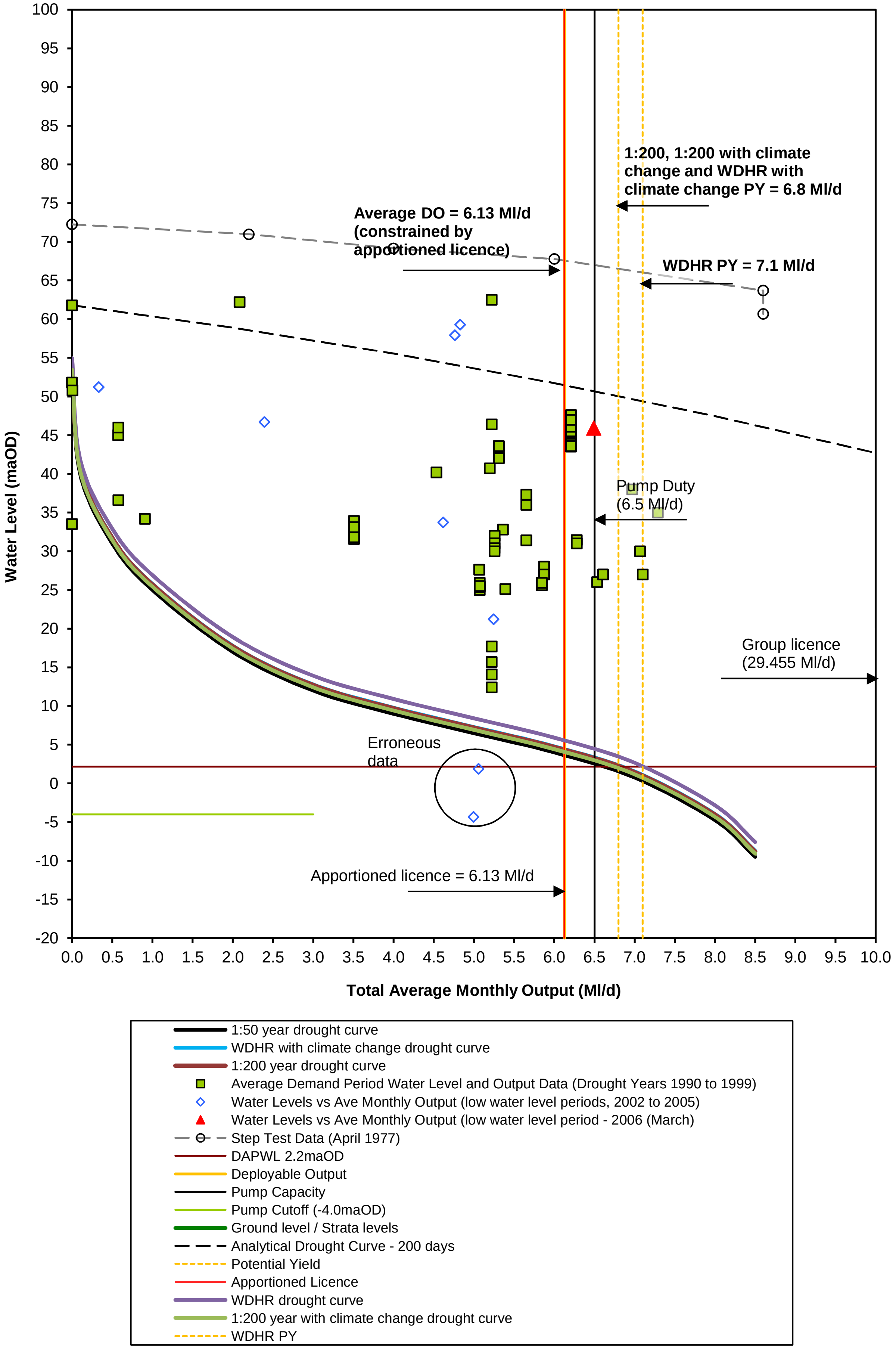
Source: **Godstone**
Condition: **Peak Demand**
PDO = 2.60 Ml/d
(constrained by licence)
Godstone licence group WTW capacity = 20 Ml/d
Site Licence (2.6 Ml/d)
PY = 3.1 Ml/d
Pump Duty (2.8 Ml/d)
Water Level (maOD)
Total Average Weekly Output (Ml/d)
1:50 Drought curve
Available water levels vs average weekly outputs (1993-1996)
Predicted WL - 7 days
Step Test Data 1991
WDHR Drought Curve
1:200 year drought curve
WDHR drought curve with climate change
1:200 year drought curve with climate change


Sources: **Hackbridge & Goatbridge**
Condition: **Minimum Resource**
Water Level (maOD)
Total Average Monthly Output (Ml/d)
Hackbridge BH3 pump duty (5Ml/d)
Average DO = 8.47 Ml/d (constrained by licence)
PY = 18.5Ml/d
suspect data
Hackbridge BH1 & Goatbridge individual pump duties (8Ml/d)
Sum of Pump Duties (21 Ml/d)
probably erroneous
Goatbridge annual site licence (5.2Ml/d)
Group Annual Licence (10.27 Ml/d)
Annual Licence minus allowance for Sunlight (8.47Ml/d)
Step test Hackbridge BH1 (Oct-Nov 1996)
Group Annual Licence (including all aggregations)
DAPWL
BH 1(C) Available Water Levels vs Monthly Average Abstraction
1996 10 day CRT - BH 1(C)
1998 12 day CRT - BH 1(C)
1998 10 day CRT - BH 1(C)
1999 29 day CRT - BH 1 (C)
1996 average levels BH3
2005 operational - BH3
2006 operational - BH3 (Goatbridge also pumping)
Deployable Output
Step test Goatbridge Jan 2000
BH3 predicted 200-day WL (all BHs pumping) (maOD)
Goatbridge Annual Licence
Goatbridge Aug 2006 (Hackbridge also pumping)
BH3 predicted 1 in 50 yr 200-day WL (all BHs pumping) (maOD)
Potential Yield
BH3 1:200 yr with climate change drought curve
BH3 1:200 drought curve
Estimated Pump Cutoffs
Pump Capacity
Predicted WL - 200 days
BH 3(B) Available Water Levels vs Monthly Average Abstraction
1998 12 day CRT - BH 3(B)
1998 10 day CRT - BH 3(B)
1999 29 day CRT - BH 3 (B)
1996 average levels BH1
2005 operational - BH1
2006 operational - BH1 (Goatbridge also pumping)
Annual Licence minus allowance for Sunlight
Step test BH3 Apr 2005 (30-day recharge test)
BH1 predicted 200-day WL (all BHs pumping) (maOD)
Goatbridge predicted 200-day WL (all BHs pumping) (maOD)
Goatbridge pump cut-off
BH1 predicted 1 in 50 yr 200-day WL (all BHs pumping) (maOD)
Goatbridge predicted 1 in 50 yr 200-day WL (all BHs pumping) (maOD)
BH3 WDHR Drought Curve
BH3 WDHR with climate change drought curve

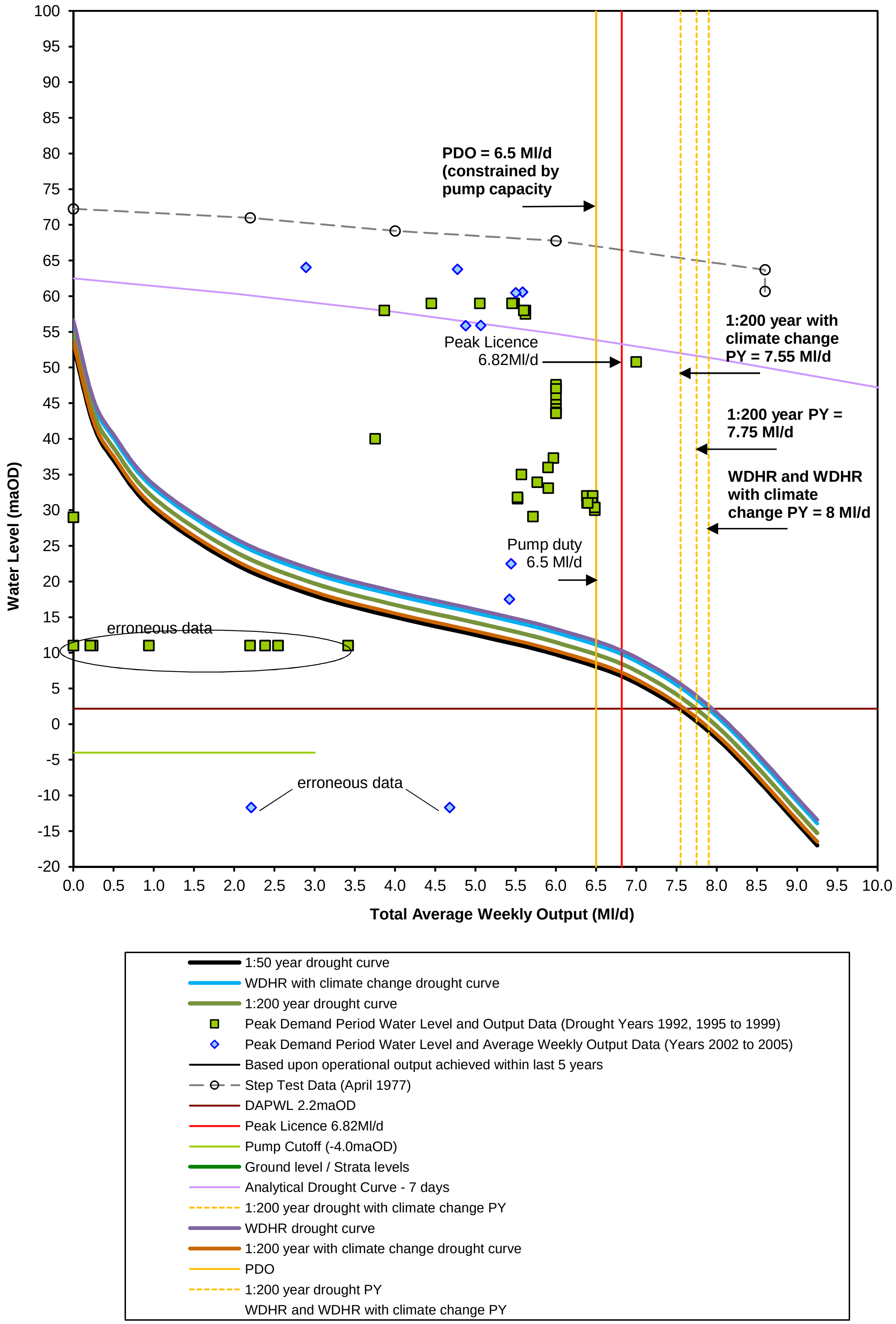
Sources: **Hackbridge & Goatbridge**
Condition: **Peak Demand**



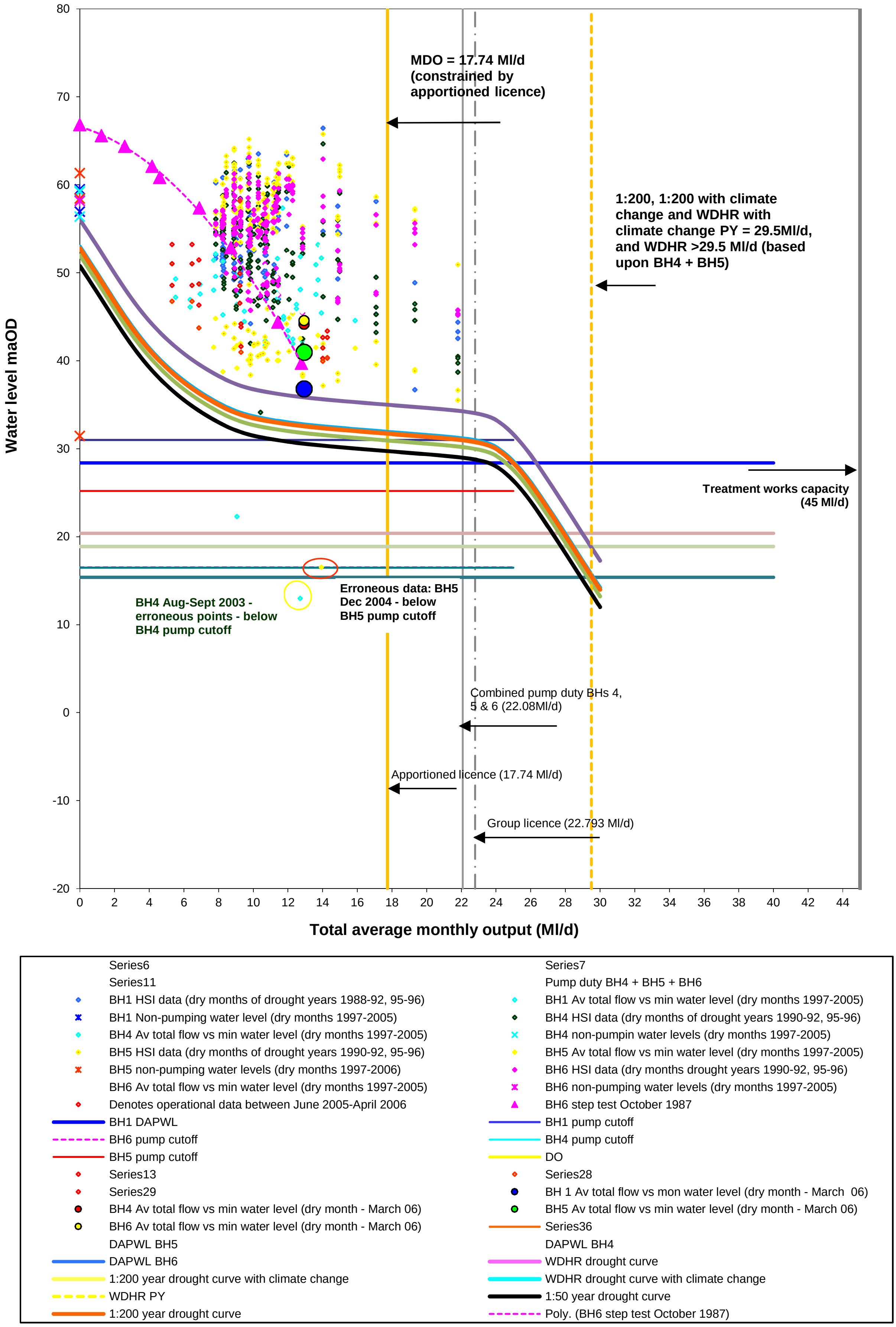
Source: **Holly Lane**
Condition: **Minimum Resource**



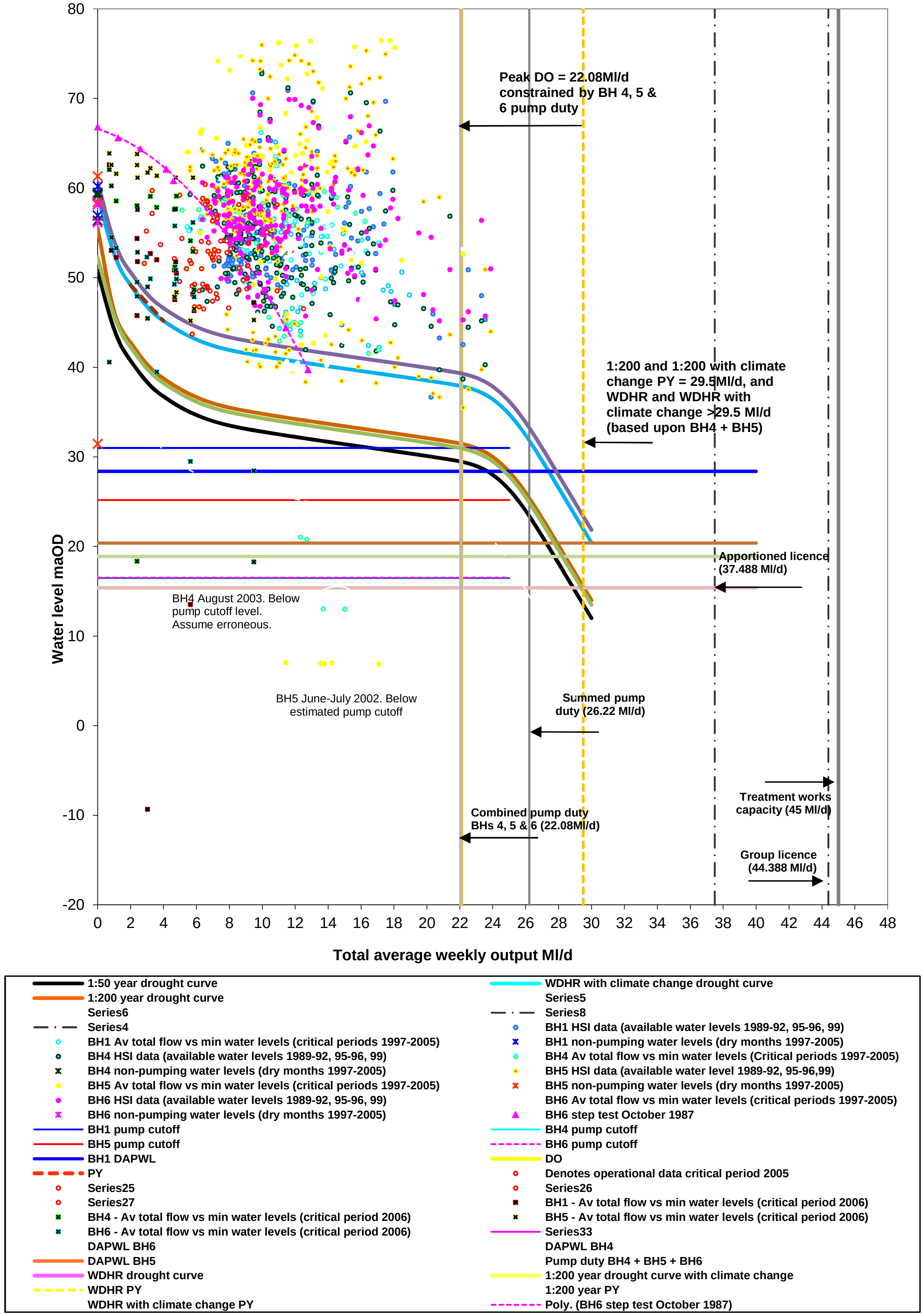
Source: **Holly Lane**
Condition: **Peak Demand**

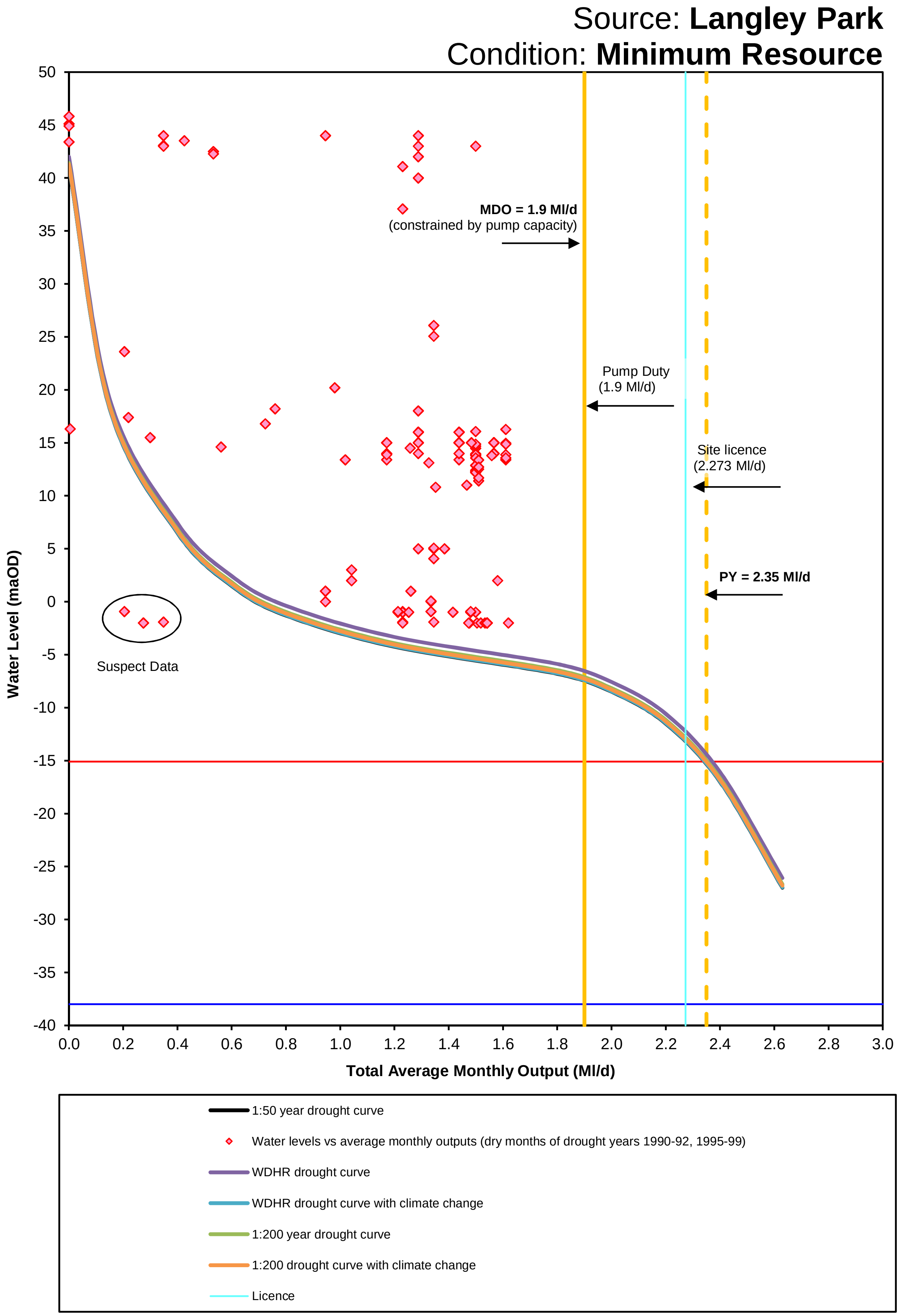


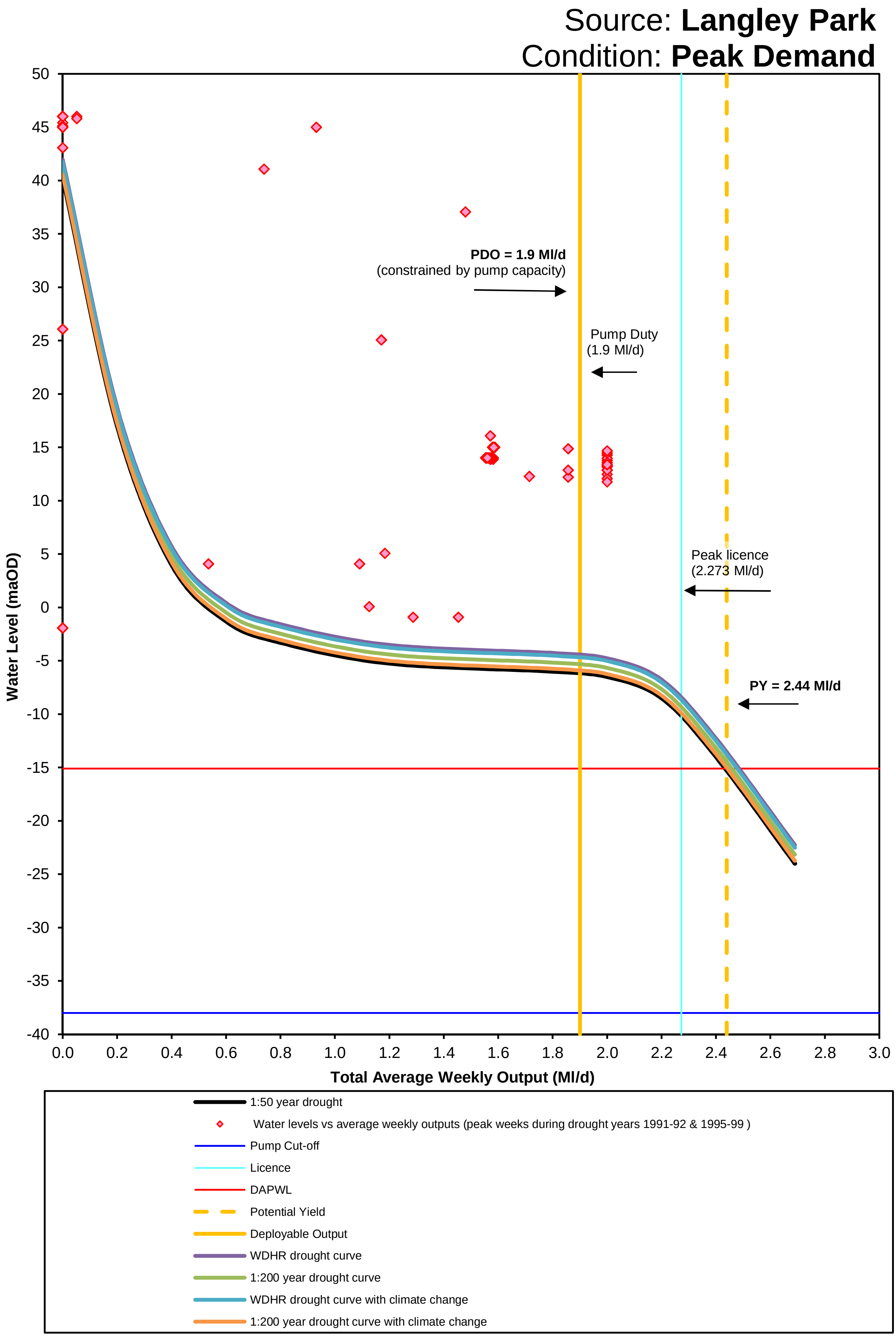
Source: **Kenley**
Condition: **Minimum Resource**



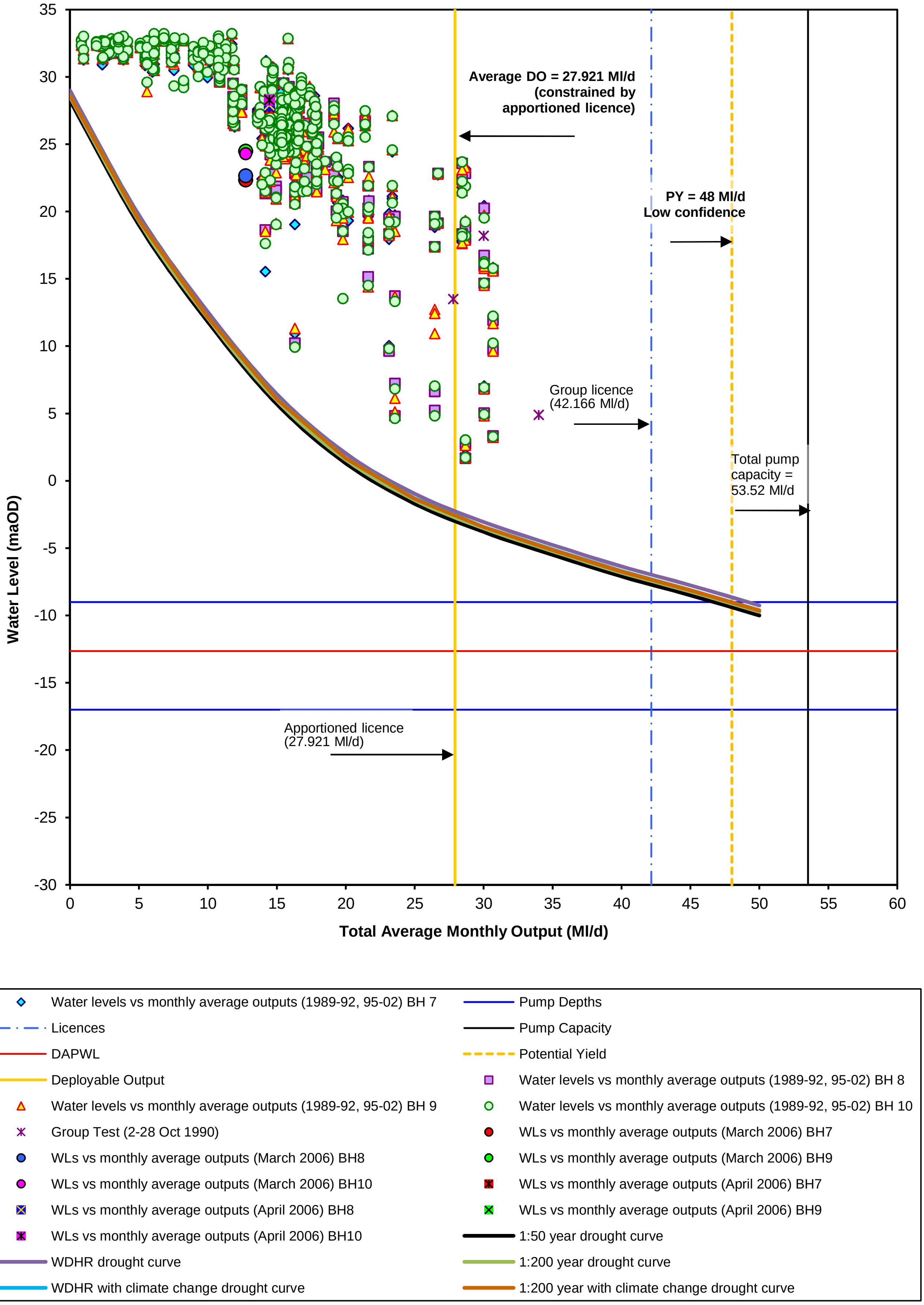
Source: **Kenley**
Condition: **Peak Demand**



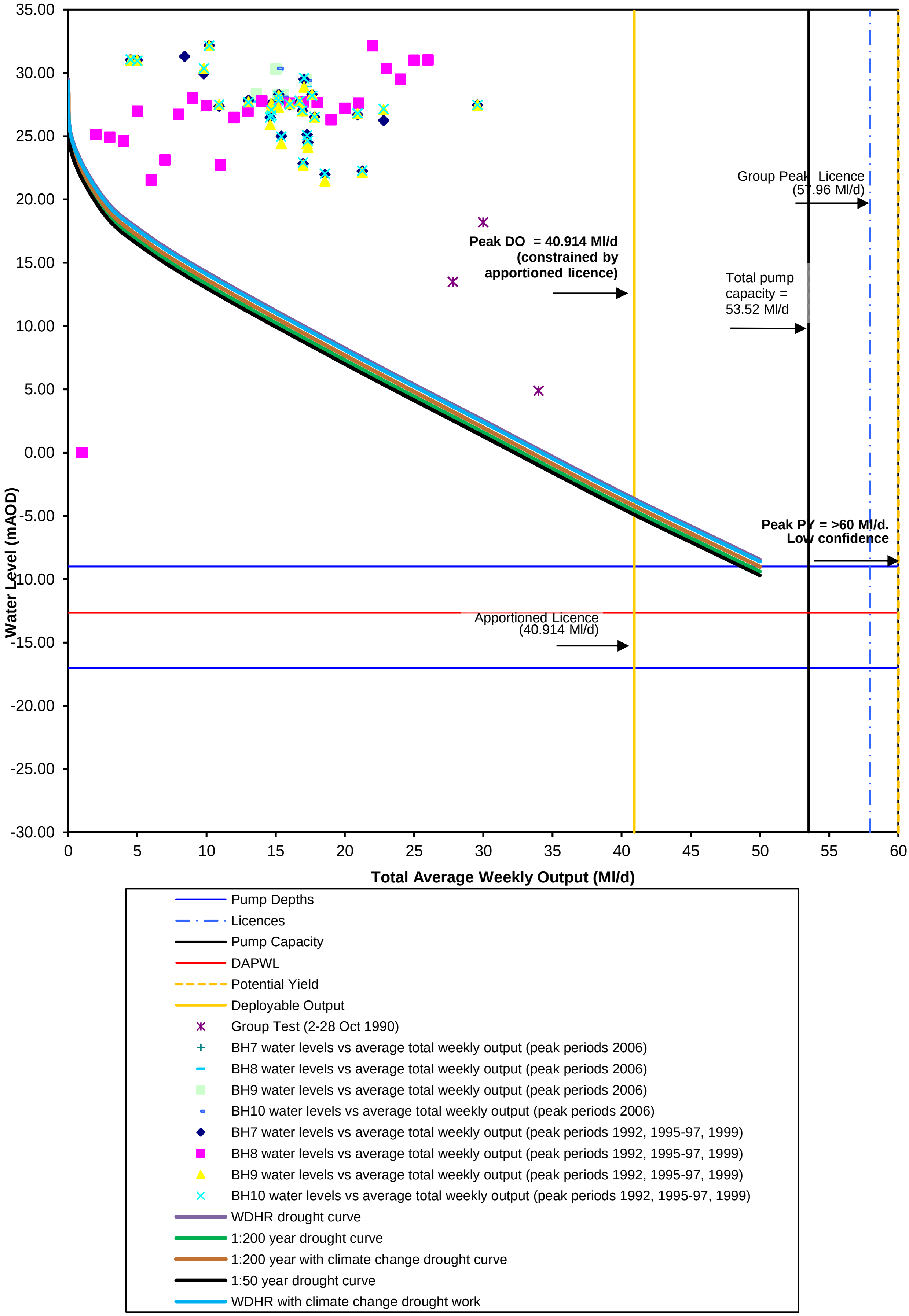

Source: Langley Park
Condition: Minimum Resource
Water Level (maOD)
Total Average Monthly Output (Ml/d)
MDO = 1.9 Ml/d
(constrained by pump capacity)
Pump Duty
(1.9 Ml/d)
Site licence
(2.273 Ml/d)
PY = 2.35 Ml/d
Suspect Data
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
1:50 year drought curve
Water levels vs average monthly outputs (dry months of drought years 1990-92, 1995-99)
WDHR drought curve
WDHR drought curve with climate change
1:200 year drought curve
1:200 drought curve with climate change
Licence


Source: **Langley Park**
Condition: **Peak Demand**
Water Level (maOD)
Total Average Weekly Output (Ml/d)
PDO = 1.9 Ml/d
(constrained by pump capacity)
Pump Duty
(1.9 Ml/d)
Peak licence
(2.273 Ml/d)
PY = 2.44 Ml/d
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
1:50 year drought
Water levels vs average weekly outputs (peak weeks during drought years 1991-92 & 1995-99)
Pump Cut-off
Licence
DAPWL
Potential Yield
Deployable Output
WDHR drought curve
1:200 year drought curve
WDHR drought curve with climate change
1:200 year drought curve with climate change

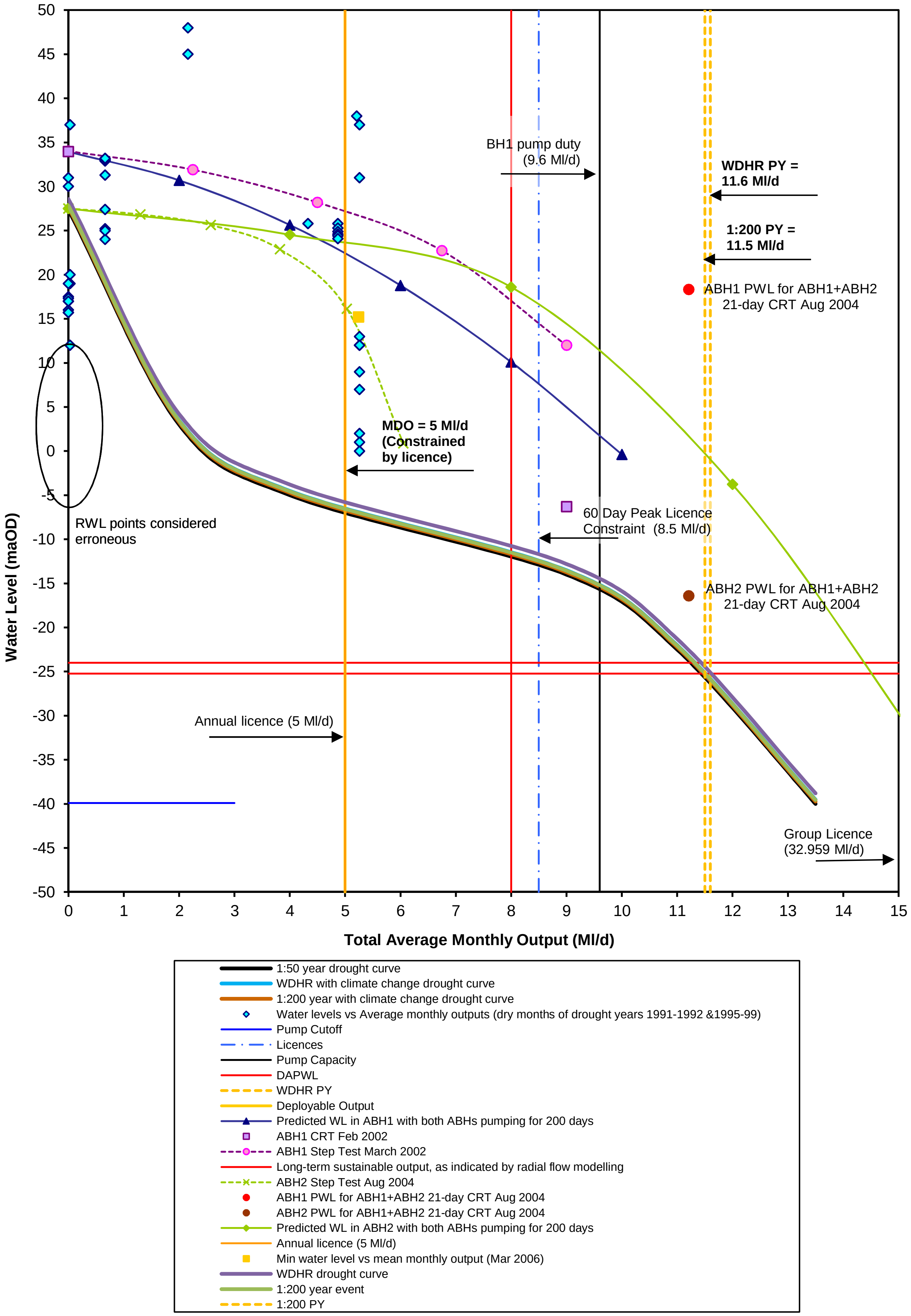
Source: **Leatherhead**
Condition: **Minimum Resource**



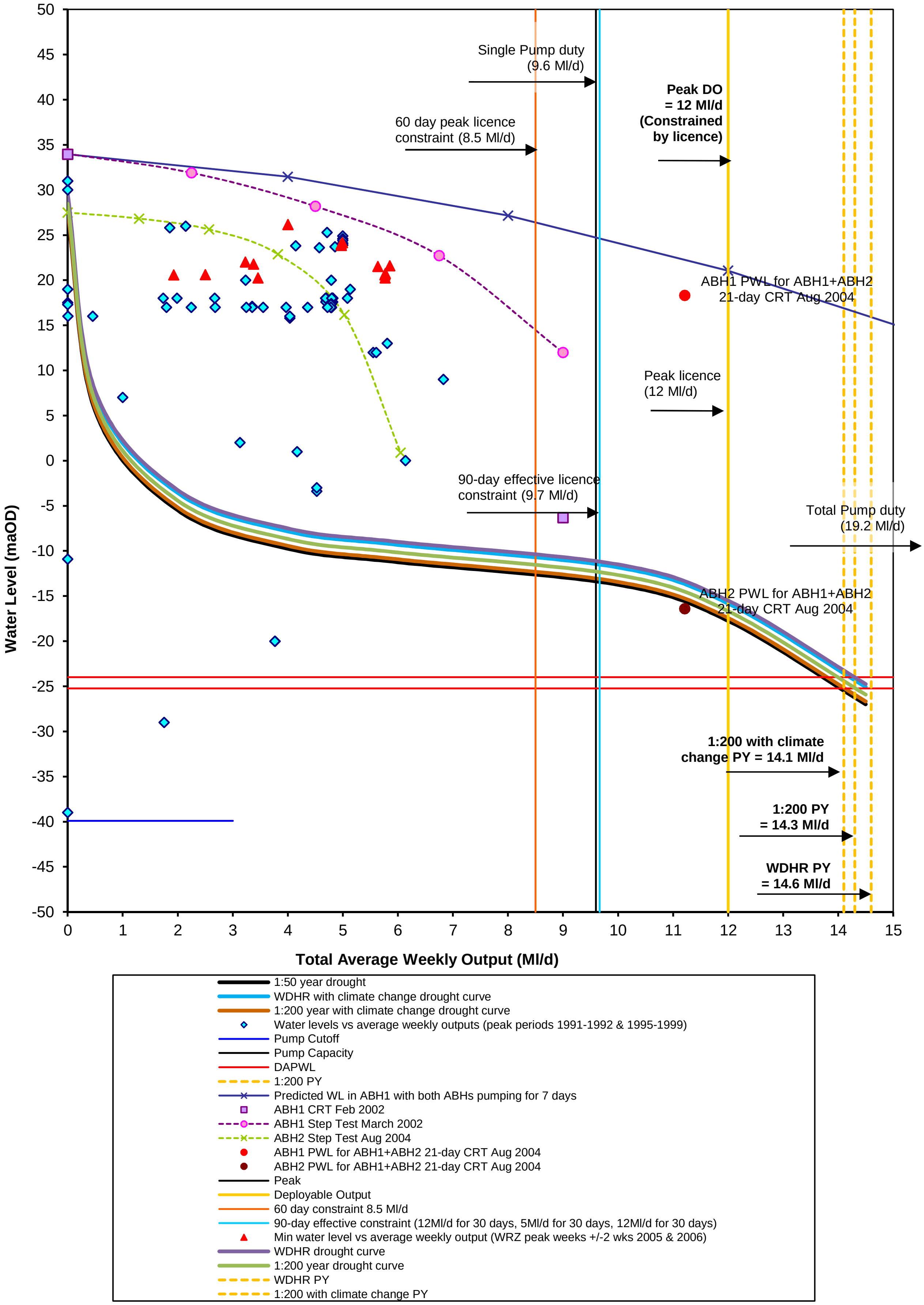
Source: **Leatherhead**
Condition: **Peak Demand**

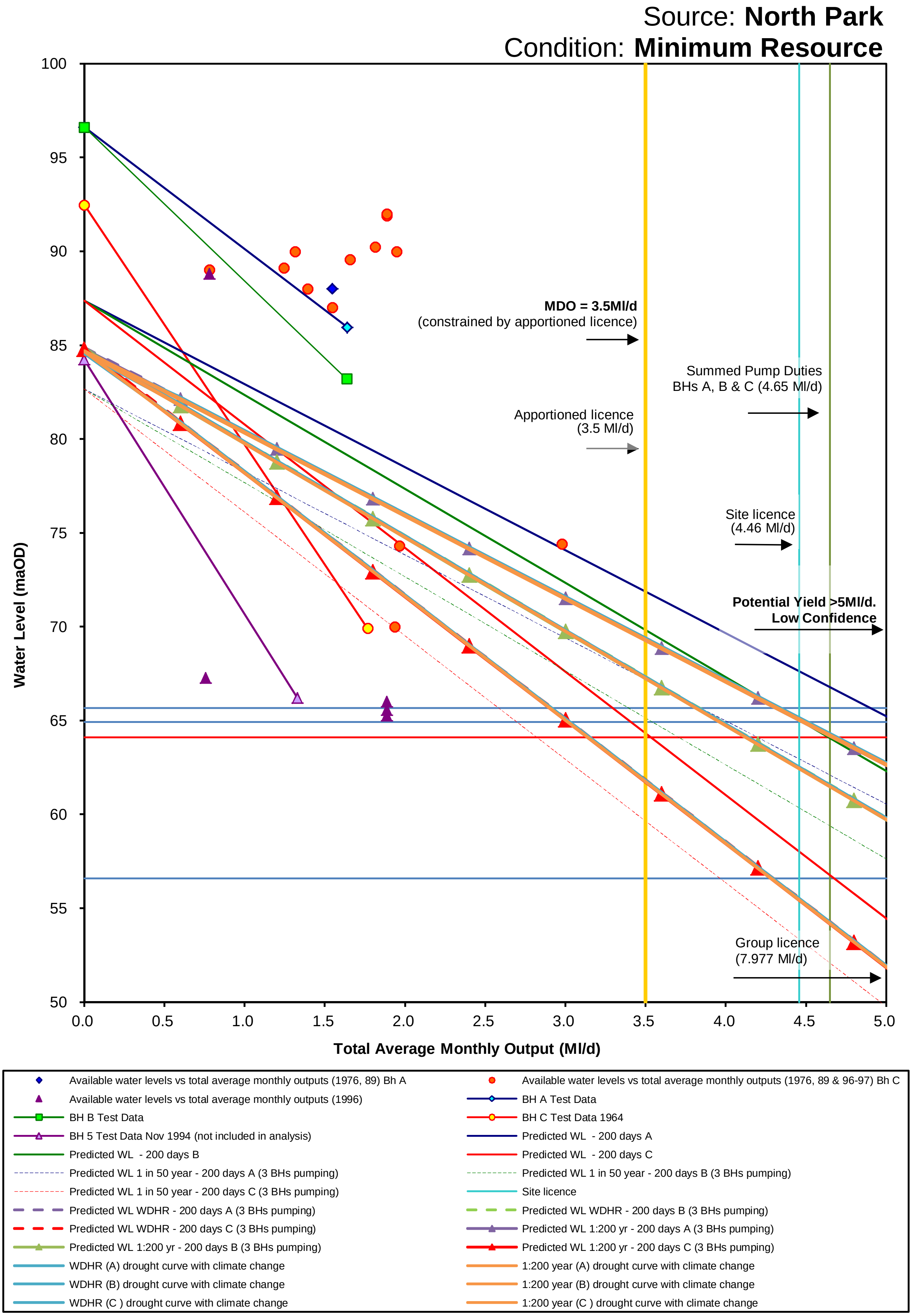


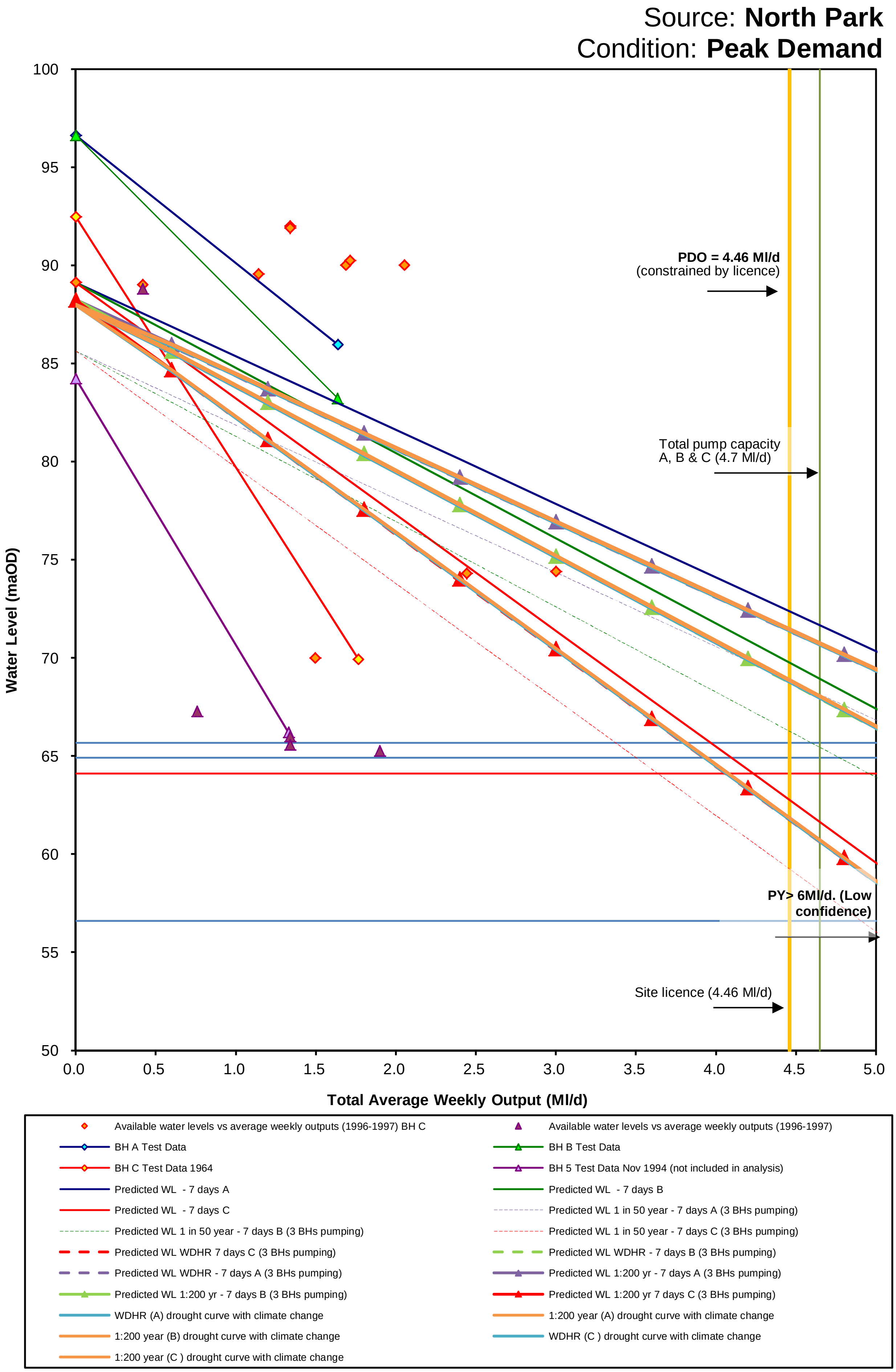
Source: **Nonsuch Park**
Condition: **Minimum Resource**



Source: **Nonsuch Park**
Condition: **Peak Demand**

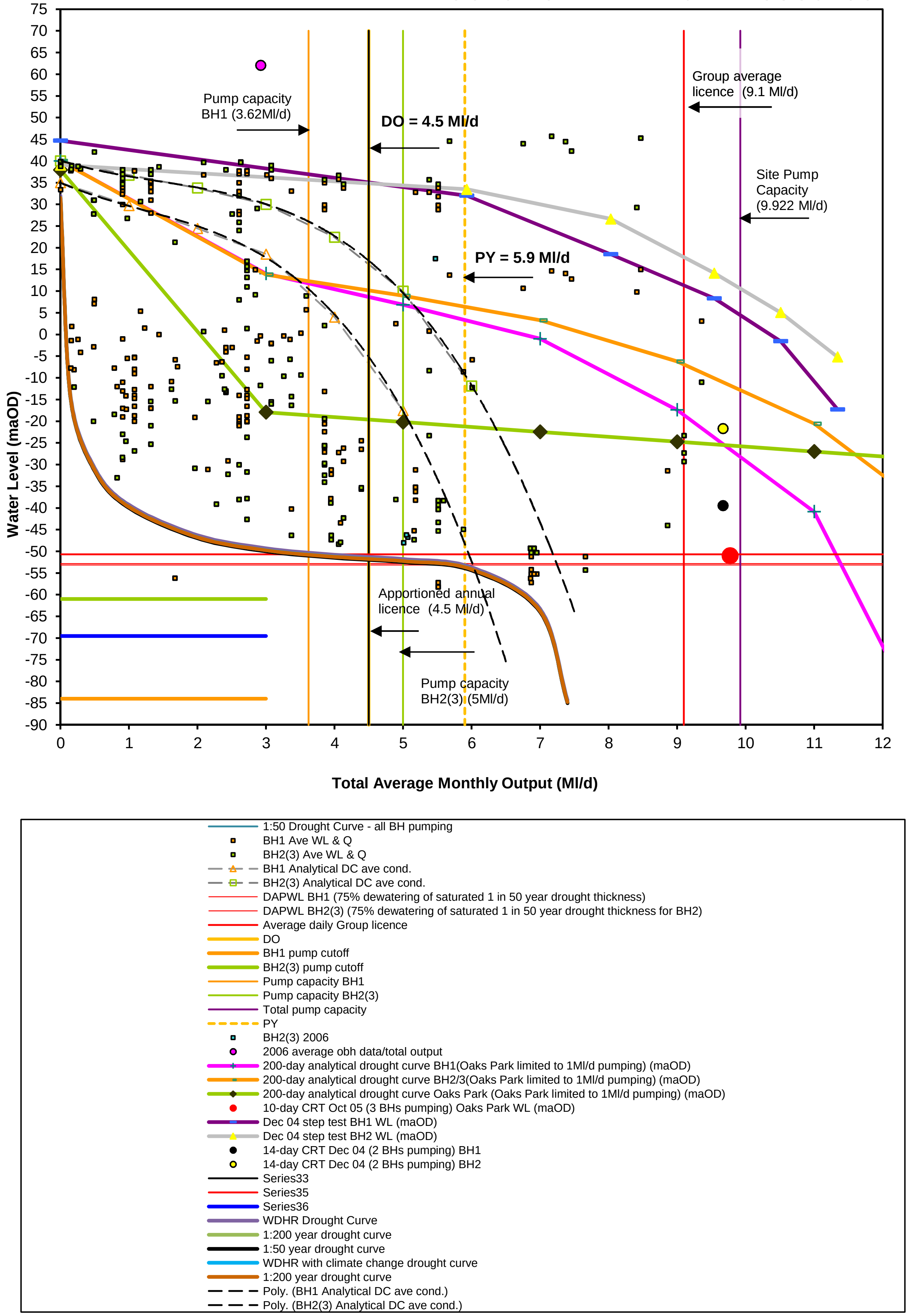



Source: **North Park**
Condition: **Minimum Resource**
Water Level (maOD)
Total Average Monthly Output (Ml/d)
MDO = 3.5Ml/d
(constrained by apportioned licence)
Summed Pump Duties
BHs A, B & C (4.65 Ml/d)
Apportioned licence
(3.5 Ml/d)
Site licence
(4.46 Ml/d)
Potential Yield >5Ml/d.
Low Confidence
Group licence
(7.977 Ml/d)
Available water levels vs total average monthly outputs (1976, 89) Bh A
Available water levels vs total average monthly outputs (1976, 89 & 96-97) Bh C
Available water levels vs total average monthly outputs (1996)
BH A Test Data
BH B Test Data
BH C Test Data 1964
BH 5 Test Data Nov 1994 (not included in analysis)
Predicted WL - 200 days A
Predicted WL - 200 days B
Predicted WL - 200 days C
Predicted WL 1 in 50 year - 200 days A (3 BHs pumping)
Predicted WL 1 in 50 year - 200 days B (3 BHs pumping)
Predicted WL 1 in 50 year - 200 days C (3 BHs pumping)
Site licence
Predicted WL WDHR - 200 days A (3 BHs pumping)
Predicted WL WDHR - 200 days B (3 BHs pumping)
Predicted WL WDHR - 200 days C (3 BHs pumping)
Predicted WL 1:200 yr - 200 days A (3 BHs pumping)
Predicted WL 1:200 yr - 200 days B (3 BHs pumping)
Predicted WL 1:200 yr - 200 days C (3 BHs pumping)
WDHR (A) drought curve with climate change
1:200 year (A) drought curve with climate change
WDHR (B) drought curve with climate change
1:200 year (B) drought curve with climate change
WDHR (C) drought curve with climate change
1:200 year (C) drought curve with climate change

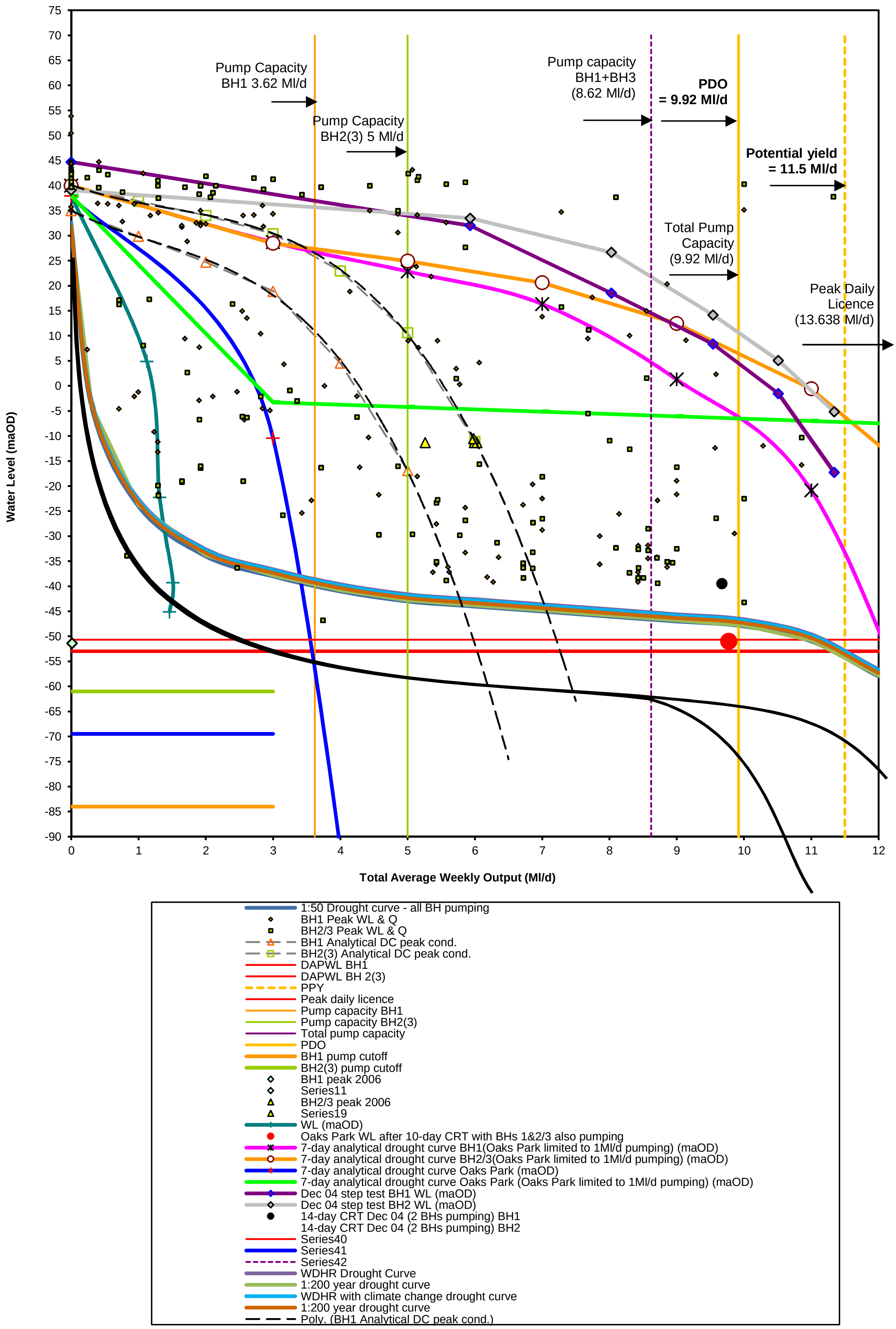


Source: North Park
Condition: Peak Demand
Water Level (maOD)
Total Average Weekly Output (Ml/d)
PDO = 4.46 Ml/d
(constrained by licence)
Total pump capacity
A, B & C (4.7 Ml/d)
PY> 6Ml/d. (Low confidence)
Site licence (4.46 Ml/d)
100
95
90
85
80
75
70
65
60
55
50
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Available water levels vs average weekly outputs (1996-1997) BH C
Available water levels vs average weekly outputs (1996-1997)
BH A Test Data
BH B Test Data
BH C Test Data 1964
BH 5 Test Data Nov 1994 (not included in analysis)
Predicted WL - 7 days A
Predicted WL - 7 days B
Predicted WL - 7 days C
Predicted WL 1 in 50 year - 7 days A (3 BHs pumping)
Predicted WL 1 in 50 year - 7 days B (3 BHs pumping)
Predicted WL 1 in 50 year - 7 days C (3 BHs pumping)
Predicted WL WDHR 7 days C (3 BHs pumping)
Predicted WL WDHR - 7 days B (3 BHs pumping)
Predicted WL WDHR - 7 days A (3 BHs pumping)
Predicted WL 1:200 yr - 7 days A (3 BHs pumping)
Predicted WL 1:200 yr - 7 days B (3 BHs pumping)
Predicted WL 1:200 yr 7 days C (3 BHs pumping)
WDHR (A) drought curve with climate change
1:200 year (A) drought curve with climate change
1:200 year (B) drought curve with climate change
WDHR (C) drought curve with climate change
1:200 year (C) drought curve with climate change

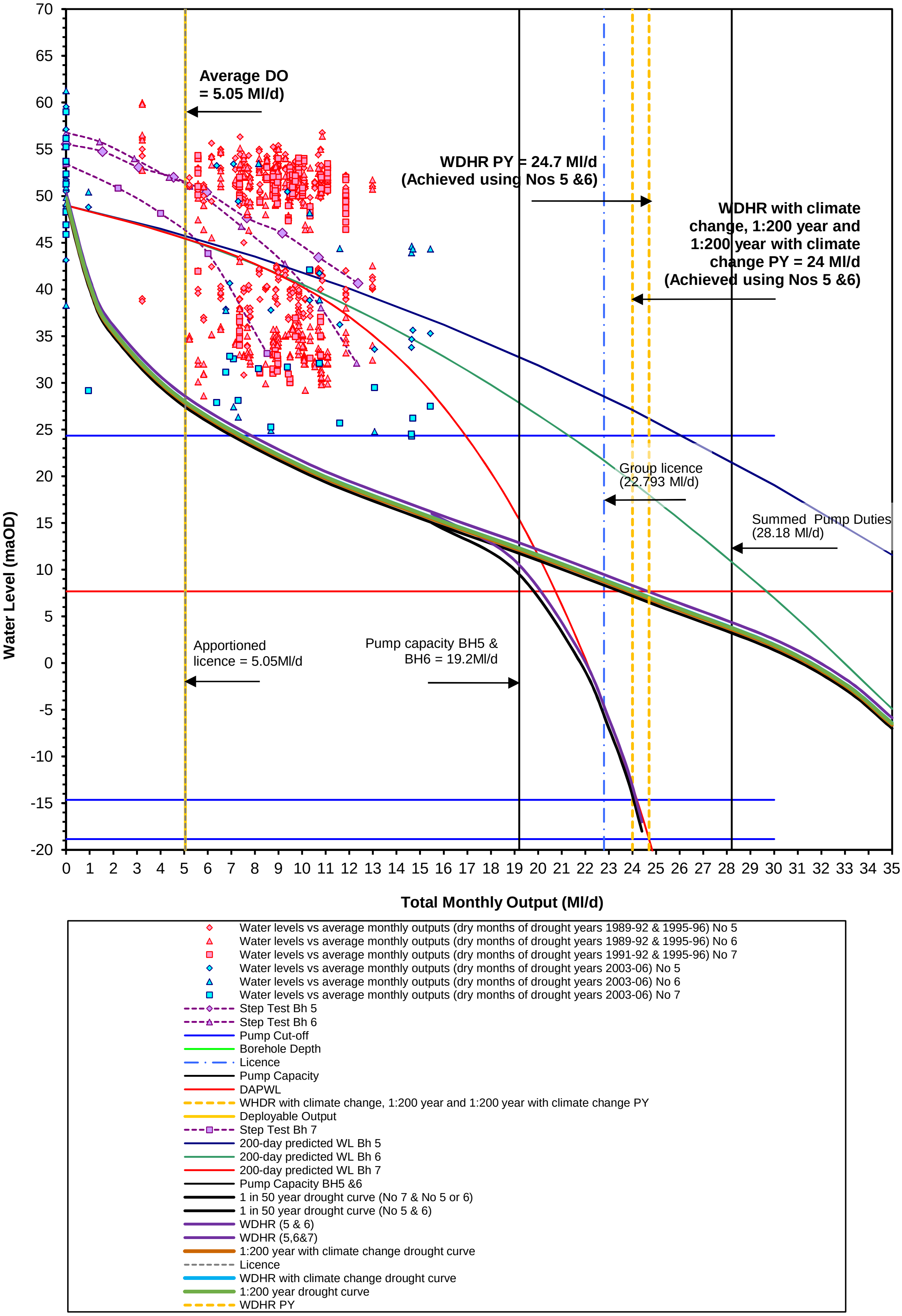
Source: **Oaks**
Condition: **Minimum Resource**



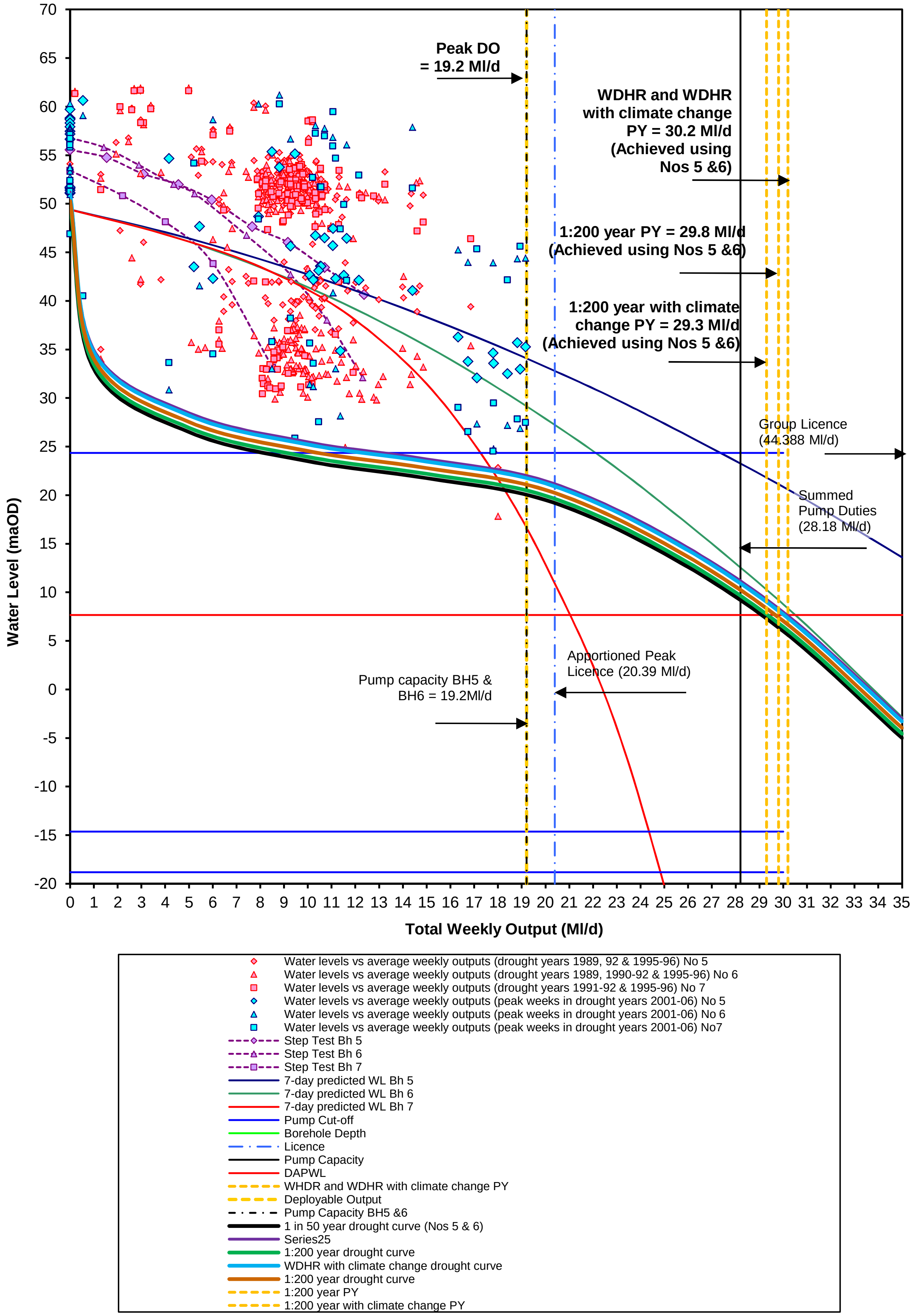
Source: **Oaks**
Condition: **Peak Demand**



Source: **Purley**
Condition: **Minimum Resource**

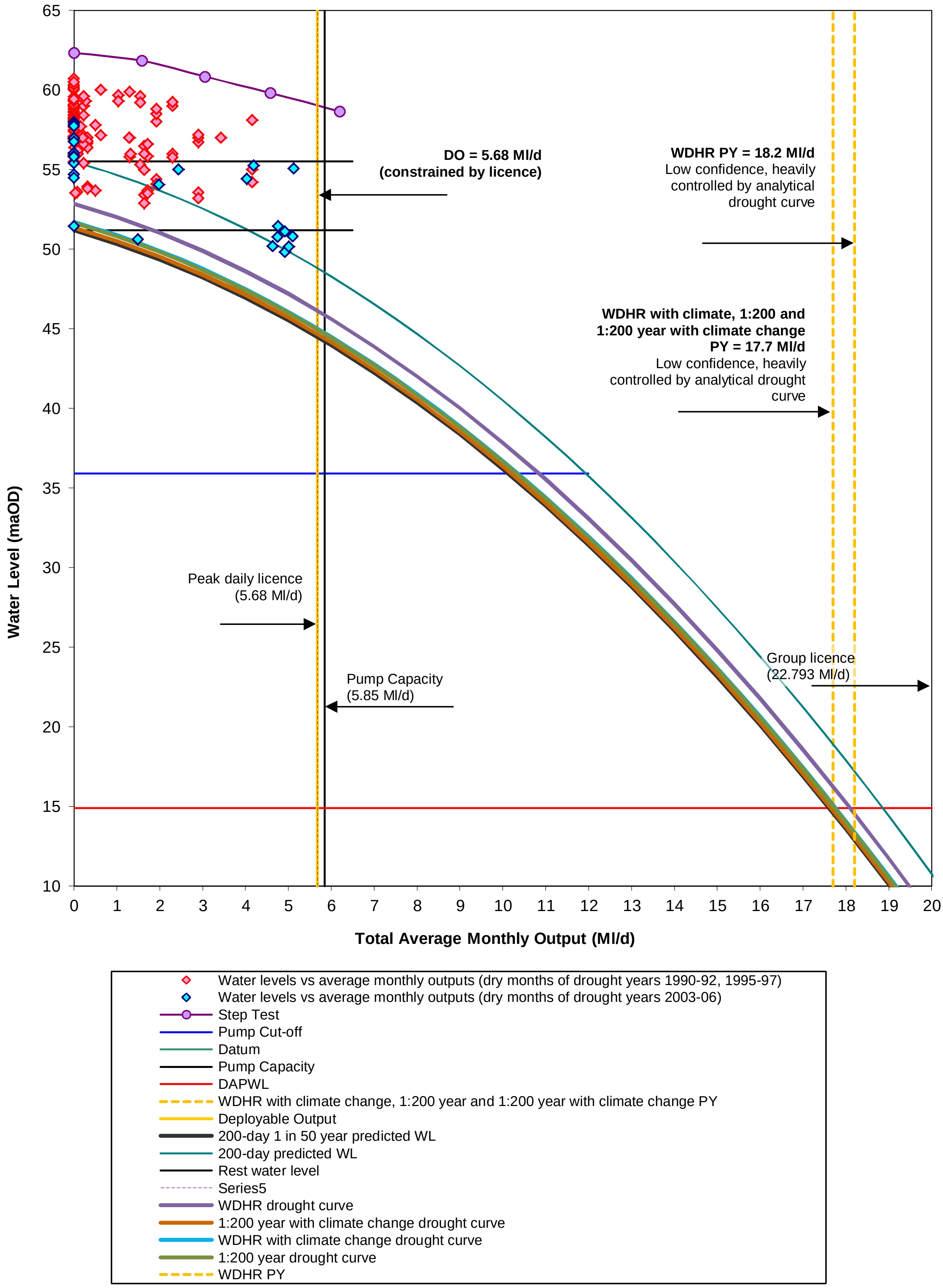


Source: **Purley**
Condition: **Peak Demand**

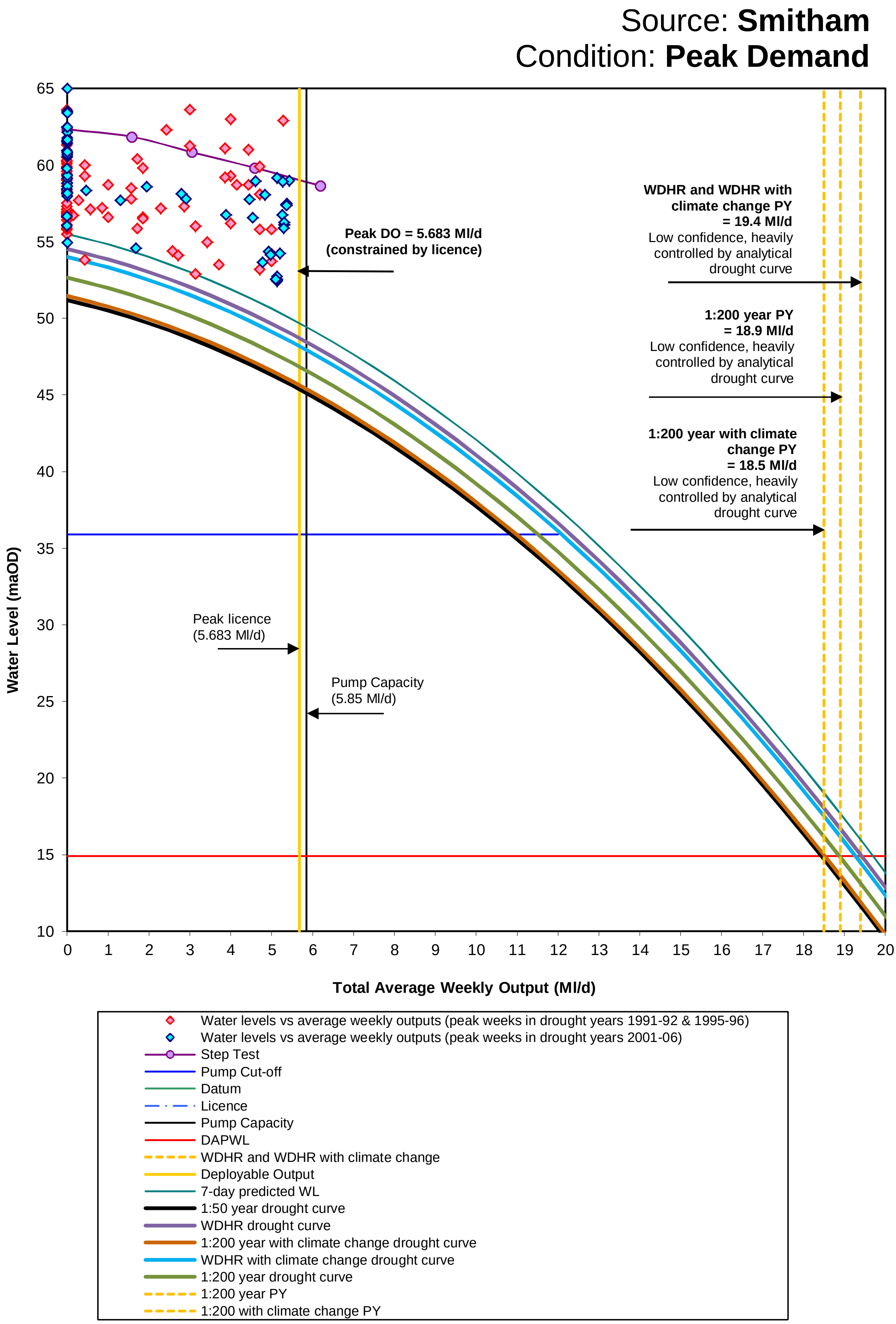


AECOM

Source: **Smitham**
Condition: **Minimum Resource**

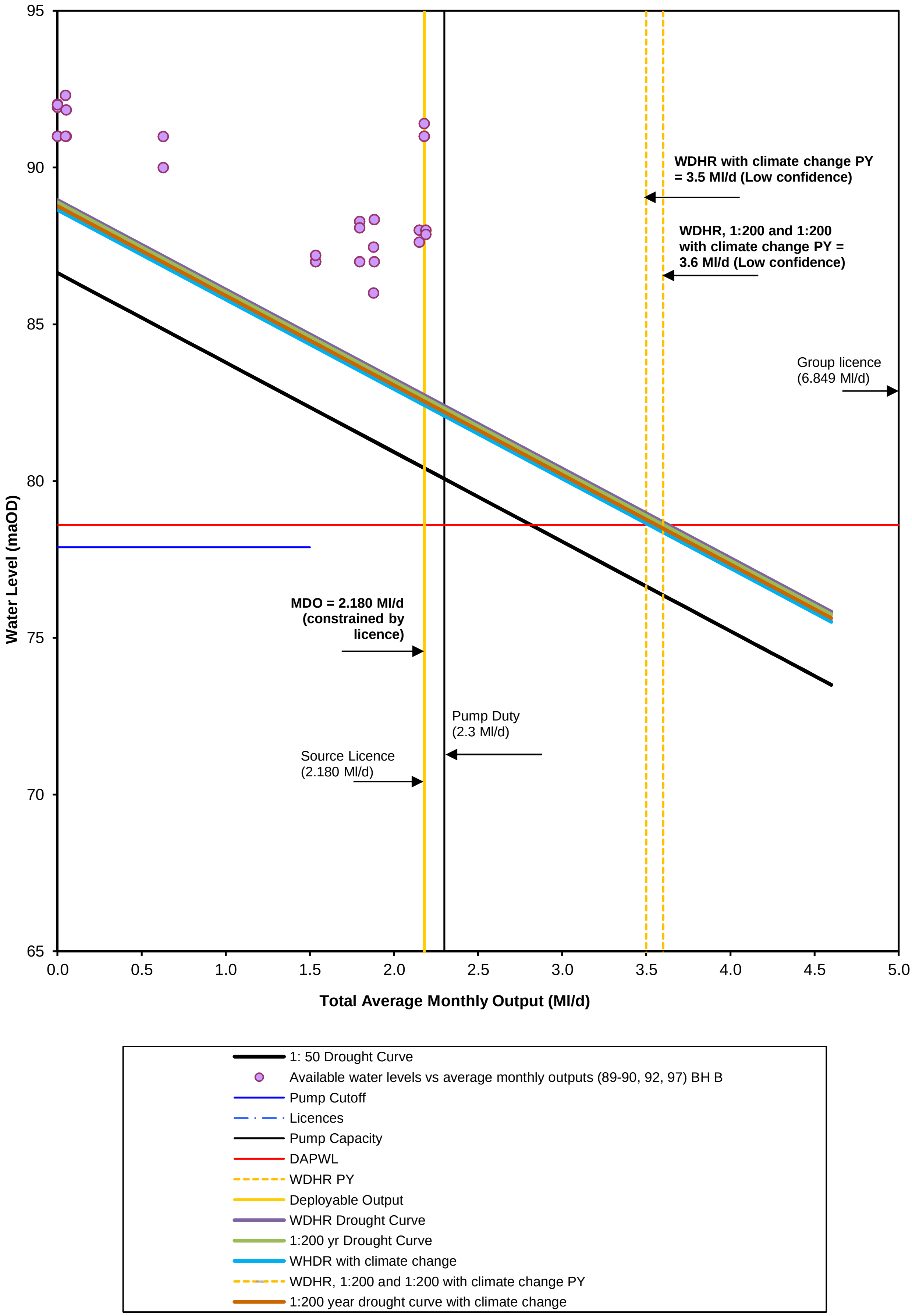


AECOM



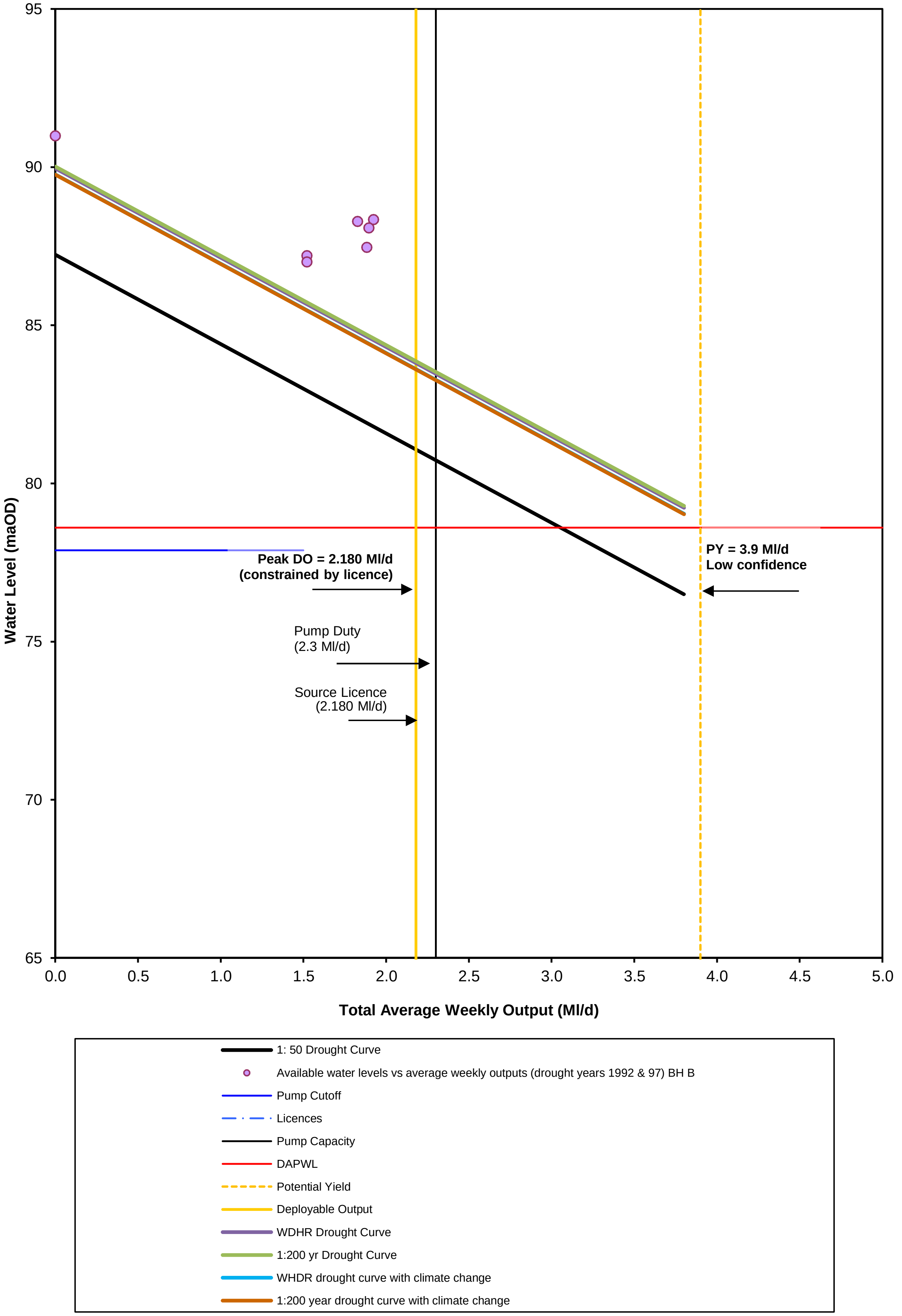
Source: **Smitham**
Condition: **Peak Demand**
Peak DO = 5.683 Ml/d
(constrained by licence)
WDHR and WDHR with climate change PY = 19.4 Ml/d
Low confidence, heavily controlled by analytical drought curve
1:200 year PY = 18.9 Ml/d
Low confidence, heavily controlled by analytical drought curve
1:200 year with climate change PY = 18.5 Ml/d
Low confidence, heavily controlled by analytical drought curve
Peak licence (5.683 Ml/d)
Pump Capacity (5.85 Ml/d)
Water Level (maOD)
Total Average Weekly Output (Ml/d)
65
60
55
50
45
40
35
30
25
20
15
10
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
Water levels vs average weekly outputs (peak weeks in drought years 1991-92 & 1995-96)
Water levels vs average weekly outputs (peak weeks in drought years 2001-06)
Step Test
Pump Cut-off
Datum
Licence
Pump Capacity
DAPWL
WDHR and WDHR with climate change
Deployable Output
7-day predicted WL
1:50 year drought curve
WDHR drought curve
1:200 year with climate change drought curve
WDHR with climate change drought curve
1:200 year drought curve
1:200 year PY
1:200 with climate change PY

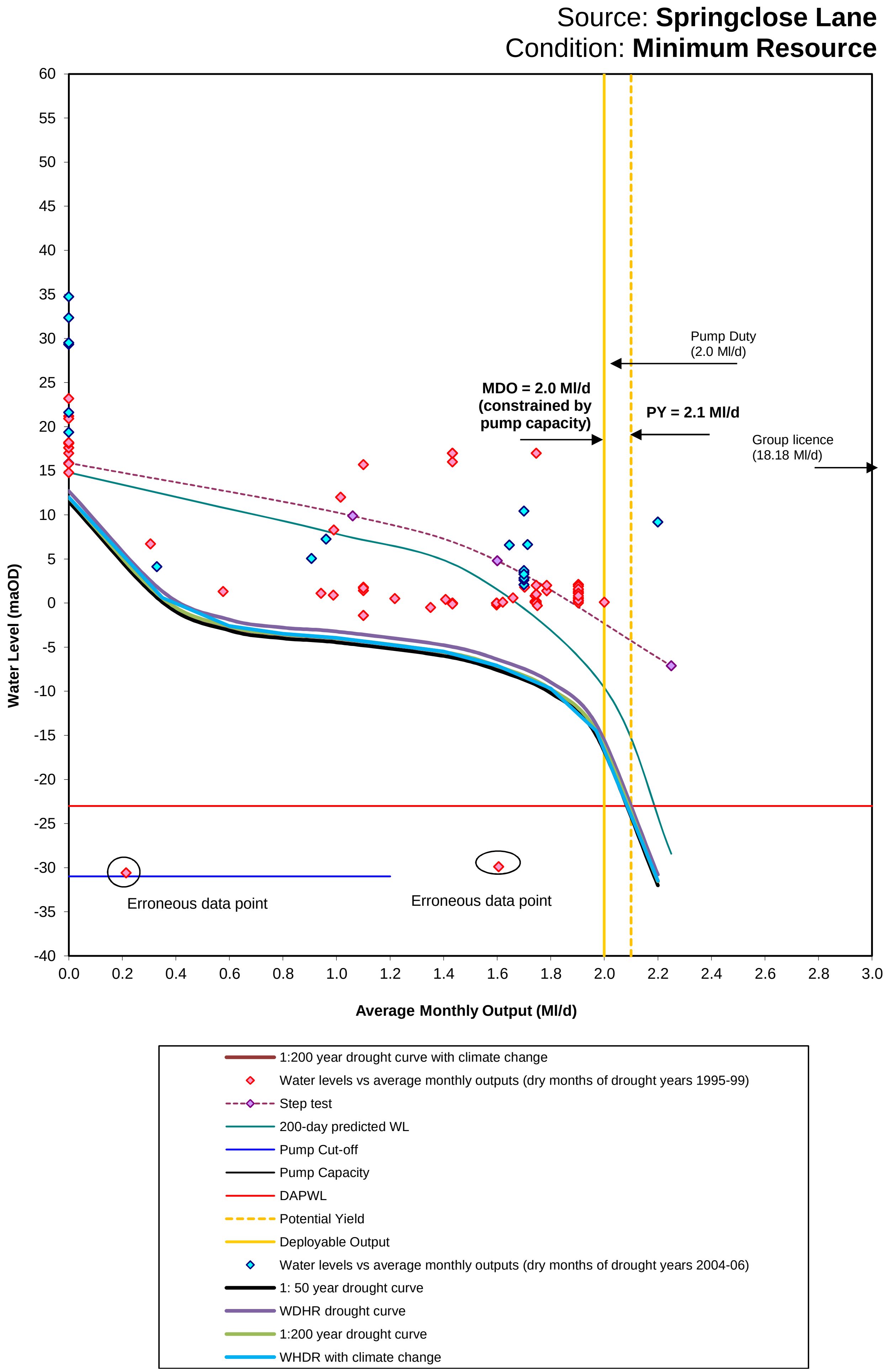
Source: **South Green**
Condition: **Minimum Resource**

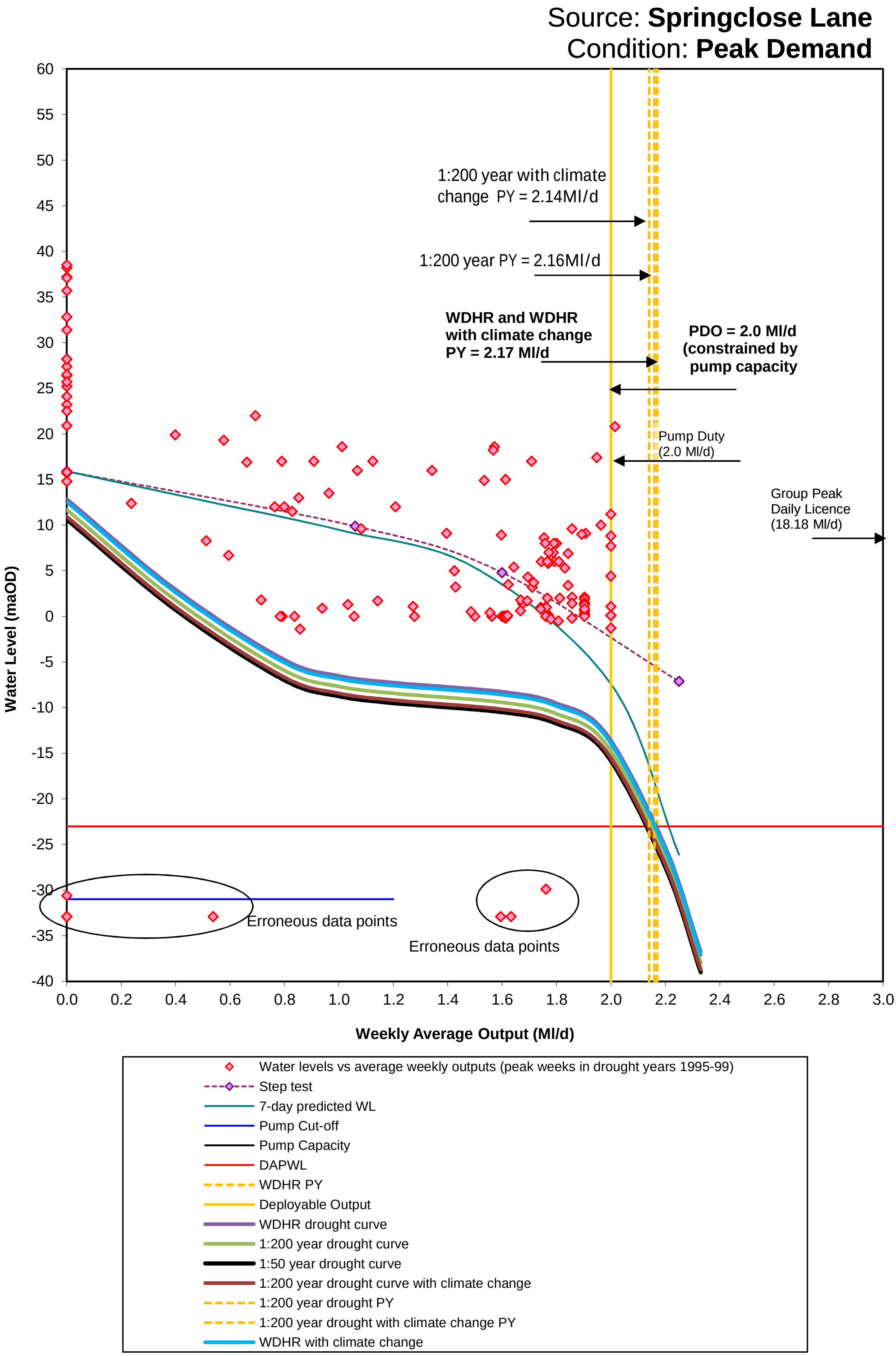


AECOM

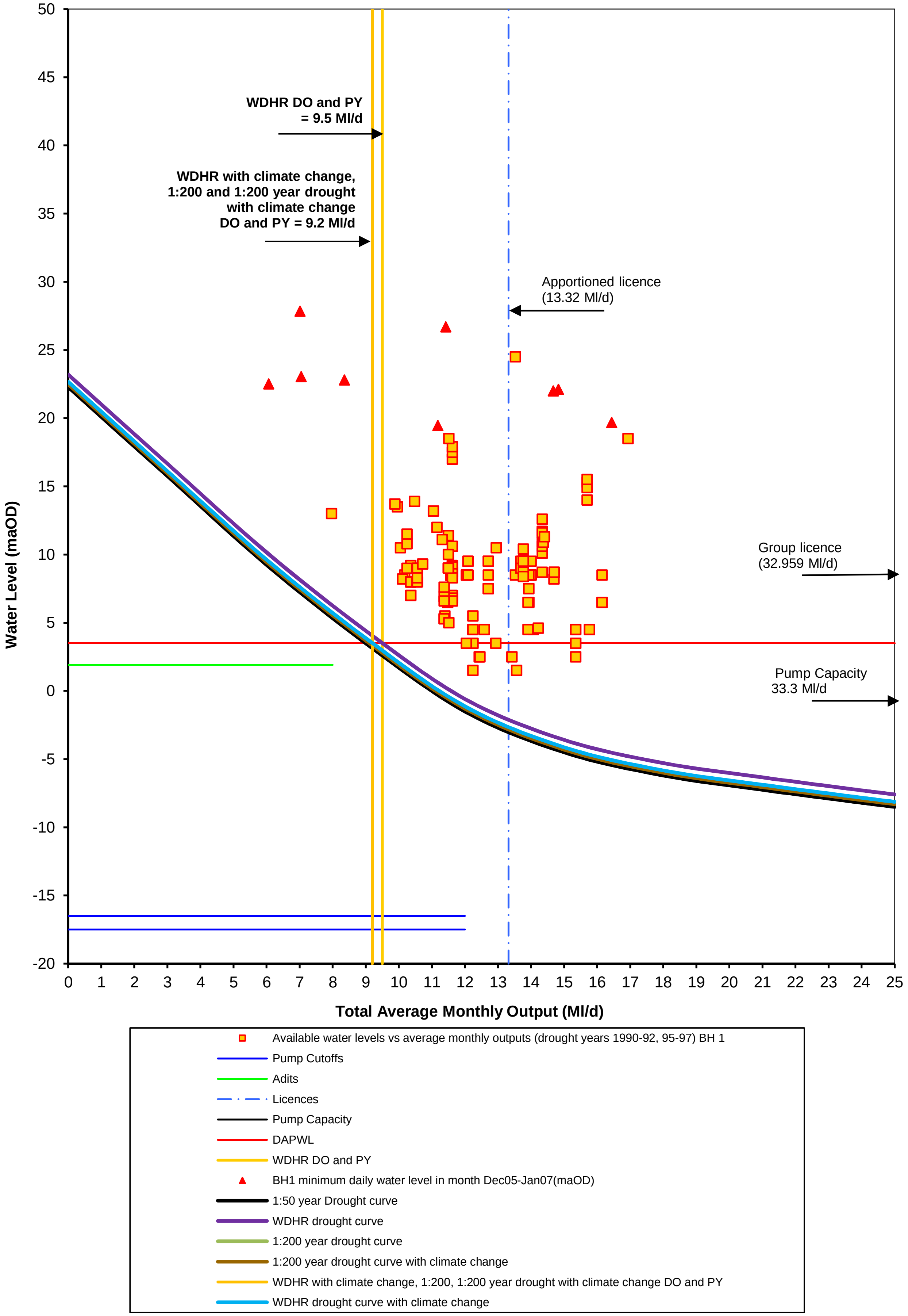
Source: **South Green**
Condition: **Peak Demand**



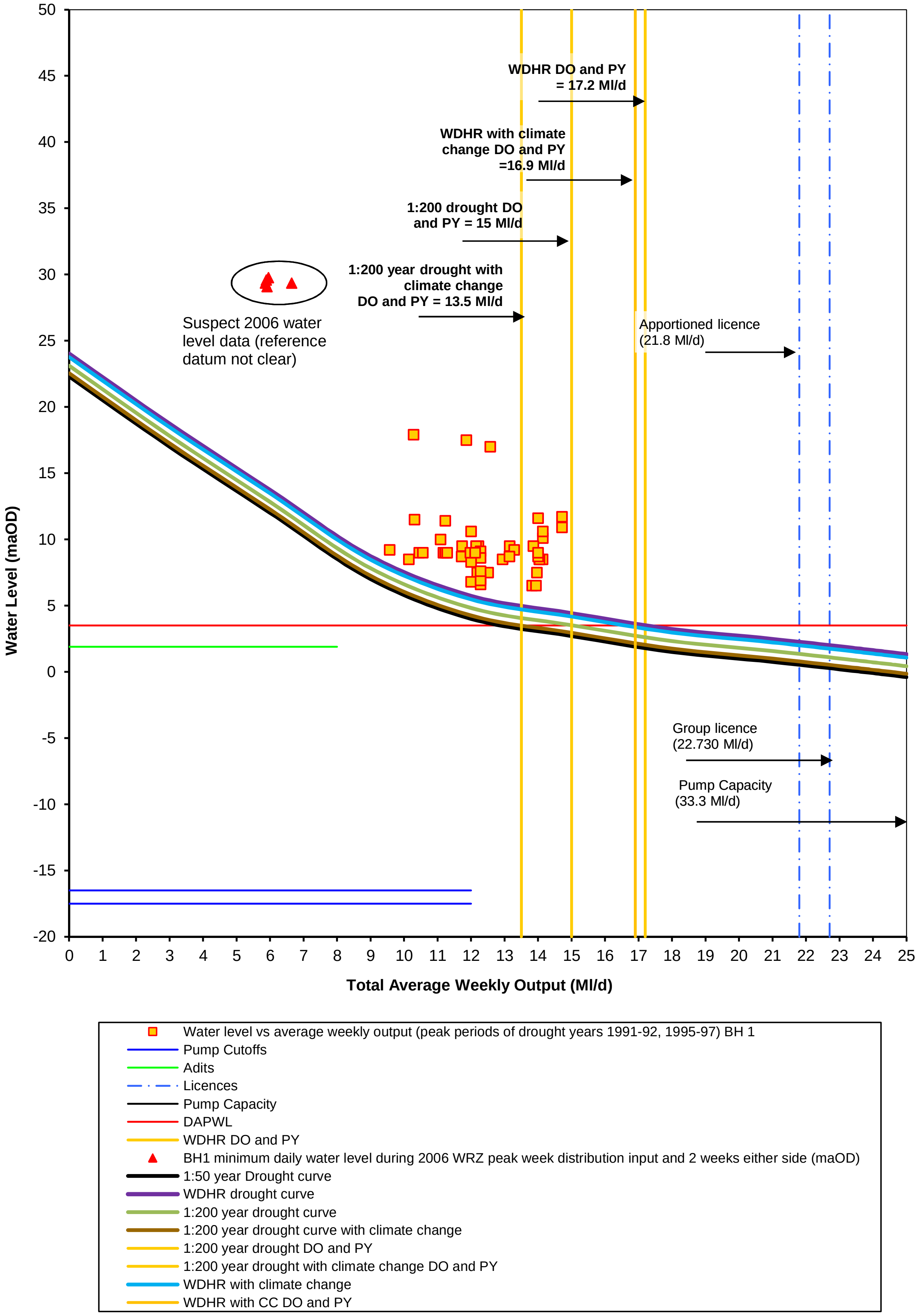

Source: **Springclose Lane**
Condition: **Minimum Resource**
Water Level (maOD)
Average Monthly Output (Ml/d)
Pump Duty
(2.0 Ml/d)
MDO = 2.0 Ml/d
(constrained by
pump capacity)
PY = 2.1 Ml/d
Group licence
(18.18 Ml/d)
Erroneous data point
Erroneous data point
1:200 year drought curve with climate change
Water levels vs average monthly outputs (dry months of drought years 1995-99)
Step test
200-day predicted WL
Pump Cut-off
Pump Capacity
DAPWL
Potential Yield
Deployable Output
Water levels vs average monthly outputs (dry months of drought years 2004-06)
1: 50 year drought curve
WDHR drought curve
1:200 year drought curve
WHDR with climate change


Source: **Springclose Lane**
Condition: **Peak Demand**
1:200 year with climate change PY = 2.14Ml/d
1:200 year PY = 2.16Ml/d
WDHR and WDHR with climate change PY = 2.17 Ml/d
PDO = 2.0 Ml/d (constrained by pump capacity
Pump Duty (2.0 Ml/d)
Group Peak Daily Licence (18.18 Ml/d)
Erroneous data points
Erroneous data points
Water Level (maOD)
Weekly Average Output (Ml/d)
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0.0
0.2
0.4
0.6
0.8
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4
2.6
2.8
3.0
Water levels vs average weekly outputs (peak weeks in drought years 1995-99)
Step test
7-day predicted WL
Pump Cut-off
Pump Capacity
DAPWL
WDHR PY
Deployable Output
WDHR drought curve
1:200 year drought curve
1:50 year drought curve
1:200 year drought curve with climate change
1:200 year drought PY
1:200 year drought with climate change PY
WDHR with climate change

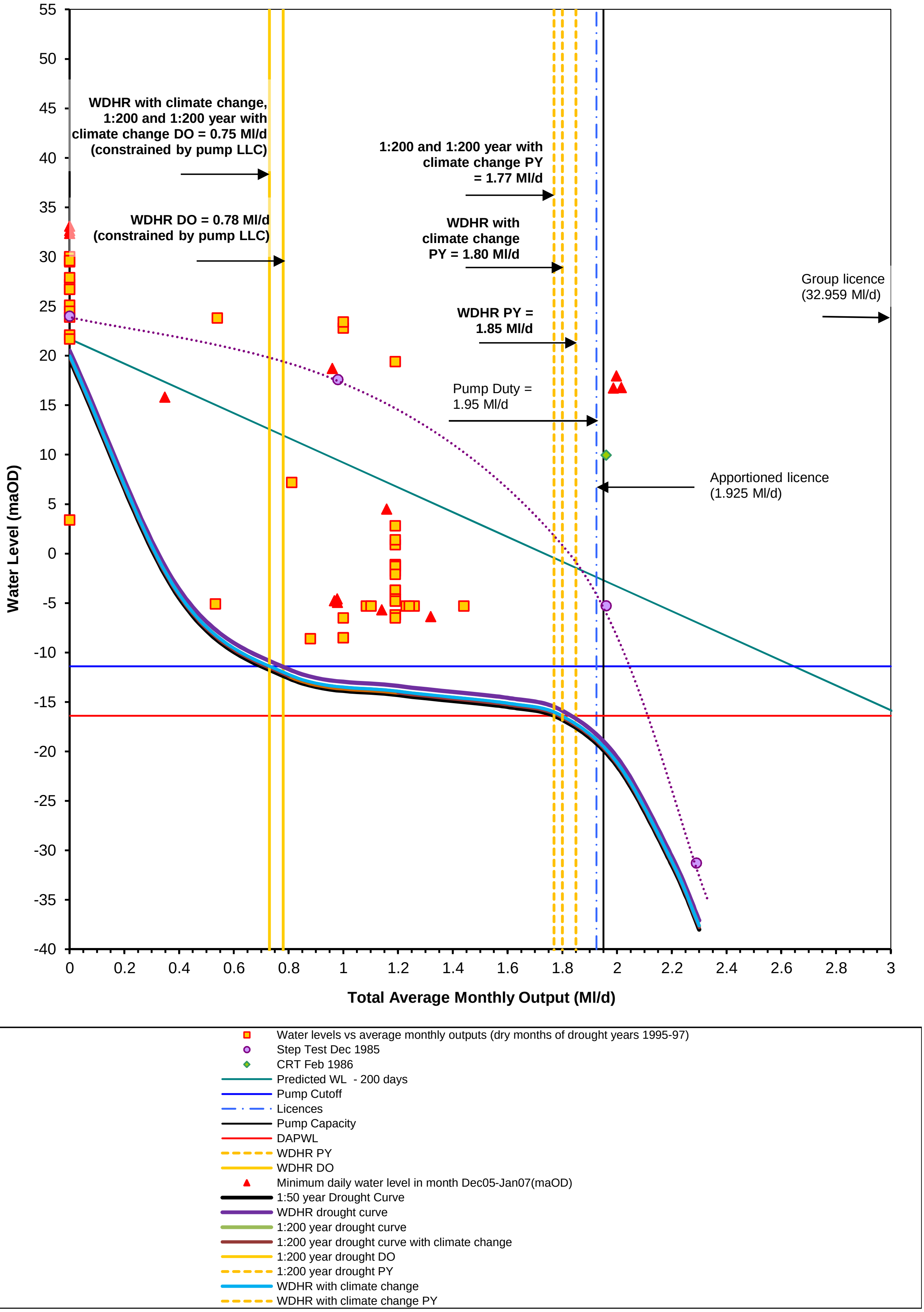
Source: **Sutton**
Condition: **Minimum Resource**



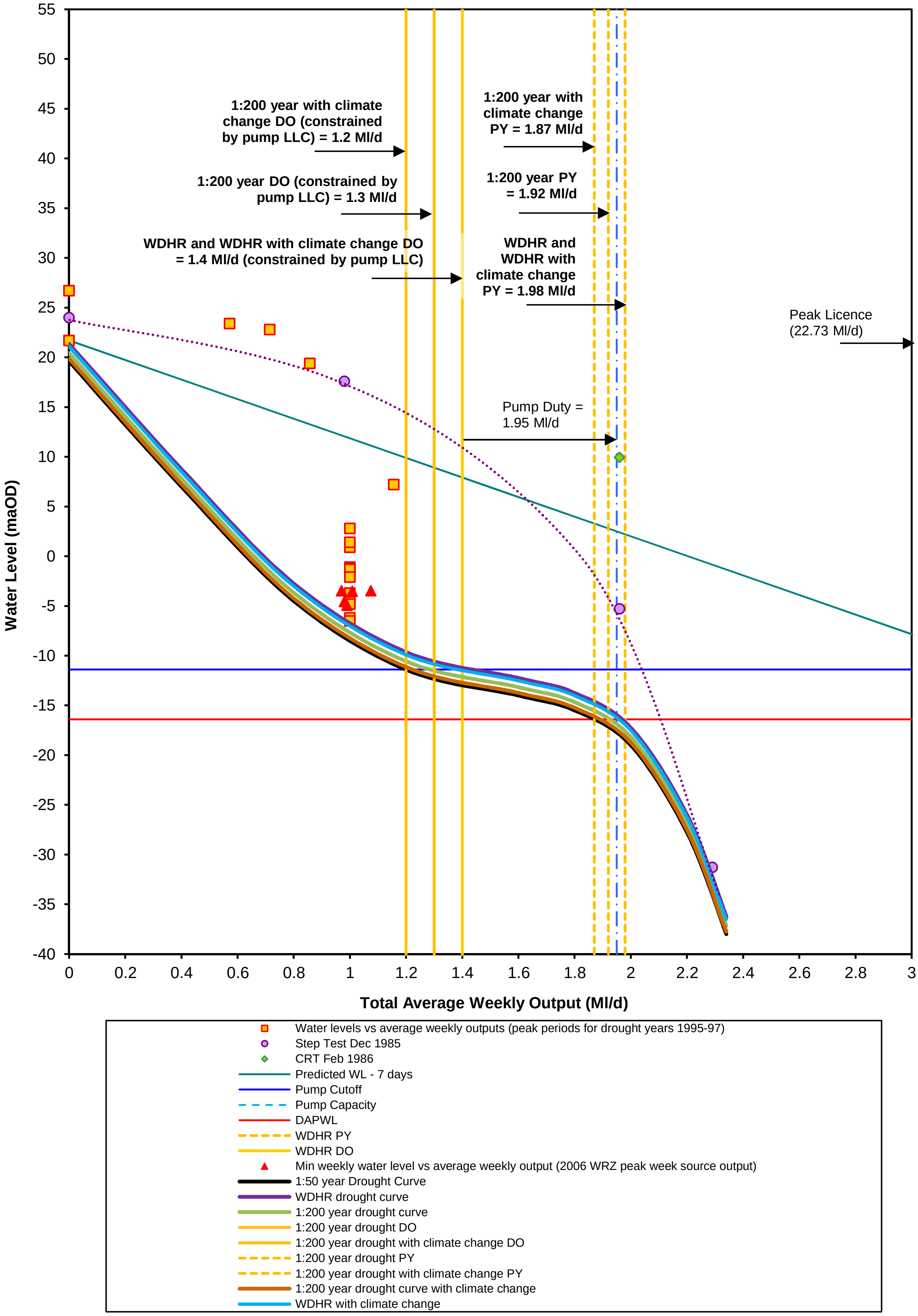
Source: **Sutton**
Condition: **Peak Demand**

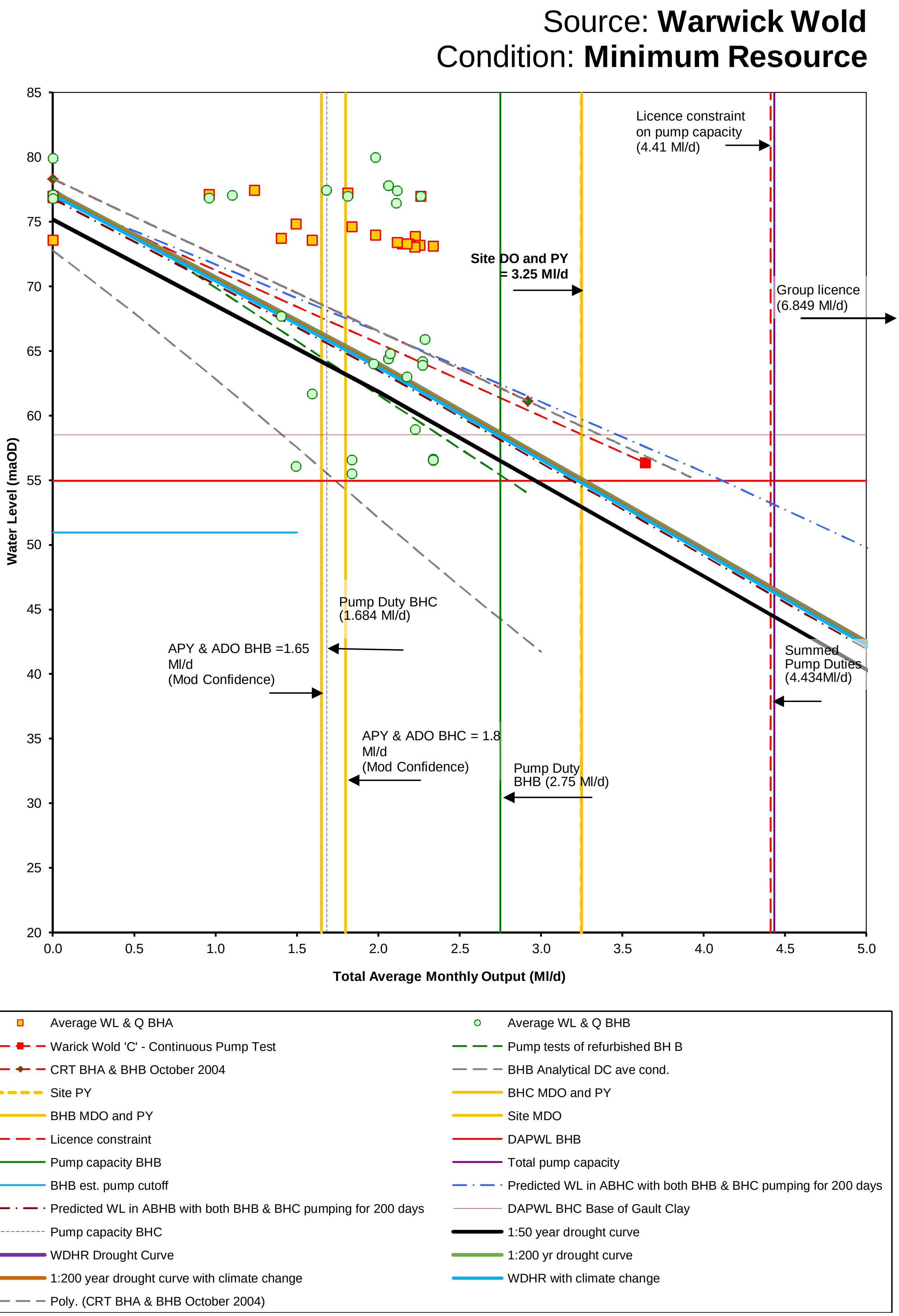


Source: **Sutton Court Road**
Condition: **Minimum Resource**



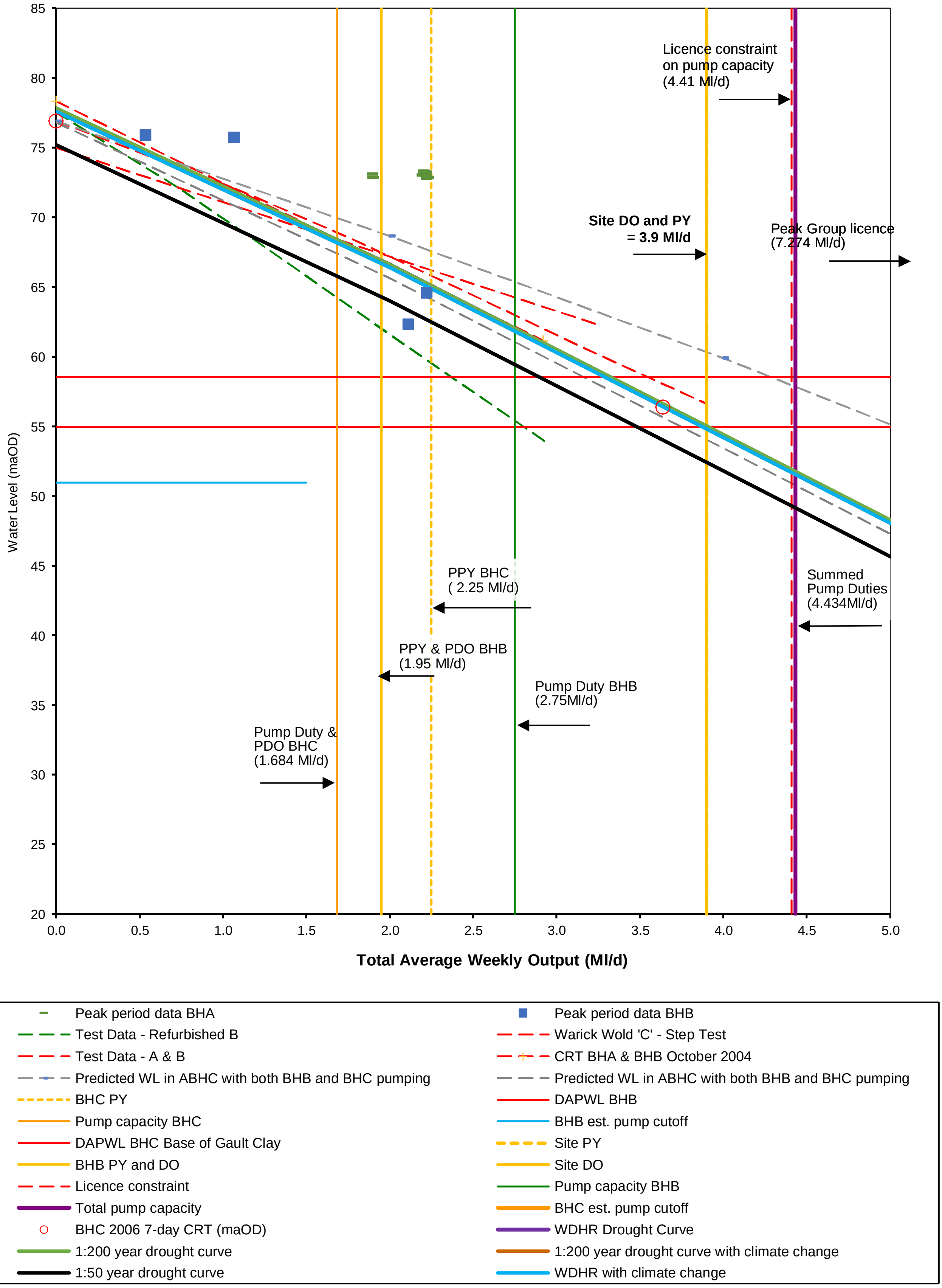
Source: **Sutton Court Road**
Condition: **Peak Demand**



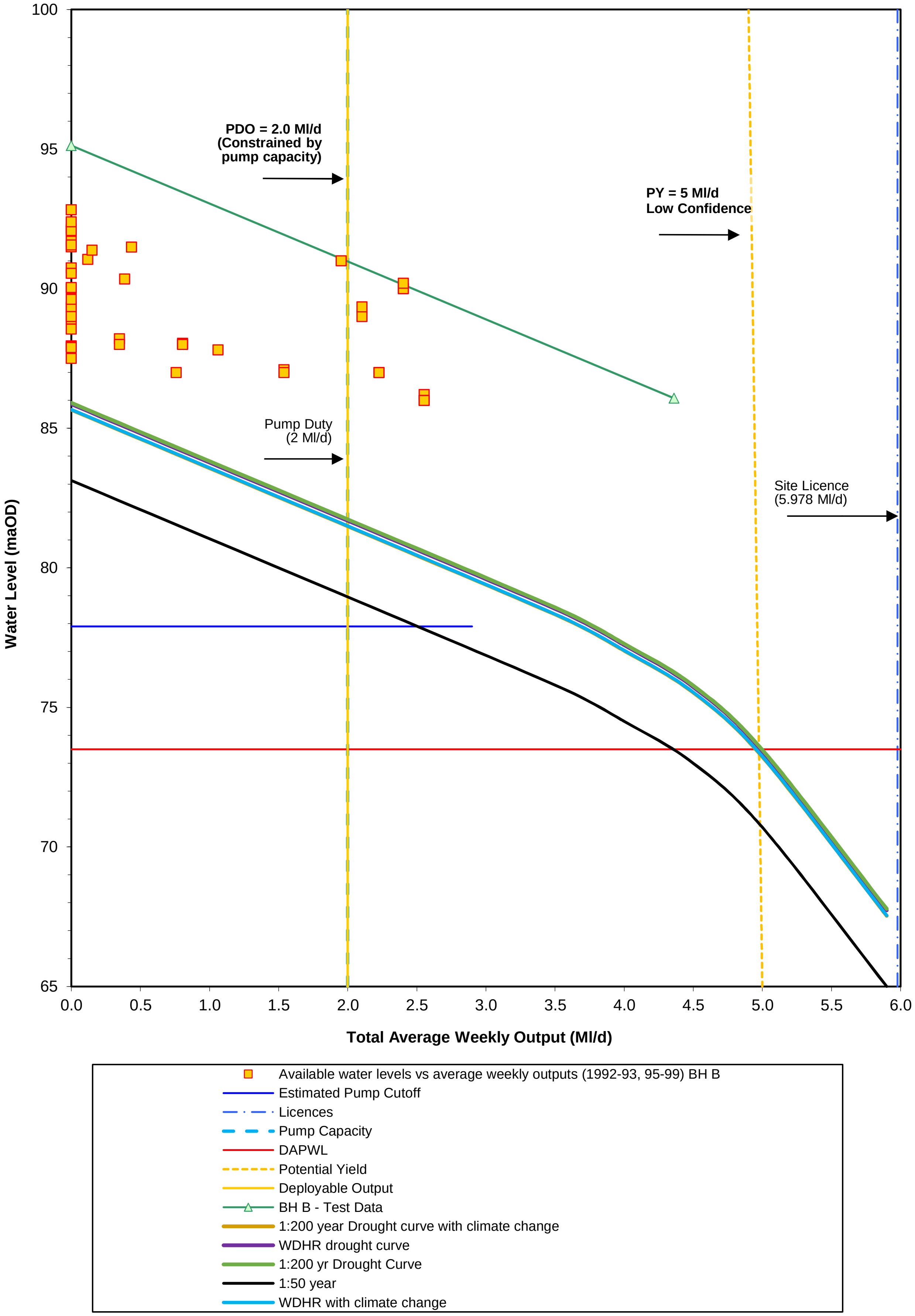


Source: **Warwick Wold**
Condition: **Minimum Resource**
Water Level (maOD)
Total Average Monthly Output (Ml/d)
85
80
75
70
65
60
55
50
45
40
35
30
25
20
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
Licence constraint on pump capacity (4.41 Ml/d)
Site DO and PY = 3.25 Ml/d
Group licence (6.849 Ml/d)
Pump Duty BHC (1.684 Ml/d)
APY & ADO BHB =1.65 Ml/d (Mod Confidence)
Summed Pump Duties (4.434Ml/d)
APY & ADO BHC = 1.8 Ml/d (Mod Confidence)
Pump Duty BHB (2.75 Ml/d)
Average WL & Q BHA
Average WL & Q BHB
Warick Wold 'C' - Continuous Pump Test
Pump tests of refurbished BH B
CRT BHA & BHB October 2004
BHB Analytical DC ave cond.
Site PY
BHC MDO and PY
BHB MDO and PY
Site MDO
Licence constraint
DAPWL BHB
Pump capacity BHB
Total pump capacity
BHB est. pump cutoff
Predicted WL in ABHC with both BHB & BHC pumping for 200 days
Predicted WL in ABHB with both BHB & BHC pumping for 200 days
DAPWL BHC Base of Gault Clay
Pump capacity BHC
1:50 year drought curve
WDHR Drought Curve
1:200 yr drought curve
1:200 year drought curve with climate change
WDHR with climate change
Poly. (CRT BHA & BHB October 2004)

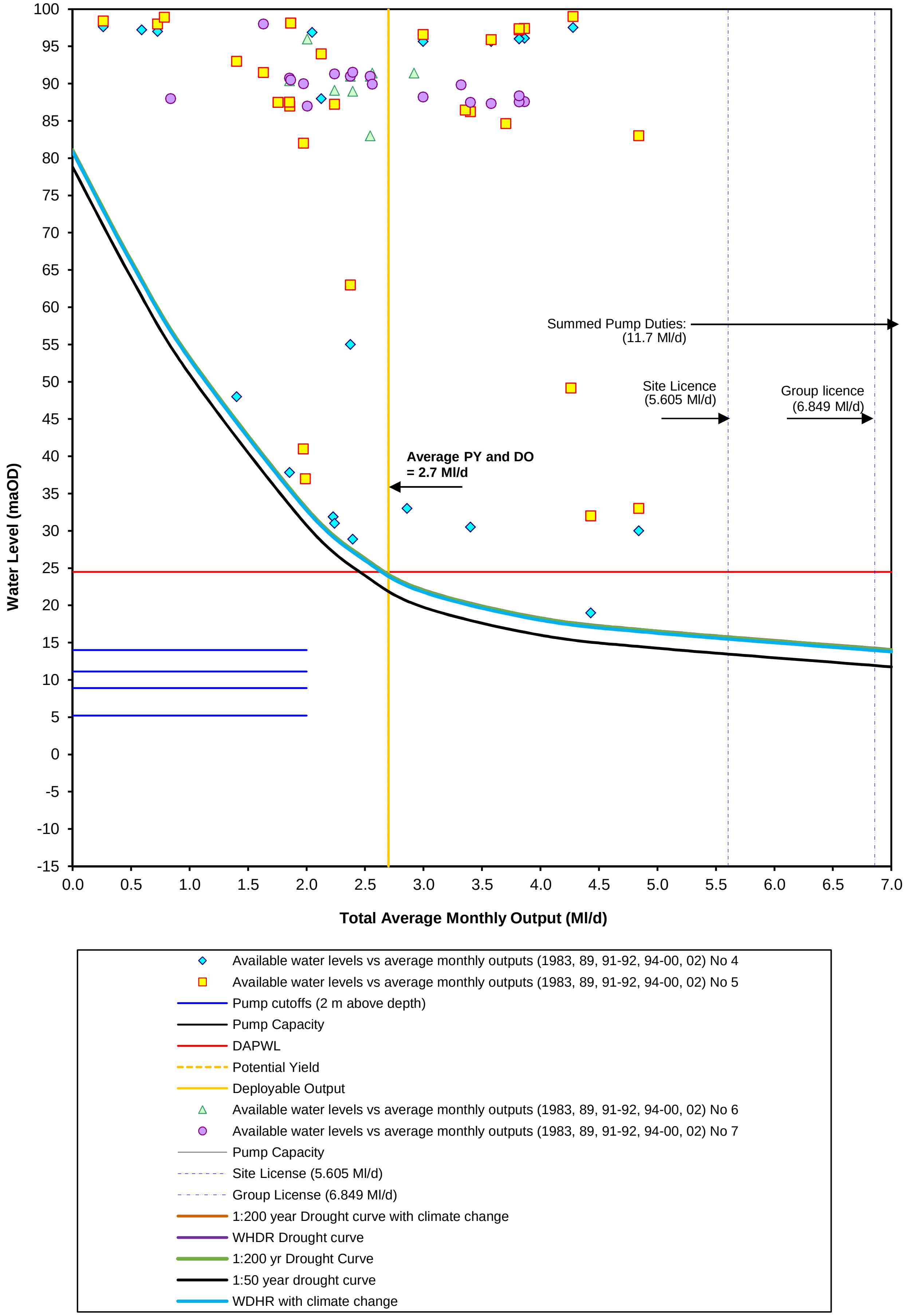
Source: **Warwick Wold**
Condition: **Peak Demand**

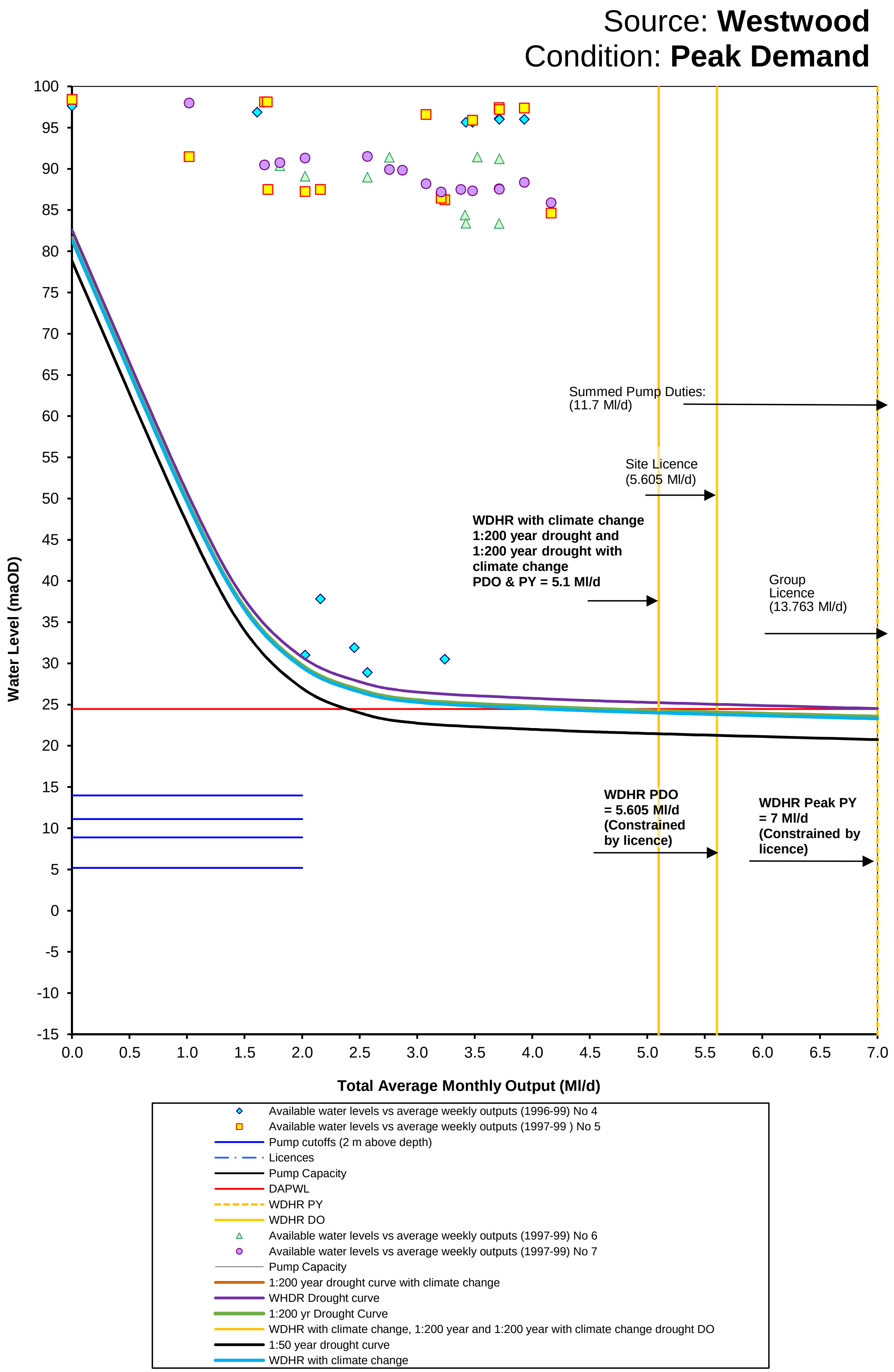


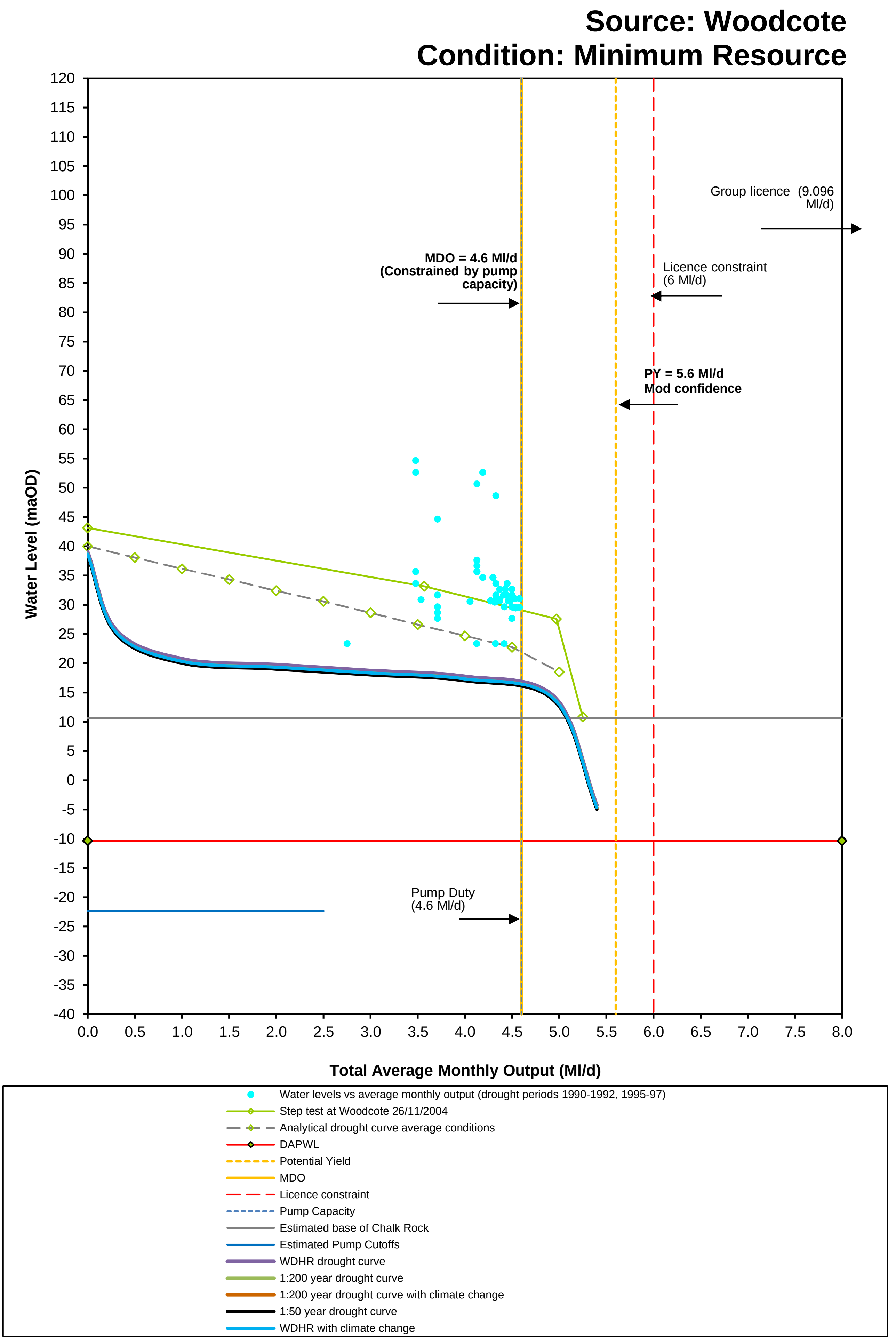
Source: **Water Lane**
Condition: **Peak Demand**



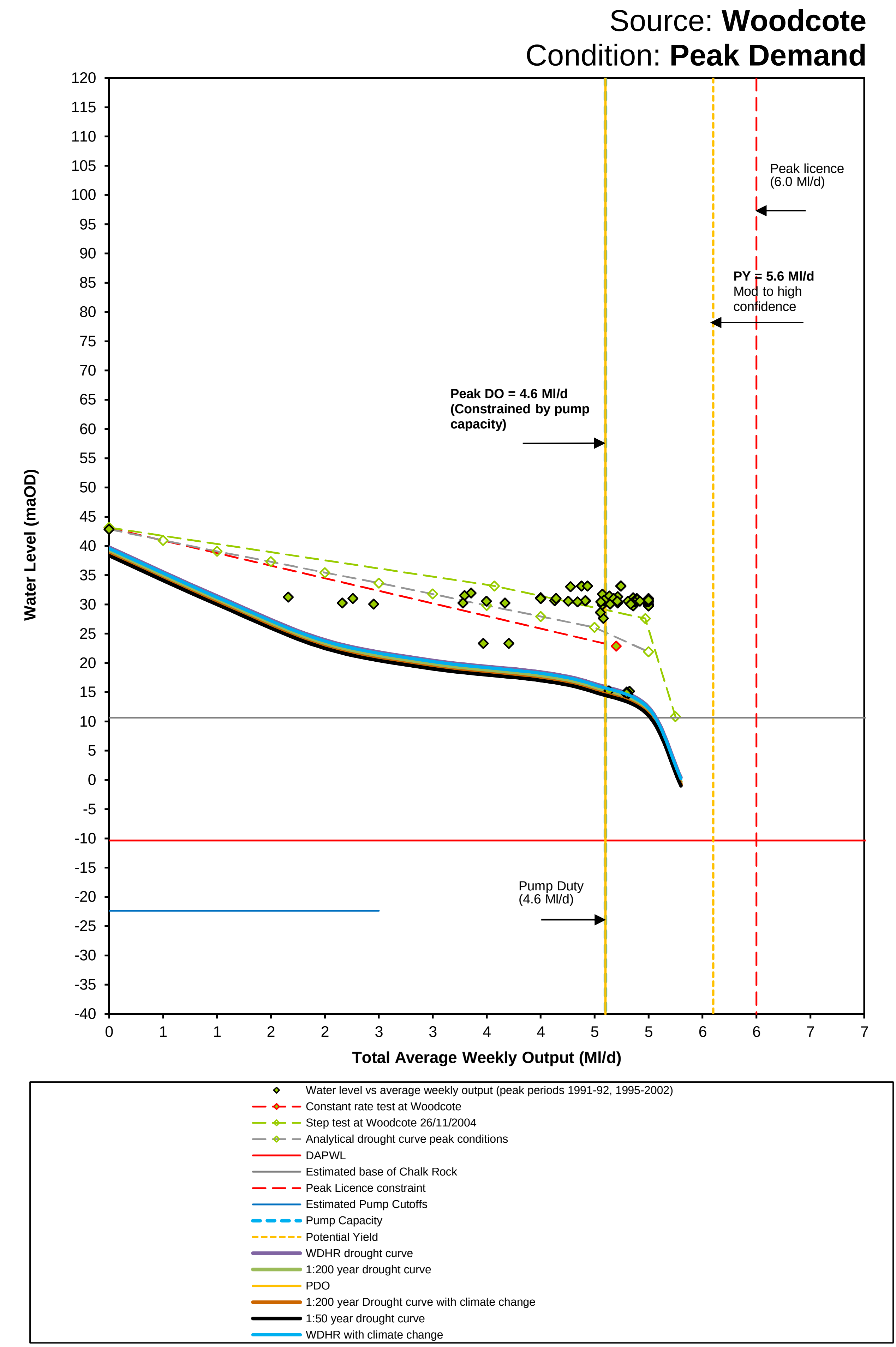
Source: **Westwood**
Condition: **Minimum Resource**




Source: **Westwood**
Condition: **Peak Demand**
Water Level (maOD)
Total Average Monthly Output (Ml/d)
Summed Pump Duties:
(11.7 Ml/d)
Site Licence
(5.605 Ml/d)
WDHR with climate change
1:200 year drought and
1:200 year drought with
climate change
PDO & PY = 5.1 Ml/d
Group
Licence
(13.763 Ml/d)
WDHR PDO
= 5.605 Ml/d
(Constrained
by licence)
WDHR Peak PY
= 7 Ml/d
(Constrained by
licence)
Available water levels vs average weekly outputs (1996-99) No 4
Available water levels vs average weekly outputs (1997-99) No 5
Pump cutoffs (2 m above depth)
Licences
Pump Capacity
DAPWL
WDHR PY
WDHR DO
Available water levels vs average weekly outputs (1997-99) No 6
Available water levels vs average weekly outputs (1997-99) No 7
Pump Capacity
1:200 year drought curve with climate change
WHDR Drought curve
1:200 yr Drought Curve
WDHR with climate change, 1:200 year and 1:200 year with climate change drought DO
1:50 year drought curve
WDHR with climate change

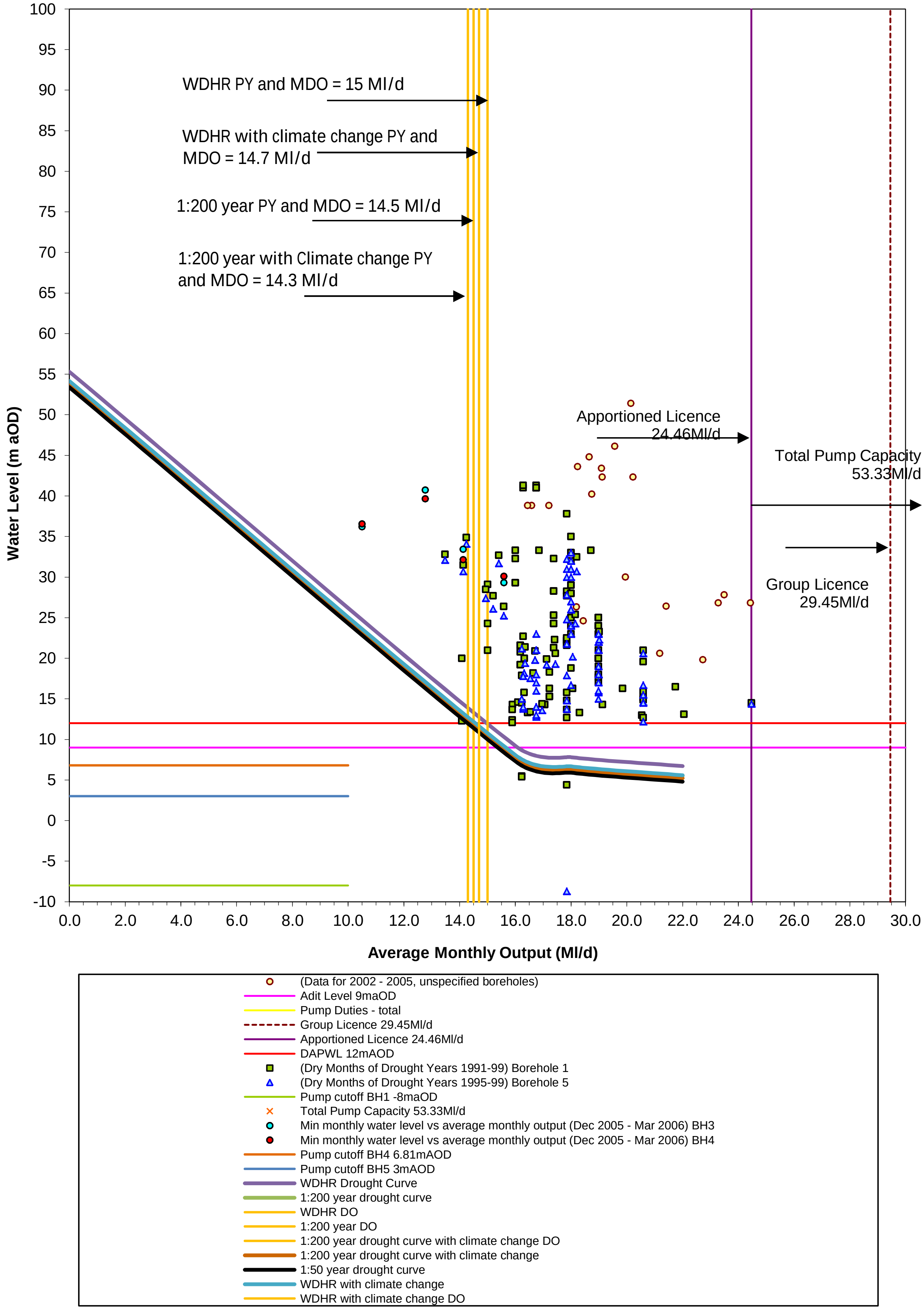


Source: Woodcote
Condition: Minimum Resource
Water Level (maOD)
Total Average Monthly Output (Ml/d)
Group licence (9.096 Ml/d)
MDO = 4.6 Ml/d (Constrained by pump capacity)
Licence constraint (6 Ml/d)
PY = 5.6 Ml/d Mod confidence
Pump Duty (4.6 Ml/d)
120
115
110
105
100
95
90
85
80
75
70
65
60
55
50
45
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
-25
-30
-35
-40
0.0
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
Water levels vs average monthly output (drought periods 1990-1992, 1995-97)
Step test at Woodcote 26/11/2004
Analytical drought curve average conditions
DAPWL
Potential Yield
MDO
Licence constraint
Pump Capacity
Estimated base of Chalk Rock
Estimated Pump Cutoffs
WDHR drought curve
1:200 year drought curve
1:200 year drought curve with climate change
1:50 year drought curve
WDHR with climate change

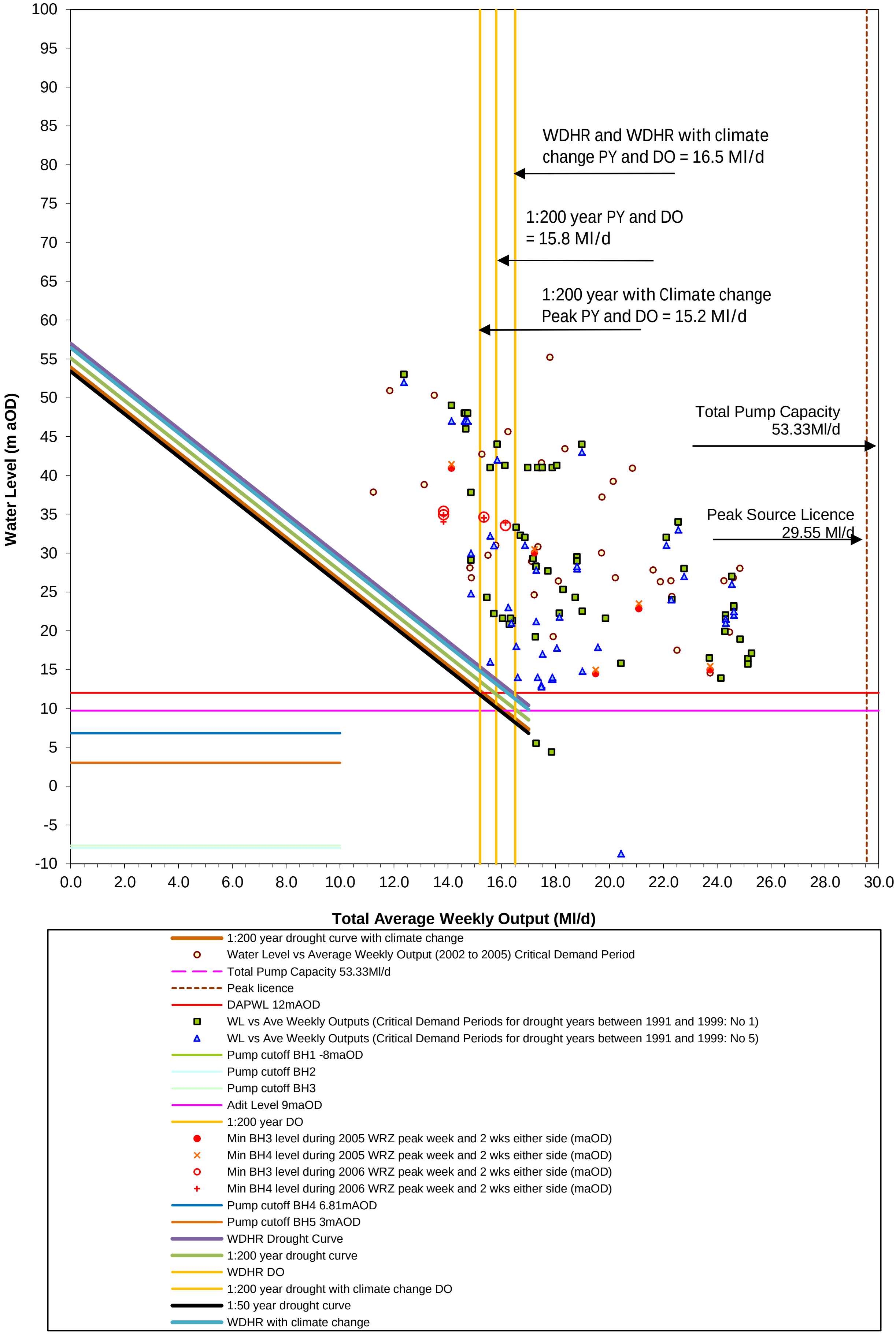


Source: **Woodcote**
Condition: **Peak Demand**
Water Level (maOD)
Total Average Weekly Output (Ml/d)
Peak licence (6.0 Ml/d)
PY = 5.6 Ml/d
Mod to high confidence
Peak DO = 4.6 Ml/d (Constrained by pump capacity)
Pump Duty (4.6 Ml/d)
Water level vs average weekly output (peak periods 1991-92, 1995-2002)
Constant rate test at Woodcote
Step test at Woodcote 26/11/2004
Analytical drought curve peak conditions
DAPWL
Estimated base of Chalk Rock
Peak Licence constraint
Estimated Pump Cutoffs
Pump Capacity
Potential Yield
WDHR drought curve
1:200 year drought curve
PDO
1:200 year Drought curve with climate change
1:50 year drought curve
WDHR with climate change

Source: **Woodmansterne**
Condition: **Minimum Resource**



Source: **Woodmansterne**
Condition: **Peak Demand**



AECOM

Appendix C Basic Vulnerability Assessment

HR Wallingford
Working with water

Sutton & East Surrey WRMP19 Support

Basic Vulnerability Assessment

MAM7911-RT001-R02-00

March 2017

Document information

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Release number	R02-00
Report date	March 2017
Client	AECOM
Client representative	Jane Sladen
Project manager	Eleanor Hall
Project director	Chris Counsell

Document history

Date	Release	Prepared	Approved	Authorised	Notes
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Document authorisation

Prepared	Approved	Authorised

Executive summary

This report describes the analysis completed to understand the vulnerability of SES Water's water supply system to climate change. This is known as the Basic Vulnerability Assessment.

Vulnerability assessments are a requirement outlined in the Environment Agency Water Resources Planning Guidelines (WRPG) and other related guidance (Environment Agency, 2012a,b; 2013b). Their purpose is to determine whether a specific water resource zone is classed as "Low", "Medium" or "High" Vulnerability to future climate change, which then influences the methodology adopted for climate change impacts assessment on Deployable Output (DO). The first stage of the process is the Basic Vulnerability Assessment. The Basic Vulnerability Assessment uses the most up-to-date information from the previous plans to rapidly evaluate the level of vulnerability and guide the methods for the subsequent steps in the climate change assessment process.

SES Water, formerly Sutton and East Surrey Water previously divided their area into two Water Resource Zones (WRZs). For WRMP 2019, the area will be considered as one WRZ. The Basic Vulnerability Assessment shows that SES Water's single WRZ should be classified as Low Vulnerability. This level of vulnerability was also exhibited by both WRZs in the previous WRMP 2014.

Both the WRMP 2019 and WRMP 2014 Basic Vulnerability Assessments considered a wide variety of information, including previous analyses on the impacts of climate change on groundwater and surface water sources, consideration of source types, sustainability reductions, experience of past drought events and connectivity within and between the zones. Like the previous Basic Vulnerability Assessment, the WRMP 2019 assessment has been able to construct a magnitude versus sensitivity plot, utilising updated data.

Abbreviations

DO	Deployable Output
DYAA	Dry-year annual average
FF	Future Flows and Groundwater Levels project
NEP	National Environmental Programme
OBH	Observation borehole
PDO	Peak Deployable Output
PET	Potential evapotranspiration
WRMP	Water Resource Management Plan
WRZ	Water Resource Zone
UKWIR	UK Water Industry Research

Contents

Figures

Tables

1. Introduction

This report describes the analysis completed to understand the vulnerability of SES Water's water supply system to climate change. This is known as the Basic Vulnerability Assessment and provides an overview of the vulnerabilities across SES Water's supply area. The assessment has made use of current knowledge of system vulnerabilities and includes reference to the latest Water Resources Management Plan (WRMP) 2014 and Drought Plan 2013 as well as other relevant information where appropriate. This approach is consistent with the Water Resources Planning Guidelines (WRPG) and related guidance (Environment Agency, 2012a,b; 2013b).

SES Water, formerly Sutton and East Surrey Water, previously divided their area into two Water Resource Zones (WRZs). For the WRMP 2019 assessment, the area will be considered as one WRZ. The Basic Vulnerability Assessment has been completed for SES Water's new, single Water Resource Zone (WRZ). However, the information used to support the assessment considers the old Sutton and East Surrey WRZs separately.

2. Methodology

The Basic Vulnerability Assessment is the first level in a tiered approach to assessing vulnerability, developed as part of the Environment Agency/UKWIR 'Climate Change and Water Supply Planning' (WSP) project. Vulnerability is defined in the report as:

> Climate vulnerability defines the extent to which a system is susceptible to, or unable to cope with, adverse effects of climate change including climate variability and extremes. It depends not only on a system's sensitivity but also on its adaptive capacity.
>
> *Environment Agency, 2012b*

The Basic Vulnerability Assessment is largely qualitative and is completed based on information already available on the water resource zone and system vulnerabilities for example, from analysis completed for WRMPs, the preparation of water company drought plans and any other relevant studies. This information is summarised in a table, with links and references to additional relevant details where necessary. Its purpose is to determine whether a specific WRZ is classed as "Low", "Medium" or "High" Vulnerability to future climate change, which then influences the methodology adopted for the climate change impact assessment on DO. The outcomes of the assessment provide an indication of the level and complexity of subsequent modelling that needs to be completed, proportionate to the assessed vulnerability.

Sections 2.1 to 2.3 outline the different components of the Basic Vulnerability Assessment method to be considered. Section 3.2 presents the magnitude versus sensitivity plot used to determine the basic vulnerability of SES Water's WRZ and a summary table of the key attributes that also contribute to the vulnerability of the WRZ. The final section concludes the findings of the assessment.

2.1. Magnitude versus sensitivity plot of the impacts of climate change on DO

This assessment makes use of a vulnerability scoring matrix to indicate the level of vulnerability for the WRZ, producing a magnitude versus sensitivity plot of the change in Deployable Output (DO), as shown in Table 2.1.

Table 2.1: Vulnerability scoring matrix

Uncertainty range (Wet-Dry % change)	Mid scenario (DO - % change)		
	>-5%	>-10%	>-15%
<5%	Low	Medium	High
<10%	Medium	Medium	High
<15%	Medium	High	High
>15%	High	High	High

Source: Environment Agency, 2013b

2.2. Supply demand balance

The results of the baseline supply demand balance from the previous WRMP inform the basic assessment of the resource zone vulnerability to the effects of climate change, and help determine the level of climate change assessment required. According to their supply demand balance the WRZs can be classified (HR Wallingford, 2012a) as:

- Low vulnerability – Baseline supply demand balance remains positive throughout the 25 years planning period;
- Medium vulnerability – Baseline supply demand balance falls into deficit in the first 10 years of the planning period;
- High vulnerability – Baseline supply demand balance falls into deficit in the first 5 years of the planning period.

2.3. Supporting information

In addition to these two quantitative criteria, tables summarising the key climate vulnerability and related information on each WRZ are collated from the WRMP 2014 and Drought Plan. This provides supporting information which can be used to justify the reassignment of vulnerability classification if vulnerabilities are not reflected in the magnitude – sensitivity plot or supply demand balance. Section 3.2 provides this supporting table.

3. Assessment

3.1. Summary of results from WRMP 2014

SES Water is a water supply only company which covers an area of 834 km^2 comprising a large proportion of Surrey, and extending into parts of Kent, West Sussex and Greater London. The Company currently provides drinking water to over 675,000 consumers in over 280,000 properties. On average, the total amount distributed each day is 160 million litres (SES Water, 2014).

3.1.1. Sources

SES Water relies on groundwater for approximately 85% of its supply from sources located within the North Downs Chalk, the Unconfined Chalk, the Mole Valley Chalk and the Lower Greensand aquifer resource units within the Company supply area (SES Water, 2013). The remaining 15% of supply comes from a single surface water source, Bough Beech reservoir, which is a pumped storage reservoir abstracting water from the River Eden during the winter period, normally September to April (SES Water, 2013). Winter rainfall is of greatest importance to SES Water as this period normally recharges the aquifers from which the Company draws the majority of its supplies through the year.

Due to the improved connectivity developed between the two WRZs over the last ten years, the two WRZs have been merged for this plan. Up to 18Ml/d of potable water can currently be transferred from Bough Beech reservoir in the old East Surrey WRZ to the old Sutton WRZ via the Company's Outwood and Buckland booster pumping stations and Margery reservoir (SES Water, 2013).

3.1.2. Drought

SES Water faces a number of potential challenges over the next 25 years, characterised by pressures on water availability due to increased demand from new and existing customers, the impacts of climate change, and the need to protect the environment. The area of South East England in which the Company operates has been classified by the Environment Agency as being under serious water stress (SES Water, 2014; Environment Agency, 2013a).

Critical drought issues are associated with multi-season droughts rather than a single dry season. A dry summer serves to increase demand, a condition that is considered in detail as part of the WRMP. Multi-season droughts have the potential to restrict the overall resource balance and this issue is reviewed within this Plan (SES Water, 2013).

Droughts have been experienced during 1990–91, 1997–98, and most severely 2003–06 and 2011–12. The groundwater levels at a number of sources fell to new historic minimum levels during the drought between 2003 and 2006, then again during the 2011–12 drought event. Sprinkler bans were imposed between July 1990 and December 1992, May 1997 and May 1998 and April 2005 and January 2007. A hosepipe ban was imposed between April 1992 and December 1992 and from March 2006 to January 2007, and temporary use restrictions were imposed from April to July 2012. A non-essential use drought order was imposed from March 2006 to November 2006 (SES Water, 2014). The Company indicate in their WRMP 2014 that they are targeting a reduction in these events in the future by setting their target Level of Service for temporary use restrictions to an occurrence on no more than once in every 10 years.

3.1.3. Supply-demand balance

In the baseline plan in WRMP 2014, the dry-year annual average (DYAA) supply-demand balance surplus is forecast to reduce over the planning period, from 22.07 Ml/d to 10.21 Ml/d by 2035-36 for the old East Surrey WRZ. The deficit in the old Sutton WRZ is forecast to increase further from -6.23 Ml/d to -17.79 Ml/d by 2035-36. In the final plan, transfers between the two WRZs (many of which are already in place) reduce the overall deficit to a surplus of 1.62 Ml/d and 0.27 Ml/d for the old East Surrey and Sutton WRZs respectively, by 2035-36. The supply-demand balance for the Final Plan Dry Year Critical Period scenario is more favourable overall than the DYAA scenario. Therefore, the Basic Vulnerability Assessment is based upon the average scenario values.

Table 3.1: Summary of the forecast supply-demand balance for SES Water in WRMP14

		Supply-demand balance (Ml/d)			
	Old WRZ name	**DYAA 2011-12**	**DYAA 2035-36**	**DYCP 2011-12**	**DYCP 2035-36**
Baseline Plan	East Surrey	22.07	10.21	24.81	6.51
	Sutton	-6.23	-17.79	-3.71	-19.34
Final Plan	East Surrey	22.07	1.62	24.81	16.71
	Sutton	-6.23	0.27	-3.71	0.18

Source: Water Resource Plan Tables for WRMP14, SES Water Plc (2014)

3.1.4. Sustainability reductions

Sustainability reductions are the reductions in abstractions licences (leading to reductions in DO) which may be required to protect international or national designated conservation sites and locally important but undesignated sites, or to deliver Water Framework Directive (WFD) objectives. The Environment Agency provided SES Water with a rolling programme of sustainability reduction updates.

The Environment Agency has stated in its Phase 4 National Environmental Programme (NEP) that there are no ‘confirmed’ or ‘likely’ sustainability reductions for the SES Company area, although there are some ‘uncertain’ sustainability reductions which could have the potential to impact on the company’s groundwater sources in future (SES Water, 2014). Whilst Phase 1 NEP investigations were already completed by the Environment Agency at Pipp Brook, Reservoir A and Gibbs brook before WRMP 2014, the Environment Agency intended to undertake a fish monitoring programme downstream of Reservoir A over subsequent few years to ensure there was no damage that had previously been undetected. As there are currently no confirmed or likely sustainability reductions, SES Water did not include any sustainability reductions in their baseline supply demand balance or target headroom assessment in WRMP 2014.

3.1.5. Climate change

For WRMP 2014, SES Water undertook a qualitative Basic Vulnerability Assessment based upon the results of the WRMP 2009 climate change assessment and then subsequently an assessment of climate change impacts on both surface water and groundwater sources. The results of the subsequent climate change impact assessment is summarised in the next few sections.

Surface water

The approach for assessing surface water used the 20 samples of the full UKCP09 10,000 as produced in 2009 as part of the UKWIR Rapid Assessment project. These samples were expressed as monthly change factors for precipitation and potential evapotranspiration (PET), which were then used to perturb historical climate time series. The resulting series were then run through a hydrological model to ascertain the impact of climate change. These figures were subsequently used in a water resources model to determine the impact on DO (SES Water, 2014).

Table 3.2 summarises the WRMP 2014 revised figures for the potential impact of climate change on the DO of the Company’s only surface water source (Bough Beech reservoir) by 2030.

Table 3.2: Changes in Bough Beech reservoir Average Deployable Output (ADO) and Peak Deployable Output (PDO) due to the estimated impacts of climate change by 2030 as reported for WRMP 2014

Source	Change in baseline ADO (Ml/d)			Change in baseline PDO (Ml/d)		
	Lower bound	Upper bound	Median	Lower bound	Upper bound	Median
Bough Beech Reservoir (base year DO 28.90 Ml/d)	−7.9	−0.4	−5.7	0	0	0

Source: SES Water (2014)

Groundwater

The approach for assessing groundwater used the 11 runs from the Future Flows and Groundwater Levels ("FF") project. These were derived from the UKCP09 climate projections models and run through a suite of rainfall-runoff and groundwater models. This data was used to produce a set of 11 change factors, which for groundwater express the change in water level at key groundwater sources. These changes were subsequently used to re-calculate DO. The full set of steps for estimating the impact of climate change on groundwater DO is provided in the latest WRMP (SES Water, 2014).

Table 3.3 and Table 3.3 summarise the estimated impacts of climate change for the 2030s on the groundwater DOs of each of the Company's sources for SES Water's old WRZs respectively. These impacts (changes in DO) were estimated as a direct result of applying the FF change factors to existing source summary diagrams and scaled using the equation provided in the WRPG (Environment Agency, 2012a) to provide the impact for each year of the planning period. The estimated impacts in the table relate to the 2030s.

Table 3.3: Changes in groundwater sources ADO and PDO due to the estimated impacts of climate change by 2030 as reported for WRMP 2014

Group	Source	Change in baseline ADO (Ml/d)			Change in baseline PDO (Ml/d)		
		Lower bound	Upper bound	Median	Lower bound	Upper bound	Median
North Downs Chalk (Unconfined Chalk)	1	−0.9	0.1	0	−0.6	0	0
	2	−0.07	0.03	0	−0.1	0.03	0
	3	0	0	0	0	0	0
	4	0	0	0	0	0	0
	5	0	0	0	0	0	0
	6	0	0	0	0	0	0
	7	−0.5	0.2	0	−0.8	0.8	−0.1
	8	−0.05	0	0	0	0	0
Source 11 Group (Unconfined Chalk)	9	−2.32	0	0	−1.47	0	0
	10	0	0	0	0	0	0
	11	−0.75	0.2	0	−0.85	0.3	0
	12	0	0	0	0	0	0
Confined Chalk	13	0	0	0	0	0	0

Group	Source	Change in baseline ADO (Ml/d)			Change in baseline PDO (Ml/d)		
North Downs Chalk (Unconfined Chalk)	14	0	0	0	0	0	0
	15	−0.5	0.25	0	0	0	0
	16	0	0	0	−0.15	0	0
Sutton WRZ Total		**−5.09**	**0.78**	**0**	**−3.97**	**1.13**	**−0.1**
North Downs Chalk (Unconfined Chalk)	17	0	0	0	−3.8	2.4	0
	18	−0.8	0.4	0	−1.7	0.3	0
Mole Valley Chalk (Unconfined Chalk)	19	0	0	0	0	0	0
	20	0	0	0	0	0	0
Lower Greensand – Well House Inn OBH predictions applied, as no data available for Lower Greensand sources. This is a conservative prediction.	21	0	0	0	−1.16	0	0
	22	0	0	0	0	0	0
	23	0	0	0	−0.67	0	0
	24	−0.6	0	0	0	0	0
	25	0	0	0	0	0	0
	26	−0.45	0.1	−0.05	−0.445	0.13	0
	27	−0.35	0.15	0	−0.4	0.1	0
	28	0	0	0	0	0	0
	29	0	0	0	0	0	0
	30	0	0	0	0	0	0
	31	−0.12	−0.01	−0.01	0	0	0
	32	0	0	0	−0.08	0	0
	33	0	0	0	0	0	0
	34	0	0	0	0	0	0
	35	−0.9	0.25	0	−1.05	0.2	0
	36	−0.12	0	0	0	0	0
	37	−0.12	0.1	0	−0.35	0.2	0
	38	0	0	0	0	0	0
East Surrey WRZ Total		**−3.46**	**0.99**	**−0.06**	**−9.65**	**3.33**	**0**

Source: SES Water (2014)

3.2. Basic Vulnerability Assessment

The vulnerability classification of the SES Water's new, single WRZ has been determined by its position on a magnitude versus sensitivity plot (see Figure 3.1). The plot shows the change in DO for the 'mid' climate change scenario against the uncertainty range (calculated as the difference between the 'wet' and 'dry' scenarios). This is based on the climate change impact assessment carried out for the WRMP 2014 (SES, 2014). Information about the sensitivity and adaptive capacity of the WRZs was collated from the Company's last WRMP (SES Water, 2014) and supporting Drought Plan (SES Water, 2013) and is presented in Table 3.4.

The data to calculate the magnitude and sensitivity of the impacts of climate change on DO were extracted from SES Water (2014) planning tables for dry year annual average scenarios.

Magnitude has been defined as the average DO impact on annual average DO.

Sensitivity has been defined as the percentage range in annual average DO impact between the lowest and highest DOs modelled.

A magnitude versus sensitivity plot has been prepared for this assessment and is presented in Figure 3.1. The red squares refer to high vulnerability; amber squares to medium vulnerability; and, green to low vulnerability.

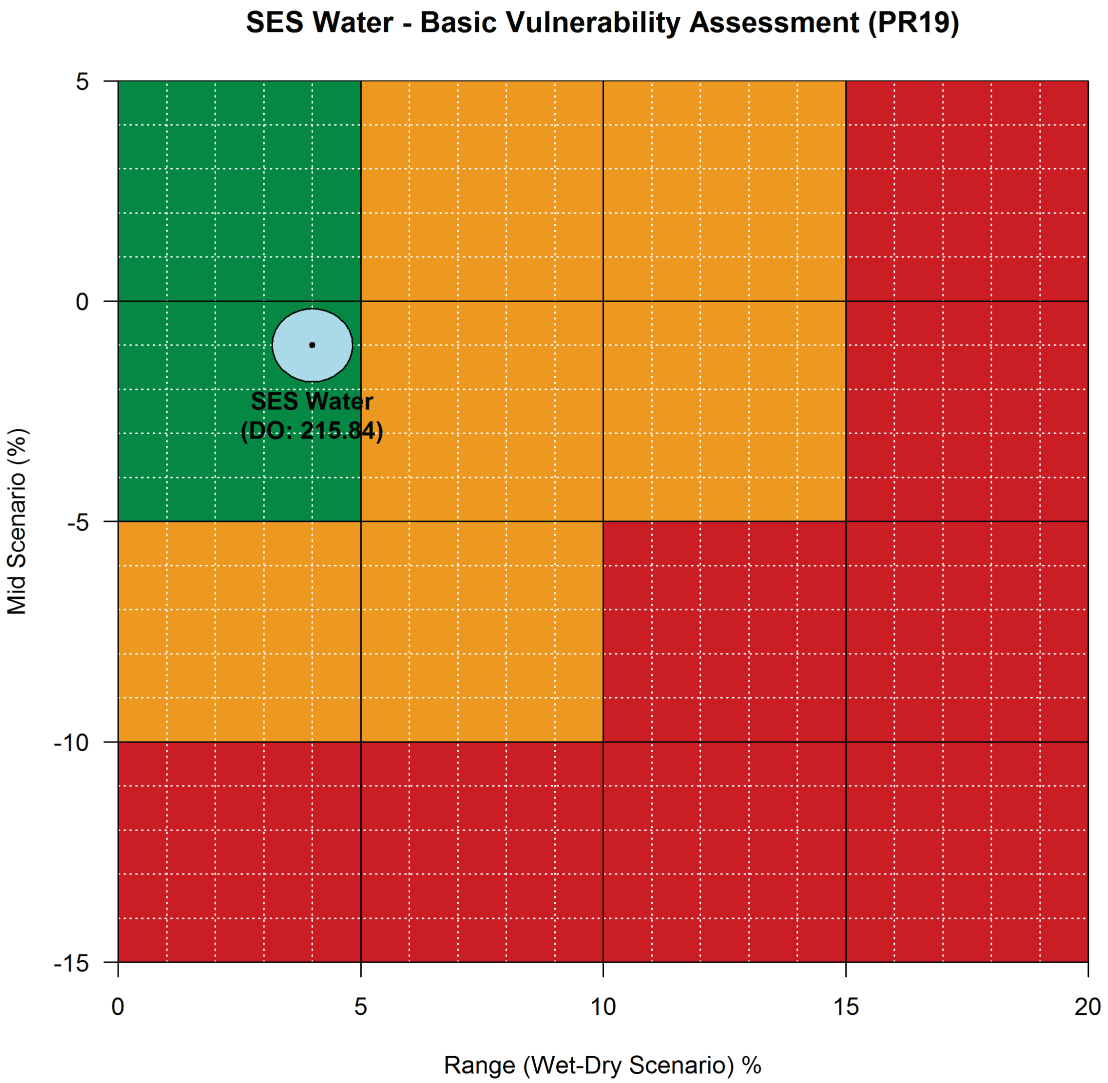

Figure 3.1: Magnitude versus sensitivity plot for SES Water's single WRZ for the 2030s; the estimated DO (in Ml/d) included in the label for information error

Source: Data sourced from SES (2014) planning tables for dry year annual average scenarios

Table 3.4: Basic Vulnerability Assessment summary table

Description	Source	Data	Comment
Critical drought years (top three)	Drought Plan/ WRMP	1997–98, 2003–06 and 2011–12 for both SES WRZs,	Groundwater levels at a number of sources fell to new historic minimum levels during the drought between 2003 and 2006, then again during the 2011–12 drought event. Hosepipe bans were imposed from March 2006 to January 2007, and temporary use restrictions were imposed from April to July 2012 in both WRZs.
Period used for analysis	Drought Plan/ WRMP	Groundwater levels at the Well House Inn observation borehole (OBH) are used to represent the North Downs Chalk aquifers, with records from 1942 - 2010. The identification of drought periods for the Mole Valley Chalk aquifer is based on river flows due to lack of long term data at Mole Valley. The Well House Inn is the only OBH used for groundwater monitoring. A time series from 1888 to 2004 is available for the surface water analysis of Bough Beech reservoir.	Levels of Service: Temporary bans: once in 10 years on average. Ordinary Drought Orders: once in 20 years on average. Emergency Drought Orders: in extreme droughts or emergency situations only.
Types of sources	Drought Plan/ WRMP	SES Water relies on groundwater sources for approximately 85% of supply. The remaining 15% of supply comes from a single surface water source; Bough Beech reservoir.	Following significant network improvements in the last AMP period, namely the Buckland Transfer and The Avenue transfers between the two old WRZs, up to 41% of the demand in the old East Surrey WRZ and up to 47% of demand in the old Sutton WRZ can be transferred between zones to mitigate any supply-demand deficit shortfalls. The Company’s supply area is now integrated well-enough to be treated as a single WRZ.
Supply-demand balance (base year)	WRMP	Sutton: DYAA base year (2011-12) DO is 78.44 Ml/d and -6.23 Ml/d deficit in base year. East Surrey: DYAA base year (2011-12) DO is 134.06 Ml/d and 22.07 Ml/d surplus in base year. In the Final Plan, the supply-demand balance is projected to be 0.27 Ml/d in 2035-36 for Sutton and 1.62 Ml/d in	The surplus in the Final Plan to the mid-2030s is largely due to the existing transfers that are now possible between the two zones. Therefore it would be anticipated that this surplus would remain, had the assessment been carried out on the Company’s area as a single zone.

Description	Source	Data	Comment
		2035/36 for East Surrey.	
Water supply or water scarcity indicators	Drought Plan/WRMP	During AMP4 SES Water increased its output from a number of its groundwater sources in Chalk and Lower Greens (applicable to both WRZs), increasing security of supply. The company-wide security of supply index is as follows: DYAA: 100, DYCP: 97 (see SES Water (2014)).	Further details on new borehole construction and refurbishment can be found in the WRMP 2014.
Critical climate variables (e.g. summer rain, winter recharge)	Drought Plan	Winter rainfall (groundwater recharge and for surface water sources is important). Summer rainfall and evaporation is important for surface water sources during multi-season droughts.	Groundwater sources in the North Downs Chalk, the Unconfined Chalk, the Mole Valley Chalk and the Lower Greensand aquifer are dependent on recharge from winter rainfall. Should little or no winter recharge occur, there is a reduction in source yields the following summer. Single season dry summers and single season dry winters are considered unlikely to have a critical effect on the supply/demand balance. Multi-season droughts have a much greater impact particularly if they are combined with a dry summer.
Climate change DOs (Dry, Mid, Wet scenarios)	WRMP	For Sutton DYAA, base year DO (2011-12) is 78.44 Ml/d. The climate change impact on DO in the medium term (2035-36) is zero. The uncertainty range is captured in the headroom calculations and is 2.08 Ml/d for 2035-36. For East Surrey DYAA, base year DO (2011-12) is 134.06 Ml/d The climate change impact on DO in the medium term (2035-36) is -5.76 Ml/d. The uncertainty range is captured in the headroom calculations and is 1.76 Ml/d for 2035-36.	Full details of the approach taken to calculate the Climate change DOs are set out within the WRMP (SES Water, 2014) and the technical report, “2007 Reassessment of Groundwater Source Deployable Outputs” (SES Water, 2007). The potential impact of climate change on groundwater source DO was investigated in accordance with the UKWIR/Environment Agency guidance 06/CI/04/8 (UKWIR/Environment Agency, 2007). A CATCHMOD rainfall-runoff model was used to derive DO and climate change-impacted DO for the Well House Inn OBH and the River catchment.

Description	Source	Data	Comment
Adaptive capacity (List of available sources and drought measures)	Drought Plan/WRMP	Potential drought measures and supply enhancements for include: drought permits to increase peak and annual average abstraction from isolated sources, an upgrade of Bough Beech reservoir, transfers across the zone from Bough Beech reservoir; new installation or replacement of boreholes in selected areas, aquifer storage recovery; demand management measures; preferential use of peak resources resilient to drought and a bulk transfer from Thames Water.	Previous efforts to improve network connectivity mean that in the Final Plan, a surplus can be maintained in the East Surrey WRZ until 2036-37 and to the end of the plan in the Sutton WRZ. Further details can be found in the Drought Plan and WRMP 2014.
Conclusion: Vulnerability (low/ medium/ high)		Low	The available information has been reviewed and considered and the assessment indicates a Low Vulnerability to climate.
Action needed	WRMP	No additional measures required to maintain adequate supply-demand balance, as no deficits are currently forecast.	Further details are provided in the WRMP.

Source: SES Water (2013; 2014)

4. Conclusions

In their last WRMP, SES Water's vulnerability to climate change was classified as 'Low'. The available information collated and reviewed in this report concludes that vulnerability to climate change can still be classified as 'Low'. Whilst SES Water's single reservoir is vulnerable to climate change (the annual average impact of climate change on this source is approximately 25%), the majority of the sources for the Company are less vulnerable groundwater sources. The climate change impact on these groundwater sources was calculated as being much lower (zero for many sources) in the previous WRMP.

Over the last AMP cycle the company has significantly improved the connectivity of its two water resource zones, enabling transfers via the Buckland Transfer and The Avenue transfer of up to 41% of the demand in the East Surrey WRZ and up to 47% of demand in the Sutton WRZ. To a large extent, this ability to transfer water between zones can mitigate any supply-demand deficit shortfalls and results in the Company being able to operate its area as a single WRZ.

SES Water do face a number of other challenges that may be exacerbated by changes in climate such as: increasing demand from existing and new customers; resilience to droughts (particularly multi-season droughts); and, the need to protect the environment. Further to this, the Company aims to improve its Level of Service to customers by reducing the number of demand restrictions to once in every 10 years.

5. References

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Appendix D Climate change modelling report

HR Wallingford
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SES Water WRMP19 Support

Climate Change Modelling

MAM7911-RT002-R01-00

May 2017

Document information

Document permissions	Confidential - client
Project number	MAM7911
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Report number	RT002
Release number	R01-00
Report date	May 2017
Client	AECOM
Client representative	Jane Sladen
Project manager	Eleanor Hall
Project director	Chris Counsell

Document history

Date	Release	Prepared	Approved	Authorised	Notes
25 May 2017	01-00	EJG	EMN	CJC	

Document authorisation

Prepared	Approved	Authorised

Executive summary

This report describes the climate change modelling undertaken by HR Wallingford as part of SES Water's Water Resource Management Plan (WRMP 2019). This report follows the Basic Vulnerability Assessment.

The Basic Vulnerability Assessment is a requirement outlined in the Environment Agency Water Resources Planning Guidelines (WRPG) and other related guidance (Environment Agency, 2012a,b; 2013; 2017). Their purpose is to determine whether a specific water resource zone is classed as “low”, “medium” or “high” vulnerability to future climate change, which then influences the methodology adopted for climate change impacts assessment on Deployable Output. The Basic Vulnerability Assessment shows that SES Water's single water resource zone should be classified as Low Vulnerability. Where a water resource zone is classified as low vulnerability and rainfall-runoff models are available, the guidance specifies that “Tier 2” analysis should be undertaken as a minimum. Tier 2 methods have been used in this climate change modelling analysis.

This study has made use of the Future Flows Climate scenarios (Prudhomme *et al.*, 2012) under a medium emissions scenario for the 2080s for the River Eden (Kent) catchment at Penshurst / Vexour Bridge.

Monthly climate change factors for precipitation and potential evapotranspiration have been calculated for the 2080s. These climate factors were used to perturb the historical climate record and input into a CatchMod hydrological model of the River Eden. From this, 11 climate change river flow series were produced (one for each of the Future Flows scenarios), from which 11 sets of monthly flow factors were generated.

The results demonstrate a tendency, due to climate change, towards reduced flows in the summer, autumn and early winter. There is a large variation in flows in the late winter and early spring although many of the scenarios indicate reduced flows between September and April. This pattern of impacts is consistent with drier summers and the warmer, wetter, winters that are typically evident in the Future Flows climate change projections. Therefore, there is the potential to adversely impact the winter refill of the reservoir and correspondingly the water resource availability and drought resilience of this part of the system.

These outputs will be used as input to the Deployable Output assessment being undertaken by other organisations in the consortium.

Suggested citation

HR Wallingford (2017). *Climate Change Modelling, SES Water WRMP19 Support, RT002 R01-00*. Report produced for AECOM.

Abbreviations

CCRA	Climate Change Risk Assessment
DO	Deployable Output
FFC	Future Flows Climate
NRFA	National Rivers Flow Archive
PET	Potential evapotranspiration
WRMP	Water Resource Management Plan
WRZ	Water Resource Zone
UKCP09	UK Climate Projections
UKWIR	UK Water Industry Research

Contents

Figures

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1. Introduction

Water companies are required to account for the impacts of climate change in their Water Resource Management Plans (WRMPs) which cover a minimum 25 year planning period from present day to the 2040s (Environment Agency, 2012a). This climate change assessment is typically undertaken using either the UKCP09 (Murphy *et al.*, 2009) or the Future Flows (Prudhomme *et al.*, 2012) climate change projections to estimate the impacts of climate change on surface water and groundwater sources. For WRMP 2019, the Environment Agency has recommended (Environment Agency, 2017) that water companies adopt the 2080s time-horizon for assessing climate change impacts, with the impacts then scaled back through the planning period.

This report provides an overview of the work undertaken by HR Wallingford to use the Future Flows Climate projections of precipitation and potential evapotranspiration to determine the resulting projected impacts on river flows on the River Eden, at Penshurst / Vexour Bridge, SES Water's only surface water resource.

The assessment of climate change impacts on groundwater resources is not covered by this report.

2. Methodology

The climate change guidance for WRMP 2019 (Environment Agency, 2017) requires water companies to undertake an assessment of each water resource zone's (WRZs) vulnerability to climate change in order to categorise it as low, medium or high vulnerability. Whether a WRZ is considered to be low, medium or high vulnerability influences the methodology adopted for climate change impacts assessment on Deployable Output (DO).

The Basic Vulnerability Assessment for WRMP 2019 for SES Water is the subject of a separate report (HR Wallingford, 2017). The Basic Vulnerability Assessment shows that SES Water's single WRZ is classified as low vulnerability. Where a water resource zone is classified as low vulnerability and rainfall-runoff models are available, the guidance specifies that "Tier 2" analysis should be undertaken as a minimum. A rainfall-runoff model is available for SES Water's surface water system therefore Tier 2 methods have been used in this climate change modelling analysis. This means that, as a minimum, either UKCP09 Spatially Coherent Projections or Future Flow Climatology must be used to evaluate the potential climate change impacts on DO. The different climate change projection options are summarised in Box 1.

As highlighted in Section 1, the Environment Agency's updated guidance on climate change (Environment Agency, 2016) recommends that, for WRMP 2019, water companies should consider the 2080s to assess the projected impacts of climate change on DO rather than the 2030s which was the case for previous WRMPs (Sutton and East Surrey Water Plc, 2014).

The Future Flows Climate projections have been used in this climate change modelling assessment. The dataset consists of 11 equally likely scenarios of climate, river flow and groundwater levels to 2098.

Box 1 Summaries of UKC09 probabilistic projections and the Future Flows and Groundwater level project

UKCP09

The UK Climate Projections (UKCP09; Murphy *et al.*, 2009) provide probabilistic projections of climate change (as monthly factors) for the low, medium and high emissions scenarios for seven overlapping time periods from 2010-2039 to 2070-2099. UKCP09 covers the whole of the UK, presenting results at different scales, although the projections are not spatially coherent between different areas at any scale. This means that it is not possible to consider the how the impacts of climate change at multiple locations coincide. UKCP09 provides a range of outcomes for a given emissions scenario, and in many cases this range is larger than the difference between emissions scenarios.

UKCP09 Spatially Coherent Projections

An additional set of climate projections for the whole of the UK were produced for those analyses that are required to consider climate change across more than one location in a way that captures the relationship between the different locations. The spatially coherent projections generate 11 plausible snapshots of climate change for the UK to 2100 for the same spatial scale as the full UKCP09 probabilistic projections. The spatially coherent projections under-sample the full range of outcomes implied by UKCP09. Another limitation is that the spatially coherent projections do not contain the probabilistic elements of UKCP09 and so there is no likelihood associated with any particular outcome. (Sexton *et al.*, 2010)

Future Flows

The Future Flows and Groundwater Level (FFGWL)[1] project carried out a consistent assessment of the impact of climate change on river flows and groundwater levels across England, Wales and Scotland using the latest climate projections at the time. The FFGWL project produced two datasets for Great Britain:

- **Future Flows Climate (FFC):** Provides transient projections of precipitation and potential evaporation for 1km grid squares across Great Britain, from 1950-2098. FFC was specifically developed for hydrological and hydrogeological applications. The climate modelling is based upon HadRM3-PPE run under the medium emissions scenario. The regional climate model HadRM3-PPE consists of an 11-member ensemble. This means that it is made up of 11 model variants which are different in the way in which atmospheric parameters such as greenhouse gases, sulphur and ozone change over time. The purpose of this is to capture the uncertainty in climate change modelling.
- **Future Flows Hydrology (FFH):** Provides projections of daily river flow and monthly groundwater levels derived from the Future Flows Climate from 1951-2098 for 281 rivers and 24 boreholes in Great Britain. Similar to FFC, this model consists of an 11-member ensemble.

The projections produced by FFC and FFH represent a nationally consistent set of 11 plausible futures (all considered equally likely) of climate, river flow and groundwater levels to 2098.

The methodology adopted for this assessment is summarised in the flow chart in Figure 2.1 below.

[1] The Future Flows Project was a partnership project co-funded by the Environment Agency of England and Wales, Defra, UK Water Industry Research, the Centre for Ecology & Hydrology, the British Geological Survey and Wallingford Hydrosolutions.

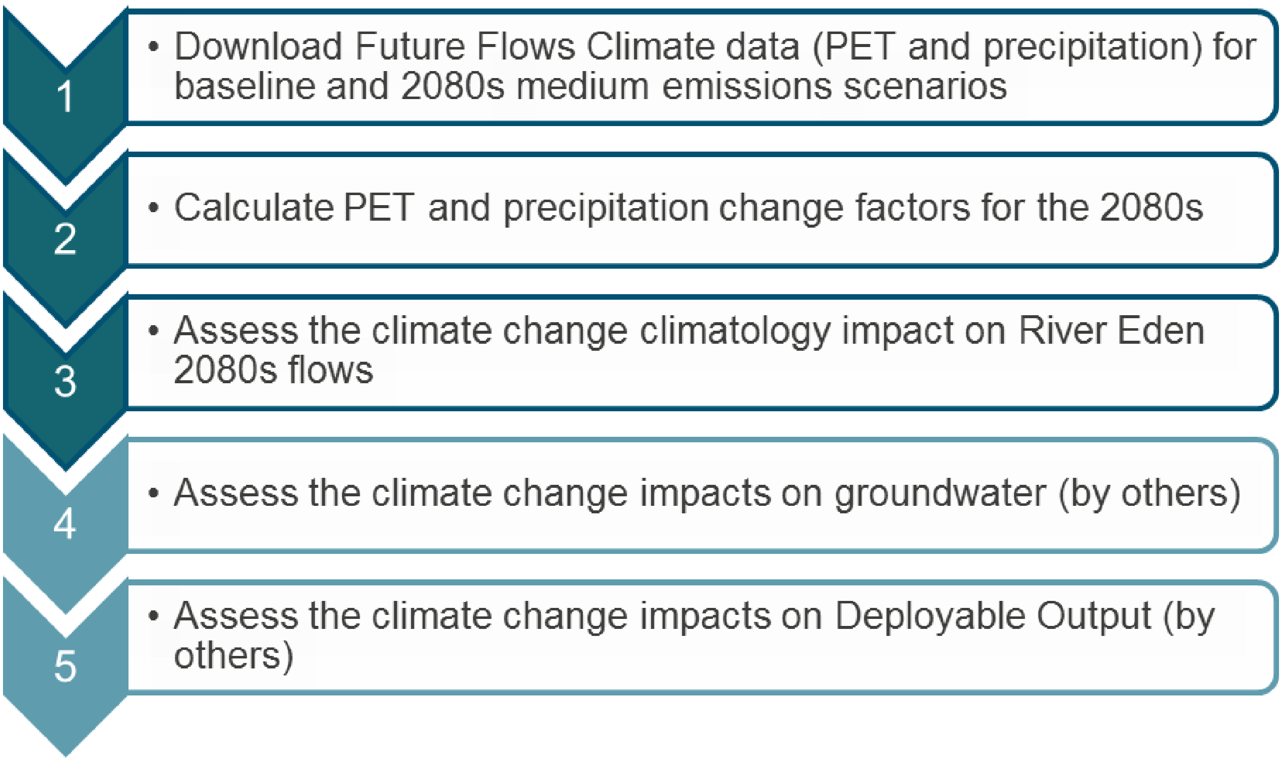

Figure 2.1: Flowchart summary of method. Only steps 1 – 3 were carried out by HR Wallingford. Therefore, only steps 1-3 are covered by this report.

3. Assessment

3.1. Future Flows Climate data

For this study, Future Flows Climate scenario data (precipitation and potential evapotranspiration, PET) under a medium emissions scenario for the 2080 time-period were downloaded for the River Eden catchment (NRFA station number 40010). Figure 3.1 shows the catchment location.

Future Flows Climate consists of projections of precipitation and PET for 1km grid squares across Great Britain, from 1950-2098. The data extracted for this study was the catchment average of the River Eden catchment, one for each of the 11 spatially coherent projections. 30 years of data was collected, the baseline (01/01/1961 – 31/12/1990) and the 2080s (01/01/2069 – 31/12/2098).

Average monthly PET and precipitation values were calculated for the baseline and 2080s Future Flows Climate data. Change factors for each of the 11 climate change scenarios are shown in Figure 3.2 and Figure 3.3.

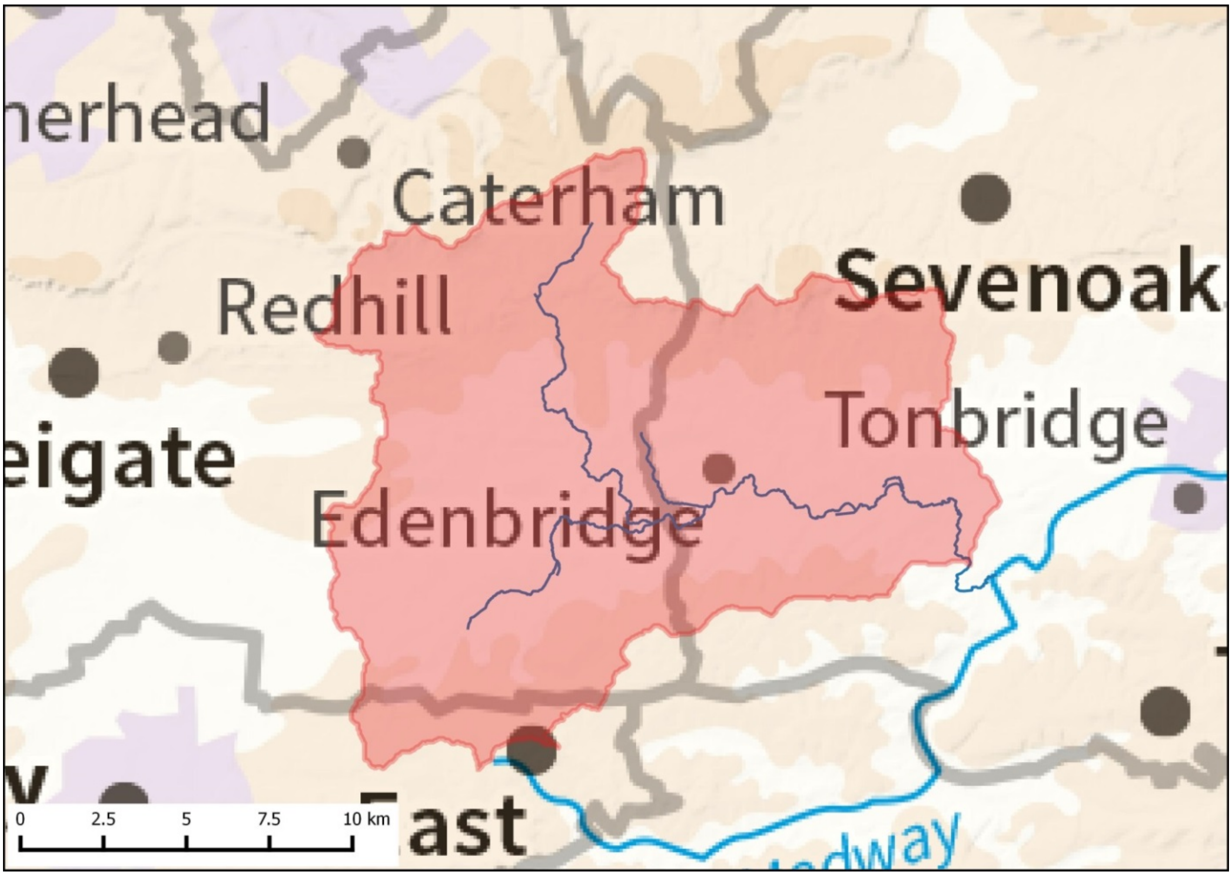

Figure 3.1: A map showing the River Eden (Kent) catchment

Contains OS data © Crown copyright and database right (2017)

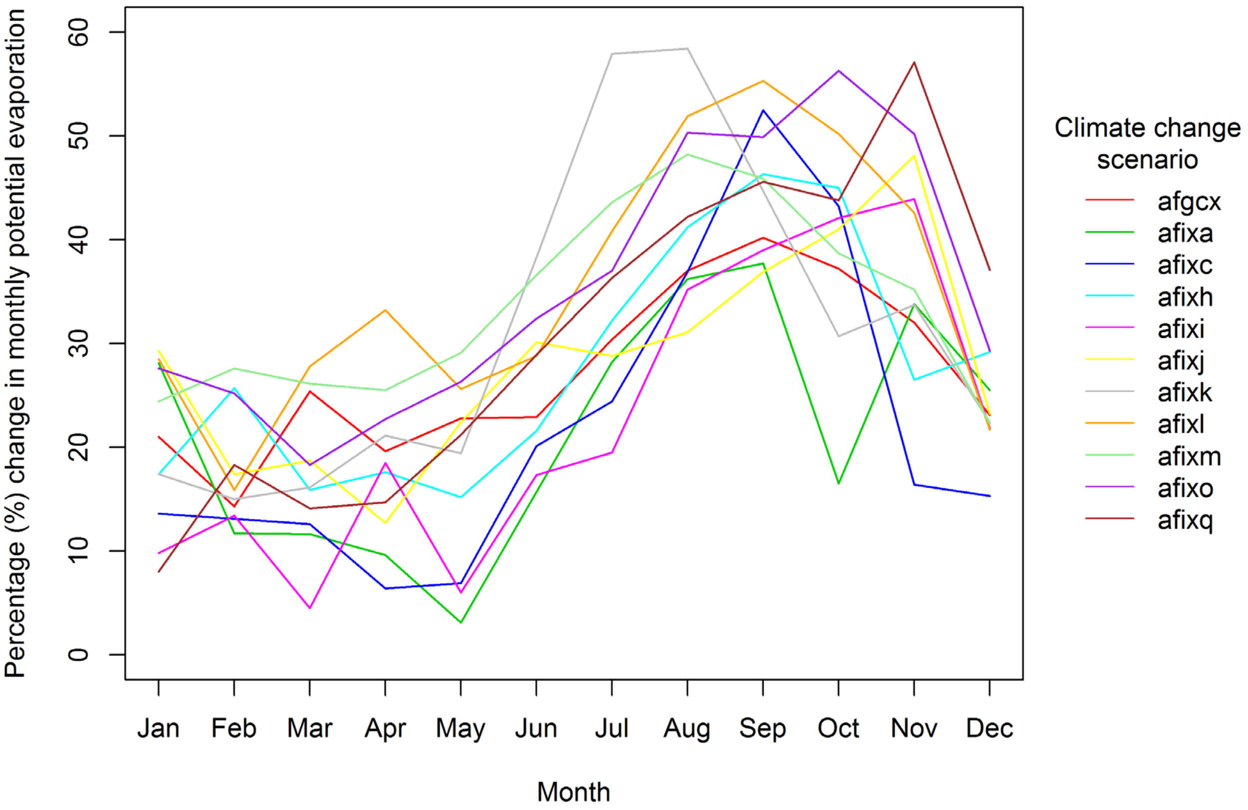

Figure 3.2: Average monthly PET factors for River Eden catchment under the 11 Future Flows Climate projections for the 2080s medium emissions scenario

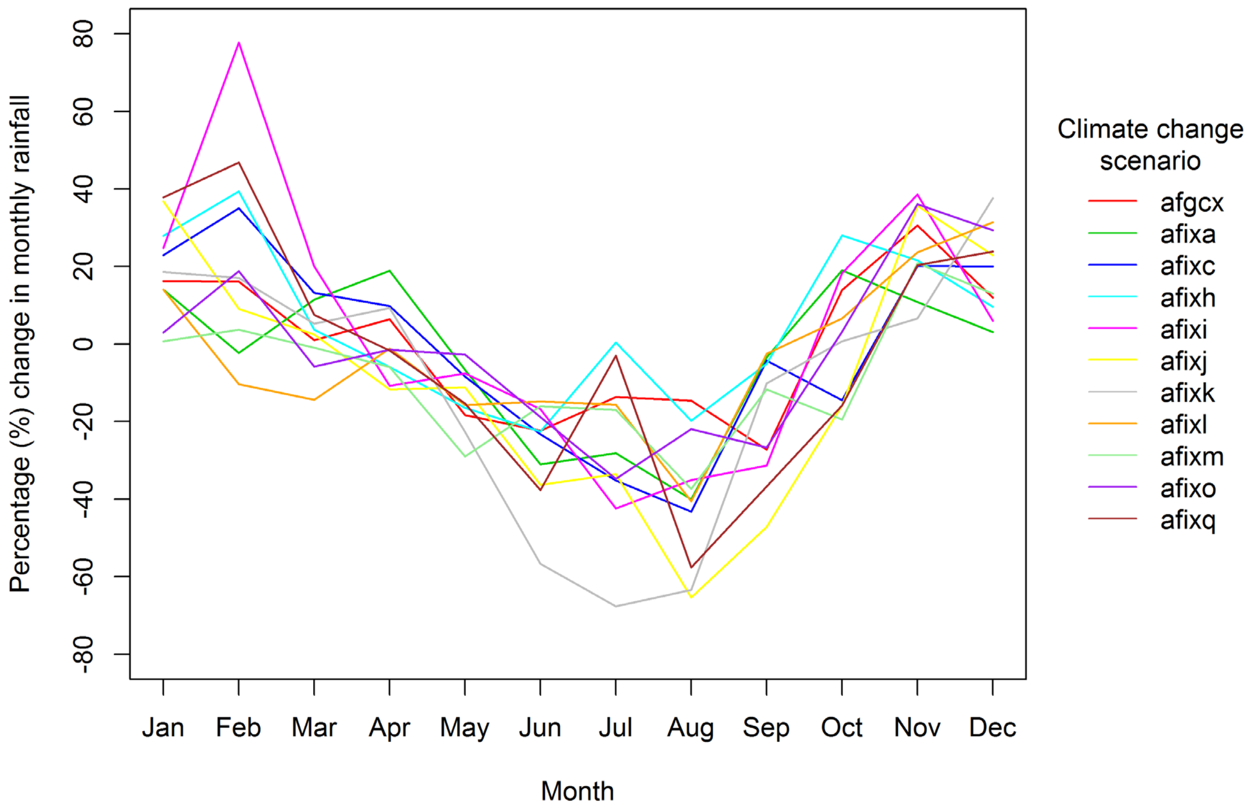

Figure 3.3: Average monthly precipitation factors for River Eden catchment under the 11 Future Flows Climate projections for the 2080s medium emissions scenario

3.2. Hydrological modelling and flow factors

This task made use of an existing, calibrated CatchMod model to assess the impacts of climate change on the surface water flows at Penshurst / Vexour Bridge on the River Eden.

CatchMod is a rainfall-runoff model used by the Environment Agency, which uses daily series of precipitation and potential evapotranspiration for the river catchment to simulate daily time series of runoff.

HR Wallingford's Kestrel-IHM modelling framework was configured to automate the use of this CatchMod hydrological model with each of the 11 Future Flows climate change scenarios. The baseline PET and precipitation data were perturbed using the 11 Future Flows Climate change factors and simulated using this modelling framework to generate 11 corresponding time-series of river flows for the River Eden.

From this, monthly river flow change factors were calculated based on comparing the historical (1961 to 1990) and climate change perturbed flow series (2069 to 2098). Figure 3.4 presents the monthly river flow change factors for the 11 scenarios. These results demonstrate a tendency, due to climate change, towards reduced flows in the Summer, Autumn and early Winter. There is a large variation in flows in the late winter and early spring although many of the scenarios indicate reduced flows between September and April. This pattern of impacts reflects the drier summers and warmer, wetter, winters that are typically evident in the Future Flows climate change projections (see Figure 3.2 and Figure 3.3). SES Water abstract from the River Eden and store the water in their Bough Beech reservoir. This provide 15% of their supply. Abstraction occurs when river flows are highest during September to April (Sutton and East Surrey Water Plc, 2013). As shown in Figure 3.4, many of the scenarios indicate that flows are projected to reduce between September and April. Therefore, there is the potential to adversely impact the winter refill of the reservoir and correspondingly the water resource availability and drought resilience of this part of the system.

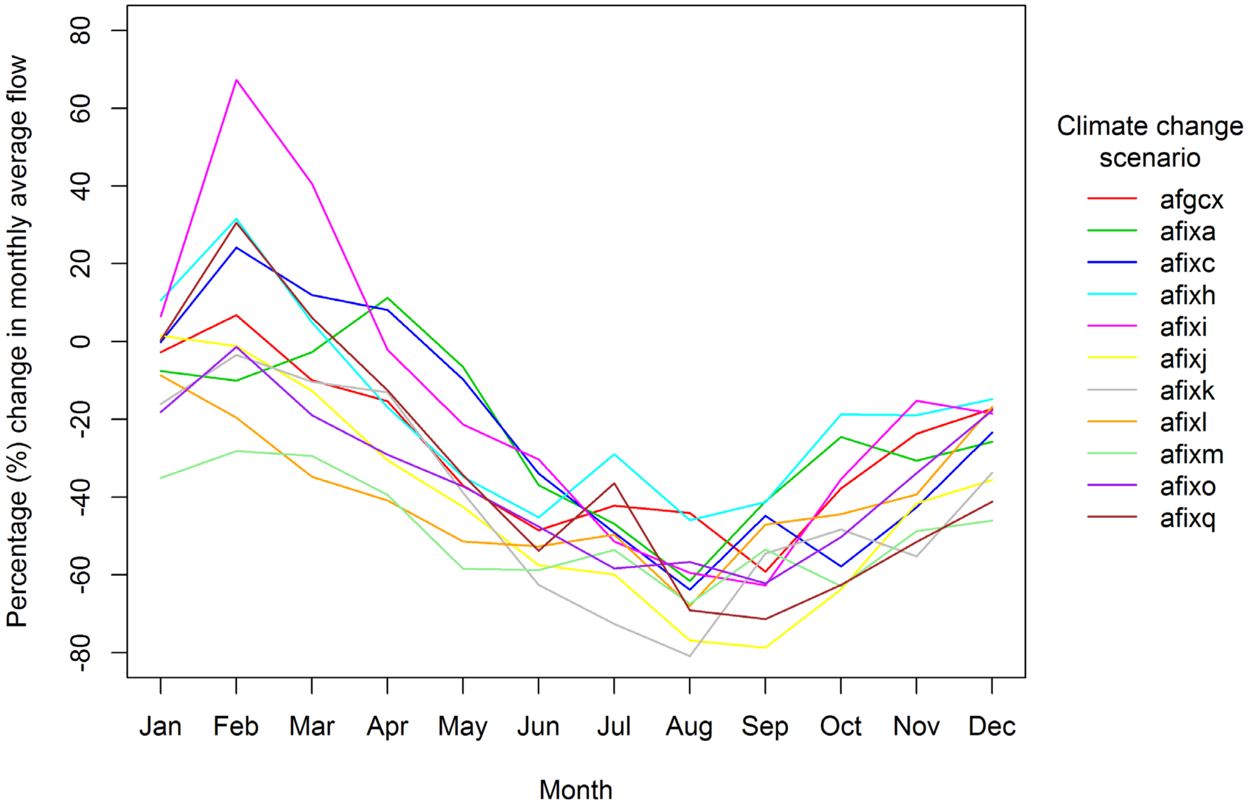

Figure 3.4: Average monthly flow factors for River Eden catchment under the 11 Future Flows projections for the 2080s medium emissions scenario

4. Output data

The following outputs have been provided in association with this report:

Table 4.1: Data sets provided in association with this report

Data
River Eden catchment average Future Flows Climate precipitation and potential evapotranspiration (PET) change factors for the 11 Future Flows projections for the 2080s medium emission scenario.
Monthly Flow Factors for 11 Future Flows projection scenarios for the 2080s medium emissions scenarios for the River Eden at Penshurst / Vexour Bridge.
River flow series from 1888 to 2017 for 11 Future Flows projection scenarios for the 2080s medium emissions scenarios for the River Eden at Penshurst / Vexour Bridge.

5. Conclusions

The analysis undertaken in this report provides SES Water with a set of climate change scenarios (and associated flow factors for the River Eden) for the 2080s under a medium emissions scenario for use in their next Water Resources Management Plan (WRMP19).

The methods adopted are consistent with the latest regulatory guidance for water resource zones of low vulnerability that already have existing rainfall-runoff models (Environment Agency, 2012a,b; 2013; 2017).

These results demonstrate a tendency, due to climate change, towards reduced flows in the summer, autumn and early winter. There is a large variation in flows in the late winter and early spring although many of the scenarios indicate reduced flows between September and April. This pattern of impacts is consistent with drier summers and the warmer, wetter, winters that are typically evident in the Future Flows climate change projections. Therefore, there is the potential to adversely impact the winter refill of the reservoir and correspondingly the water resource availability and drought resilience of this part of the system.

6. References

HR Wallingford (2017) Sutton & East Surry WRMP19 Support Basic Vulnerability Assessment. MAM7911-RT001-RT02-00

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Appendix E Scaling of climate change impacts

INPUT SCREEN - SES Water COMPANY CLIMATE CHANGE IMPACTS (DEPLOYABLE OUTPUT)

Baseline D.O. (Climate change assessment only) 206.50

PLANNING SCENARIO	1:200 year event - DYAA
D.O. DEFINITION	AVERAGE DEPLOYABLE OUTPUT
DATE ENTERED	21/09/2017
UNITS	ML/D
DATA SOURCE	AECOM workings

NOTES: Minimum, Mean and Maximum Climate Change impacts on deployable output (2080s) calculated from 11 scenarios by HRW

DEPLOYABLE OUTPUT **Climate Change scenario stats**	**Climate Change Impact Year 2085 (Midpoint of 2080s)**	***Change in DO***	**Interpolated Across Planning Horizon 2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum	204.14	***-2.36***	-0.86	-0.88	-0.90	-0.92	-0.94	-0.97	-0.99	-1.01	-1.03	-1.05	-1.07	-1.09	-1.12	-1.14	-1.16	-1.18	-1.20	-1.22	-1.24	-1.27	-1.29	-1.31	-1.33	-1.35	-1.37	-1.39	-1.42	-1.44	-1.46	-1.48	-1.50	-1.52	-1.54	-1.57	-1.59	-1.61
Mean	209.84	***3.34***	1.21	1.24	1.28	1.31	1.34	1.37	1.40	1.43	1.46	1.49	1.52	1.55	1.58	1.61	1.64	1.67	1.70	1.73	1.76	1.79	1.82	1.85	1.88	1.91	1.94	1.97	2.00	2.03	2.06	2.10	2.13	2.16	2.19	2.22	2.25	2.28
Maximum	215.04	***8.54***	3.11	3.18	3.26	3.34	3.42	3.49	3.57	3.65	3.73	3.80	3.88	3.96	4.04	4.11	4.19	4.27	4.35	4.43	4.50	4.58	4.66	4.74	4.81	4.89	4.97	5.05	5.12	5.20	5.28	5.36	5.43	5.51	5.59	5.67	5.75	5.82

		Change in DO	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**	**2069**	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum	204.14	***-2.36***	-1.63	-1.65	-1.67	-1.69	-1.72	-1.74	-1.76	-1.78	-1.80	-1.82	-1.85	-1.87	-1.89	-1.91	-1.93	-1.95	-1.97	-2.00	-2.02	-2.04	-2.06	-2.08	-2.10	-2.12	-2.15	-2.17	-2.19	-2.21	-2.23	-2.25	-2.27	-2.30	-2.32	-2.34	-2.36
Mean	209.84	***3.34***	2.31	2.34	2.37	2.40	2.43	2.46	2.49	2.52	2.55	2.58	2.61	2.64	2.67	2.70	2.73	2.76	2.79	2.82	2.85	2.88	2.91	2.95	2.98	3.01	3.04	3.07	3.10	3.13	3.16	3.19	3.22	3.25	3.28	3.31	3.34
Maximum	215.04	***8.54***	5.90	5.98	6.06	6.13	6.21	6.29	6.37	6.44	6.52	6.60	6.68	6.75	6.83	6.91	6.99	7.06	7.14	7.22	7.30	7.38	7.45	7.53	7.61	7.69	7.76	7.84	7.92	8.00	8.07	8.15	8.23	8.31	8.38	8.46	8.54

Climate Change Deployable Output Variation
S8 Uncertainty range

		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum - Mean	0.00	-2.07	-2.12	-2.18	-2.23	-2.28	-2.33	-2.38	-2.44	-2.49	-2.54	-2.59	-2.64	-2.69	-2.75	-2.80	-2.85	-2.90	-2.95	-3.01	-3.06	-3.11	-3.16	-3.21	-3.26	-3.32	-3.37	-3.42	-3.47	-3.52	-3.58	-3.63	-3.68	-3.73	-3.78	-3.83	-3.89
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	1.89	1.94	1.99	2.03	2.08	2.13	2.17	2.22	2.27	2.32	2.36	2.41	2.46	2.51	2.55	2.60	2.65	2.69	2.74	2.79	2.84	2.88	2.93	2.98	3.03	3.07	3.12	3.17	3.21	3.26	3.31	3.36	3.40	3.45	3.50	3.55

		2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**	**2069**	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum - Mean	0.00	-3.94	-3.99	-4.04	-4.09	-4.15	-4.20	-4.25	-4.30	-4.35	-4.40	-4.46	-4.51	-4.56	-4.61	-4.66	-4.72	-4.77	-4.82	-4.87	-4.92	-4.97	-5.03	-5.08	-5.13	-5.18	-5.23	-5.29	-5.34	-5.39	-5.44	-5.49	-5.54	-5.60	-5.65	-5.70
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	3.59	3.64	3.69	3.73	3.78	3.83	3.88	3.92	3.97	4.02	4.07	4.11	4.16	4.21	4.25	4.30	4.35	4.40	4.44	4.49	4.54	4.59	4.63	4.68	4.73	4.77	4.82	4.87	4.92	4.96	5.01	5.06	5.11	5.15	5.20

INPUT SCREEN - SES Water COMPANY CLIMATE CHANGE IMPACTS (DEPLOYABLE OUTPUT)

Baseline D.O. (Climate change assessment only) 287.04

PLANNING SCENARIO	1:200 year event - DYCP
D.O. DEFINITION	PEAK DEPLOYABLE OUTPUT
DATE ENTERED	21/09/2017
UNITS	ML/D
DATA SOURCE	AECOM workings

NOTES: Minimum, Mean and Maximum Climate Change impacts on deployable output (2080s) calculated from 11 scenarios by HRW

DEPLOYABLE OUTPUT

Interpolated Across Planning Horizon

Climate Change scenario stats	**Climate Change Impact Year 2085 (Midpoint of 2080s)**	***Change in DO***	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Minimum	280.14	***-6.90***	-2.51	-2.57	-2.63	-2.70	-2.76	-2.82	-2.89	-2.95	-3.01	-3.07	-3.14	-3.20	-3.26	-3.32	-3.39	-3.45	-3.51	-3.57
Mean	287.74	***0.70***	0.25	0.26	0.27	0.27	0.28	0.29	0.29	0.30	0.30	0.31	0.32	0.32	0.33	0.34	0.34	0.35	0.36	0.36
Maximum	295.76	***8.72***	3.17	3.25	3.33	3.41	3.49	3.57	3.65	3.73	3.81	3.89	3.96	4.04	4.12	4.20	4.28	4.36	4.44	4.52

Climate Change scenario stats	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum	-3.64	-3.70	-3.76	-3.83	-3.89	-3.95	-4.01	-4.08	-4.14	-4.20	-4.26	-4.33	-4.39	-4.45	-4.52	-4.58	-4.64	-4.70
Mean	0.37	0.37	0.38	0.39	0.39	0.40	0.41	0.41	0.42	0.43	0.43	0.44	0.44	0.45	0.46	0.46	0.47	0.48
Maximum	4.60	4.68	4.76	4.84	4.92	5.00	5.07	5.15	5.23	5.31	5.39	5.47	5.55	5.63	5.71	5.79	5.87	5.95

		Change in DO	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**
Minimum	280.14	***-6.90***	-4.77	-4.83	-4.89	-4.95	-5.02	-5.08	-5.14	-5.21	-5.27	-5.33	-5.39	-5.46	-5.52	-5.58	-5.64	-5.71	-5.77	-5.83
Mean	287.74	***0.70***	0.48	0.49	0.49	0.50	0.51	0.51	0.52	0.53	0.53	0.54	0.55	0.55	0.56	0.56	0.57	0.58	0.58	0.59
Maximum	295.76	***8.72***	6.03	6.11	6.18	6.26	6.34	6.42	6.50	6.58	6.66	6.74	6.82	6.90	6.98	7.06	7.14	7.22	7.29	7.37

	2069	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum	-5.90	-5.96	-6.02	-6.08	-6.15	-6.21	-6.27	-6.33	-6.40	-6.46	-6.52	-6.59	-6.65	-6.71	-6.77	-6.84	-6.90
Mean	0.60	0.60	0.61	0.62	0.62	0.63	0.63	0.64	0.65	0.65	0.66	0.67	0.67	0.68	0.69	0.69	0.70
Maximum	7.45	7.53	7.61	7.69	7.77	7.85	7.93	8.01	8.09	8.17	8.25	8.33	8.40	8.48	8.56	8.64	8.72

Climate Change Deployable Output Variation

S8 Uncertainty range

		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Minimum - Mean	0.00	-2.76	-2.83	-2.90	-2.97	-3.04	-3.11	-3.18	-3.25	-3.32	-3.38	-3.45	-3.52	-3.59	-3.66	-3.73	-3.80	-3.87	-3.94
Most Likely	0.00	0.00	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00	13.00	14.00	15.00	16.00	17.00
Maximum - Mean	0.00	2.92	2.99	3.06	3.14	3.21	3.28	3.36	3.43	3.50	3.57	3.65	3.72	3.79	3.87	3.94	4.01	4.08	4.16

	2033	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum - Mean	-4.01	-4.07	-4.14	-4.21	-4.28	-4.35	-4.42	-4.49	-4.56	-4.63	-4.70	-4.77	-4.83	-4.90	-4.97	-5.04	-5.11	-5.18
Most Likely	18.00	19.00	20.00	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00	31.00	32.00	33.00	34.00	35.00
Maximum - Mean	4.23	4.30	4.38	4.45	4.52	4.60	4.67	4.74	4.81	4.89	4.96	5.03	5.11	5.18	5.25	5.33	5.40	5.47

		2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**
Minimum - Mean	0.00	-5.25	-5.32	-5.39	-5.46	-5.53	-5.59	-5.66	-5.73	-5.80	-5.87	-5.94	-6.01	-6.08	-6.15	-6.22	-6.28	-6.35	-6.42
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	5.54	5.62	5.69	5.76	5.84	5.91	5.98	6.05	6.13	6.20	6.27	6.35	6.42	6.49	6.57	6.64	6.71	6.78

	2069	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum - Mean	-6.49	-6.56	-6.63	-6.70	-6.77	-6.84	-6.91	-6.98	-7.04	-7.11	-7.18	-7.25	-7.32	-7.39	-7.46	-7.53	-7.60
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	6.86	6.93	7.00	7.08	7.15	7.22	7.29	7.37	7.44	7.51	7.59	7.66	7.73	7.81	7.88	7.95	8.02

INPUT SCREEN - SES Water COMPANY CLIMATE CHANGE IMPACTS (DEPLOYABLE OUTPUT)

Baseline D.O. (Climate change assessment only) 215.70

PLANNING SCENARIO	Worst drought on historic record - DYAA
D.O. DEFINITION	AVERAGE DEPLOYABLE OUTPUT
DATE ENTERED	21/09/2017
UNITS	ML/D
DATA SOURCE	AECOM workings

NOTES: Minimum, Mean and Maximum Climate Change impacts on deployable output (2080s) calculated from 11 scenarios by HRW

DEPLOYABLE OUTPUT **Climate Change scenario stats**	**Climate Change Impact Year 2085 (Midpoint of 2080s)**	***Change in DO***	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum	202.69	***-13.01***	-4.73	-4.85	-4.97	-5.09	-5.20	-5.32	-5.44	-5.56	-5.68	-5.80	-5.91	-6.03	-6.15	-6.27	-6.39	-6.51	-6.62	-6.74	-6.86	-6.98	-7.10	-7.21	-7.33	-7.45	-7.57	-7.69	-7.81	-7.92	-8.04	-8.16	-8.28	-8.40	-8.52	-8.63	-8.75	-8.87
Mean	207.30	***-8.40***	-3.05	-3.13	-3.21	-3.28	-3.36	-3.44	-3.51	-3.59	-3.67	-3.74	-3.82	-3.89	-3.97	-4.05	-4.12	-4.20	-4.28	-4.35	-4.43	-4.51	-4.58	-4.66	-4.73	-4.81	-4.89	-4.96	-5.04	-5.12	-5.19	-5.27	-5.35	-5.42	-5.50	-5.57	-5.65	-5.73
Maximum	211.92	***-3.78***	-1.37	-1.41	-1.44	-1.48	-1.51	-1.55	-1.58	-1.62	-1.65	-1.68	-1.72	-1.75	-1.79	-1.82	-1.86	-1.89	-1.92	-1.96	-1.99	-2.03	-2.06	-2.10	-2.13	-2.16	-2.20	-2.23	-2.27	-2.30	-2.34	-2.37	-2.41	-2.44	-2.47	-2.51	-2.54	-2.58

(**Interpolated Across Planning Horizon**)

		Change in DO	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**	**2069**	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum	202.69	***-13.01***	-8.99	-9.11	-9.23	-9.34	-9.46	-9.58	-9.70	-9.82	-9.93	-10.05	-10.17	-10.29	-10.41	-10.53	-10.64	-10.76	-10.88	-11.00	-11.12	-11.24	-11.35	-11.47	-11.59	-11.71	-11.83	-11.95	-12.06	-12.18	-12.30	-12.42	-12.54	-12.66	-12.77	-12.89	-13.01
Mean	207.30	***-8.40***	-5.80	-5.88	-5.96	-6.03	-6.11	-6.19	-6.26	-6.34	-6.41	-6.49	-6.57	-6.64	-6.72	-6.80	-6.87	-6.95	-7.03	-7.10	-7.18	-7.25	-7.33	-7.41	-7.48	-7.56	-7.64	-7.71	-7.79	-7.87	-7.94	-8.02	-8.09	-8.17	-8.25	-8.32	-8.40
Maximum	211.92	***-3.78***	-2.61	-2.65	-2.68	-2.71	-2.75	-2.78	-2.82	-2.85	-2.89	-2.92	-2.96	-2.99	-3.02	-3.06	-3.09	-3.13	-3.16	-3.20	-3.23	-3.26	-3.30	-3.33	-3.37	-3.40	-3.44	-3.47	-3.51	-3.54	-3.57	-3.61	-3.64	-3.68	-3.71	-3.75	-3.78

Climate Change Deployable Output Variation
S8 Uncertainty range

		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum - Mean	0.00	-1.68	-1.72	-1.76	-1.80	-1.84	-1.89	-1.93	-1.97	-2.01	-2.05	-2.10	-2.14	-2.18	-2.22	-2.26	-2.31	-2.35	-2.39	-2.43	-2.47	-2.51	-2.56	-2.60	-2.64	-2.68	-2.72	-2.77	-2.81	-2.85	-2.89	-2.93	-2.98	-3.02	-3.06	-3.10	-3.14
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	1.68	1.72	1.76	1.81	1.85	1.89	1.93	1.97	2.02	2.06	2.10	2.14	2.18	2.23	2.27	2.31	2.35	2.39	2.44	2.48	2.52	2.56	2.60	2.65	2.69	2.73	2.77	2.81	2.86	2.90	2.94	2.98	3.02	3.07	3.11	3.15

		2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**	**2069**	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum - Mean	0.00	-3.19	-3.23	-3.27	-3.31	-3.35	-3.39	-3.44	-3.48	-3.52	-3.56	-3.60	-3.65	-3.69	-3.73	-3.77	-3.81	-3.86	-3.90	-3.94	-3.98	-4.02	-4.07	-4.11	-4.15	-4.19	-4.23	-4.27	-4.32	-4.36	-4.40	-4.44	-4.48	-4.53	-4.57	-4.61
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	-3.19	-3.23	-3.28	-3.32	-3.36	-3.40	-3.44	-3.49	-3.53	-3.57	-3.61	-3.65	-3.70	-3.74	-3.78	-3.82	-3.86	-3.91	-3.95	-3.99	-4.03	-4.07	-4.12	-4.16	-4.20	-4.24	-4.28	-4.33	-4.37	-4.41	-4.45	-4.49	-4.54	-4.58	-4.62

INPUT SCREEN - SES WATER COMPANY CLIMATE CHANGE IMPACTS (DEPLOYABLE OUTPUT)

Baseline D.O. (Climate change assessment only): 300.70

PLANNING SCENARIO	Worst drought on historic record - DYCP
D.O. DEFINITION	PEAK DEPLOYABLE OUTPUT
DATE ENTERED	21/09/2017
UNITS	ML/D
DATA SOURCE	AECOM workings

NOTES: Minimum, Mean and Maximum Climate Change impacts on deployable output (2080s) calculated from 11 scenarios by HRW

DEPLOYABLE OUTPUT

Interpolated Across Planning Horizon

Climate Change scenario stats	**Climate Change Impact Year 2085 (Midpoint of 2080s)**	***Change in DO***	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Minimum	278.10	***-22.60***	-8.22	-8.42	-8.63	-8.83	-9.04	-9.25	-9.45	-9.66	-9.86	-10.07	-10.27	-10.48	-10.68	-10.89	-11.09	-11.30	-11.51	-11.71
Mean	290.61	***-10.09***	-3.67	-3.76	-3.85	-3.94	-4.04	-4.13	-4.22	-4.31	-4.40	-4.49	-4.59	-4.68	-4.77	-4.86	-4.95	-5.05	-5.14	-5.23
Maximum	297.80	***-2.90***	-1.05	-1.08	-1.11	-1.13	-1.16	-1.19	-1.21	-1.24	-1.27	-1.29	-1.32	-1.34	-1.37	-1.40	-1.42	-1.45	-1.48	-1.50

Climate Change scenario stats	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum	-11.92	-12.12	-12.33	-12.53	-12.74	-12.94	-13.15	-13.35	-13.56	-13.77	-13.97	-14.18	-14.38	-14.59	-14.79	-15.00	-15.20	-15.41
Mean	-5.32	-5.41	-5.50	-5.60	-5.69	-5.78	-5.87	-5.96	-6.05	-6.15	-6.24	-6.33	-6.42	-6.51	-6.60	-6.70	-6.79	-6.88
Maximum	-1.53	-1.56	-1.58	-1.61	-1.63	-1.66	-1.69	-1.71	-1.74	-1.77	-1.79	-1.82	-1.85	-1.87	-1.90	-1.92	-1.95	-1.98

		Change in DO	**2051**	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**
Minimum	278.10	***-22.60***	-15.61	-15.82	-16.03	-16.23	-16.44	-16.64	-16.85	-17.05	-17.26	-17.46	-17.67	-17.87	-18.08	-18.29	-18.49	-18.70	-18.90	-19.11
Mean	290.61	***-10.09***	-6.97	-7.06	-7.15	-7.25	-7.34	-7.43	-7.52	-7.61	-7.71	-7.80	-7.89	-7.98	-8.07	-8.16	-8.26	-8.35	-8.44	-8.53
Maximum	297.80	***-2.90***	-2.00	-2.03	-2.06	-2.08	-2.11	-2.14	-2.16	-2.19	-2.21	-2.24	-2.27	-2.29	-2.32	-2.35	-2.37	-2.40	-2.43	-2.45

	2069	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum	-19.31	-19.52	-19.72	-19.93	-20.13	-20.34	-20.55	-20.75	-20.96	-21.16	-21.37	-21.57	-21.78	-21.98	-22.19	-22.39	-22.60
Mean	-8.62	-8.71	-8.81	-8.90	-8.99	-9.08	-9.17	-9.26	-9.36	-9.45	-9.54	-9.63	-9.72	-9.81	-9.91	-10.00	-10.09
Maximum	-2.48	-2.50	-2.53	-2.56	-2.58	-2.61	-2.64	-2.66	-2.69	-2.72	-2.74	-2.77	-2.79	-2.82	-2.85	-2.87	-2.90

Climate Change Deployable Output Variation

S8 Uncertainty range

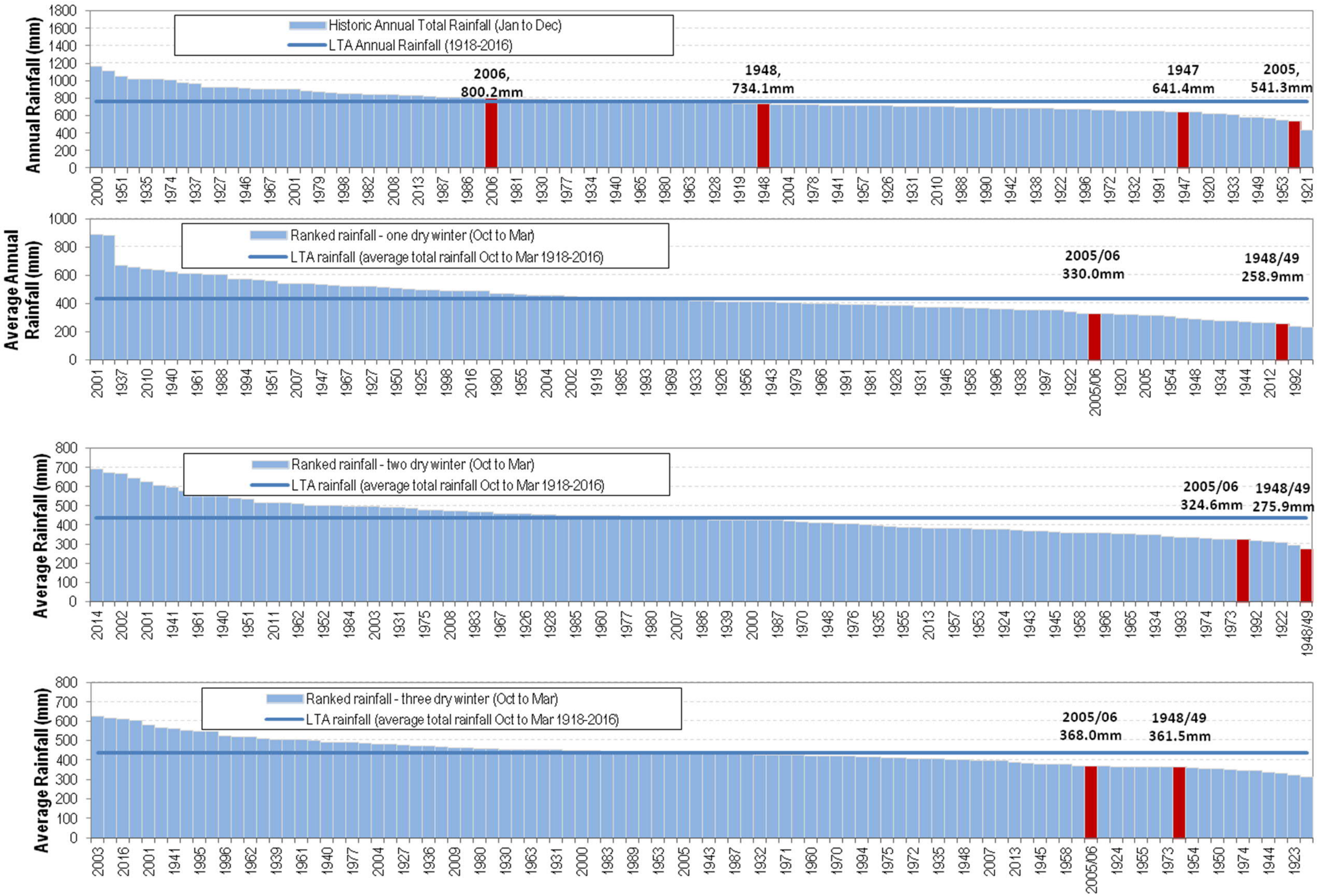
		2015	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Minimum - Mean	0.00	-4.55	-4.66	-4.78	-4.89	-5.00	-5.12	-5.23	-5.35	-5.46	-5.57	-5.69	-5.80	-5.91	-6.03	-6.14	-6.26	-6.37	-6.48
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	2.61	2.68	2.75	2.81	2.88	2.94	3.01	3.07	3.14	3.20	3.27	3.33	3.40	3.46	3.53	3.60	3.66	3.73

	2033	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**	**2043**	**2044**	**2045**	**2046**	**2047**	**2048**	**2049**	**2050**
Minimum - Mean	-6.60	-6.71	-6.82	-6.94	-7.05	-7.16	-7.28	-7.39	-7.51	-7.62	-7.73	-7.85	-7.96	-8.07	-8.19	-8.30	-8.42	-8.53
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	3.79	3.86	3.92	3.99	4.05	4.12	4.18	4.25	4.31	4.38	4.44	4.51	4.58	4.64	4.71	4.77	4.84	4.90

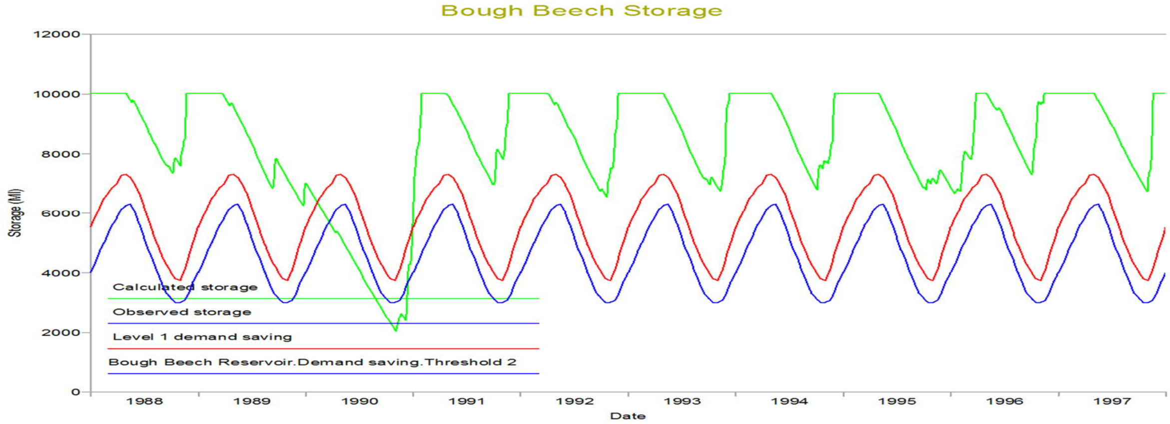
		2051	**2052**	**2053**	**2054**	**2055**	**2056**	**2057**	**2058**	**2059**	**2060**	**2061**	**2062**	**2063**	**2064**	**2065**	**2066**	**2067**	**2068**
Minimum - Mean	0.00	-8.64	-8.76	-8.87	-8.98	-9.10	-9.21	-9.33	-9.44	-9.55	-9.67	-9.78	-9.89	-10.01	-10.12	-10.24	-10.35	-10.46	-10.58
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	0.00	8.97	9.09	9.21	9.33	9.45	9.57	9.68	9.80	9.92	10.04	10.16	10.27	10.39	10.51	10.63	10.75	10.86	10.98

	2069	**2070**	**2071**	**2072**	**2073**	**2074**	**2075**	**2076**	**2077**	**2078**	**2079**	**2080**	**2081**	**2082**	**2083**	**2084**	**2085**
Minimum - Mean	-10.69	-10.80	-10.92	-11.03	-11.15	-11.26	-11.37	-11.49	-11.60	-11.71	-11.83	-11.94	-12.06	-12.17	-12.28	-12.40	-12.51
Most Likely	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Maximum - Mean	11.10	11.22	11.34	11.45	11.57	11.69	11.81	11.93	12.05	12.16	12.28	12.40	12.52	12.64	12.75	12.87	12.99

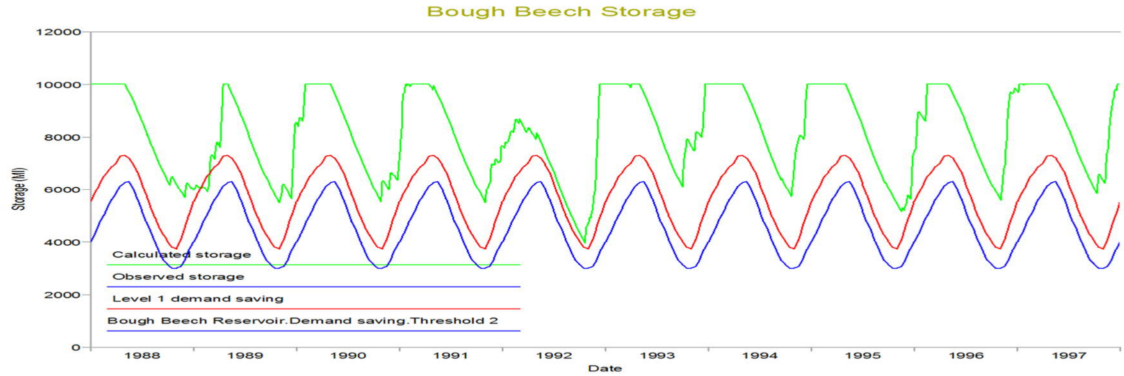
Appendix F Supporting information for the final WRMP



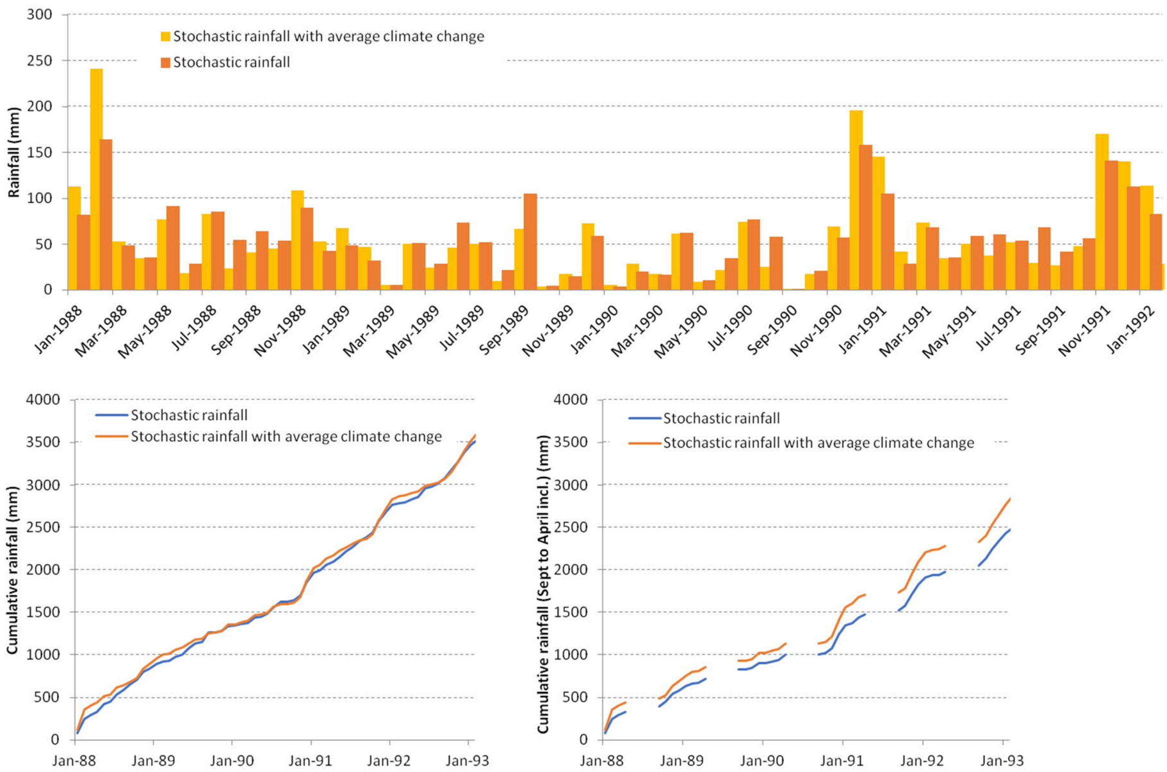
Ranking of rainfall events



1 in 200 year event



1 in 200 year event with average climate change



1 in 200 year event rainfall with and without climate change

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