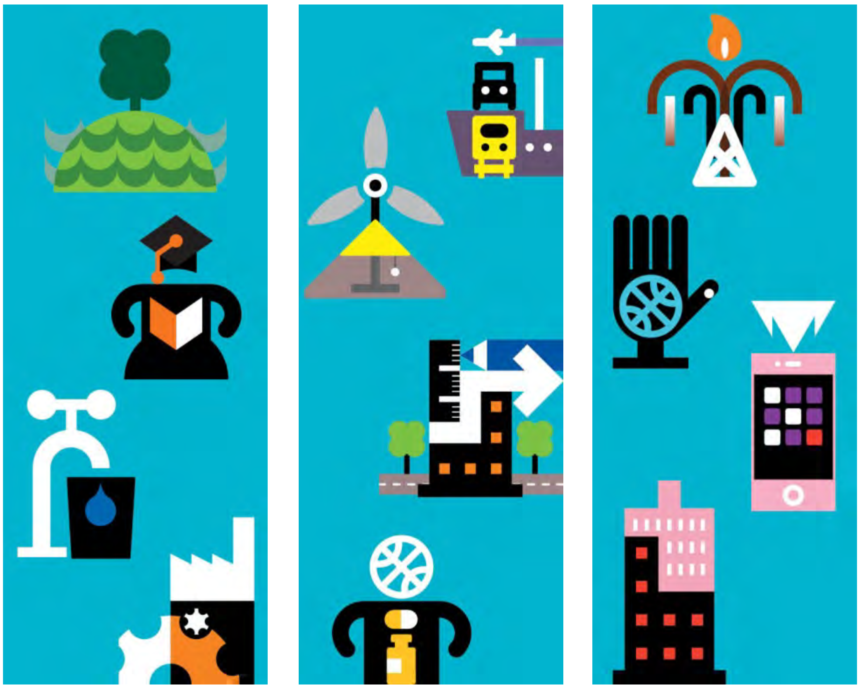

Drought Impact Analysis

Drought Plan Support

October 2016

Cambridge Water Company

Mott MacDonald

Climate Change and Source Vulnerability

Drought Plan Support

November 2016

Cambridge Water Company

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Contents

Abbreviations and acronyms

ABH:	Abstraction borehole
CWC:	Cambridge Water Company
DAPWL:	Deepest advisable pumping water level
DO:	Deployable Output
EA:	Environment Agency
GWL:	Groundwater Level
MLR:	Multiple Linear Regression
MM:	Mott MacDonald
OBH:	Observation Borehole
PY:	Potential Yield
PWL:	Pumping Water Level
RD:	Recharge Deficit
RWL:	Rest Water Level
RWL1 – RWL5:	Rest water level trigger values used in Drought Management Tool
S1 – S4:	Supply actions 1 to 4 as defined in Drought Management Tool
SR2:	Science Report 2 (Environment Agency guidance document)
SRO:	Source Reliable Output
UKCP09:	UK Climate Projection 09
UKWIR:	UK Water Industry Research
WRMP:	Water Resources Management Plan

Executive Summary

Mott MacDonald (MM) was commissioned by Cambridge Water Company (CWC) to revise the source vulnerability assessments undertaken in 2012/13 to be in accordance with the company's Water Resources Management Plan (WRMP) and Environment Agency (EA) Water Resources Planning Guideline 2016. The revision of the source assessments included hindcasting groundwater elevations to account for the worst drought conditions. The conditions included the succession of three dry winters in the early 1920s, which is considered to be the worst drought on record in the Cambridge area.

The hindcast groundwater elevation for each source was estimated by regression analysis using rainfall data available from 1902, together with EA observation borehole data. The minimum groundwater elevation was used to revise the existing UK Water Industry Research (UKWIR) summary diagrams. The results indicate that the following 13 sources may be at risk from severe drought, for both average and peak demand conditions (unless noted otherwise):

- Dullingham;
- Duxford (average demand only);
- Duxford Grange;
- Euston (peak demand only)
- Fleam Dyke 36";
- Fulbourn;
- Great Chishill;
- Great Wilbraham;
- Heydon (peak demand only);
- Kingston;
- Mordon Grange;
- Westley; and
- Weston Colville.

CWC currently uses a Drought Indicator Management Tool to assess the available water resources during drought periods. The tool has been reviewed to investigate its capacity for improvement: the current methodology for defining trigger levels, using abstraction borehole rest water levels and recharge deficit, is considered to give a good indication of the status of groundwater elevations. It is concluded that incorporating the UKWIR diagrams into the management tool will not provide any useful additional information that is not already captured in the tool.

CWC currently defines drought triggers using rest water levels for six indicator source borehole sites, in combination with the cumulative recharge deficit. The continued use of source borehole rest water levels may not be possible when sources are continuously in operation. Therefore the use of alternative water levels, such as local Environment Agency observation boreholes, was considered as an alternative option.

The correlations between source borehole rest water levels and observation borehole water levels were analysed for periods in which water elevation data are available for both the abstraction boreholes (ABH) and observation boreholes (OBH). The correlations are considered to be a good fit. Correlation graphs were used to calculate percentiles to define the trigger levels for the OBH and the results have been incorporated into the management tool. The preliminary assessment shows that the results for the OBH correlate well with the ABH water levels which trigger the requirements for drought actions. Similar drought periods, with a need for actions, are indicated by the ABH and OBH data. There are, however, some differences in the timing and level of triggers within these periods.

1 Introduction

In 2012, Mott MacDonald (MM) revised Source Reliable Output reports for Cambridge Water Company (CWC) to provide updated information regarding the potential yield and deployable output for 25 of CWC's sources.

Following this work, Mott MacDonald was commissioned by CWC in 2013 to assess the source vulnerability with regard to potential climate change, in accordance with their Water Resources Management Plan (WRMP) and following Environment Agency (EA) ***et al.*** guidance[1],

In 2016, Mott MacDonald was asked by CWC to undertake a review of the source vulnerability, building on the results of the 2012 SRO studies. One objective of the review was to incorporate worst case drought conditions into the source output diagrams to gain an improved understanding of constraints posed by drought on each of the sources.

This report discusses the results of assessing and incorporating worst case drought conditions, using the hindcasting method for establishing likely drought conditions dating back to 1902. Source output diagrams have been reviewed and revised to include the worst case drought conditions, with the results presented herein.

In addition, the drought indicator tool, which was developed my Mott MacDonald in 2006, has been updated and improved to reflect additional requirements of CWC and comment received by CWC from the Environment Agency. The drought indicator tool now includes the results of worst case drought conditions and a system for better highlighting potential drought conditions.

[1] Environment Agency, Ofwat, Defra, Welsh Government (2012). Water Resources Planning Guideline; The Guiding Principles for Developing a Water Resources Management Plan. June 2012.

2 Objectives

2.1 Key objectives for Cambridge Water Company

Cambridge Water Company (CWC) is seeking to revise some of the source assessments undertaken previously by Mott MacDonald in 2012 / 2013, in accordance with their Water Resources Management Plan (WRMP). There are three tasks that CWC asked Mott MacDonald to undertake in order to do this:

1. Update Source Reliable Output (SRO) studies for those sources for which a SRO report was produced in 2012/3. This entails hindcasting groundwater elevations using rainfall data available since 1902 to account for the worst drought conditions in the 1920s. Following hindcasting, the source yield curves can be revised to include worst case drought conditions and identify the sources most at risk from drought.

2. Revise the climate change predictions included in the March 2013 Technical Memorandum which presented the results of applying UKCP09 climate modelling to identify how deployable output might vary with climate change. The previous assessment included a climate change forecast and predictions in groundwater levels at eight vulnerable sources. The assessment was then used to determine DO, applying the UKWIR methodology. A vulnerability classification was determined following guidance in the Environment Agency Water Resources Planning Guideline (June 2012). The Water Resources Planning Guideline was due to be published in Spring 2016 but was not published by July 2016.

3. A more comprehensive assessment of vulnerability is now required, in line with previous comments from the Environment Agency (EA) (2013).

4. Update and improve the existing drought management spreadsheet, as revised by Mott MacDonald in 2012. The management spreadsheet should be reviewed to consider additional functions to reflect the Environment Agency's requirements, such as the hindcasting, drought curves and revised approach to source vulnerability, in addition to incorporating drought trigger levels based on local observation boreholes rather than the source rest water levels.

2.2 Aims of this report

2.2.1 Task 1 – hindcasting worst case drought water levels

Mott MacDonald has previously produced Source Reliable Output assessments in 1997/98 following the drought of 1996/97. These were subsequently revised in 2012 to identify specific changes in groundwater levels, incorporating a longer period of data for pumped water levels (PWLs) and rest water levels (RWLs).

There is some uncertainty regarding the 2012 assessments as to whether they fully encompass worst case drought conditions. It is understood that the 1920's included a drought that was more prolonged and more severe than the worst drought conditions observed in the 1990s and used in previous SRO assessments. A method of hindcasting was used to establish how the drought conditions similar to the conditions in the 1920s might impact groundwater elevations at the CWC sources.

Section 3.1 of this report documents:

- the hindcasting methodology and results; and,
- the results of incorporating the data from hindcasting into the drought curves, to include the lowest assessed groundwater level (GWL).

From this exercise, potentially vulnerable abstraction borehole sources are identified as documented in Section 3.1.4.

2.2.2 Task 2 – Revision of climate change predictions

The way in which climate change predictions can be incorporated into the assessment of impact on groundwater resources was previously incorporated by using a spreadsheet model and a regression analysis between groundwater elevation and rainfall. The spreadsheet model was then used to define the change in groundwater elevations based on predicted rainfall. There are various methods of applying climate change to analyse variability in groundwater elevations. Task 2 would require a review of the methods which have been used by others, and how well they could be applied to CWC sources.

A review of practices by others in applying climate change to the analysis was not possible, however, within the programme for the work and, therefore, Task 2 is not covered in this document.

2.2.3 Task 3 - Drought Indicator Management Tool

CWC indicated that the existing drought indicator management tool should be reviewed to determine whether additional functionality can be incorporated, such as the hindcast modelling data and indications of better communication management systems. In addition, some or all of the current indicator sites may no longer be used to provide suitable rest water level (RWL) data for use in the management tool. Local Environment Agency (EA) Observation Boreholes (OBH) groundwater elevations might be used instead of the RWLs.

CWC considered incorporating the hindcasting and climate change results into the Drought Indicator Management Tool. The current tool, revised by MM in 2012, uses six indicator sites across the CWC supply area. The rest water levels (RWL) at these sites are currently used to indicate the severity of drought through a series of five progressive trigger levels.

Section 4.3 of this report discusses a potential revision to the methodology, incorporating groundwater elevation data from observation boreholes rather than using RWLs at the abstraction sources.

3 Task 1: Worst case drought conditions

3.1 Update of Source Reliable Output (SRO) Studies

3.1.1 Review of existing SRO reports

The SRO reports for each of CW's 25 sources were reviewed, with particular focus on the potential yield (PY) and deployable output (DO) of these sources. The UKWIR summary diagrams, which form part of the SRO assessments, present constraints posed on the operation of the source boreholes. These constraints could include pump rate restrictions, licensed abstraction rate restrictions or hydrogeological constraints such as groundwater elevation or particular flow horizons.

The previous summary diagrams incorporated minimum groundwater elevation data for various periods from 1991 to 2011. In most cases, the summary diagrams include data for drought periods in the 1990s.

The summary diagrams have been revised to incorporate the worst case drought conditions, rather than just data for those years where groundwater elevation data are available. To do this, a method of hindcasting was applied. The method was used to correlate rainfall and groundwater elevation. The correlation was then used to simulate groundwater elevations for periods of available rainfall data dating back to the early 1900's.

3.1.2 Hindcasting of groundwater levels

3.1.2.1 Methodology

Extended major drought periods are understood to include 1854-60, 1887-88, 1890-1910, 1921-22, 1933-34, 1959, 1976, 1990-92 and 1995-97 (Marsh, Cole and Wilby, 2007). The worst case droughts in the Anglian region are understood to have been 1933-34 and potentially 1943-44 (Cole and Marsh, 2006). Drought conditions usually occur due to two or more successive dry winters.

The hindcasting methodology uses the approach presented in the Environment Agency Science Report SR2 (EA, 2006). Historical annual groundwater elevation minima are reconstructed using a regression model calibrated using real groundwater elevation minima and rainfall data. A multiple linear regression (MLR) is used to calibrate observed annual minima with antecedent rainfall and / or temperature. The EA SR2 report demonstrates that inclusion of particular months of rainfall and / or temperature data varies, and is dependent on the site under assessment.

The method for hindcasting annual groundwater elevation minima applied for the CWC sources involved correlating the observed groundwater levels from the closest observation borehole (OBH) which best reflects rest water levels at the source, with available rainfall data. Observed groundwater elevation data were available from the 1980's until 2013 for the majority of sites. Rainfall data were based on Met Office 5km grid squares for the East Anglian region. A regression analysis was undertaken for each CWC source using the observed annual minimum groundwater elevation and monthly rainfall data for the preceding year.

For this study, the preceding year of rainfall data was compared with annual minimum groundwater elevations representative of a one year drought. To capture two and three years of antecedent conditions that could lead to a greater reduction in groundwater elevations, two and three years of antecedent rainfall data were included in the analysis. Due to limitations of the use of MLR in Excel, a maximum of 12 regression parameters can be included in the regression model. This means that monthly rainfall data needs to be combined effectively to represent the overall conditions. Table 3.1 demonstrates how the rainfall data have been applied for the one, two and three year regression models.

Table 3.1: Rainfall scenarios for groundwater level hindcasting

Scenario												Rainfall Variables
1 year (monthly)	Oct (y-1)	Nov (y-1)	Dec (y-1)	Jan (y)	Feb (y)	Mar (y)	Apr (y)	May (y)	Jun (y)	Jul (y)	Aug (y)	Sept (y)
2 year (bi-monthly)	Oct-Nov (y-2)	Dec-Jan (y-2)	Feb-Mar (y-1)	Apr-May (y-1)	Jun-Jul (y-1)	Aug-Sept (y-1)	Oct-Nov (y-1)	Dec-Jan (y-1)	Feb-Mar (y)	Apr-May (y)	Jun-Jul (y)	Aug-Sept (y)
3 year (tri-monthly)	Oct-Dec (y-3)	Jan-Mar (y-2)	Apr-Jun (y-2)	Jul-Sept (y-2)	Oct-Dec (y-2)	Jan-Mar (y-1)	Apr-Jun (y-1)	Jul-Sept (y-1)	Oct-Dec (y-1)	Jan-Mar (y)	Apr-Jun (y)	Jul-Sept (y)

Note: y-1 = Preceding year data (i.e. year before the groundwater elevation data, y-2 = two years before the groundwater elevation data and y-3 = three years before the groundwater elevation data

In order to model the minimum groundwater levels, the regression analysis was undertaken by applying the following equation:

$$\mathbf{Z_{min} = B_{Oct\text{-}1}R_{Oct\text{-}1} + B_{Nov\ \text{-}1}R_{Nov\text{-}1} + B_{Dec\text{-}1}R_{Dec\text{-}1} + B_{Jan0}R_{Jan0} + B_{Feb0}R_{Feb0} + B_{Mar0}R_{Mar0} + B_{Apr0}R_{Apr0} + B_{May0}T_{May0} \ldots\ldots + c}$$

Where;

- Z_{min} = simulated minimum annual groundwater level in the hydrometric year, y0 (mAOD)
- R_{Oct-1} = monthly total rainfalls for selected months (in this case for the preceding year, y-1) (mm)
- B_{Oct-1} = regression coefficients determined following the statistical multiple regression analysis
- c = multiple regression intercept constant

Monthly rainfall data are available for the period 1902-2010. The rainfall data is based on Met Office 5km grid squares for the East Anglian region and these data have been used to hindcast the groundwater elevations.

Groundwater elevation data for the nearest representative Environment Agency (EA) observation boreholes were used to represent the groundwater sources for hindcasting. The nearest and most representative EA OBH used for each source was identified in previous SRO studies. The EA OBH was used rather than the RWLs at each abstraction source as the data available are generally more reliable and are available over a longer period of time. **Error! Reference source not found.** Table 3.2 indicates the EA OBH used for the hindcasting at each source.

3.1.2.2 Correction Factor

The hindcast OBH data and the available OBH data have been compared to determine whether a correction factor (CF1) needs to be added to the hindcast data to ensure it adequately represents the groundwater minima observed. The correction value is specific and consistent for each abstraction.

There may also be a second correction factor required (CF2) to allow for the difference between the OBH groundwater elevations and the RWL at the abstraction borehole (ABH). As for CF1, the correction value CF2 is specific and consistently applied to data for each abstraction.

The correction factors are defined as follows:

CF 1: The difference between the minimum observed GWL at the OBH and the minimum hindcast GWL during the period for which observed data are available. This difference is applied throughout the modelled series to ensure the minimum modelled GWL is adequately captured.

CF 2: The difference between the OBH GWL and the ABH RWL, to ensure the modelled data are converted to a water elevation that is more representative of the RWLs at the source. This is calculated using the difference between the minimum ABH RWL and the OBH GWL measured at the same date.

Following the application of CF1 and CF2, the minimum modelled ABH RWLs have been applied to the UKWIR diagrams (Appendix D). Table 3.2 summarises the minimum groundwater elevations from the worst case drought scenario modelled, including observed and modelled elevations for each of the abstraction sources. Appendix A provides the full results for the modelled elevations for the one, two and three year model periods. Appendix C contains graphs comparing modelled hindcast, observed and the corrected groundwater elevations following application of CF1 and CF2. Appendix B contains maps showing where the OBH are relative to the ABH.

Table 3.2: Minimum modelled groundwater elevations

ABH Source	OBH	Minimum observed OBH GWL (mAOD)	Minimum observed ABH RWL (mAOD)	Year of minimum modelled GWL (mAOD)	Rainfall scenario	Minimum modelled ABH RWL with correction (mAOD)	DAPWL (mAOD)
Abington	TL54/102	20.61	19.92	1921	3	19.07	-17
Babraham	TL45/017	12.28	11.05	1921	2	10.24	-4.5
Brettenham	TL88/013	12.58	11.35	1921	2	10.01	-5.75
Croydon	TL35/001	18.08	17.6	1979	3	13.66	-3.91
Dullingham	TL65/043	9.85	8.66	1976	1	4.80	-26.2
Duxford Grange	TL44/240	20.18	18.98	1932	3	17.32	6.68
Duxford	TL44/048	19.10	19.22	1921	3	17.42	14.5
Euston	TL88/013	12.61	12.72	1921	1	12.73	11.2
Fleam Dyke 12"	TL55/133	8.84	5.49	1948	2	5.02	-8.8
Fleam Dyke 36"	TL55/133	8.84	6.70	1948	2	5.18	-9
Fowlmere	TL44/293	18.29	18.51	1960	3	13.52	12.5
Fulbourn	TL45/017	12.28	8.11	1921	2	6.78	4.4

ABH Source	OBH	Minimum observed OBH GWL (mAOD)	Minimum observed ABH RWL (mAOD)	Year of minimum modelled GWL (mAOD)	Rainfall scenario	Minimum modelled ABH RWL with correction (mAOD)	DAPWL (mAOD)
Great Chishill	TL44/234	25.9	25.11	1974	1	21.79	-4.19
Great Wilbraham	TL55/144	10.02	5.39	1997	3	4.99	-9.4
Heydon	TL44/238	22.52	23.21	1922	3	18.40	10.3
Hinxton Grange	TL54/002	20.89	20.46	1976	1	20.15	6
Kingston	TL35/004	12.13	12.86	1947	1	10.54	-9.9
Linton	TL54/028	21.11	28.11	1989	1	27.17	-15.5
Lowerfield	TL44/234	25.32	27.87	1922	3	22.30	17.9
Melbourn	TL44/427	20.85	19.70	1942	1	18.81	-0.82
Mordon Grange	TL34/007	39.23	37.24	1922	3	36.48	27
Rivey	TL54/001	35.93	32.93	1976	1	30.89	-38
Sawston	TL54/006	19.65	14.79	1976	1	14.03	0
Westley	TL55/009	8.99	8.00	1912	2	5.22	-14.6
Weston Colville	TL65/042	11.38	11.38	1919	3	0*	-14.38

Note: * ABH RWL was modelled as -9.82mAOD which cannot occur under natural conditions. As such, a nominal groundwater elevation of 0mAOD has been taken as the lowest possible elevation.

For Weston Colville a minimum RWL of 0mAOD was taken as the modelled groundwater minimum was below 0mAOD, which is not possible. The extremely low modelled groundwater elevation is a result of the large variation in observed groundwater elevation at Weston Colville (25m between the observed minimum and maximum) which is produced from modelling. Such a large variation is not observed to the same degree at the other sites. During the 1920's drought the variations becomes particularly prominent, for the three dry winter scenario. The difference between observed and modelled groundwater elevation is significant and, in reality, groundwater elevations will not have fallen to the level modelled, which is an artefact of the modelling methodology. The minimum modelled groundwater levels are not constrained in any way, for example they are not constrained to a minimum possible elevation (0mAOD).

3.1.3 Drought curves

The UKWIR summary diagrams presented in the Source Reliable Output reports (MM, 2011) for 25 of Cambridge Water's groundwater sources have been revised to incorporate the modelled hindcast groundwater minima. The UKWIR summary diagrams indicate the Deployable Output (DO) and Potential Yield (PY) for each source, applying either Option C (an operational approach using pumping water levels) or Option D (using pumping test data are available). The diagrams were revised by shifting the option C or D curves down so that the starting point of the curve (where abstraction is 0 Ml/d) was equivalent to the hindcast minimum for each source.

It is not possible to accurately define the peak demand rest water level, using the hindcast data. Therefore the minimum hindcast groundwater elevation has been applied to both the peak and average UKWIR curves to provide an indication of the likely impact on PY and DO.

Appendix D contains the revised UKWIR summary diagrams.

3.1.4 Vulnerable sources

The most vulnerable sources are defined as those where the revised groundwater minima indicate a significant impact on the Annual Average DO. The sensitivity of PY is only included for information.

Table 3.3 and Table 3.4 provide a summary of the sources and whether they are considered to be vulnerable, based on the most vulnerable scenario modelled, with the lowest minima (refer to Table 3.2). The tables include the calculated DO and PY for the average conditions. The vulnerability with regard to DO is defined as follows:

- low (highlighted in green in the table), where the hindcast minima do not impact DO;
- medium (highlighted in orange), where there is a reduction in DO of up to 15%; and
- high (highlighted in red), where there is a reduction in DO in excess of 15%.

The sensitivity of PY is defined as follows:

- low (highlighted in green in the table), where the PY is more than 15% of the annual / daily licence;
- medium (highlighted in orange), where PY is between 5 and 15% more than the annual / daily licence; and
- high (highlighted in red), where the PY is less than 5% higher than the annual / daily licence.

In summary, vulnerable sources are considered to be those where either DO or PY have decreased by more than 15%, or if both DO and PY have decreased by up to 15%, providing the PY is within the defined limits of the annual or daily licence.

Table 3.3: Potentially vulnerable sources using average demand conditions

Source	DO using observed data (Ml/d)	DO using hindcast data (Ml/d)	PY using observed data (Ml/d)	PY using hindcast data (Ml/d)	Annual licence (Ml/d)	Vulnerable
Abington	1.00 (Annual licence)	1.00 (Annual licence)	>18 (DAPWL)	>18 (DAPWL)	1.00	No
Babraham	9.09 (Annual licence)	9.09 (Annual licence)	12.30 (DAPWL)	11.80 (DAPWL)	9.09	No
Brettenham	11.34 (Annual licence)	11.34 (Annual licence)	>20 (DAPWL)	>20 (DAPWL)	11.34	No
Croydon	1.99 (Annual licence / treatment capacity)	1.99 (Annual licence / treatment)	>3 (DAPWL)	>3 (DAPWL)	1.99	No
Dullingham	3.60 (DAPWL option D)	3.50 (DAPWL option D)	3.70 (DAPWL, option C)	3.60 (DAPWL option C)	4.50	Yes
Duxford Grange	3.41 (Annual licence)	3.05 (DAPWL, Option D)	3.60 (DAPWL option C))	3.05 (DAPWL, option C)	3.41	Yes
Duxford	4.56 (Annual Licence)	4.08 (DAPWL)	6.22 (DAPWL)	4.08 (DAPWL)	4.56	Yes
Euston	8.00 (Annual licence)	8.00 (Annual licence)	>12 (DAPWL)	>12 (DAPWL)	8.00	No
Fleam Dyke 12"	3.27 (Annual licence)	2.90 (DAPWL)	>4.00 (DAPWL, option C)	>4.00 (DAPWL, option C)	3.27	No
Fleam Dyke 36"	12.30 (DAPWL)	11.62 (DAPWL)	12.30 (DAPWL)	11.62 (DAPWL)	12.61	Yes
Fowlmere	3.60 (Annual licence)	3.60 (Annual licence)	7.35 (DAPWL at 12.5m AOD)	7.35*	3.60	No
Fulbourn	1.49 (Annual licence)	0.76 (DAPWL)	1.77 (DAPWL, Option C)	0.76 (DAPWL, Option C)	1.49	Yes

Source	DO using observed data (Ml/d)	DO using hindcast data (Ml/d)	PY using observed data (Ml/d)	PY using hindcast data (Ml/d)	Annual licence (Ml/d)	Vulnerable
Gt. Chishill	1.06 (DAPWL, option C)	0.92 (DAPWL, option C)	1.06 (DAPWL, option C)	0.92 (DAPWL, option C)	1.15	Yes
Gt. Wilbraham	5.67 (Annual licence)	5.67 (Annual licence)	13.00 (DAPWL, BHs 1/2)	13.00 (DAPWL, BHs 1/2)	5.67	No
Heydon	1.13 (Annual licence)	1.13 (Annual licence)	2.80 (DAPWL)	2.80 (DAPWL)	1.13	No
Hinxton Gr	5.77 (Annual licence)	5.77 (Annual licence)	16.3 (maximum monthly output)	16.3 (maximum monthly output)	5.77	No
Kingston	1.00 (Annual licence)	0.50 (pump cut-out) 1.00 (Annual licence)[1]	>5 (DAPWL)	>5 (DAPWL)	1.00	Yes
Linton	1.93 (Annual licence)	1.93 (Annual licence)	>10 (DAPWL)	>10 (DAPWL)	1.93	No
Lowerfield	3.41 (Annual licence)	3.41 (Annual licence)	9.5 (DAPWL, option C)	5.0 (DAPWL, option C)	3.41	No
Melbourn	7.94 (Annual licence)	7.94 (Annual licence)	9.15 (DAPWL, option D)	7.94 (DAPWL, option C&D)	7.94	Yes
Mordon Grange	1.5 (pump capacity)	1.39 (DAPWL)	1.5 (DAPWL, option C)	1.39 (DAPWL, option C)	2.27	Yes
Rivey	2.2 (Annual licence)	2.2 (Annual licence)	>4 (DAPWL)	>4 (DAPWL)	2.20	No
Sawston	1.49 (Annual licence)	1.49 (Annual licence)	3.15 (DAPWL)	3.15 (DAPWL)	1.49	No
Westley	11.39 (Annual licence)	5.1 (DAPWL)	11.39 (DAPWL)	5.1 (DAPWL)	11.39	Yes
Weston Colville	2.7 (DAPWL, option D)	1.28 (DAPWL, option D)	2.92 (DAPWL, option C)	1.28 (DAPWL, option C & D)	3.65	Yes

Note* for Fowlmere the hindcast groundwater elevation is below the DAPWL at 12m AOD and the hydrogeological properties of the aquifer below the DAPWL are not known and so the DO and PY cannot be effectively determined.
[1] Mott MacDonald (2012). Source Reliable Output Study: Kingston

Table 3.4: Potentially vulnerable sources using peak demand conditions

Source	DO using observed data (Ml/d)	DO using hindcast data (Ml/d)	PY using observed data (Ml/d)	PY using hindast data (Ml/d)	Daily licence (Ml/d)	Vulnerable
Abington	4.44 (pump rating)	4.44 (pump rating)	>18 (DAPWL)	>18 (DAPWL)	4.55	No
Babraham	9.09 (daily licence)	9.09 (daily licence)	>14 (DAPWL)	12.9 (DAPWL)	9.09	No
Brettenham	15.0 (daily licence)	15.0 (daily licence)	>20 (DAPWL)	>20 (DAPWL)	15.0	No
Croydon	1.99 (treatment capacity)	1.99 (treatment capacity)[2] 2.5 (Daily licence)	>3 (DAPWL)	>3 (DAPWL)	2.50	No
Dullingham	3.63 (DAPWL, option D)	3.50 (DAPWL, option D)	3.73 (DAPWL, option C)	3.63 (DAPWL, option C)	5.62	Yes

Source	DO using observed data (Ml/d)	DO using hindcast data (Ml/d)	PY using observed data (Ml/d)	PY using hindast data (Ml/d)	Daily licence (Ml/d)	Vulnerable
Duxford Grange	3.95 (DAPWL)	3.95 (DAPWL)	3.95 (DAPWL)	3.95 (DAPWL)	4.27	Yes
Duxford	5.68 (daily licence)	5.0 (DAPWL)	7.26 (pump capacity)	7.26 (pump capacity)	5.68	Yes
Euston	10.0 (daily licence)	10.0 (daily licence)	12.0 (DAPWL)	12.0 (DAPWL)	10.0	No
Fleam Dyke 12"	3.27 (daily licence)	3.27 (daily licence)	3.60 (DAPWL)	3.42 (DAPWL)	3.27	No
Fleam Dyke 36"	12.70 (operational practice / DAPWL, option C)	11.6 (DAPWL, option C)	12.70 (operational practice / DAPWL, option C)	11.6 (DAPWL, option C)	17.27 (shared with 12")	Yes
Fowlmere*	5.4 (daily licence)	5.4 (daily licence)	8.0 (DAPWL, 12.5mAOD)	8.0	5.40	No
Fulbourn	1.70 (DAPWL)	1.02 (DAPWL)	1.70 (DAPWL)	1.02 (DAPWL)	1.88	Yes
Gt. Chishill	1.056 (DAPWL, option C)	0.94 (DAPWL, option C)	1.68 (DAPWL, option D)	1.55 (DAPWL, option D)	1.42	Yes
Gt. Wilbraham	8.65 (DAPWL, option D, BH1/2)	5.7 (DAPWL, option D, BH1/2)	14.4 (DAPWL, option D, BH3)	13.0 (DAPWL, option D, BH3)	9.09	Yes
Heydon	2.13 (pump cut-out)	1.67 (pump cut-out)[3] 2.27 (Daily licence)	2.97 (DAPWL)	2.69 (DAPWL)	2.27	Yes
Hinxton Grange	6.82 (daily licence)	6.82 (daily licence)	17.4 (DAPWL)	17.0 (DAPWL)	6.82	No
Kingston	1.18 (daily licence)	0.5 (pump cut-out)[4] 1.182 (Daily licence)	>5 (DAPWL)	>5 (DAPWL)	1.182	Yes
Linton	2.73 (daily licence)	2.73 (daily licence)	>10 (shallow DAPWL)	>10 (shallow DAPWL)	2.73	No
Lowerfield	4.27 (daily licence)	4.27 (daily licence)	9.1 (DAPWL, option C)	5.2 (DAPWL, option C)	4.27	No
Melbourn	9.15 (DAPWL, option D)	8.45 (DAPWL, option D)	9.15 (DAPWL, option D)	8.45 (DAPWL, option D)	13.64	No
Mordon Grange	1.5 (pump capacity)	1.28 (DAPWL)	2.1 (DAPWL, option C)	1.28 (DAPWL)	2.85	No
Rivey	2.75 (daily licence)	2.75 (daily licence)	>4 (DAPWL)	>4 (DAPWL)	2.75	No
Sawston	2.16 (pump rating)	2.16 (pump rating[5] 2.18 (Daily licence)	3.26 (DAPWL)	3.26 (DAPWL)	2.18	No
Westley	11.39 (DAPWL)	6.1 (DAPWL)	11.39 (DAPWL)	6.1 (DAPWL)	15.91	Yes
Weston Colville	2.92 (DAPWL)	2.15 (DAPWL)	2.92 (DAPWL)	2.15 (DAPWL)	4.55	Yes

Note* for Fowlmere the hindcast groundwater elevation is below the DAPWL at 12m AOD. The hydrogeological properties of the aquifer below the DAPWL are not known and so the DO and PY cannot be effectively determined.
[2] Mott MacDonald (2012). Source Reliable Output Study: Croydon; [3] Mott MacDonald (2012). Source Reliable Output Study: Heydon

[4] Mott MacDonald (2012). Source Reliable Output Study: Kingston; [5] Mott MacDonald (2012). Source Reliable Output Study: Sawston

In summary, the most vulnerable sources are those where the groundwater elevations were such that the DO or PY was defined by the DAPWL or where the hindcast modelling has produced significantly lower groundwater elevations (ABH RWLs).

For Weston Colville a minimum RWL of 0mAOD was taken to derive the UKWIR diagrams as the modelled groundwater minimum was below 0mAOD, which is not possible.

A summary of the total DO and PY for all sources using the existing values and hindcast values is provided in Table 3.5. The total includes Fowlmere, although a hindcast DO and PY could not be determined using the data available.

Table 3.5: Comparison between total DO and PY for all sources between current and hindcast values

	DO (Current), Ml/d	DO (hindcast), Ml/d	Hindcast as % of current DO	PY (Current), Ml/d	PY (hindcast), Ml/d	Hindcast as % of current PY
TOTAL Average conditions	110.84	99.66	90% (10% reduction in DO)	194.01	175.14	90% (10% reduction in PY)
TOTAL Peak conditions	133.56	119.78	90% (10% reduction in DO	201.31	184.46	92% (8% reduction in PY)

It is important to note that the changes to DO and PY as a result of the hindcasting should be considered in light of the conservatism and uncertainty in the modelling. The hindcast modelling considers only the relationship between rainfall and groundwater elevation. It does not account for any hydrogeological or geological features that may constrain the extremes of groundwater elevation.

As a result, the DO and PY determined using the hindcasting should provide a worst case scenario. The revised values, taking into account the hindcasting, might be considered alongside the existing DO/PY values which are based on recorded data.

4 Drought Indicator Management Tool

4.1 Drought Indicators

CWC's current drought indicator management tool is used to assess water resources during drought periods, incorporating the rest water level (RWL) for six representative indicator abstraction sources within the CWC supply area together with the recharge deficit (RD) assessment. The drought indicator management tool was developed by MM in 2006 (Mott MacDonald, November 2006).

The indicator tool was reviewed as part of this study to re-assess its ongoing applicability in terms of defining the actions required under certain levels of drought conditions. The existing tool continues to provide a robust approach to defining the response to the trigger levels. However, the trigger levels themselves have also been reviewed to ensure they continue to be the most appropriate levels for defining when to implement the drought measures.

4.2 Trigger Levels

Currently there are five progressive trigger levels associated with rest water levels calculated using a combination of RWLs and RD as defined in the MM 2006 report (Mott MacDonald, November 2006). RWL values at each of the six indicator sites are used to indicate the degree of potential drought severity by evaluation against five trigger levels (RWL1 – RWL5). RWL1 is the least severe condition and RWL5 is the most severe.

RWL1 – RWL4 are defined through statistical analyses as the rest water levels (mAOD) equivalent to the 95th, 97th, 98th and 99th percentile low levels for each of the indicator sources using the data available. RWL5 is calculated as the rest water level midway between:

- the 'critically low ***rest water level associated with DAPWL***', which allows for drawdown to the DAPWL in pumping (Mott MacDonald, November 2006; Mott MacDonald, August 2011); and
- RWL4.

The trigger levels are considered appropriate for continuing to define the objectives of the drought and response plan.

4.3 Improvement of Management Tool

CWC are seeking to improve the current Drought Indicator Management Tool to include additional functions to reflect the Environment Agency's requirements. Updates to the existing tool should include improved communications, identification of severe droughts, and the incorporation of groundwater level data for local observation boreholes into the drought trigger levels, rather than relying on source RWLs.

The following sub-sections describe each of the proposed improvements that could be incorporated into the tool, and how the improvement may be beneficial. Use of information from the UKWIR diagrams was also considered in relation to the management tool.

4.3.1 UKWIR Summary diagrams

The UKWIR diagrams, incorporating hindcast data, provide a conservative approach to defining the DO and PY. The DAPWL defined in the UKWIR diagrams is already taken account of in the trigger levels, in calculating trigger level RWL5.However, additional information from the diagrams cannot be usefully incorporated into the management tool for predicting and defining the source operation and management during periods of drought.

The purpose of the diagrams and the management tool are separate. The diagrams provide an assessment of DO and PY which is unchanged by current conditions, though they may be subject to revision from time to time. The management tool is a means of anticipating changing conditions in water resources as they occur.

4.3.2 Severe Droughts

At present the trigger levels are defined statistically and do not account for the minimum hindcast groundwater elevations. The table below presents the RWL triggers in the hindcast tool and the minimum overall hindcast groundwater elevation for each source, after applying the one, two or three year succession of data (mimicking the one, two and three year successive droughts). The most severe drought giving the lowest hindcast groundwater level is indicated in the table for each source.

Table 4.1: Management tool RWL triggers and minimum hindcast groundwater elevation

	Fleam Dyke	Melbourn	Babraham	Lowerfield	Fowlmere	Gt. Wilbraham
RWL1	8.0	21.9	13.2	28.9	19.5	10.0
RWL2	7.8	21.5	12.8	28.2	19.3	9.1
RWL3	7.5	21.3	12.5	28.0	19.1	8.9
RWL4	7.2	21.0	12.3	27.9	19.0	8.1
RWL5	4.7	20.0	7.9	24.3	17.3	4.8
Minimum hindcast GWL	**4.44**	**19.09**	**10.24**	**22.30**	**12.52**	**4.99**
Hindcast Scenario	**2 year drought**	**1 year drought**	**2 year drought**	**3 year drought**	**3 year drought**	**3 year drought**

The comparison between hindcast minimum groundwater elevations and the minimum hindcast RWLs indicates that, for Babraham and Great Wilbraham, the hindcast minimum groundwater elevations are higher than RWL5. Therefore a severe drought (defined in this instance as the lowest hindcast groundwater elevation following a one, two or three year successive drought, as indicated in the table) could occur before rest water levels at the site decline to RWL5.

For Fleam Dyke, Melbourn and Great Wilbraham the hindcast minima are only marginally different to the RWL5 and, as such, RWL5 may be reached in a potential severe drought situation. For Lowerfield, Fowlmere and Heydon, the hindcast minima are below RWL5. Therefore, RWL5 for these three sites should occur in advance of a severe drought.

At Babraham the hindcast minimum is higher than RWL5 and therefore may require a review of RWL5 and potentially the other RWL triggers to ensure that there is a trigger before the potential severe drought (worst case modelled hindcast scenario) minimum is reached. For this abstraction, the RWL5 trigger is significantly lower than the hindcast minimum, which suggests that the worst drought conditions prompting RWL5 actions will never be met. A further review may be required but, at present, RWL5 for Babraham could be revised to consider the hindcast minimum rather than the existing elevation in the calculation, particularly as the DAPWL is -4.5mAOD.

4.3.3 Drought Triggers

CWC currently defines drought triggers using rest water levels of six indicator borehole sources in combination with cumulative recharge deficit. The six indicator sources are Babraham, Melbourn, Fleam Dyke, Great Wilbraham, Fowlmere and Lowerfield (substituted for Heydon in 2011).

CWC have identified that the continued use of ABH rest water levels may not be possible where sources are continuously in operation, such as at Heydon and Melbourn, as identified in the 2011 report (Mott MacDonald, August 2011). Therefore the use of alternative water levels, such as levels for EA observation boreholes, is considered as an option in this report.

Water levels for a nearby representative EA observation boreholes for each of the six indicator sources have been used to develop trigger levels based on the OBH groundwater elevations, as outlined in Table 3.2. The correlations between source borehole rest water levels and OBH water levels have been analysed to define trigger levels for the OBH, in addition to the existing trigger levels for the source boreholes.

The correlation between source borehole rest water levels and observation boreholes are graphically presented in Appendix E. The graphs represent the water levels ranked in order of magnitude, for time periods where water elevation data are available for both the ABH and OBH. The correlations are considered to be a good fit. The trigger levels for the OBH were determined from these correlation graphs.

To calculate RWL5 for the OBH, a correlation between the statistical distributions for the ABH and OBH measured groundwater elevations was used for each indicator site. The RWL5 value for the OBH was determined from the distributions at the point of correlation with the RWL5 value for the ABH. In some cases, RWL5 may appear lower than anticipated. This is due to RWL5 being derived for the OBH by using the direct correlation between the ABH and OBH data.

The trigger levels developed from analysis of the observation borehole water level data are provided in Table 4.2. The water levels at the ABH sources currently used by CWC are also shown for comparison.

Table 4.2: Water Level Triggers

Source Borehole	RWL	Percentage	Current ABH Trigger Level (mAOD)	OBH Trigger Level (mAOD)
Babraham (TL45/017)	RWL5	Assessed for ABH using RWL4, drawdown and DAPWL	7.9	4.96
	RWL4	99 (exceeded by 99% of recorded values)	12.3	12.74
	RWL3	98 (exceeded by 98% of recorded values)	12.5	12.97

Source Borehole	RWL	Percentage	Current ABH Trigger Level (mAOD)	OBH Trigger Level (mAOD)
	RWL2	97 (exceeded by 97% of recorded values)	12.8	13.05
	RWL1	95 (exceeded by 95% of recorded values)	13.2	13.20
Melbourn (TL44/427)	RWL5	Midway between RWL4 and DAPWL	20.0	20.38
	RWL4	99 (exceeded by 1% of recorded values)	21.0	21.29
	RWL3	98 (exceeded by 2% of recorded values)	21.3	21.47
	RWL2	97 (exceeded by 3% of recorded values)	21.5	21.71
	RWL1	95 (exceeded by 5% of recorded values)	21.9	21.89
Fleam Dyke (TL55/005)	RWL5	Midway between RWL4 and DAPWL	4.7	5.80
	RWL4	99 (exceeded by 1% of recorded values)	7.2	9.75
	RWL3	98 (exceeded by 2% of recorded values)	7.5	9.86
	RWL2	97 (exceeded by 3% of recorded values)	7.8	10.02
	RWL1	95 (exceeded by 5% of recorded values)	8.0	10.34
Gt Wilbraham (TL55/144)	RWL5	Midway between RWL4 and DAPWL	4.8	6.0
	RWL4	99 (exceeded by 1% of recorded values)	8.1	10.76
	RWL3	98 (exceeded by 2% of recorded values)	8.9	11.69
	RWL2	97 (exceeded by 3% of recorded values)	9.1	11.96
	RWL1	95 (exceeded by 5% of recorded values)	10.0	12.38
Fowlmere (TL44/293)	RWL5	Midway between RWL4 and DAPWL	17.3	18.89
	RWL4	99 (exceeded by 1% of recorded values)	19.0	20.32
	RWL3	98 (exceeded by 2% of recorded values)	19.1	20.40
	RWL2	97 (exceeded by 3% of recorded values)	19.3	20.48
	RWL1	95 (exceeded by 5% of recorded values)	19.5	20.59
Lowerfield (TL44/234)	RWL5	Midway between RWL4 and DAPWL	24.3	22.06
	RWL4	99 (exceeded by 1% of recorded values)	27.9	25.73
	RWL3	98 (exceeded by 2% of recorded values)	28.0	25.88

Source Borehole	RWL	Percentage	Current ABH Trigger Level (mAOD)	OBH Trigger Level (mAOD)
	RWL2	97 (exceeded by 3% of recorded values)	28.2	26.04
	RWL1	95 (exceeded by 5% of recorded values)	28.9	26.19

Source: MM, November 2006; MM, August 2011

Observation borehole water levels and the developed OBH trigger levels have been incorporated into Cambridge Water's Drought Management Spreadsheet. Observed borehole data shows a good correlation with source borehole data. Periods of low groundwater elevations are consistent using both ABH and OBH data and result in 'supply' actions being triggered.

A comparison of timing and severity level of the 'supply' action triggered for ABH data and for OBH data is illustrated in Figure F.1 to Figure F.4 of Appendix F, for 1990-93 and 1997-99. These were periods of drought when 'supply' actions were triggered. For both periods, the drought spanned over two years / seasons. During the 1990-92/3 drought period, RWL4 was triggered which prompted supply action S3 to be activated. This was the same for both the ABH and OBH data. During the 1997-99 drought period, RWL3 was triggered and S3 was again activated for both ABH and OBH data.

During the 1990-92 drought, the triggers are broadly similar between the ABH data and the OBH data, although there are differences. For example, the months when trigger levels are activated differ slightly, as does the severity:

- The OBH data set off triggers one month earlier than the ABH data, in October 1990, (and extending to February 1991).
- Later in 1991, the OBH does not activate triggers again until November (extending to February 1992), whereas the ABH data activate triggers much earlier in August 1991.
- Action S3 is triggered more frequently in the ABH data than for the OBH during the period August 1991 to March 1992, although the OBH data activate S3 in December 1990, whereas the ABH data do not.

These differences may be caused by the OBH showing smoother hydrographs than those for the ABH, particularly as the RWL triggers are defined with consideration of abstraction at the ABH and the exacerbated effects on groundwater elevations at the source. For the majority of the indicator sites the OBH and ABH data show a good fit. In some cases, for example for Fowlmere, there is a divergence in the OBH and ABH data between 1990 and 1997.

For the 1997-99 drought period the triggers for ABH and OBH are also similar. However, the following differences are noted:

- the OBH data cause S3 to be triggered far more frequently than the ABH data;
- during November 1997 no triggers are activated with the ABH data, but are with the OBH data.

At Fowlmere the ABH data appear to be similar to the OBH data from 1997 onwards.
Average water levels in the ABHs are also used in the original spreadsheet as a means for triggering the cumulative recharge deficit calculations. The cumulative recharge deficit calculation begins in the month when rest water levels at three or more of the indicator sites drop below average annual rest water levels.

Calculation of the cumulative recharge deficit continues until rest water levels at three or more of the indicator sites rise above average annual rest water level for three or more months.

A separate worksheet has been produced using the observation borehole data to trigger the cumulative recharge deficit calculations. Comparison of the recharge deficit triggers in Appendix F indicate that cumulative deficits are calculated for the same overall periods using ABH and OBH data. However, there are variations in the detail within these periods with calculations made using ABH and OBH data.

The comparison between the ABH and OBH derived management tools broadly demonstrate the applicability of using the OBH data. However, it also highlights the potential for actions to be implemented at a slightly different time and with differing severity, should there be significant divergence between the ABH and OBH data.

In general, using the ABH and OBH data do not result in significantly differing actions being triggered, although using the OBH data does appear to trigger supply actions one month sooner than the ABH data (for the two drought periods assessed for 1990 and 1997). For the 1997 drought period, the OBH data appears to be more conservative, with the supply actions lasting for seven months rather than the five months (in a six month period) for the ABH data. Conversely, the ABH data provide a slightly more conservative outcome for the 1990-92 drought, triggering supply actions in a total of 13 months (in a 23 month period) compared to the total of 11 months (in a 24 month period) when the OBH data are used.

In conclusion, using the OBH data rather than the ABH data will provide sufficient information regarding the implementation of supply actions. However, there is no specific trend identified that could indicate using either OBH or ABH data, as the trigger periods and response to drought using OBH or ABH data appear to be specific to individual drought conditions.

5 Conclusions and Recommendations

The hindcast modelling identified 13 sources at which average demand and/or peak demand could be vulnerable in a worst case scenario drought. The worst case scenario drought can be defined as the period over which the lowest groundwater elevation would occur. Hindcast modelling has been undertaken for a one, two and three year drought period. The worst case drought does not always occur using the three year data period. Therefore, the lowest groundwater minima from the one, two or three year modelling periods has been used to define the worst case scenario.

The 13 sources comprise:

- Dullingham (average and peak demand);
- Duxford (average demand only);
- Duxford Grange (average and peak demand);
- Euston (peak demand only)
- Fleam Dyke 36" (average and peak demand);
- Fulbourn (average and peak demand);
- Great Chishill (average and peak demand);
- Great Wilbraham (average and peak demand);
- Heydon (peak demand only);
- Kingston (average and peak demand);
- Mordon Grange (average demand only);
- Westley (average and peak demand); and
- Weston Colville (average and peak demand).

The changes to DO and PY as a result of the hindcasting should be considered in light of the conservatism and uncertainty in the hindcast modelling. The modelling considers only the relationship between rainfall and groundwater elevation. It does not account for any hydrogeological or geological features that may constrain the extremes of groundwater elevation.

As a result, the DO and PY determined using the hindcasting should provide a worst case scenario. The revised values, taking into account the hindcasting, might be considered alongside the existing DO/PY values which are based on recorded data.

The drought indicator tool was reviewed to understand whether:

- it remains a robust methodology; and,
- any of the triggers should be revised, taking into account the results of the hindcast modelling.

The RWL5 values for Babraham could be revised to incorporate the hindcast minimum. The minimum is higher than RWL5 for Babraham. Hence, RWL5 might be re-established as the modelled minimum.

RWL trigger levels were derived for the drought indicator management tool using OBH data. Applying OBH data rather than the ABH RWLs was tested in the drought indicator management tool. The preliminary assessment shows that the results for the OBH correlate reasonably well with the ABH water levels which trigger the requirements for drought actions.

Similar drought periods, with a need for actions, are indicated by the ABH and OBH data. There are, however, some differences in the timing and level of triggers within these periods. Use of the OBH RWLs should be tested against the ABH RWLs in drought or low groundwater elevation conditions in order to fully check effectiveness.

Cambridge Water should continue to collect water level data for the six indicator sites (Babraham, Melbourn, Fleam Dyke, Great Wilbraham, Fowlmere and Lowerfield) in order that a further comparison can be made at a time when a period of low groundwater levels occurs.

6 References

Cole and Marsh, 2006. Major droughts in England and Wales from 1800 and evidence of impact. Environment Agency Science Report: SC040068/SR – Part 1

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Mott MacDonald (November 2006). Development of Drought Indicators. Report 229921/02/B

Mott MacDonald (January 2013). Source Reliable Output Study

Appendices

Appendix A. Hindcast modelling results

Table A1: Minimum modelled groundwater elevations – All periods (lowest GWL highlighted in blue)

ABH Source	OBH	Minimum observed OBH GWL (mAOD)	Minimum observed ABH RWL (mAOD)	Min Modelled ABH GWL – 1 Year Period	Min Modelled ABH GWL – 2 Year Period	Min Modelled ABH GWL – 3 Year Period	DAPWL (mAOD)
Abington	TL54/102	20.61	19.92	19.81	19.39	19.07	-17
Babraham	TL45/017	12.28	11.05	10.55	10.24	10.51	-4.5
Brettenham	TL88/013	12.58	11.35	10.02	10.01	10.42	-5.75
Croydon	TL35/001	18.08	17.6	14.01	14.00	13.66	-3.91
Dullingham	TL65/043	9.85	8.66	4.80	6.93	6.53	-26.2
Duxford Grange	TL44/240	20.18	18.98	18.16	18.02	17.32	6.68
Duxford	TL44/048	19.10	19.22	17.48	18.23	17.42	14.5
Euston	TL88/013	12.61	12.72	12.73	13.00	12.93	11.2
Fleam Dyke 12"	TL55/005	8.84	5.49	5.27	5.02	6.22	-8.8
Fleam Dyke 36"	TL55/005	8.84	6.70	5.81	5.18	6.28	-9
Fowlmere	TL44/293	18.29	18.51	14.50	14.50	13.52	12.5
Fulbourn	TL45/017	12.28	8.11	7.55	6.78	7.27	4.4
Great Chishill	TL44/234	25.9	25.11	21.79	23.32	22.69	-4.19
Great Wilbraham	TL55/144	10.02	5.39	5.11	5.24	4.99	-9.4
Heydon	TL44/238	22.52	23.21	21.23	21.21	18.40	10.3
Hinxton Grange	TL54/002	20.89	20.46	20.15	20.37	20.22	6
Kingston	TL35/004	12.13	12.86	10.54	11.98	10.60	-9.9
Linton	TL54/028	21.11	28.11	27.17	27.67	27.36	-15.5
Lowerfield	TL44/234	25.32	27.87	24.37	25.77	22.30	17.9
Melbourn	TL44/427	20.85	19.70	18.81	19.42	19.19	-0.82
Mordon Grange	TL34/007	39.23	37.24	36.89	36.68	36.48	27
Rivey	TL54/001	35.93	32.93	30.89	31.92	30.92	-38
Sawston	TL54/006	19.65	14.79	14.03	14.37	14.36	0
Westley	TL55/009	8.99	8.00	6.11	5.22	6.47	-14.6
Weston Colville	TL65/042	11.38	11.38	0.38	0.11	-9.82	-14.38

Appendix B. Location maps of OBH and ABH

Figure A.1. Location of Abington ABH and local OBH

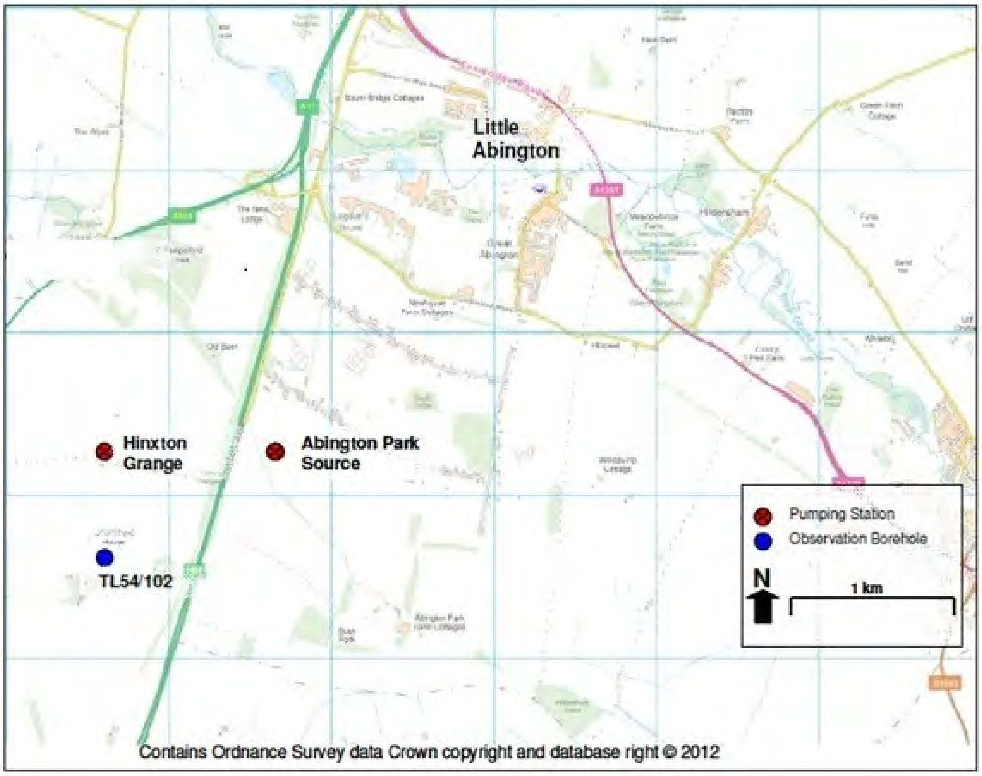


Figure A.2. Location of Babraham ABH and local OBH

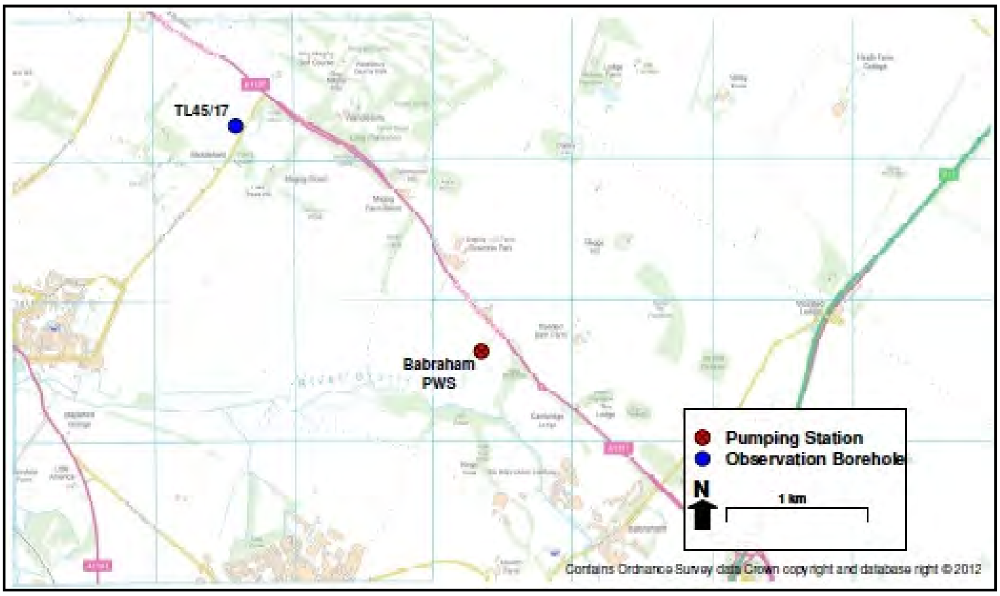


Figure A.3. Location of Brettenham ABH and local OBH

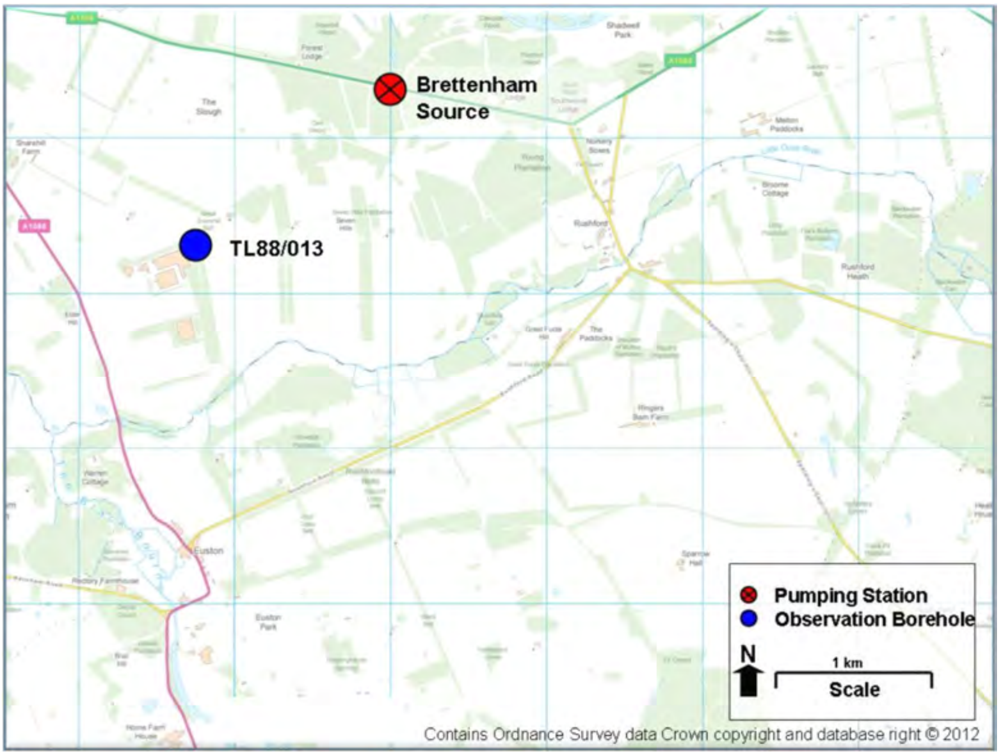


Figure A.4. Location of Croydon ABH and local OBH

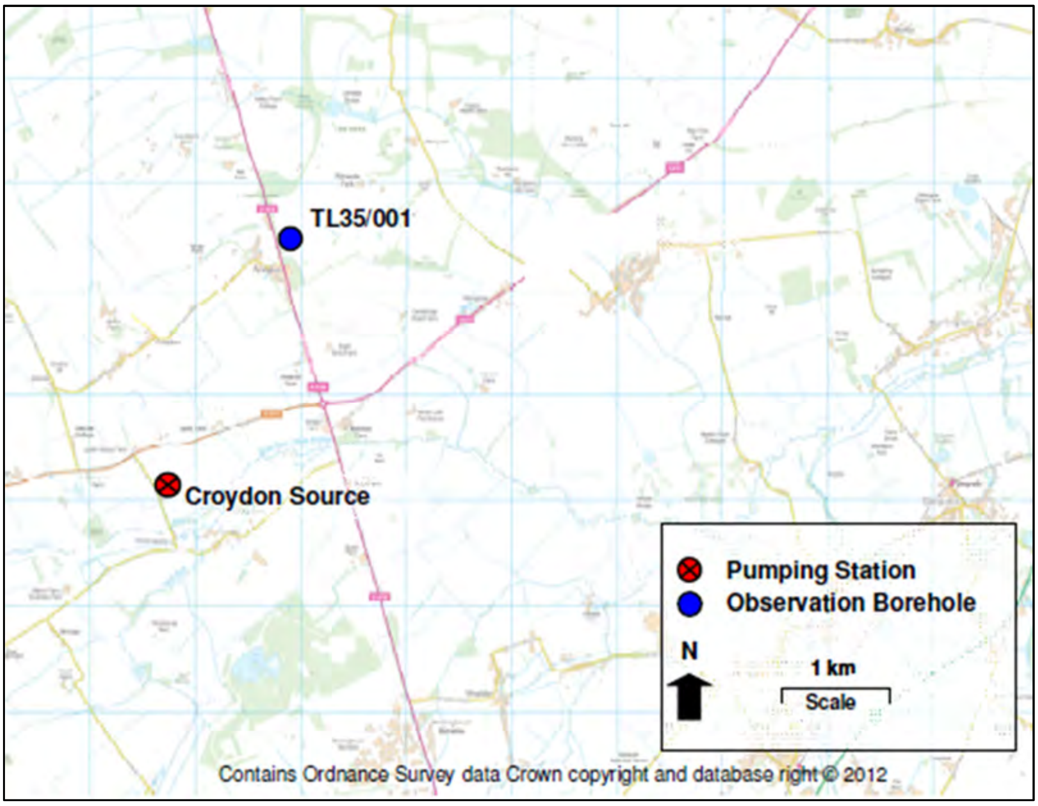


Figure A.5. Location of Dullingham ABH and local OBH

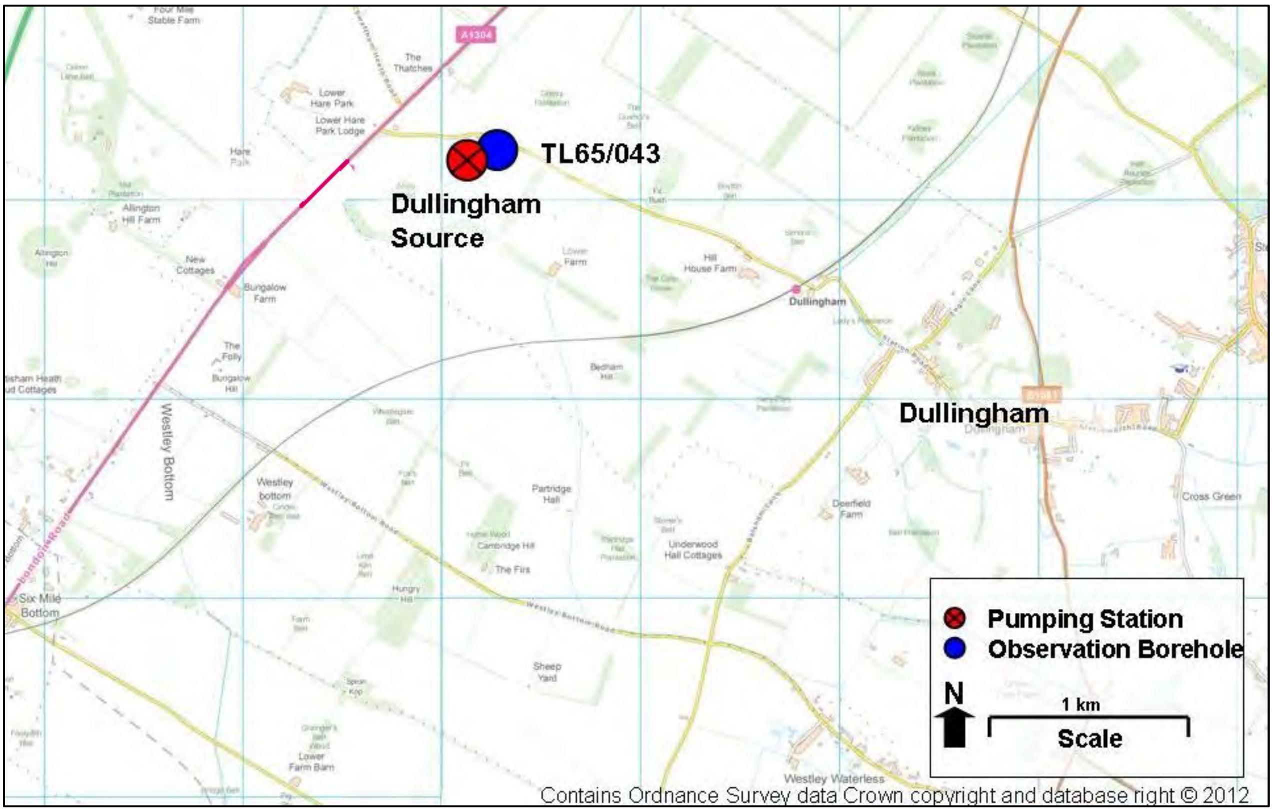


Figure A.6. Location of Duxford Grange ABH and local OBH

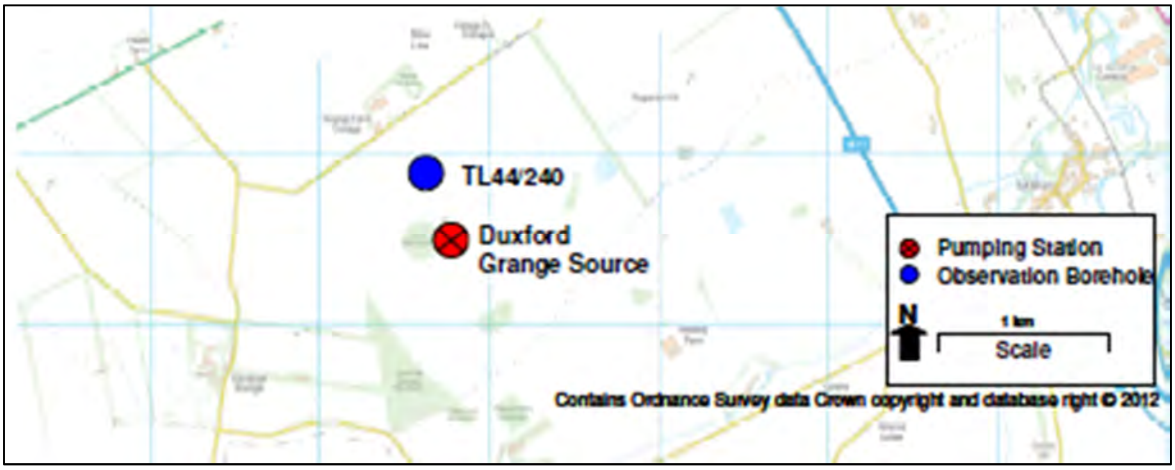


Figure A.7. Location of Duxford Airfield ABH and local OBH

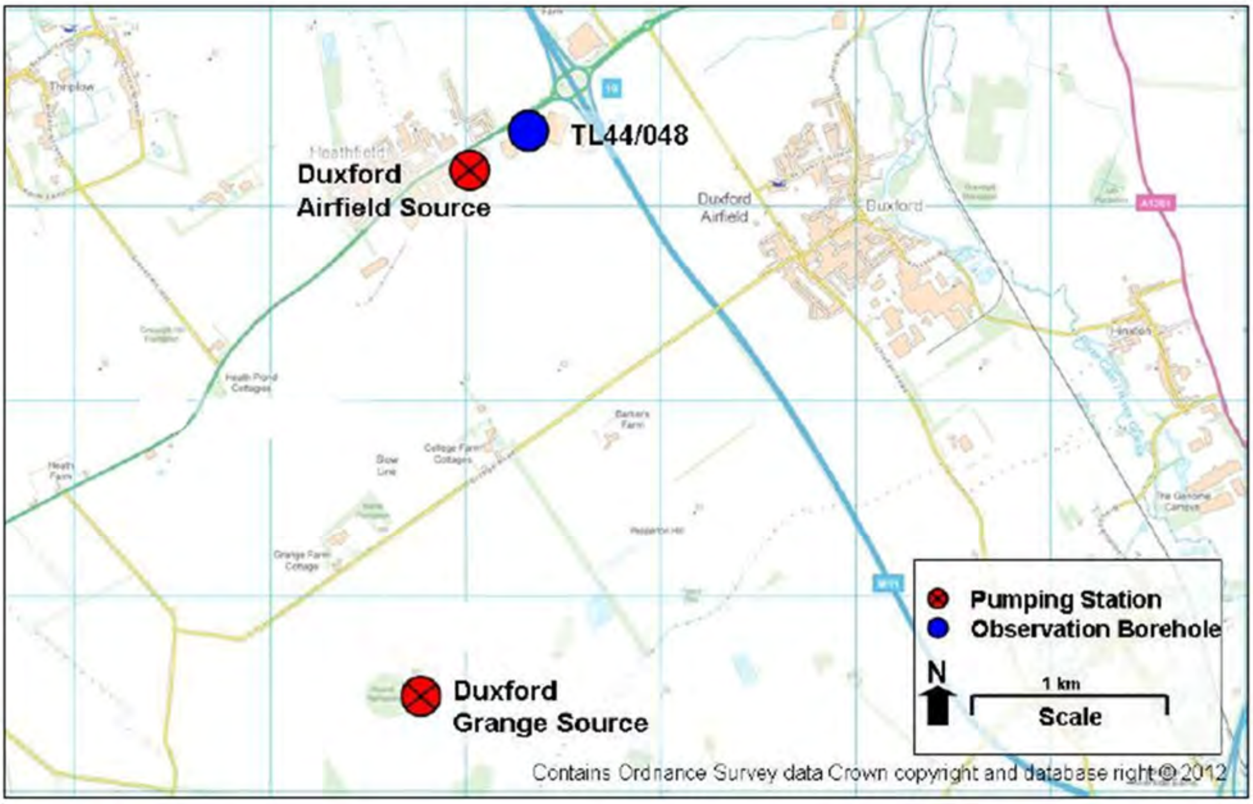


Figure A.8. Location of Euston ABH and local OBH

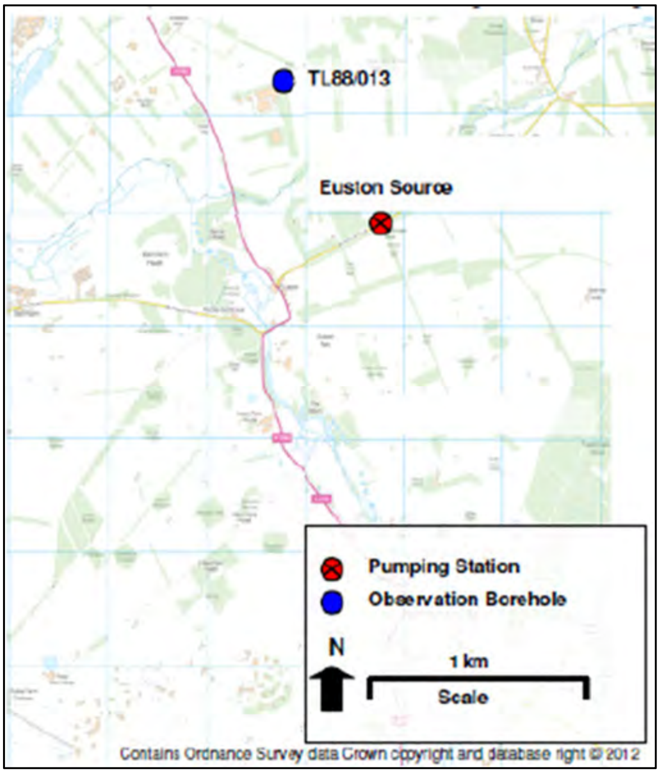


Figure A.9. Location of Fleam Dyke 12" and 36" ABH and local OBH

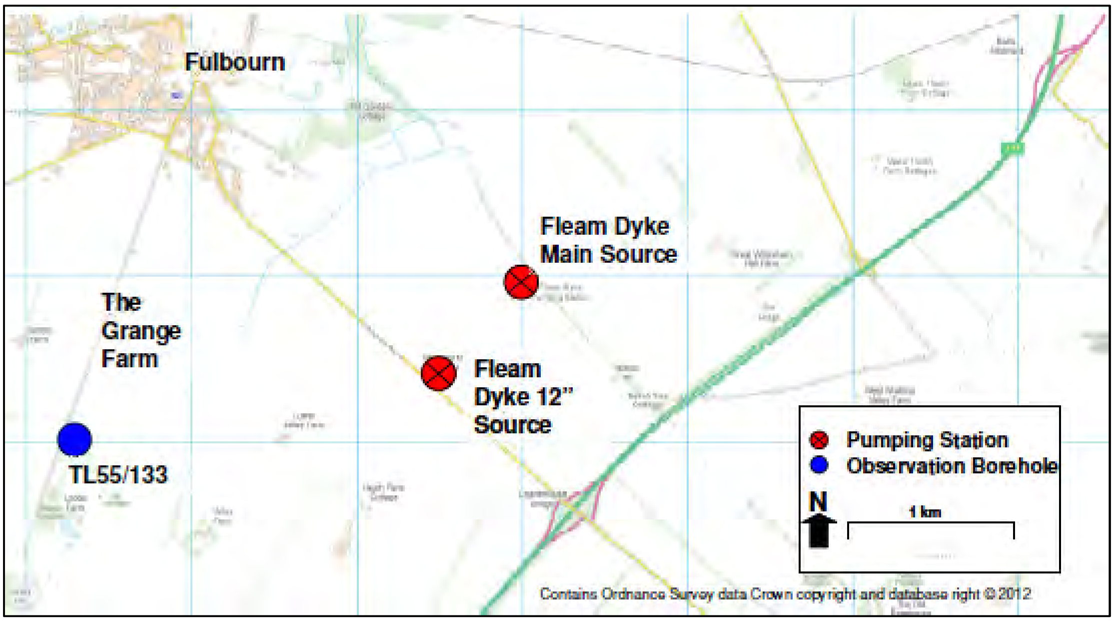


Figure A.10. Location of Fowlmere ABH and local OBH

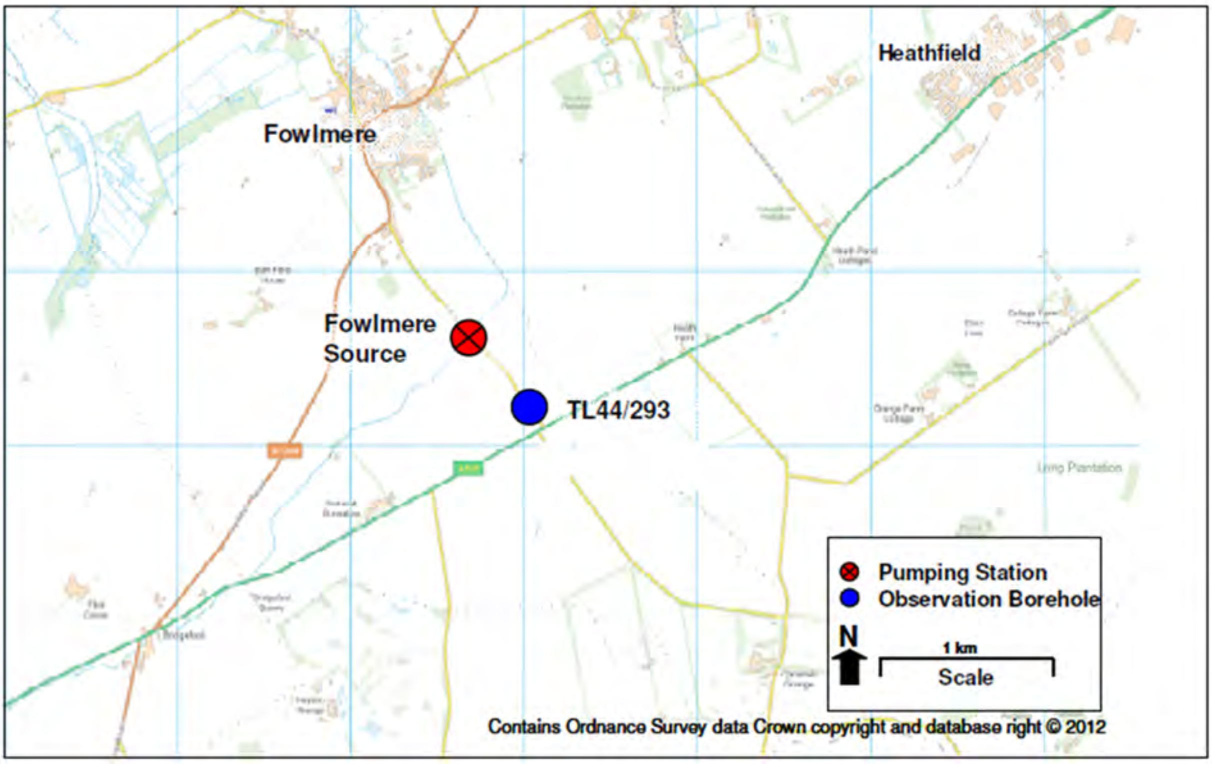


Figure A.11. Location of Fulbourn ABH and local OBH

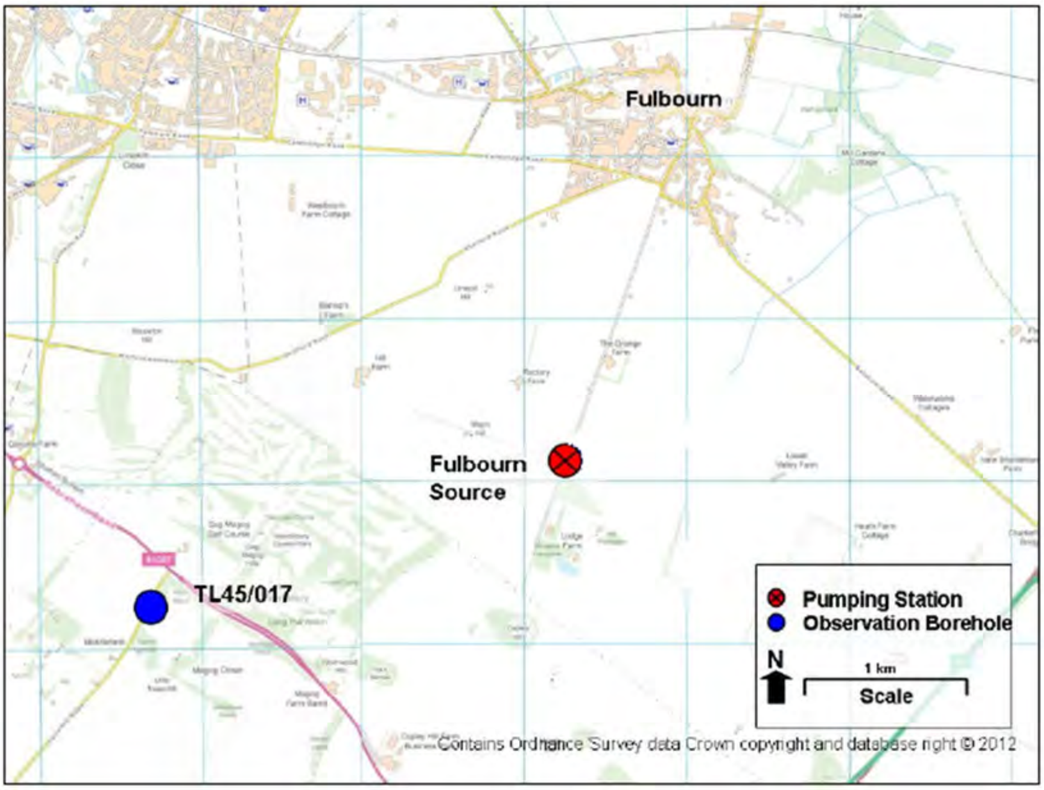


Figure A.12. Location of Great Chishill ABH and local OBH

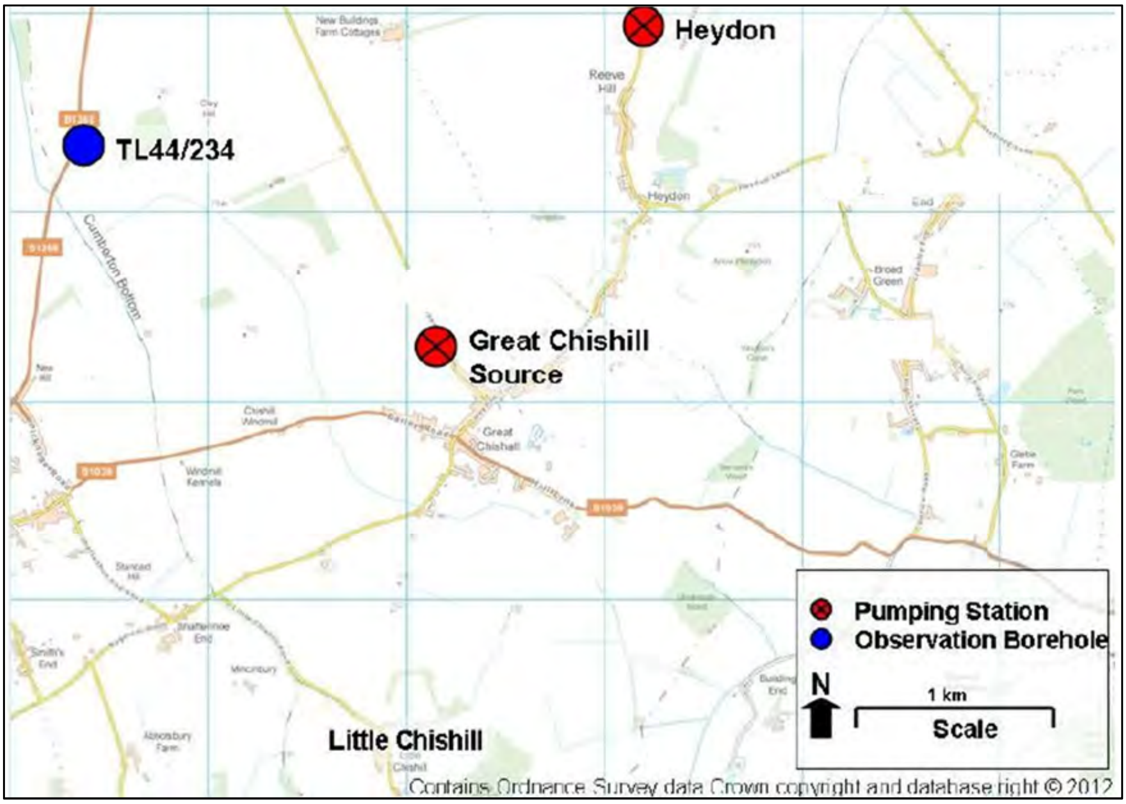


Figure A.13. Location of Great Wilbraham ABH and local OBH

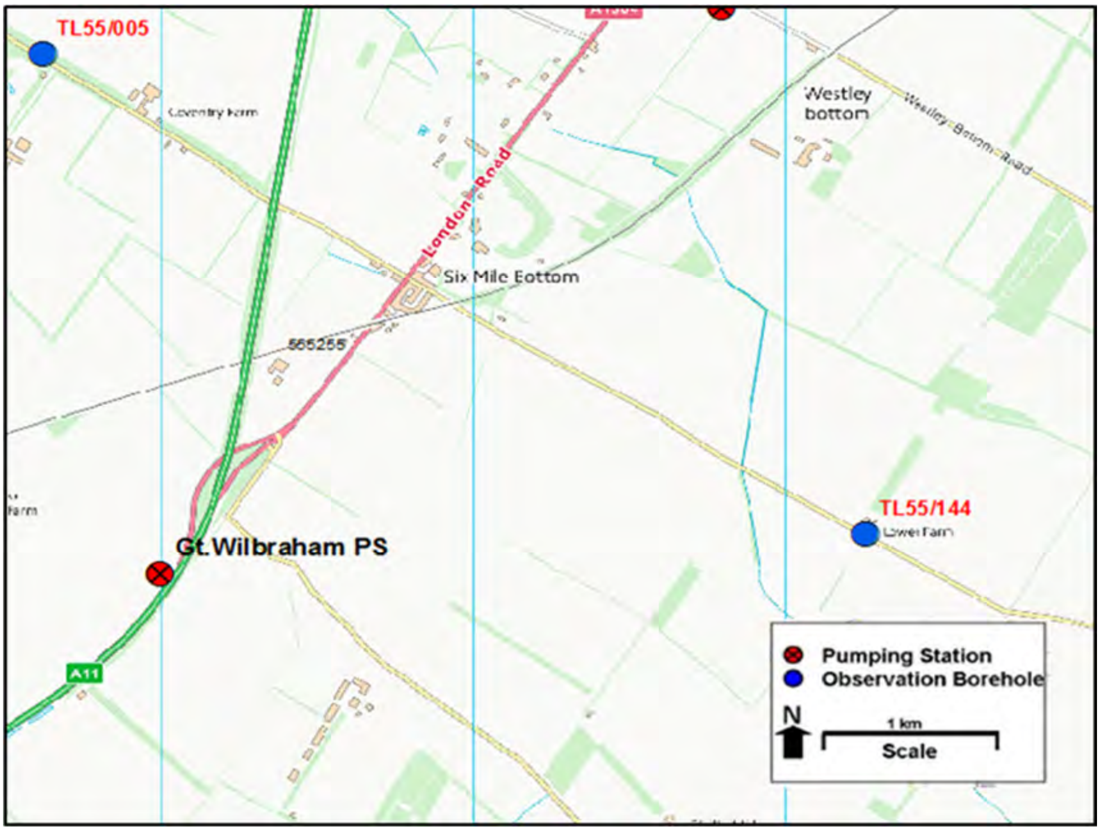


Figure A.14. Location of Heydon ABH and local OBH

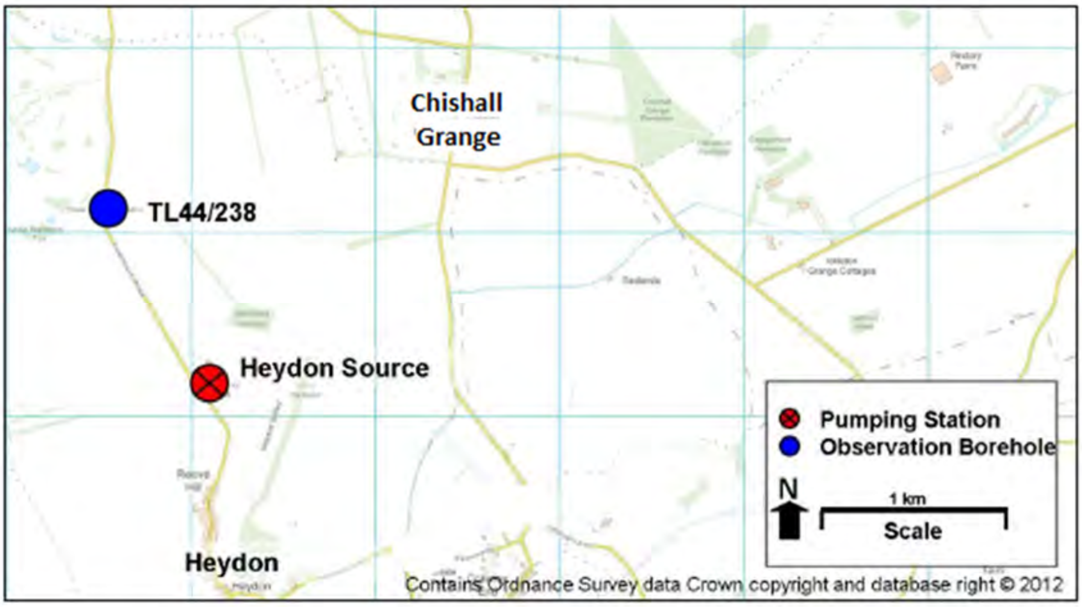


Figure A.15. Location of Hinxton Grange ABH and local OBH

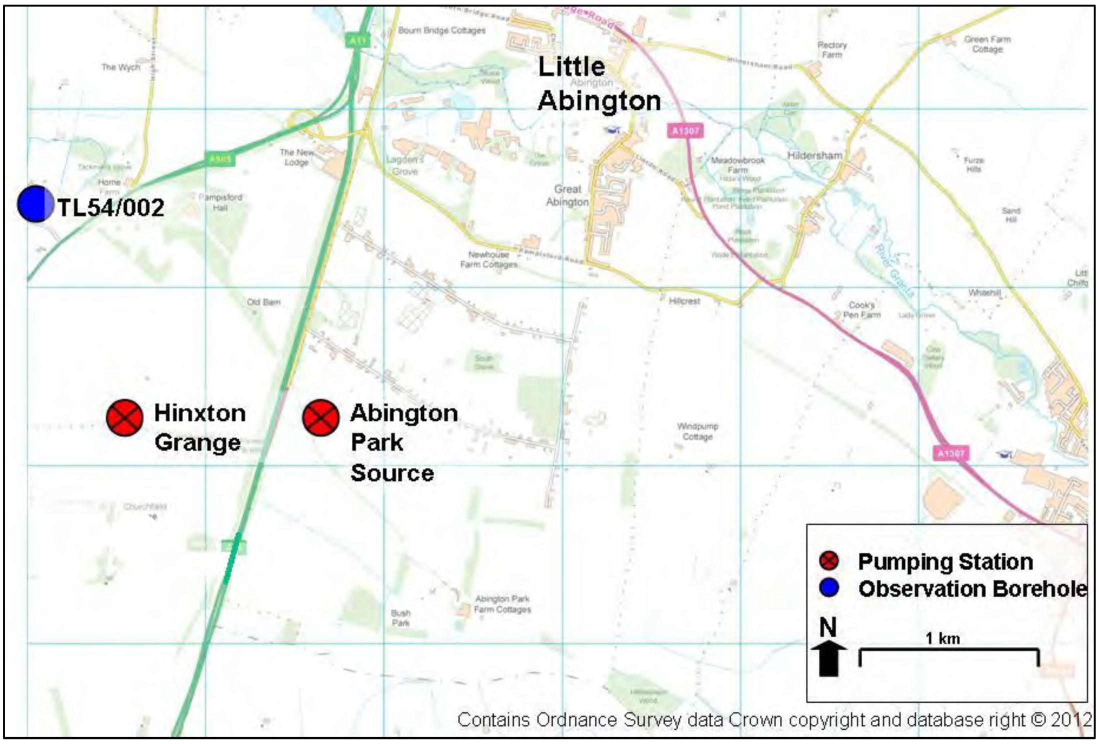


Figure A.16. Location of Kingston ABH and local OBH

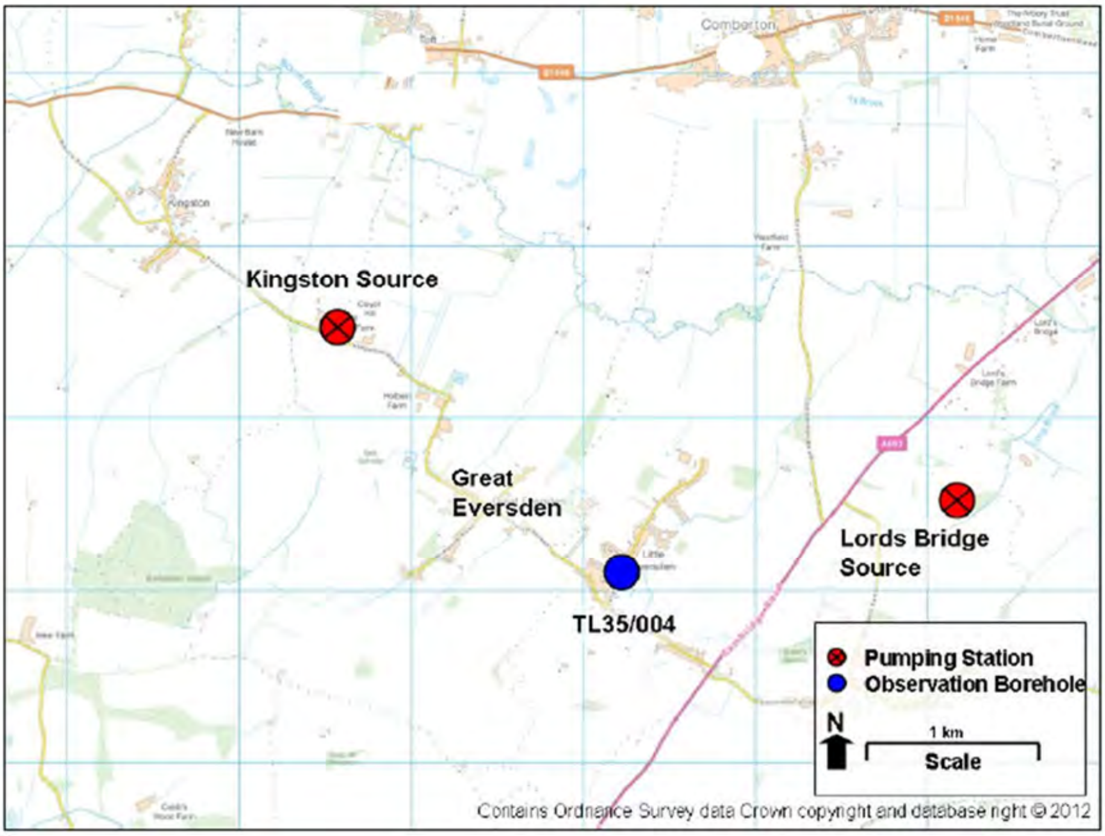


Figure A.17. Location of Linton ABH and local OBH

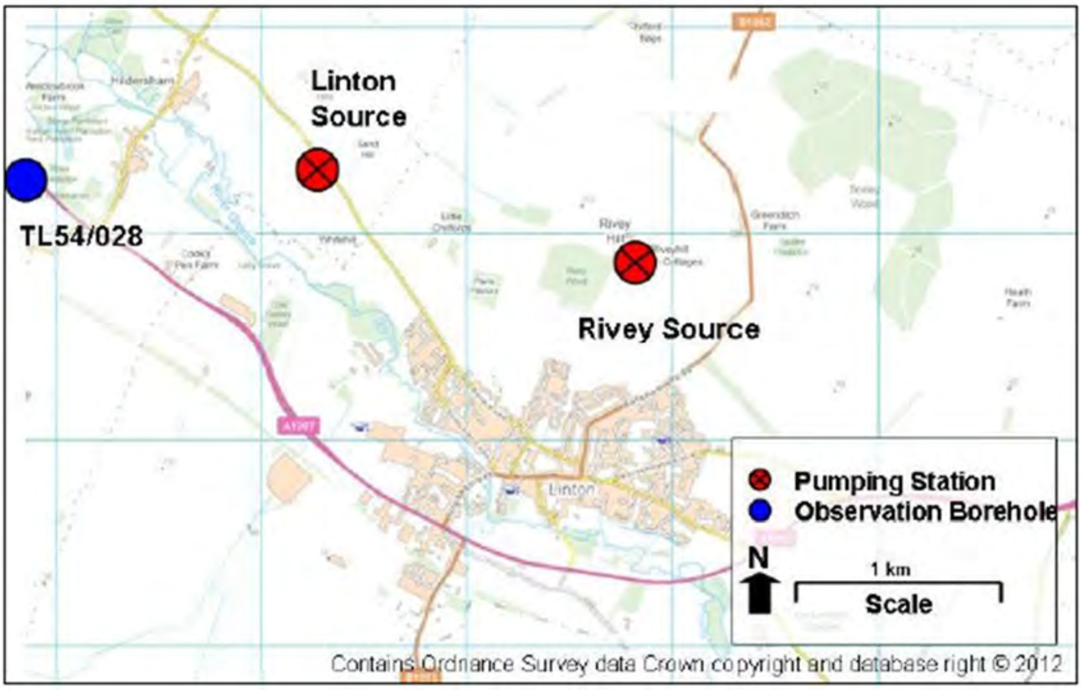


Figure A.18. Location of Lowerfield ABH and local OBH

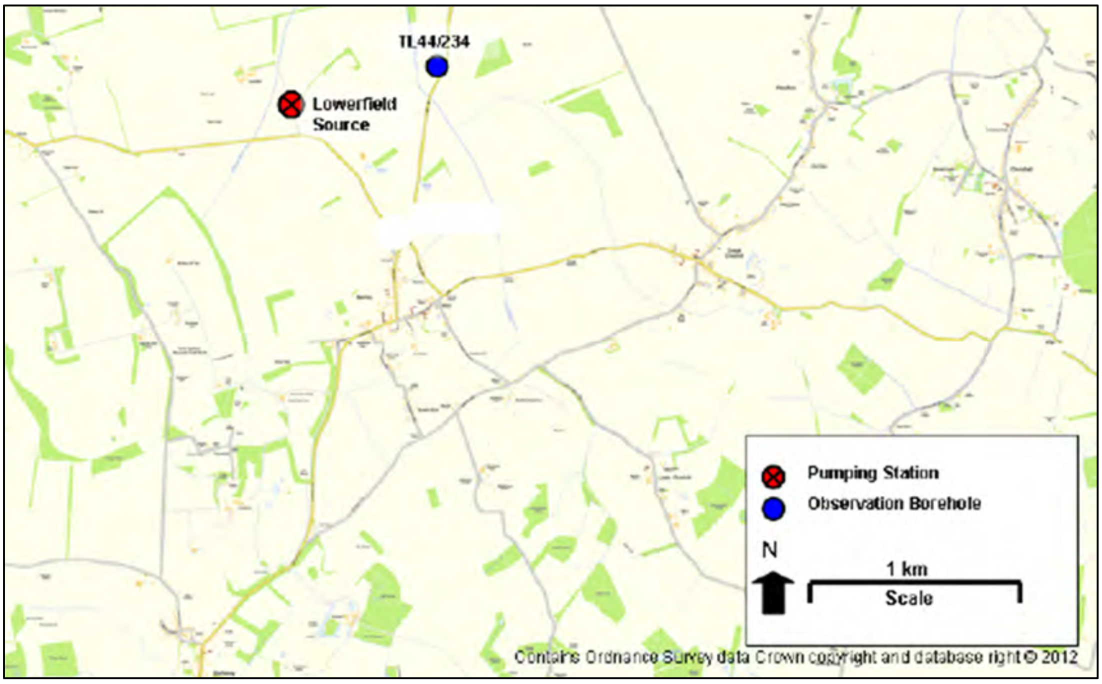


Figure A.19. Location of Melbourn ABH and local OBH

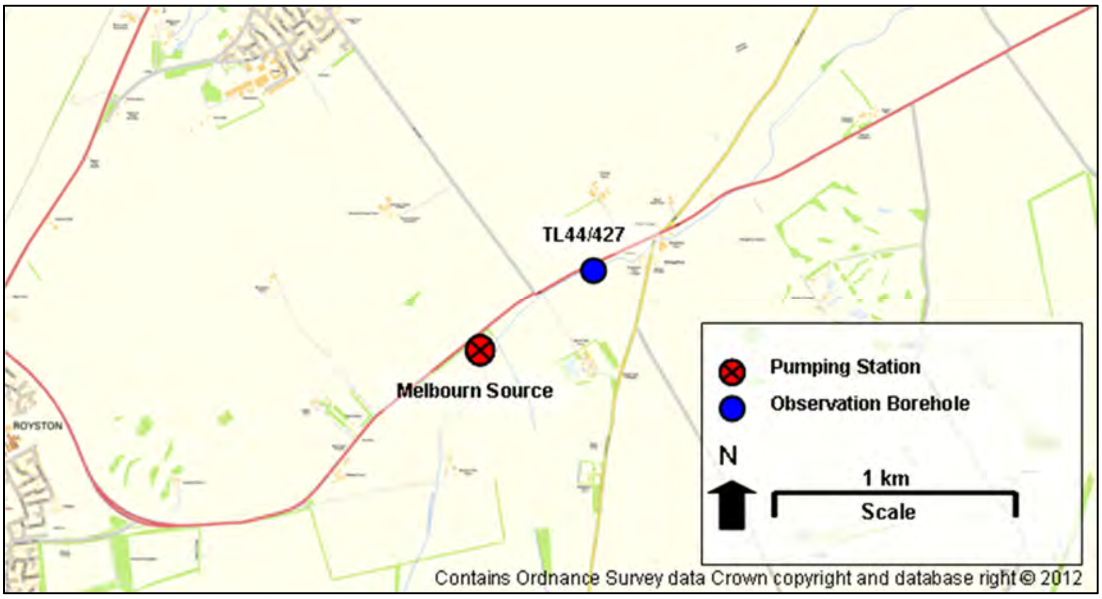


Figure A.20. Location of Morden Grange ABH and local OBH

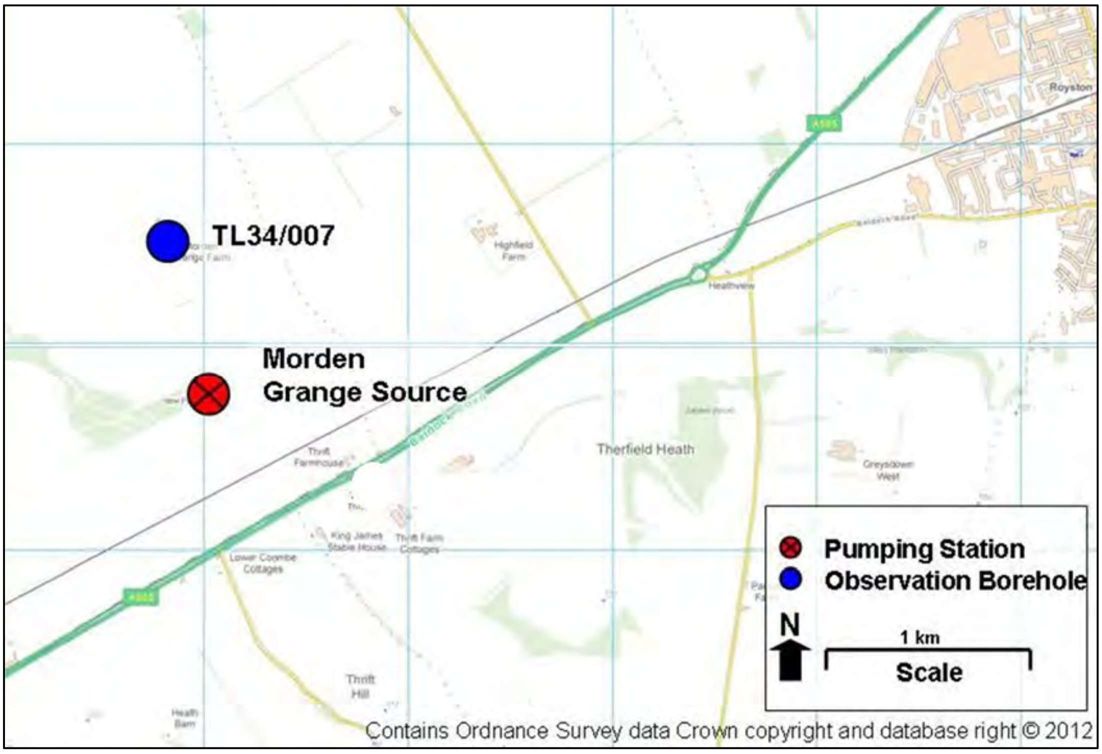


Figure A.21. Location of Rivey ABH and local OBH

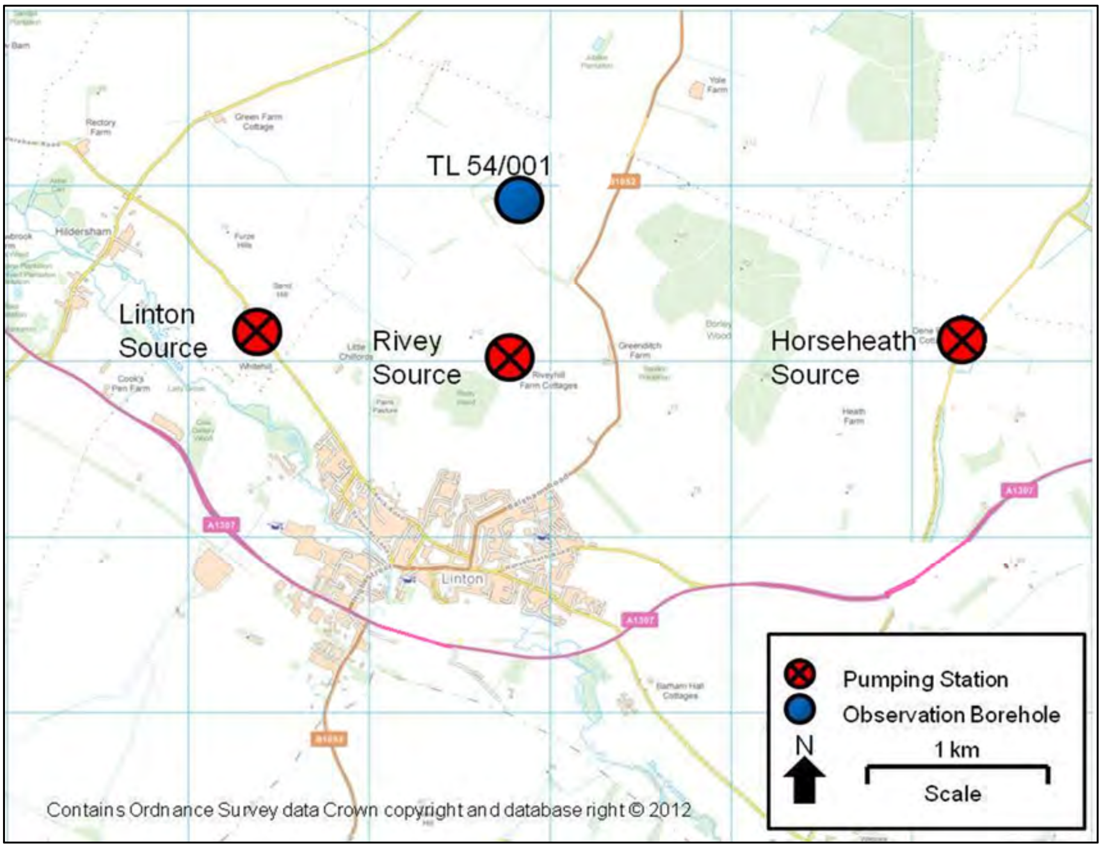


Figure A.22. Location of Sawston ABH and local OBH

Figure A.23. Location of Westley ABH and local OBH

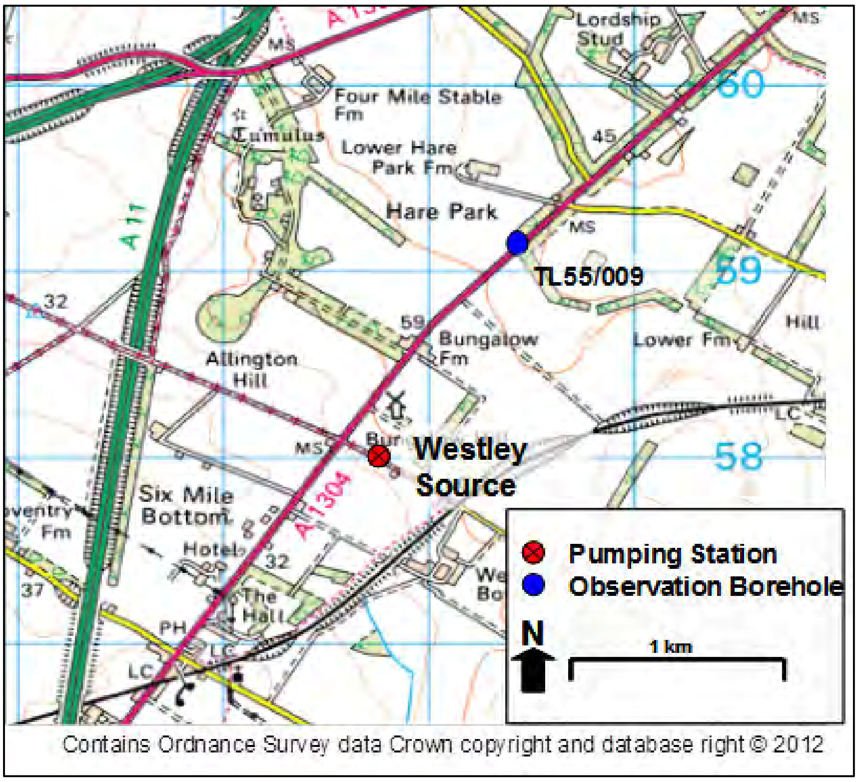
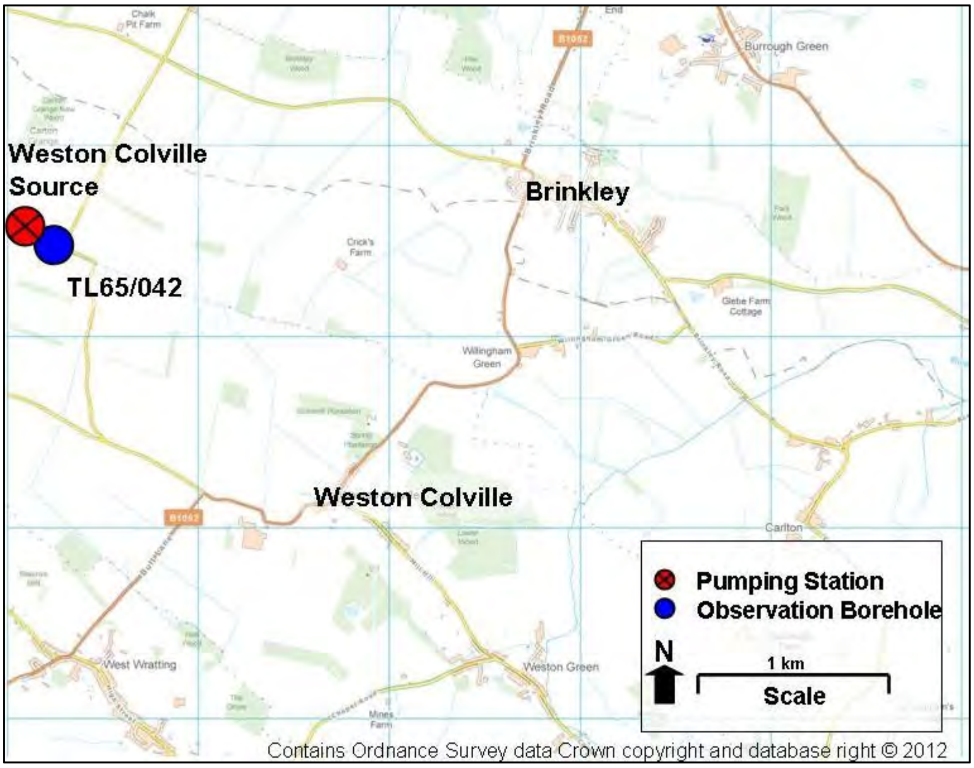
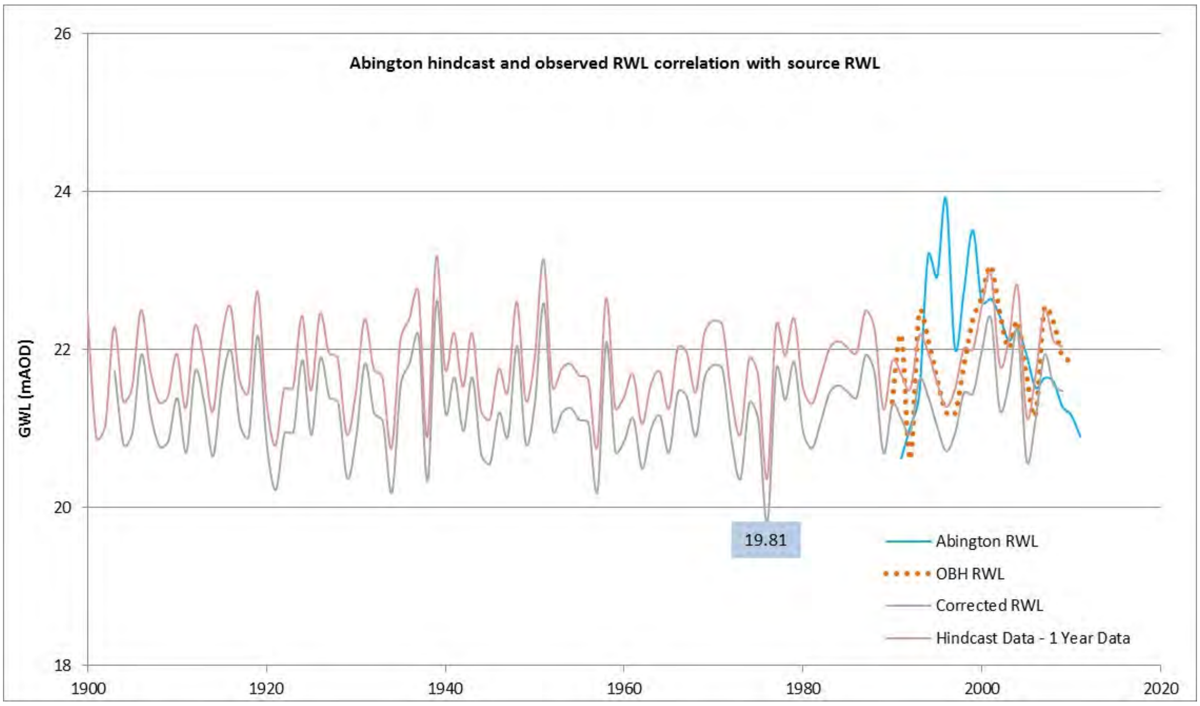
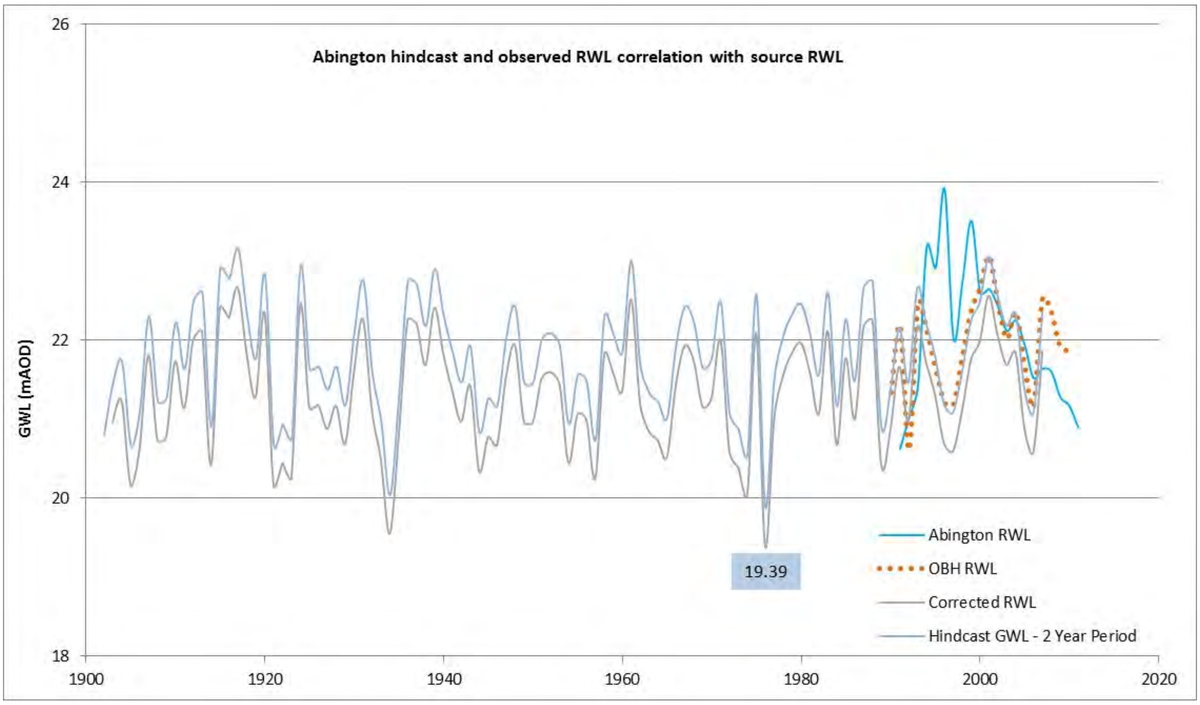


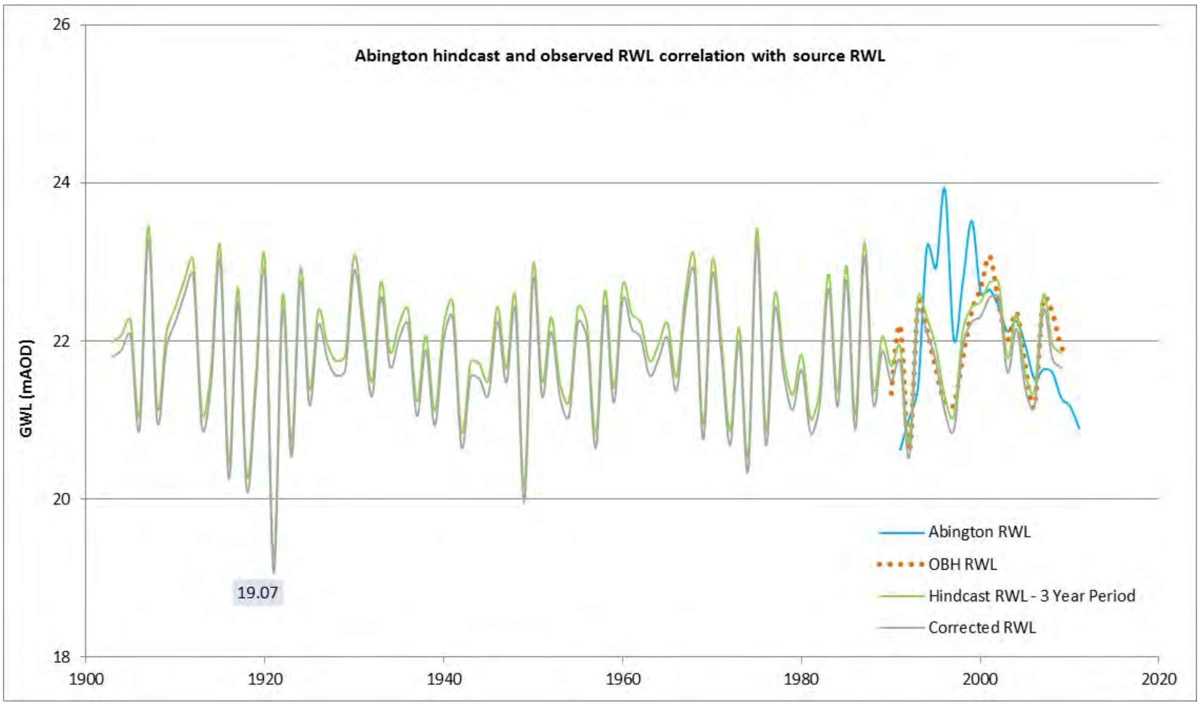
Figure A.24. Location of Weston Colville ABH and local OBH

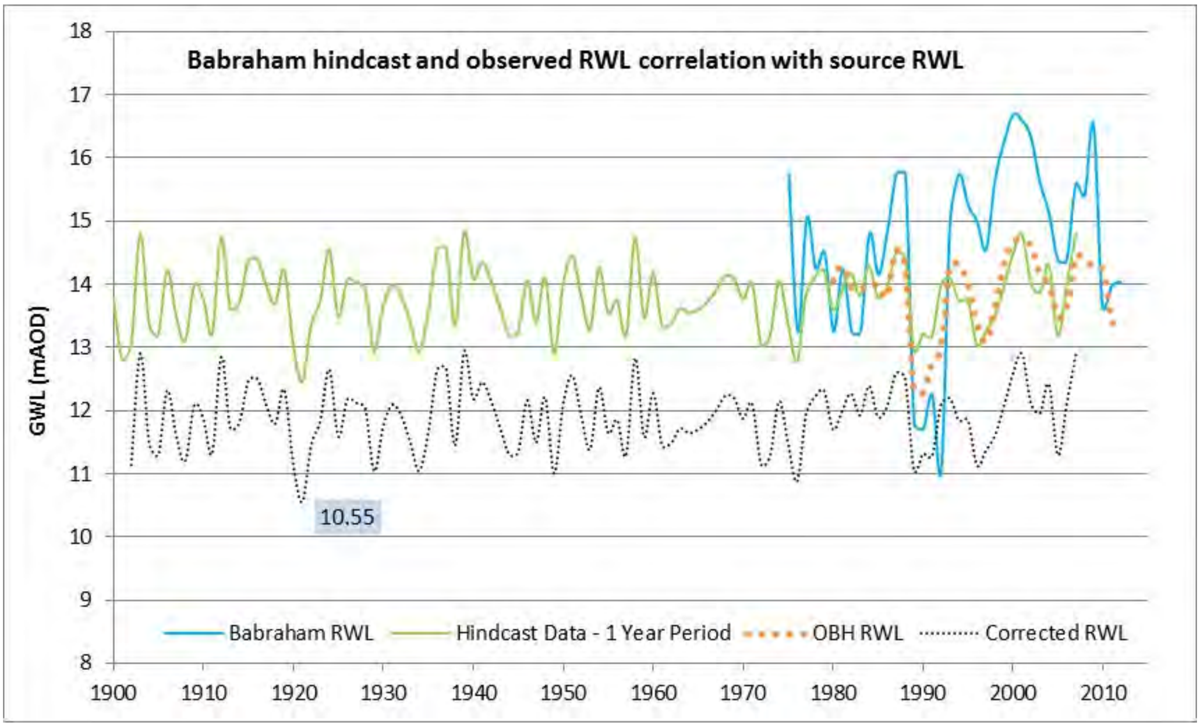


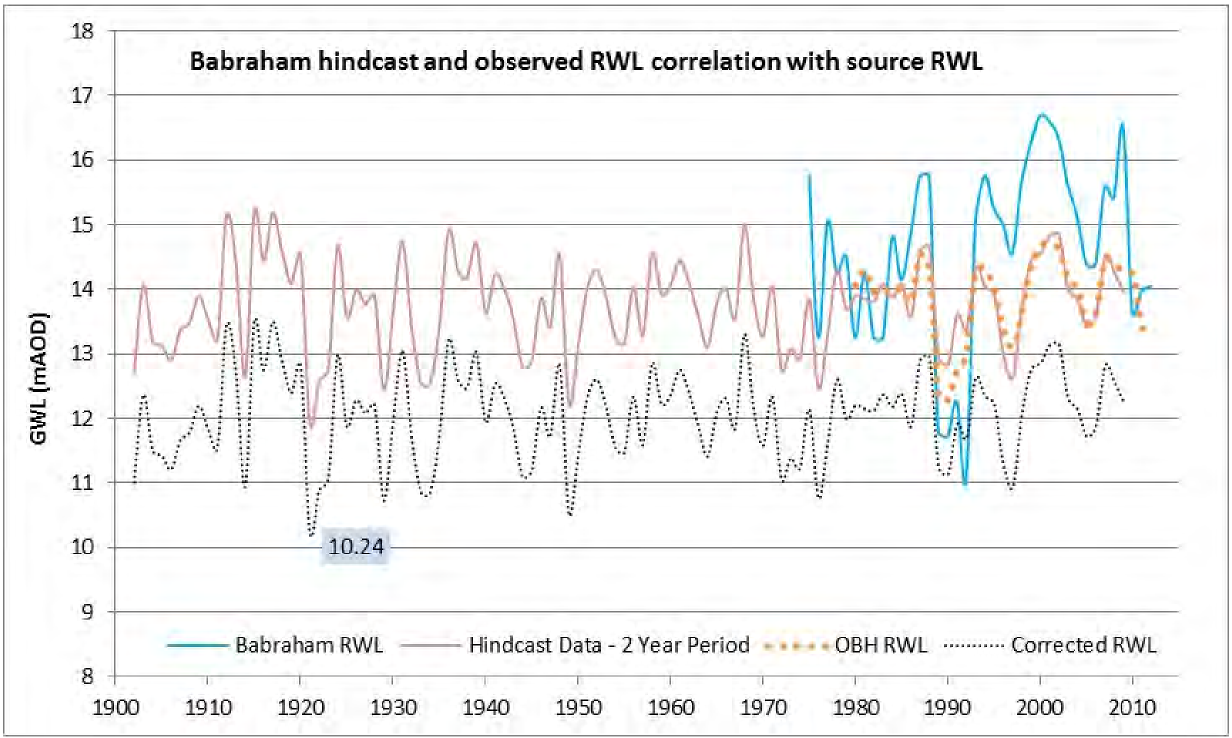
Appendix C. Hindcast Groundwater Levels

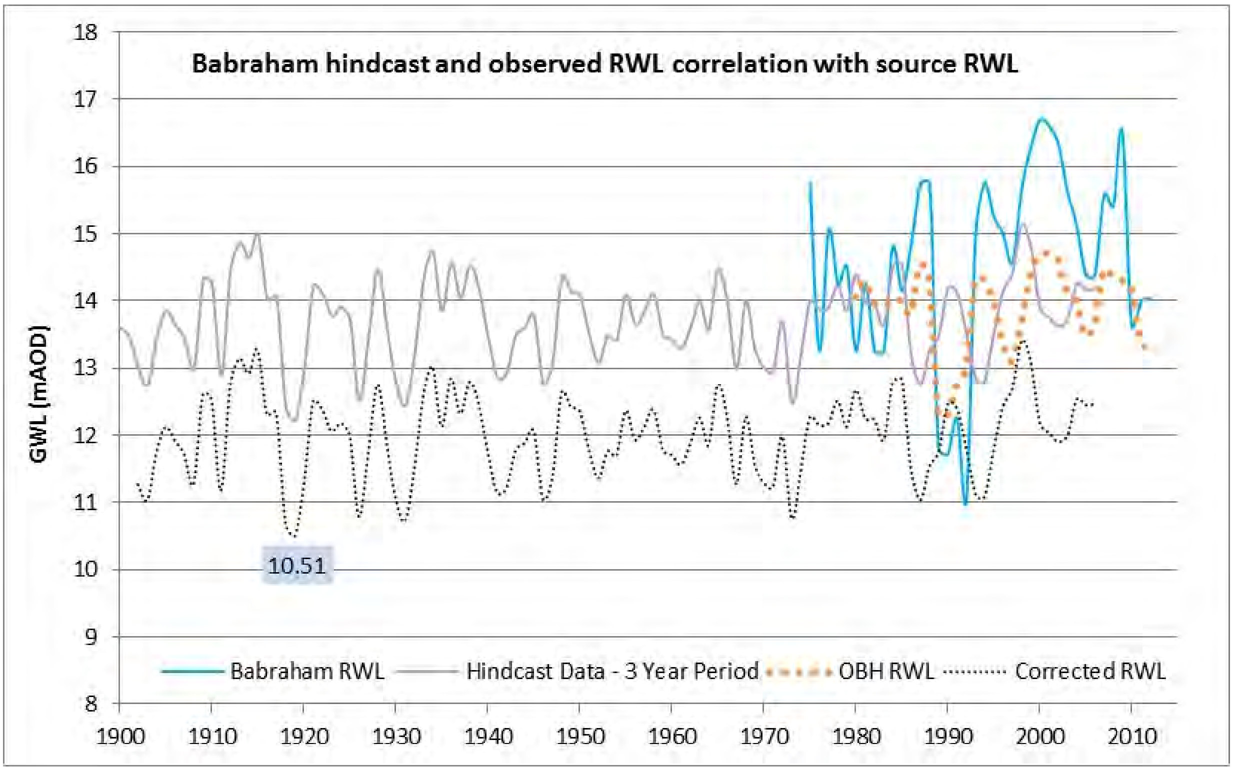


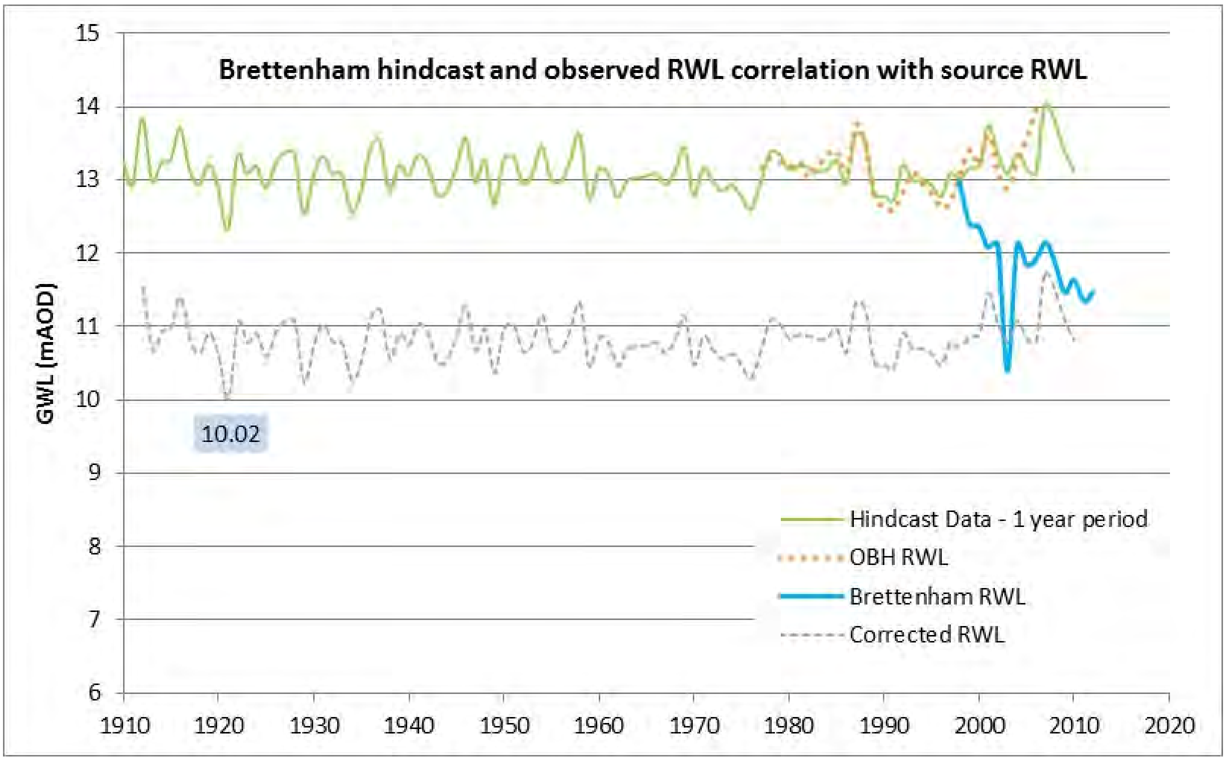


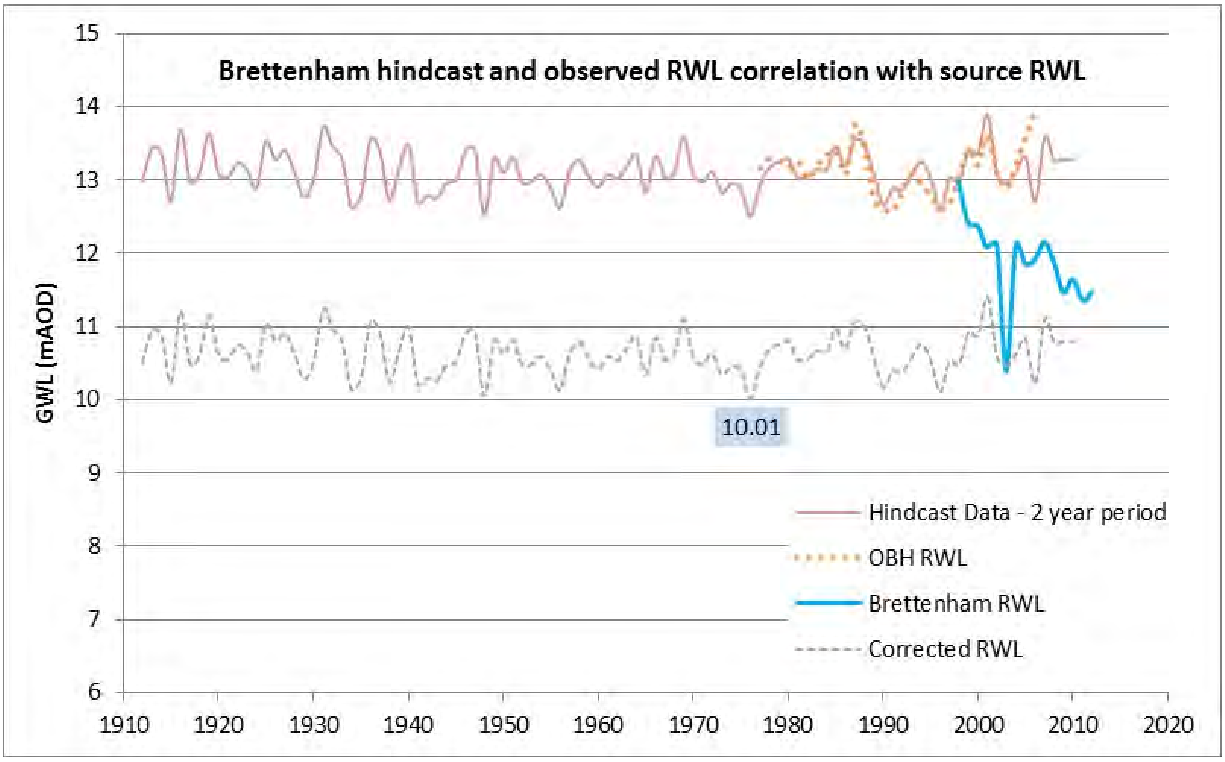

Abington hindcast and observed RWL correlation with source RWL
GWL (mAOD)
26
24
22
20
18
1900
1920
1940
1960
1980
2000
2020
19.07
Abington RWL
OBH RWL
Hindcast RWL - 3 Year Period
Corrected RWL

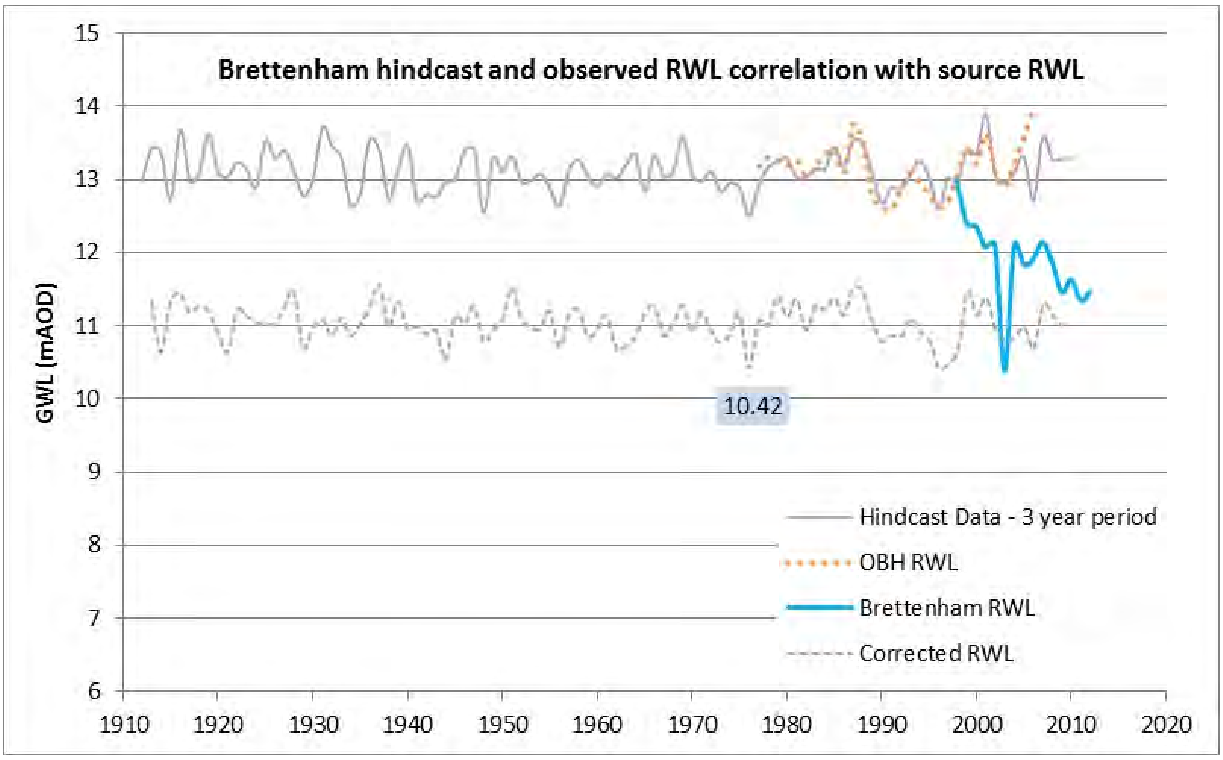

Babraham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
17
16
15
14
13
12
11
10
9
8
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
10.55
Babraham RWL
Hindcast Data - 1 Year Period
OBH RWL
Corrected RWL

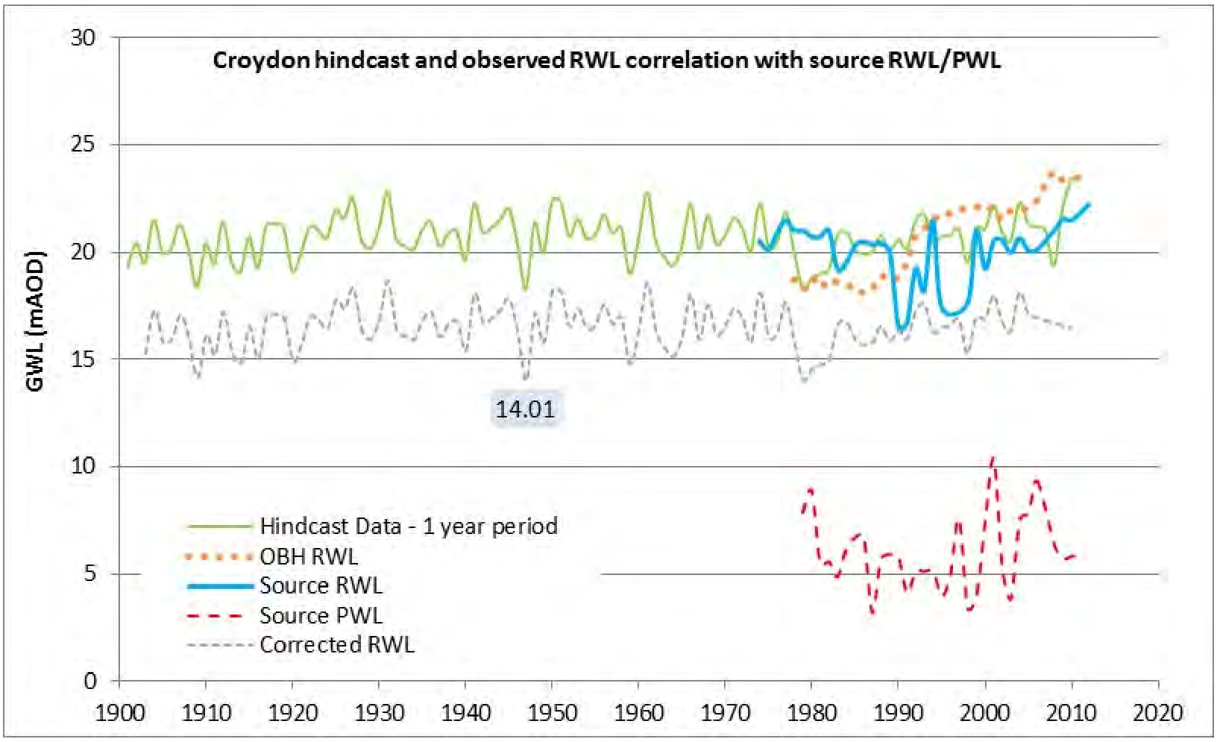

Babraham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
17
16
15
14
13
12
11
10
9
8
10.24
Babraham RWL
Hindcast Data - 2 Year Period
OBH RWL
Corrected RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

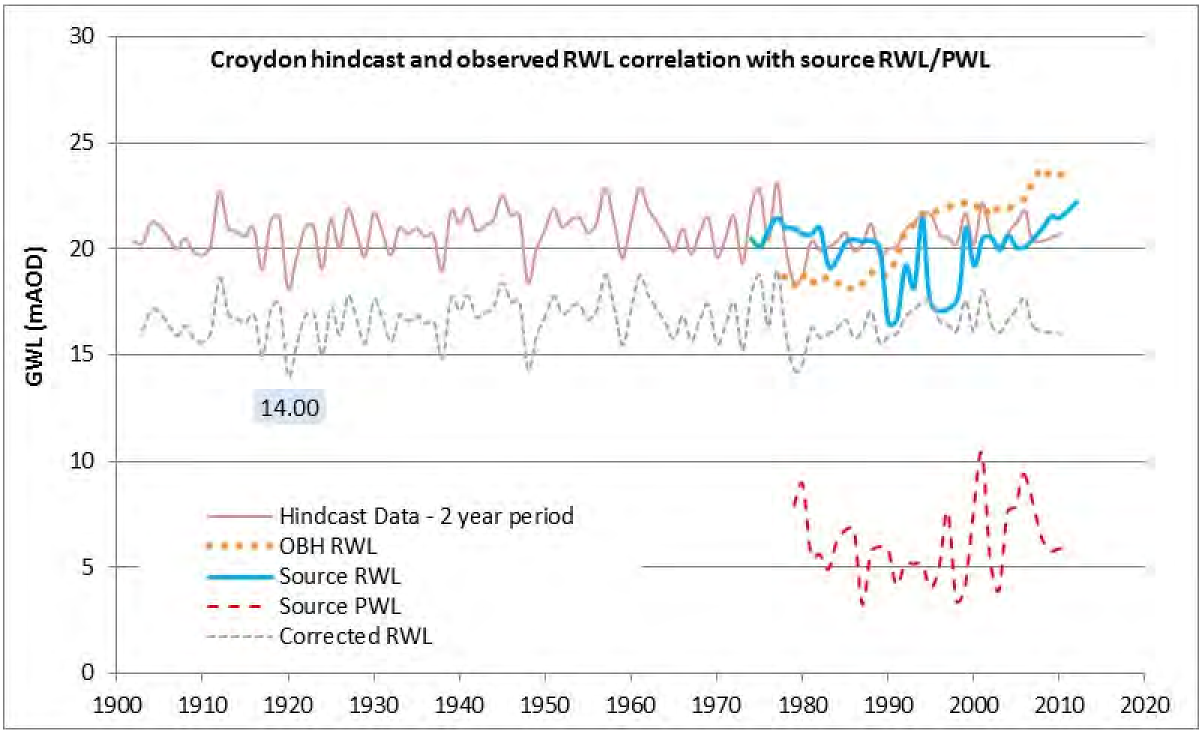

Babraham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
17
16
15
14
13
12
11
10
9
8
10.51
Babraham RWL
Hindcast Data - 3 Year Period
OBH RWL
Corrected RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010

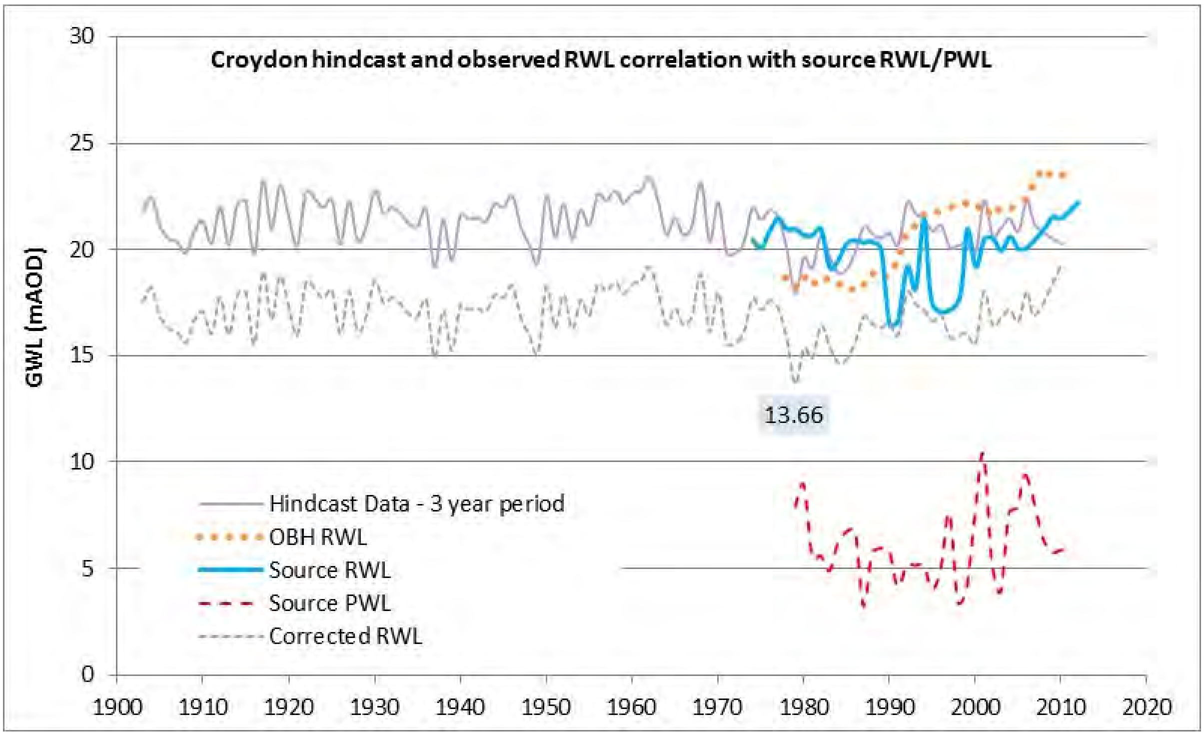

Brettenham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
15
14
13
12
11
10
9
8
7
6
10.02
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Hindcast Data - 1 year period
OBH RWL
Brettenham RWL
Corrected RWL

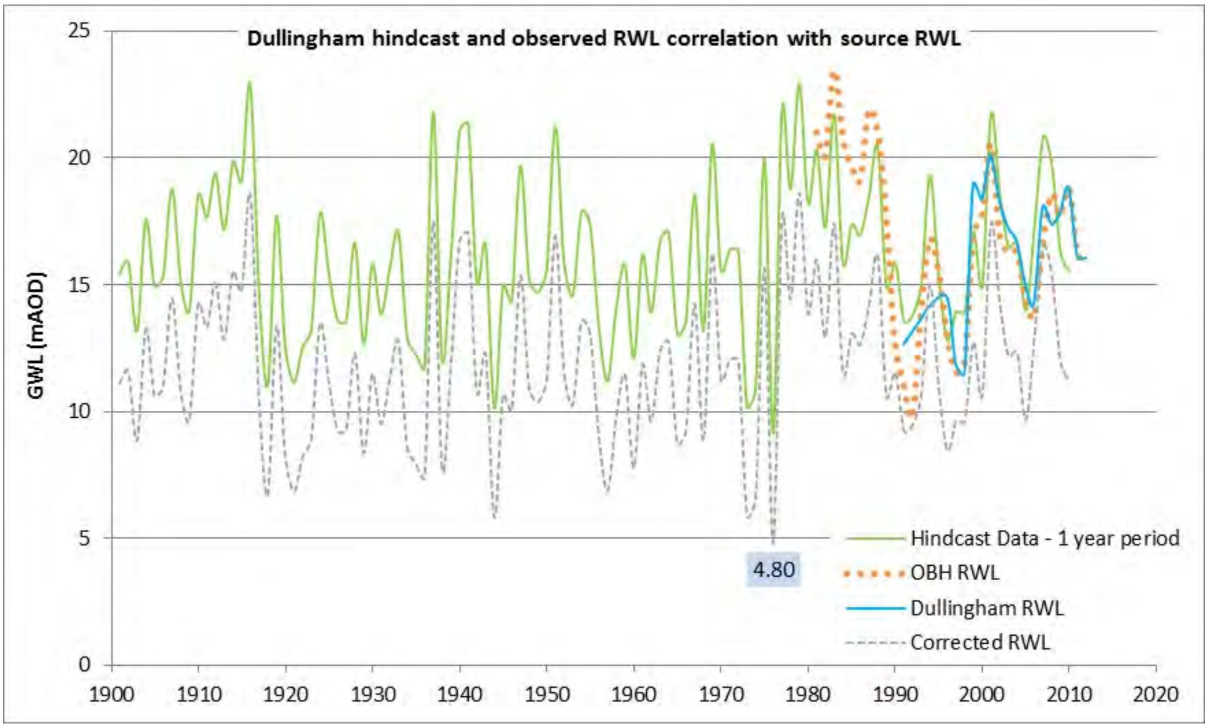

Brettenham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
15
14
13
12
11
10
9
8
7
6
10.01
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Hindcast Data - 2 year period
OBH RWL
Brettenham RWL
Corrected RWL

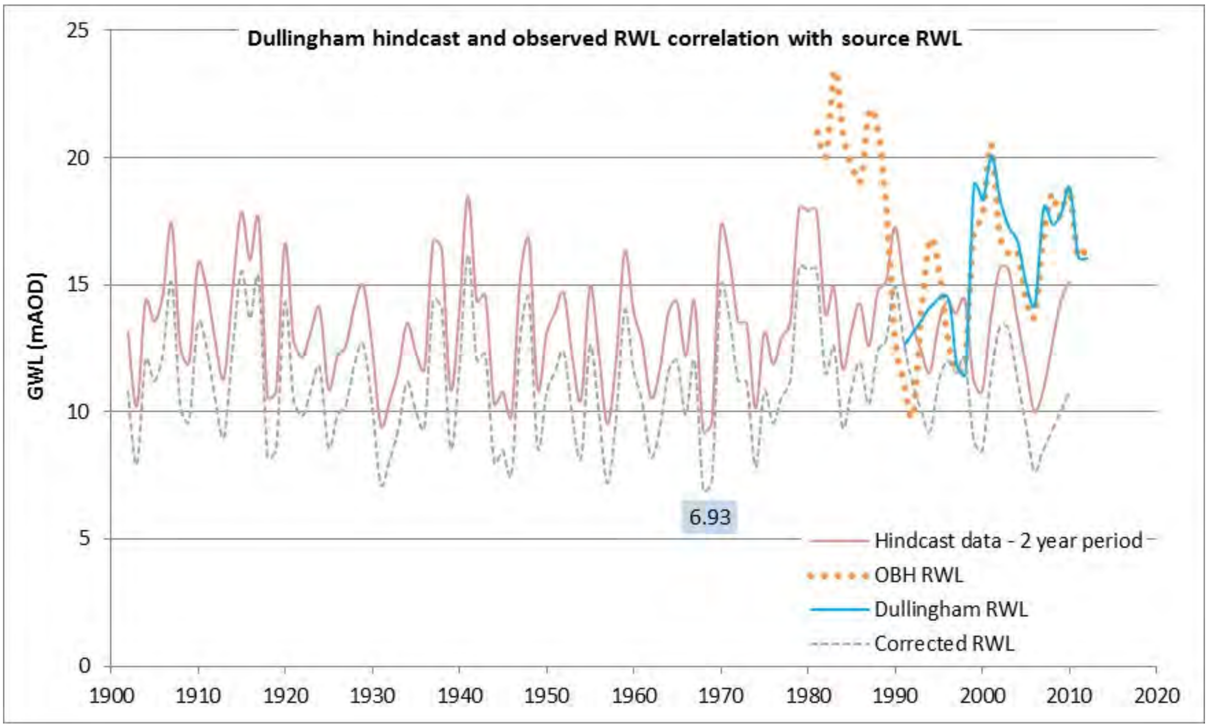

Brettenham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
15
14
13
12
11
10
9
8
7
6
10.42
Hindcast Data - 3 year period
OBH RWL
Brettenham RWL
Corrected RWL
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

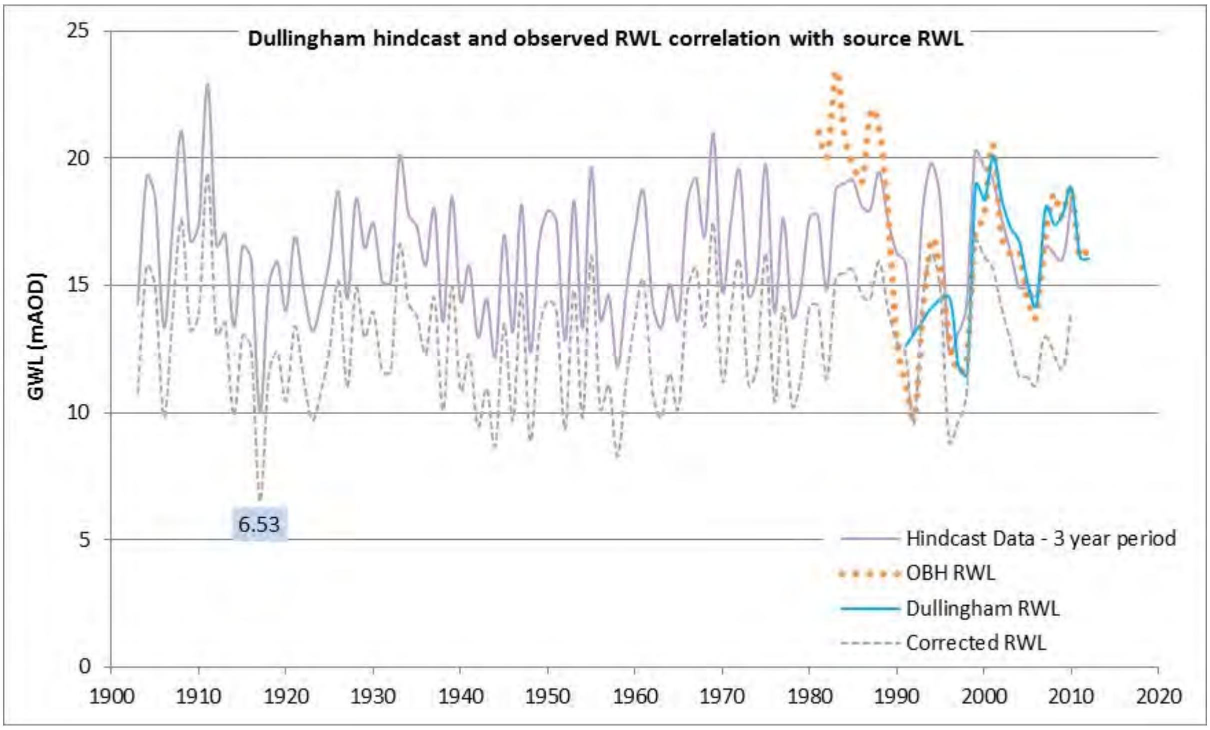

Croydon hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
30
25
20
15
10
5
0
14.01
Hindcast Data - 1 year period
OBH RWL
Source RWL
Source PWL
Corrected RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

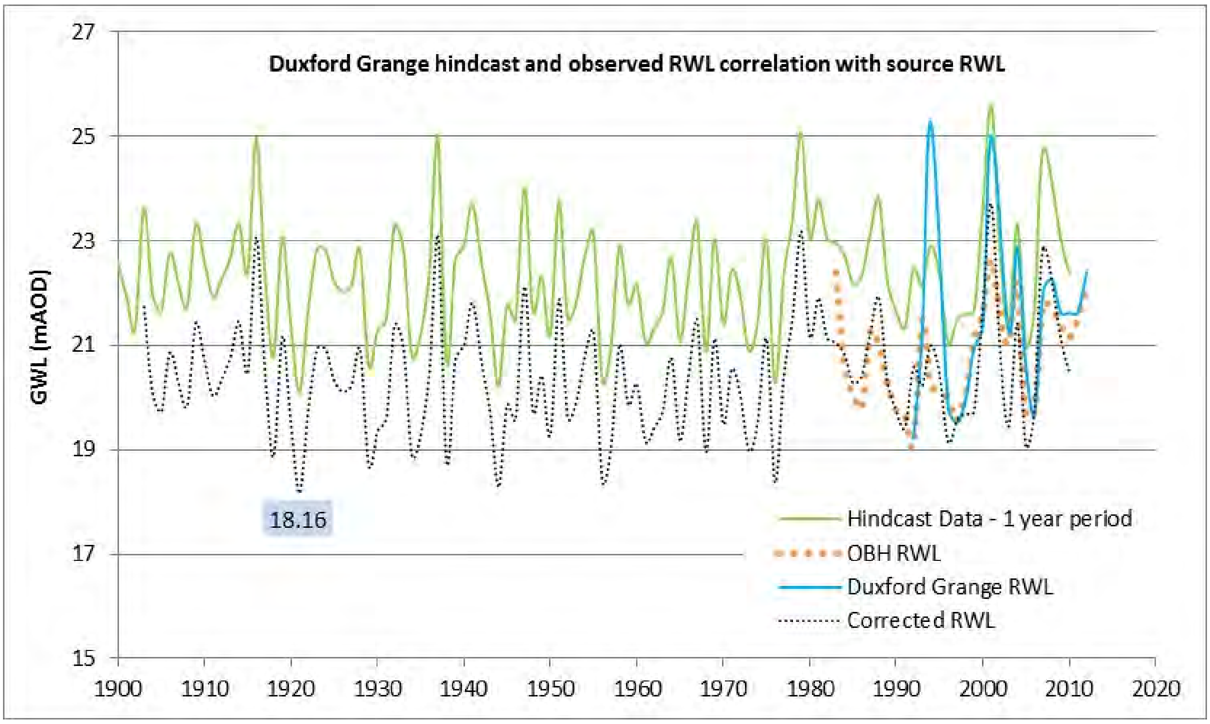

Croydon hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
14.00
Hindcast Data - 2 year period
OBH RWL
Source RWL
Source PWL
Corrected RWL
0
5
10
15
20
25
30
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

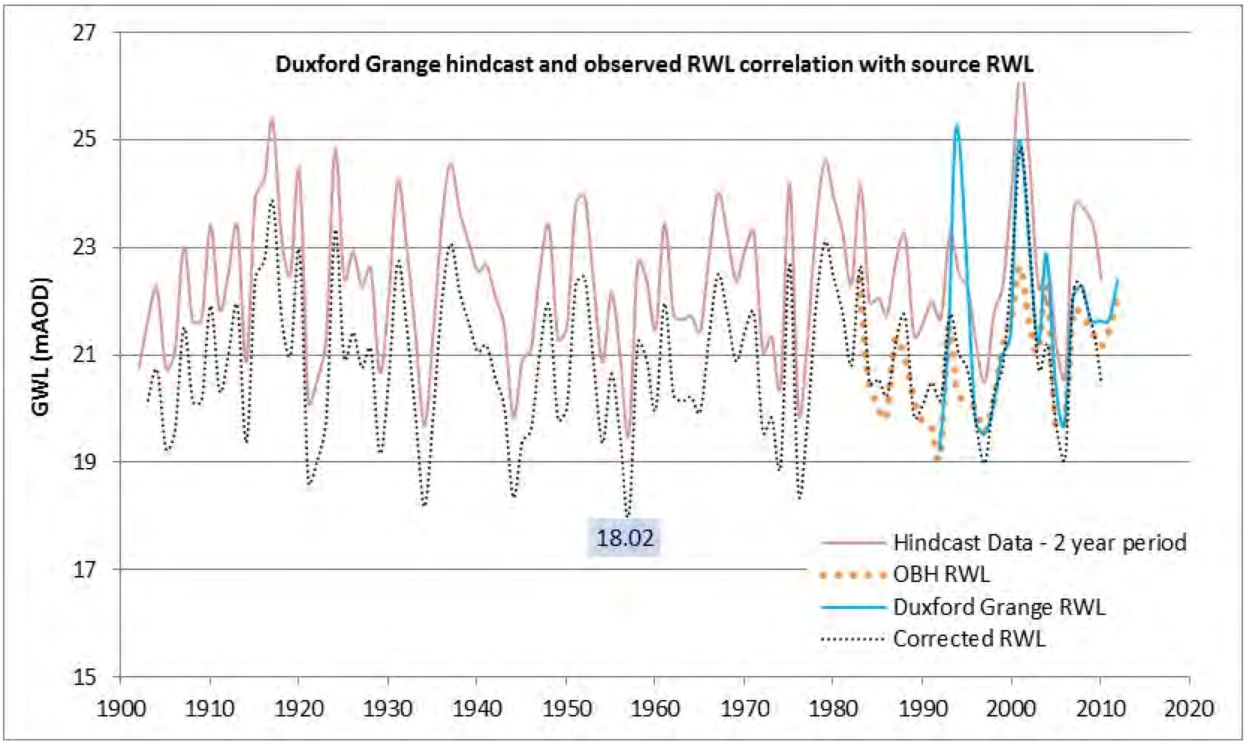

Croydon hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
13.66
Hindcast Data - 3 year period
OBH RWL
Source RWL
Source PWL
Corrected RWL
0
5
10
15
20
25
30
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

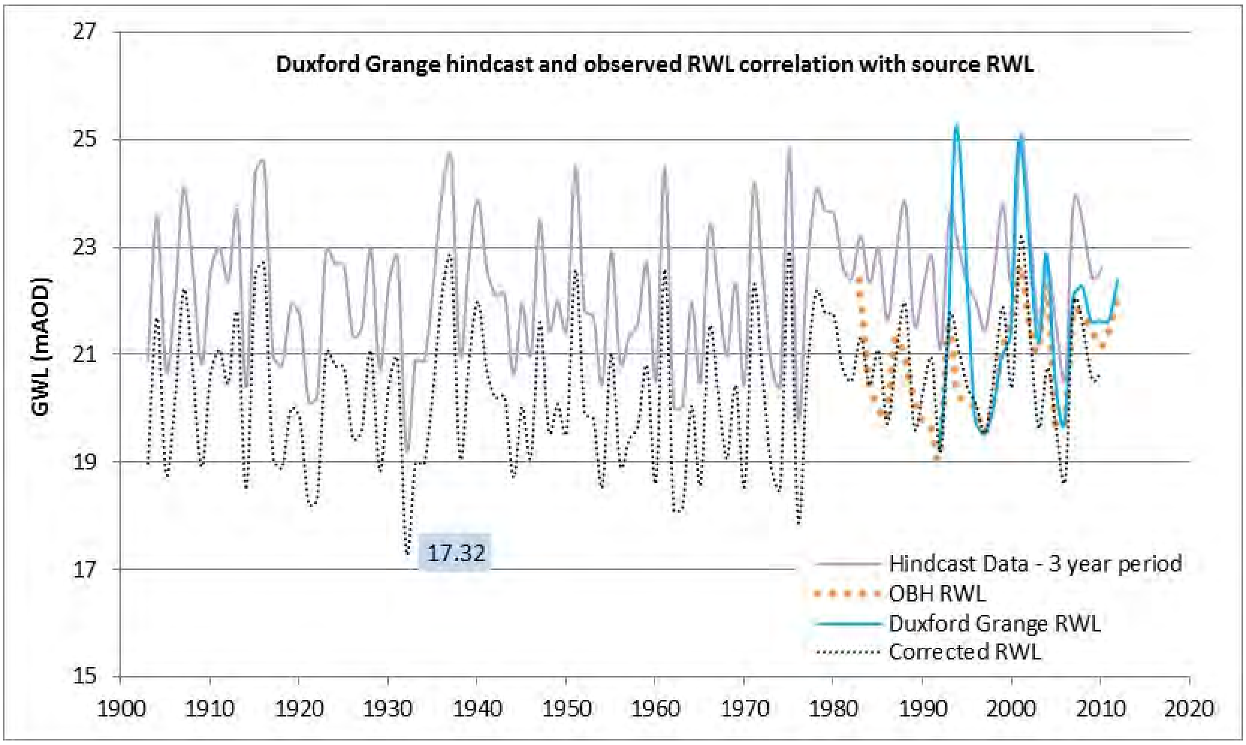

Dullingham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
25
20
15
10
5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
4.80
Hindcast Data - 1 year period
OBH RWL
Dullingham RWL
Corrected RWL

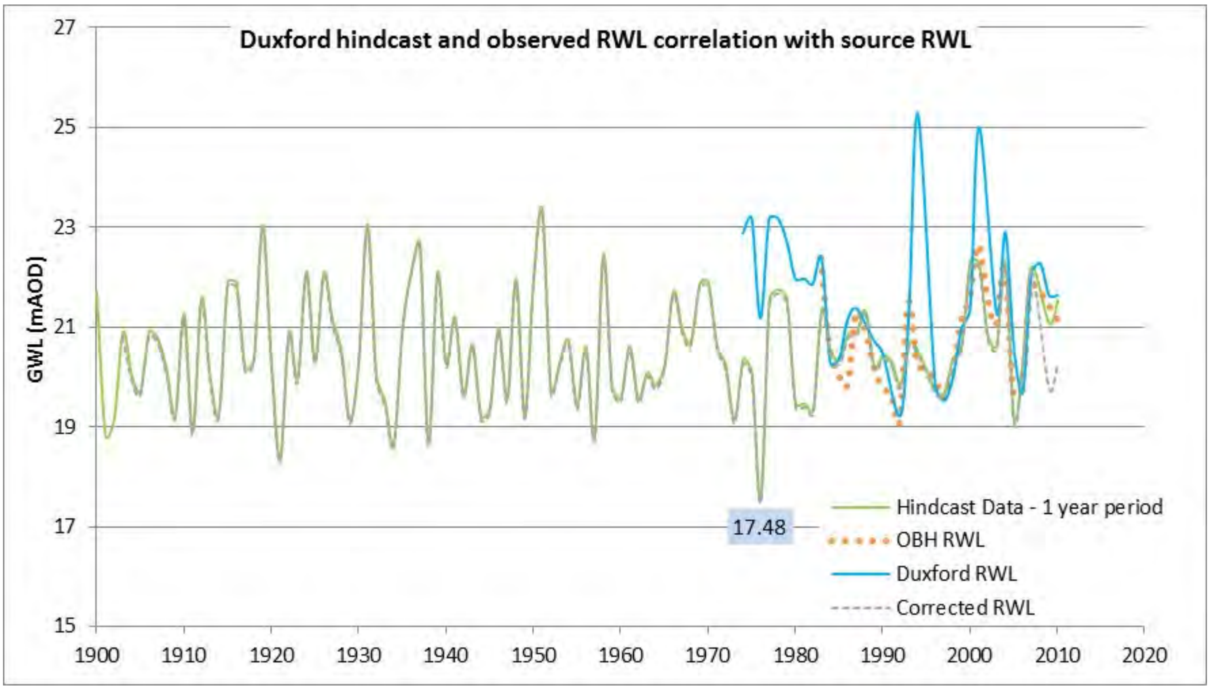

Dullingham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
25
20
15
10
5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
6.93
Hindcast data - 2 year period
OBH RWL
Dullingham RWL
Corrected RWL

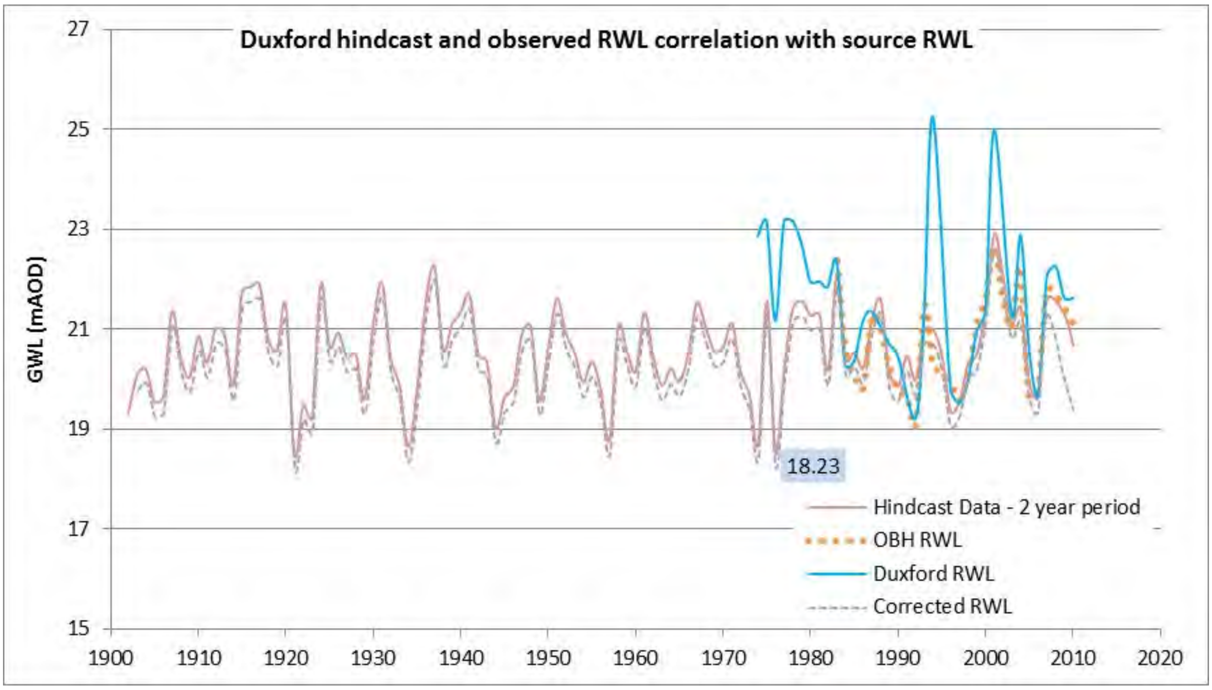

Dullingham hindcast and observed RWL correlation with source RWL
GWL (mAOD)
25
20
15
10
5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
6.53
Hindcast Data - 3 year period
OBH RWL
Dullingham RWL
Corrected RWL

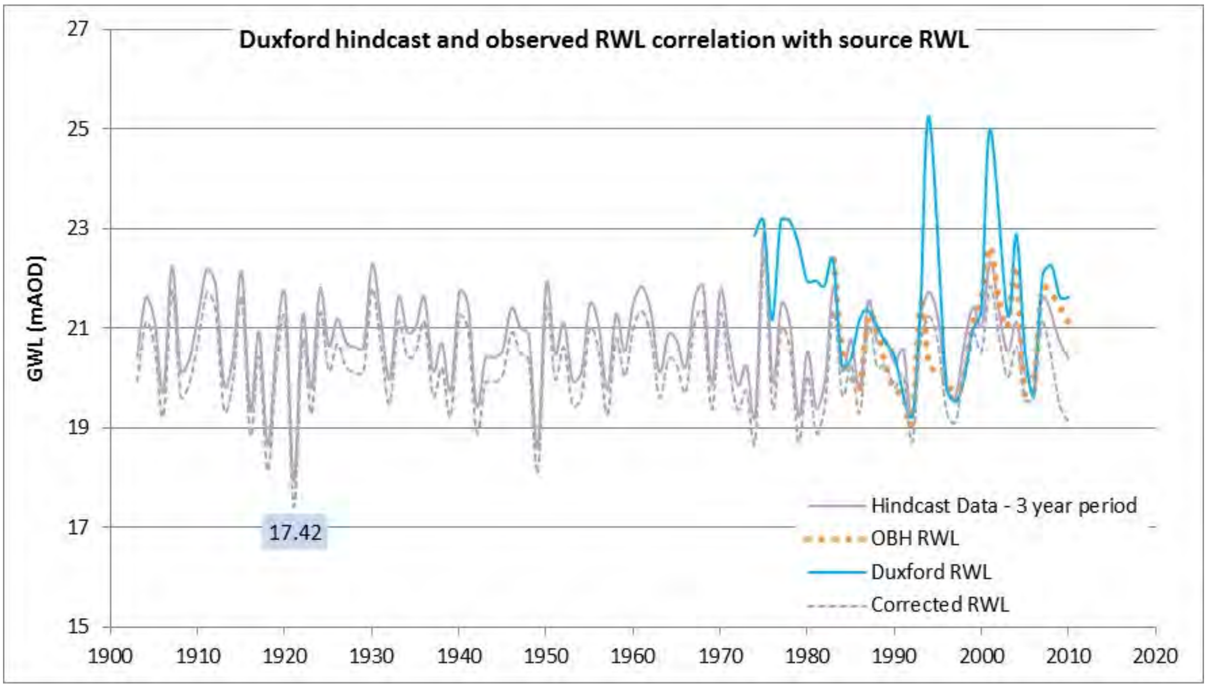

Duxford Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
27
25
23
21
19
17
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
18.16
Hindcast Data - 1 year period
OBH RWL
Duxford Grange RWL
Corrected RWL

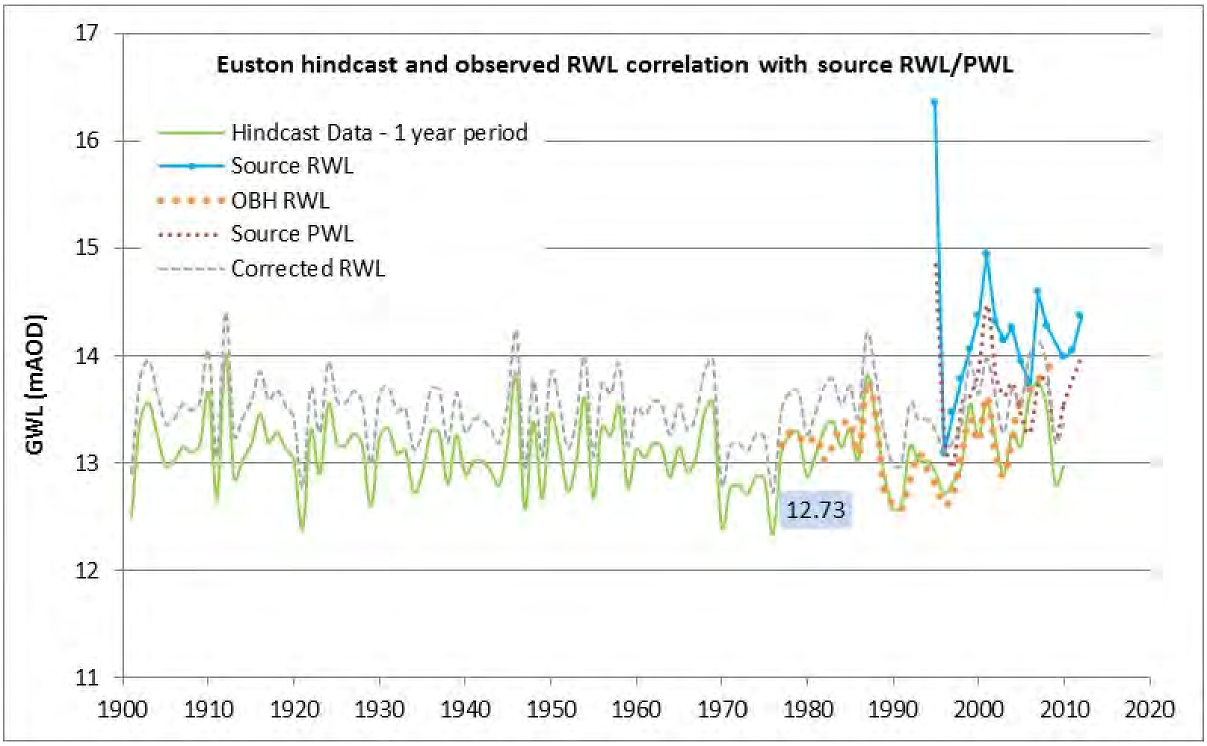

Duxford Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
27
25
23
21
19
17
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
18.02
Hindcast Data - 2 year period
OBH RWL
Duxford Grange RWL
Corrected RWL

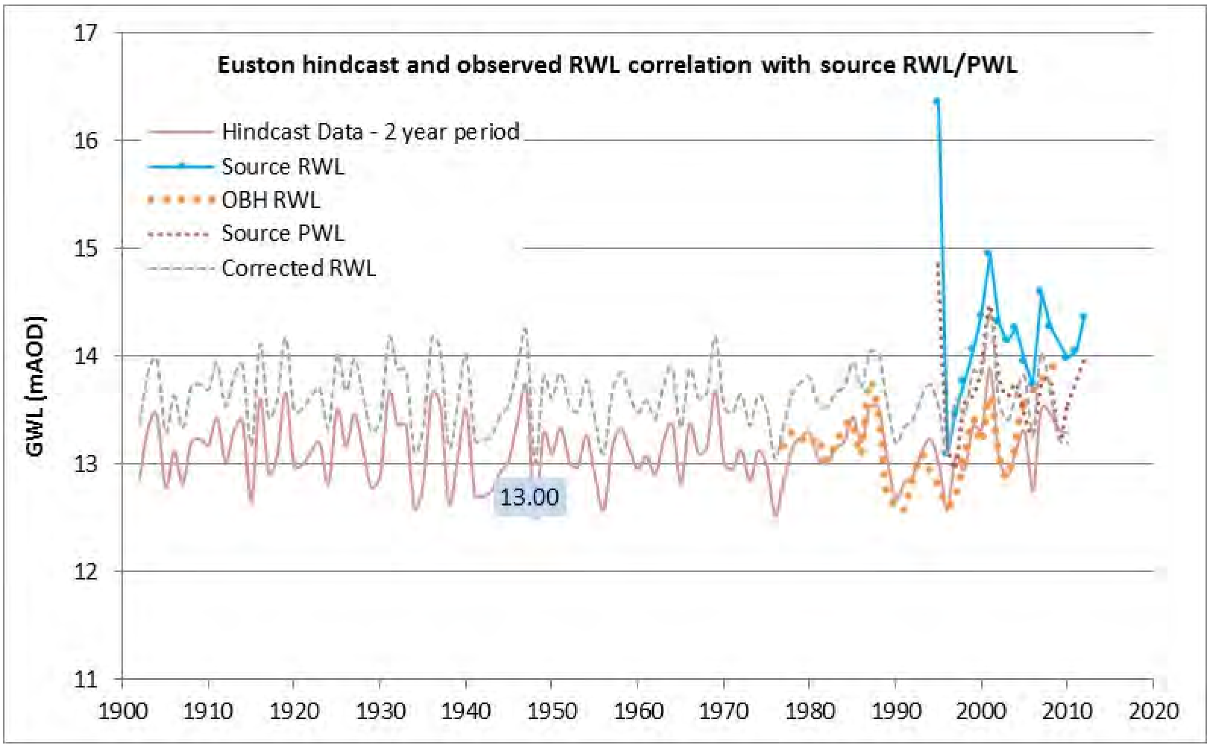

Duxford Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
27
25
23
21
19
17
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
17.32
Hindcast Data - 3 year period
OBH RWL
Duxford Grange RWL
Corrected RWL

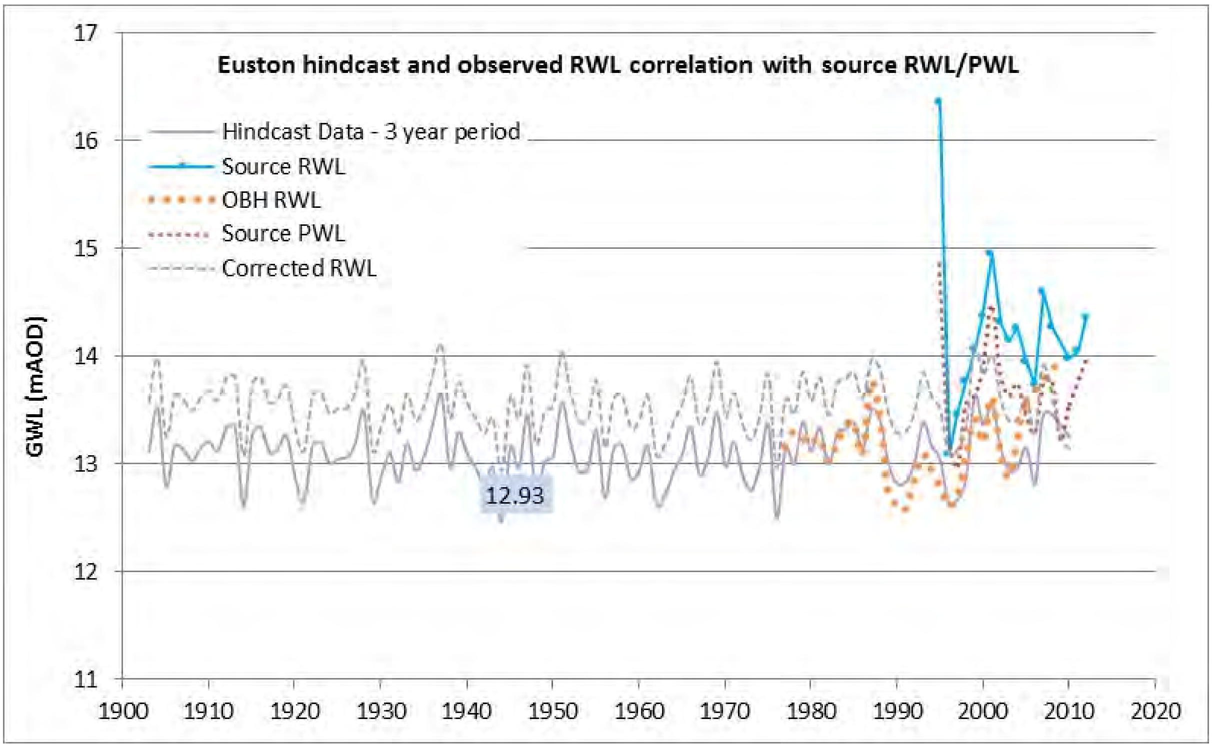

Duxford hindcast and observed RWL correlation with source RWL
GWL (mAOD)
27
25
23
21
19
17
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
17.48
Hindcast Data - 1 year period
OBH RWL
Duxford RWL
Corrected RWL

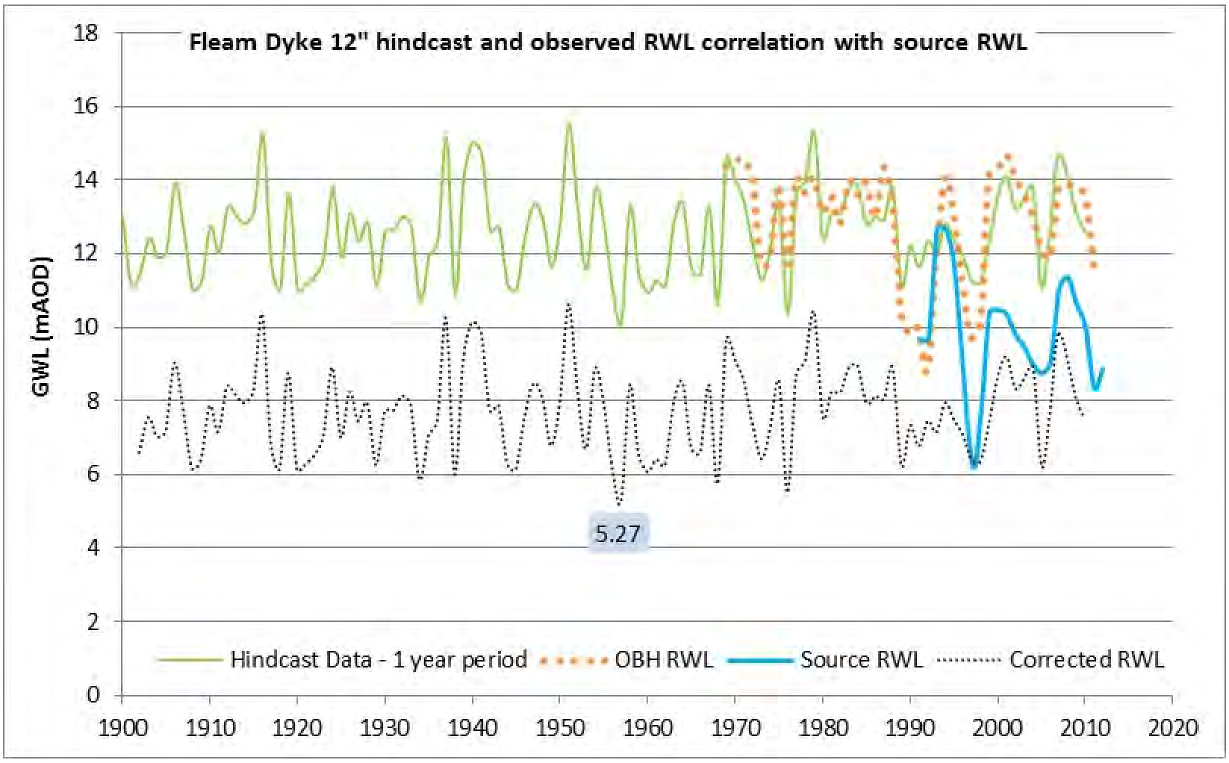

Duxford hindcast and observed RWL correlation with source RWL
GWL (mAOD)
27
25
23
21
19
17
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
18.23
Hindcast Data - 2 year period
OBH RWL
Duxford RWL
Corrected RWL

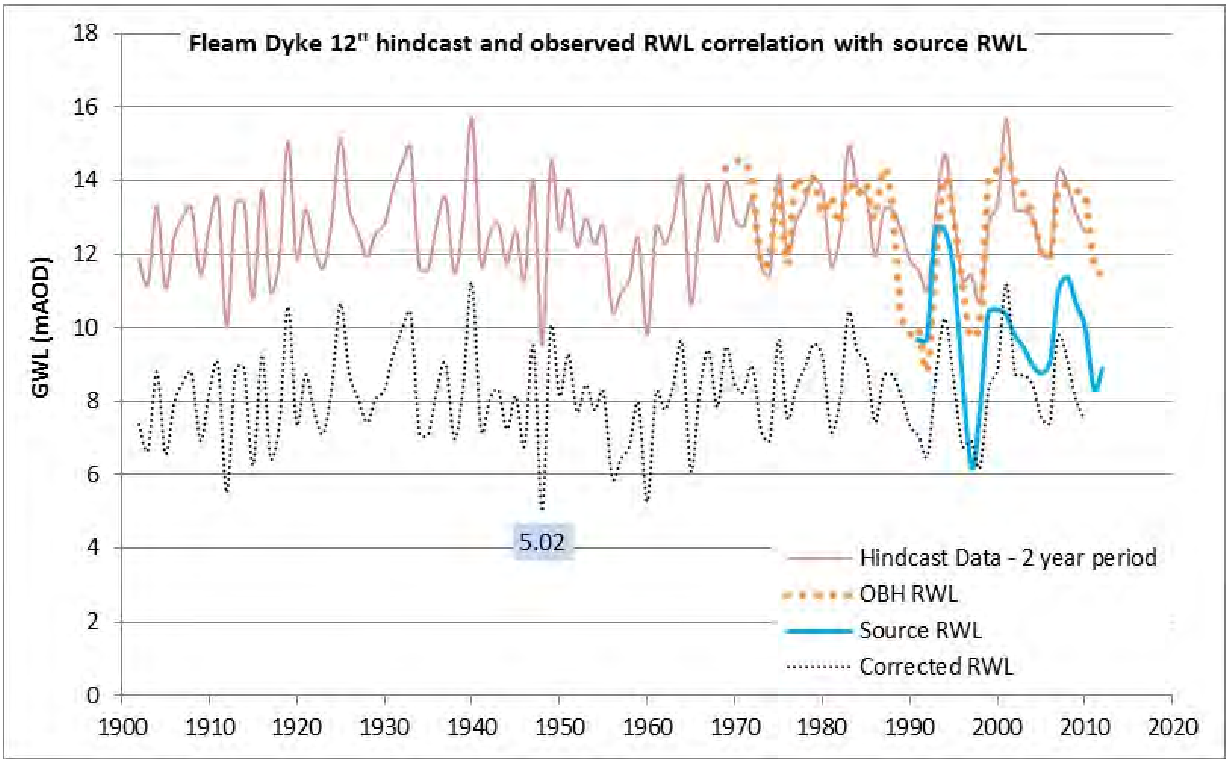

Duxford hindcast and observed RWL correlation with source RWL
GWL (mAOD)
27
25
23
21
19
17
15
17.42
Hindcast Data - 3 year period
OBH RWL
Duxford RWL
Corrected RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

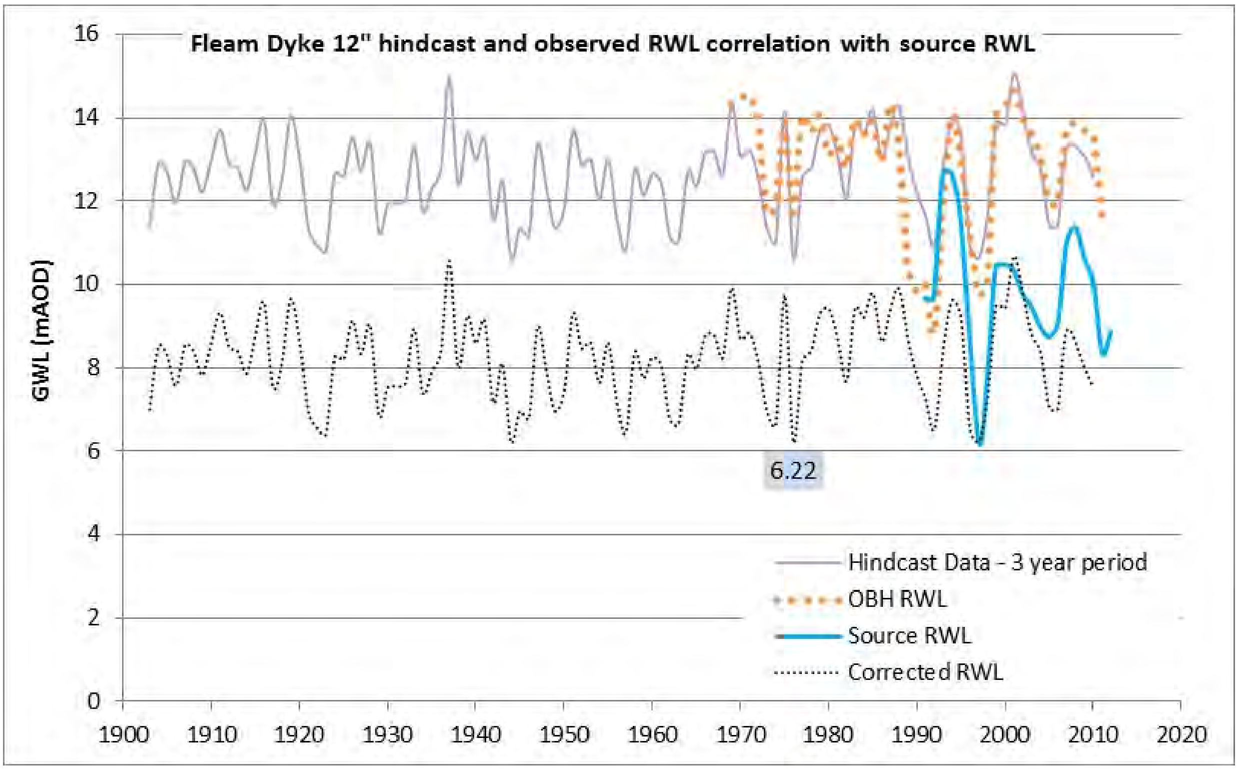

Euston hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
17
16
15
14
13
12
11
Hindcast Data - 1 year period
Source RWL
OBH RWL
Source PWL
Corrected RWL
12.73
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

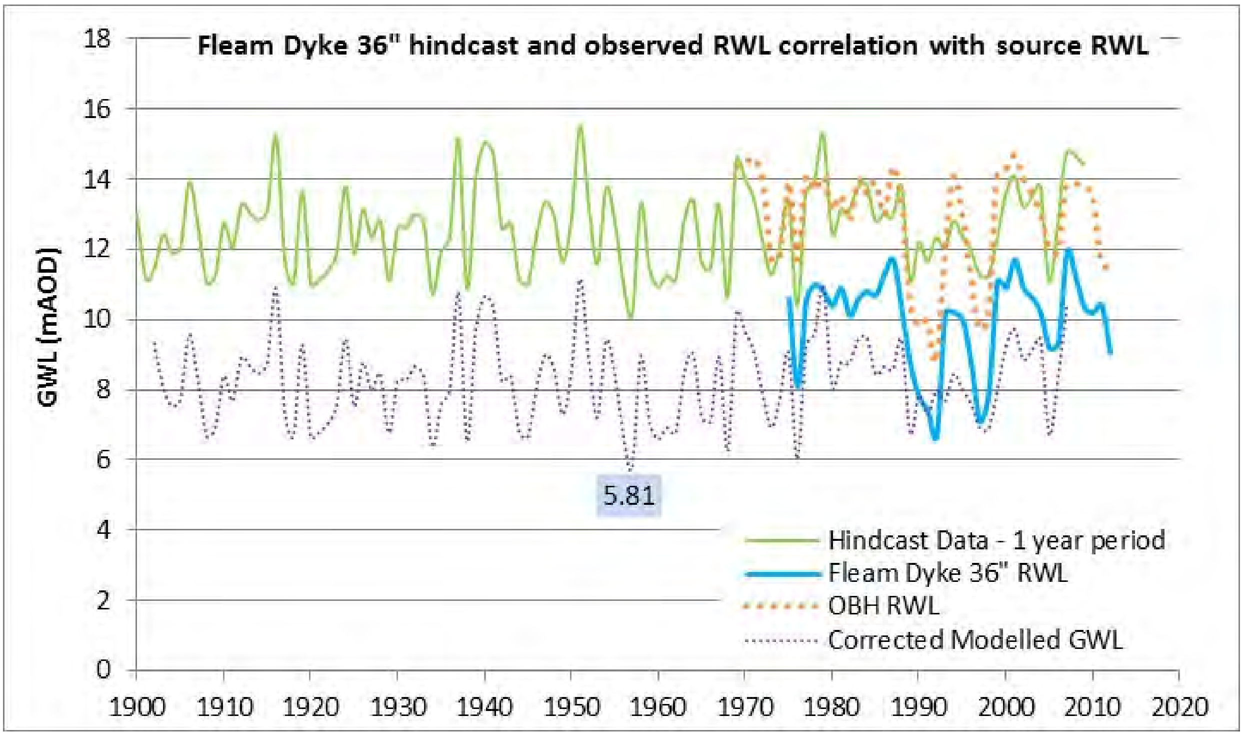

Euston hindcast and observed RWL correlation with source RWL/PWL
Hindcast Data - 2 year period
Source RWL
OBH RWL
Source PWL
Corrected RWL
GWL (mAOD)
13.00
17
16
15
14
13
12
11
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

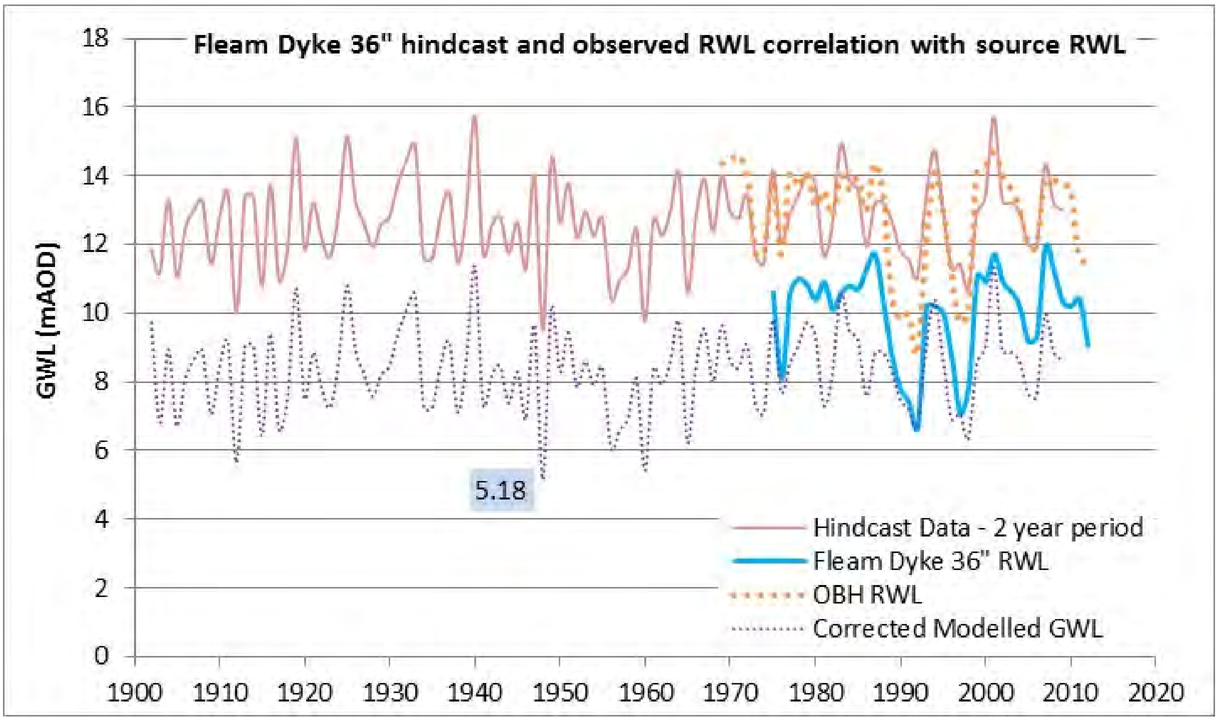

Euston hindcast and observed RWL correlation with source RWL/PWL
Hindcast Data - 3 year period
Source RWL
OBH RWL
Source PWL
Corrected RWL
GWL (mAOD)
12.93
17
16
15
14
13
12
11
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

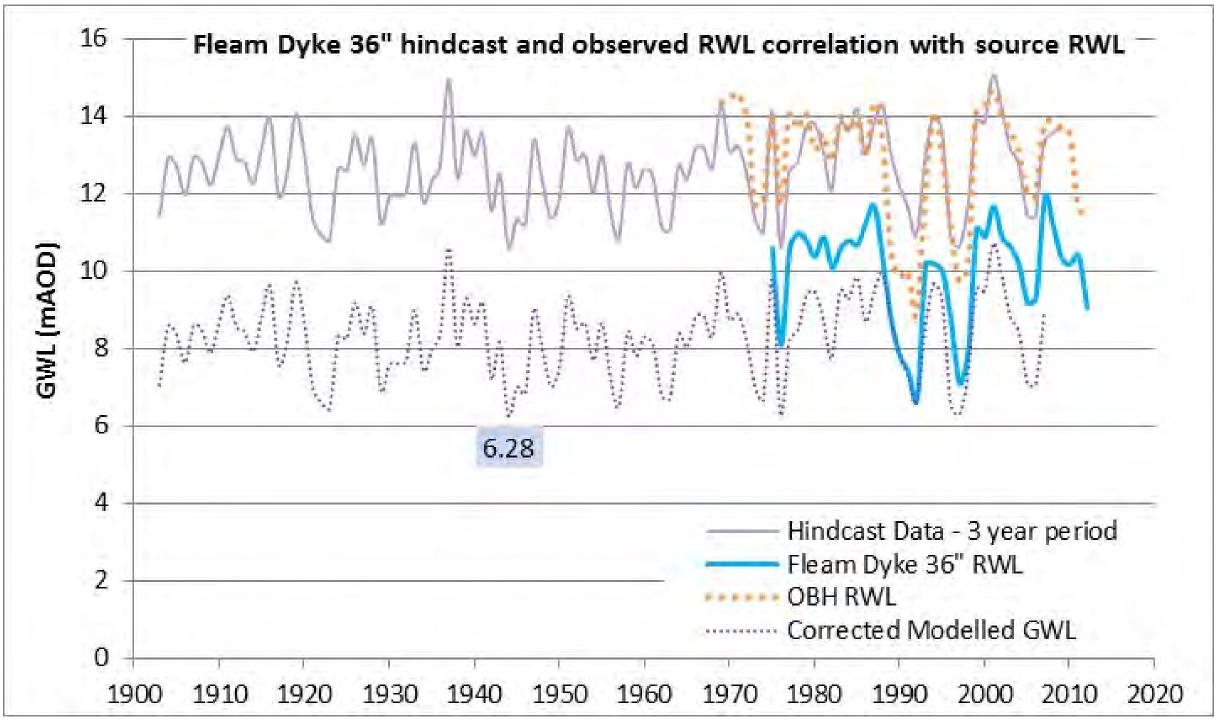

Fleam Dyke 12" hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
5.27
Hindcast Data - 1 year period
OBH RWL
Source RWL
Corrected RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

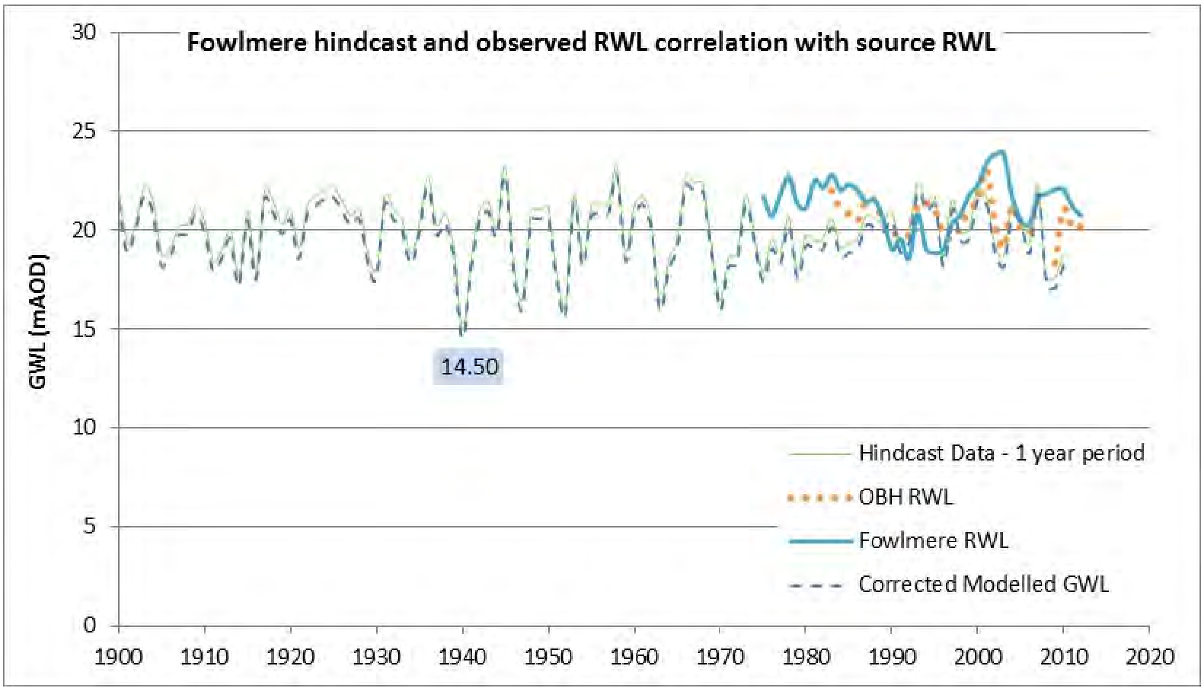

Fleam Dyke 12" hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
5.02
Hindcast Data - 2 year period
OBH RWL
Source RWL
Corrected RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

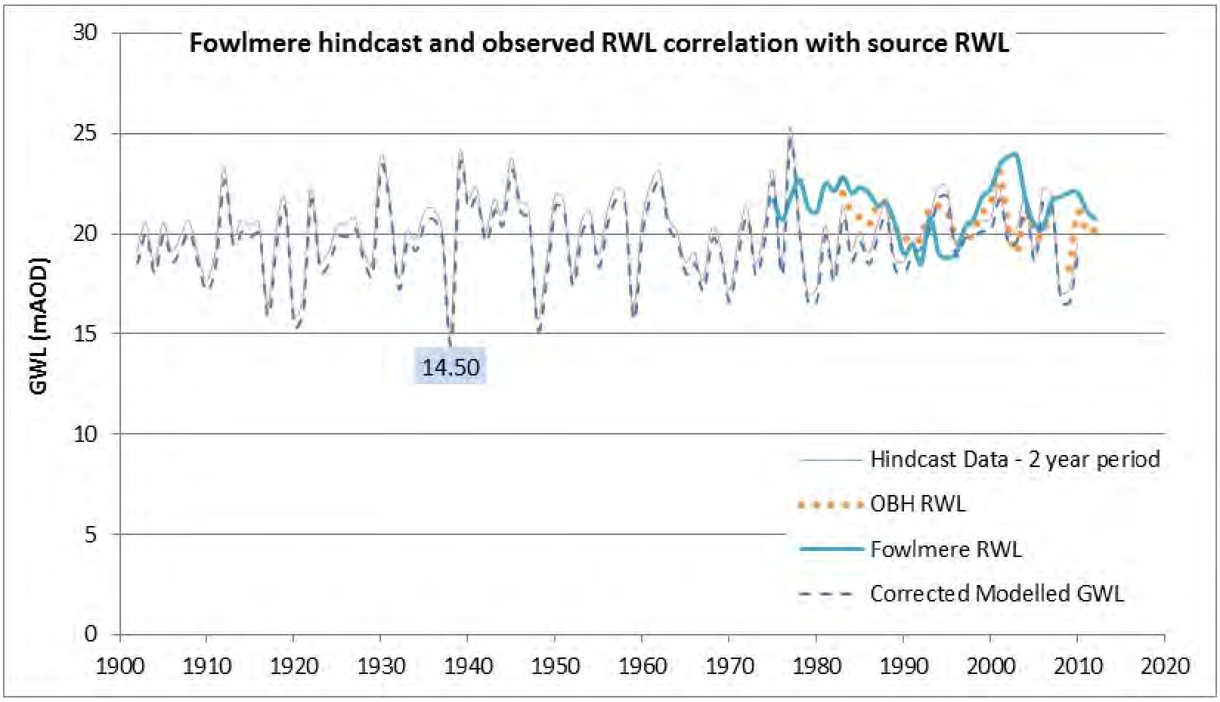

Fleam Dyke 12" hindcast and observed RWL correlation with source RWL
GWL (mAOD)
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
6.22
Hindcast Data - 3 year period
OBH RWL
Source RWL
Corrected RWL

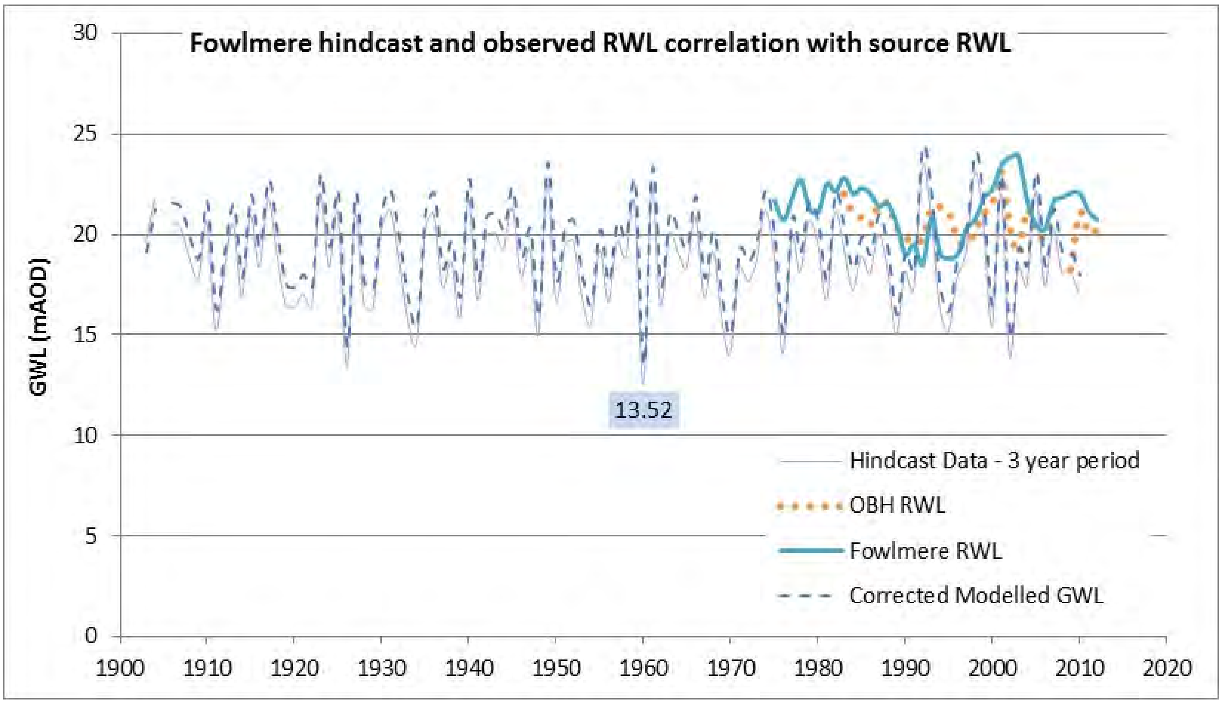

Fleam Dyke 36" hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
5.81
Hindcast Data - 1 year period
Fleam Dyke 36" RWL
OBH RWL
Corrected Modelled GWL

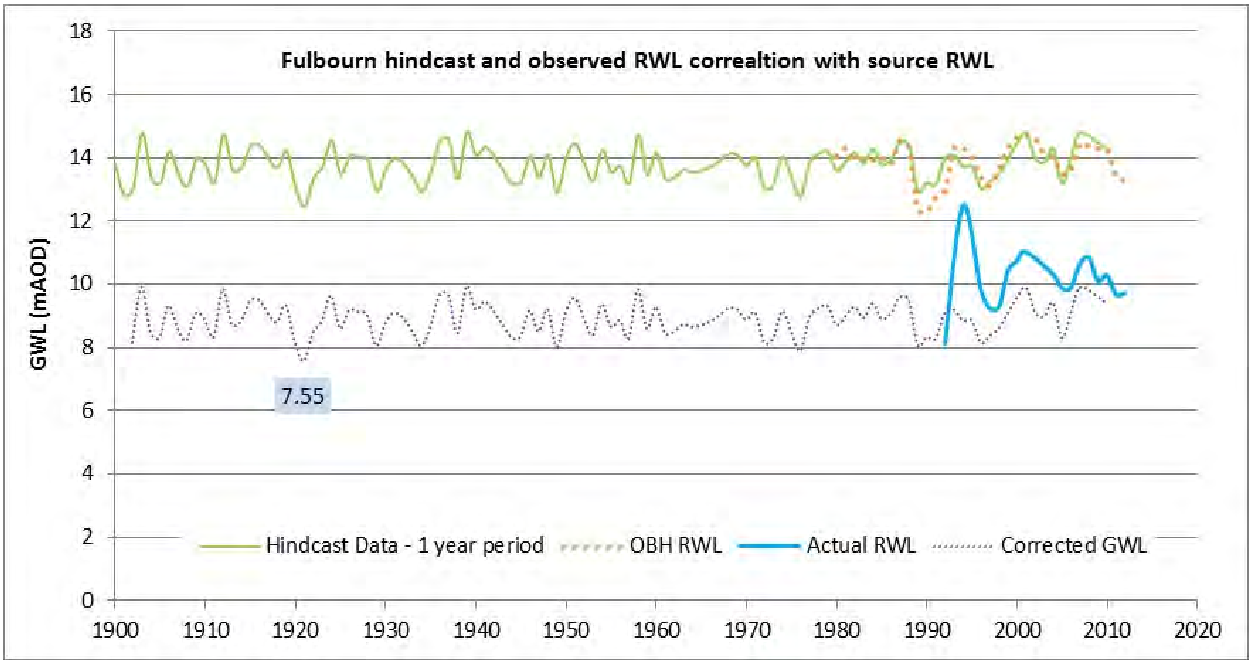

Fleam Dyke 36" hindcast and observed RWL correlation with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
5.18
Hindcast Data - 2 year period
Fleam Dyke 36" RWL
OBH RWL
Corrected Modelled GWL

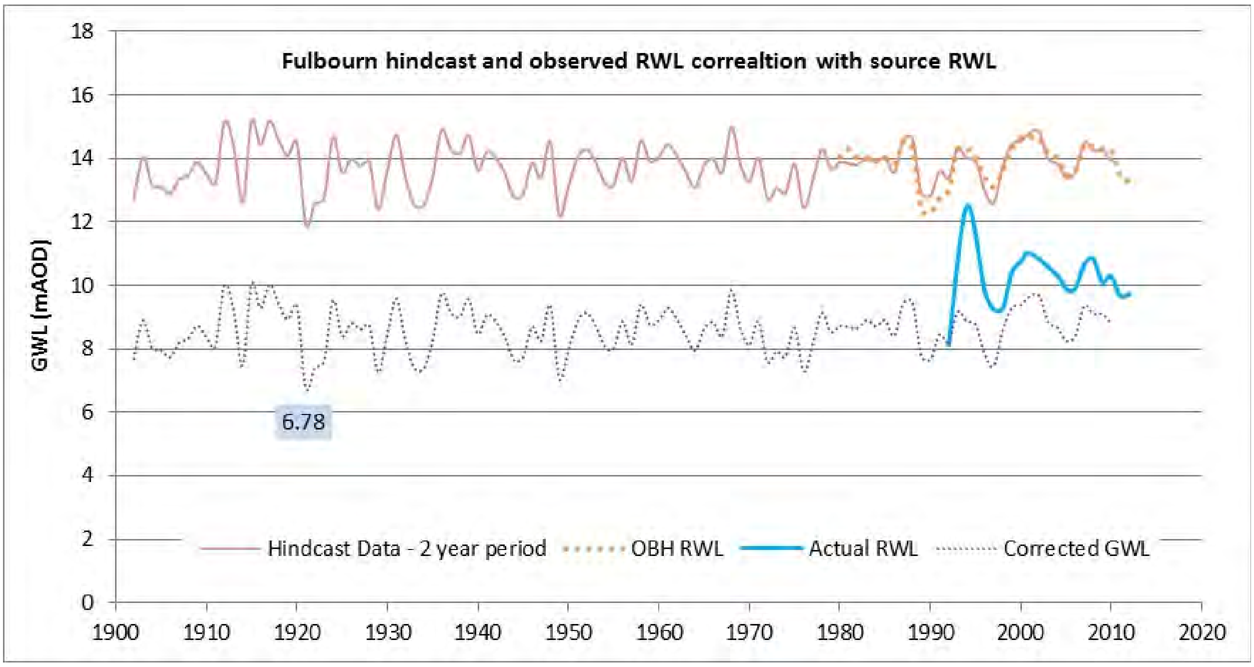

Fleam Dyke 36" hindcast and observed RWL correlation with source RWL
GWL (mAOD)
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
6.28
Hindcast Data - 3 year period
Fleam Dyke 36" RWL
OBH RWL
Corrected Modelled GWL

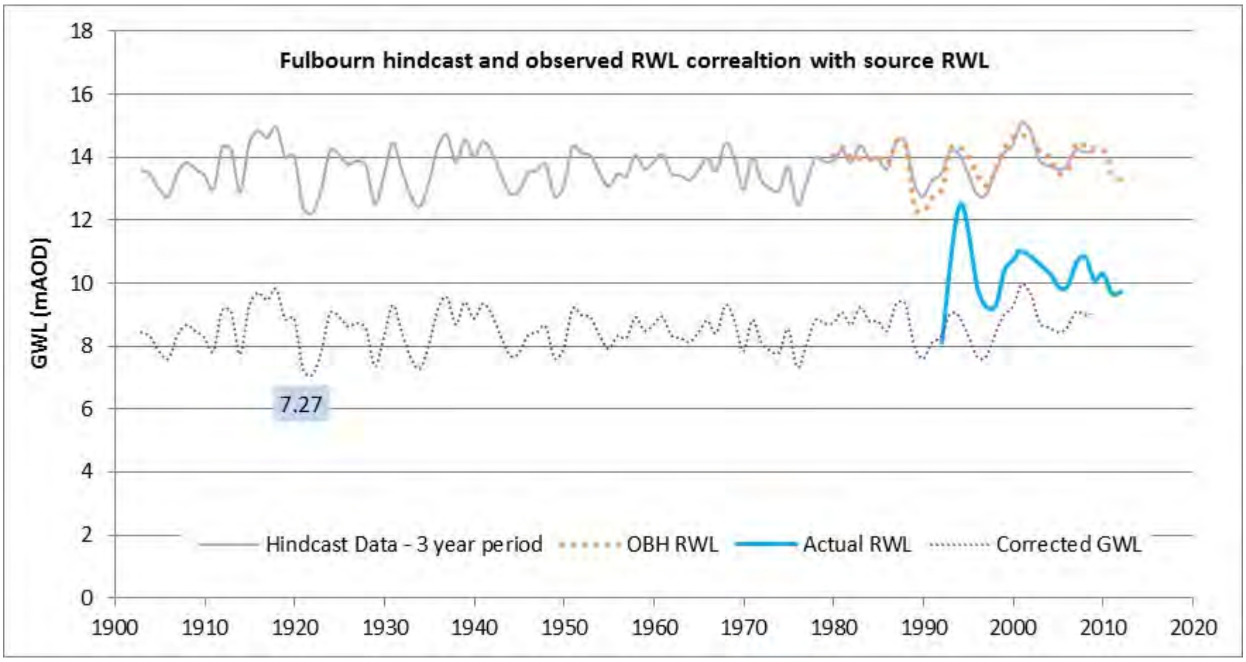

Fowlmere hindcast and observed RWL correlation with source RWL
GWL (mAOD)
30
25
20
15
10
5
0
14.50
Hindcast Data - 1 year period
OBH RWL
Fowlmere RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

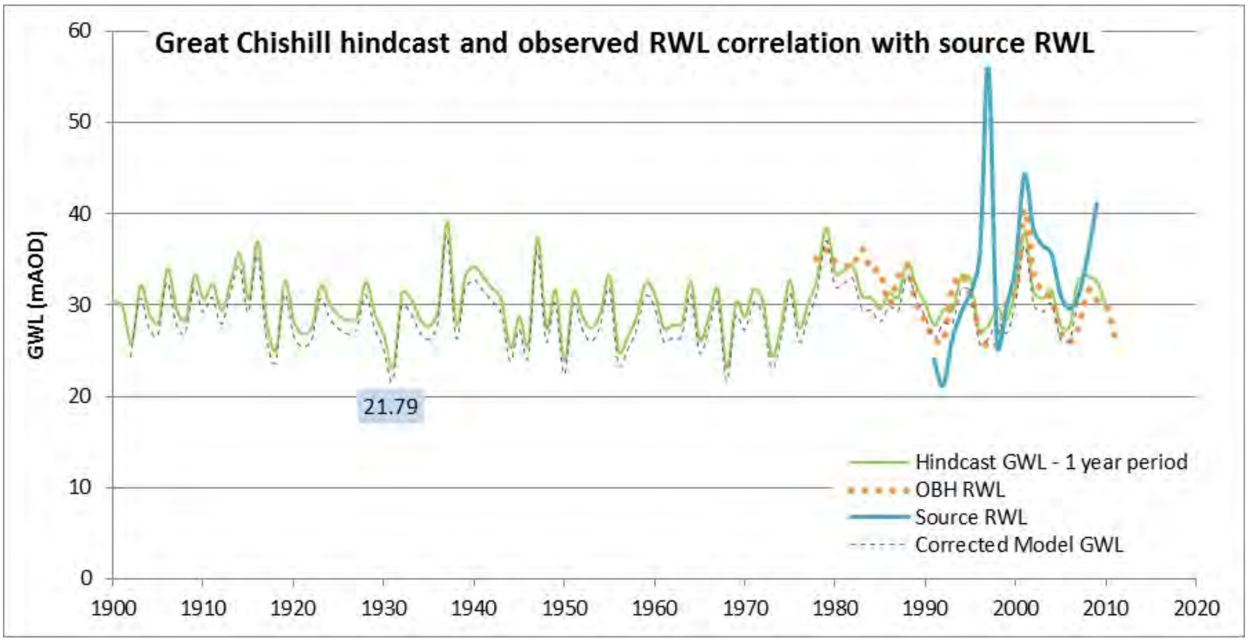

Fowlmere hindcast and observed RWL correlation with source RWL
GWL (mAOD)
30
25
20
15
10
5
0
14.50
Hindcast Data - 2 year period
OBH RWL
Fowlmere RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

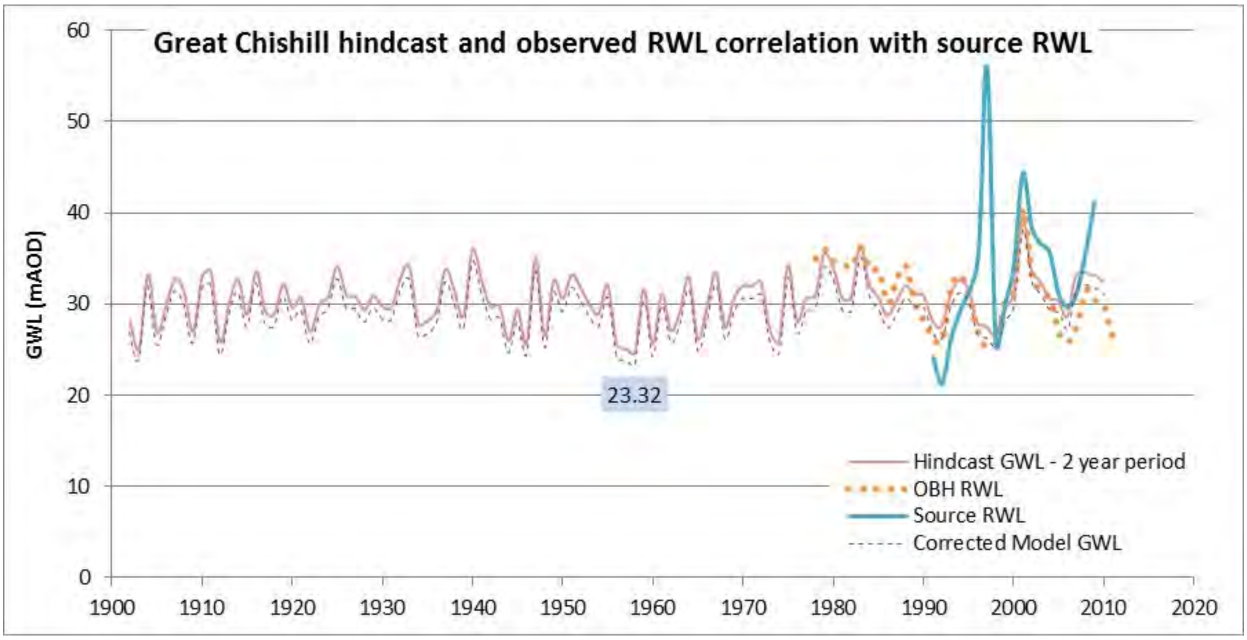

Fowlmere hindcast and observed RWL correlation with source RWL
GWL (mAOD)
30
25
20
15
10
5
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
13.52
Hindcast Data - 3 year period
OBH RWL
Fowlmere RWL
Corrected Modelled GWL

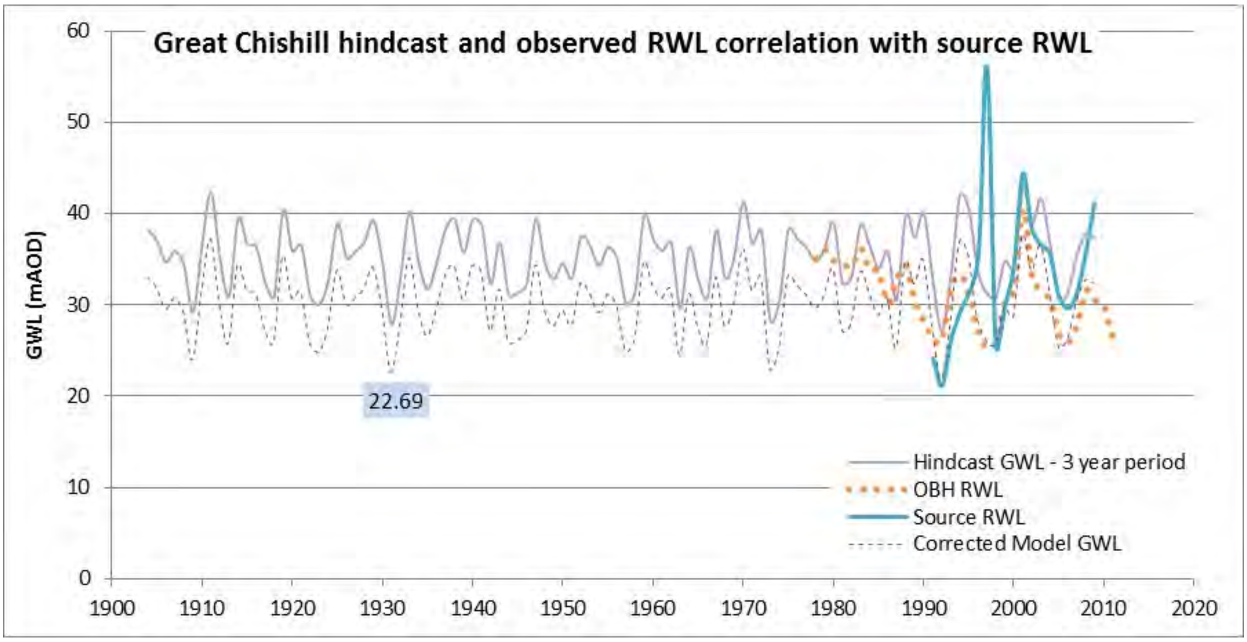

Fulbourn hindcast and observed RWL correaltion with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
7.55
Hindcast Data - 1 year period
OBH RWL
Actual RWL
Corrected GWL

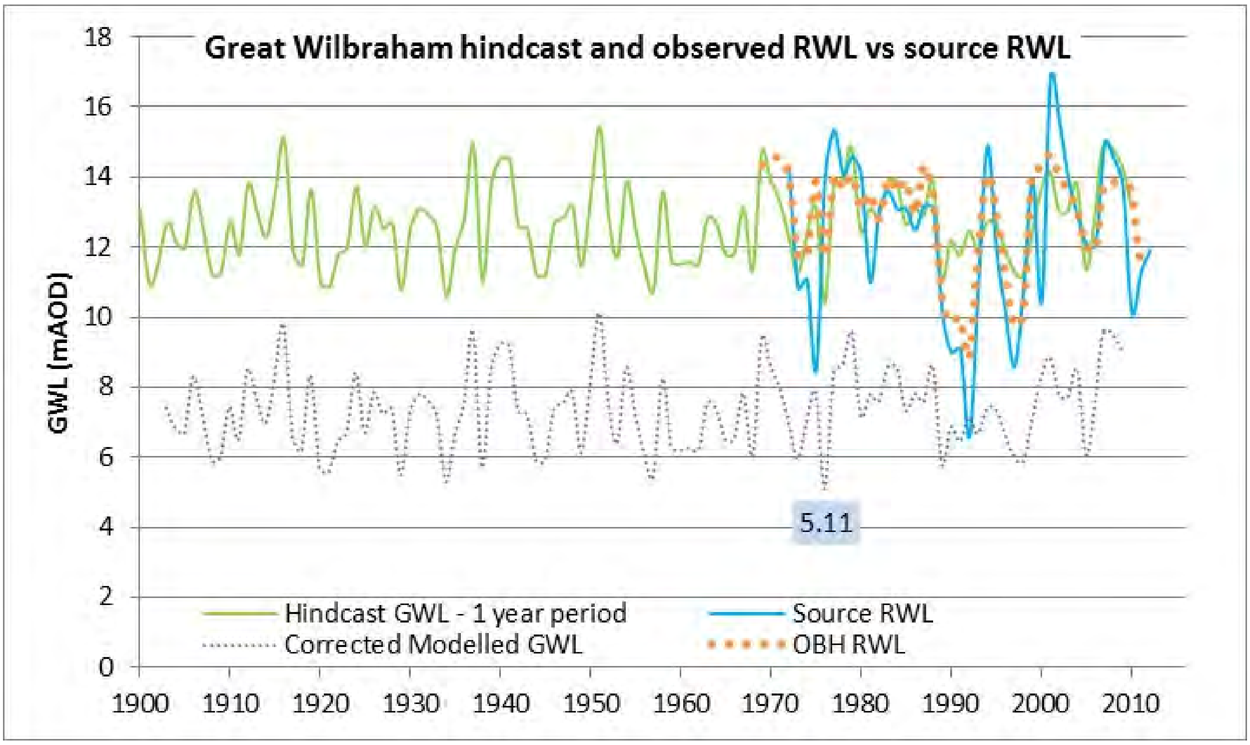

Fulbourn hindcast and observed RWL correaltion with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
6.78
Hindcast Data - 2 year period
OBH RWL
Actual RWL
Corrected GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

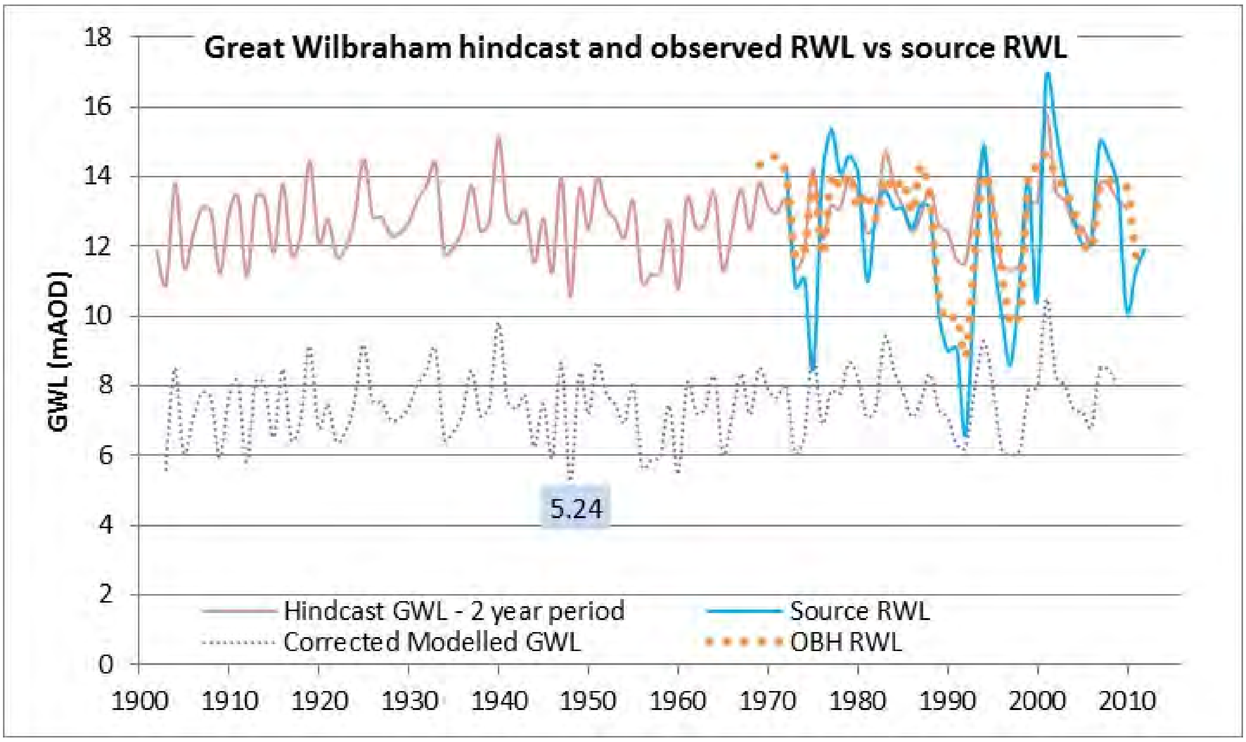

Fulbourn hindcast and observed RWL correaltion with source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
7.27
Hindcast Data - 3 year period
OBH RWL
Actual RWL
Corrected GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

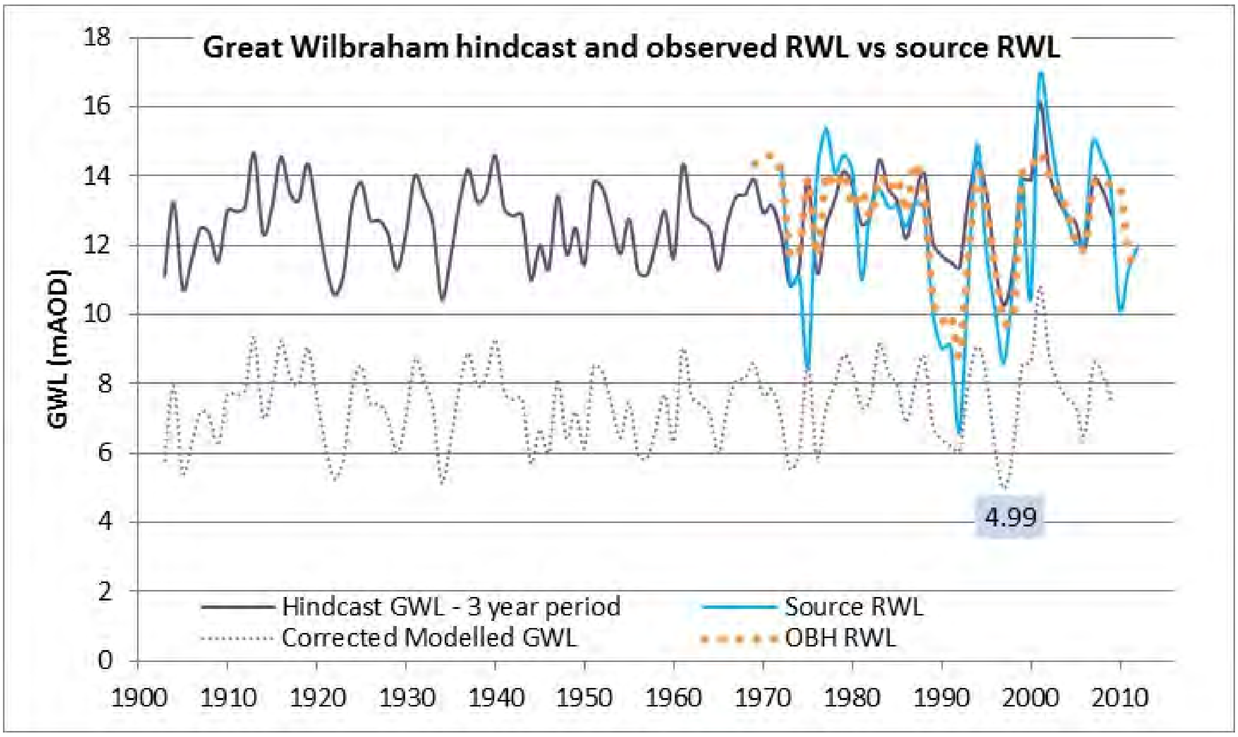

Great Chishill hindcast and observed RWL correlation with source RWL
GWL (mAOD)
60
50
40
30
20
10
0
21.79
Hindcast GWL - 1 year period
OBH RWL
Source RWL
Corrected Model GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

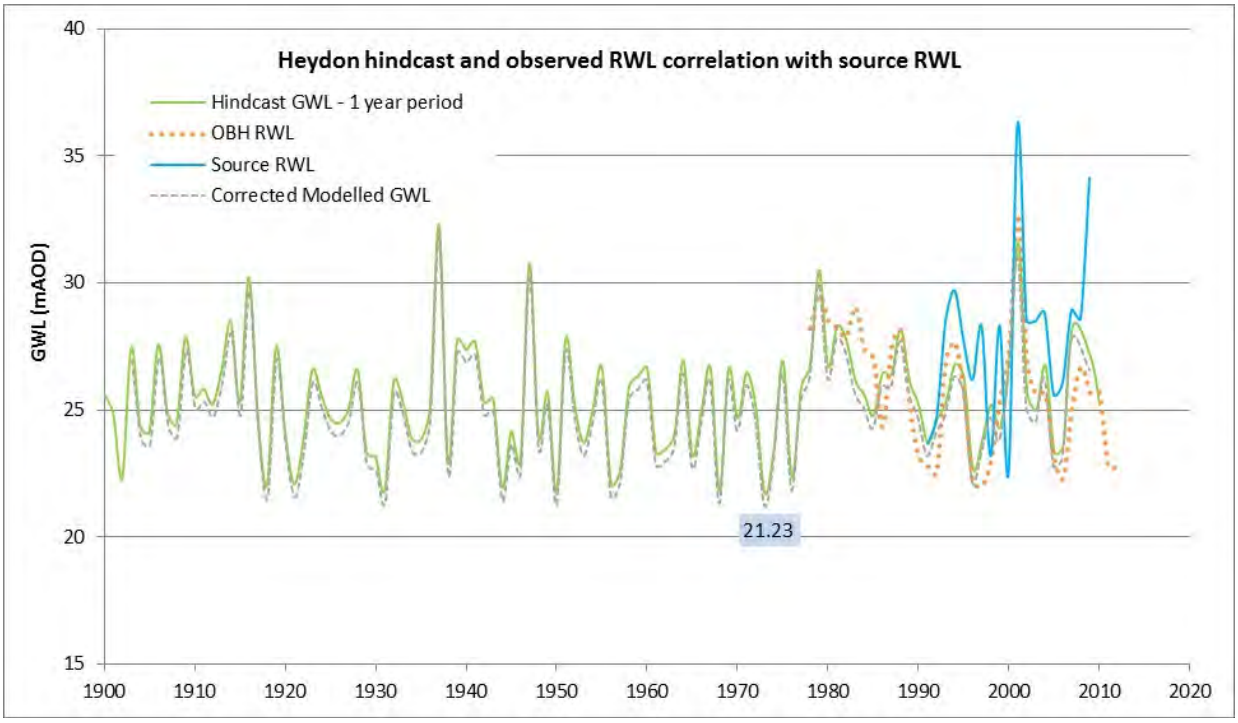

Great Chishill hindcast and observed RWL correlation with source RWL
GWL (mAOD)
60
50
40
30
20
10
0
23.32
Hindcast GWL - 2 year period
OBH RWL
Source RWL
Corrected Model GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

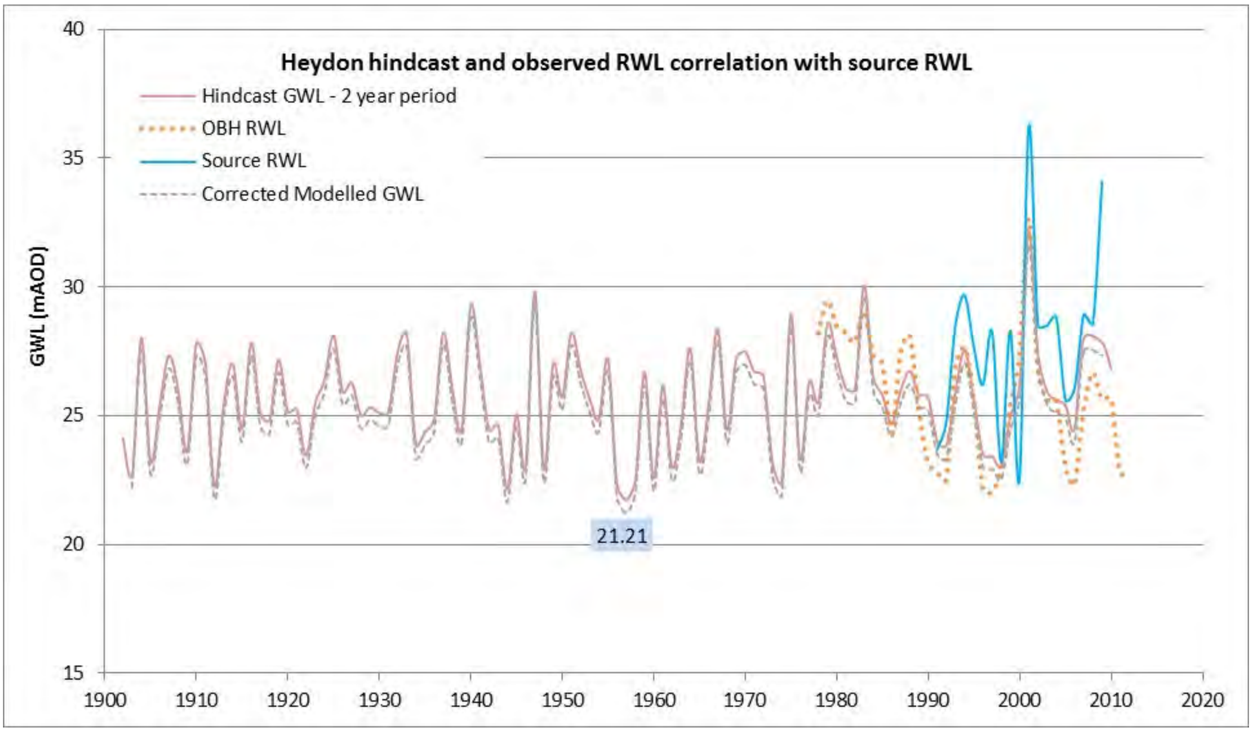

Great Chishill hindcast and observed RWL correlation with source RWL
GWL (mAOD)
0
10
20
30
40
50
60
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
22.69
Hindcast GWL - 3 year period
OBH RWL
Source RWL
Corrected Model GWL

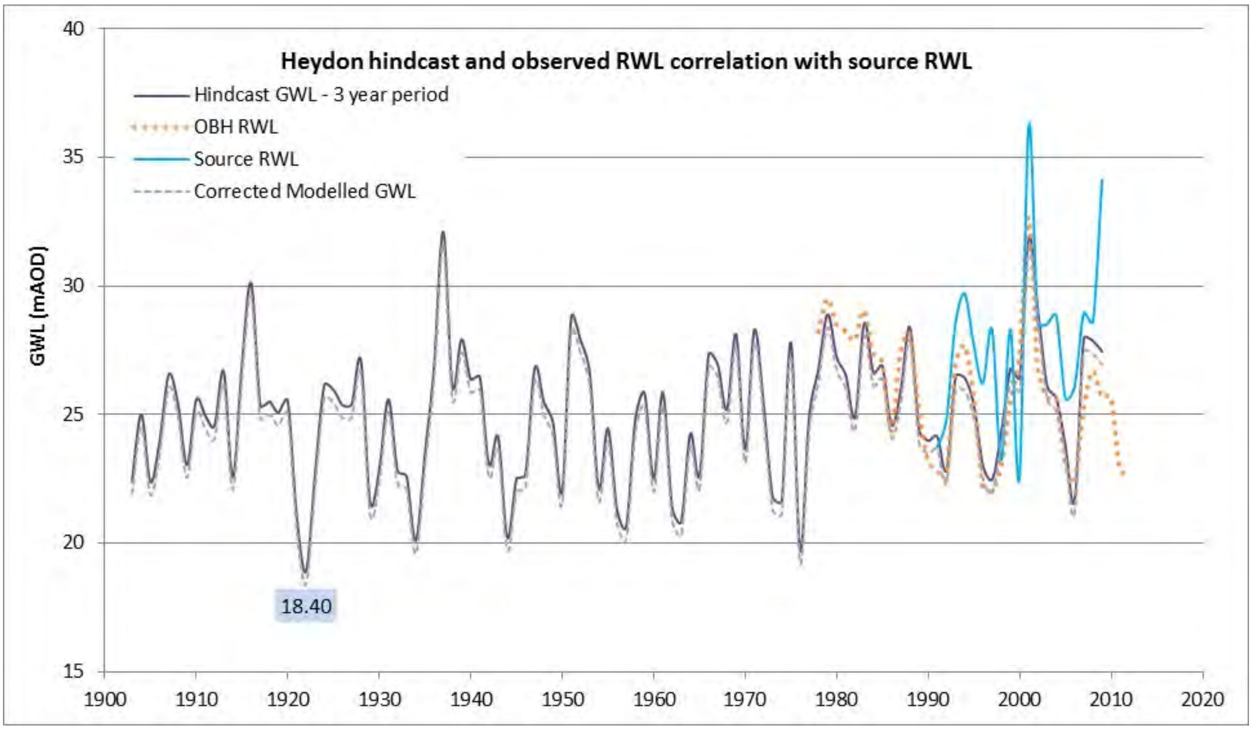

Great Wilbraham hindcast and observed RWL vs source RWL
GWL (mAOD)
0
2
4
6
8
10
12
14
16
18
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
5.11
Hindcast GWL - 1 year period
Corrected Modelled GWL
Source RWL
OBH RWL

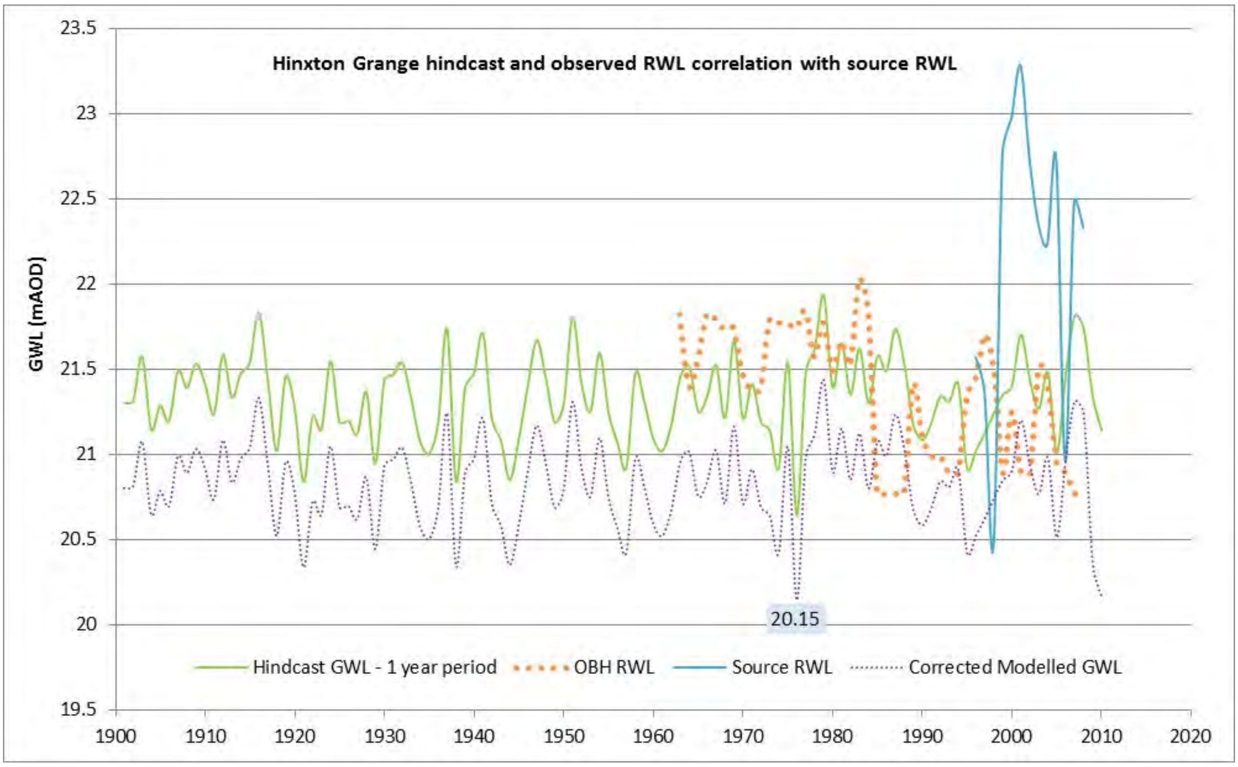

Great Wilbraham hindcast and observed RWL vs source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
5.24
Hindcast GWL - 2 year period
Corrected Modelled GWL
Source RWL
OBH RWL

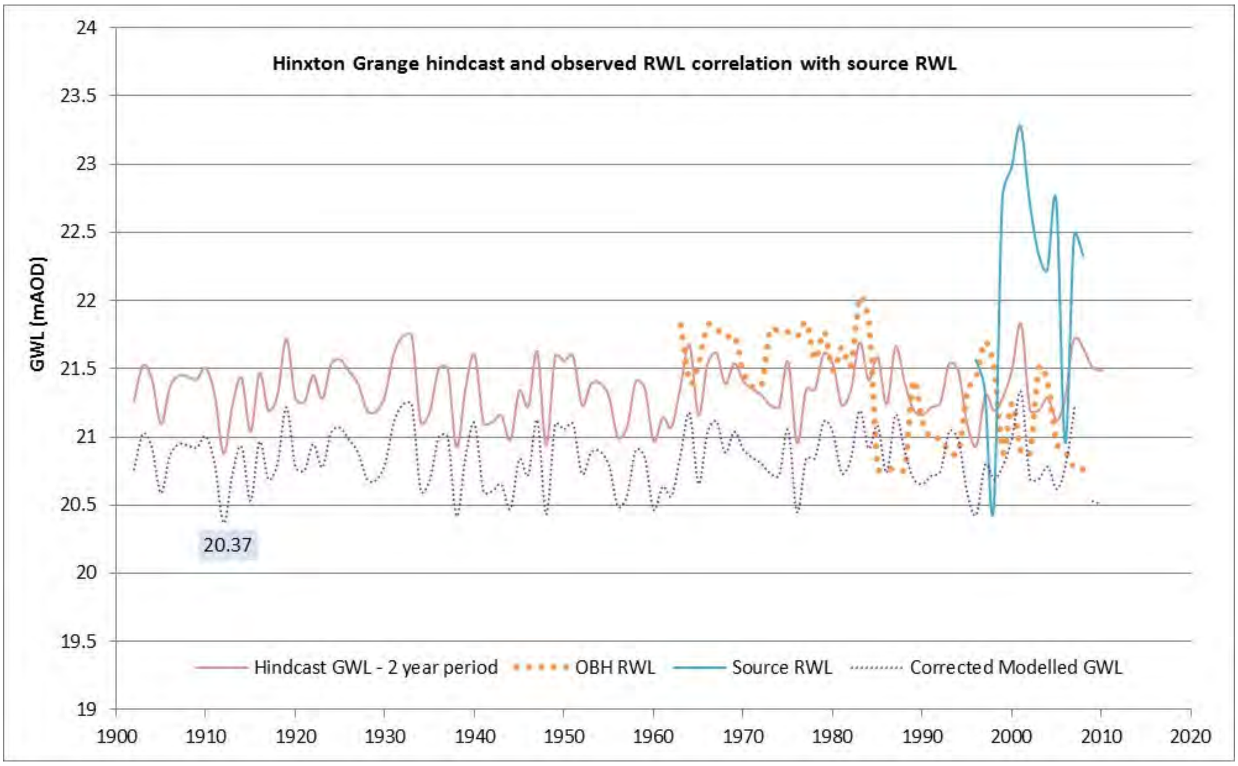

Great Wilbraham hindcast and observed RWL vs source RWL
GWL (mAOD)
18
16
14
12
10
8
6
4
2
0
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
4.99
Hindcast GWL - 3 year period
Corrected Modelled GWL
Source RWL
OBH RWL

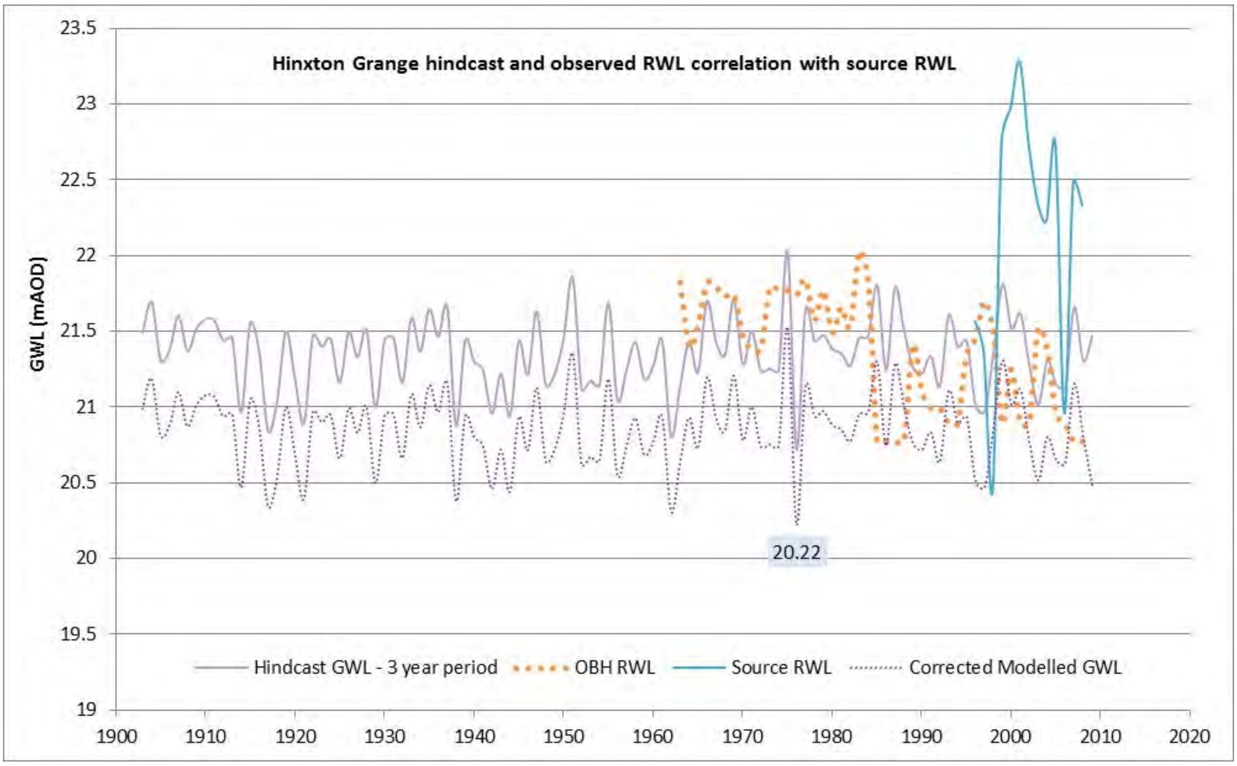

Heydon hindcast and observed RWL correlation with source RWL
Hindcast GWL - 1 year period
OBH RWL
Source RWL
Corrected Modelled GWL
GWL (mAOD)
40
35
30
25
20
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
21.23

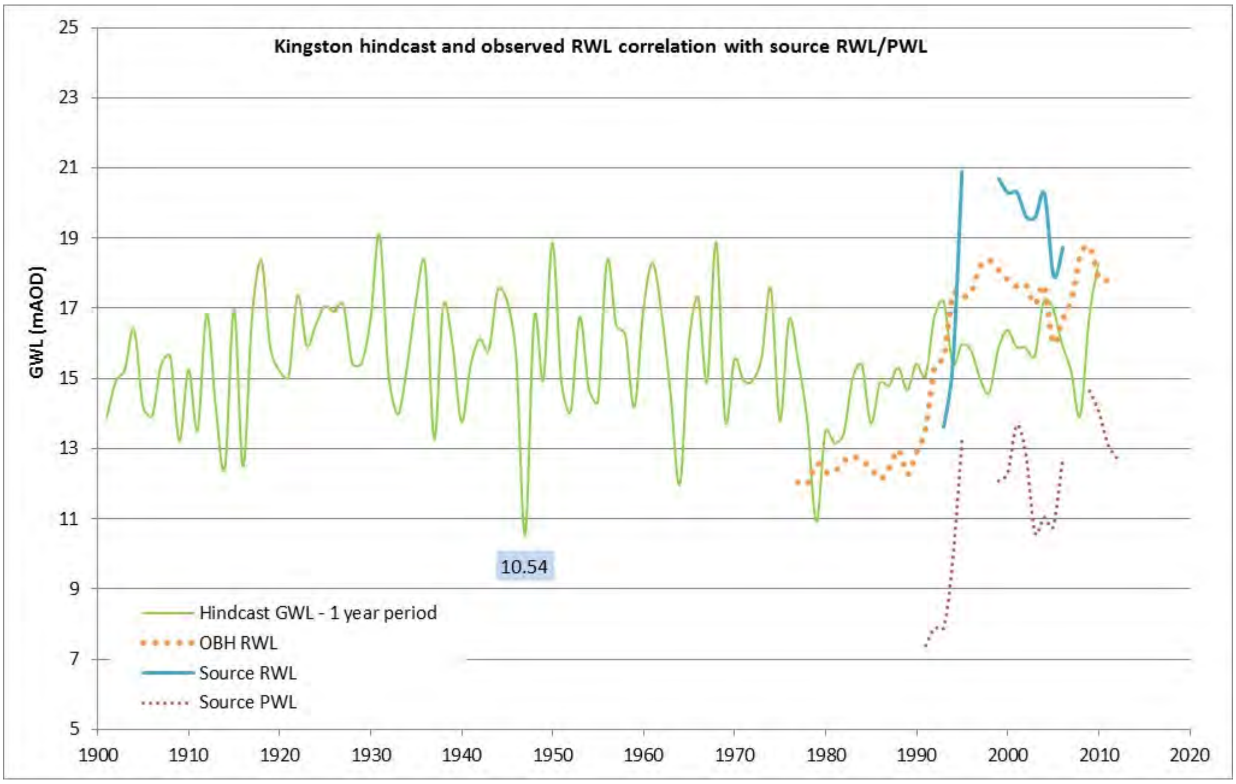

Heydon hindcast and observed RWL correlation with source RWL
Hindcast GWL - 2 year period
OBH RWL
Source RWL
Corrected Modelled GWL
GWL (mAOD)
40
35
30
25
20
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
21.21

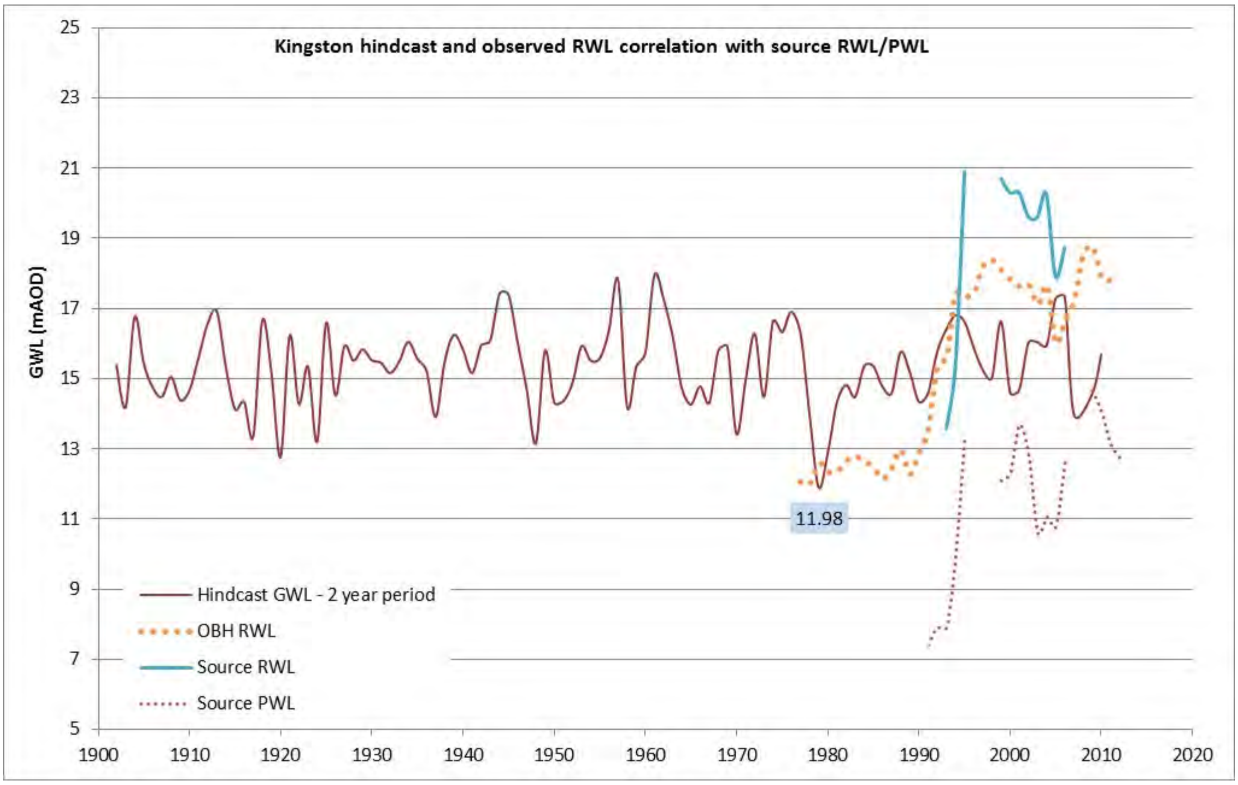

Heydon hindcast and observed RWL correlation with source RWL
Hindcast GWL - 3 year period
OBH RWL
Source RWL
Corrected Modelled GWL
GWL (mAOD)
18.40
40
35
30
25
20
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

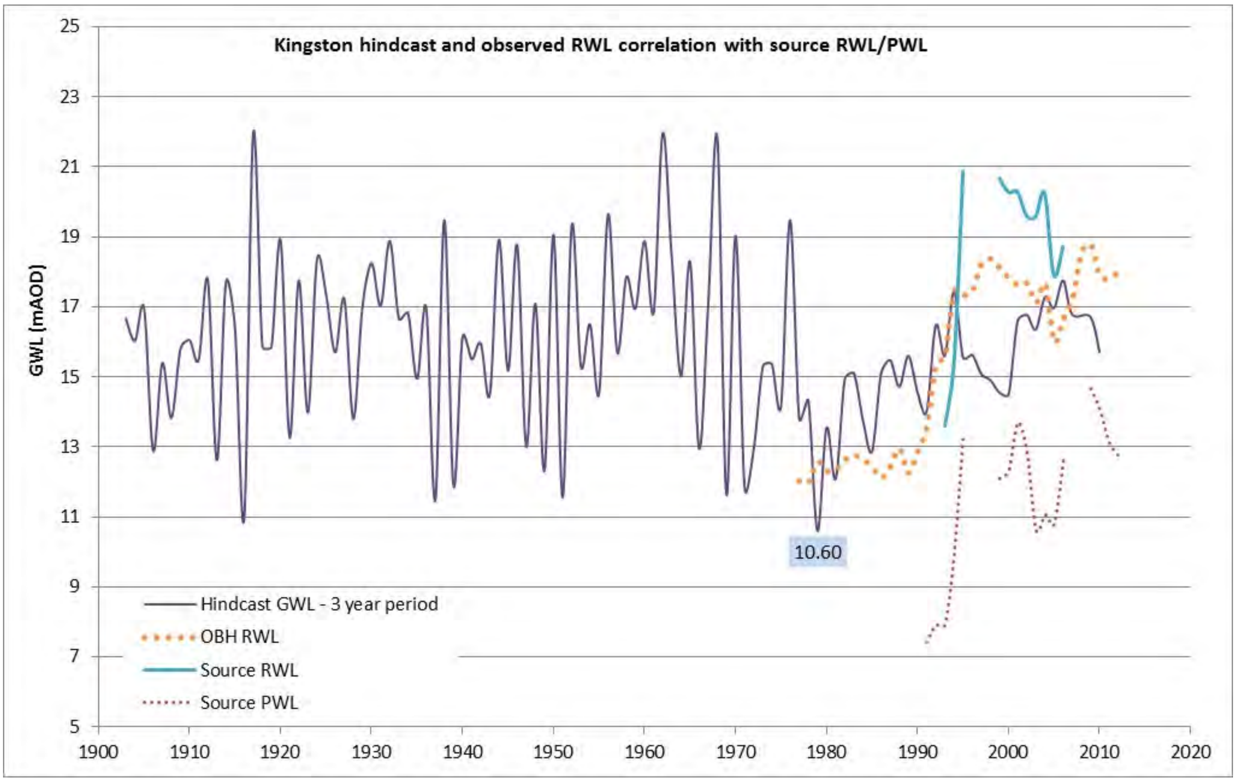

Hinxton Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
20.15
Hindcast GWL - 1 year period
OBH RWL
Source RWL
Corrected Modelled GWL
23.5
23
22.5
22
21.5
21
20.5
20
19.5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

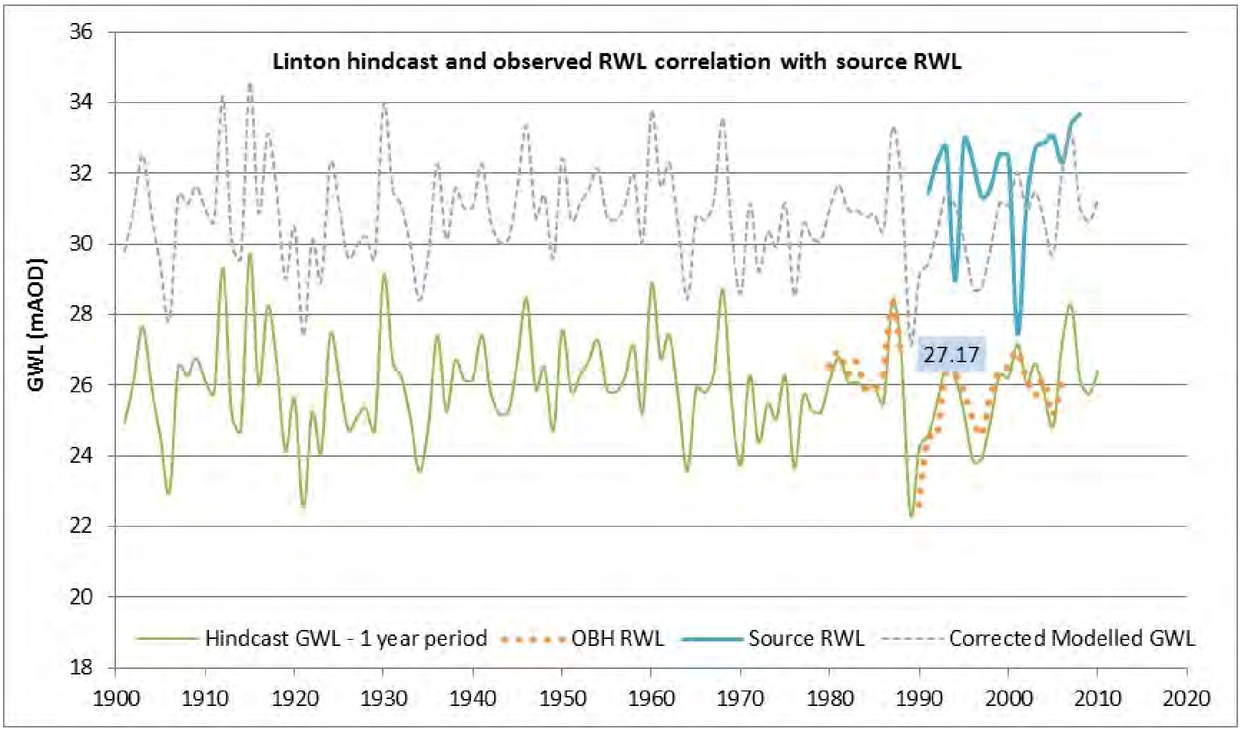

Hinxton Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
24
23.5
23
22.5
22
21.5
21
20.5
20
19.5
19
20.37
Hindcast GWL - 2 year period
OBH RWL
Source RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

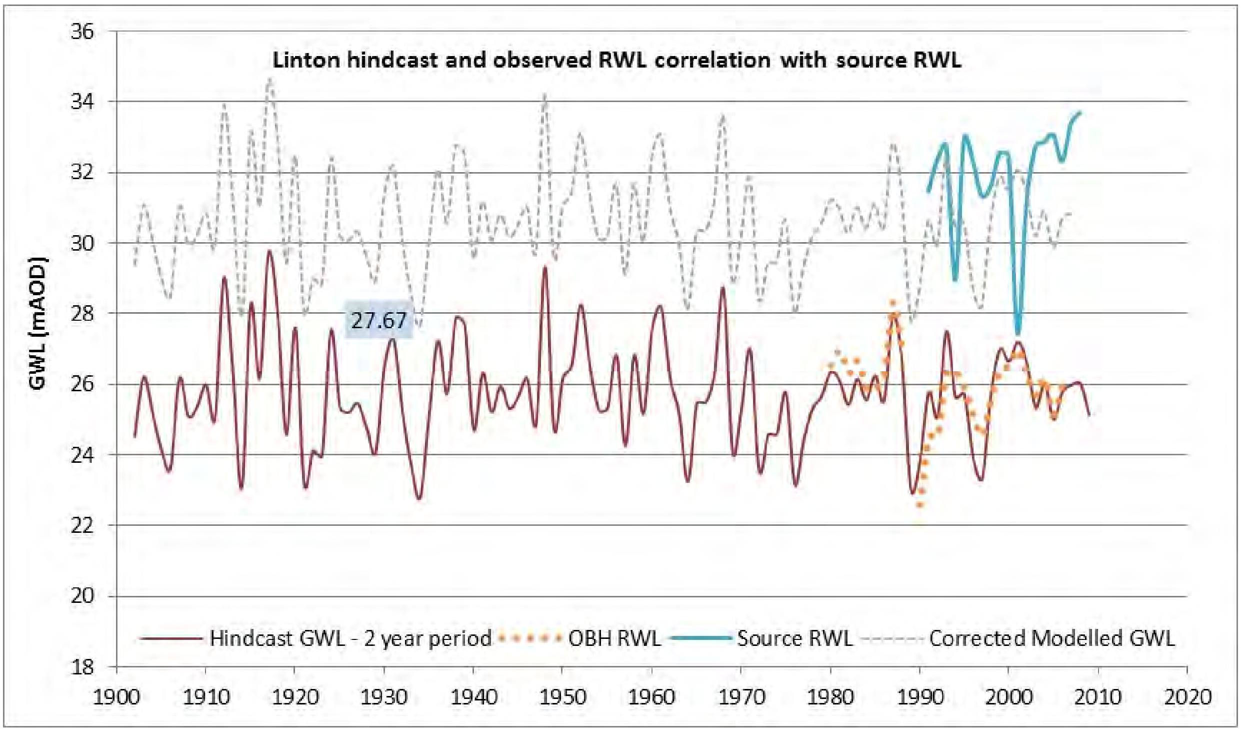

Hinxton Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
23.5
23
22.5
22
21.5
21
20.5
20
19.5
19
20.22
Hindcast GWL - 3 year period
OBH RWL
Source RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

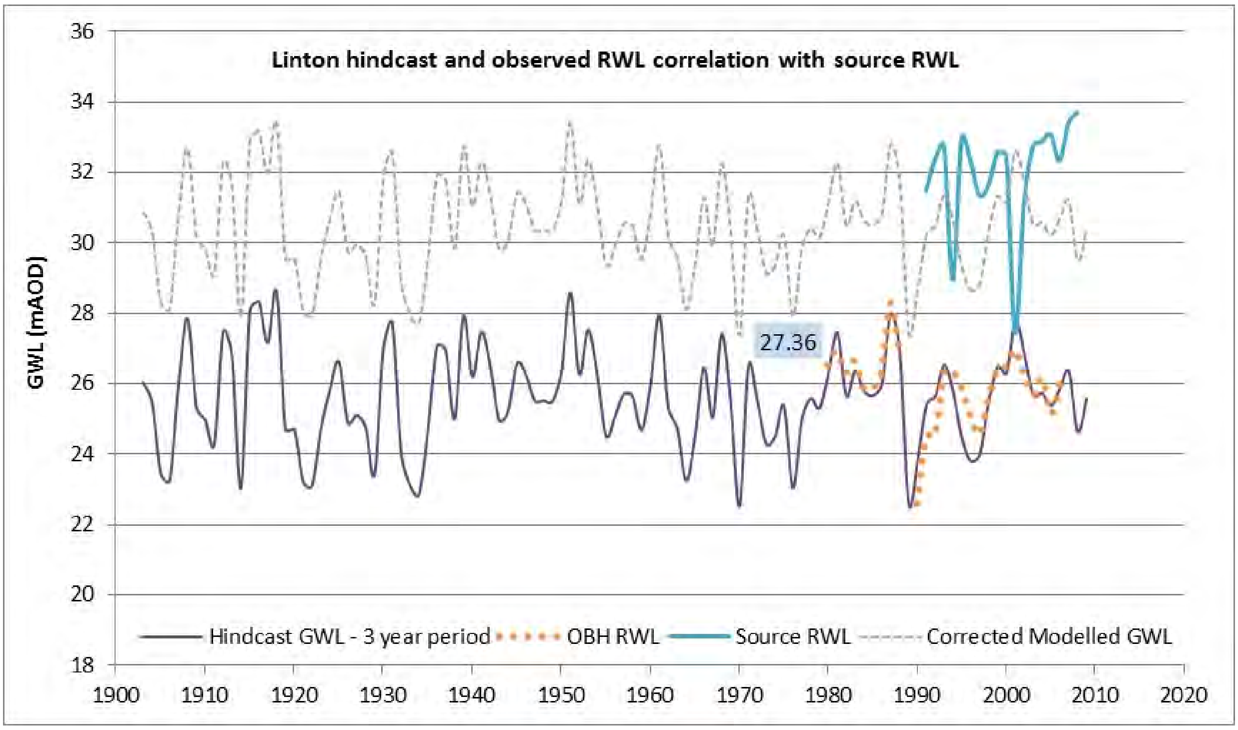

Kingston hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
25
23
21
19
17
15
13
11
9
7
5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
10.54
Hindcast GWL - 1 year period
OBH RWL
Source RWL
Source PWL

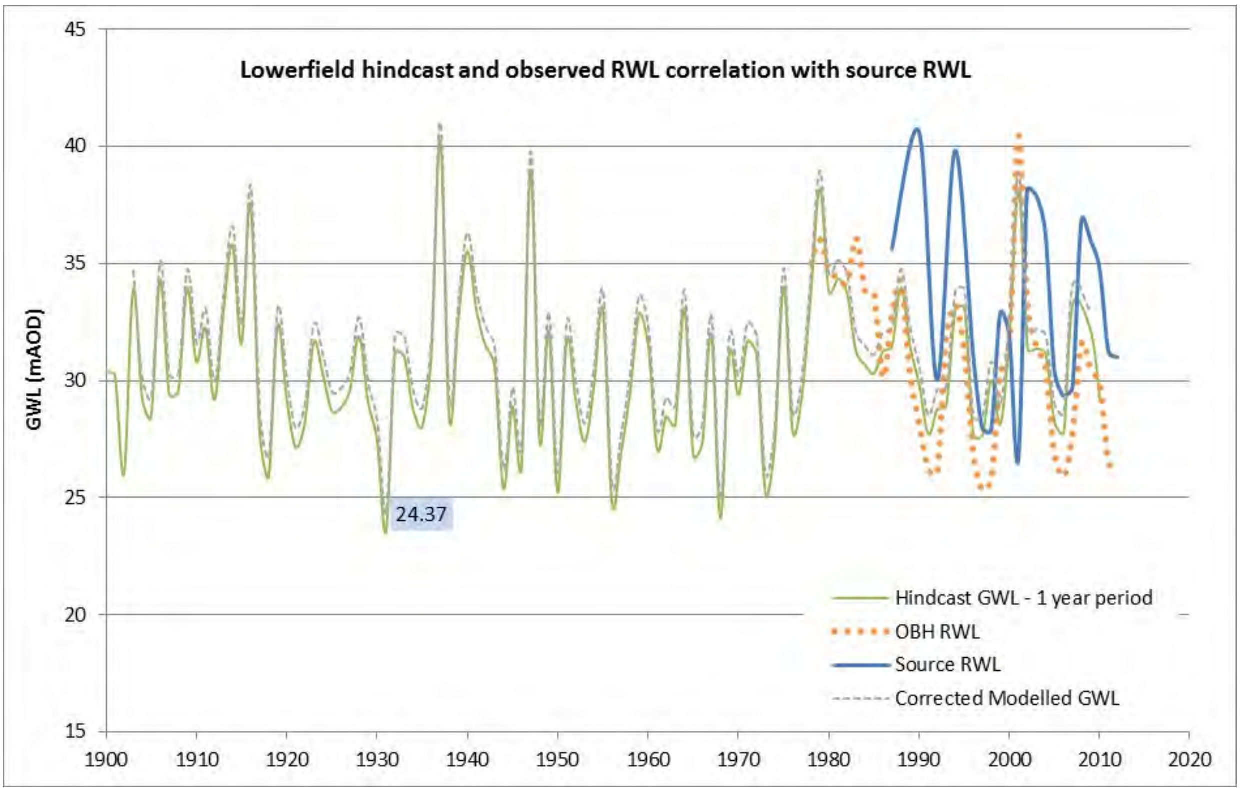

Kingston hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
25
23
21
19
17
15
13
11
9
7
5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
11.98
Hindcast GWL - 2 year period
OBH RWL
Source RWL
Source PWL

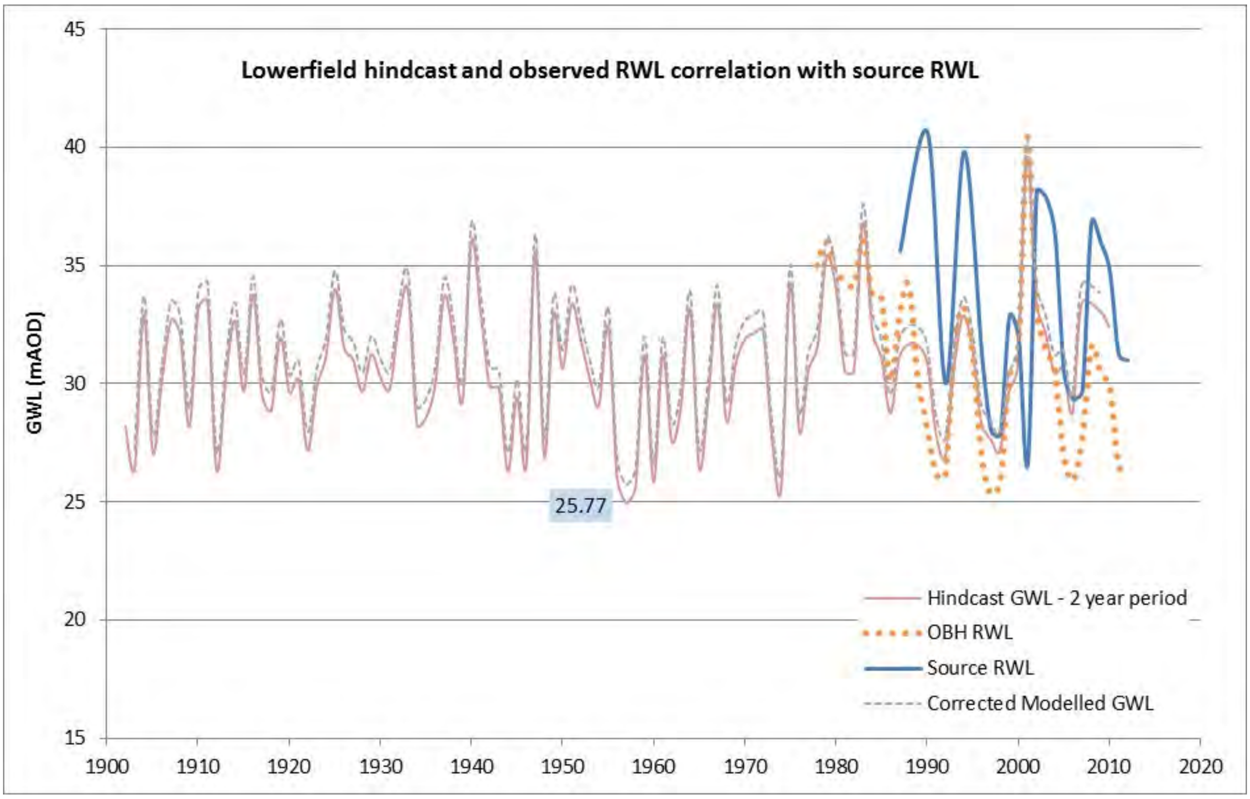

Kingston hindcast and observed RWL correlation with source RWL/PWL
GWL (mAOD)
25
23
21
19
17
15
13
11
9
7
5
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
10.60
Hindcast GWL - 3 year period
OBH RWL
Source RWL
Source PWL

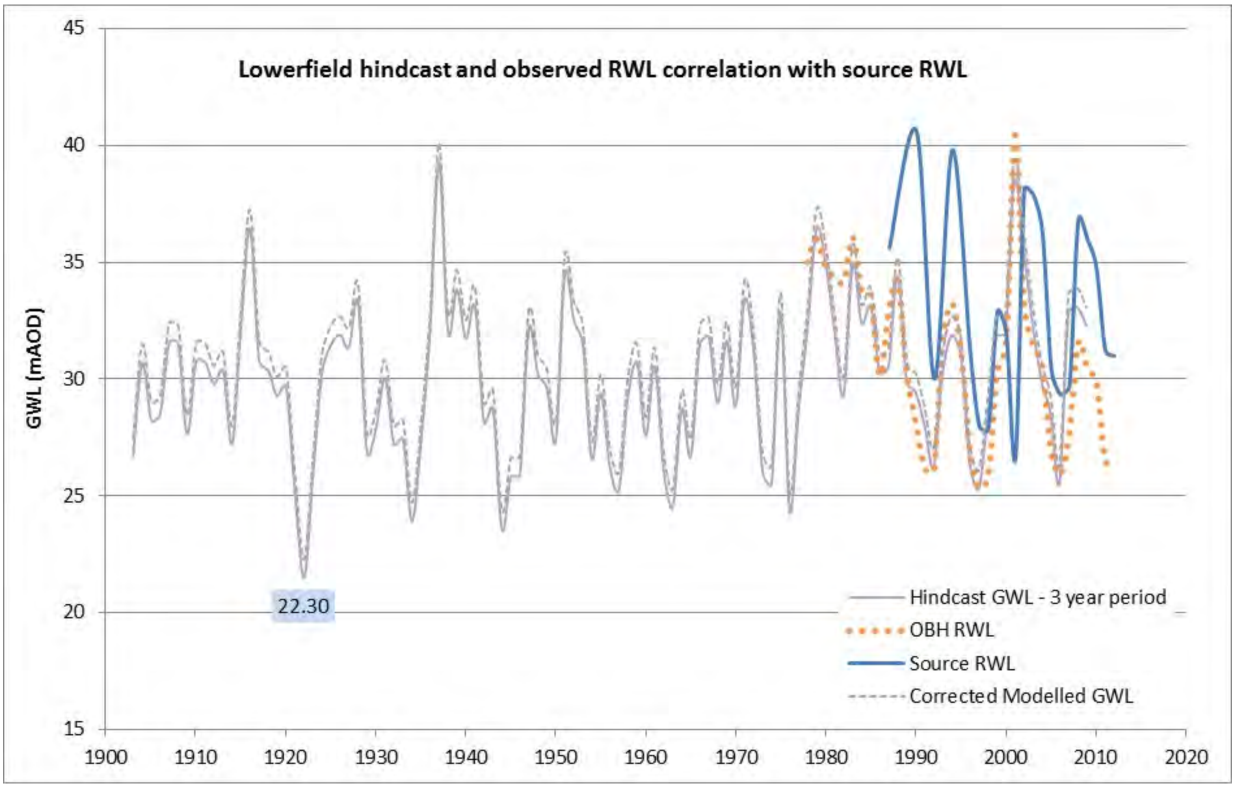

Linton hindcast and observed RWL correlation with source RWL
GWL (mAOD)
36
34
32
30
28
26
24
22
20
18
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
27.17
Hindcast GWL - 1 year period
OBH RWL
Source RWL
Corrected Modelled GWL

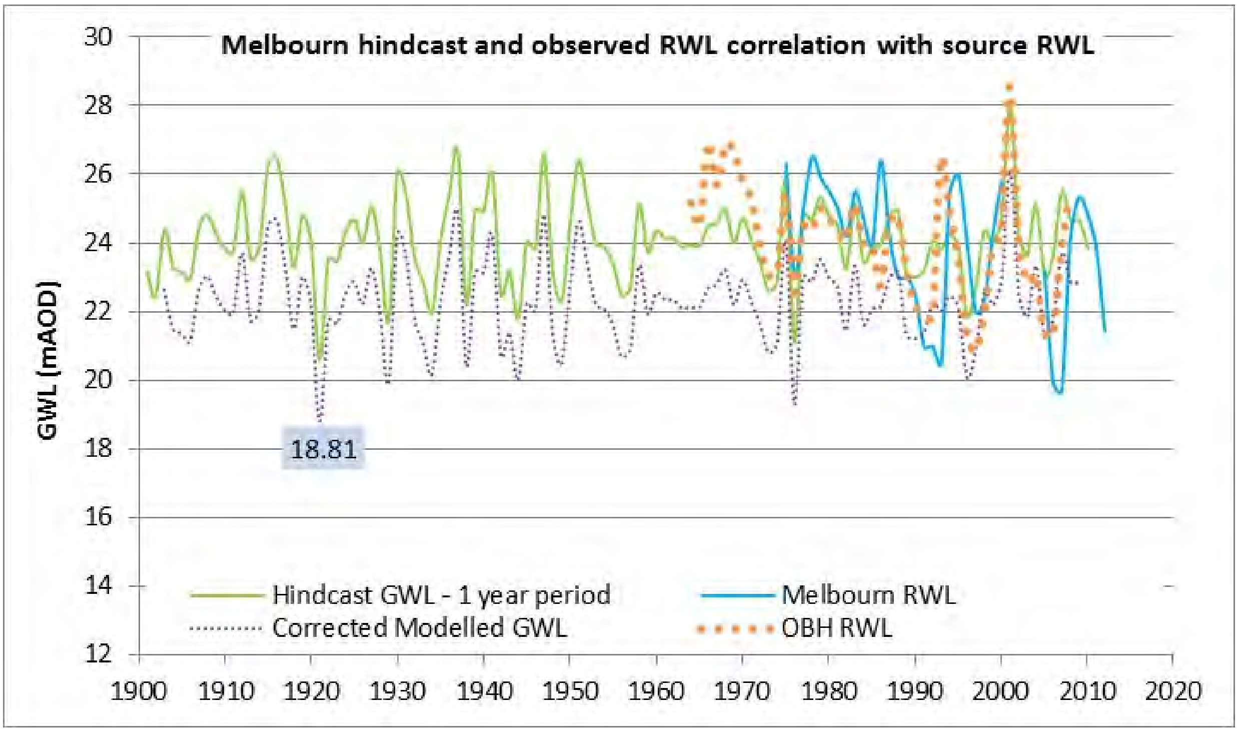

Linton hindcast and observed RWL correlation with source RWL
GWL (mAOD)
36
34
32
30
28
26
24
22
20
18
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
27.67
Hindcast GWL - 2 year period
OBH RWL
Source RWL
Corrected Modelled GWL

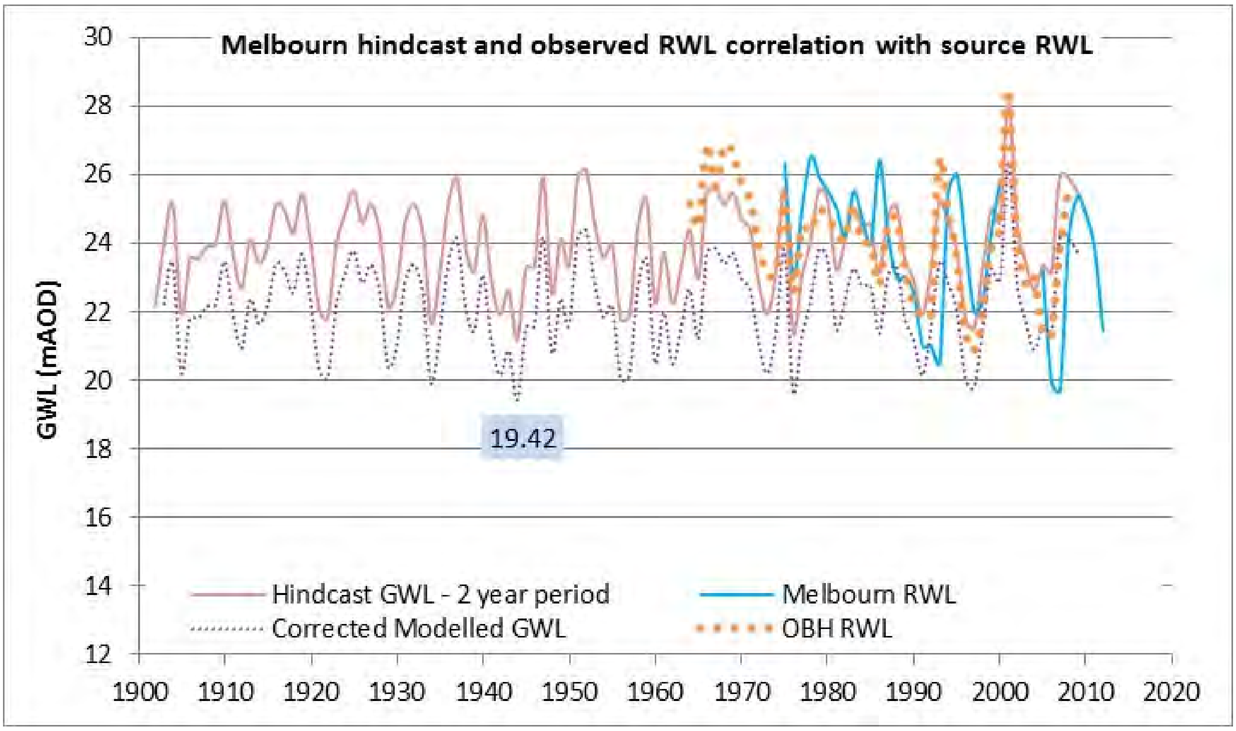

Linton hindcast and observed RWL correlation with source RWL
GWL (mAOD)
36
34
32
30
28
26
24
22
20
18
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
27.36
Hindcast GWL - 3 year period
OBH RWL
Source RWL
Corrected Modelled GWL

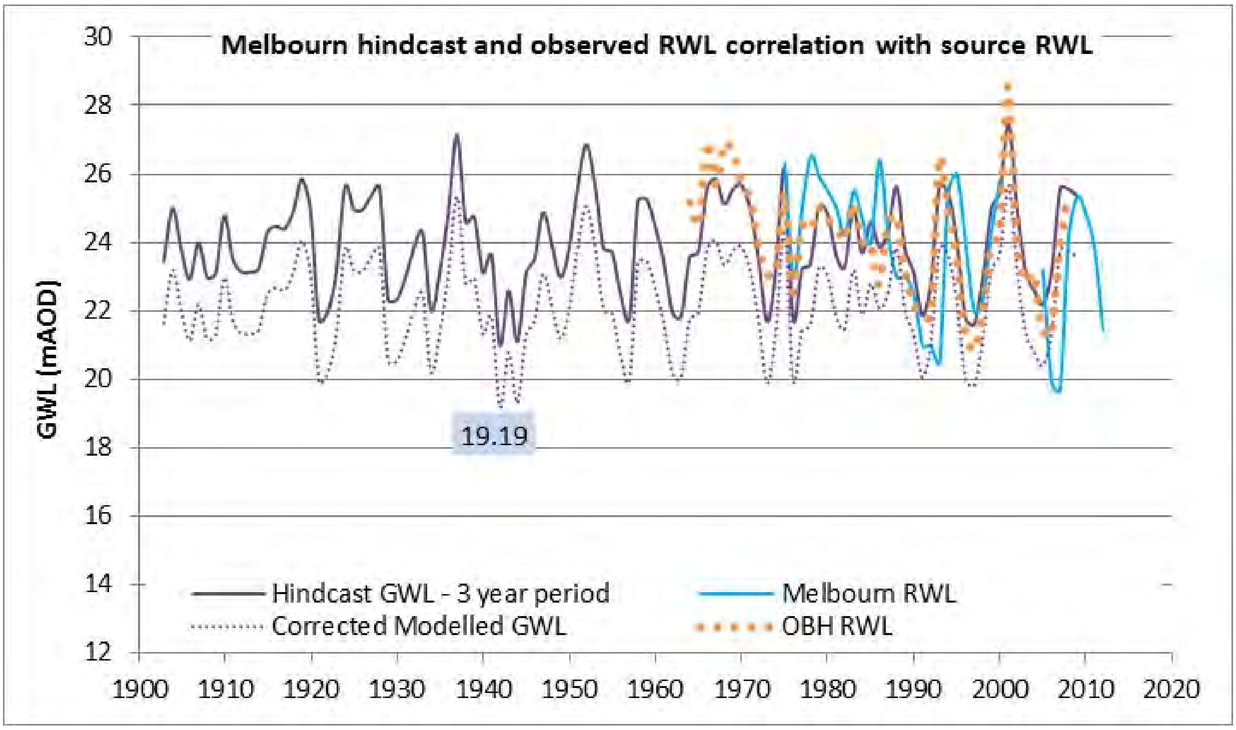

Lowerfield hindcast and observed RWL correlation with source RWL
GWL (mAOD)
45
40
35
30
25
20
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
24.37
Hindcast GWL - 1 year period
OBH RWL
Source RWL
Corrected Modelled GWL

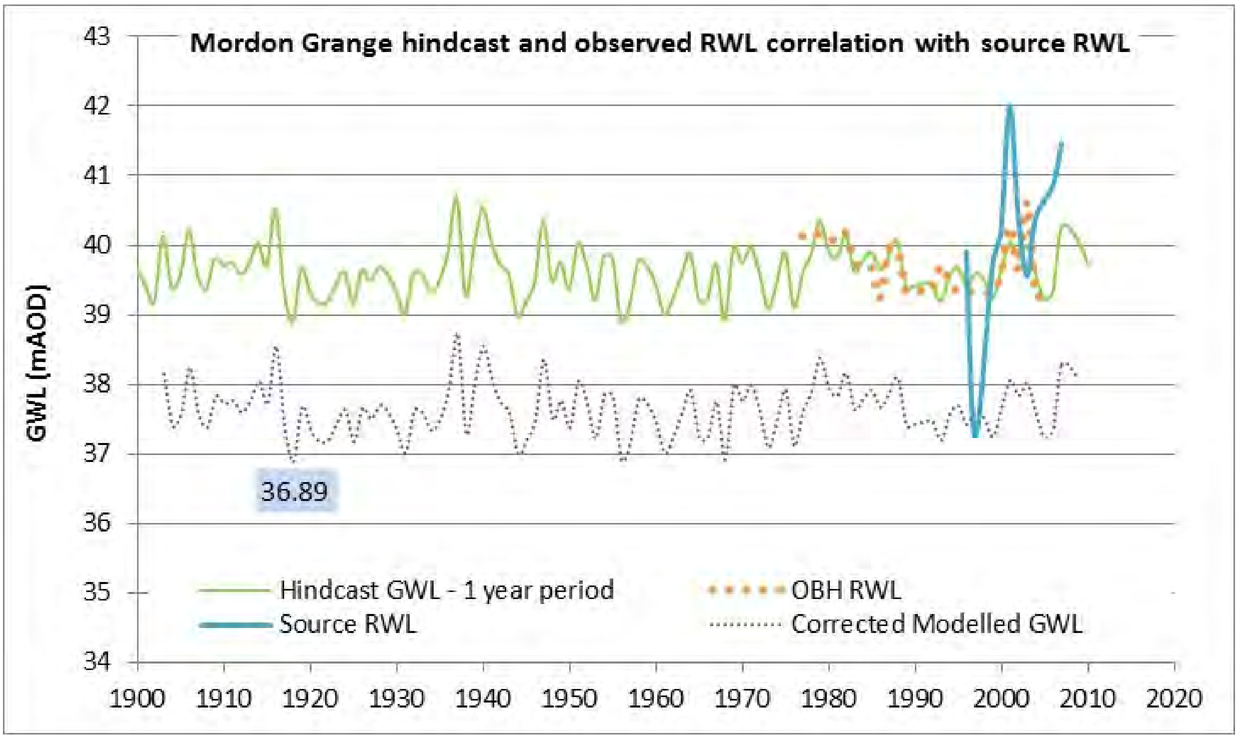

Lowerfield hindcast and observed RWL correlation with source RWL
GWL (mAOD)
45
40
35
30
25
20
15
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
25.77
Hindcast GWL - 2 year period
OBH RWL
Source RWL
Corrected Modelled GWL

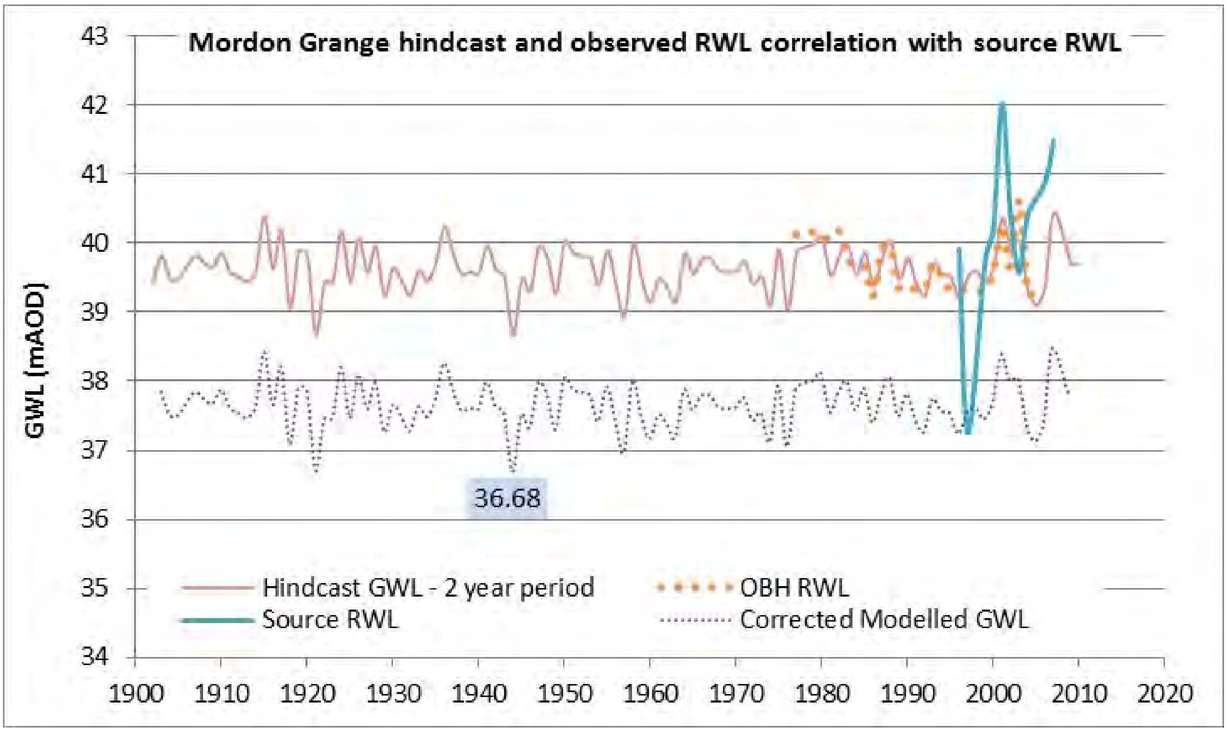

Lowerfield hindcast and observed RWL correlation with source RWL
GWL (mAOD)
45
40
35
30
25
20
15
22.30
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Hindcast GWL - 3 year period
OBH RWL
Source RWL
Corrected Modelled GWL

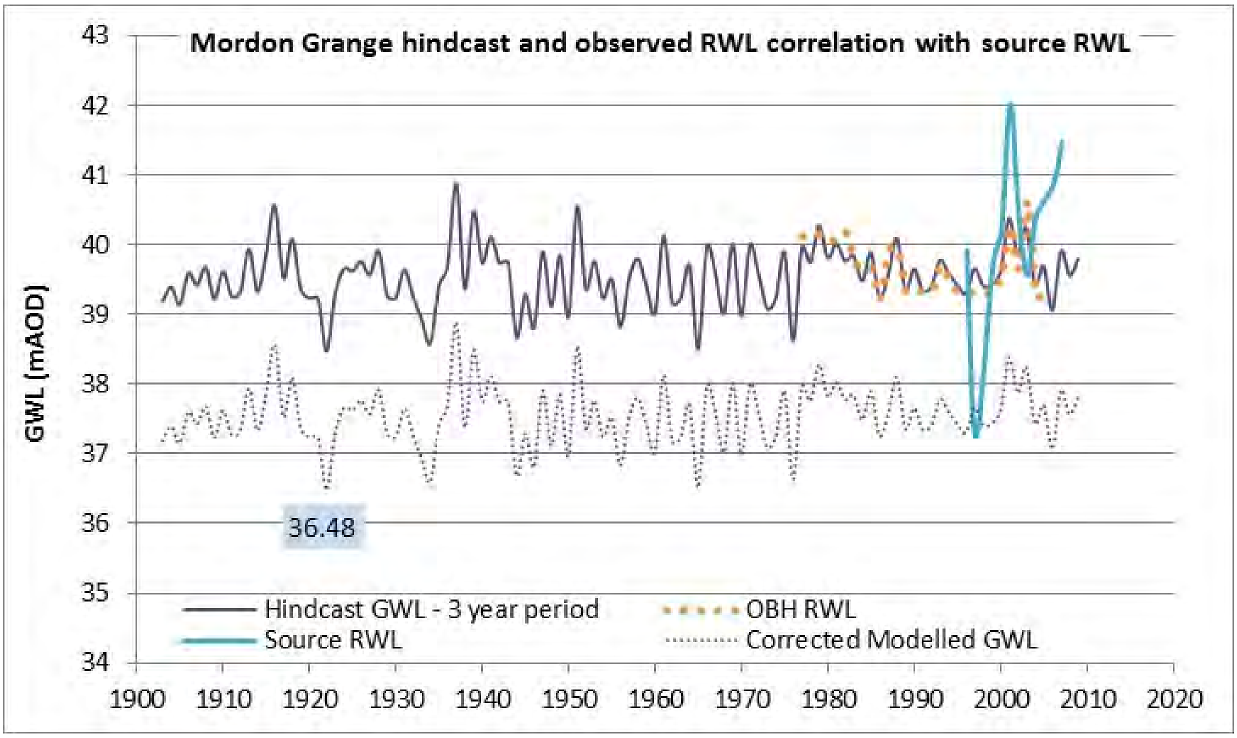

Melbourn hindcast and observed RWL correlation with source RWL
GWL (mAOD)
30
28
26
24
22
20
18
16
14
12
18.81
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
Hindcast GWL - 1 year period
Corrected Modelled GWL
Melbourn RWL
OBH RWL

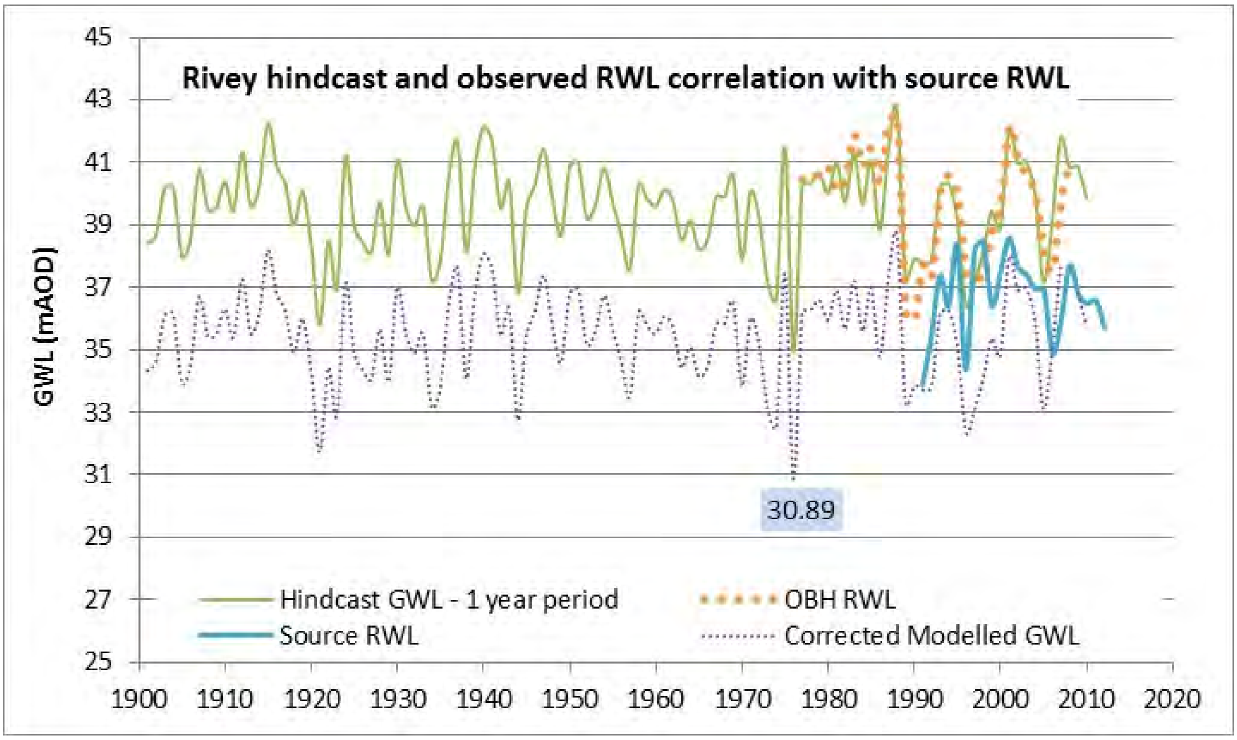

Melbourn hindcast and observed RWL correlation with source RWL
GWL (mAOD)
30
28
26
24
22
20
18
16
14
12
19.42
Hindcast GWL - 2 year period
Corrected Modelled GWL
Melbourn RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

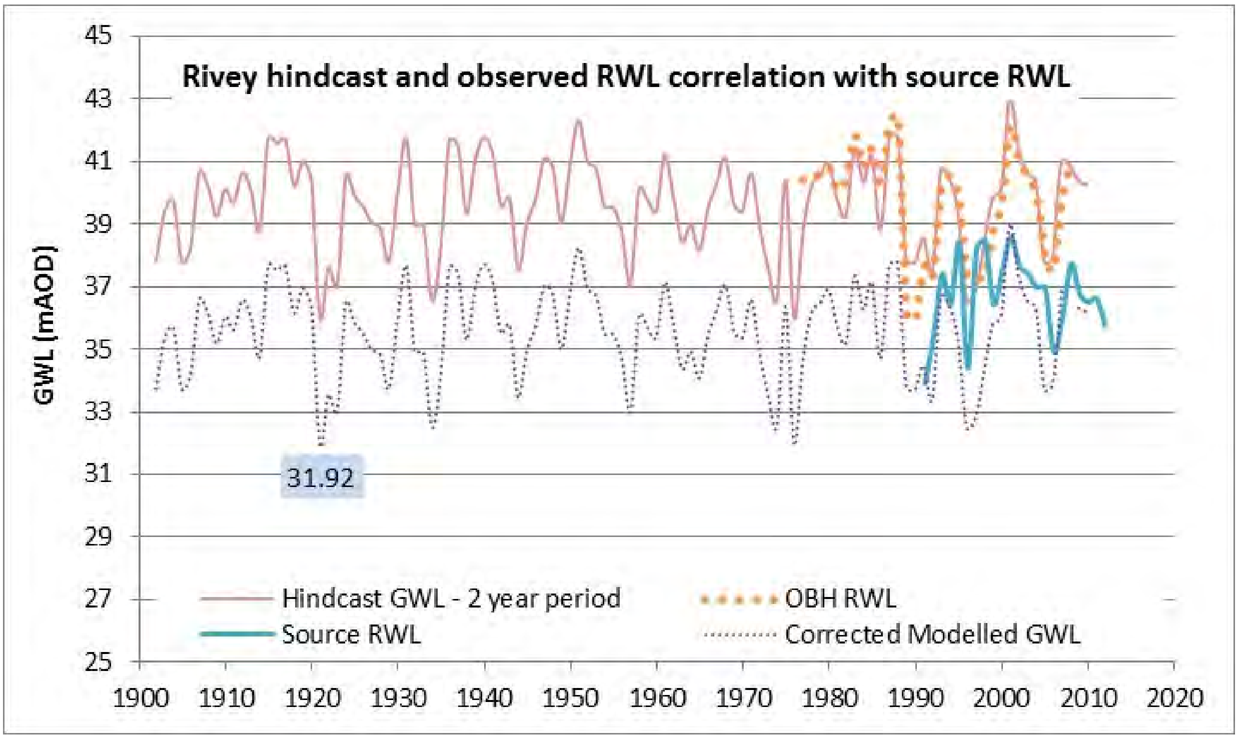

Melbourn hindcast and observed RWL correlation with source RWL
GWL (mAOD)
30
28
26
24
22
20
18
16
14
12
19.19
Hindcast GWL - 3 year period
Corrected Modelled GWL
Melbourn RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

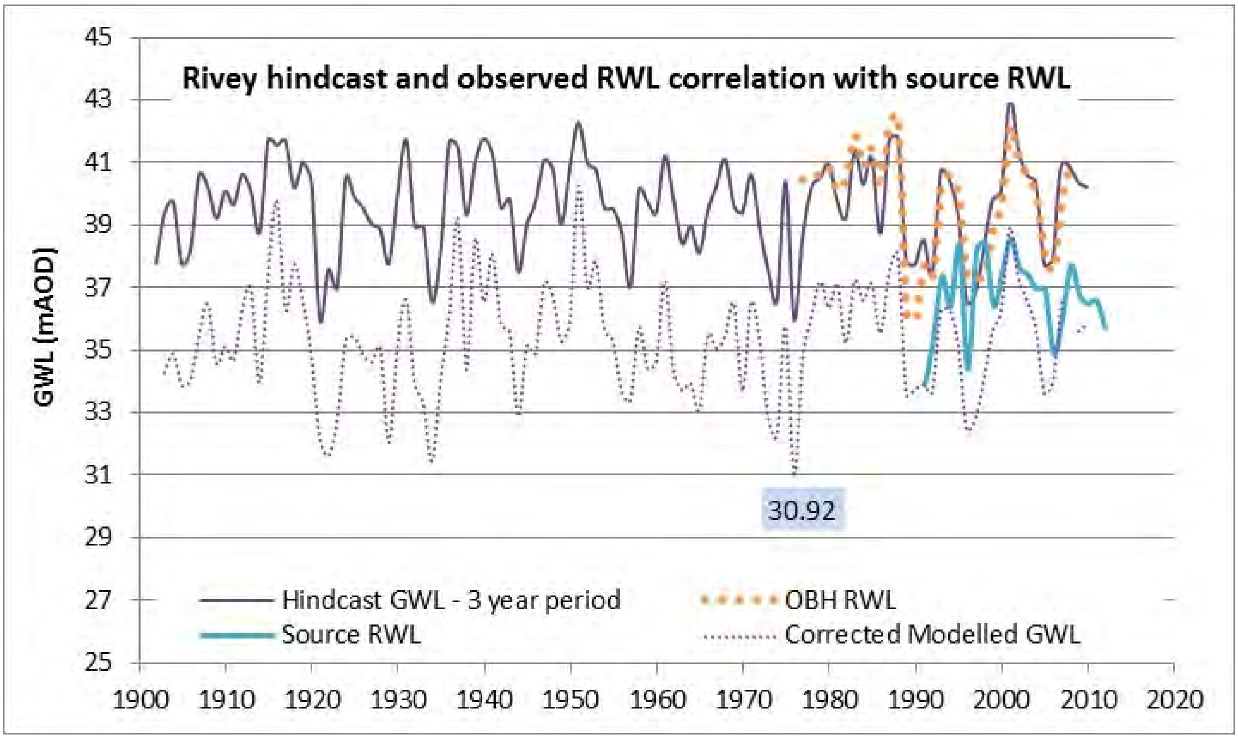

Mordon Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
43
42
41
40
39
38
37
36
35
34
36.89
Hindcast GWL - 1 year period
Source RWL
OBH RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

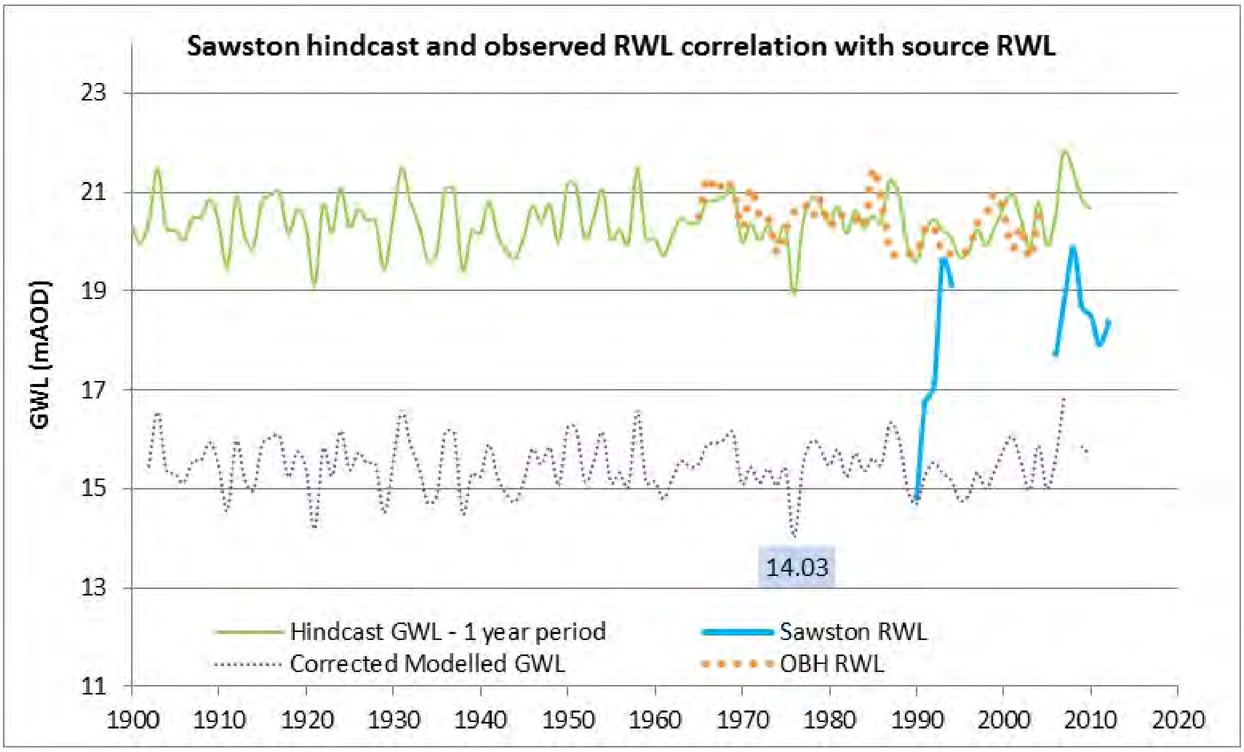

Mordon Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
43
42
41
40
39
38
37
36
35
34
36.68
Hindcast GWL - 2 year period
Source RWL
OBH RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

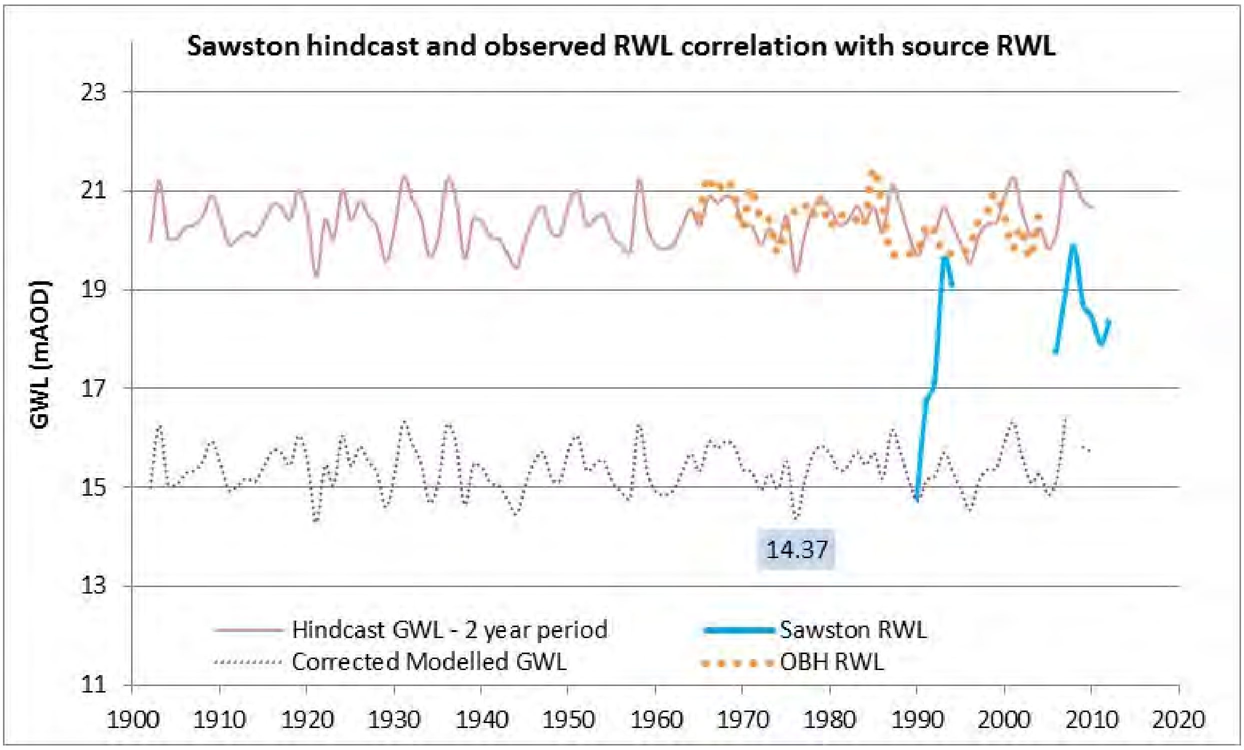

Mordon Grange hindcast and observed RWL correlation with source RWL
GWL (mAOD)
43
42
41
40
39
38
37
36
35
34
36.48
Hindcast GWL - 3 year period
Source RWL
OBH RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

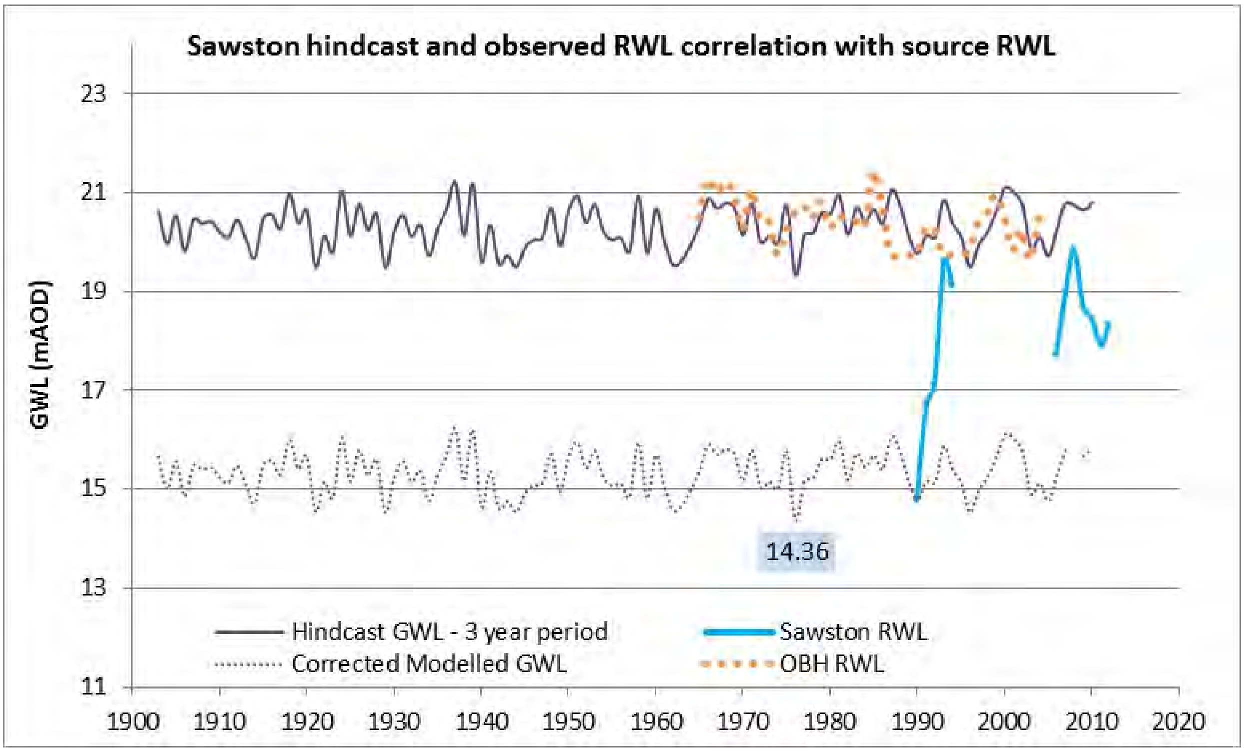

Rivey hindcast and observed RWL correlation with source RWL
GWL (mAOD)
45
43
41
39
37
35
33
31
29
27
25
30.89
Hindcast GWL - 1 year period
Source RWL
OBH RWL
Corrected Modelled GWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

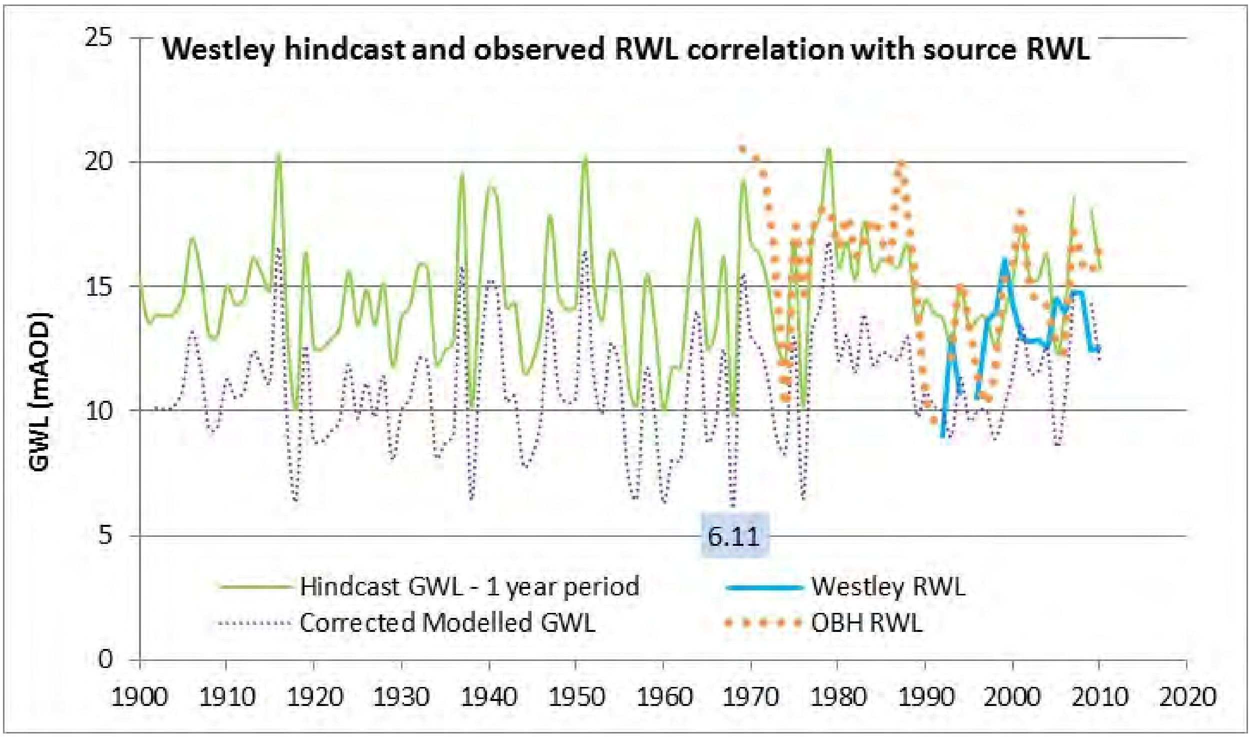

Rivey hindcast and observed RWL correlation with source RWL
GWL (mAOD)
45
43
41
39
37
35
33
31
29
27
25
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
31.92
Hindcast GWL - 2 year period
Source RWL
OBH RWL
Corrected Modelled GWL

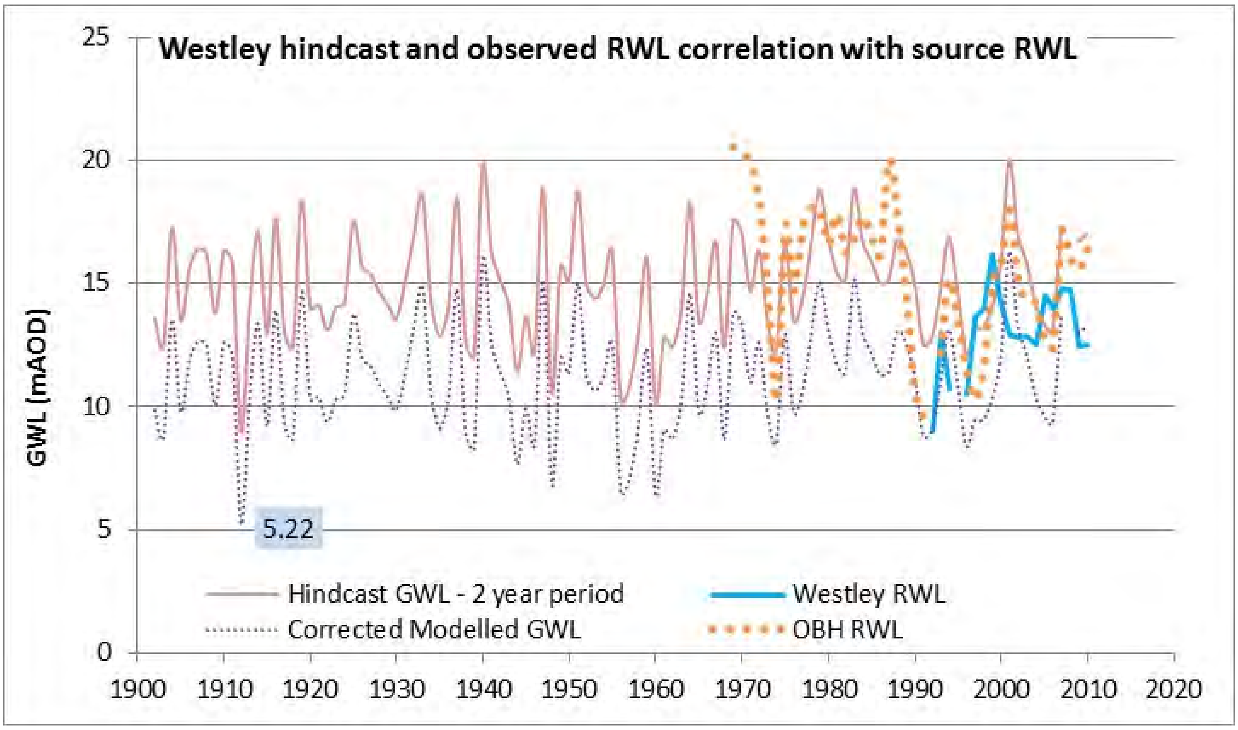

Rivey hindcast and observed RWL correlation with source RWL
GWL (mAOD)
45
43
41
39
37
35
33
31
29
27
25
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020
30.92
Hindcast GWL - 3 year period
Source RWL
OBH RWL
Corrected Modelled GWL

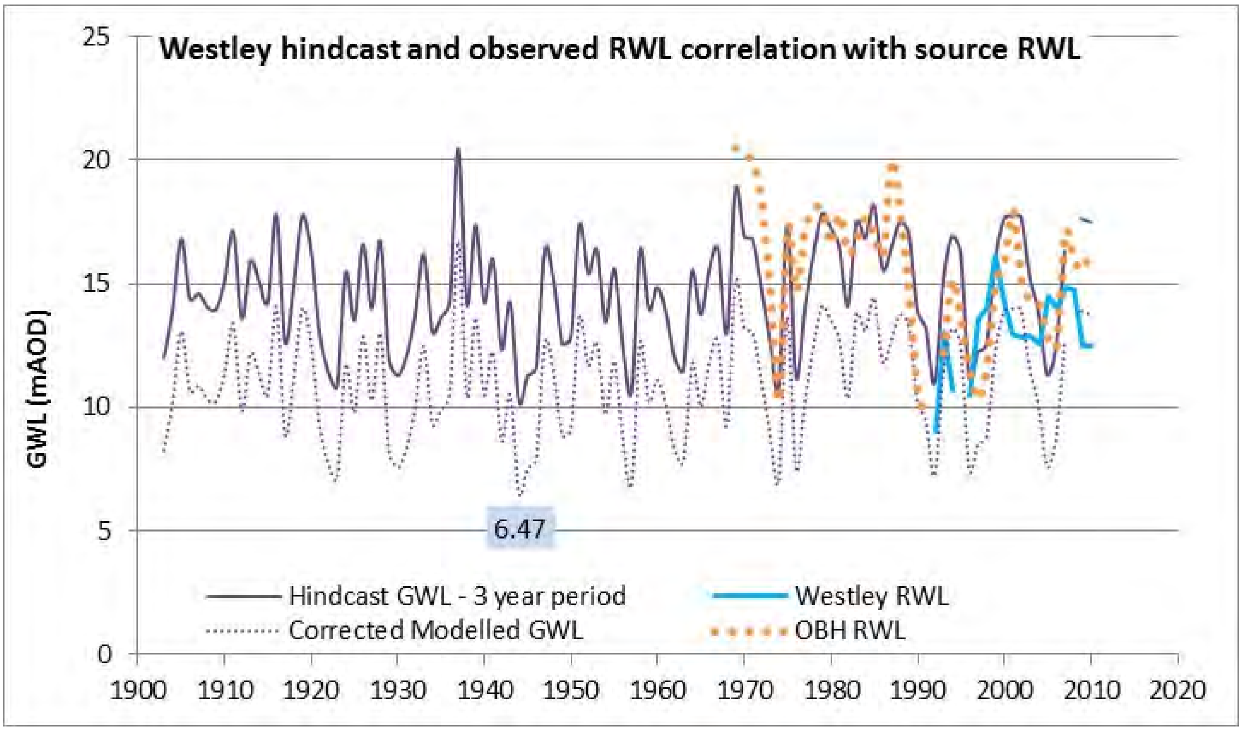

Sawston hindcast and observed RWL correlation with source RWL
GWL (mAOD)
23
21
19
17
15
13
11
14.03
Hindcast GWL - 1 year period
Corrected Modelled GWL
Sawston RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

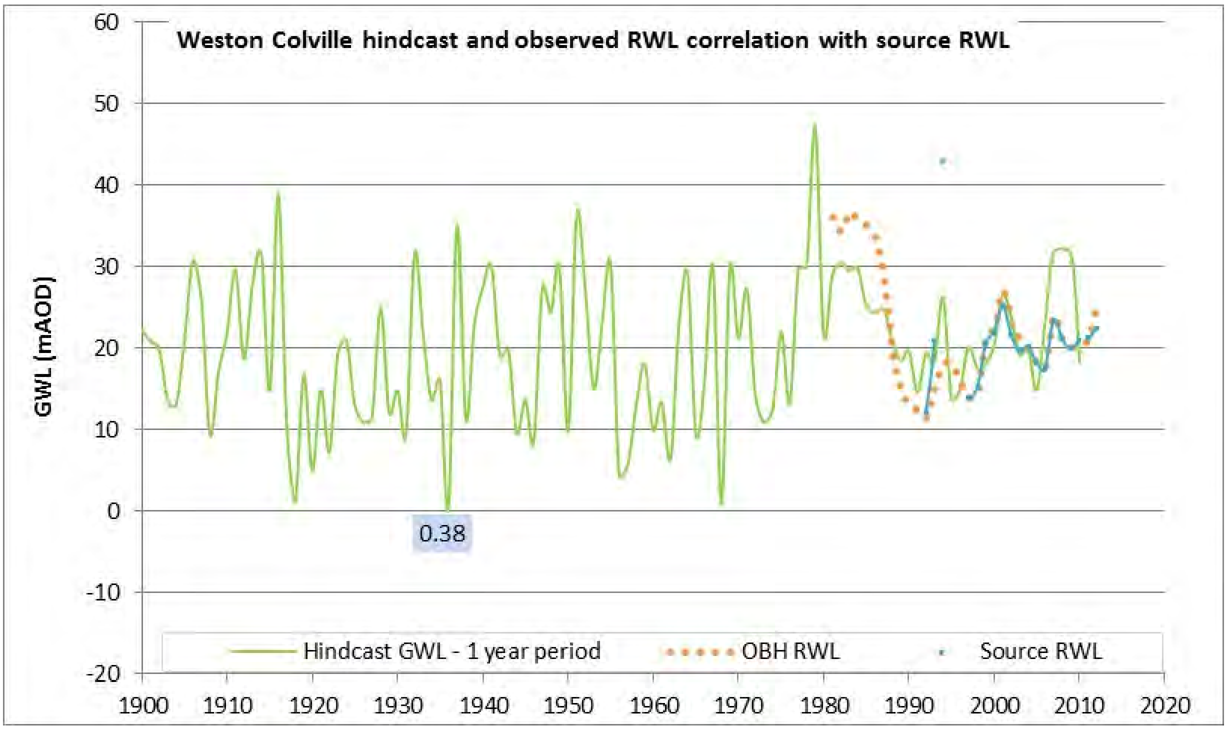

Sawston hindcast and observed RWL correlation with source RWL
GWL (mAOD)
23
21
19
17
15
13
11
14.37
Hindcast GWL - 2 year period
Corrected Modelled GWL
Sawston RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

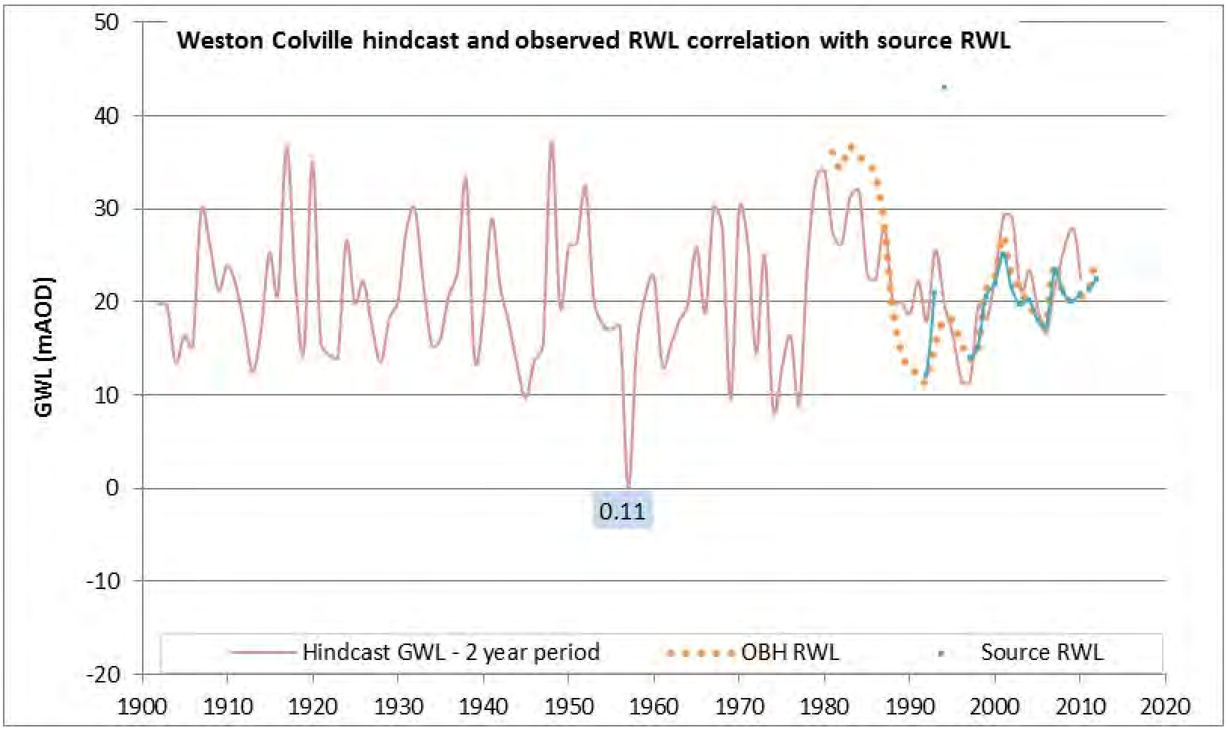

Sawston hindcast and observed RWL correlation with source RWL
GWL (mAOD)
23
21
19
17
15
13
11
14.36
Hindcast GWL - 3 year period
Corrected Modelled GWL
Sawston RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

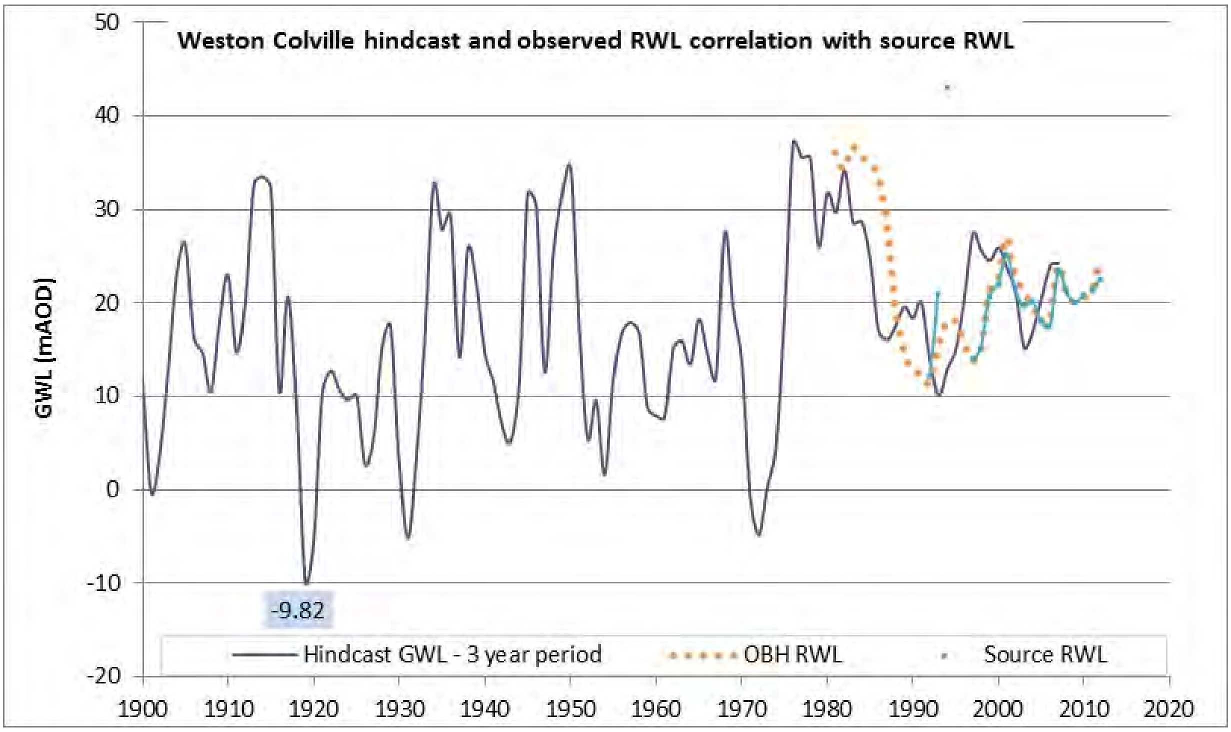

Westley hindcast and observed RWL correlation with source RWL
GWL (mAOD)
25
20
15
10
5
0
6.11
Hindcast GWL - 1 year period
Corrected Modelled GWL
Westley RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020


Westley hindcast and observed RWL correlation with source RWL
GWL (mAOD)
25
20
15
10
5
0
5.22
Hindcast GWL - 2 year period
Corrected Modelled GWL
Westley RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020


Westley hindcast and observed RWL correlation with source RWL
GWL (mAOD)
25
20
15
10
5
0
6.47
Hindcast GWL - 3 year period
Corrected Modelled GWL
Westley RWL
OBH RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

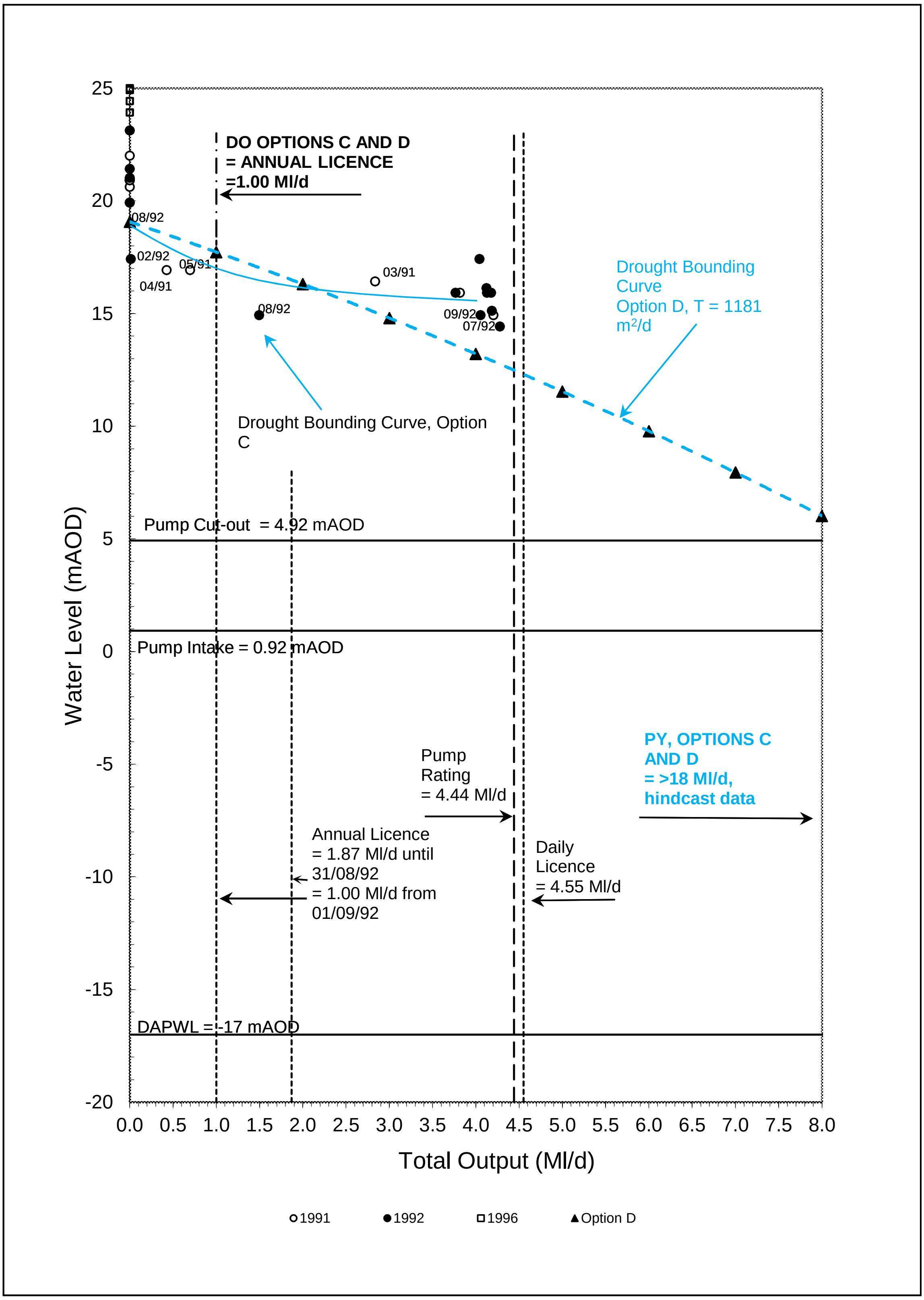

Weston Colville hindcast and observed RWL correlation with source RWL
GWL (mAOD)
60
50
40
30
20
10
0
-10
-20
0.38
Hindcast GWL - 1 year period
OBH RWL
Source RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

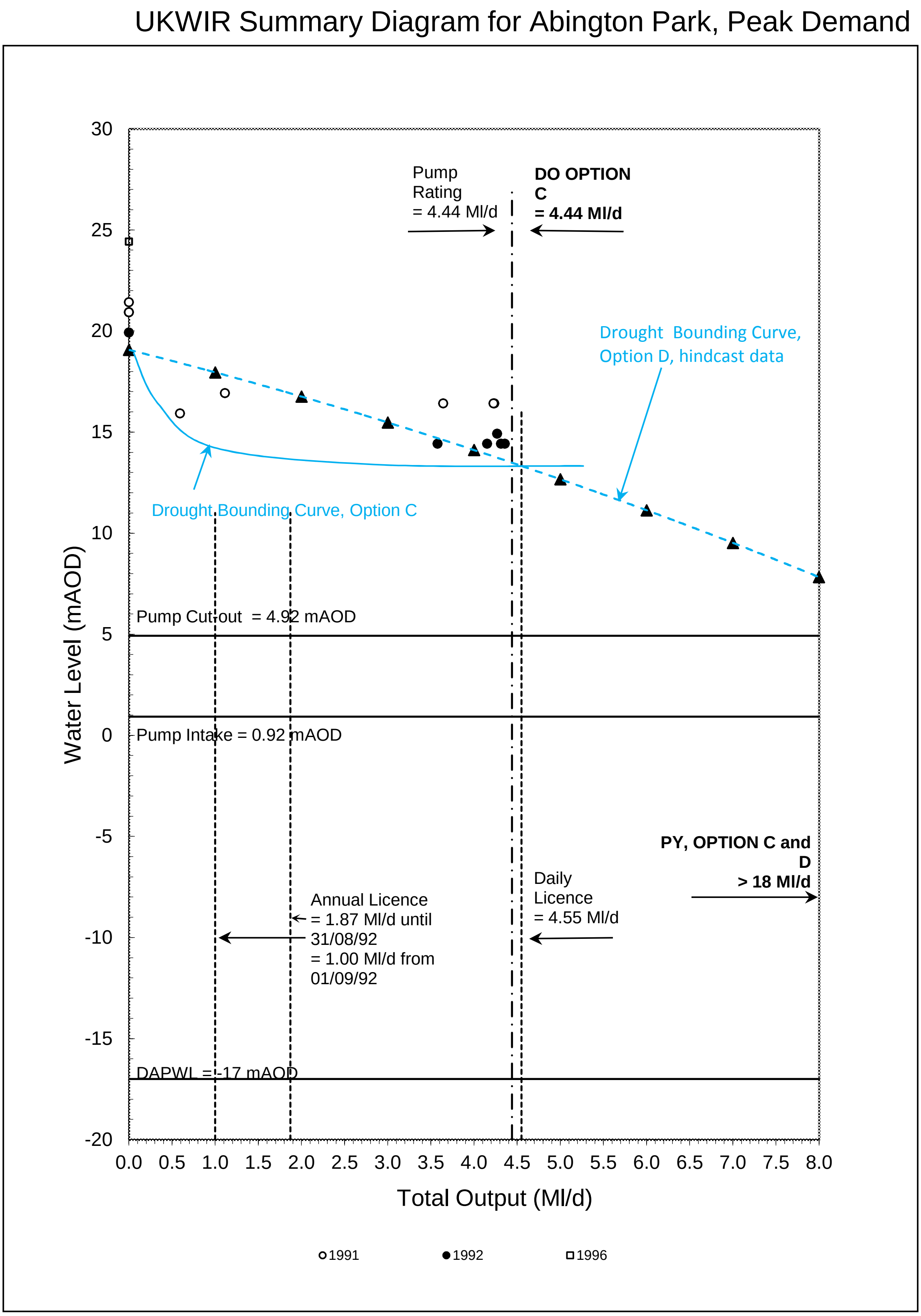

Weston Colville hindcast and observed RWL correlation with source RWL
GWL (mAOD)
50
40
30
20
10
0
-10
-20
0.11
Hindcast GWL - 2 year period
OBH RWL
Source RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020


Weston Colville hindcast and observed RWL correlation with source RWL
GWL (mAOD)
50
40
30
20
10
0
-10
-20
-9.82
Hindcast GWL - 3 year period
OBH RWL
Source RWL
1900
1910
1920
1930
1940
1950
1960
1970
1980
1990
2000
2010
2020

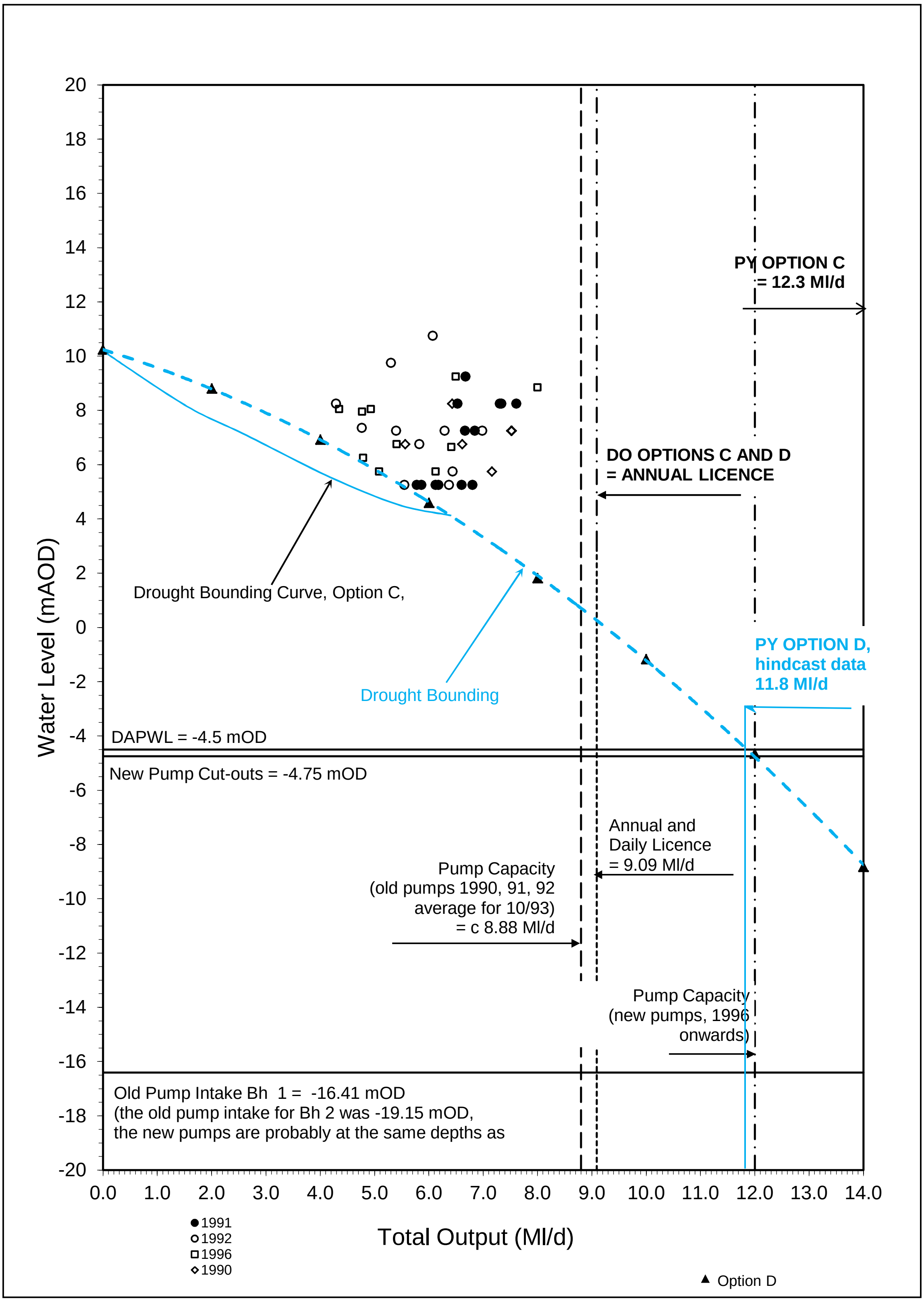
Appendix D. Drought Curves

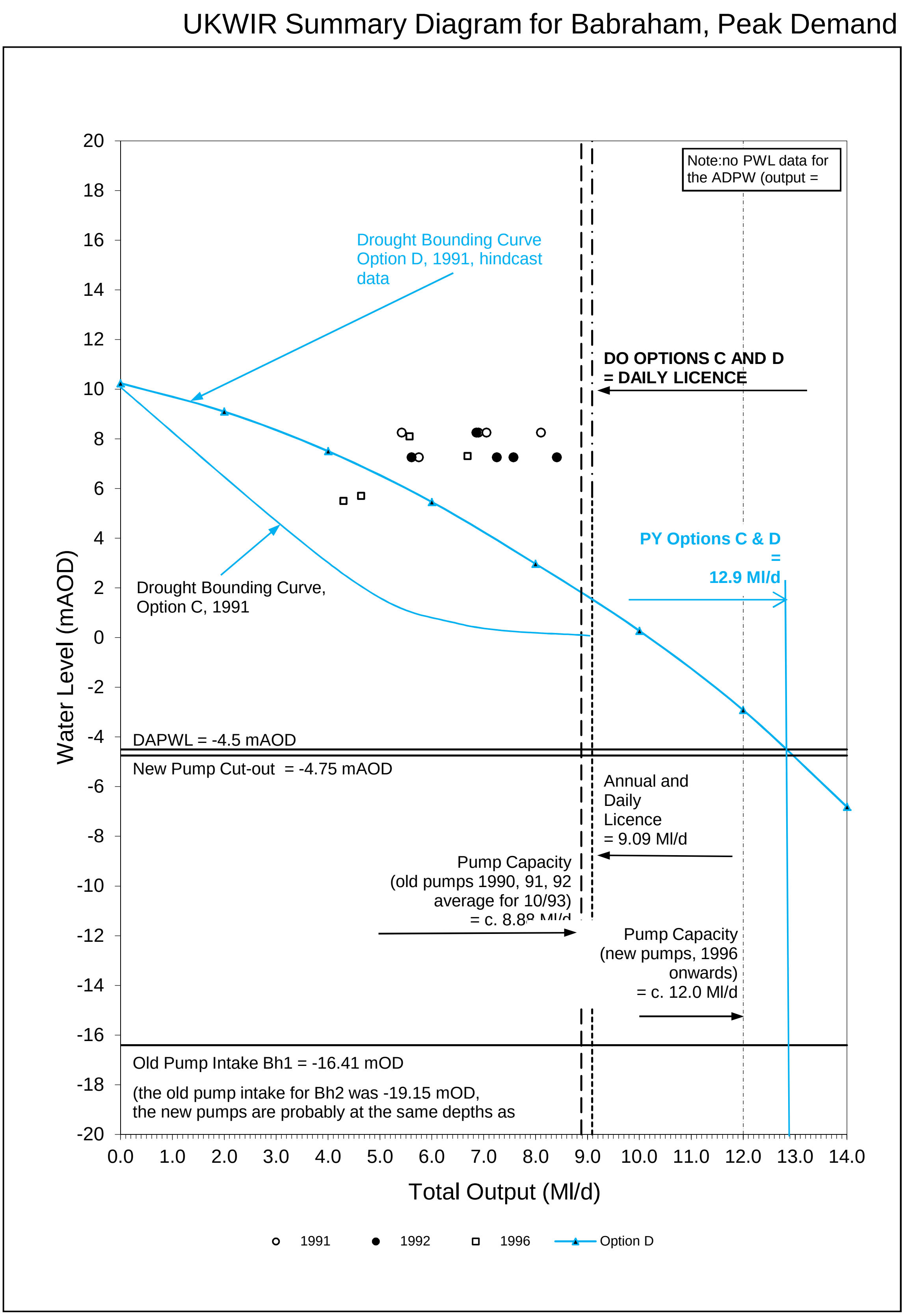
UKWIR Summary Diagram for Abington Park, Average Demand




UKWIR Summary Diagram for Abington Park, Peak Demand
Pump Rating = 4.44 Ml/d
DO OPTION C = 4.44 Ml/d
Drought Bounding Curve, Option D, hindcast data
Drought Bounding Curve, Option C
Pump Cut-out = 4.92 mAOD
Pump Intake = 0.92 mAOD
PY, OPTION C and D > 18 Ml/d
Daily Licence = 4.55 Ml/d
Annual Licence = 1.87 Ml/d until 31/08/92 = 1.00 Ml/d from 01/09/92
DAPWL = -17 mAOD
Water Level (mAOD)
30
25
20
15
10
5
0
-5
-10
-15
-20
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
Total Output (Ml/d)
1991
1992
1996

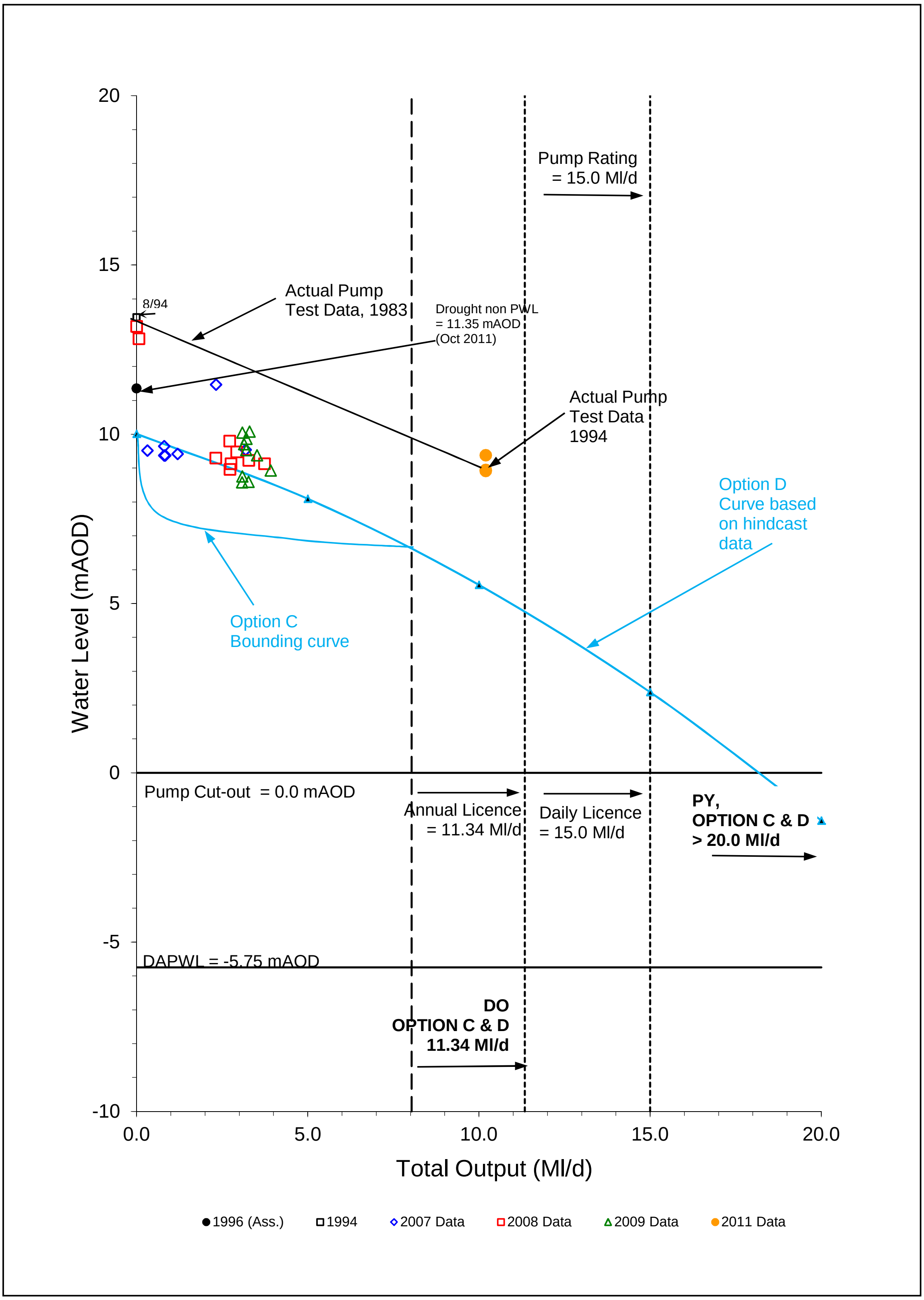
UKWIR Summary Diagram for Babraham, Average Demand



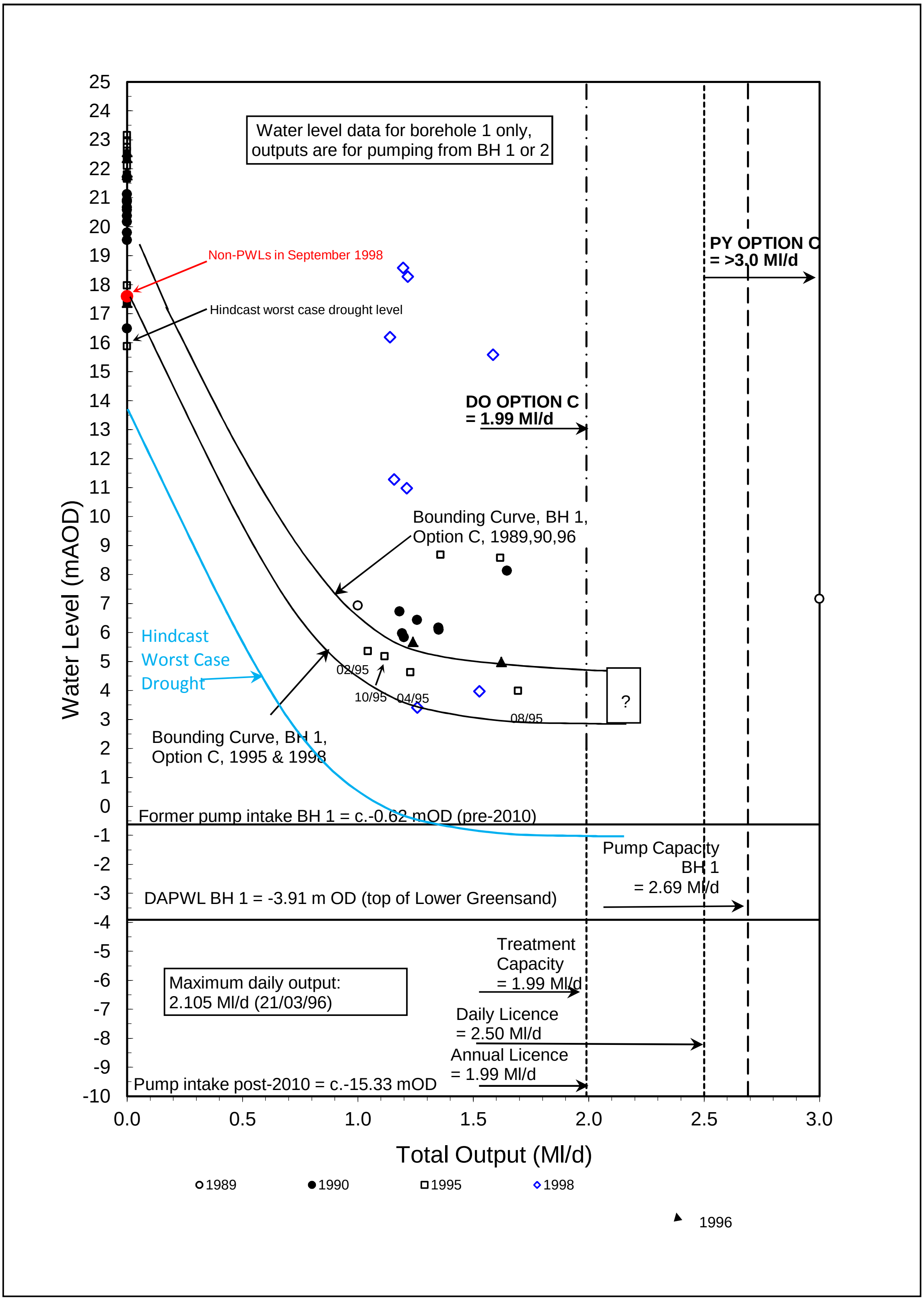


UKWIR Summary Diagram for Babraham, Peak Demand
Note:no PWL data for the ADPW (output =
Drought Bounding Curve Option D, 1991, hindcast data
DO OPTIONS C AND D = DAILY LICENCE
PY Options C & D = 12.9 Ml/d
Drought Bounding Curve, Option C, 1991
DAPWL = -4.5 mAOD
New Pump Cut-out = -4.75 mAOD
Annual and Daily Licence = 9.09 Ml/d
Pump Capacity (old pumps 1990, 91, 92 average for 10/93) = c. 8.8
Pump Capacity (new pumps, 1996 onwards) = c. 12.0 Ml/d
Old Pump Intake Bh1 = -16.41 mOD
(the old pump intake for Bh2 was -19.15 mOD, the new pumps are probably at the same depths as
Water Level (mAOD)
Total Output (Ml/d)
1991
1992
1996
Option D

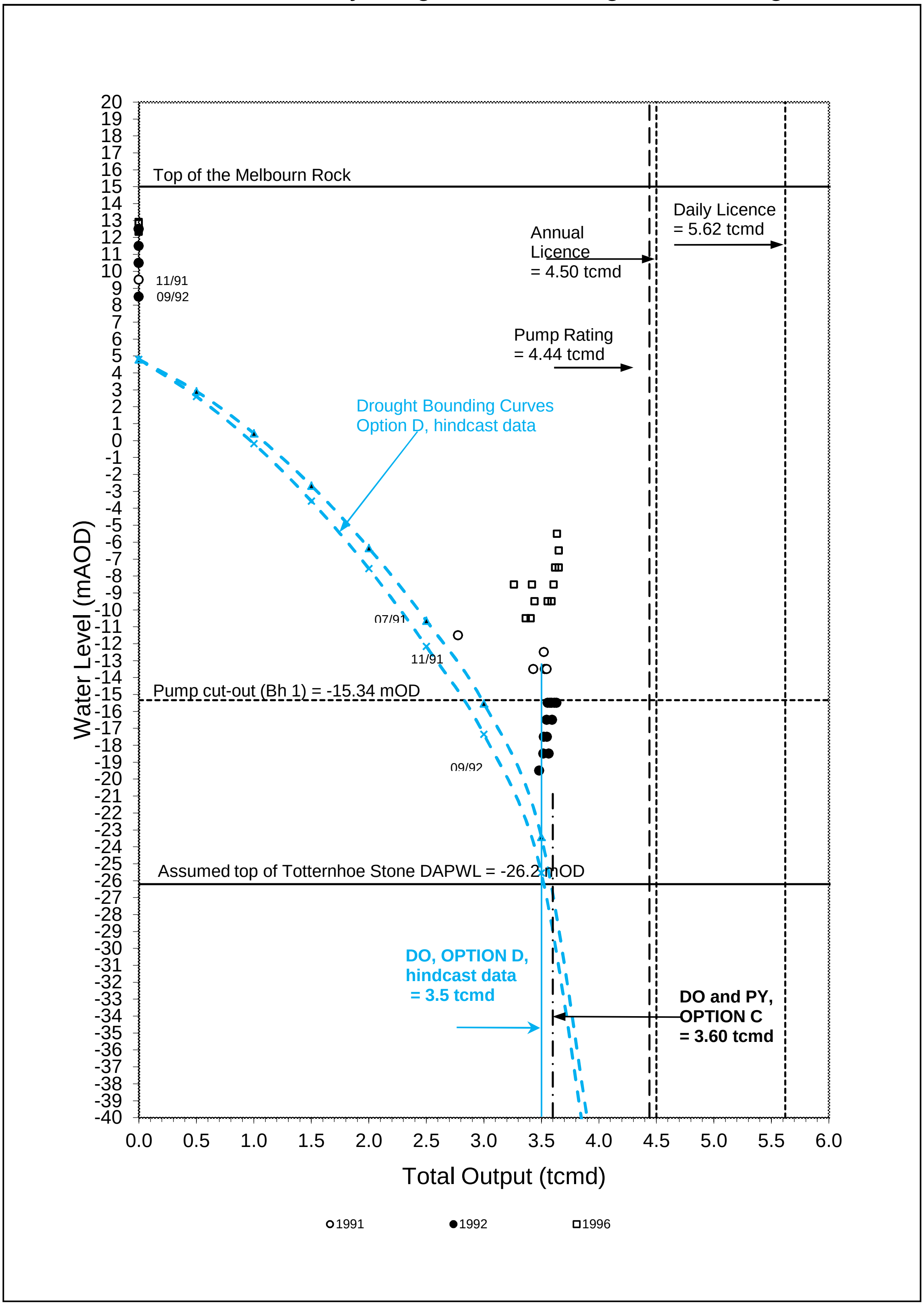
UKWIR Summary Diagram for Brettenham, Average Demand



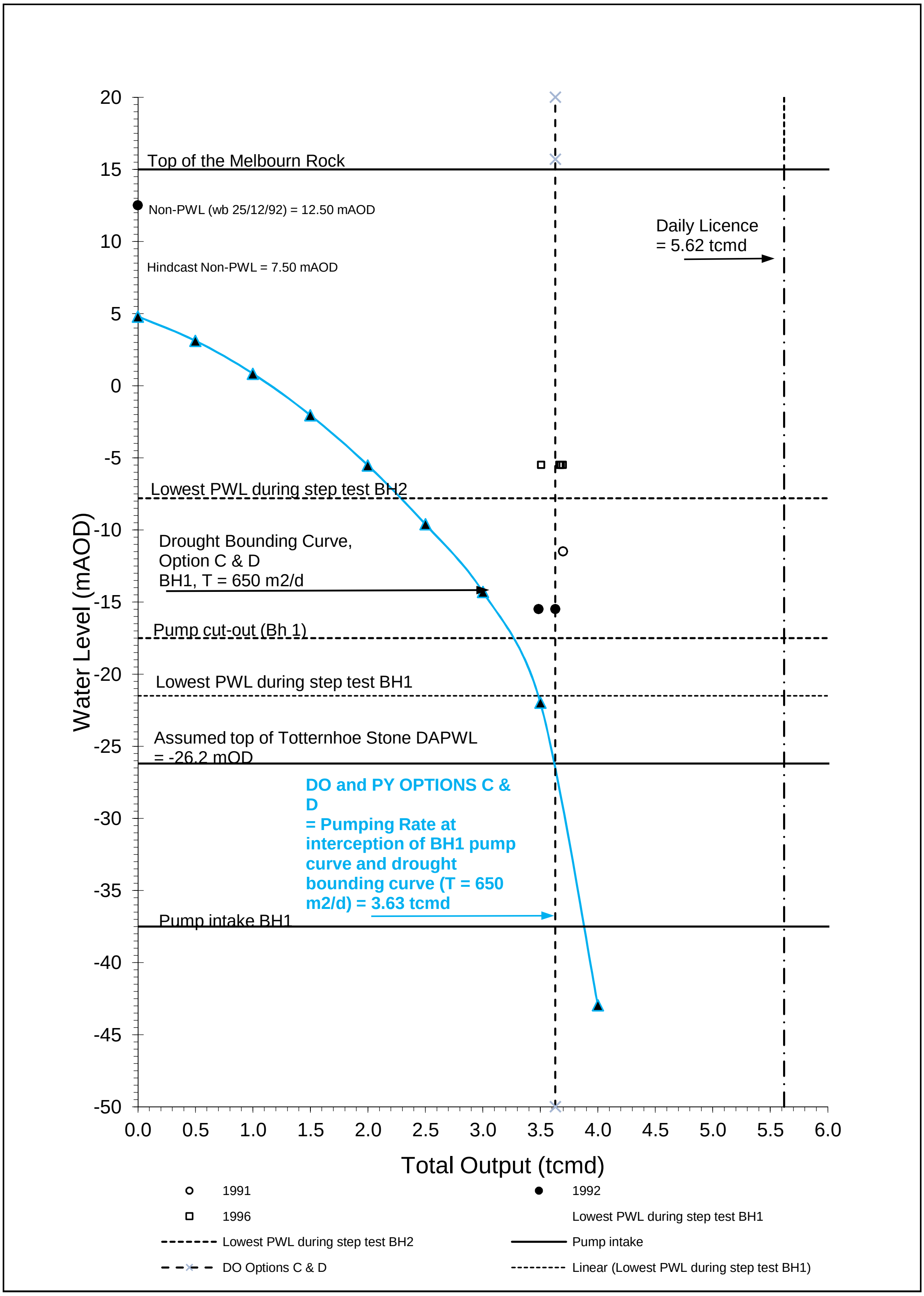
UKWIR Summary Diagram for Croydon, Borehole 1, Average



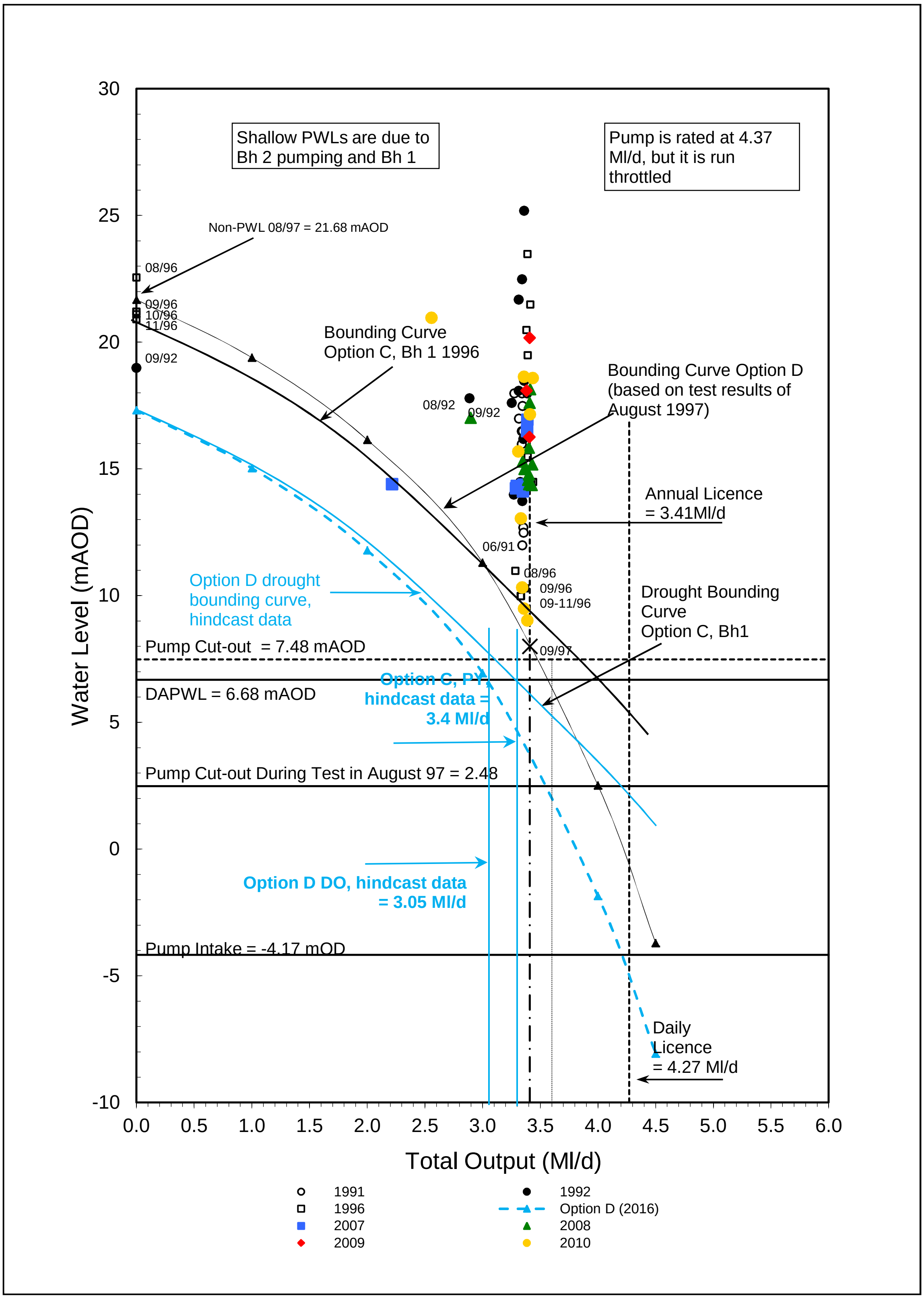
UKWIR Summary Diagram for Dullingham, Average Demand



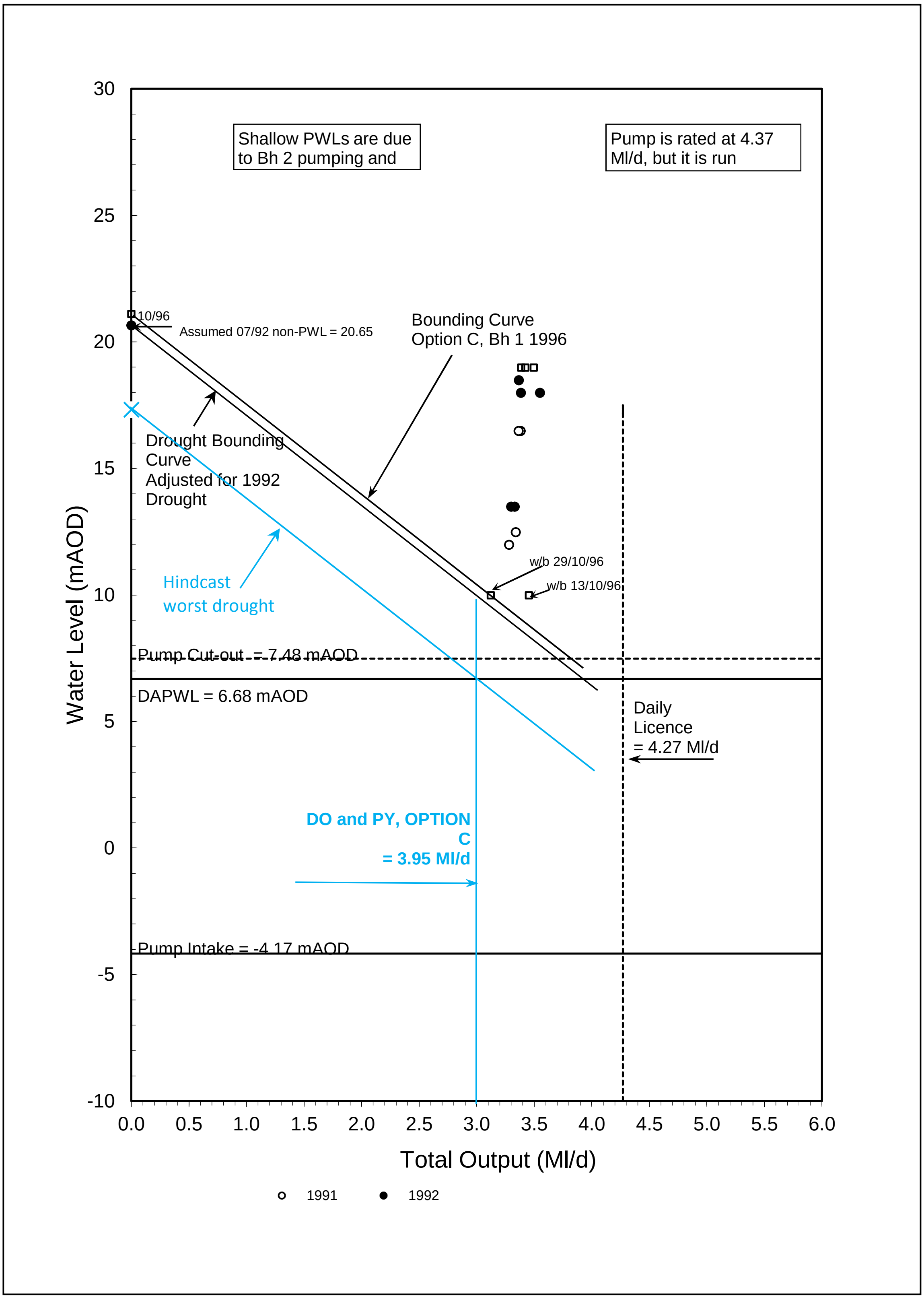
UKWIR Summary Diagram for Dullingham, Peak Demand



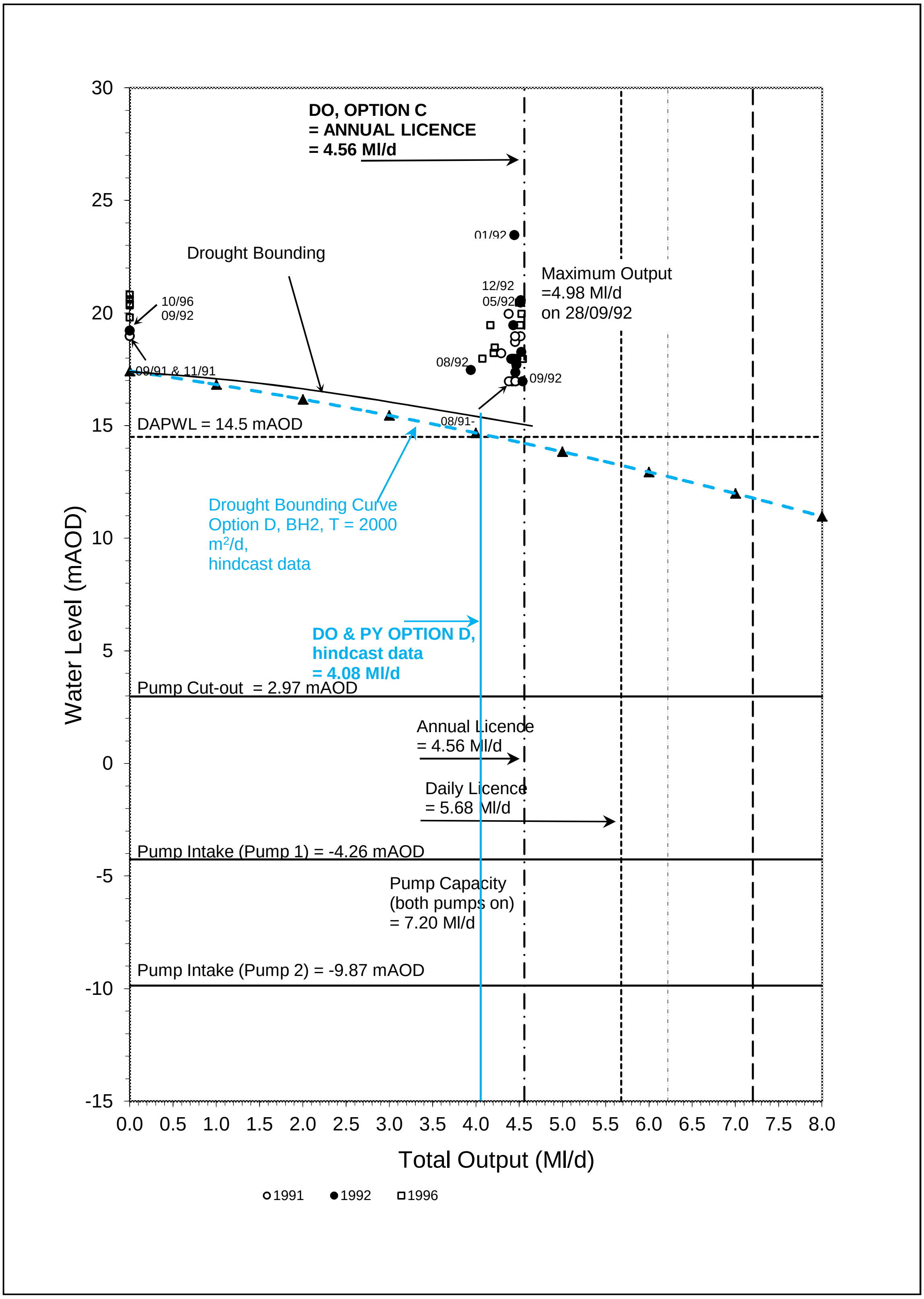
UKWIR Summary Diagram for Duxford Grange Bh 1, Average



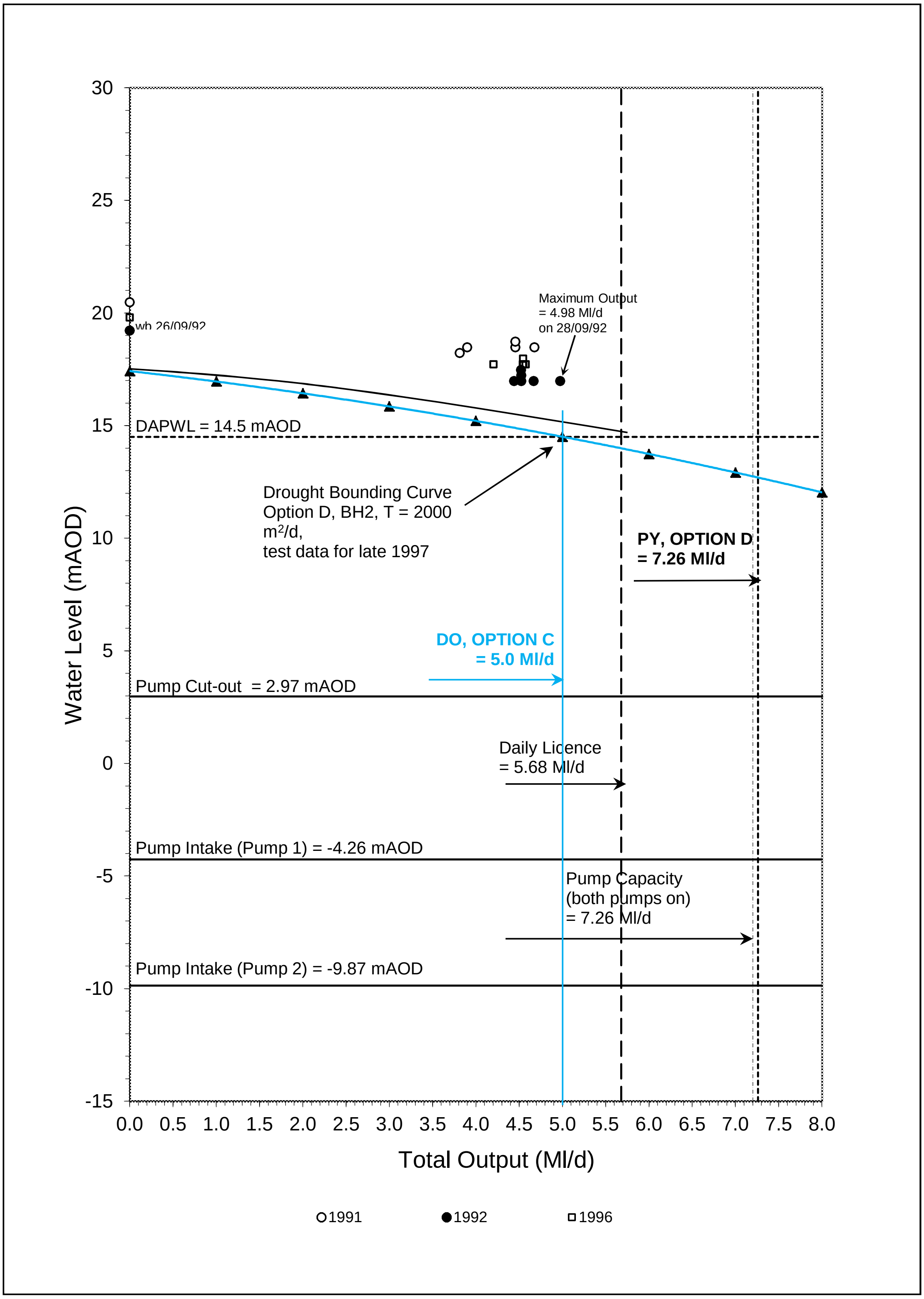
UKWIR Summary Diagram for Duxford Grange Bh 1, Peak Demand



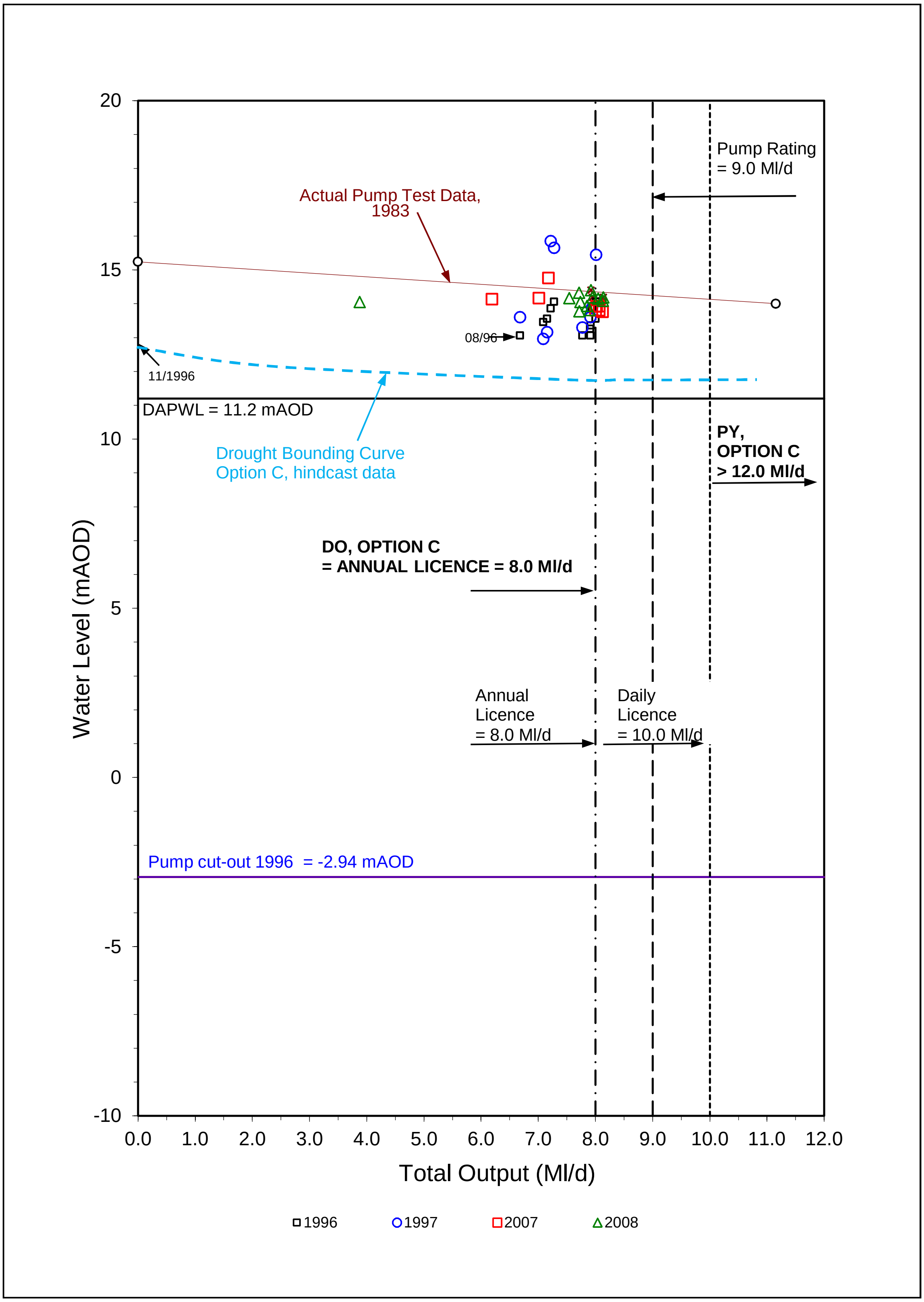
UKWIR Summary Diagram for Duxford Airfield Bh 2, Average



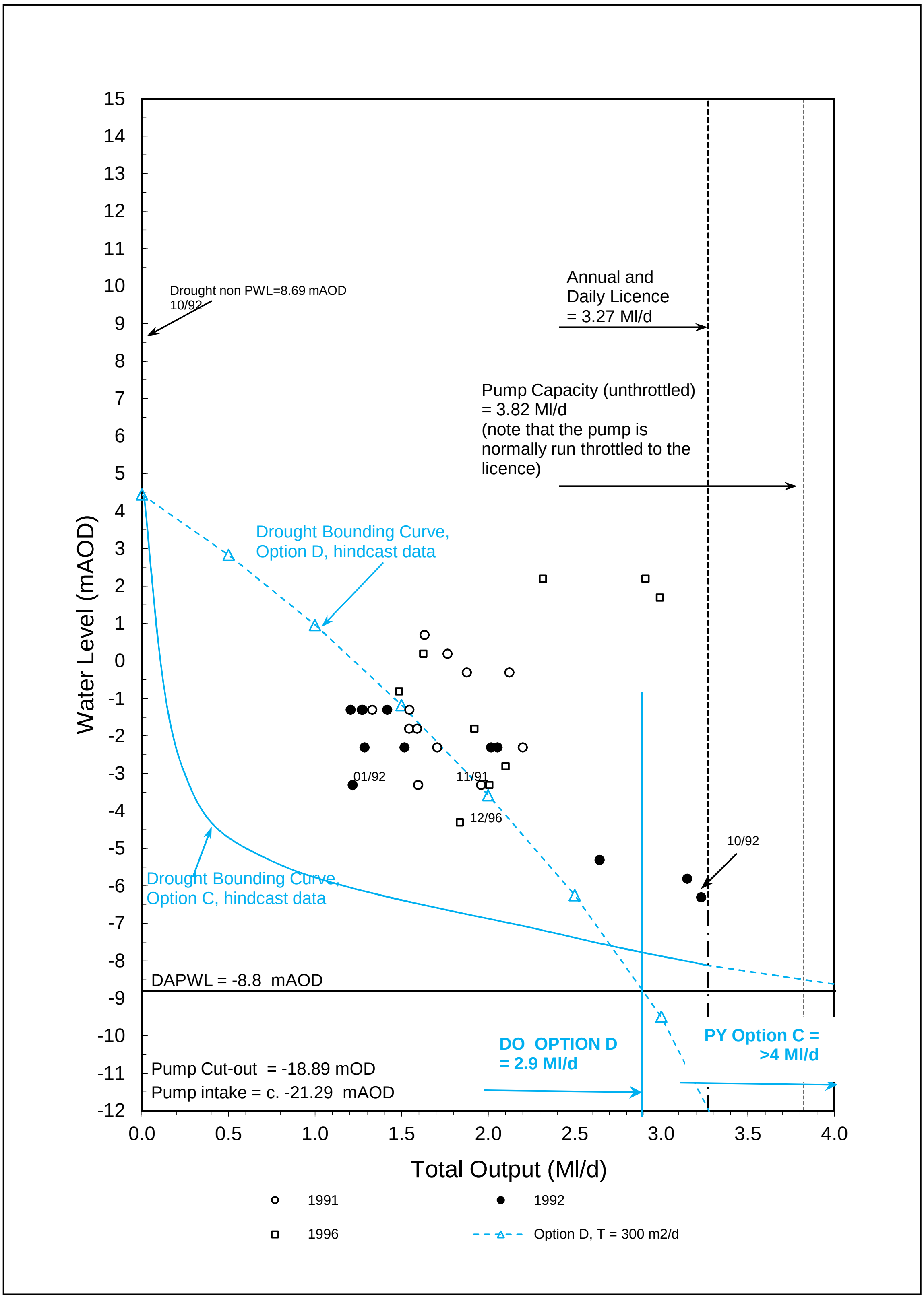
UKWIR Summary Diagram for Duxford Airfield Bh 2, Peak Demand



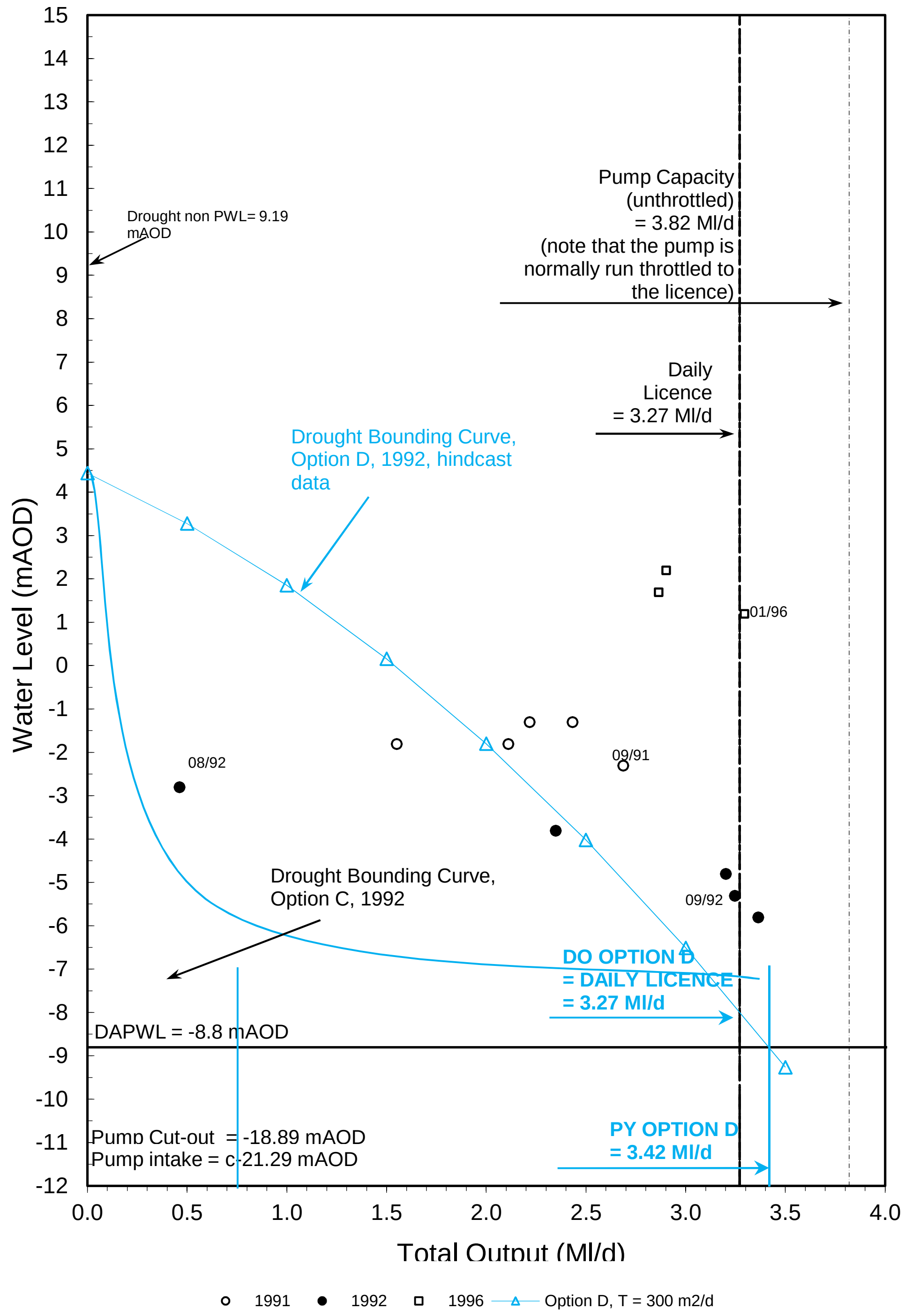
UKWIR Summary Diagram for Euston, Average Demand



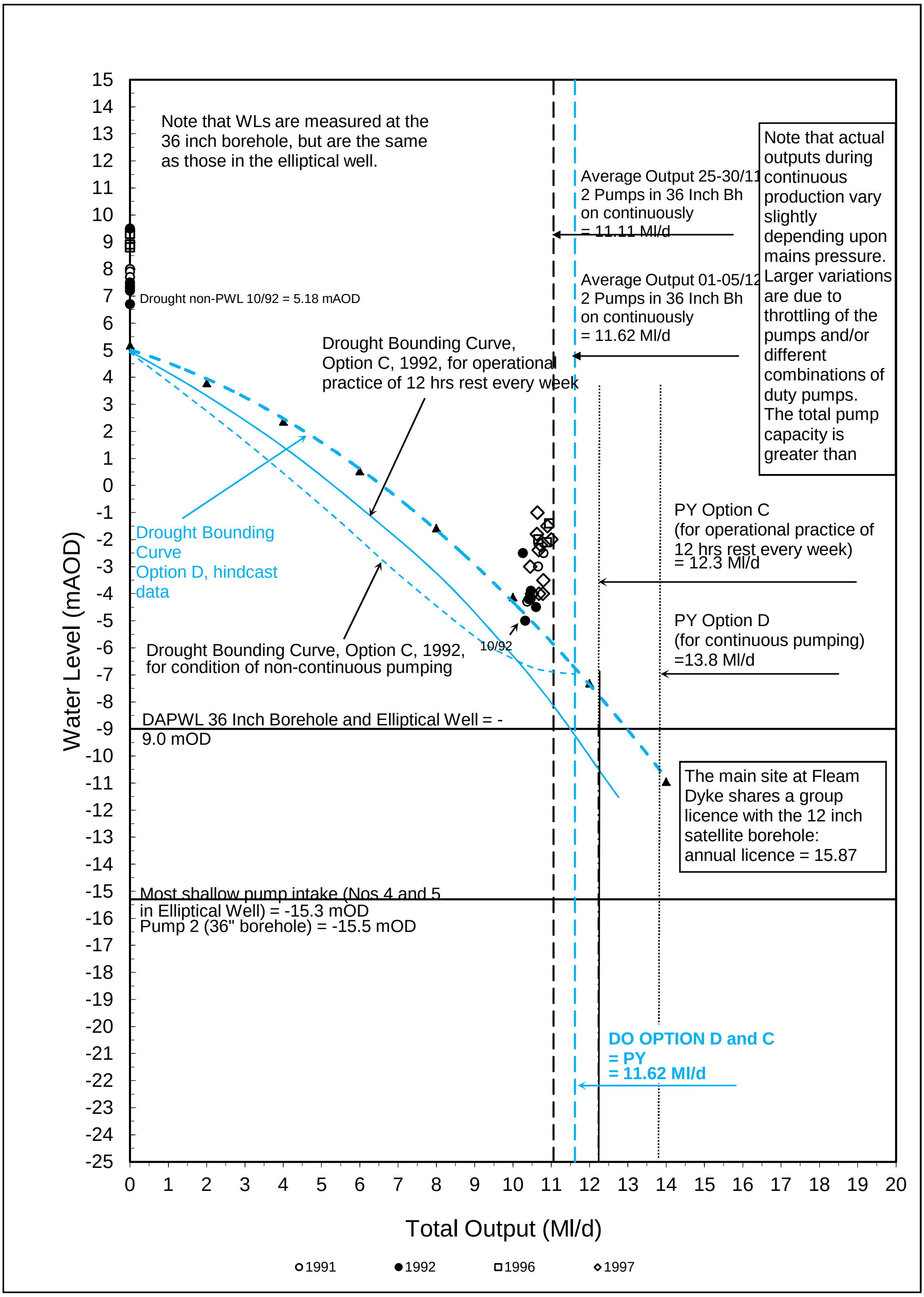
UKWIR Summary Diagram for Fleam Dyke 12 Inch, Average



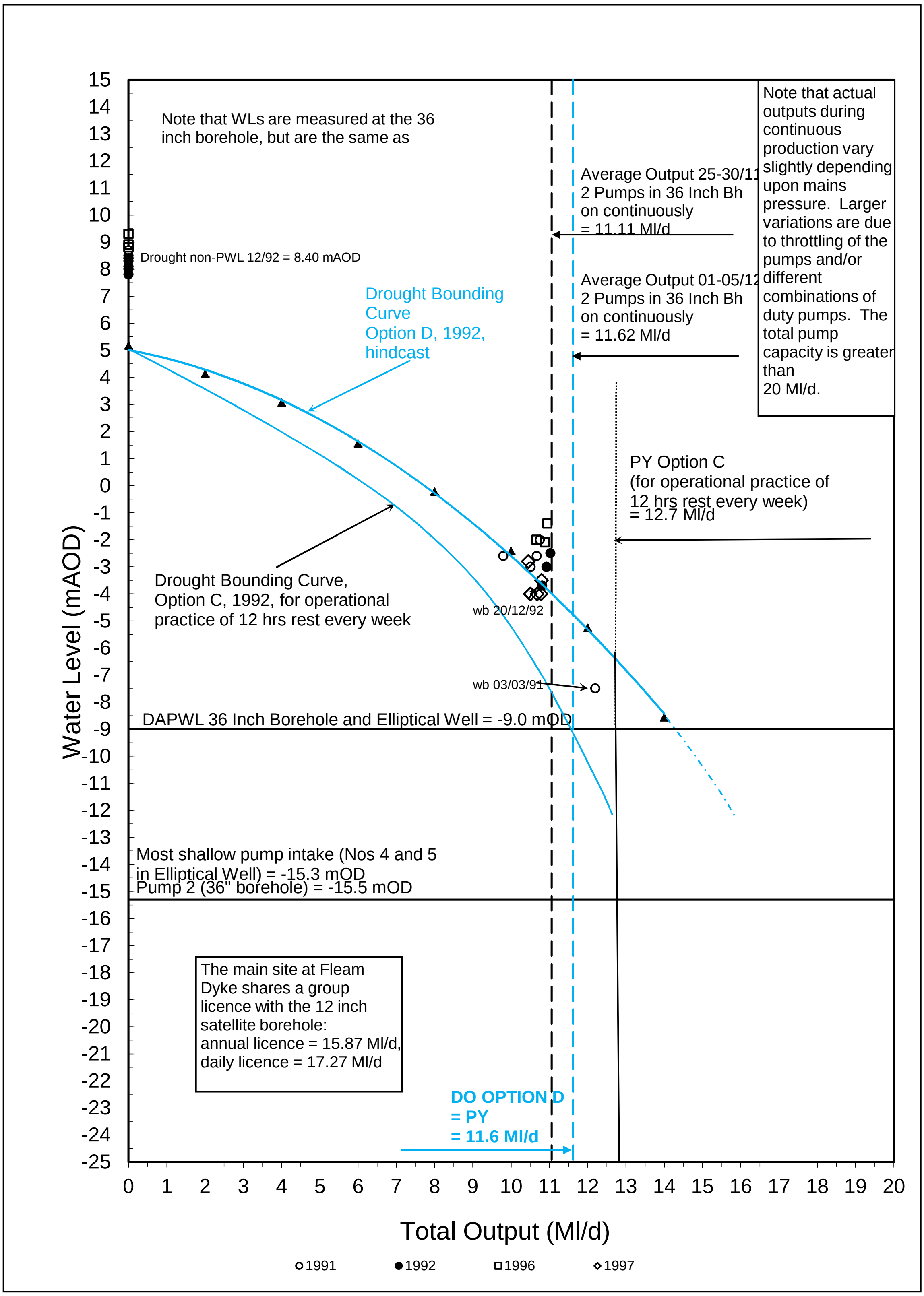
UKWIR Summary Diagram for Fleam Dyke 12 Inch, Peak Demand



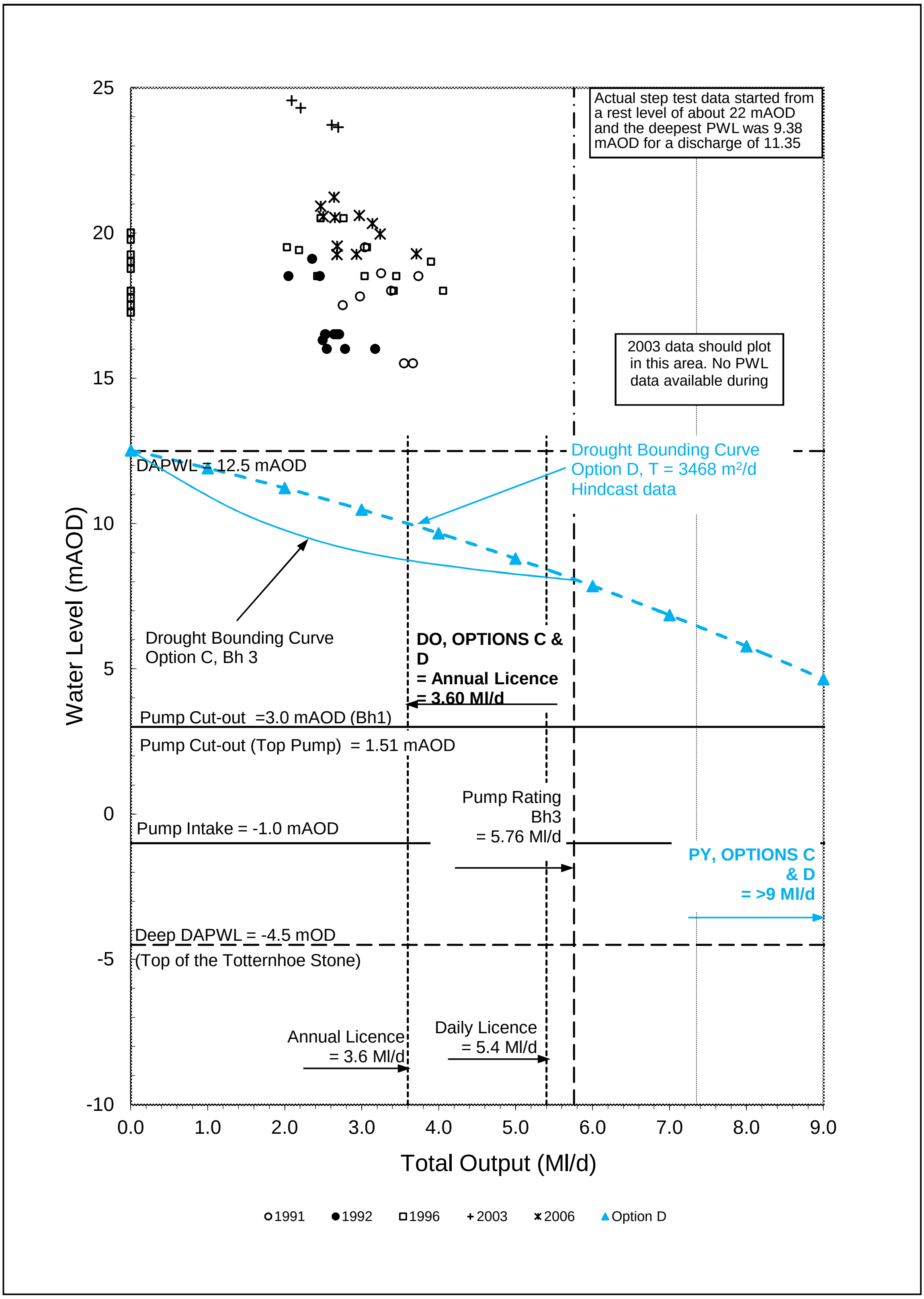
UKWIR Summary Diagram for Fleam Dyke, Main Site, Average



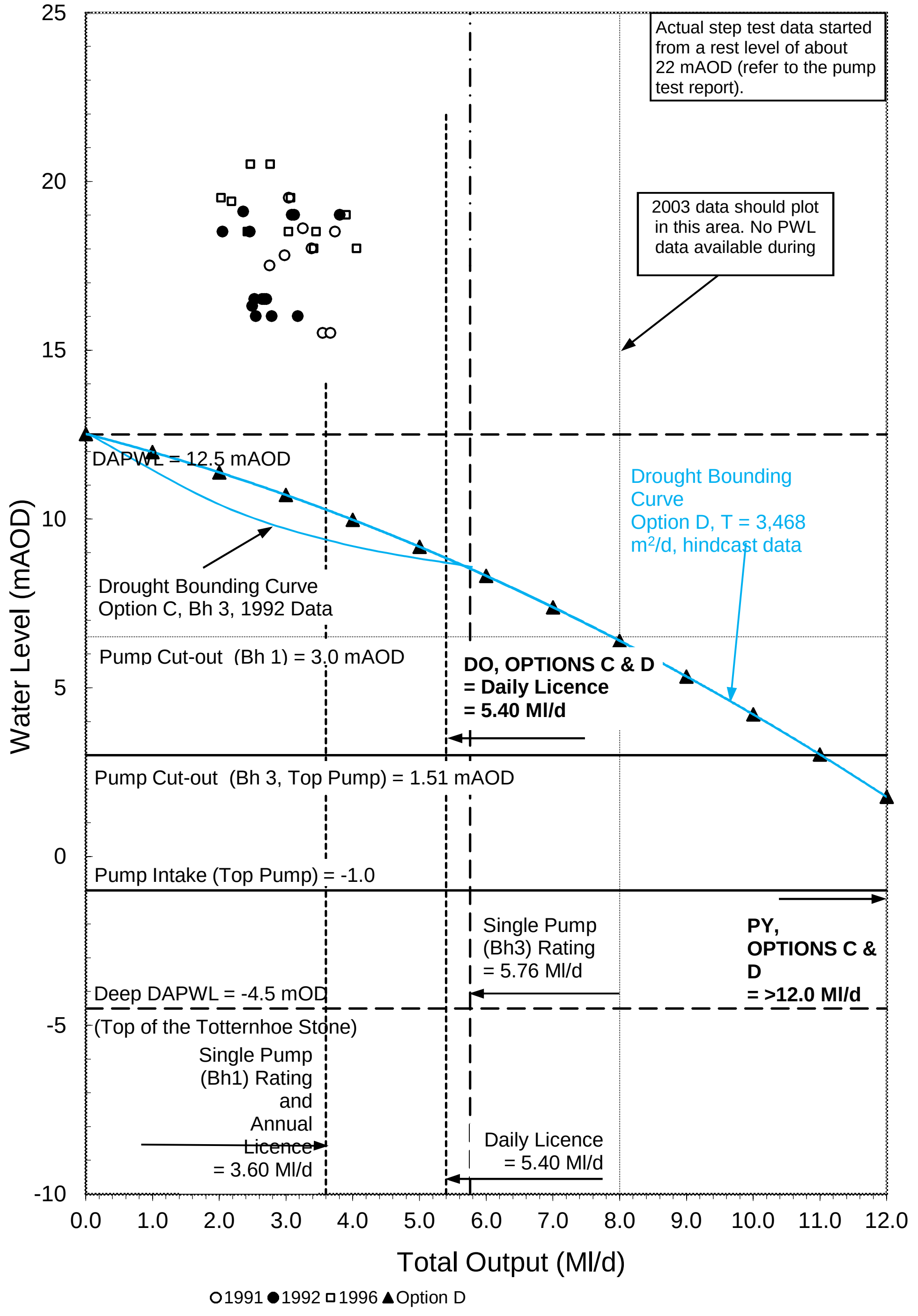
UKWIR Summary Diagram for Fleam Dyke, Main Site, Peak Demand

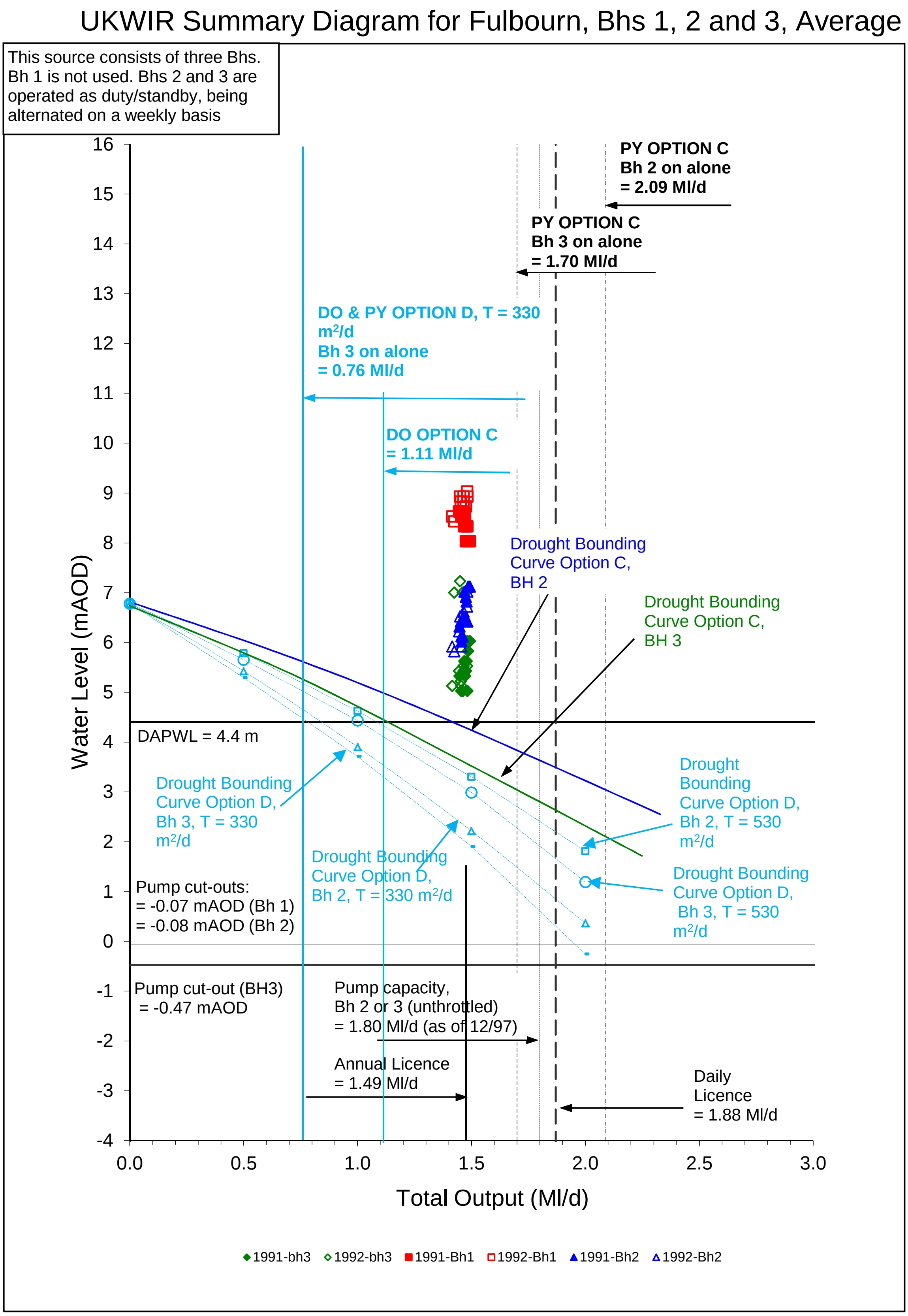


UKWIR Summary Diagram for Fowlmere Bh 3, Average Demand

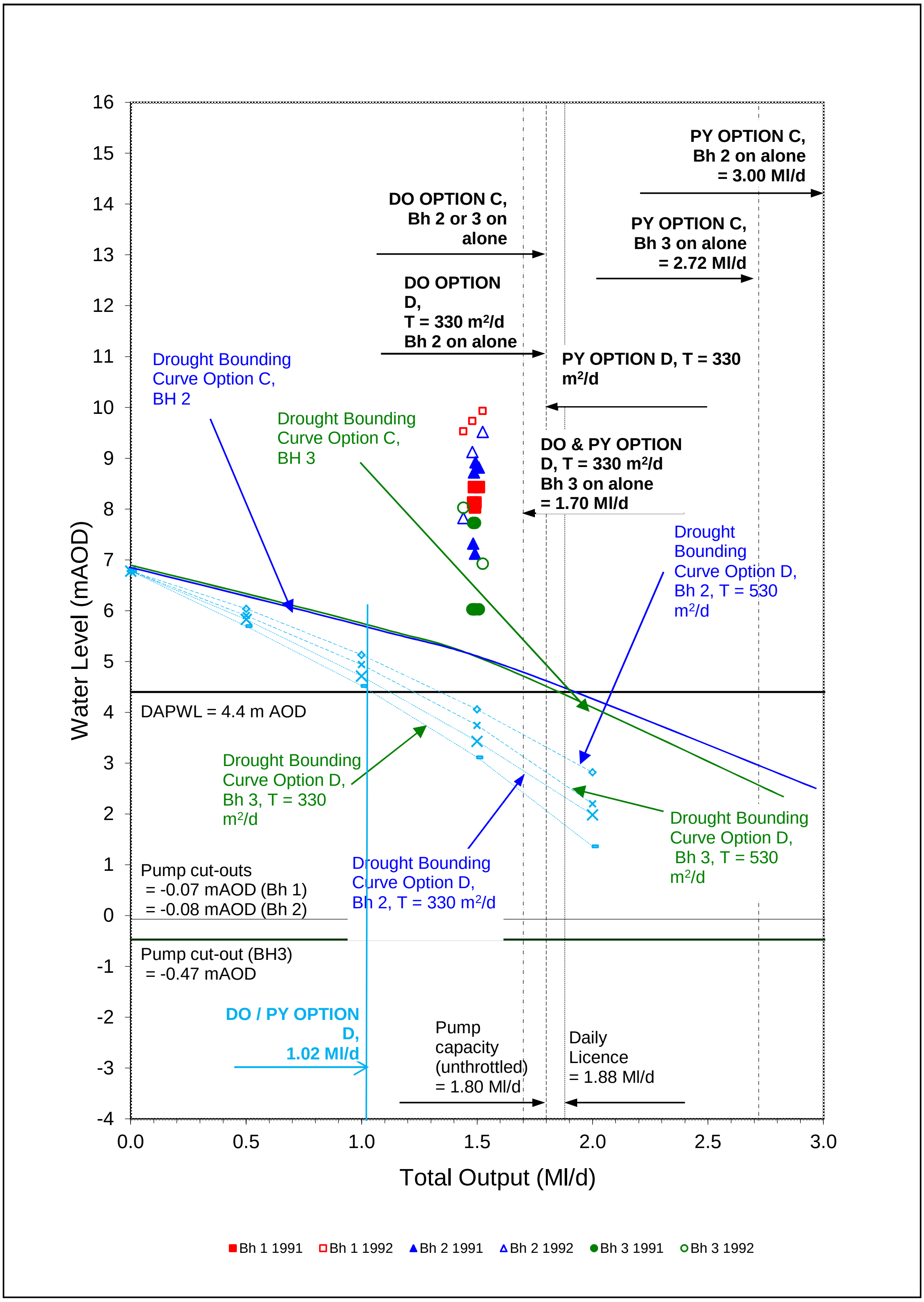


UKWIR Summary Diagram for Fowlmere Bh 3, Peak Demand

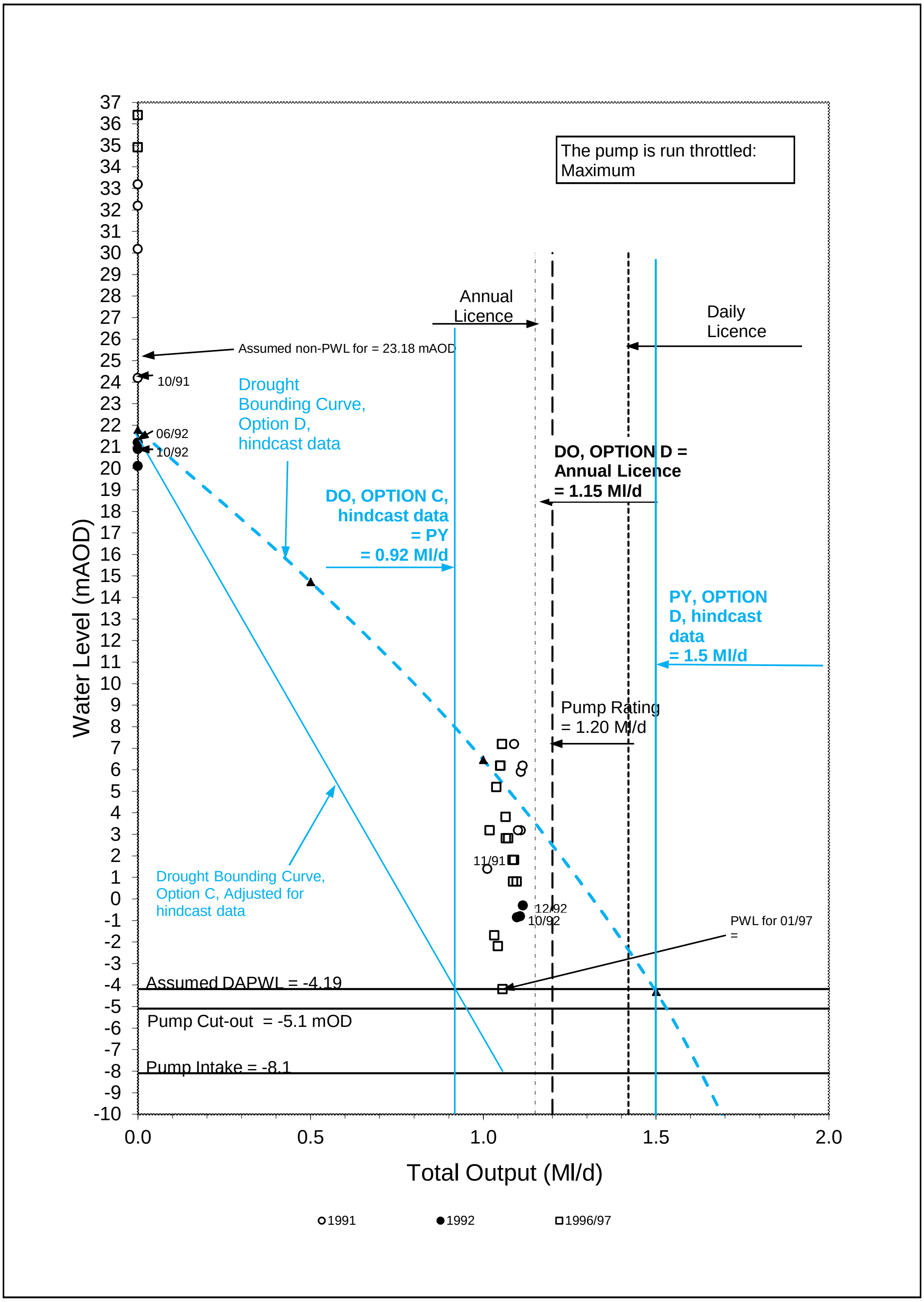



UKWIR Summary Diagram for Fulbourn, Bhs 1, 2 and 3, Average
This source consists of three Bhs. Bh 1 is not used. Bhs 2 and 3 are operated as duty/standby, being alternated on a weekly basis
PY OPTION C
Bh 2 on alone
= 2.09 Ml/d
PY OPTION C
Bh 3 on alone
= 1.70 Ml/d
DO & PY OPTION D, T = 330 m2/d
Bh 3 on alone
= 0.76 Ml/d
DO OPTION C
= 1.11 Ml/d
Drought Bounding Curve Option C, BH 2
Drought Bounding Curve Option C, BH 3
DAPWL = 4.4 m
Drought Bounding Curve Option D, Bh 3, T = 330 m2/d
Drought Bounding Curve Option D, Bh 2, T = 530 m2/d
Drought Bounding Curve Option D, Bh 2, T = 330 m2/d
Drought Bounding Curve Option D, Bh 3, T = 530 m2/d
Pump cut-outs:
= -0.07 mAOD (Bh 1)
= -0.08 mAOD (Bh 2)
Pump cut-out (BH3)
= -0.47 mAOD
Pump capacity,
Bh 2 or 3 (unthrottled)
= 1.80 Ml/d (as of 12/97)
Annual Licence
= 1.49 Ml/d
Daily Licence
= 1.88 Ml/d
Water Level (mAOD)
Total Output (Ml/d)
1991-bh3
1992-bh3
1991-Bh1
1992-Bh1
1991-Bh2
1992-Bh2

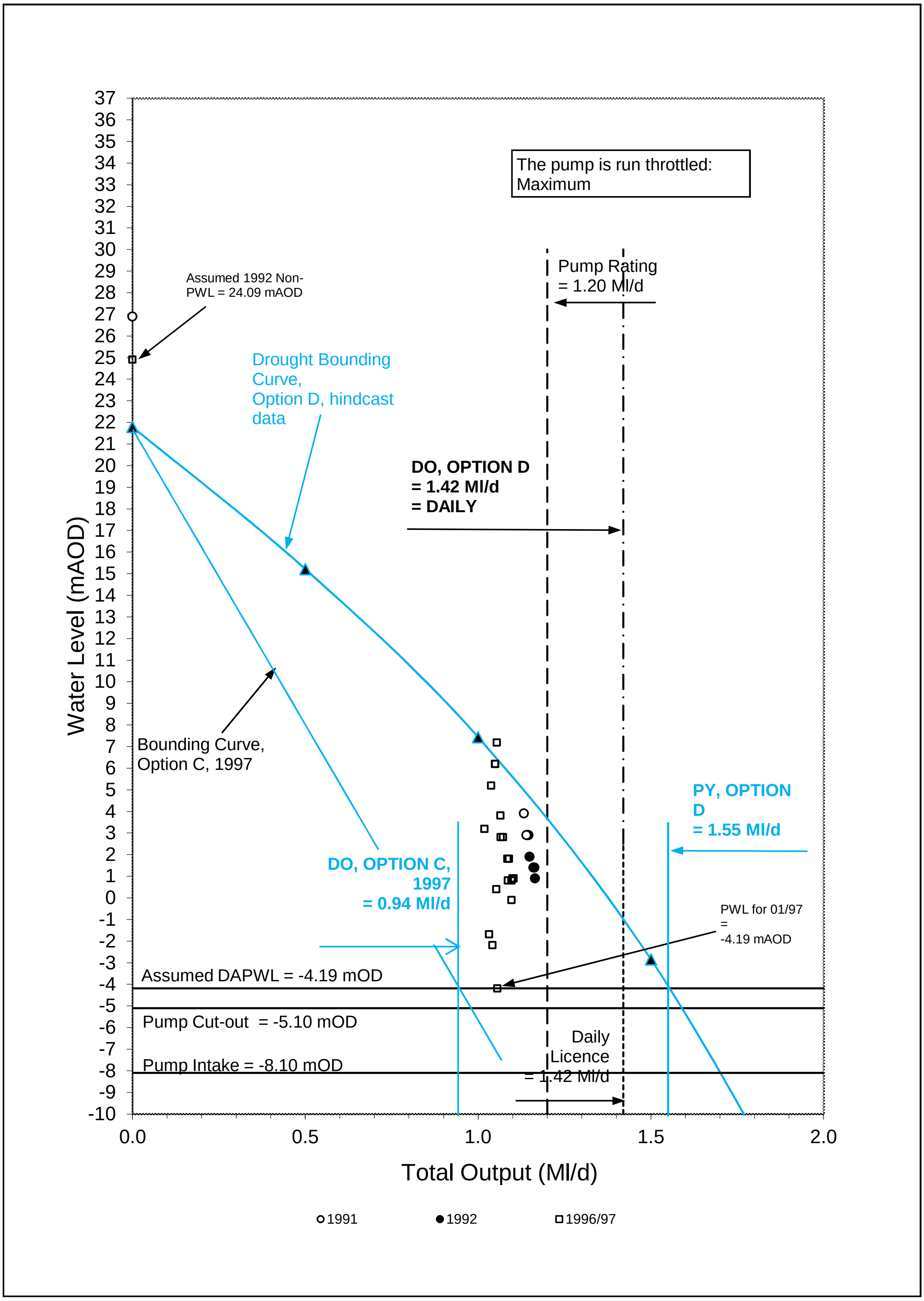
UKWIR Summary Diagram for Fulbourn, Bhs 1, 2 and 3, Peak



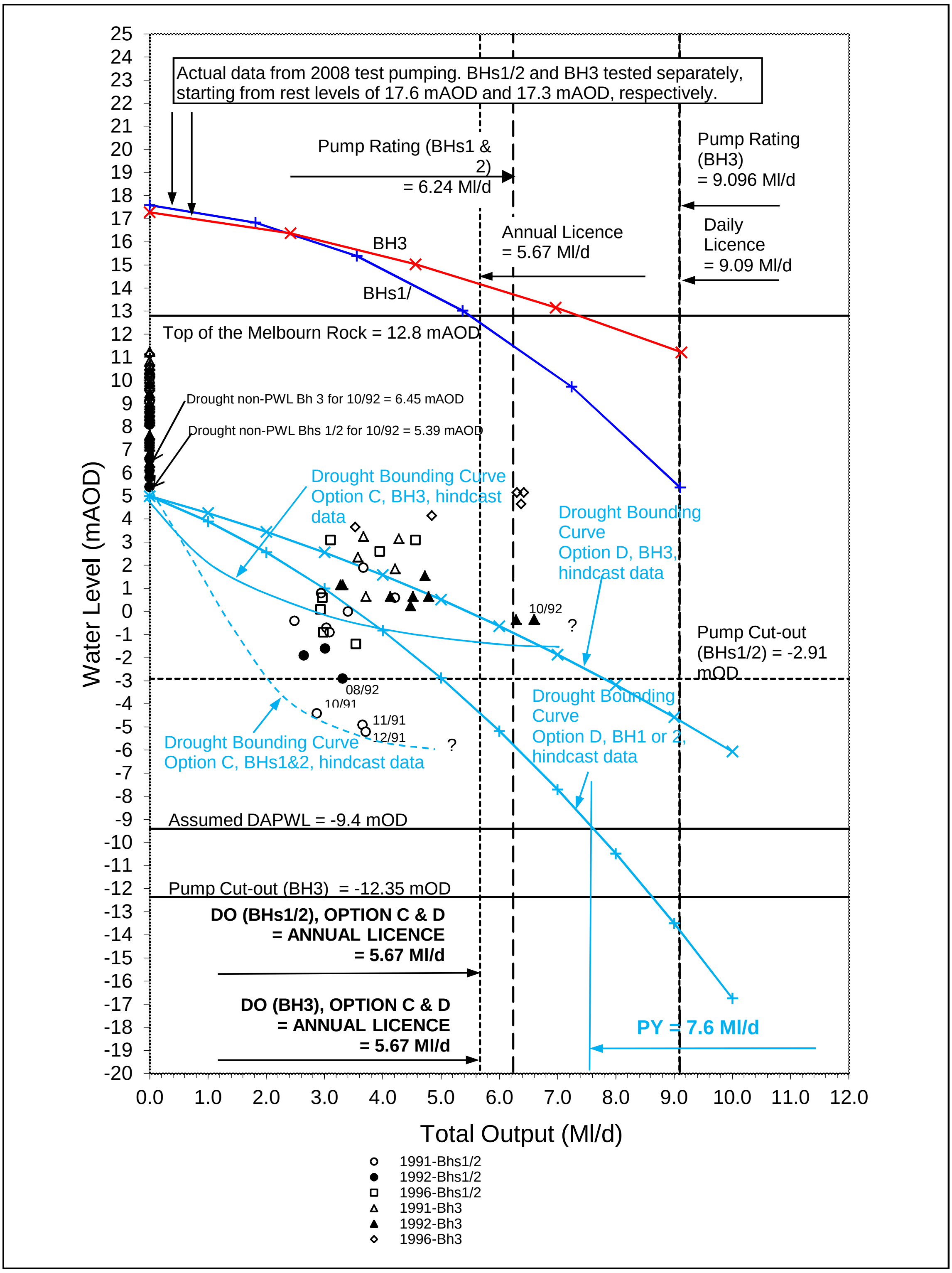
UKWIR Summary Diagram for Great Chishill, Average Demand



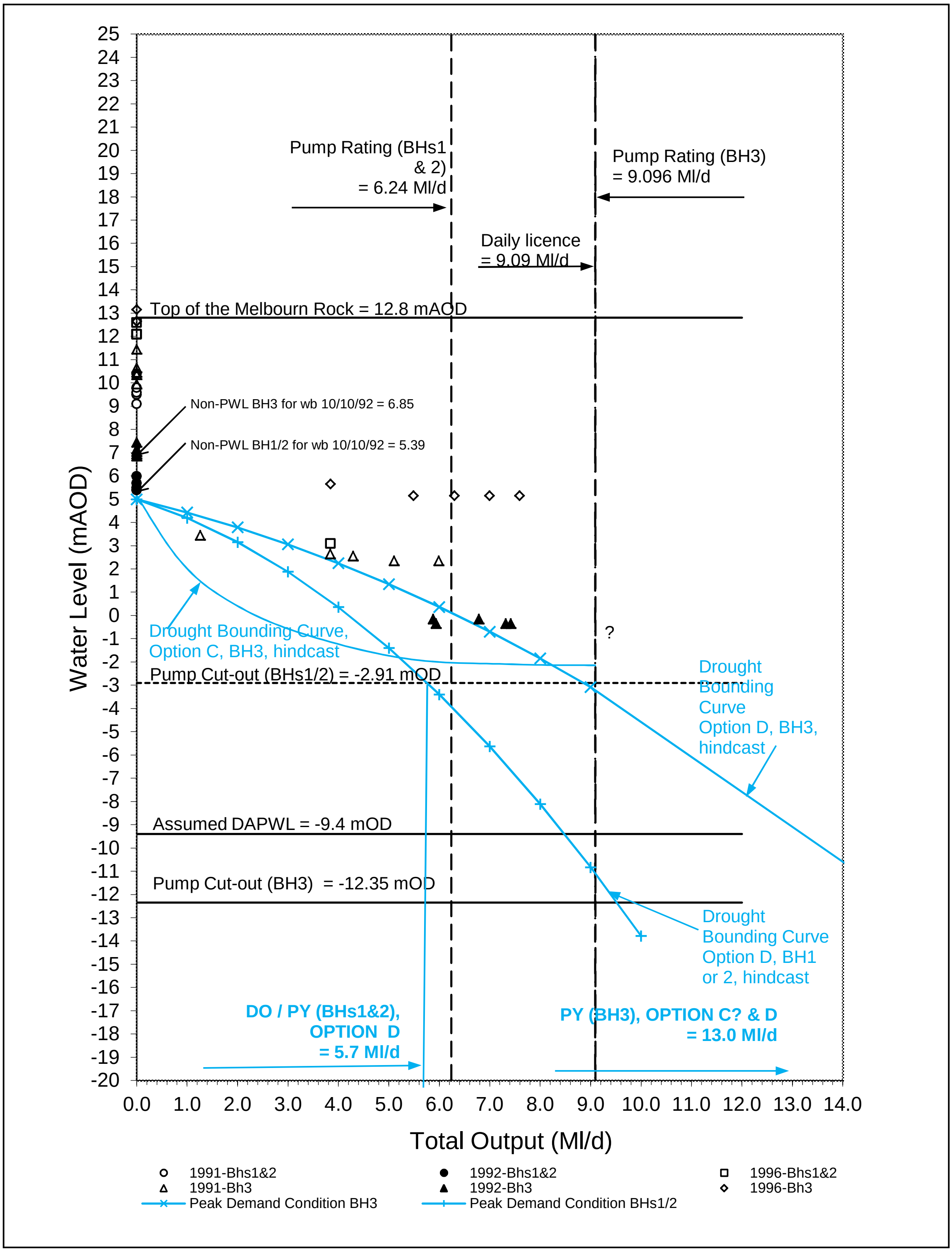
UKWIR Summary Diagram for Great Chishill, Peak Demand



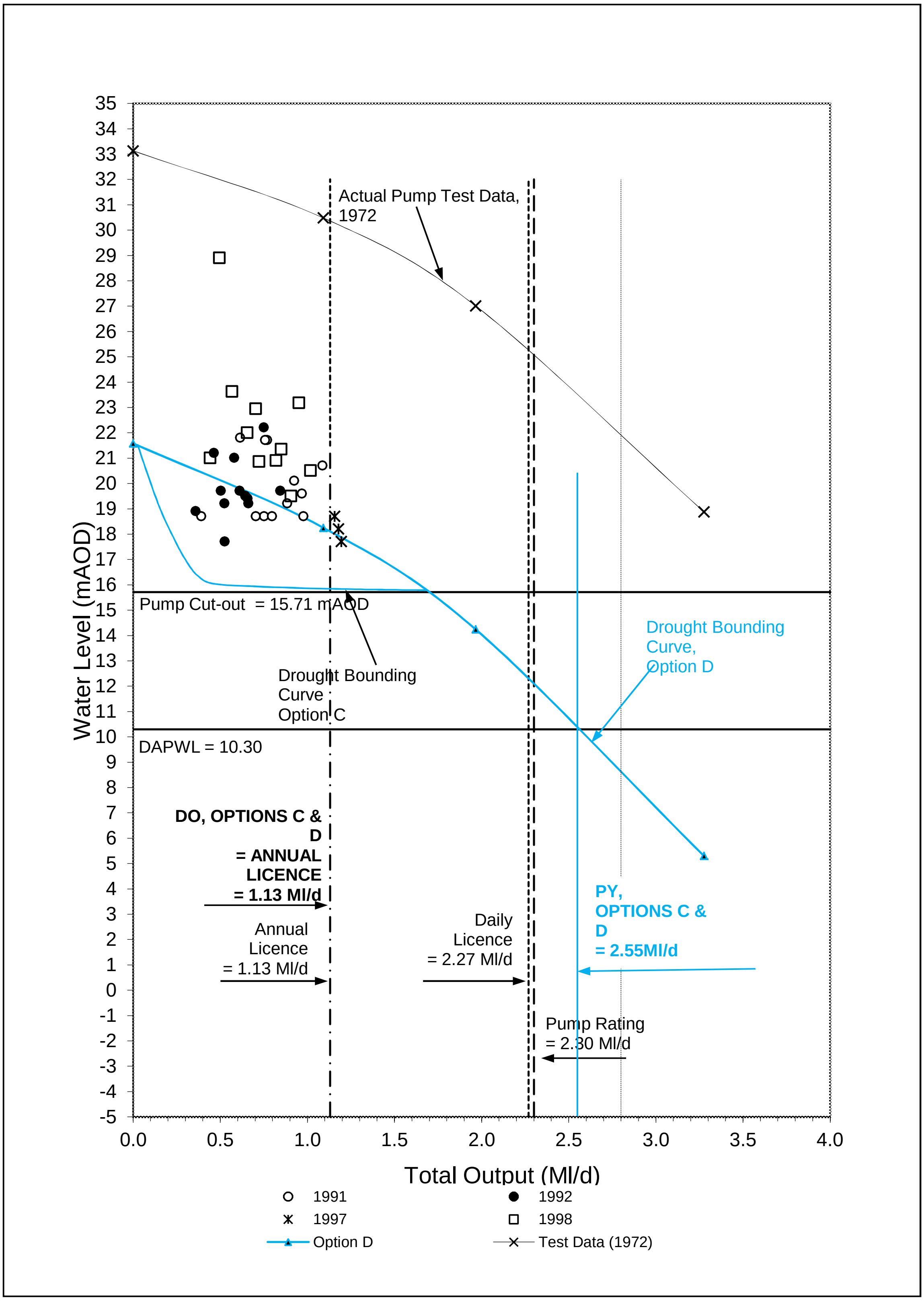
UKWIR Summary Diagram for Great Wilbraham, Average Demand



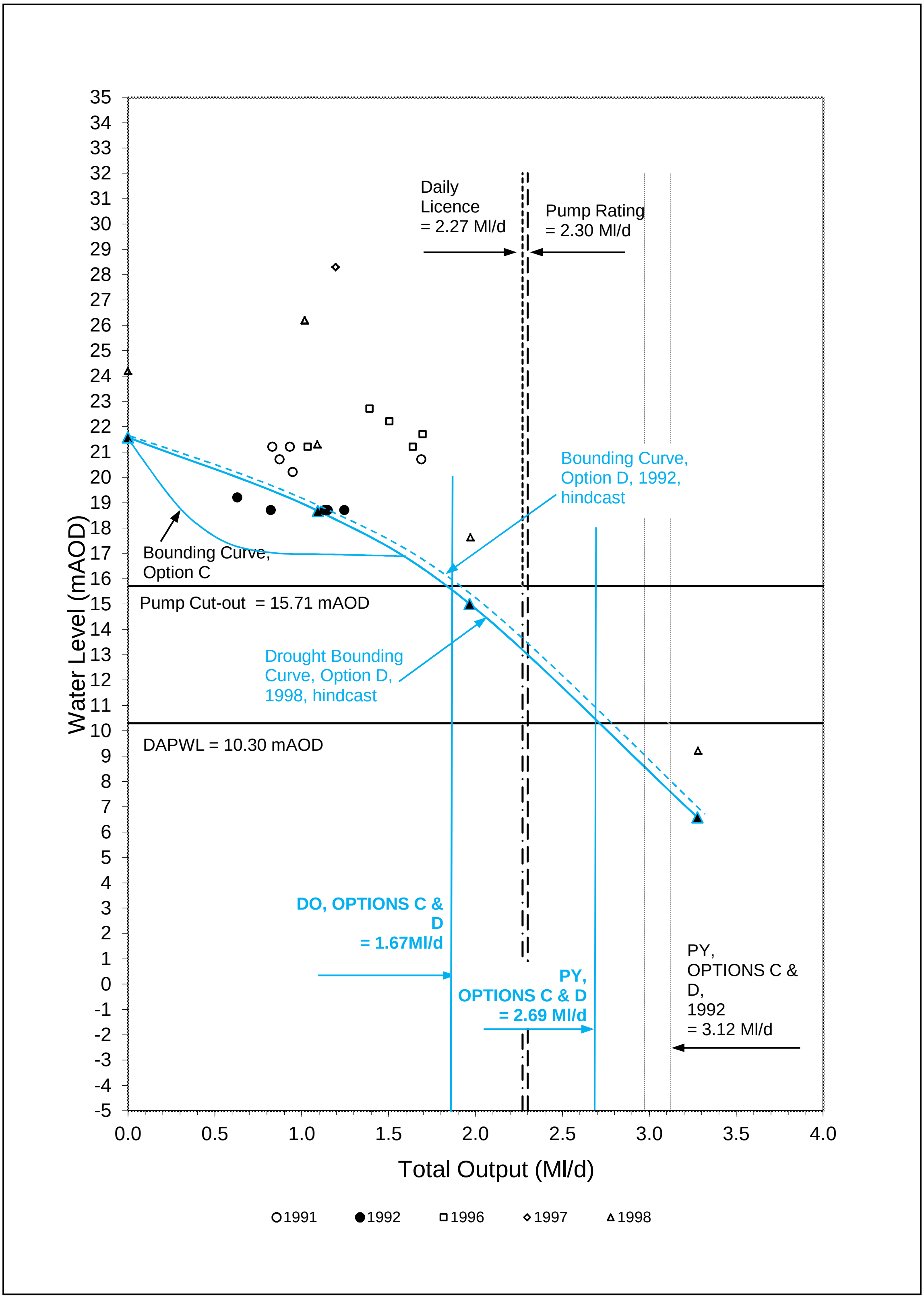
UKWIR Summary Diagram for Great Wilbraham, Peak Demand



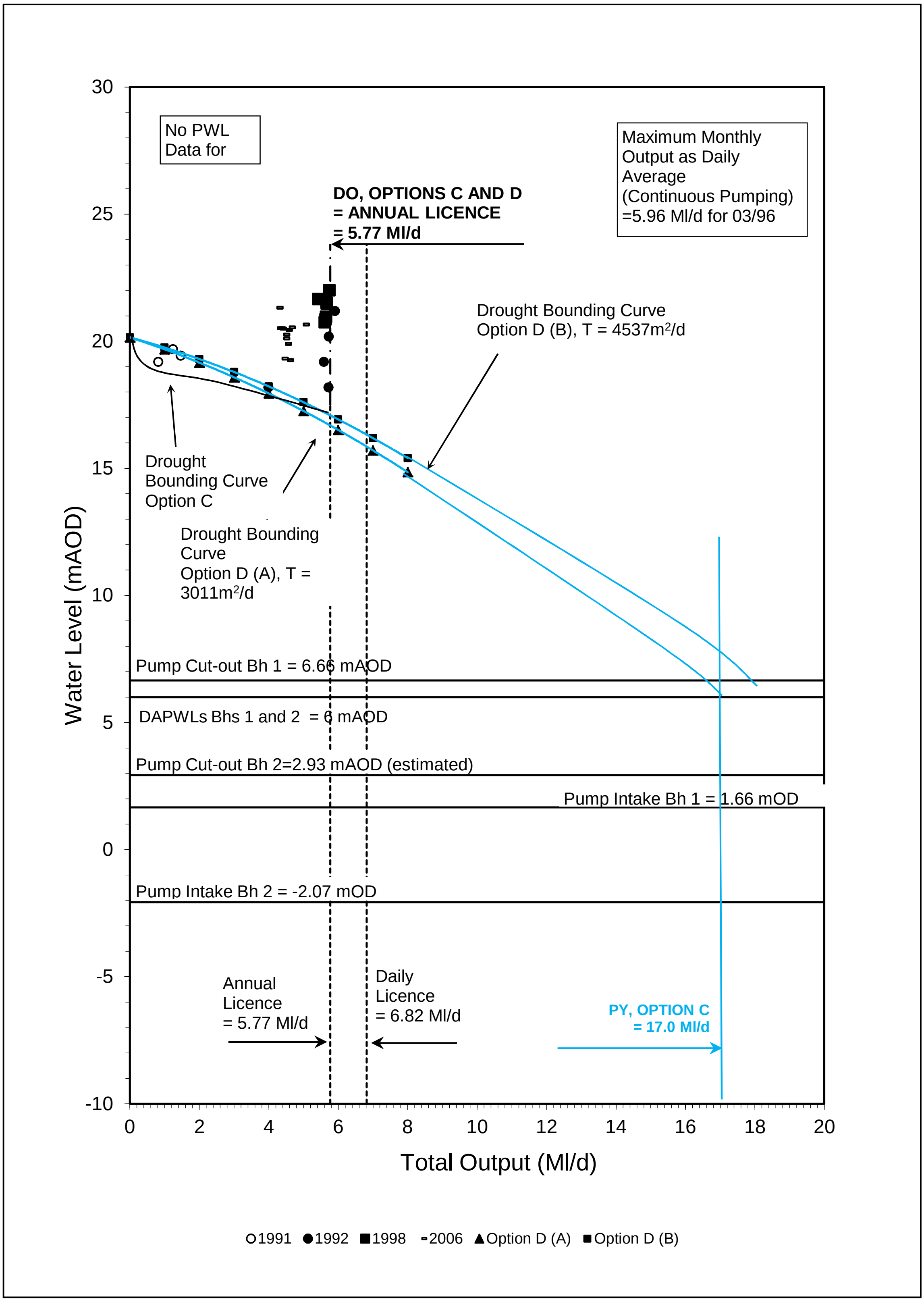
UKWIR Summary Diagram for Heydon, Average Demand

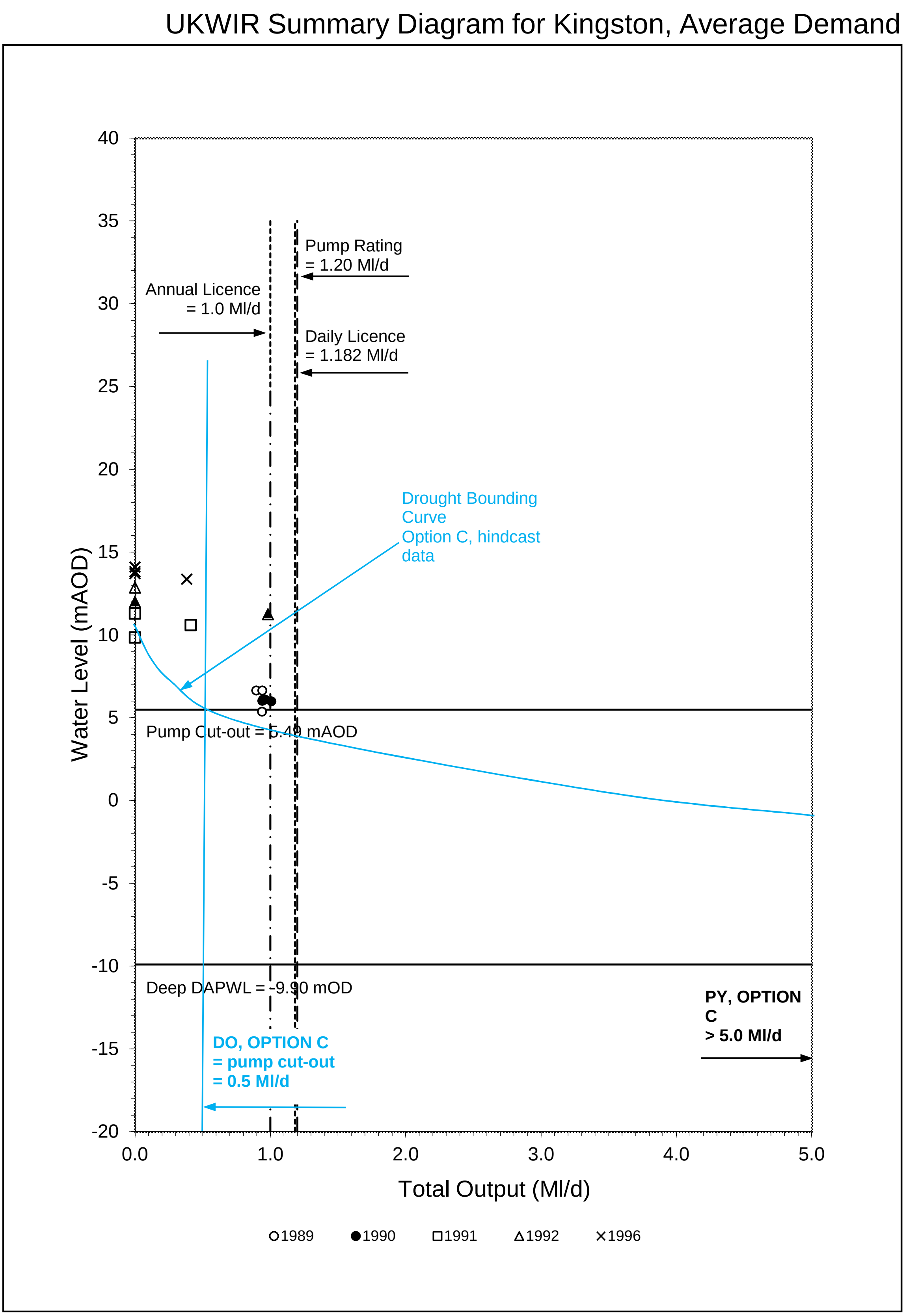


UKWIR Summary Diagram for Heydon, Peak Demand



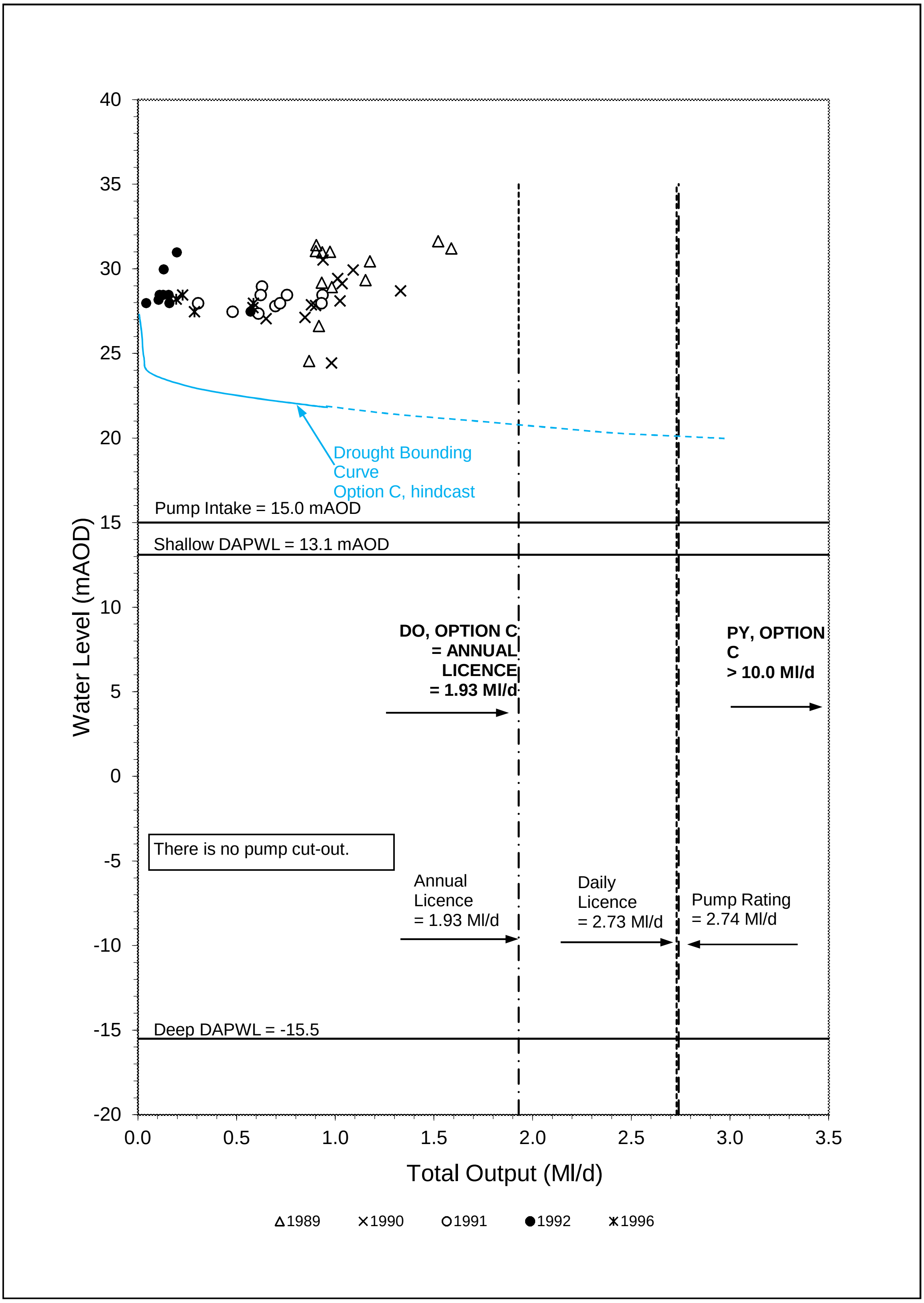
UKWIR Summary Diagram for Hinxton Grange Bh 2, Average



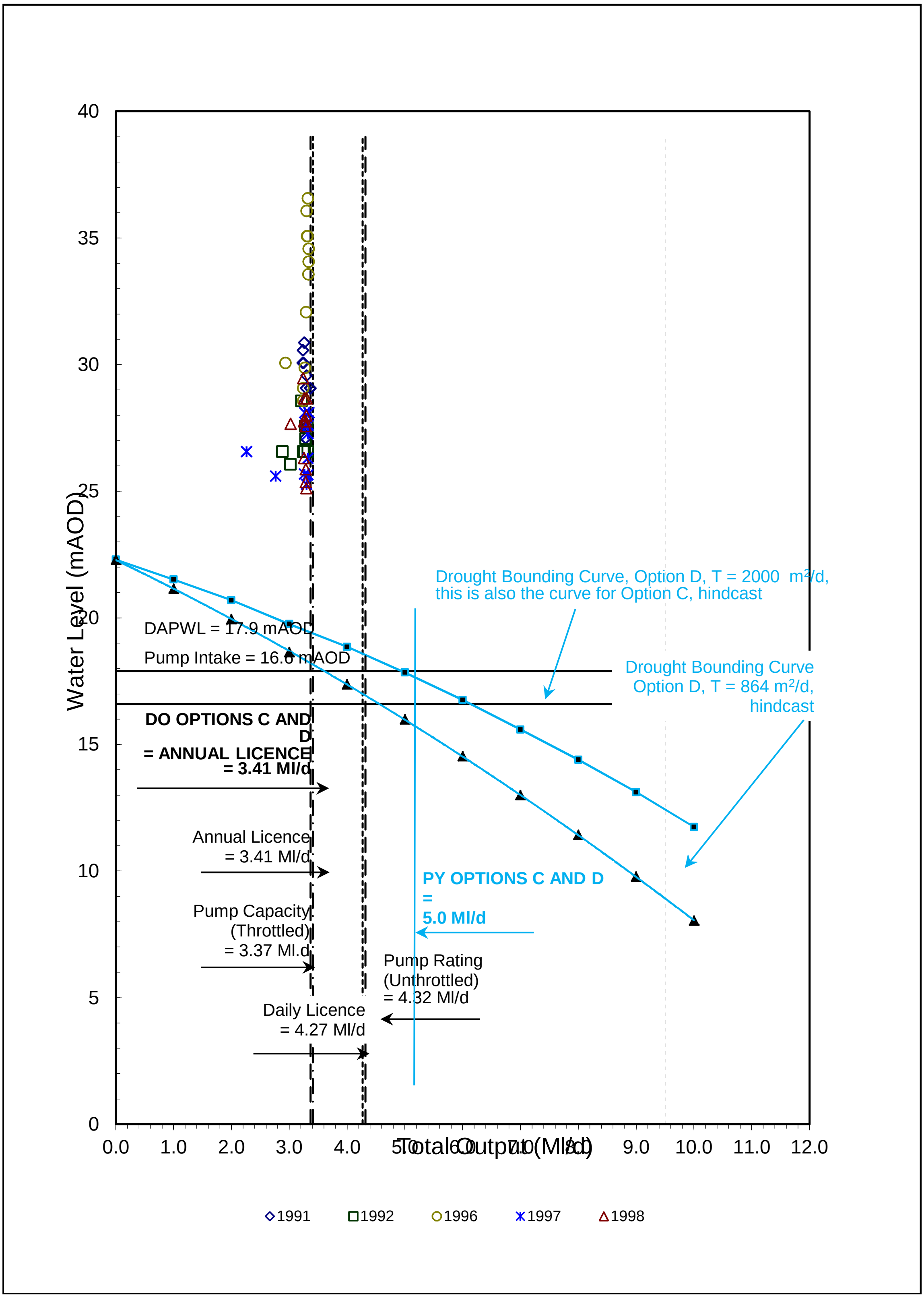


UKWIR Summary Diagram for Kingston, Average Demand
Water Level (mAOD)
40
35
30
25
20
15
10
5
0
-5
-10
-15
-20
0.0
1.0
2.0
3.0
4.0
5.0
Total Output (Ml/d)
Pump Rating
= 1.20 Ml/d
Annual Licence
= 1.0 Ml/d
Daily Licence
= 1.182 Ml/d
Drought Bounding
Curve
Option C, hindcast
data
Pump Cut-out = 5.40 mAOD
Deep DAPWL = -9.90 mOD
PY, OPTION
C
> 5.0 Ml/d
DO, OPTION C
= pump cut-out
= 0.5 Ml/d
1989
1990
1991
1992
1996

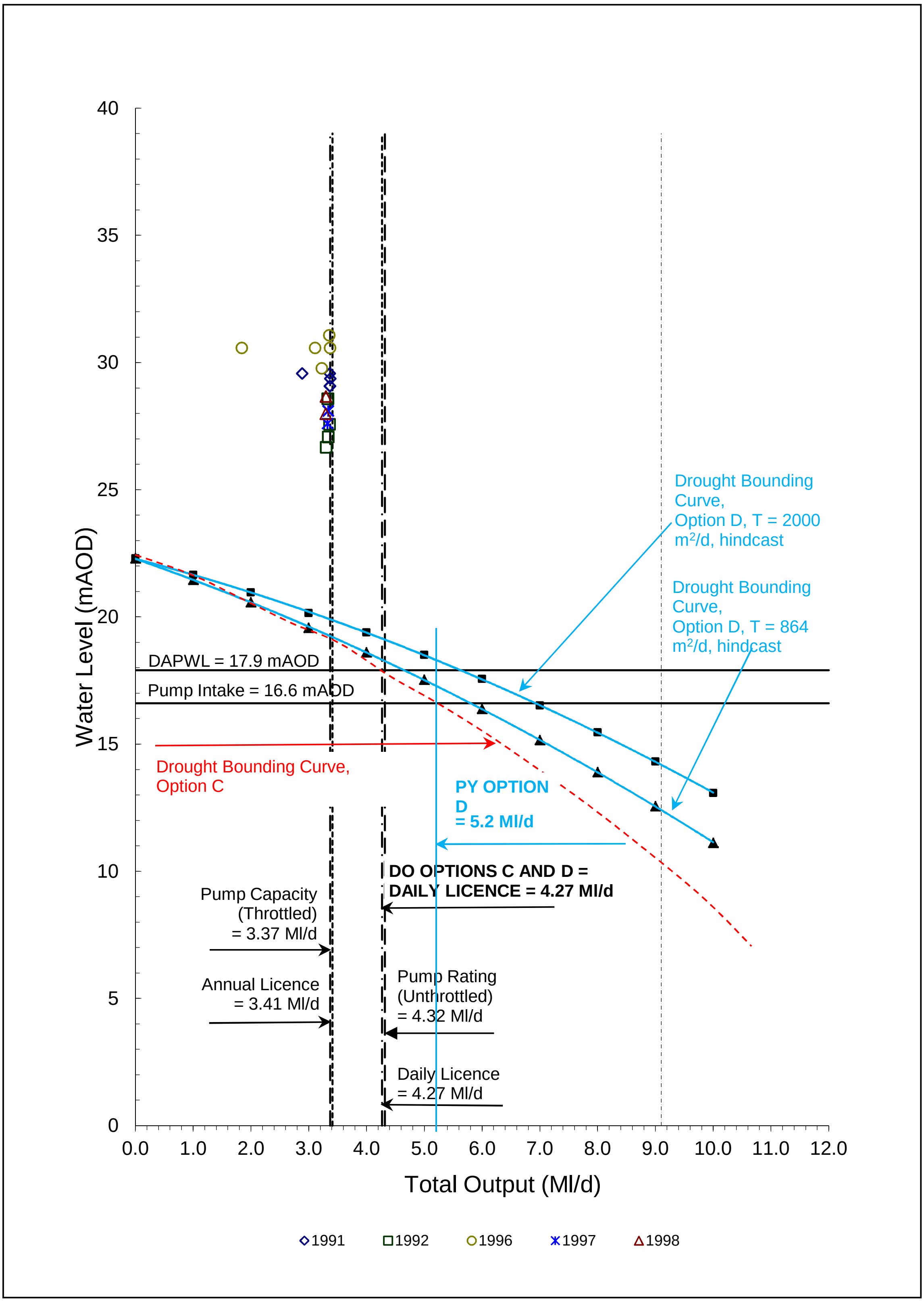
UKWIR Summary Diagram for Linton Bh 1, Average Demand

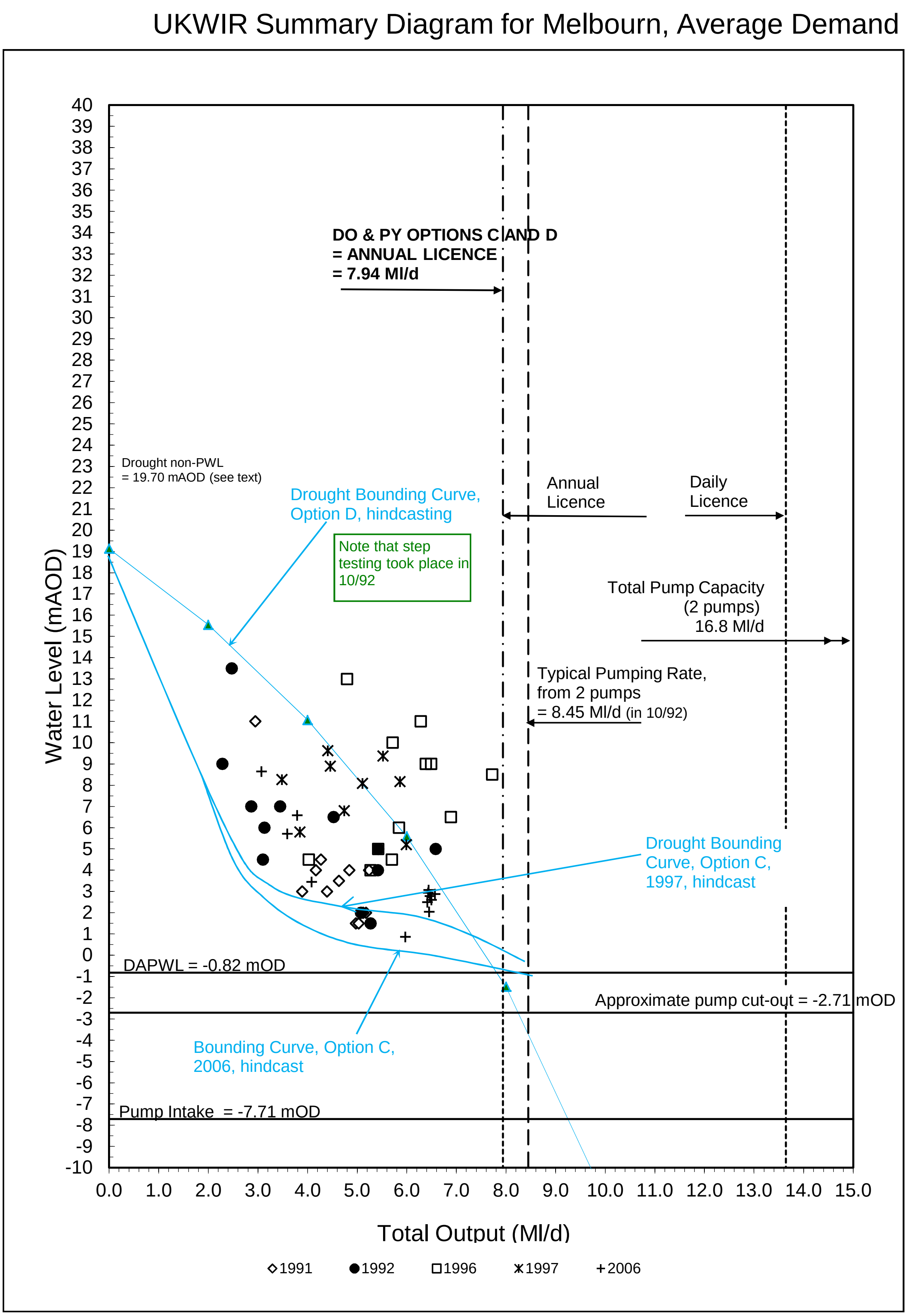


UKWIR Summary Diagram for Lowerfield, Average Demand

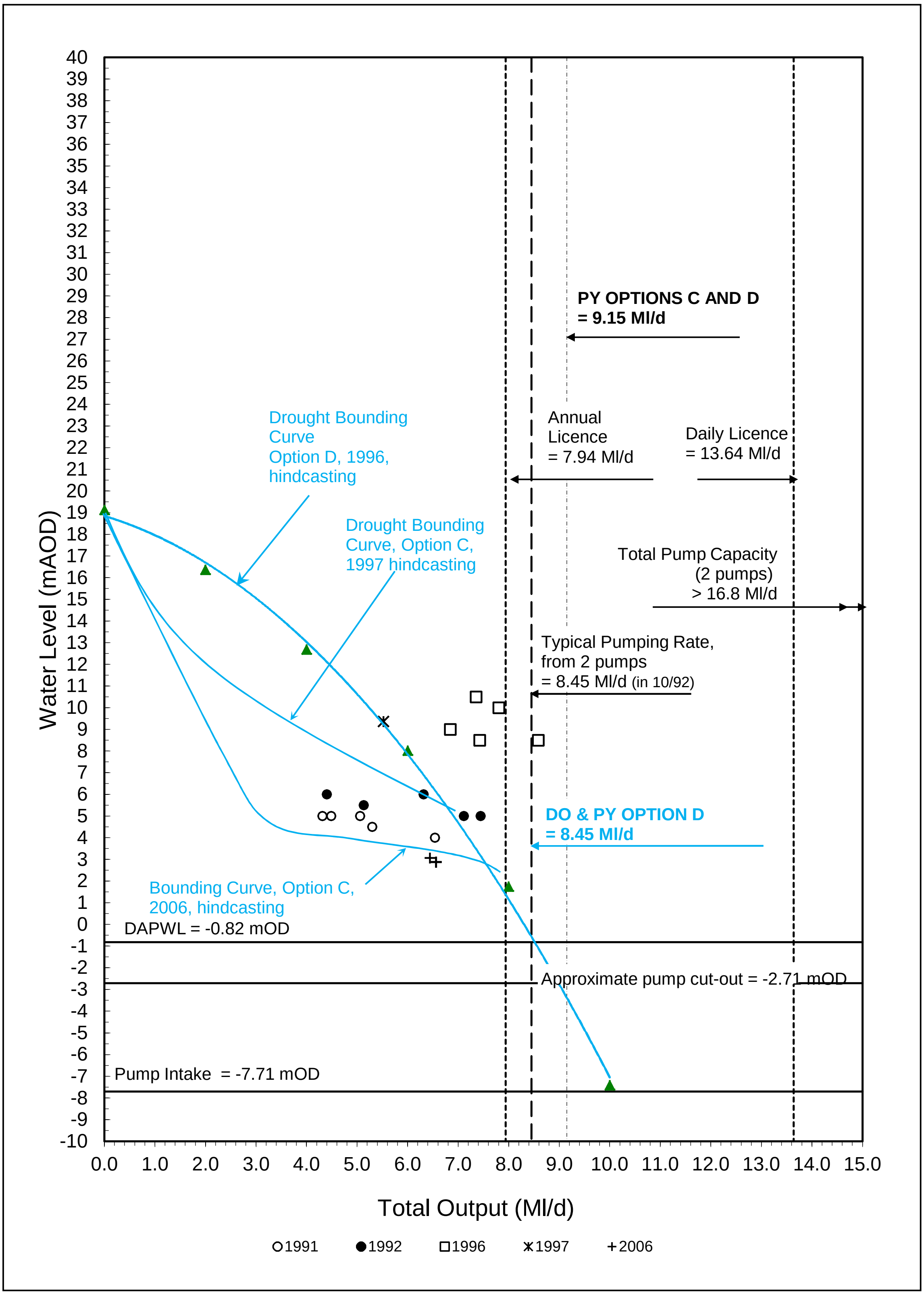


UKWIR Summary Diagram for Lowerfield, Peak Demand

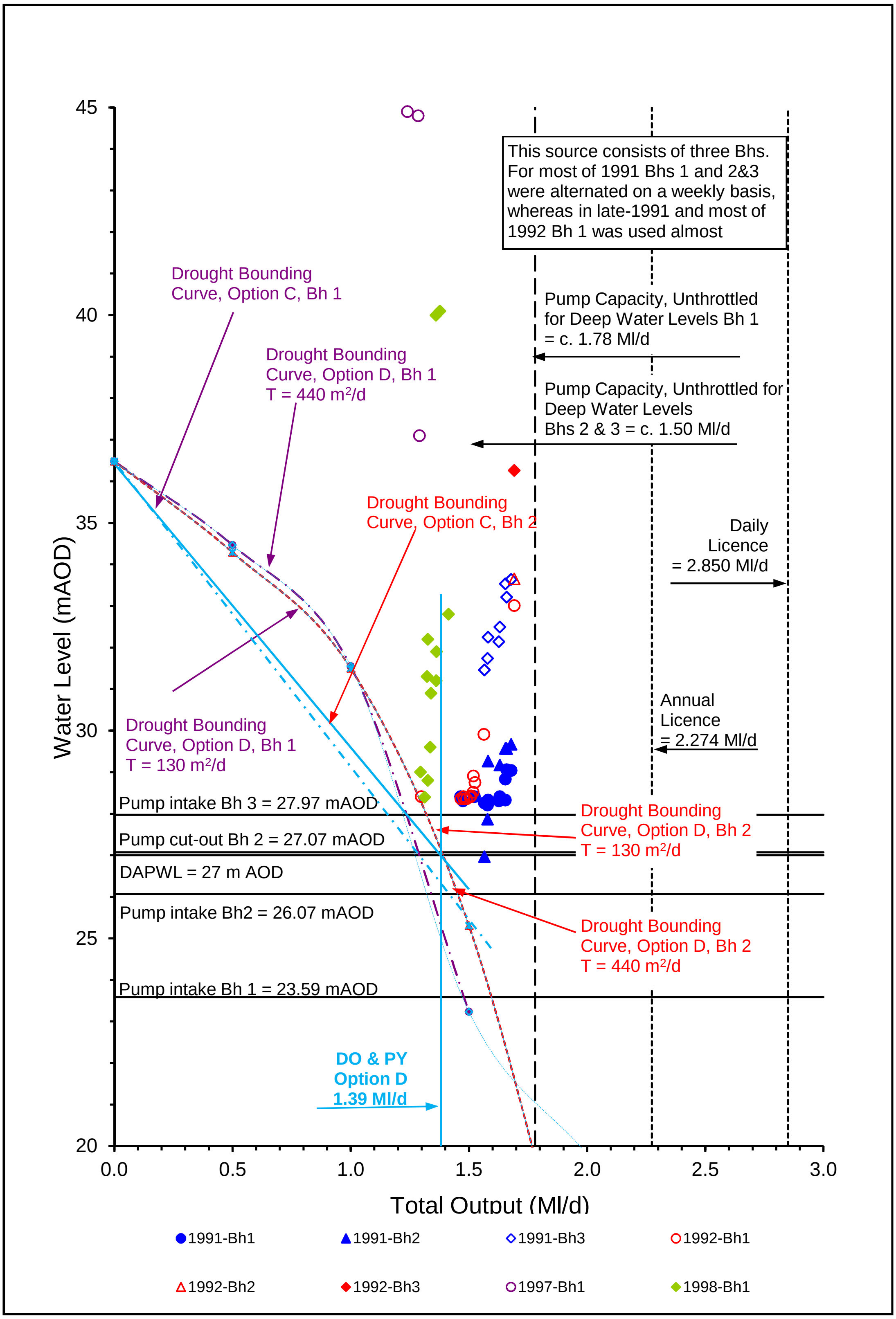



UKWIR Summary Diagram for Melbourn, Average Demand
DO & PY OPTIONS C AND D
= ANNUAL LICENCE
= 7.94 Ml/d
Drought non-PWL
= 19.70 mAOD (see text)
Drought Bounding Curve, Option D, hindcasting
Note that step testing took place in 10/92
Annual Licence
Daily Licence
Total Pump Capacity (2 pumps) 16.8 Ml/d
Typical Pumping Rate, from 2 pumps = 8.45 Ml/d (in 10/92)
Drought Bounding Curve, Option C, 1997, hindcast
DAPWL = -0.82 mOD
Approximate pump cut-out = -2.71 mOD
Bounding Curve, Option C, 2006, hindcast
Pump Intake = -7.71 mOD
Water Level (mAOD)
Total Output (Ml/d)
1991
1992
1996
1997
2006

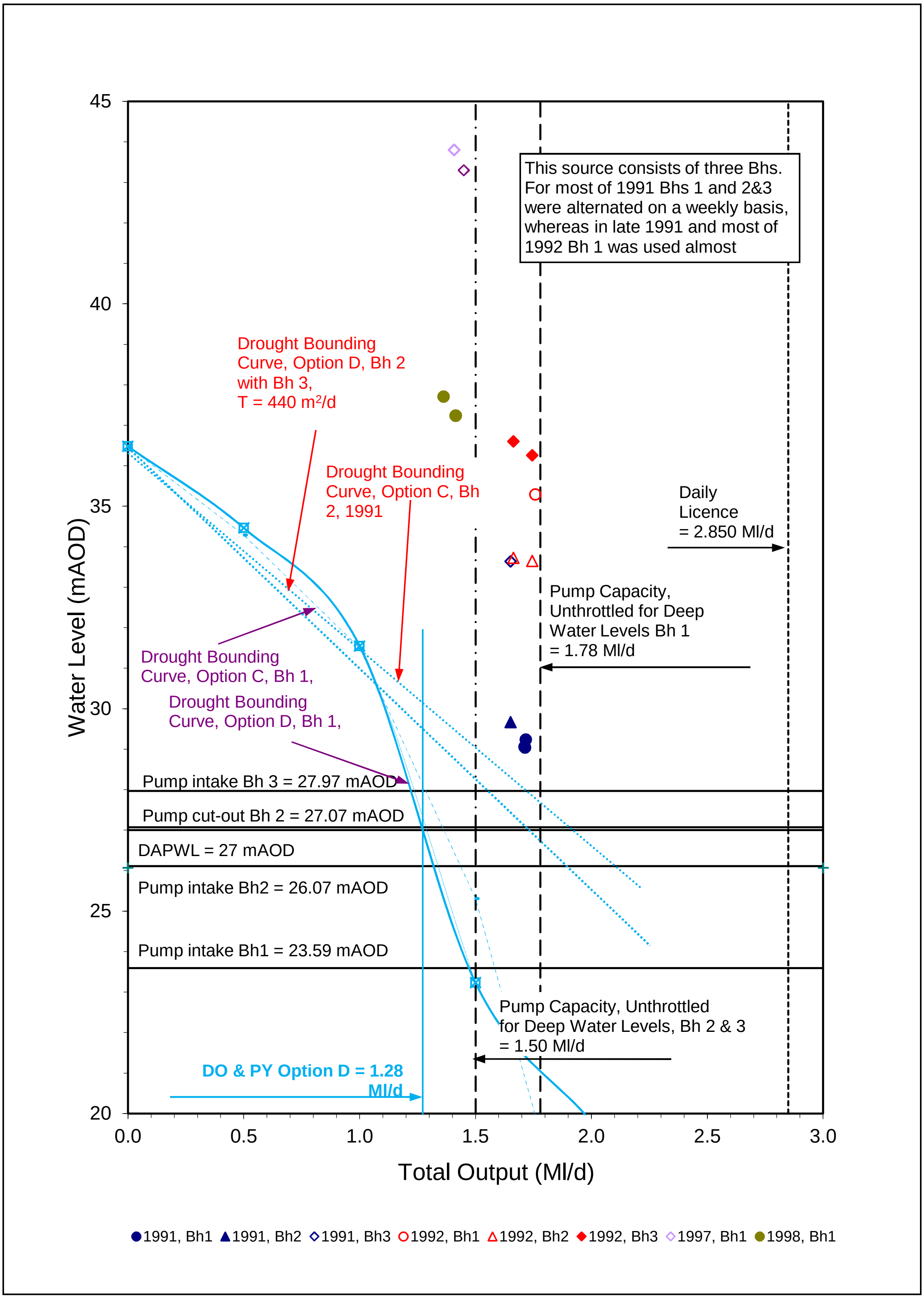
UKWIR Summary Diagram for Melbourn, Peak Demand



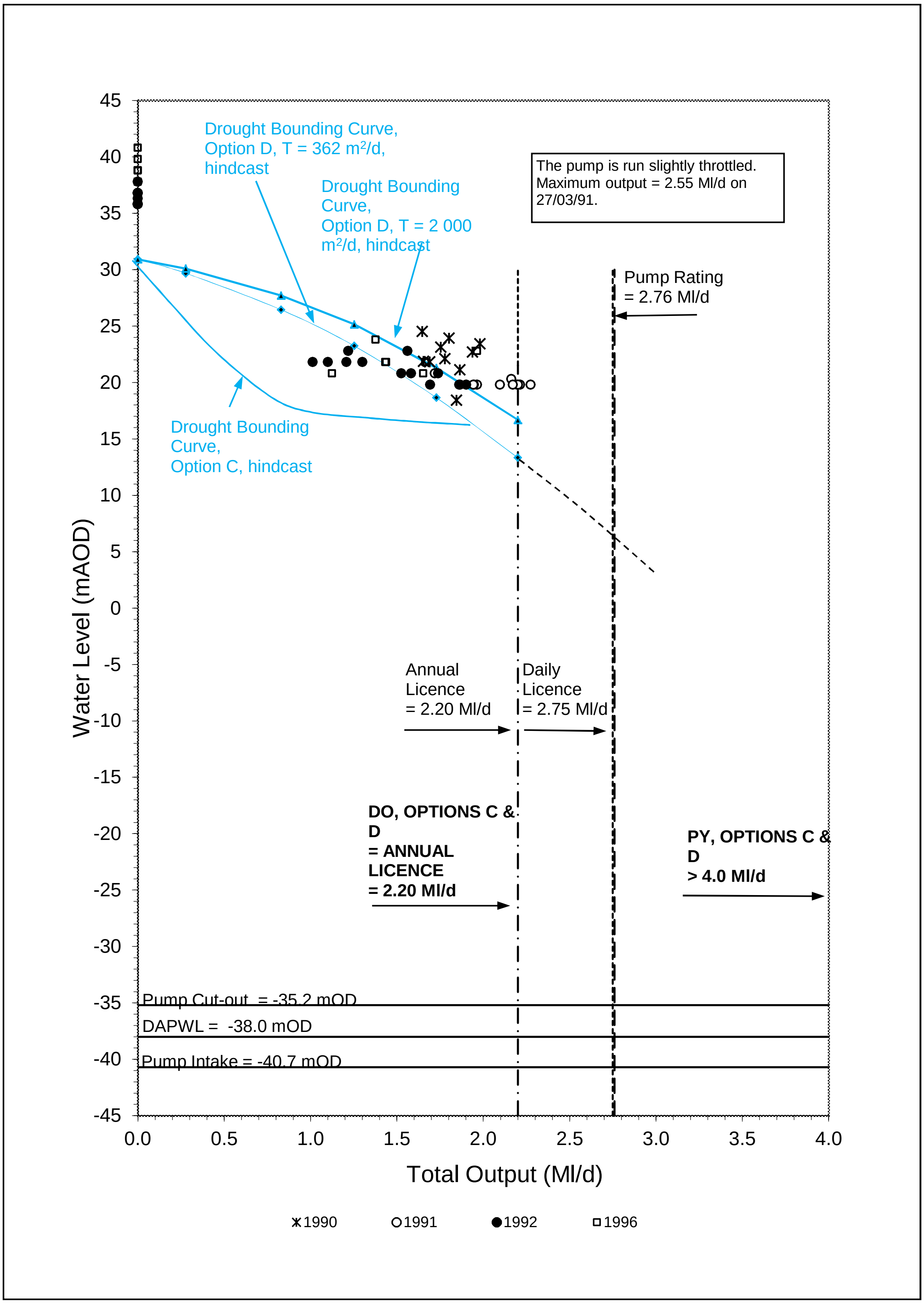
UKWIR Summary Diagram for Morden Grange, Bhs 1, 2 and 3, Average Demand



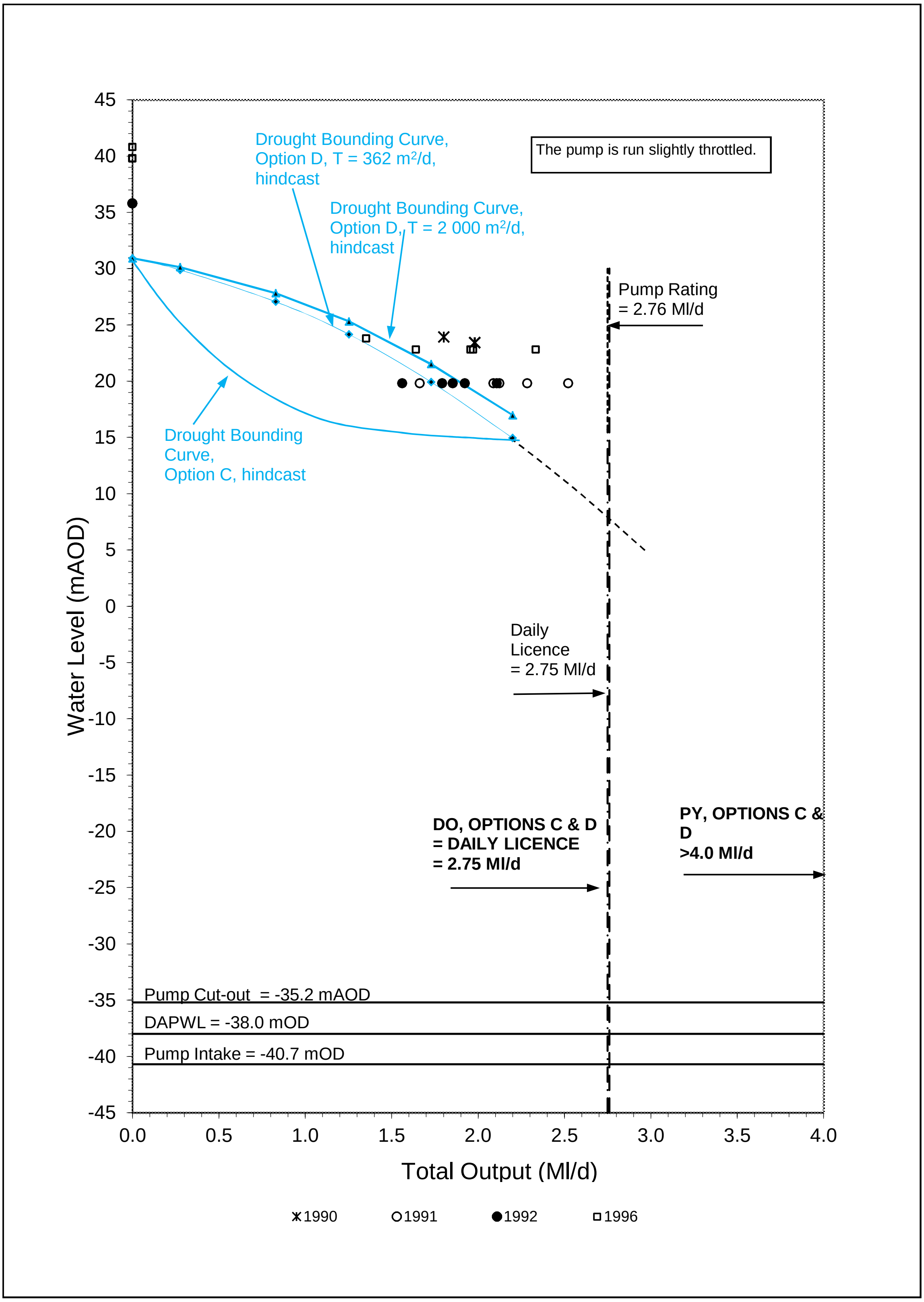
UKWIR Summary Diagram for Morden Grange, Bhs 1, 2 and 3, Peak Demand



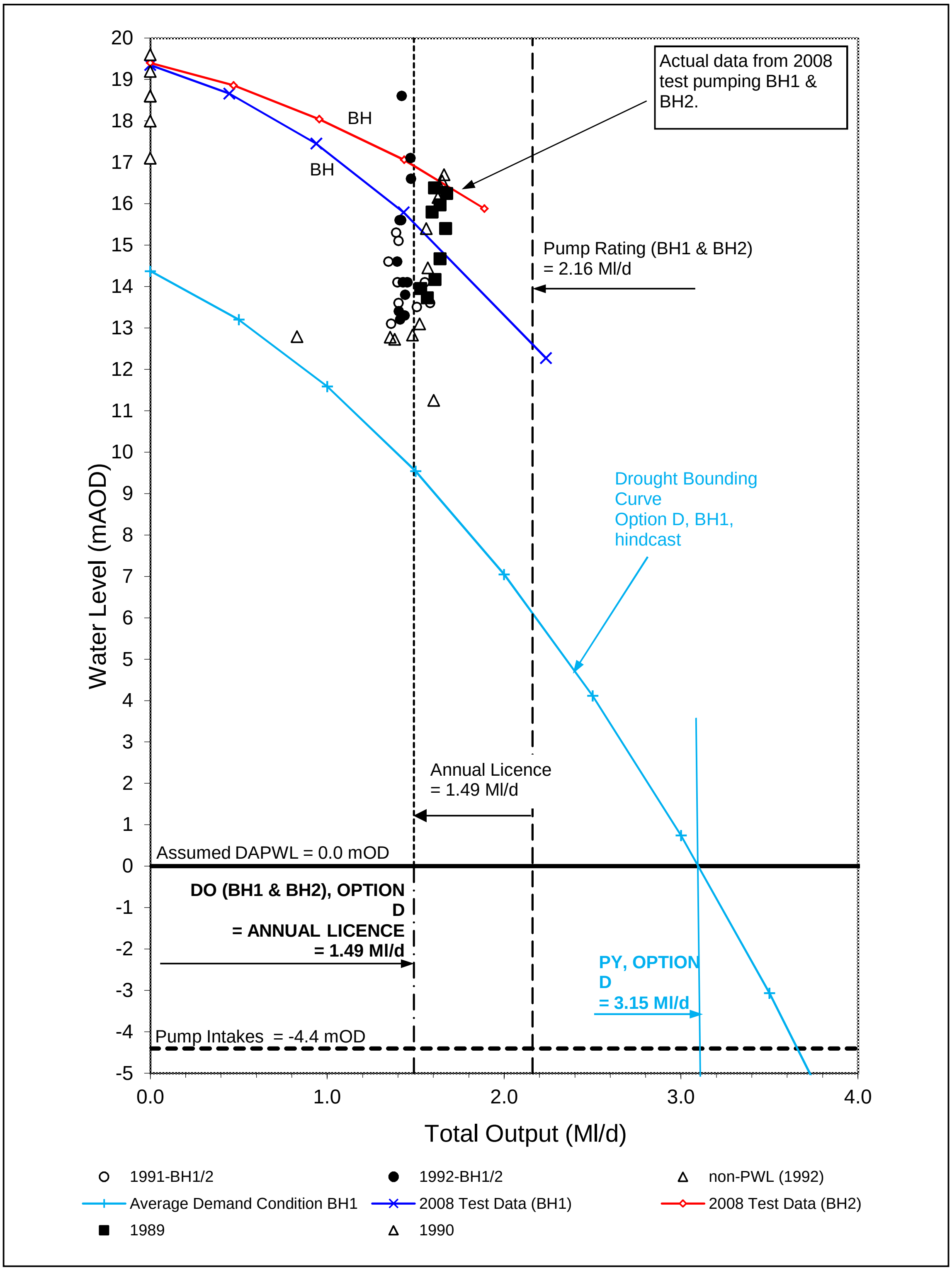
UKWIR Summary Diagram for Rivey, Average Demand

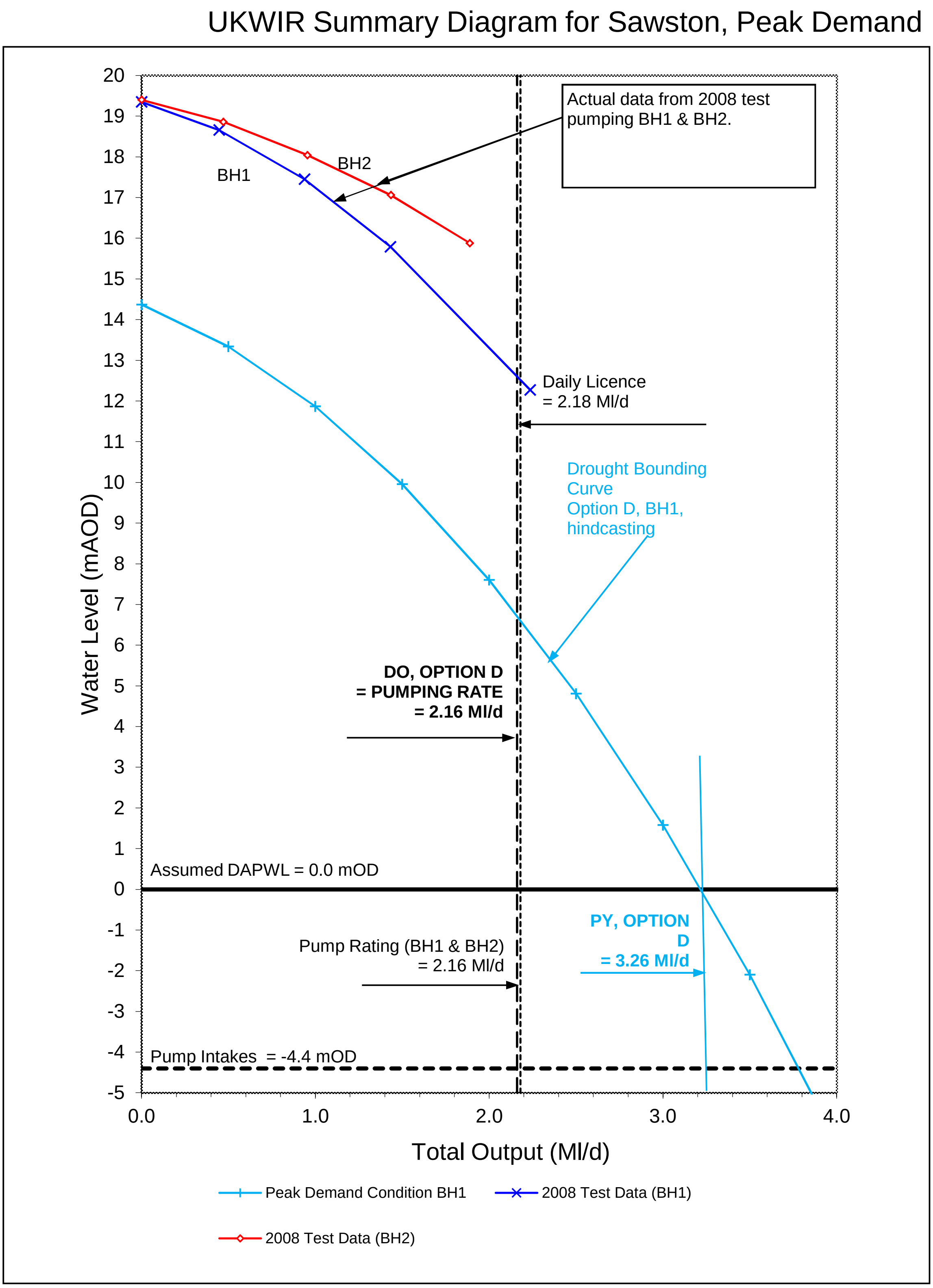


UKWIR Summary Diagram for Rivey, Peak Demand



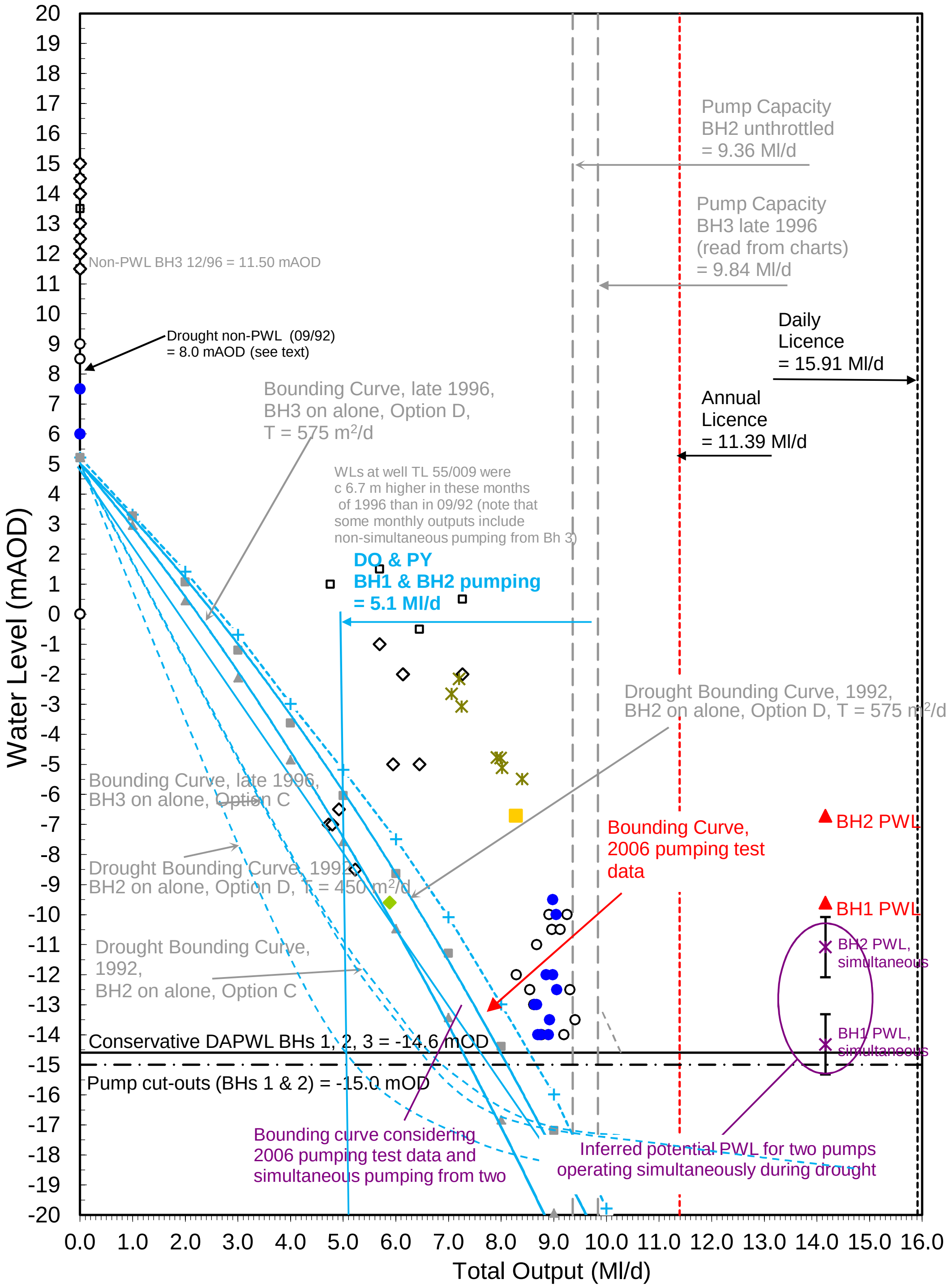
UKWIR Summary Diagram for Sawston, Average Demand





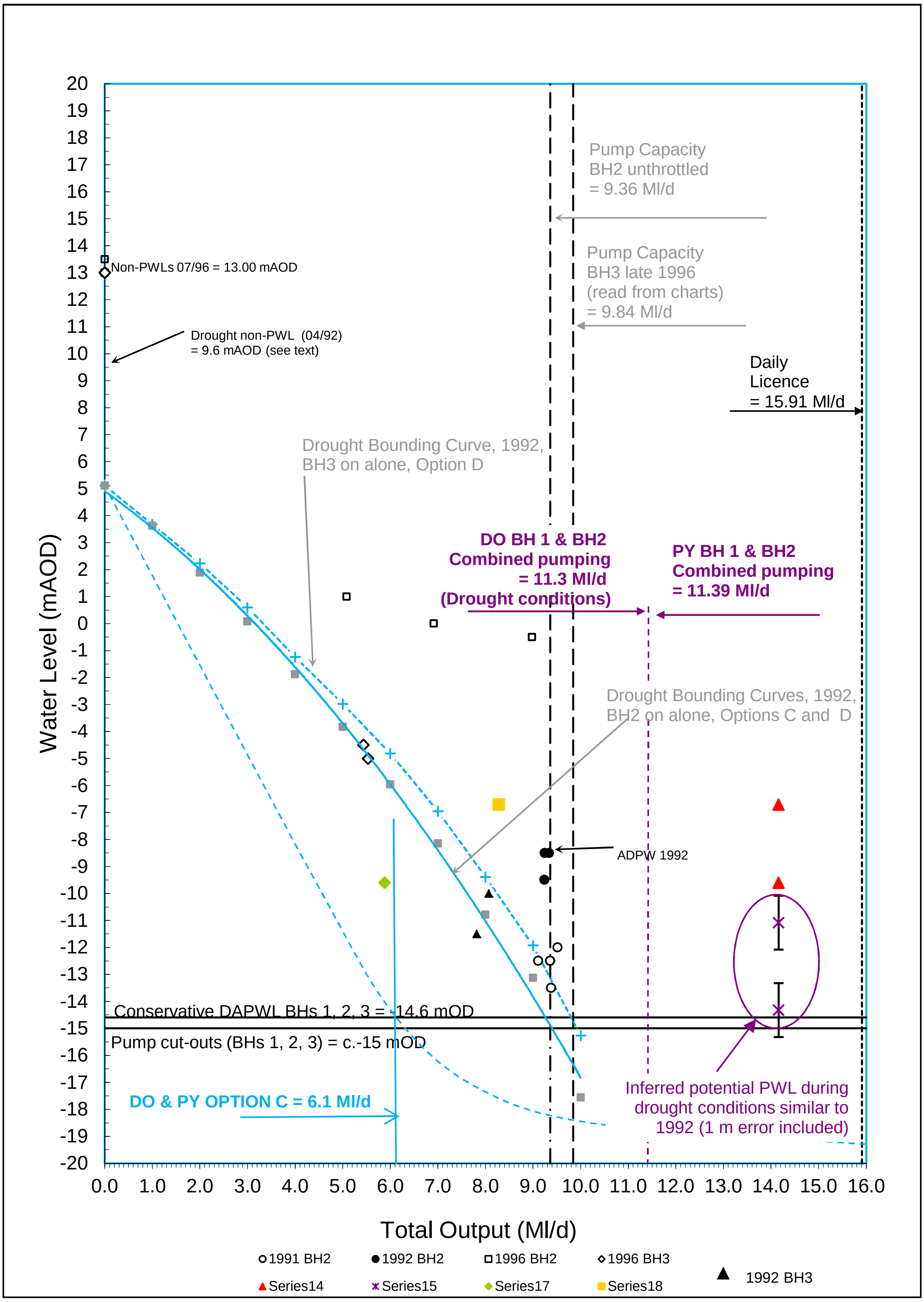
UKWIR Summary Diagram for Sawston, Peak Demand
Water Level (mAOD)
Total Output (Ml/d)
Actual data from 2008 test pumping BH1 & BH2.
BH1
BH2
Daily Licence = 2.18 Ml/d
Drought Bounding Curve Option D, BH1, hindcasting
DO, OPTION D = PUMPING RATE = 2.16 Ml/d
Assumed DAPWL = 0.0 mOD
Pump Rating (BH1 & BH2) = 2.16 Ml/d
PY, OPTION D = 3.26 Ml/d
Pump Intakes = -4.4 mOD
Peak Demand Condition BH1
2008 Test Data (BH1)
2008 Test Data (BH2)

UKWIR Summary Diagram for Westley, Average Demand

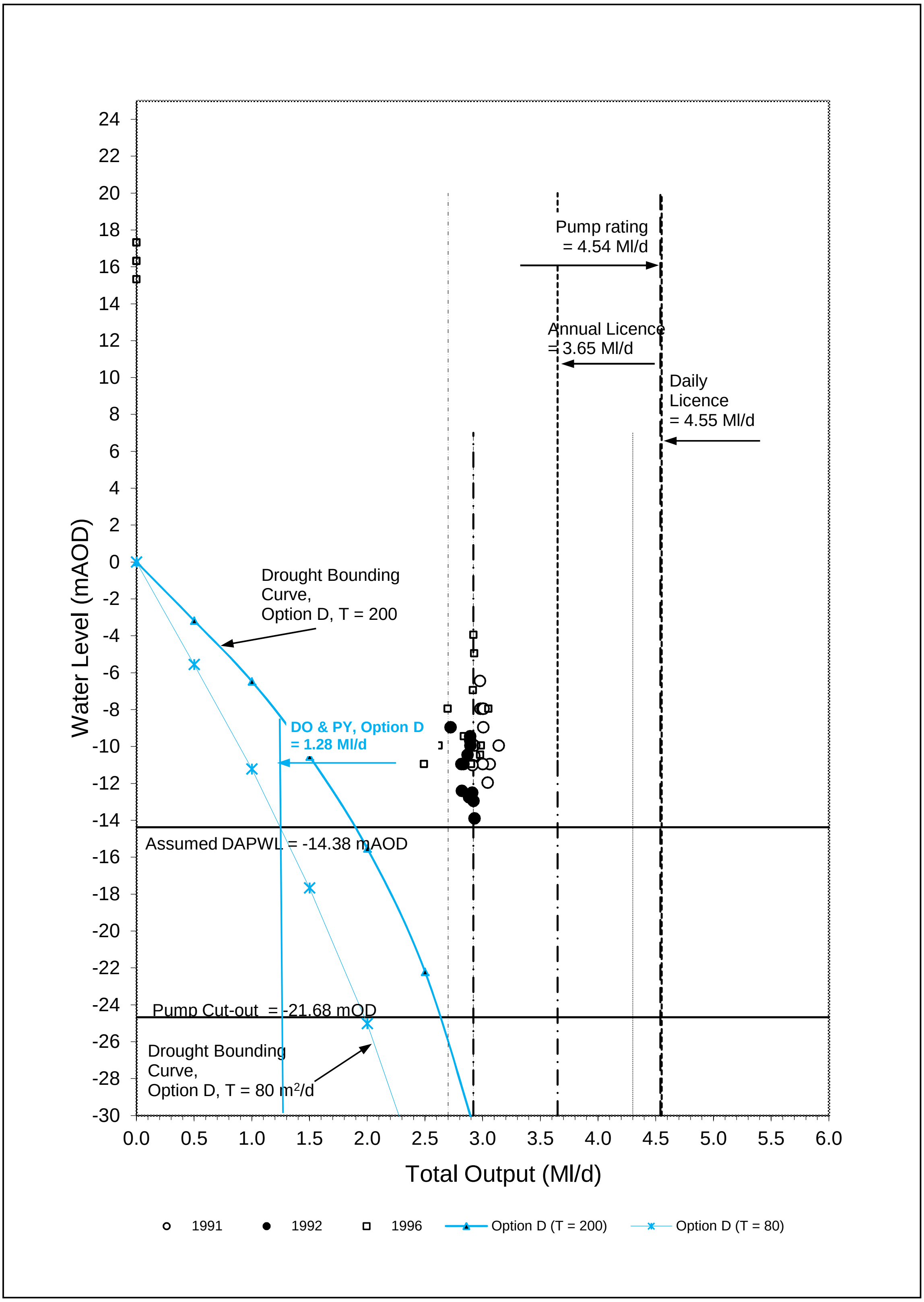


1991 BH2
1992 BH2
1996 BH2
1996 BH3
BH2 2006 Pump Test
BH1 7 day extrapolation (2006 test)
BH2 7 day extrapolation (2006 test)
BH1 & BH2 combined pumping (7 day extrapolation)

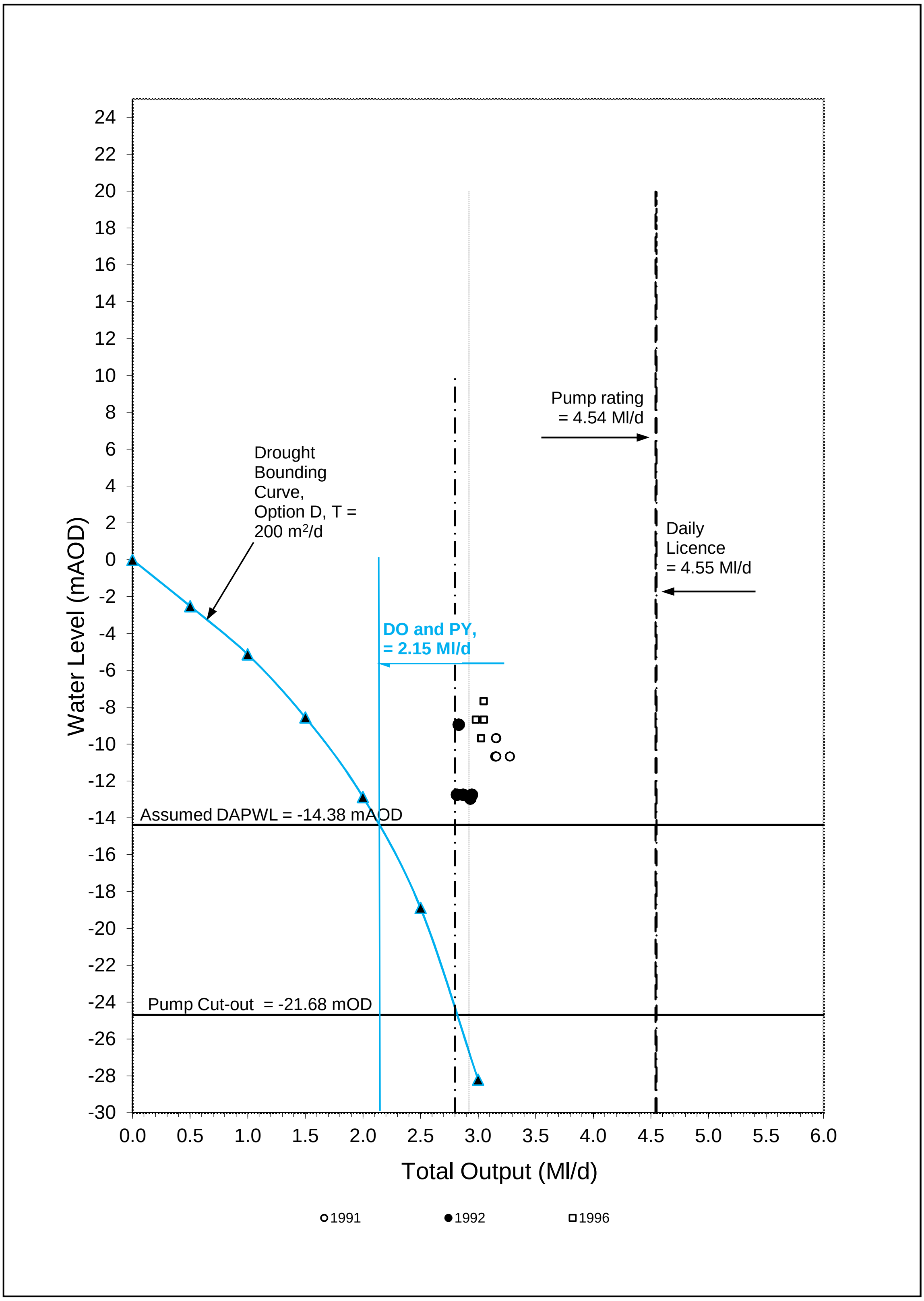
UKWIR Summary Diagram for Westley, Peak Demand



UKWIR Summary Diagram for Weston Colville, Average Demand



UKWIR Summary Diagram for Weston Colville, Peak Demand



Appendix E. Drought Trigger Correlation Percentile Graphs

Figure E.1: Babraham ABH and OBH water level correlation (Jan 1980 – May 2011)

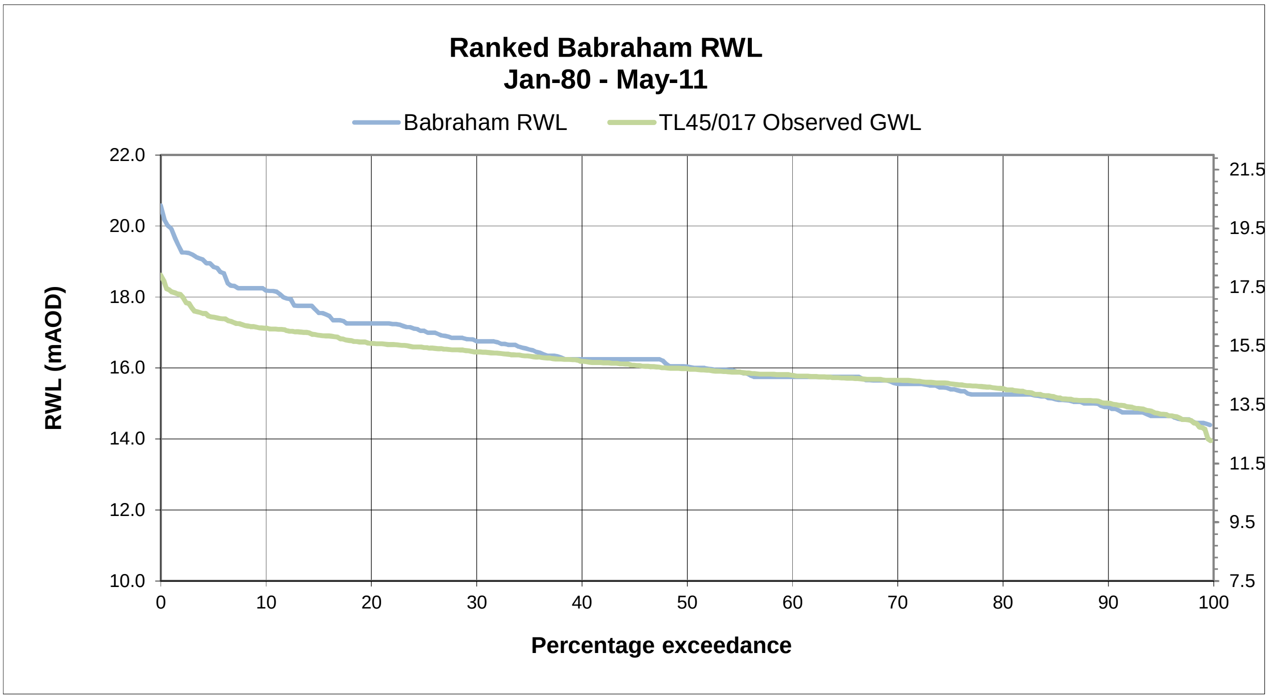


Figure E.2: Melbourn ABH and OBH water level correlation (Aug 1975 – February 2008)

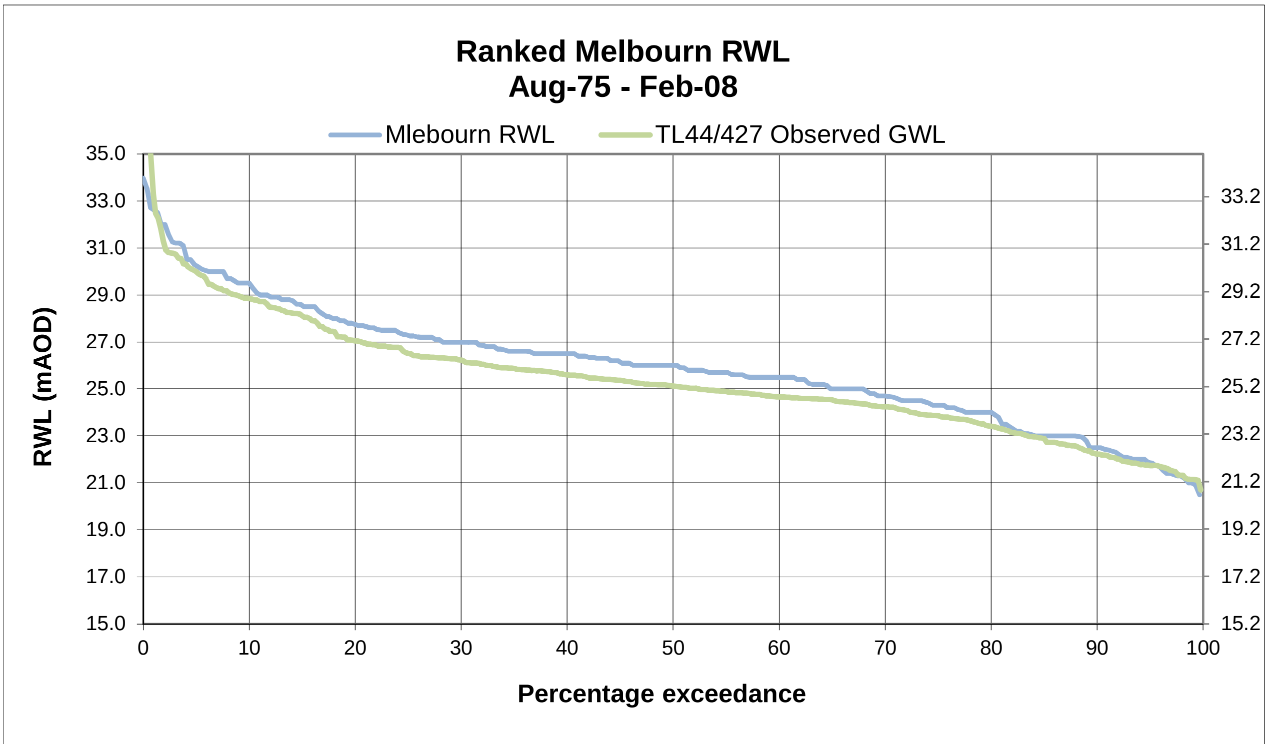


Figure E.3: Fleam Dyke ABH and OBH water level correlation (August 1975 – February 2008)

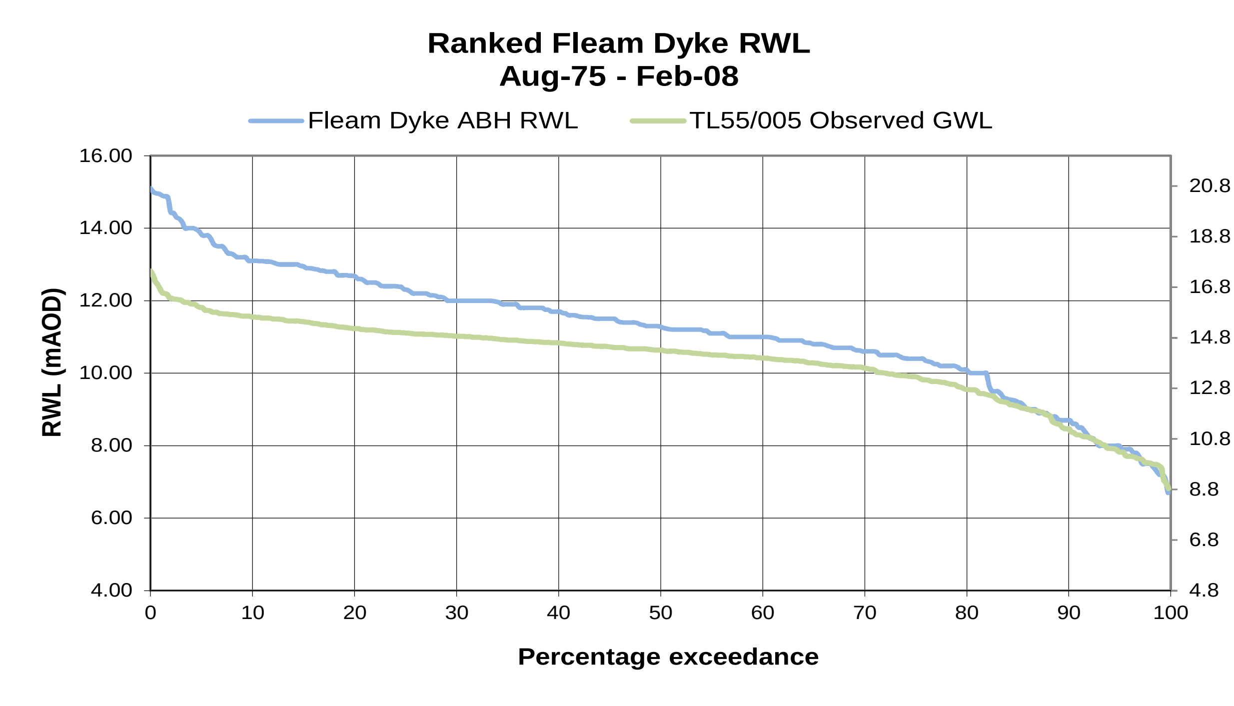


Figure E.4: Great Wilbraham ABH and OBH water level correlation (February 1983 – May 2011)

Figure E.5: Fowlmere ABH and OBH water level correlation (October 1983 – May 2011)

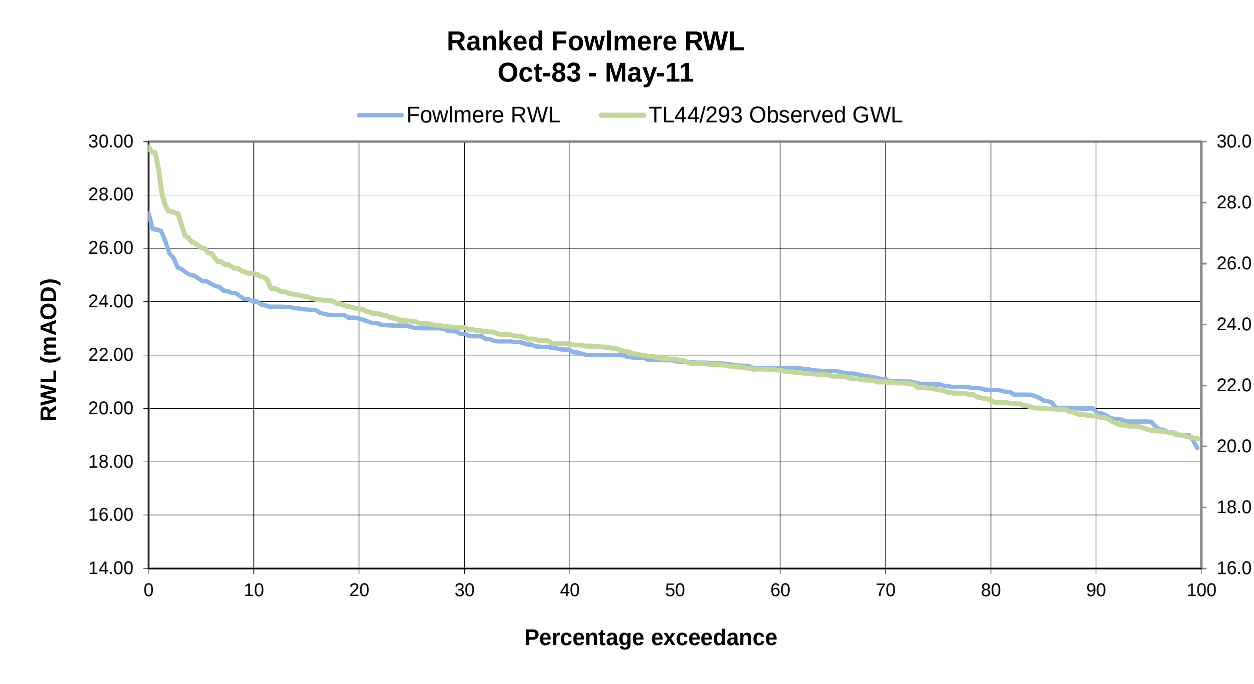
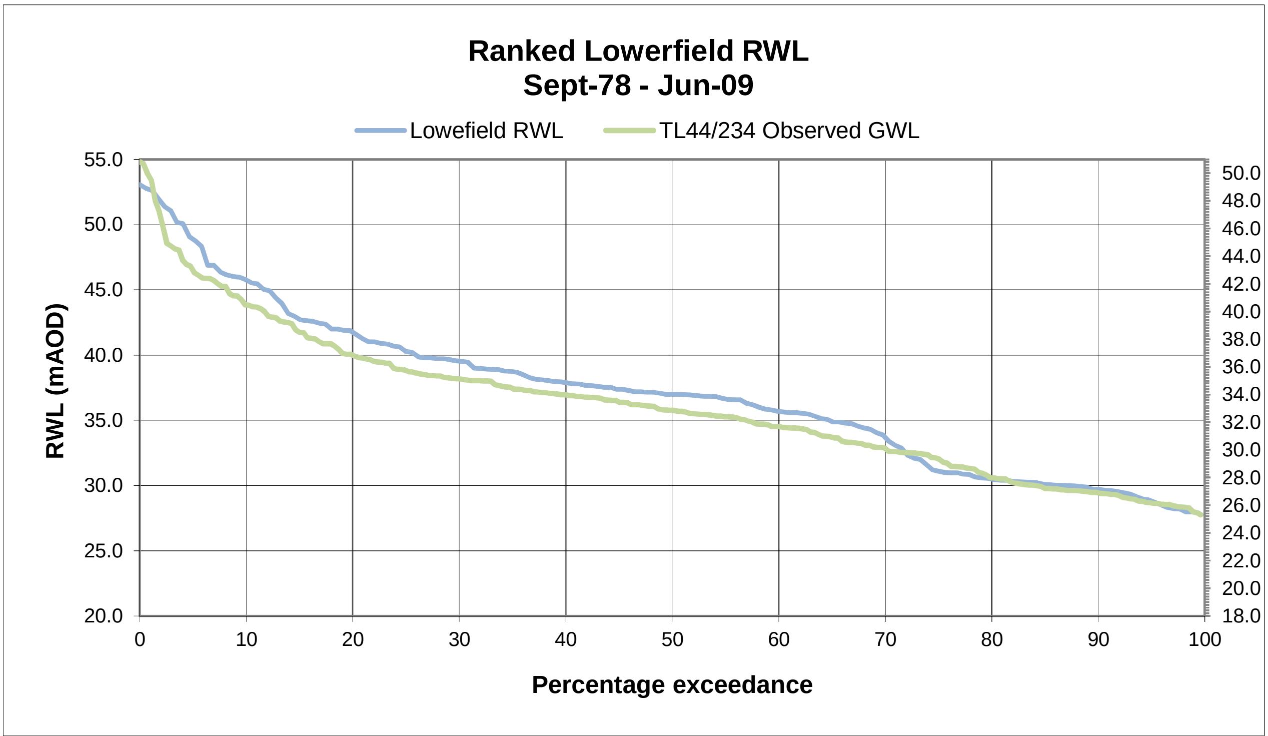
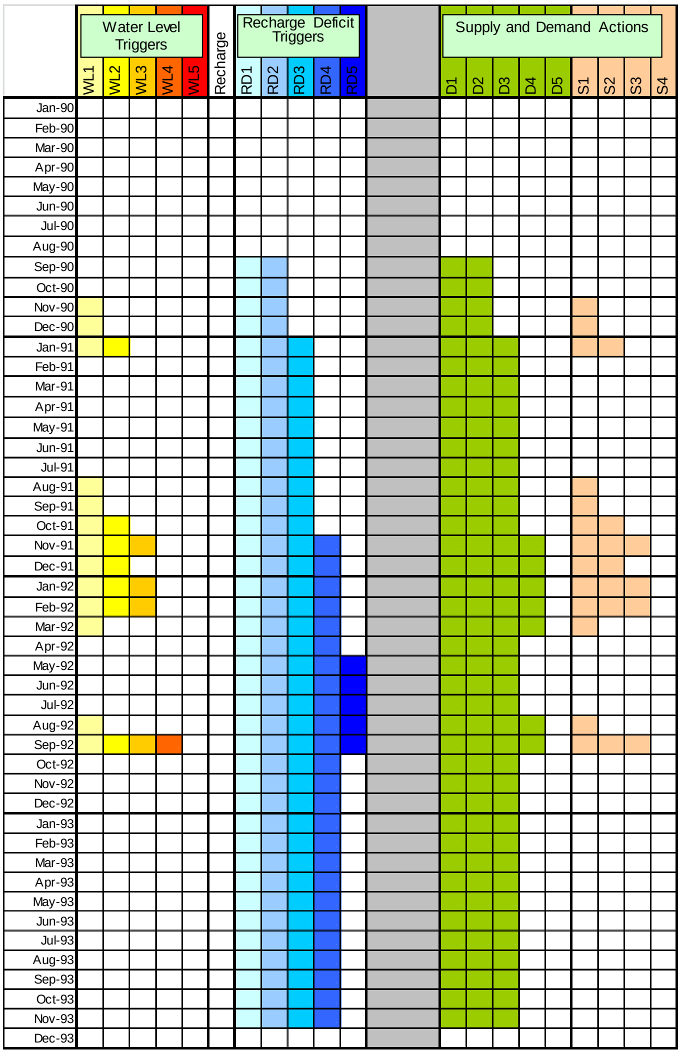


Figure E.6: Lowerfield ABH and OBH water level correlation (September 1987 – May 2011)



Appendix F. Drought Actions

Figure F.1: 1990-93 Dry Period Drought Actions (ABH rest water level triggers)



Lowerfield		Fleam Dyke		
% 30 year Exceedance	Level	% 30 year E	Level	
1 in 100 year	24.3	1 in 100 year	4.7	RWL5
99	27.9	99	7.2	RWL4
98	28.0	98	7.5	RWL3
97	28.2	97	7.8	RWL2
95	28.9	95	8.0	RWL1

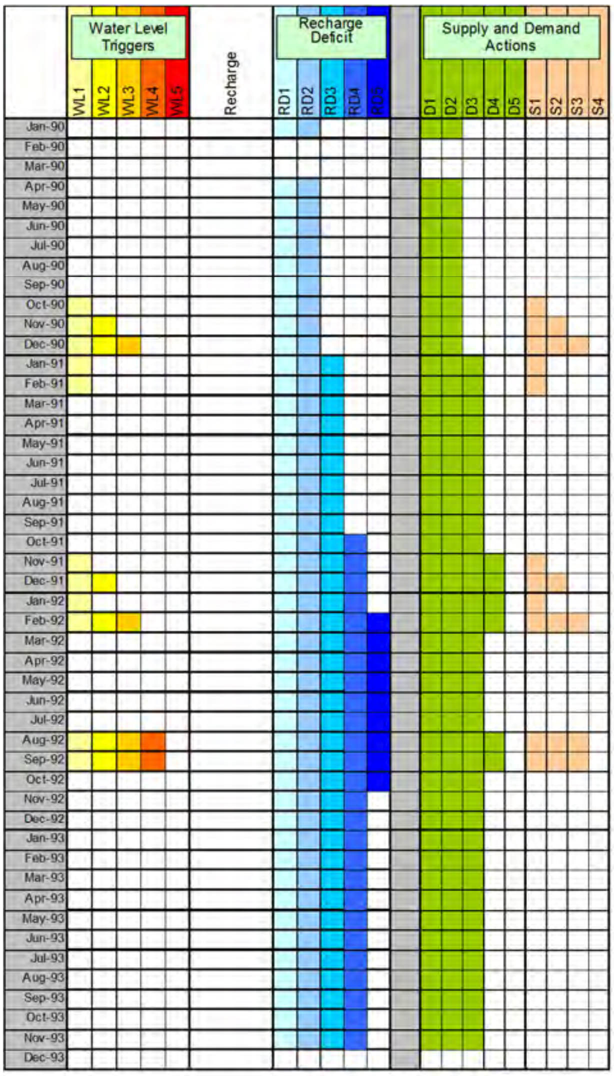
Fowlmere		Melbourn		
% 30 year Exceedance	Level	% 30 year E	Level	
1 in 100 year	17.3	1 in 100 year	20.0	RWL5
99	19.0	99	21.0	RWL4
98	19.1	98	21.3	RWL3
97	19.3	97	21.5	RWL2
95	19.5	95	21.9	RWL1

Gt. Wilbraham		Babraham		
% 30 year Exceedance	Level	% 30 year E	Level	
1 in 100 year	4.8	1 in 100 year	7.9	RWL5
99	8.1	99	12.3	RWL4
98	8.9	98	12.5	RWL3
97	9.1	97	12.8	RWL2
95	10.0	95	13.2	RWL1

Recharge	
% 30 year Exceedance	Approx
99	-260
90	-180
80	-120
70	-55
70	-55

2011 Update Values

Figure F.2: 1990-93 Dry Period Drought Actions (OBH water level triggers)



Six Indicator Sites Water Level Triggers

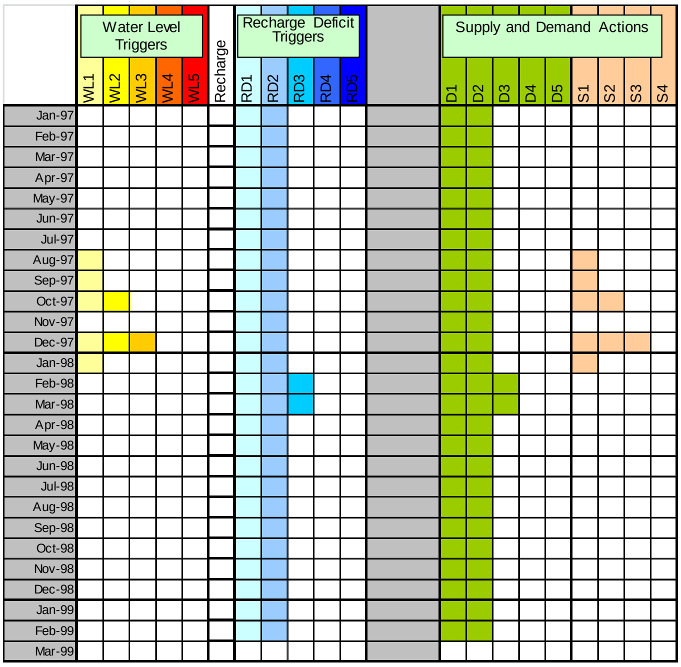
TL44/234 (Lowerfield)		TL55/005 (Fleam Dyke)		
% 30 year Exceedance	Level	% 30 year Exceedance	Level	
1 in 100 year	22.06	1 in 100 year	5.80	RWL5
99	25.73	99	9.75	RWL4
98	25.88	98	9.86	RWL3
97	26.04	97	10.02	RWL2
95	26.19	95	10.34	RWL1

TL44/293 (Fowlmere)		TL44/427 (Melbourn)		
% 30 year Exceedance	Level	% 30 year Exceedance	Level	
1 in 100 year	18.89	1 in 100 year	20.38	RWL5
99	20.32	99	21.2919	RWL4
98	20.40	98	21.4738	RWL3
97	20.48	97	21.7099	RWL2
95	20.59	95	21.89	RWL1

TL55/144 (Gt. Wilbraham)		TL45/017 (Babraham)		
% 30 year Exceedance	Level	% 30 year Exceedance	Level	
1 in 100 year	6.00	1 in 100 year	4.96	RWL5
99	10.76	99	12.74	RWL4
98	11.69	98	12.97	RWL3
97	11.96	97	13.05	RWL2
95	12.38	95	13.2025	RWL1

Recharge	
% 30 year Exceedance	Approx
99	-260
90	-180
80	-120
70	-55
70	-55

Figure F.3: 1997-99 Dry Period Drought Actions (ABH rest water level triggers)



Lowerfield		Fleam Dyke		
% 30 year Exceedance	Level	% 30 year E	Level	
1 in 100 year	24.3	1 in 100 year	4.7	RWL5
99	27.9	99	7.2	RWL4
98	28.0	98	7.5	RWL3
97	28.2	97	7.8	RWL2
95	28.9	95	8.0	RWL1

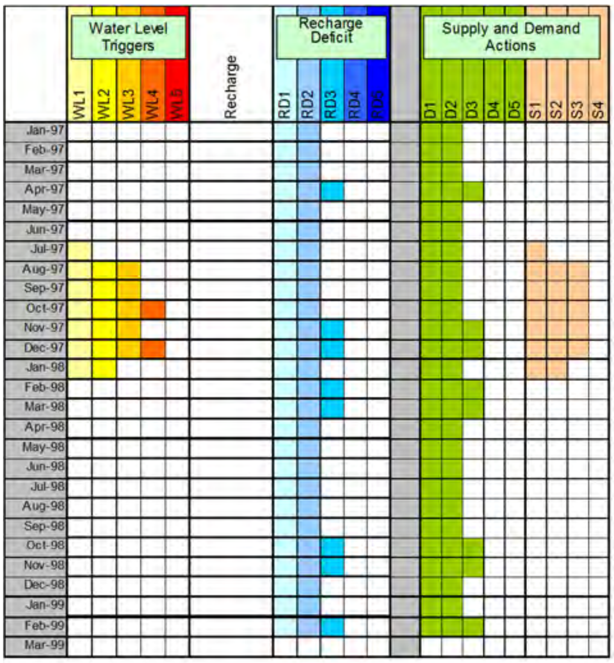
Fowlmere		Melbourn		
% 30 year Exceedance	Level	% 30 year E	Level	
1 in 100 year	17.3	1 in 100 year	20.0	RWL5
99	19.0	99	21.0	RWL4
98	19.1	98	21.3	RWL3
97	19.3	97	21.5	RWL2
95	19.5	95	21.9	RWL1

Gt. Wilbraham		Babraham		
% 30 year Exceedance	Level	% 30 year E	Level	
1 in 100 year	4.8	1 in 100 year	7.9	RWL5
99	8.1	99	12.3	RWL4
98	8.9	98	12.5	RWL3
97	9.1	97	12.8	RWL2
95	10.0	95	13.2	RWL1

Recharge	
% 30 year Exceedance	Approx
99	-260
90	-180
80	-120
70	-55
70	-55

2011 Update Values

Figure F.4: 1997-99 Dry Period Drought Actions (OBH rest water level triggers)



Six Indicator Sites Water Level Triggers

TL44/234 (Lowerfield)		TL55/005 (Fleam Dyke)		
% 30 year Exceedance	Level	% 30 year Exceedance	Level	
1 in 100 year	22.06	1 in 100 year	5.80	RWL5
99	25.73	99	9.75	RWL4
98	25.88	98	9.86	RWL3
97	26.04	97	10.02	RWL2
95	26.19	95	10.34	RWL1

TL44/293 (Fowlmere)		TL44/427 (Melbourn)		
% 30 year Exceedance	Level	% 30 year Exceedance	Level	
1 in 100 year	18.89	1 in 100 year	20.38	RWL5
99	20.32	99	21.2919	RWL4
98	20.40	98	21.4738	RWL3
97	20.48	97	21.7099	RWL2
95	20.59	95	21.89	RWL1

TL55/144 (Gt. Wilbraham)		TL45/017 (Babraham)		
% 30 year Exceedance	Level	% 30 year Exceedance	Level	
1 in 100 year	6.00	1 in 100 year	4.96	RWL5
99	10.76	99	12.74	RWL4
98	11.69	98	12.97	RWL3
97	11.96	97	13.05	RWL2
95	12.38	95	13.2025	RWL1

Recharge	
% 30 year Exceedance	Approx
99	-260
90	-180
80	-120
70	-55
70	-55