revised draft Drought Plan 2022

Appendix 6

Drought management for Anglian Water groundwater sources

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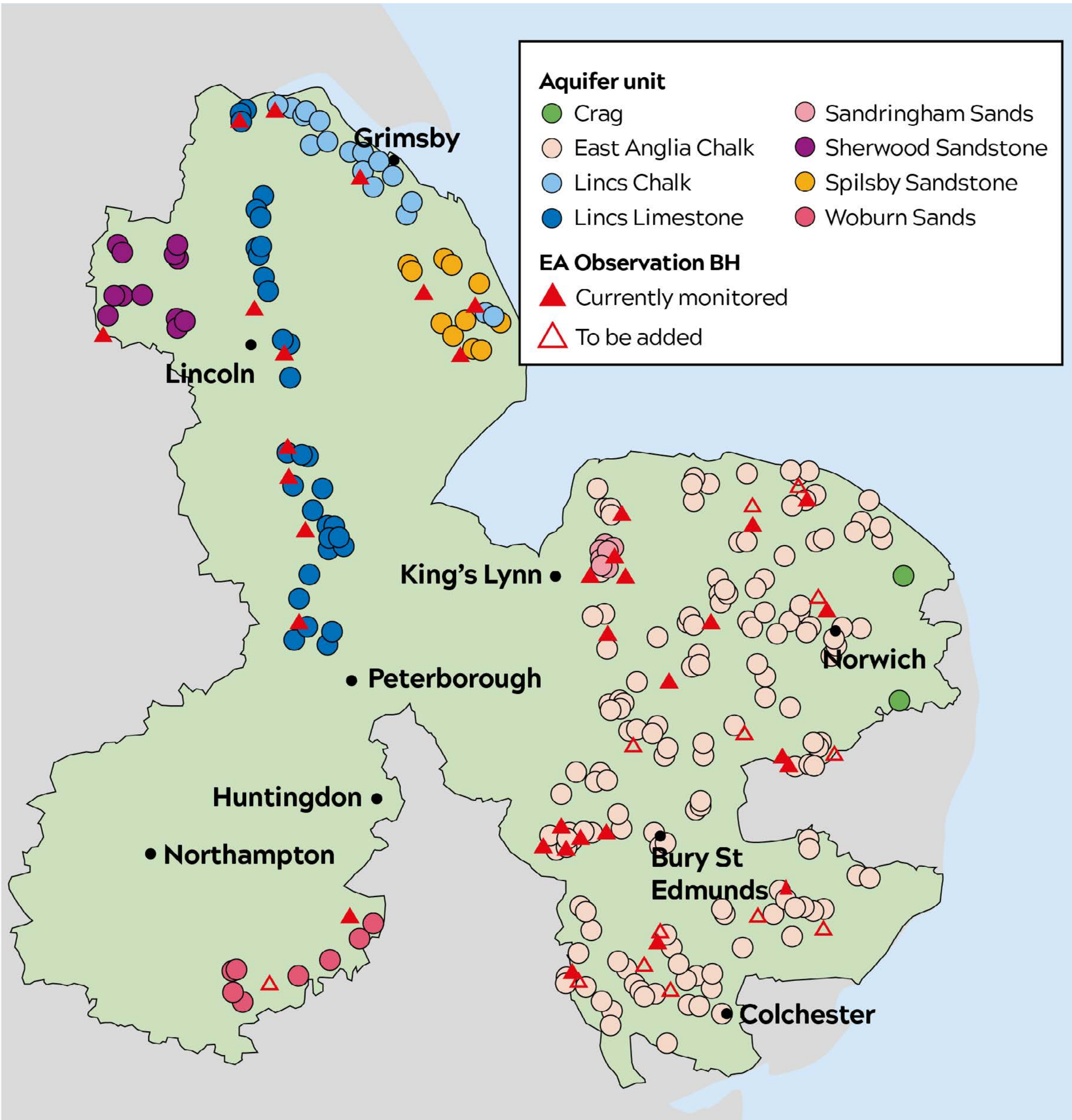
1. Introduction

Approximately 50 per cent of supply is provided by groundwater abstracted from over 200 sources comprising more than 450 operational boreholes. These range in depth from 10m to 500m, and penetrate several major aquifers across the region. Each aquifer will respond differently in a drought.

We rely predominantly on groundwater for public water supply in the east and north of our region. The principal aquifer that we abstract from is the Chalk (with 65 per cent of licensed groundwater abstraction). The remaining groundwater sources abstract from the Lincolnshire Limestone (13.5 per cent), Sherwood Sandstone (7.5 per cent), Magnesian Limestone (5.5 per cent), Lower Greensand (3.5 per cent), Spilsby Sandstone (3 per cent), Sandringham Sands (1.5 per cent) and a combination of Crag, Sands and Gravels (0.5 per cent). The spread of our boreholes across the principal aquifers in the Anglian region are show in Figure 1.1. The figure also shows the Environment Agency's observation boreholes that we currently use, along with the ones that we are hoping to add to our network, to help monitor our sources. **Section 3.3** includes more detail about observation boreholes.

Figure 1.1: Anglian Water groundwater sources by aquifer and Environment Agency observation boreholes

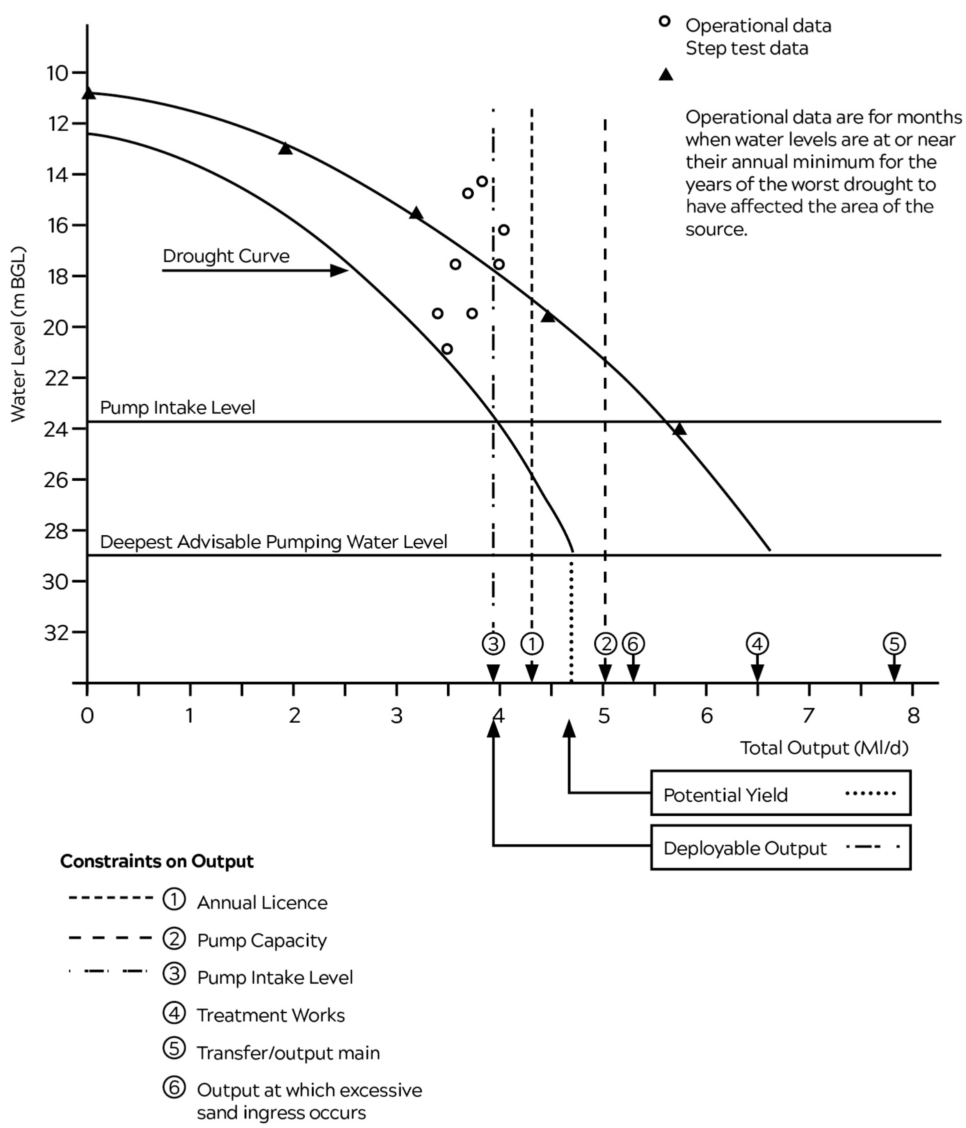


2. Yield assessment

The potential yield for each of our groundwater sources is calculated in accordance with the industry-accepted UKWIR methodology[1], and we have calculated this for both the worst historic drought experienced and a 1 in 200 year event, in line with our revised Level of Service (as detailed in the WRMP 2019). In Lincolnshire where we have historically already experienced a 1 in 200 year groundwater drought event, we have also calculated yields for a drought worse than 1 in 200.

The potential yield for each of our groundwater sources is a measure of how much water the source can reliably provide for supply during a 'worst-case' drought. The UKWIR yield assessment methodology applied to all AWS groundwater sources involves the relationship between total source abstraction rates against measured and predicted drought water levels, and comparing them with the deepest advisable pumping water level (DAPWL). The methodology plots key water level and yield data on to a 'summary diagram' and uses this to define a 'drought curve'. Figure 2.1 shows an example summary diagram.

Figure 2.1: UKWIR summary diagram for drought vulnerable groundwater sources



[1] *UKWIR (1995) A methodology for the determination of outputs Groundwater sources*

Groundwater source potential yields (PY) were reviewed and updated in preparation for the Water Resources Management Plan (WRMP) 2019. 47 groundwater sources were considered to require a PY update, based on a weighted prioritisation process covering the following criteria:

- Average PY close to licence
- Peak PY close to licence
- DO constrained by PY
- Drought Risk Status
- PY recently reviewed
- Significant change to source
- Growth Forecast for the Water Resource Zone (WRZ)

The updates considered various factors including new / decommissioned boreholes, updated test pumping data, operational regime and more accurate DAPWL assumptions.

Average groundwater yields are calculated as the monthly average daily abstraction during a drought year. Peak PY is calculated as the maximum seven day rolling daily average abstraction in a drought year[2]. Full details of the methodology and yield updates are presented in 'Source Reliable Output Update, Groundwater' (Mott MacDonald, 2017).

To understand the impact of severe droughts on our groundwater sources, we also undertook a severe drought groundwater yield assessment.

Two hundred stochastically generated weather sequences, developed as part of the Water Resources East project, were run through a lumped parameter model (LPM) for each regional aquifer to output time series of LPM groundwater storage. To determine the relevant drought yields, the first stage was to identify storage values from the stochastic series. Historical modelled LPM storage versus observed groundwater level was plotted for key observation boreholes across the region in aquifers potentially vulnerable to drought, and these were used to identify severe drought groundwater level responses, taking account of uncertainties in the level - storage relationship.

A workshop involving experienced members of Anglian Water's Water Resource Management Team was then held to determine severe drought yield at every groundwater source, following the baseline UKWIR source reliable output summary diagram approach. Possible water quality effects were also accounted for, through expert judgement, which could limit yield unless significant additional investment in treatment infrastructure was undertaken. This approach was subject to an independent peer review. The results have been used to review the drought vulnerable borehole list detailed in **Section 3**.

2 *Mott MacDonald (2017) Source Reliable Output Update, Groundwater*

3. Drought management

3.1 Drought vulnerable boreholes

The potential for reductions in yields for groundwater supplies is particularly acute during periods of drought when low groundwater levels increase the risk of operational pumping water levels approaching or breaching their defined DAPWLs as illustrated in Figure 2.1. The DAPWL may be set at the point where a principle flow horizon starts to dewater when the piezometric surface lowers. Groundwater sources that rely on discrete high level flow horizons may be particularly vulnerable to the onset of a drought.

A classification scheme for drought risk was introduced for the 2014 Drought Plan, with three tiers of groundwater drought vulnerability: Tier 1, Tier 2 and Tier 3. Tier 1 sources are those where drought yield is significantly below the abstraction licence and there is some risk to supply during drought. Tier 2 is for those sources where although PY is impacted by drought, the yield is very unlikely to fall below the maximum abstraction rate licensed for the source, such that the risk of a loss of supply is very low. Tier 3 included a further group of sources that could be at risk during a severe drought, identified through a 2012 study by Mott MacDonald for Anglian Water.

Using our severe drought yield assessment for the WRMP 2019, the risk that drought may result in a loss of yield or supply at each of these sources has been reviewed for up to a 1 in 200 year drought, for both the WRMP 2019 and this Drought Plan 2022. The drought vulnerability has been evaluated based on improved understanding of behaviour of the sources under drought conditions, drought investment, and groundwater modelling.

We have identified 17 operational sources that are considered to be drought vulnerable at Tier 1 level, a reduction from 19 in 2014. A summary of all the changes across the tiers, as well as a description of the tier, is in Table 3.1. A list of all the groundwater sources within each tier is in Table 3.2.

Strategic investment in new boreholes or other contingencies means that even for Tier 1 sources, there should be no risk to supply at times of average demand during 1 in 200 year droughts. However for sources in five zones identified in the WRMP 2019 to still have drought vulnerabilities, we are proposing strategic investment by 2024. We have identified potential interim options to support the zones until the investment is completed, which are detailed in **Appendix 3**.

Table 3.1: Changes to drought vulnerable borehole tiers between Drought Plan 2014 and Drought Plan 2022

	Drought Plan 2014 drought vulnerable boreholes		Drought Plan 2022 drought vulnerable boreholes	
Drought tier	**Source count**	**Description**	**Source count**	**Description**
T1	19	Drought impact on yield and supply	17	Drought impact on yield and supply
T2	8	Drought impact on yield but licence limits supply impact	9	Drought impact on yield but licence limits supply impact
T3	18	Severe drought risk	20	Uncertain severe drought risk or risk is for droughts >1in200yr severity

Table 3.2: Groundwater sources and drought vulnerable tiers

Source	Aquifer unit	WRZ	Drought tier 2022	Drought tier comment
Risby	East Anglia Chalk	Bury Haverhill	1	Source added to the drought vulnerable tier 1 list - severe drought risk to yield and supply impacts identified in WRMP 2019
Goxhill 2	Lincs Chalk	Central Lincs	1	No change
Welton	Lincs Limestone	Central Lincs	1	No change
Winterton Holmes	Lincs Limestone	Central Lincs	1	Reviewing and monitoring groundwater level data to establish the new borehole's susceptibility to drought following its recent commissioning in 2018
Lower Links	East Anglia Chalk	Cheveley	1	Severe drought risk to yield and supply impacts identified in WRMP 2019
Belstead	East Anglia Chalk	East Suffolk	1	General risk due of saline intrusion particularly at peak demand / low groundwater levels
Westerfield	East Anglia Chalk	East Suffolk	1	No change
Whitton	East Anglia Chalk	East Suffolk	1	No change
Newmarket AR	East Anglia Chalk	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP 2019
Long Hill	East Anglia Chalk	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP 2019
Moulton	East Anglia Chalk	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP 2019
Southfields	East Anglia Chalk	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP 2019
Congham	East Anglia Chalk	North Fenland	1	Spring flow licence condition
Gayton	East Anglia Chalk	North Fenland	1	No change
Metton	East Anglia Chalk	North Norfolk Coast	1	No change
North Walsham	East Anglia Chalk	North Norfolk Coast	1	Source added to the drought vulnerable tier 1 list - severe drought risk to yield and potential supply impacts
Marham	East Anglia Chalk	South Fenland	1	Severe drought risk to yield and supply impacts identified in WRMP 2019
Waneham Bridge (Dunston)	Lincs Limestone	Central Lincs	2	Severe drought risk to yield but no risk to supply
Eriswell 1	East Anglia Chalk	Ely	2	Severe drought risk to yield but no risk to supply. Downgraded from T1 as new boreholes imminent. Review once boreholes commissioned
Isleham	East Anglia Chalk	Ely	2	No change

Source	Aquifer	WRZ	Drought tier 2022	Drought tier comment
Didlington	East Anglia Chalk	Norfolk Rural North	2	Severe drought risk to yield but reduced risk to supply after borehole 3 commissioned
Fring - Osier Carr	East Anglia Chalk	North Fenland	2	No change
Hillington (Chalk)	East Anglia Chalk	North Fenland	2	No change - severe drought risk to yield but no risk to supply
Sedgeford	East Anglia Chalk	North Fenland	2	Risk increased from T3. Severe drought risk to yield but no risk to supply
Matlaske	East Anglia Chalk	North Norfolk Coast	2	Risk increased from T3. Severe drought risk to yield but no risk to supply
Birchmoor	Woburn Sands	RHF South	2	Severe drought risk to yield but no risk to supply
Etton	Lincs Limestone	Bourne	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Pilsgate	Lincs Limestone	Bourne	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Wilsthorpe	Lincs Limestone	Bourne	3	Severe drought risk to yield but >1in200yr only
Barrow	Lincs Chalk	Central Lincs	3	Loss of yield possible, but DAPWL is very uncertain. >1in200yr risk only
Fosters Bridge-Moors Farm	Lincs Limestone	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Redbourne	Lincs Limestone	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Spridlington	Lincs Limestone	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Ulceby	Lincs Chalk	Central Lincs	3	Severe drought risk to yield but >1in200yr only
Waddingham	Lincs Limestone	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Winterton Carrs	Lincs Limestone	Central Lincs	3	Possible severe drought risk to yield but >1in200yr only
Fordington	Spilsby Sandstone	East Lincs	3	Severe drought risk to yield but >1in200yr only
Barnoldby	Lincs Chalk	East Lincs	3	Severe drought risk to yield but >1in200yr only
Welton le Marsh	Spilsby Sandstone	East Lincs	3	Severe drought risk to yield and possible water quality issues but >1in200yr only
Wellington Wellfield	East Anglia Chalk	North Fenland	3	Severe drought risk to wider Wellfield performance uncertain - needs further investigation

Source	Aquifer	WRZ	Drought tier 2022	Drought tier comment
Lyng Forge	East Anglia Chalk	Norwich and the Broads	3	Possible severe drought risk to yield from water quality, but no risk to supply
Battlesden	Woburn Sands	RHF South	3	Possible severe drought risk to yield but no risk to supply
Pulloxhill	Woburn Sands	RHF South	3	Possible severe drought risk to yield but no risk to supply
Denton Lodge	East Anglia Chalk	South Fenland	3	Severe drought risk to wider Wellfield performance uncertain - needs further investigation
Aswarby	Lincs Limestone	South Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Sleaford DL	Lincs Limestone	South Lincs	3	Possible severe drought risk to yield but >1in200yr only

The revised Tier 3 also includes boreholes which have been identified to be at risk from a drought more severe than 1 in 200 years. This is beyond our proposed Level of Service and there is considerable uncertainty about the yield impacts at these sources, but nonetheless it was considered prudent to include them for future reference.

To improve our understanding of individual source response to severe and extreme droughts, we have commissioned a modelling pilot project into the response of the aquifers in the Newmarket area. This is an area identified as being vulnerable to drought. The Newmarket sources lie within the area covered by the Environment Agency's North-East Anglian Chalk (NEAC) regional groundwater model. A more detailed sub-model will be built using a MODFLOW6 unstructured grid, to model aquifer and borehole response under low piezometry and under severe and extreme drought events.

3.2 Groundwater sources with drought-related licence conditions

In addition to the drought risk at groundwater sources arising from low groundwater levels impacting on the borehole yield, there are some sources with licences subject to drought restrictions which may constrain the deployable output. These constraints on the deployable output are already accounted for in our WRMP 2019 planning and do not therefore require any specific drought management actions.

The sources where we have groundwater level related licence conditions for environmental reasons are included in Table 3.3 and the monitoring boreholes specified in these restrictions are included in monthly monitoring reports that we receive from the Environment Agency.

An agreement also exists with the Environment Agency for Anglian Water groundwater sources in the Northern Lincolnshire Chalk which results in abstraction licence reductions at times of low water levels to minimise risk of saline intrusion to the aquifer. The introduction of licence controls depends on the outcome of regional groundwater modelling as carried out by the Environment Agency towards the end of the recharge season.

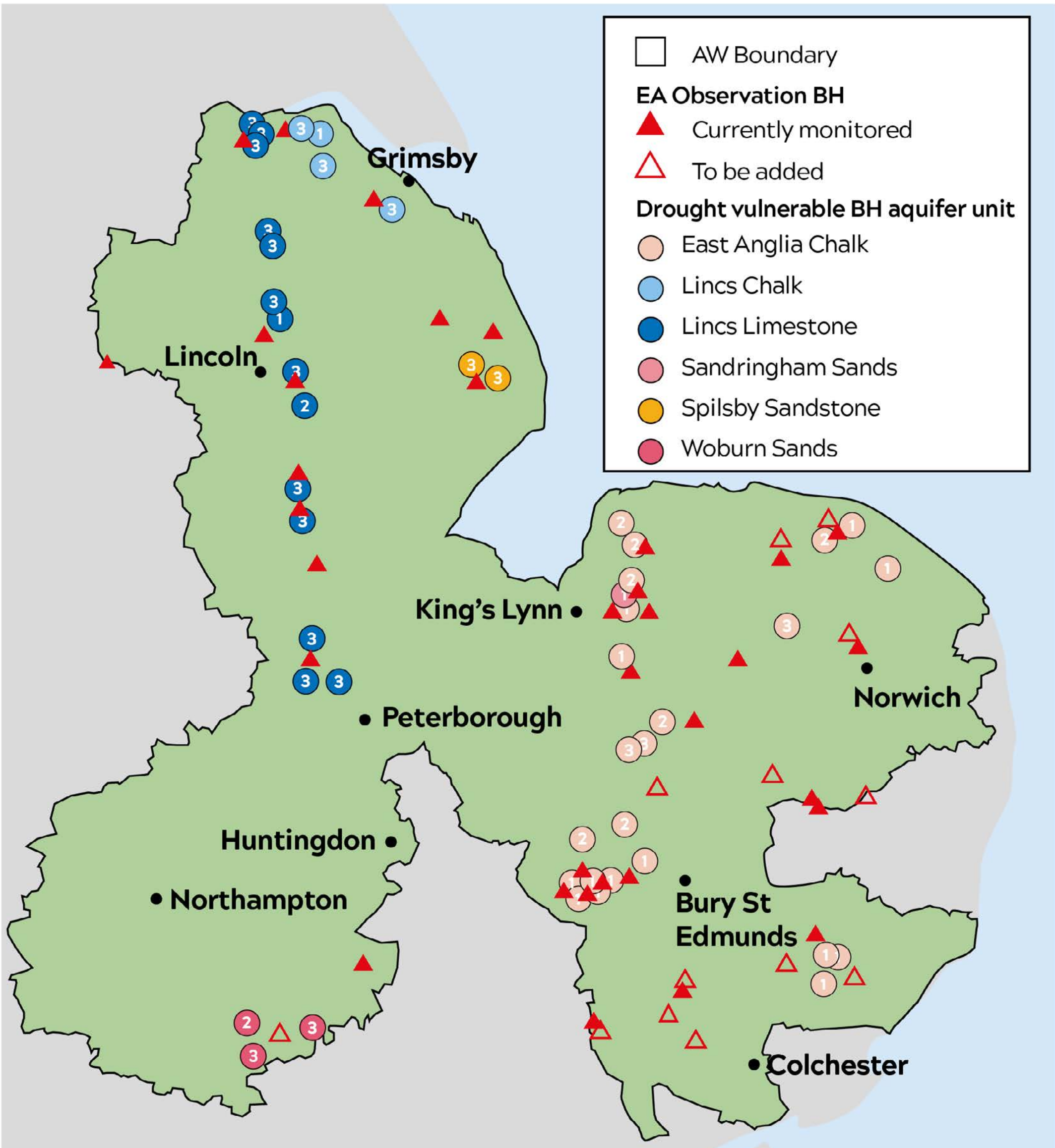
Table 3.3: Groundwater source licence conditions

<table>
<tr><th>Source</th><th>Licence restriction trigger</th><th>Impact on abstraction licence</th></tr>
<tr><td>Aslackby</td><td rowspan="6">Observation borehole (ref 3-901) = <8 mAOD</td><td rowspan="2">Aslackby / Rippingale combined licence reduced to 18.1Ml/d</td></tr>
<tr><td>Rippingale</td></tr>
<tr><td>Pinchbeck (Jockey)</td><td rowspan="2">West Pinchbeck / Jockey combined abstraction reduces to 9Ml/d</td></tr>
<tr><td>West Pinchbeck</td></tr>
<tr><td>Haconby</td><td rowspan="2">Group licence reduction</td></tr>
<tr><td>Billingborough</td></tr>
<tr><td>Raithby</td><td rowspan="3">Observation borehole (ref 7-071). Raithby = <28 mAOD for 6-months (consecutive). Manby / Grimoldby = <24.5 mAOD 6-months</td><td>Reduce annual abstraction to 3,683 Ml/yr</td></tr>
<tr><td>Manby</td><td rowspan="2">Reduce annual abstraction to 925 Ml/yr</td></tr>
<tr><td>Grimoldby</td></tr>
<tr><td>Billingborough</td><td>Cowgate Drain = <2l/s for 3-months (consecutive)</td><td>Abstraction reduces to 200 Ml/yr</td></tr>
<tr><td>Congham</td><td>Springs flow at gauging station = <40l/s</td><td>Licence reduction to 2.27 Ml/d</td></tr>
<tr><td>East Watton</td><td>Observation boreholes <45 and 37 mAOD</td><td>Monthly abstraction licence reduction</td></tr>
<tr><td>Hope House</td><td>Abstraction borehole <5.8 mAOD</td><td>Abstraction from boreholes to cease</td></tr>
<tr><td>Hopper House</td><td>Abstraction borehole <18 mAOD</td><td>Abstraction from boreholes to cease</td></tr>
<tr><td>Tetney</td><td>Blowwells = <0.73 mAOD
Boreholes = <1.95 mAOD
Drain = <28.3l/s</td><td>Abstraction from boreholes to cease</td></tr>
<tr><td>Waterloo</td><td>Abstraction borehole >52.1 mBOD</td><td>Abstraction from boreholes to cease</td></tr>
</table>

3.3 Groundwater drought management curves

The Environment Agency has a network of observation boreholes that are used to monitor regional groundwater levels across various aquifer units. Groundwater drought management curves have been developed to replace the existing Drought Alert Curves (DACs) for the majority of observation boreholes that are close to one of our Drought Vulnerable (DV) sources. The methodology for calculating the drought management curves is outlined below and is similar to the one used to create the existing DACs in Drought Plan 2019, with the exception of 66-055 in the Lodes Chalk and TF72-007 in the West Norfolk Babingley Chalk (where the existing DACs used alternative methods). The observation boreholes that these curves have been created for have been selected due to their proximity to our DV source boreholes, whilst ensuring they are not affected by the operation of nearby source boreholes, together with the length of record and frequency of their data. For some aquifer units and Water Resource Zones (WRZs), we monitor multiple observation boreholes to ensure that each DV source has an associated observation borehole. Two additional observation boreholes that did not have existing DACs; TG11/619 in the East Norfolk Wensum & Yare Chalk and TF73/007 in the West Norfolk Chalk, have also been assigned drought management curves as they are indicative of some of our Tier 3 DV supply bores. We are looking into expanding our network of observation boreholes that we monitor. This is to not only increase coverage in our DV aquifers but to also include all aquifer units in our region. Figure 3.1 shows all the observation boreholes that we currently monitor, not just the ones that are associated with our DV sources. It also displays the observation boreholes that we are looking to add to our monitoring list.

Figure 3.1: Locations of our drought vulnerable boreholes (number indicates tier and colour indicates aquifer unit) and all the Environment Agency observational boreholes that we currently monitor as well as the ones that we are looking to add to our monitoring list



The aim of these drought management curves is to provide an early indication of the potential onset of drought at least 3-4 months in advance, taking into account natural seasonal variation. This time period has been shortened from Drought Plan 2019 as a review of the data shows that, for the majority of our DV boreholes, it is quite possible for a large summer recession to result in a potential loss of deployable output (DO) in most years.

The methodology used to determine the drought management curves was designed to be as simple and transparent as possible, allowing for differences in aquifer characteristics and the variable responses of individual boreholes.

The first stage was to identify the shallowest water level at each observation borehole below which some loss in deployable output may occur at the related drought-vulnerable source. The drought management curves have been developed to try and identify when there may be a risk that water levels will fall below this level within 3 to 4 months.

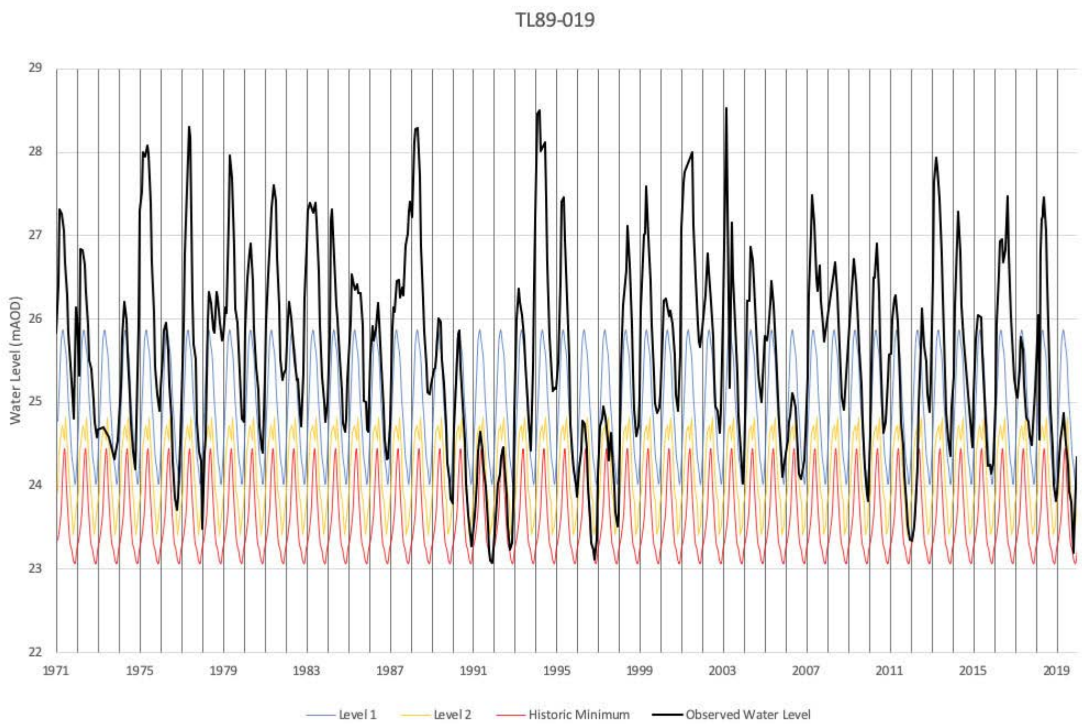
The three drought management curves have been calculated by determining the worst level experienced in each month that is:

- Level 1 - Exceeded once in every 5-year period
- Level 2 - Exceeded once in every 10-year period
- Historic Minimum - Lowest historic water level by month

The drought management curves were determined by plotting a series of percentile curves grouped by month against the actual observed water level, then dividing the number of years in the dataset by the number of times the actual water level fell below each percentile curve. The data was manually reviewed for each observational borehole to remove extreme values which are not indicative of the historic groundwater levels.

These groundwater curves have been developed to align with the latest Environment Agency Drought Plan guidelines However, given the complex nature of most of the distribution systems supplied by groundwater sources, these curves are indicative and are not designed to directly result in specific drought actions or restrictions at the respective levels. Crossing a groundwater curve would be used in conjunction with other indicators in the drought management framework to determine relevant actions.

Figure 3.2: An example of the new curves plotted against the actual observed water level for the historic record of the EA observation borehole TL89/019 in the West Norfolk Wissey Chalk



Drought management curves - no existing curves

For some of the observation boreholes, the water level is so erratic that it is not possible to assign meaningful drought management curves to fit any return period. We are currently reviewing the use of the observation borehole TL14-001 in the Sandy Woburn Sands as an example of this behaviour.

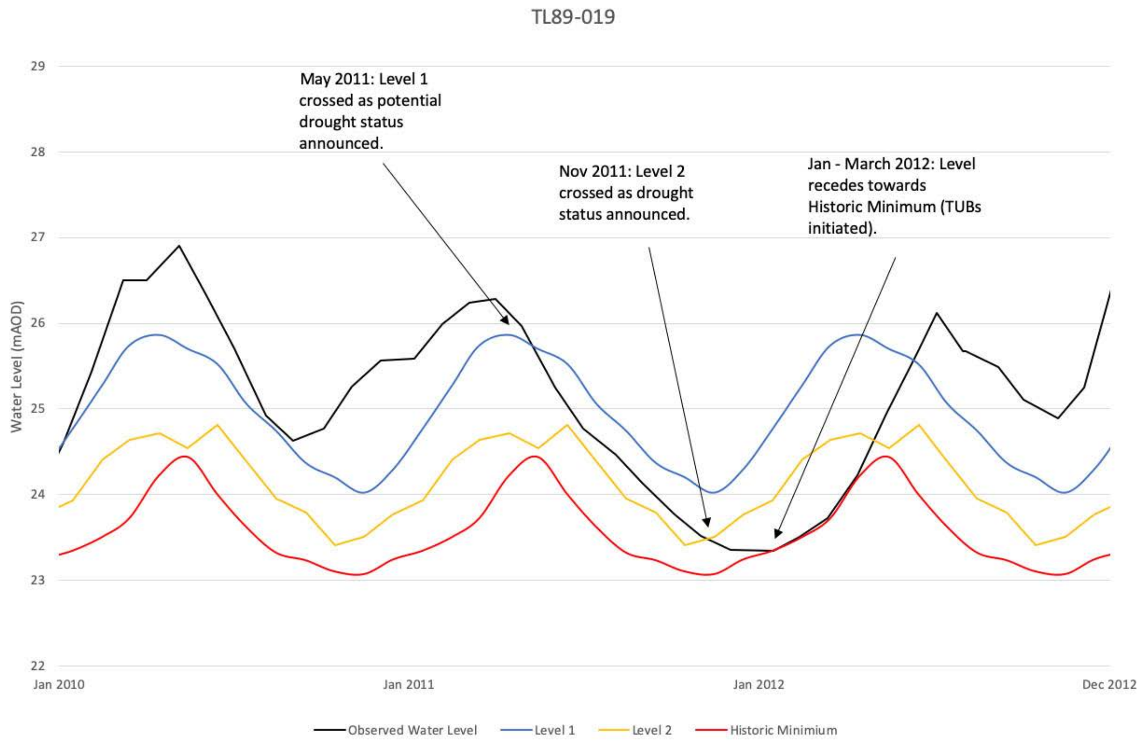
The drought vulnerable sources in this area are Birchmoor, Battlesden and Pulloxhill. These sources currently use an adjacent Environment Agency observation borehole without drought management curves, and we are currently reviewing the need to develop further curves. We are also looking into developing curves on some of our own drought vulnerable sources and will be monitoring them closely for any indication of potential drought.

Drought management curves - more severe drought

We previously undertook a pilot study to develop a curve to reflect a 1 in 200 year or worse than historic drought. This was achieved by identifying the return period of the worst historic drought on record, using a comparison of simulated lumped parameter model storage results with the historical observational borehole water level record, to allow the worst historic recession curve to be shifted down to represent a 1 in 200 year event[3]. We are looking into developing this method to create worse than historic curves by adapting our new Level 2 curves.

This would enable the relationship between the curves and worse than historic curves to be explored in more detail, and can be used to identify the severity of the groundwater recession. For example, if groundwater levels cross the worst historic drought curve in the winter months, and continues into the summer, there is a high risk we would cross the worse than historic curve and see a reduction in source yield.

Figure 3.3: Worked example of the drought management curves for the 2011/12 drought



3.4 Testing of drought management curves

For each borehole the drought management curves have been assessed by examining previous drought scenarios when the levels would have been crossed, and reviewing drought management actions that were taken at the time, to determine whether they will be appropriate within the new framework. Figure 3.3 shows a worked example of one such scenario.

However, it is worth noting that due to the complex nature of groundwater systems and our groundwater distribution systems, these curves are indicative and will be used in conjunction with other indicators in the drought management framework before actions are decided. We will continually review the use of these curves to ensure that they are indicative of drought actions being taken in the future.

[3] *Mott MacDonald, 2018, Drought alert curves methodology - Southfields example*

The drought management curves for a selection of the key Environment Agency observation boreholes are plotted against observed historic groundwater levels in the following figures.

Figure 3.4: Drought management curves used for Southfields

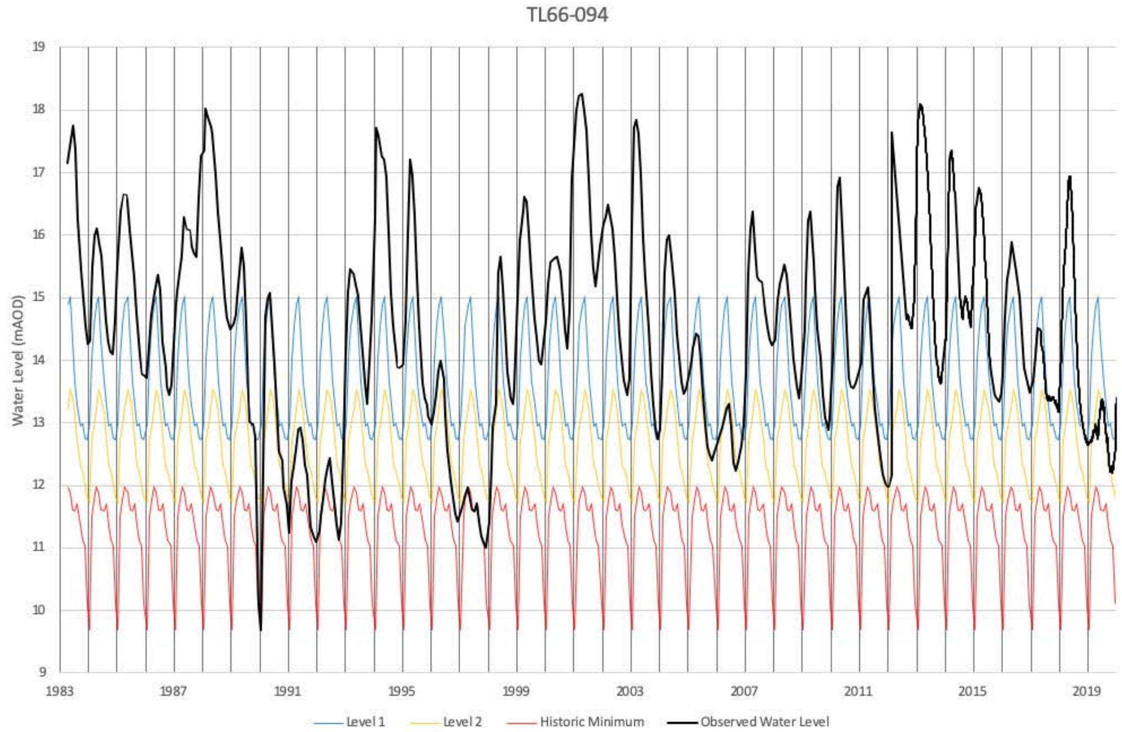


Figure 3.5: Drought management curves used for Welton

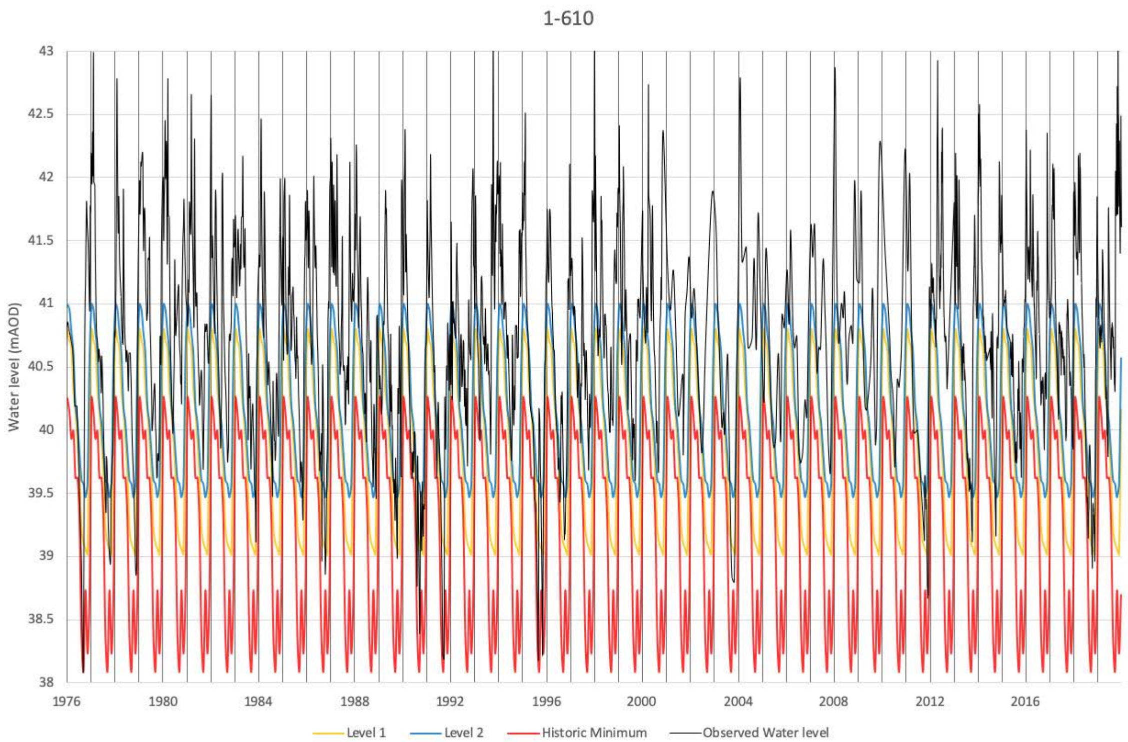


Figure 3.6: Drought management curves used for Goxhill 2

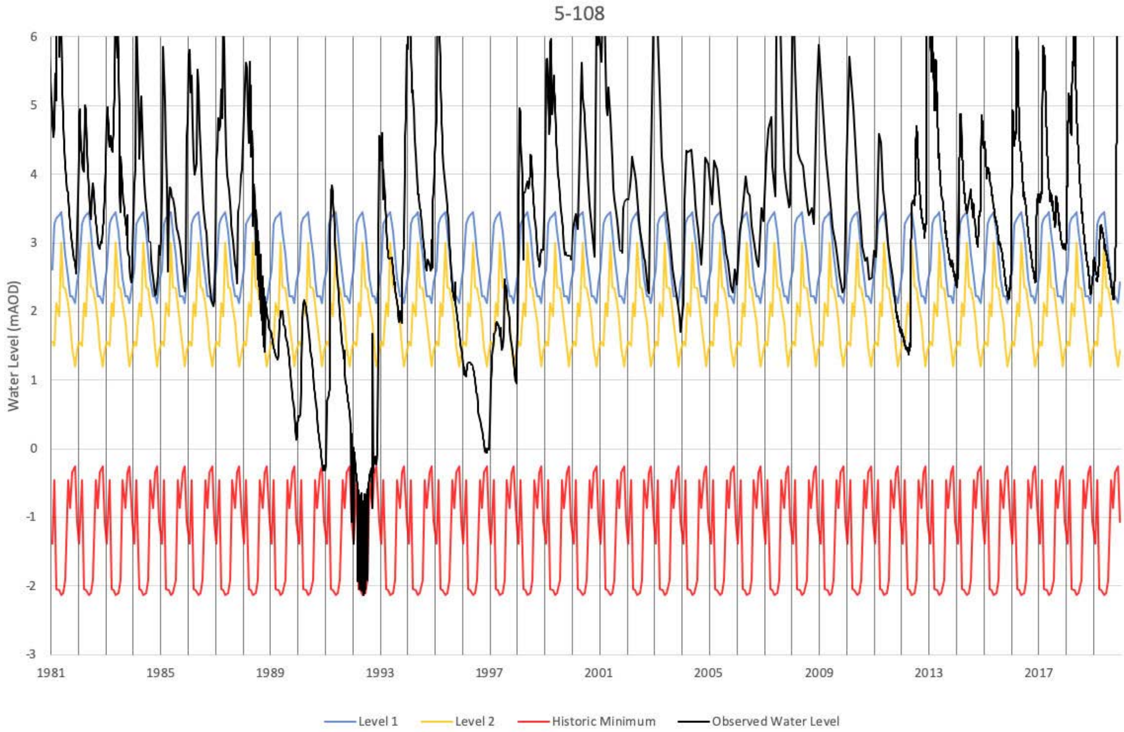


Figure 3.7: Drought management curves used for South Lincolnshire Limestone borehole conditions

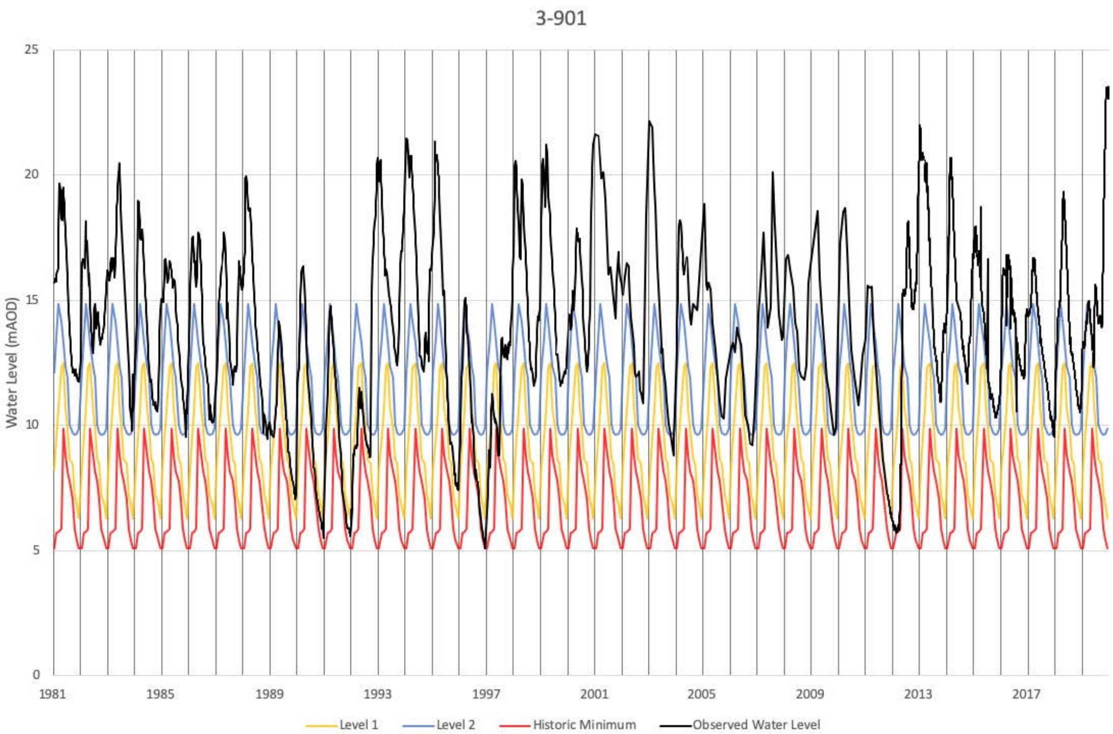


Figure 3.8: Drought management curves used for Metton

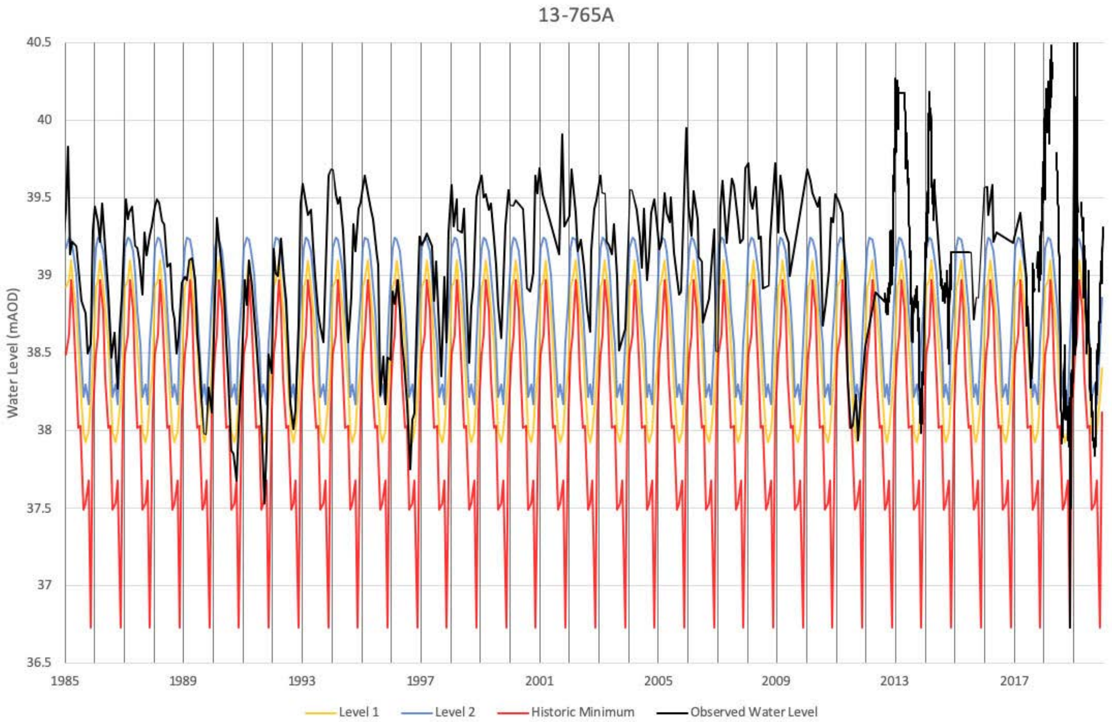


Figure 3.9: Drought management curves used for Eriswell 1 and Isleham

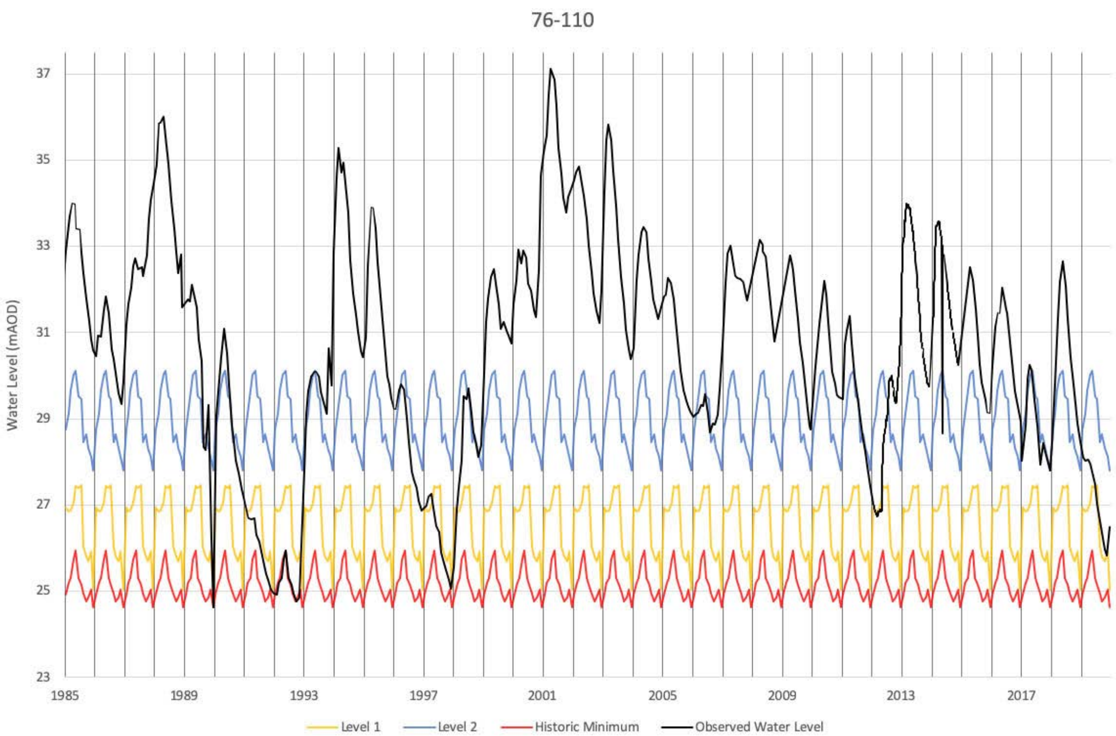


Figure 3.10: Drought management curves used for Newmarket AR and Lower Links

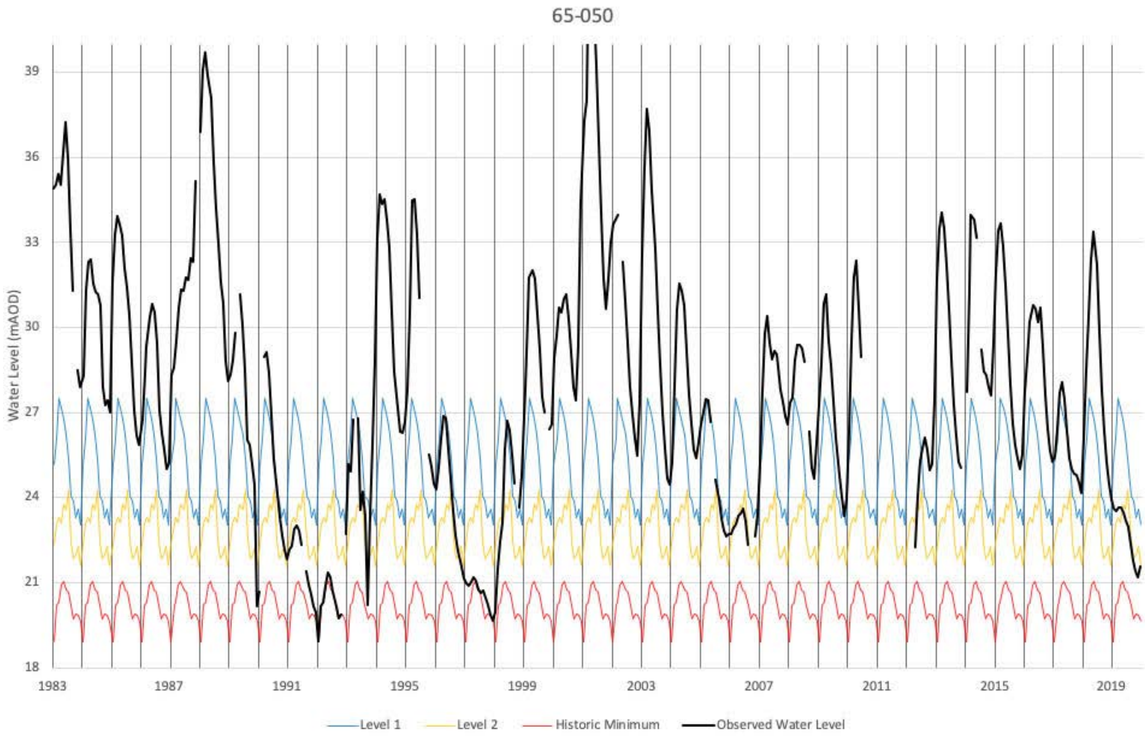


Figure 3.11: Drought management curves used for Long Hill

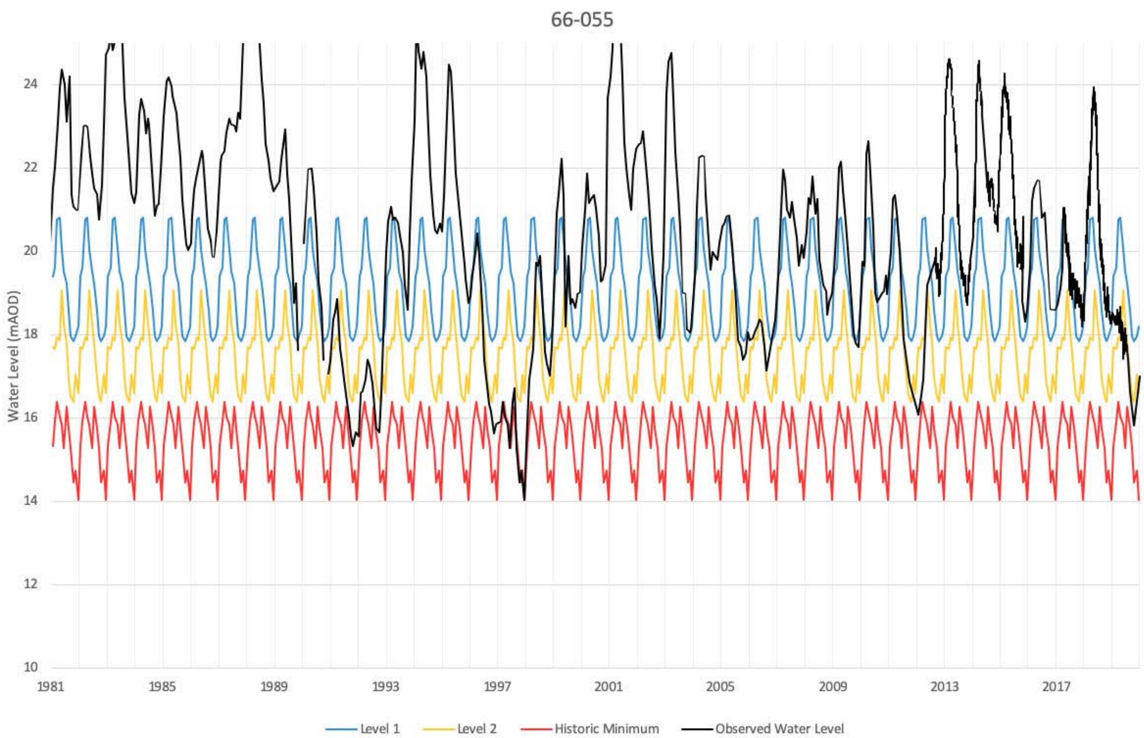


Figure 3.12: Drought management curves used for Winterton Carrs 1 and Winterton Holmes

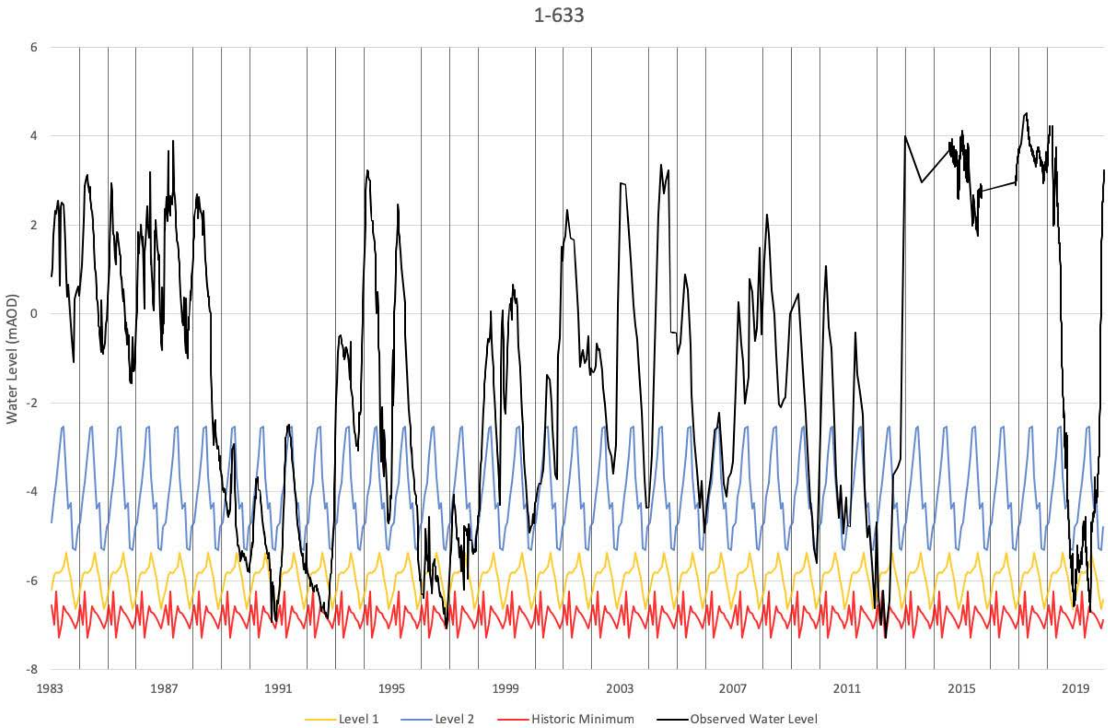


Figure 3.13: Drought management curves used for Marham

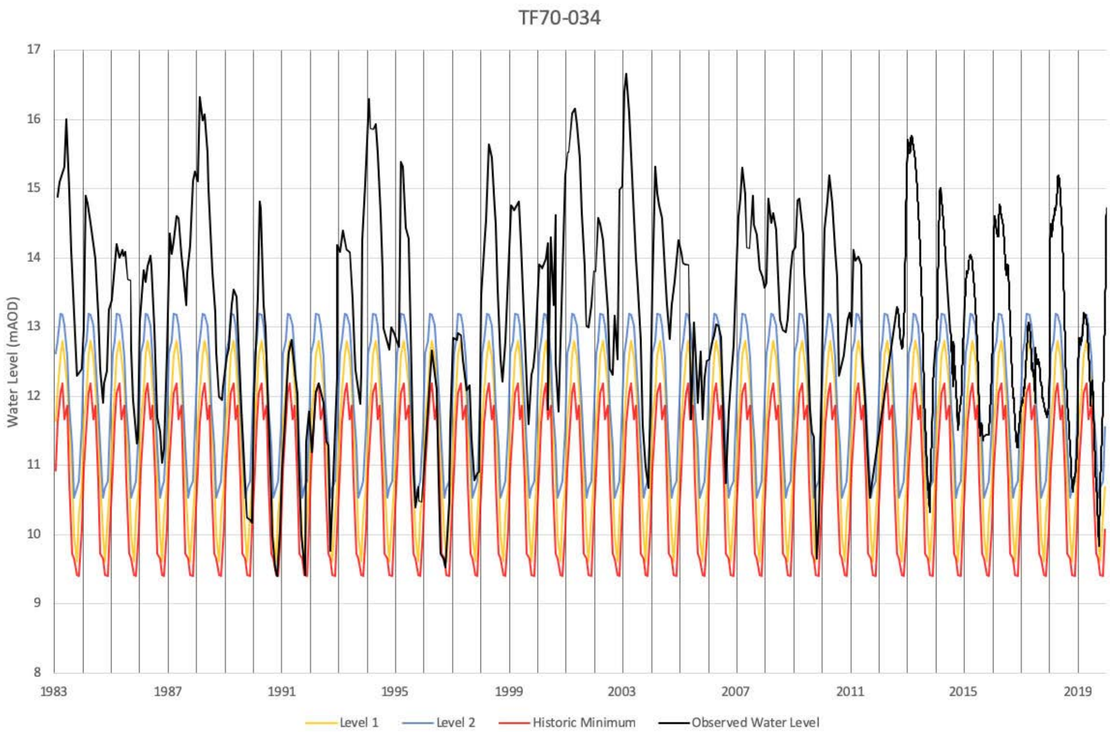


Figure 3.14: Drought management curves used for Didlington and Bradenham

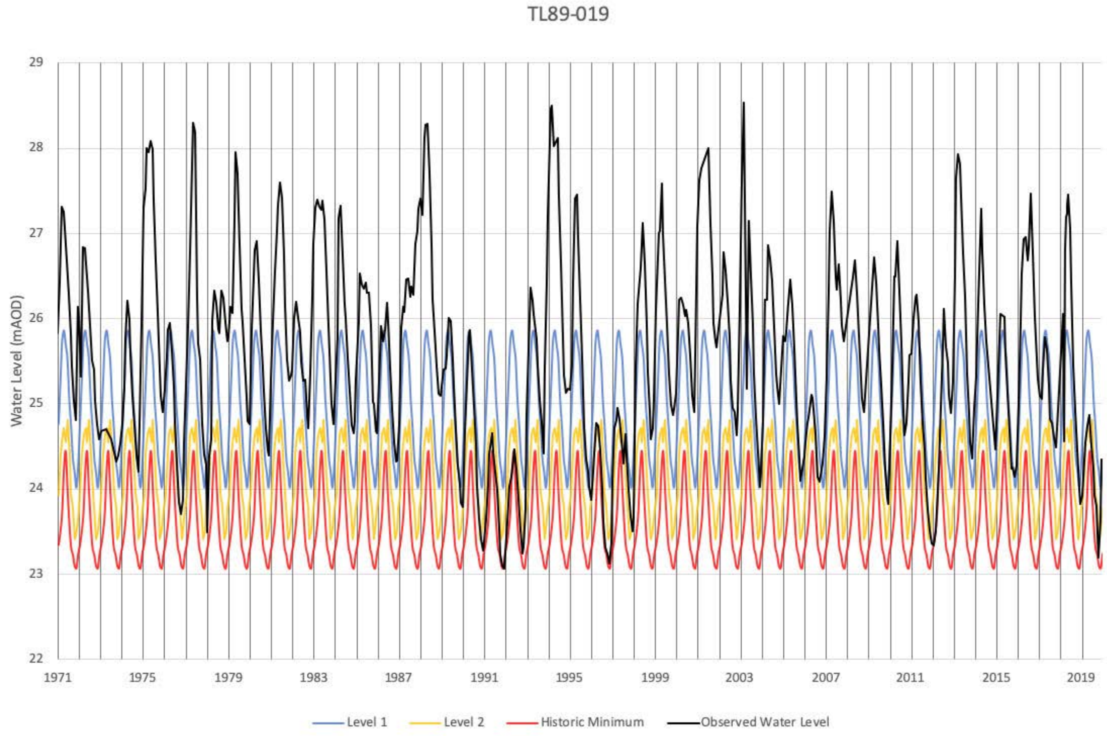


Figure 3.15: Drought management curves used for Waneham Bridge

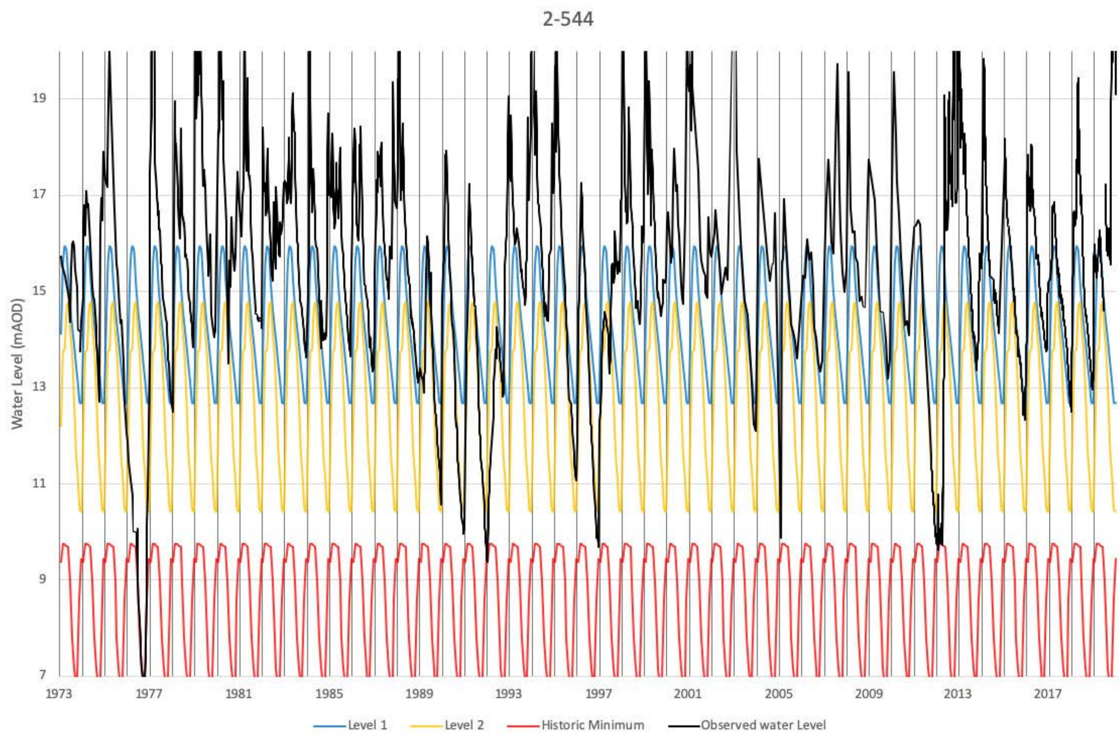


Figure 3.16: Drought management curves used for Congham and Gayton

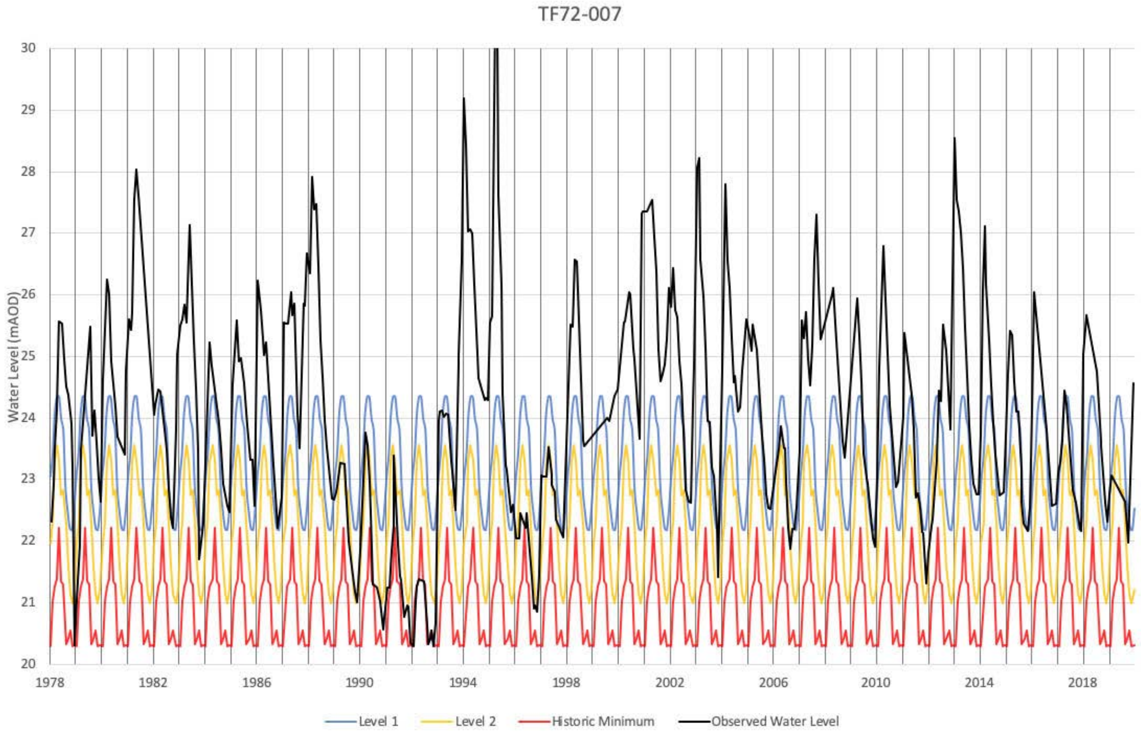


Figure 3.17: Drought management curves used for Fring Osier Carr and Sedgeford

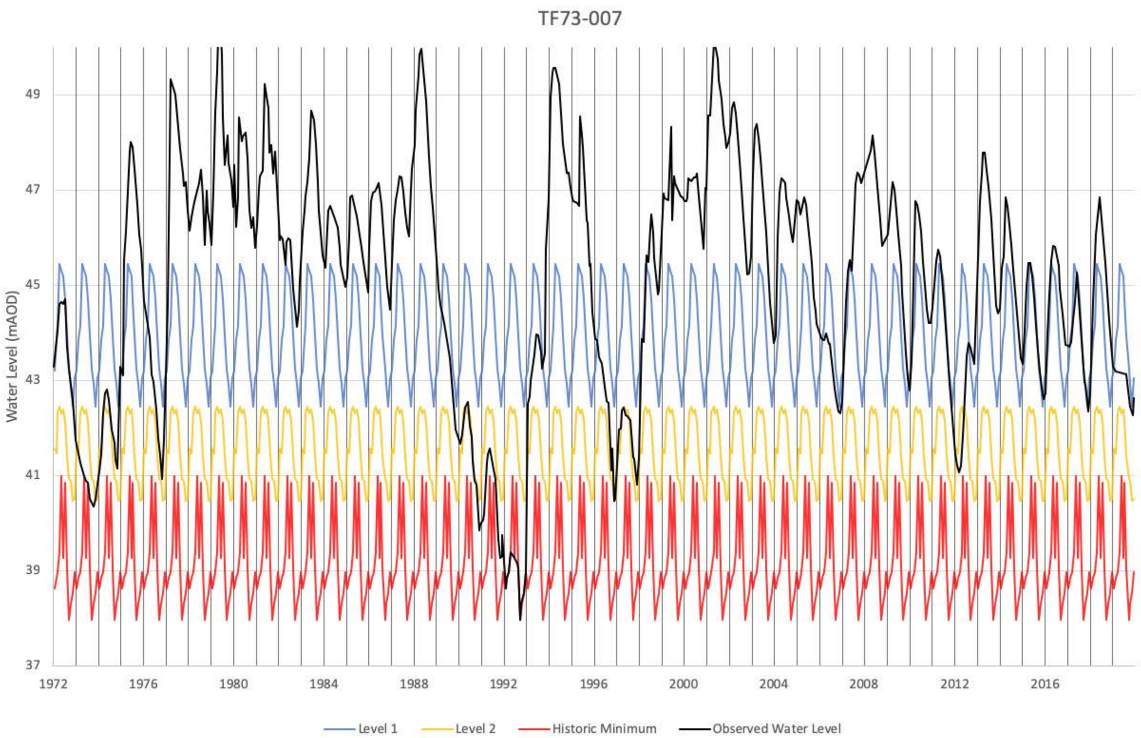


Figure 3.18: Drought management curves used for Fosters Bridge (Moor Farm)

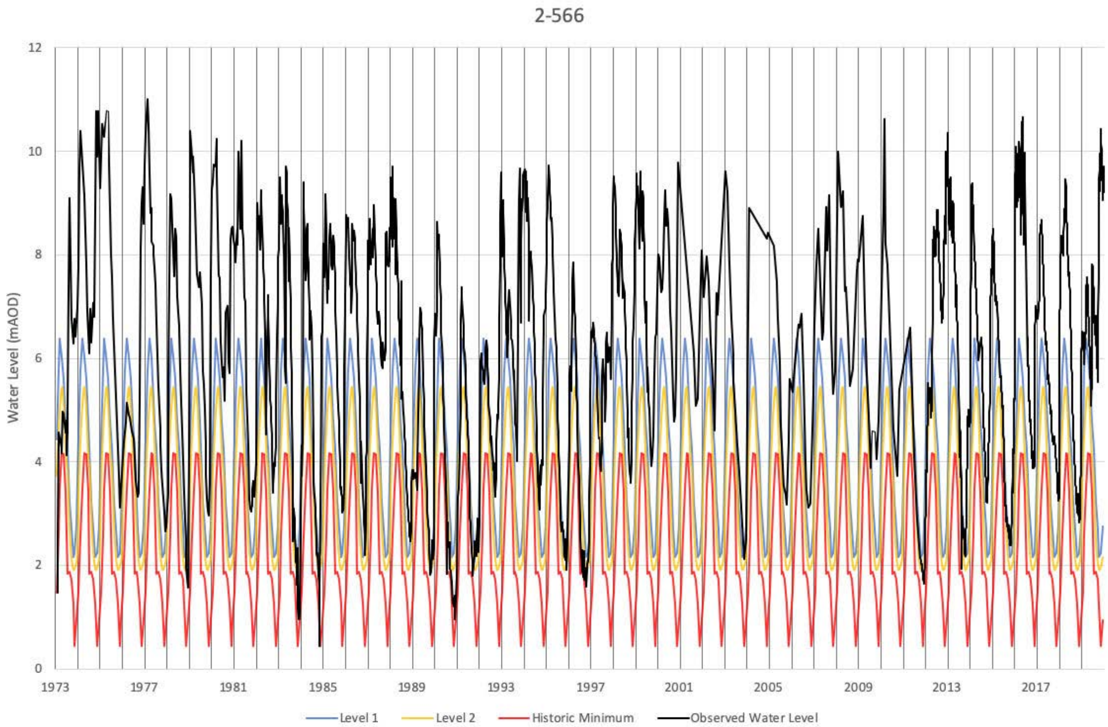


Figure 3.19: Drought management curves used for Lyng Forge

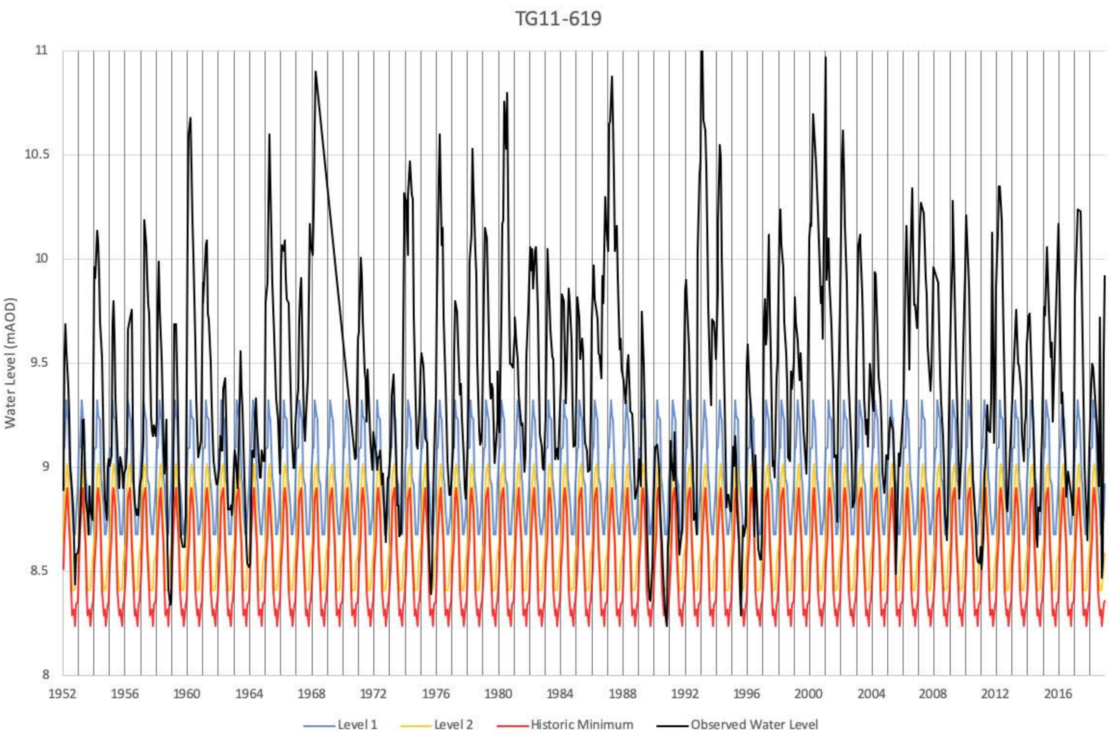
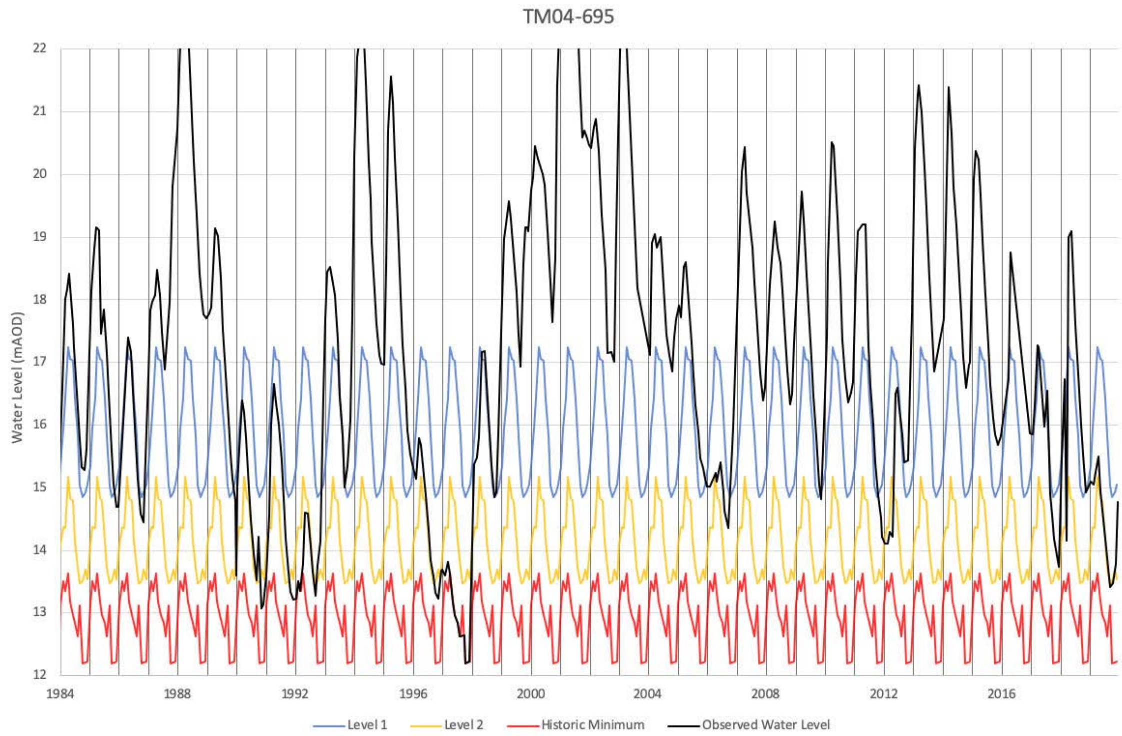


Figure 3.20: Drought management curves used for Belstead, Westerfield and Whitton



Cover photo - The location of one of Anglian Water's groundwater sources. Approximately 50 percent of supply is provided by groundwater abstracted from over 200 sources comprising more than 450 operational boreholes.