

Appendix 6

Drought Management for Anglian Water Groundwater Sources



Contents



1. Introduction	3
2. Yield Assessment	4
3. Drought Management	6
3.1 Drought Vulnerable Boreholes	6
3.2 Groundwater sources with drought-related licence conditions	9
3.3 Groundwater Drought Alert Curves	11
Drought alert curves - worst case drought	12
Drought alert curves - 5 year return period drought	13
Drought alert curves - spring alert level	13
3.4 Testing of drought alert curves	15

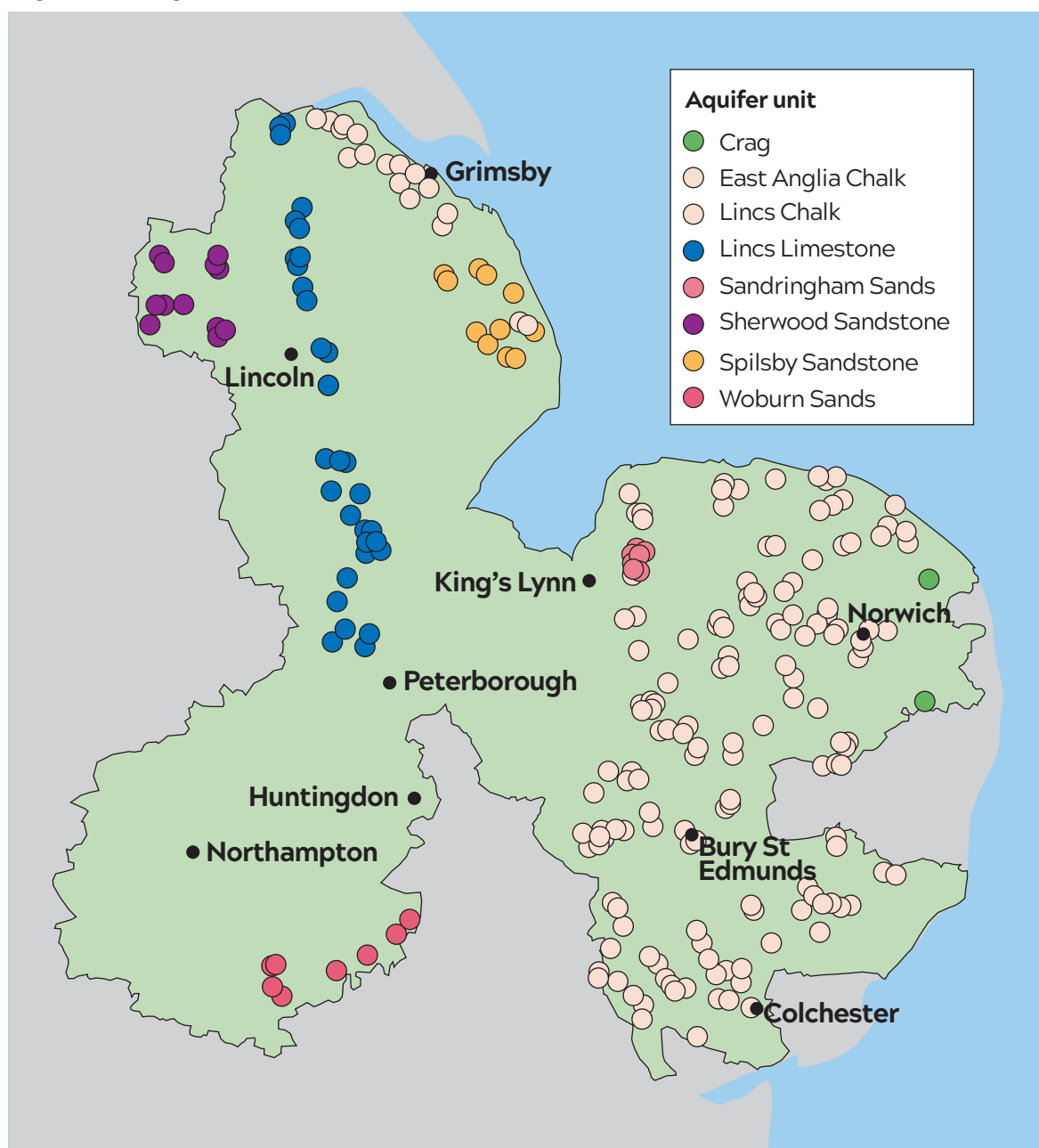
1. Introduction

Approximately 50 per cent of supply is provided by groundwater abstracted from over 200 sources comprising over 450 operational boreholes. These range in depth from 10m to 500m, and penetrate several major aquifers across the region. Each of which 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 shown in Figure 1.

Figure 1: Anglian Water groundwater sources by aquifer



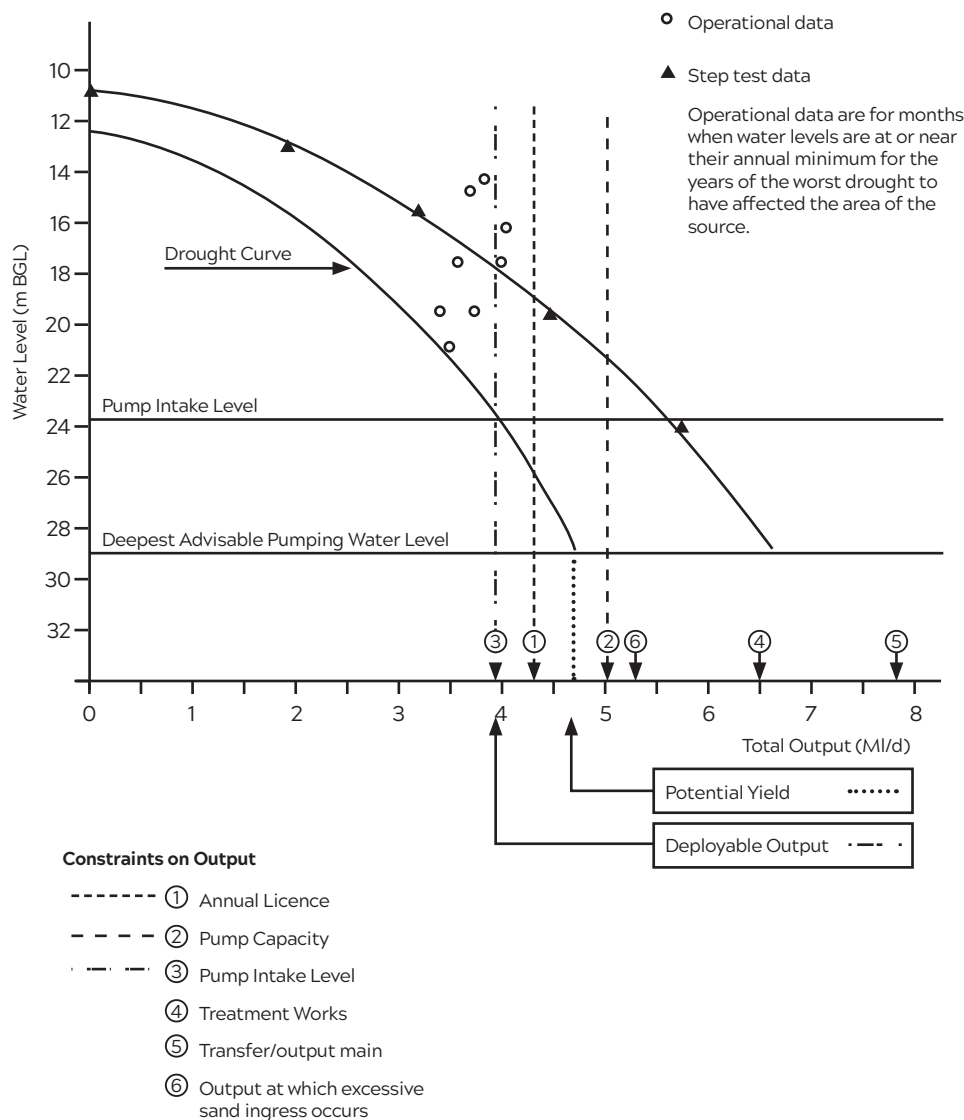
2. Yield Assessment

The potential yield for each of our groundwater sources is calculated in accordance with the industry-accepted UKWIR methodology¹, 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 WRMP19). 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.

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 onto a 'summary diagram' and uses this to define a 'drought curve'. Figure 2 shows an example summary diagram.

The potential yield for each of our groundwater sources is a measure of how much water the source

Figure 2: 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 year². 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 v observed groundwater level was plotted for key observation boreholes across the region in aquifers potentially vulnerable to drought, and used these 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. 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 WRMP19, 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 WRMP19 and this Drought Plan 2019. 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 1. A list of all the groundwater sources within each Tier is in Table 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 WRMP19 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 1: Changes to drought vulnerable borehole Tiers between 2014 and 2019 Drought Plans.

Drought Tier	2014 Drought Plan drought vulnerable boreholes		2019 Drought Plan drought vulnerable boreholes	
	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	21	Uncertain severe drought risk or risk is for droughts >1in200yr severity

Table 2: Groundwater sources and drought vulnerable tiers

Source	WRZ	Drought Tier 2019	Drought Tier Comment
Risby	Bury Haverhill	1	New drought vulnerable borehole - severe drought risk to yield and supply impacts identified in WRMP19
Goxhill 2	Central Lincs	1	No change
Welton	Central Lincs	1	No change
Winterton Holmes	Central Lincs	1	Potential to remove from list - dependent on performance of new borehole
Lower Links	Cheveley	1	Severe drought risk to yield and supply impacts identified in WRMP19
Belstead	East Suffolk	1	General risk due of saline intrusion particularly at peak demand/low groundwater levels
Westerfield	East Suffolk	1	No change
Whitton	East Suffolk	1	No change
Ashley Road	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP19
Long Hill	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP19
Moulton	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP19
Southfields	Newmarket	1	Severe drought risk to yield and supply impacts identified in WRMP19
Congham	North Fenland	1	Spring flow licence condition
Gayton	North Fenland	1	No change
Metton	North Norfolk Coast	1	No change
North Walsham	North Norfolk Coast	1	New drought vulnerable borehole - severe drought risk to yield and potential supply impacts.
Marham	South Fenland	1	Severe drought risk to yield and supply impacts identified in WRMP19
Waneham Bridge (Dunston)	Central Lincs	2	Severe drought risk to yield but no risk to supply
Eriswell 1	Ely	2	Severe drought risk to yield but no risk to supply. Downgraded from T1 as new boreholes imminent. Review once boreholes commissioned
Isleham	Ely	2	No change
Didlington	Norfolk Rural North	2	Severe drought risk to yield but reduced risk to supply after borehole 3 commissioned

Source	WRZ	Drought Tier 2019	Drought Tier Comment
Fring - Osier Carr	North Fenland	2	No change
Hillington (Chalk)	North Fenland	2	No change - severe drought risk to yield but no risk to supply
Sedgeford	North Fenland	2	Risk increased from T3. Severe drought risk to yield but no risk to supply
Matlaske	North Norfolk Coast	2	Risk increased from T3. Severe drought risk to yield but no risk to supply
Birchmoor	RHF South	2	Severe drought risk to yield but no risk to supply
Etton	Bourne	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Pilsgate	Bourne	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Wilsthorpe	Bourne	3	Severe drought risk to yield but >1in200yr only
Barrow	Central Lincs	3	Loss of yield possible, but DAPWL is very uncertain. >1in200yr risk only
Fosters Bridge-Moors Farm	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Redbourne	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Spridlington	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Ulceby	Central Lincs	3	Severe drought risk to yield but >1in200yr only
Waddingham	Central Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Winterton Carrs 1	Central Lincs	3	Possible severe drought risk to yield but >1in200yr only
Winterton Carrs 2	Central Lincs	3	Possible severe drought risk to yield but >1in200yr only
Fordington	East Lincs	3	Severe drought risk to yield but >1in200yr only
Barnoldby	East Lincs	3	Severe drought risk to yield but >1in200yr only
Welton le Marsh	East Lincs	3	Severe drought risk to yield and possible water quality issues but >1in200yr only
Wellington Wellfield	North Fenland	3	Severe drought risk to wider Wellfield performance uncertain - needs further investigation

Source	WRZ	Drought Tier 2019	Drought Tier Comment
Lyng Forge	Norwich and the Broads	3	Possible severe drought risk to yield from water quality, but no risk to supply
Battlesden	RHF South	3	Possible severe drought risk to yield but no risk to supply
Pulloxhill	RHF South	3	Possible severe drought risk to yield but no risk to supply
Denton Lodge	South Fenland	3	Severe drought risk to wider Wellfield performance uncertain - needs further investigation
Aswarby	South Lincs	3	Potential PY impact due to reduction of hydraulic performance of flow horizons under lower head. >1in200yr risk only
Drove Lane	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 WRMP19 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 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: Groundwater source licence conditions

Source	Licence Restriction Trigger	Impact on abstraction licence
Aslackby	Observation borehole (ref 3-901) = <8m mAOD	Aslackby/Rippingale combined licence reduced to 18.1MI/d
Rippingale		
Pinchbeck (Jockey)		West Pinchbeck/Jockey combined abstraction reduces to 9MI/d
West Pinchbeck		
Haconby		Group licence reduction
Billingborough		
Raithby	Observation borehole (ref 7-071). Raithby = <28m mAOD for 6-months (consecutive). Manby/ Grimoldby = <24.5m mAOD 6-months	Reduce annual abstraction to 3,683 MI/yr
Manby		Reduce annual abstraction to 925 MI/yr
Grimoldby		
Billingborough	Cowgate Drain = <2l/s for 3-months (consecutive)	Abstraction reduces to 200 MI/yr
Bocking	Observation borehole <12m mAOD	Licence reduction as directed by Environment Agency
Congham	Springs flow at gauging station = <40l/s	Licence reduction to 2.27 MI/d
East Watton	Observation boreholes <45 and 37m mAOD	Monthly abstraction licence reduction
Hope House	Abstraction borehole <5.8m mAOD	Abstraction from boreholes to cease
Hopper House	Abstraction borehole <18m mAOD	Abstraction from boreholes to cease
Tetney	Blowwells = <0.73m mAOD Boreholes = <1.95m mAOD Drain = <28.3l/s	Abstraction from boreholes to cease
Waterloo	Abstraction borehole >52.1m below mAOD	Abstraction from boreholes to cease

3.3 Groundwater Drought Alert Curves

The Environment Agency has a network of observation boreholes that are used to monitor regional groundwater levels, across various aquifer units. Groundwater drought alert curves have been developed for each aquifer monitoring borehole that is in close proximity to one of our drought-vulnerable sources (see Figure 3).

Figure 3: Locations of drought vulnerable boreholes (number indicates tier and colour indicates aquifer unit) and EA observation boreholes



The aim of this alert curve is to provide an early indication of the potential onset of drought at least 6 to 12 months in advance, taking account of natural seasonal variation. Given the complex nature of most of the distribution systems supplied by groundwater sources, the groundwater drought alert curves are not designed to result in any specific drought restrictions to customers. Crossing a groundwater alert curve would, however, instigate the framework for drought management actions as the severity of the drought increases or recedes.

Drought alert curves consider aquifer characteristics and individual trends in water levels. The drought alert curves for each observation borehole have been calculated using the worst historical drought recession curve for each corresponding observation borehole.

The methodology used to determine the drought alert curves was designed to be as simple and transparent as possible, but where 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 alert curves have been developed to try and identify when there may be a risk that water levels will fall below this level within 6 to 12 months.

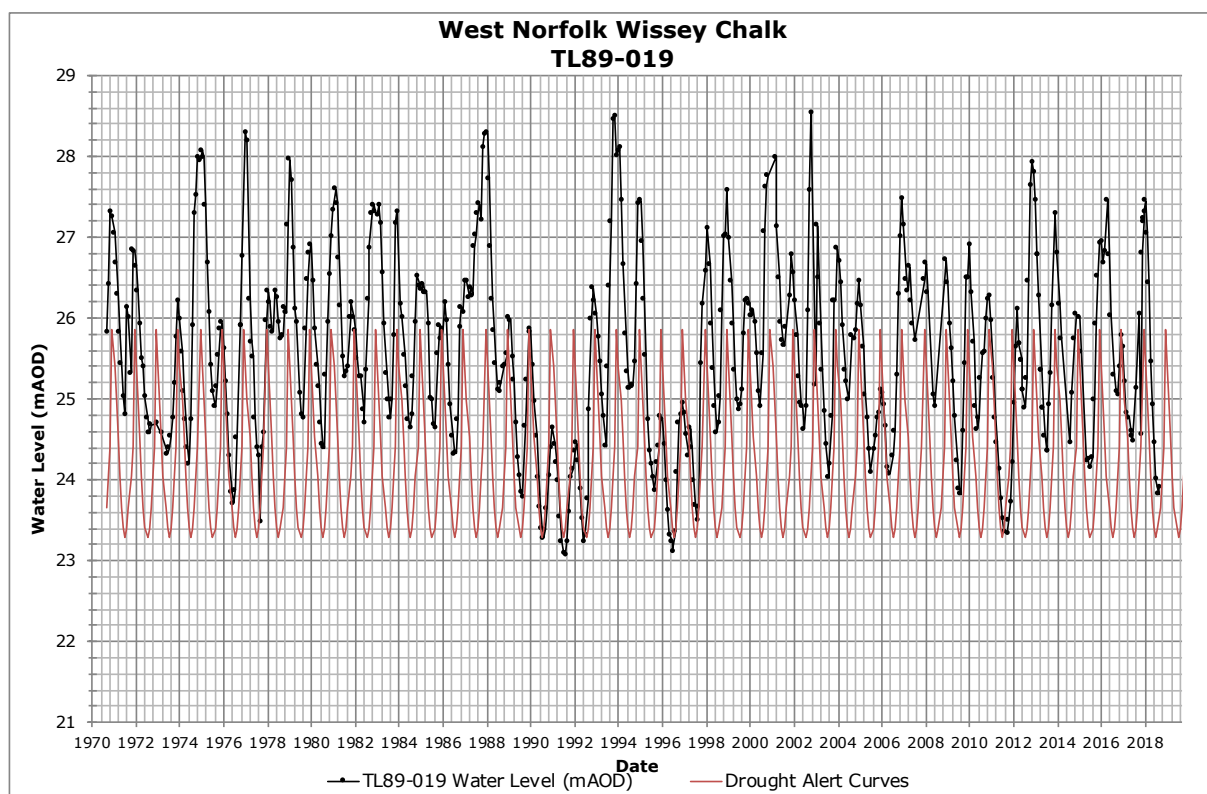
For those boreholes that have significant seasonal variation in water levels and large annual recessions where a drought could occur with only a 3 to 4-month warning the drought alert curve has been calculated statistically by determining the worst level experienced in each month that is exceeded once in every 5-year period. This approach provides an early indication of the potential for drought conditions to occur in sources that are sensitive to summer demands and are at greater risk of drought.

Drought alert curves - worst case drought

For some observation boreholes, this can be done by plotting the actual observed groundwater recession which occurred the year before the most significant drought as recorded. An example is shown in Figure 4 for the hydrograph at borehole TL89/19 in the Wissey Chalk of northwest Norfolk. Based on an assessment of the UKWIR summary diagram for the Didlington source, the groundwater levels in August 1991 may result in a loss of deployable output (DO). The recession curve for the preceding summer, 1990, and recovery curve during winter 1990-1991 have therefore been plotted to provide a DAC based on actual recession data.

Other drought-vulnerable sources with similar characteristics are Ashley Road, Congham, Eriswell 1, Gayton, Long Hill, Lower Links, Metton, Southfields and West Bradenham.

Figure 4: Drought alert curve for Environment Agency observation borehole TL89/19 based on actual drought recession data



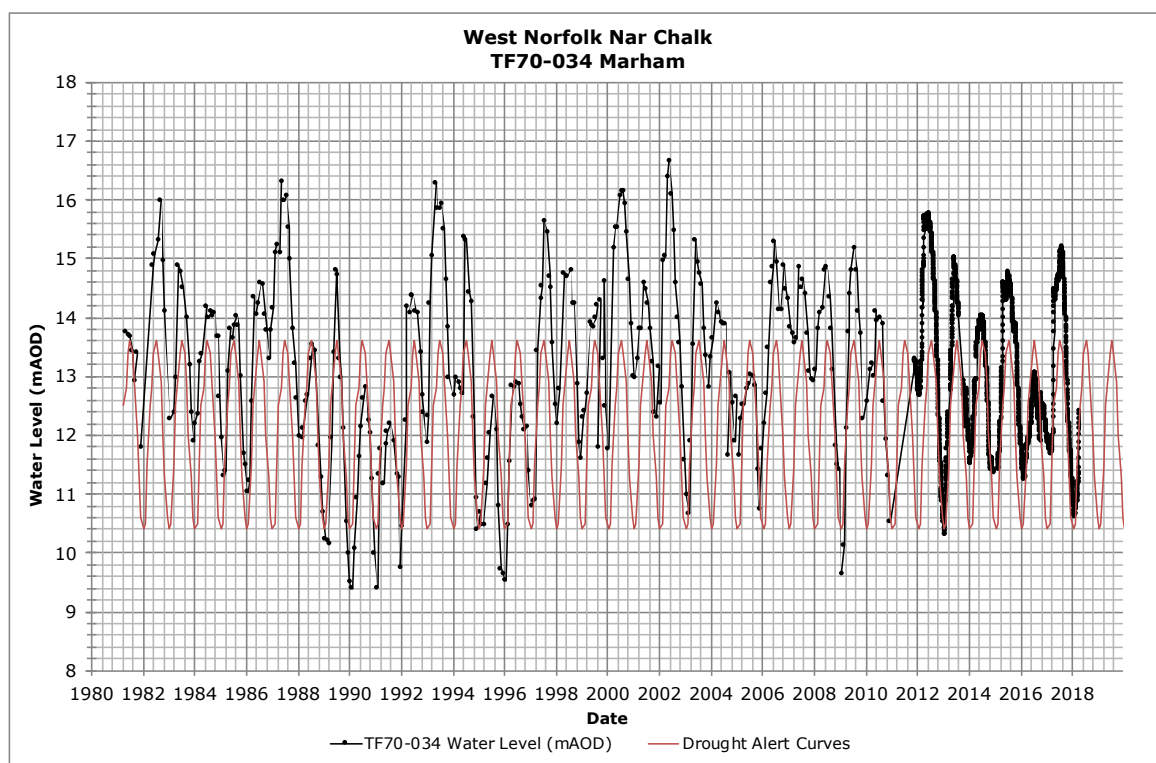
Drought alert curves-5 year return period drought

For some boreholes, it is not possible to apply the recession curve preceding a worst-case drought because the water levels have such a large seasonal variation that it is quite possible for a large summer recession to result in a potential loss of deployable output in most years. These sources which are highly sensitive to summer demand, and therefore at higher risk of drought occurring, require a different approach. The chosen option is to use a statistical calculation, by determining the water level for each month which is exceeded only once in every 5 years. Therefore although a loss of deployable output could occur in any year, the alert curve gives a useful point

of reference, and some idea of how likely drought conditions are to occur. For all of these sources, it must be understood that drought could occur with only 3 or 4 months warning. An example is shown in Figure 5 for the observation borehole TF70-034 in the Marham Chalk, where the 1 in 5-year and loss of deployable output curves are presented for the Marham groundwater source.

Other sources with similar characteristics are Waneham Bridge, Goxhill, Welton, Winterton Carrs and Winterton Holmes. We have also used this methodology for the New Red Lion observation borehole which has licence restriction implications for the sources as listed in Table 3.

Figure 5: Drought alert curve for EA observation borehole TF70-034 based on a statistical approach due to large seasonal fluctuations in water level



Drought alert curves - spring alert level

For a final category of boreholes, the water level variation is so large and erratic that it is not possible to assign a meaningful drought curve to fit any return period. We are currently reviewing the use of the observation borehole TM14/6819 in the East Suffolk Gipping Chalk as an example of this behaviour. The curve was assigned using a peak spring water level below which the risk of drought impact at the related drought-vulnerable sources may be considered higher than usual during the following summer. This alert curve is used for the Belstead, Whitton and

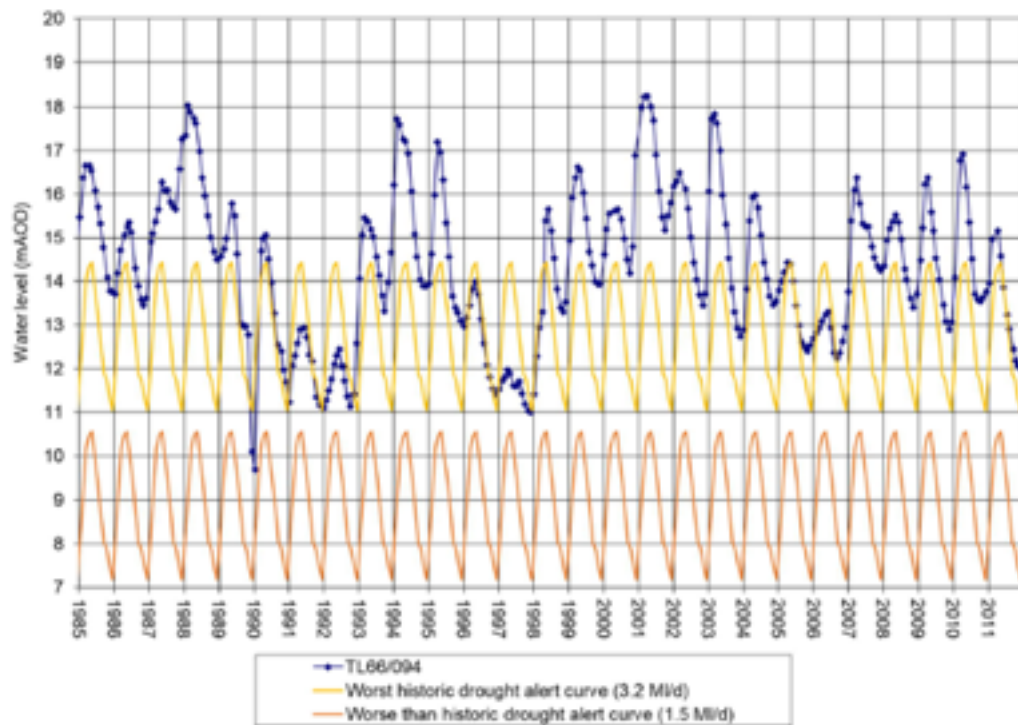
Westerfield groundwater sources. These sources also use an adjacent EA observation borehole without a DAC, and we are currently reviewing the need to develop another DAC.

Drought alert curves - more severe drought

We have also commissioned a pilot study to develop groundwater curves for a drought vulnerable borehole itself, and also develop a curve to reflect a 1 in 200 year or worse than historic drought³ (Figure 6).

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

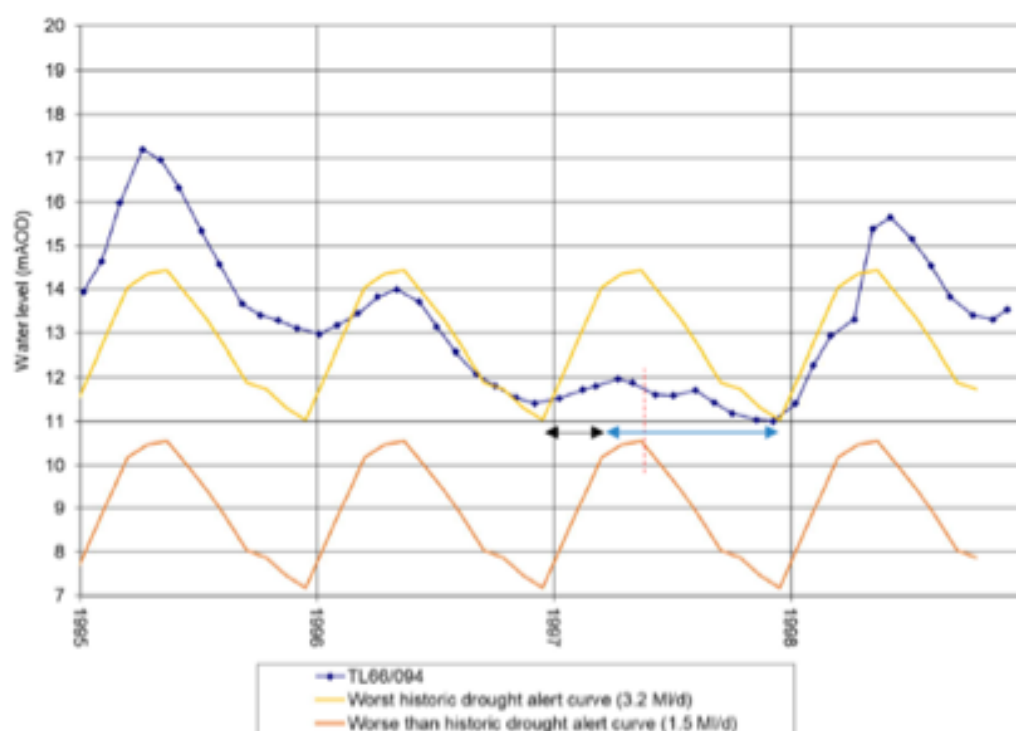
Figure 6: Example groundwater alert curves for worst historic and 1 in 200 year/worse than historic droughts



This enables the relationship between the worst historic drought and worse than historic drought alert 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. This is shown in more detail in Figure 7.

Figure 7: Drought alert curve detailing the, 1996/1997 drought



The focused graph in Figure 7 enables the relationship between the worst historic drought and worse than historic drought alert curves to be explored in more detail. Seasonal variations in the drought alert curves leads to the shortest duration between the two sets of curves being between December and March, as shown by the black arrow. The blue arrow shows the longer duration between the two sets of curves, between April and November.

Therefore, if groundwater levels cross the worst historic drought alert curve and continue to recede between December and March they would be nearer to the worse than historic drought alert curve. This is demonstrated on the graph by the 1997 groundwater levels.

The groundwater level crosses the worst historic drought alert curve in January 1997, during the time when the two sets of curves are closest, as indicated by the black arrow on the graph. There is very little recharge for the remainder of 1997, which following on from the 1996 recession leads to the groundwater levels nearing the worse than historic drought curve through the summer months (red dashed line shows where water levels are closest to the worse than historic drought alert curve).

Therefore, if groundwater levels cross the worst historic drought curve in the winter months, and following a strong recession, early warnings should be raised especially if the recession continues into the summer.

This work is in its early stages and we are continuing to review and consider the best application for these curves.

3.4 Testing of drought alert curves

The DACs for each of the key Environment Agency observation boreholes are plotted against observed historic groundwater levels in the following Figures.

We will continue to monitor the groundwater levels in all of these observation boreholes. If water levels fall below the DAC at a given monitoring borehole, we will start an internal review of the available drought management actions. Given the complex nature of most of the distribution systems supplied by groundwater sources, the alert curves, unlike for the surface water reservoirs, are not designed to result in any specific drought restrictions to customers.

Figure 8: Drought alert curve used for Ashley Road and Lower Links (data missing between June 2010 and April 2012)

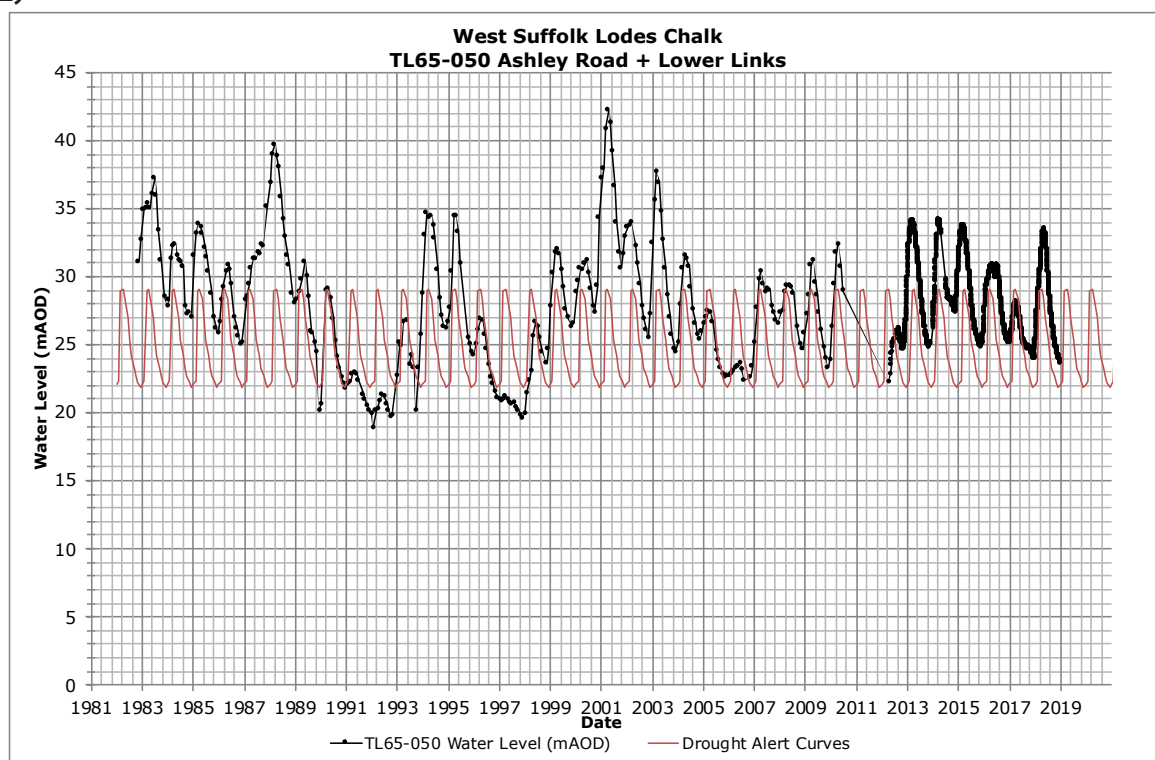


Figure 9: Drought alert curve used for Congham and Gayton

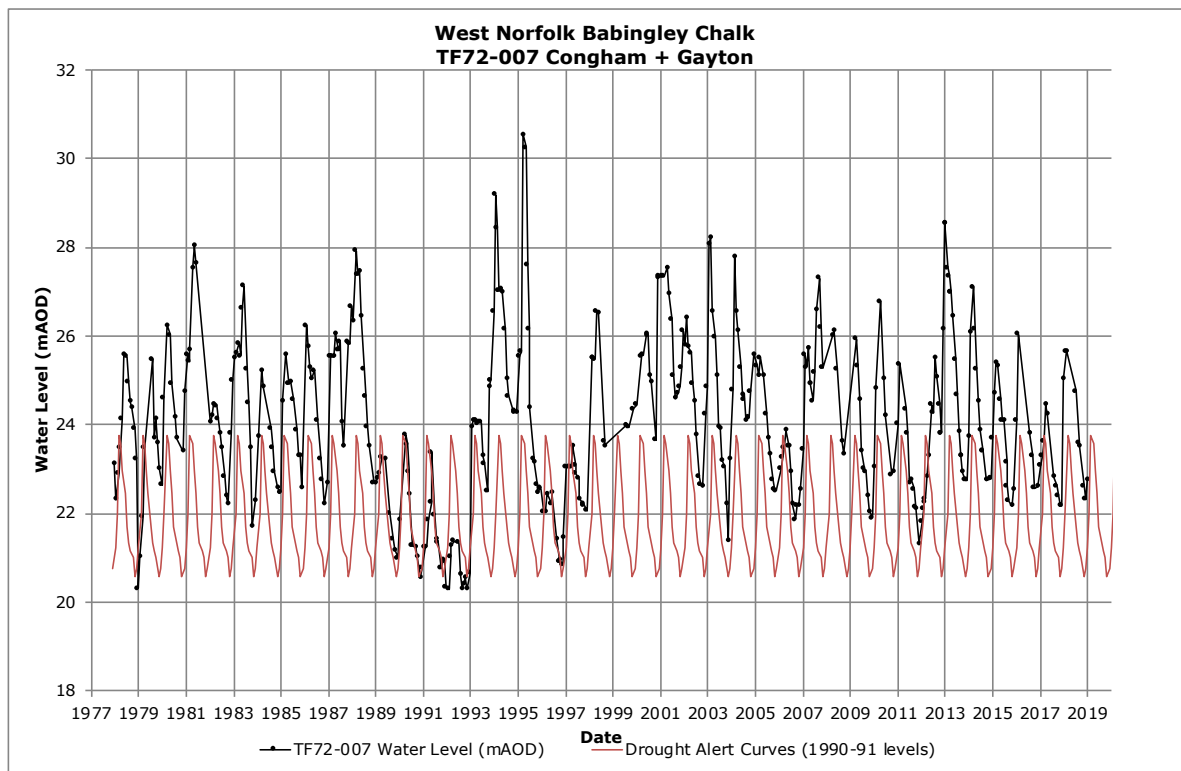


Figure 10: Drought alert curve used for Didlington and Bradenham

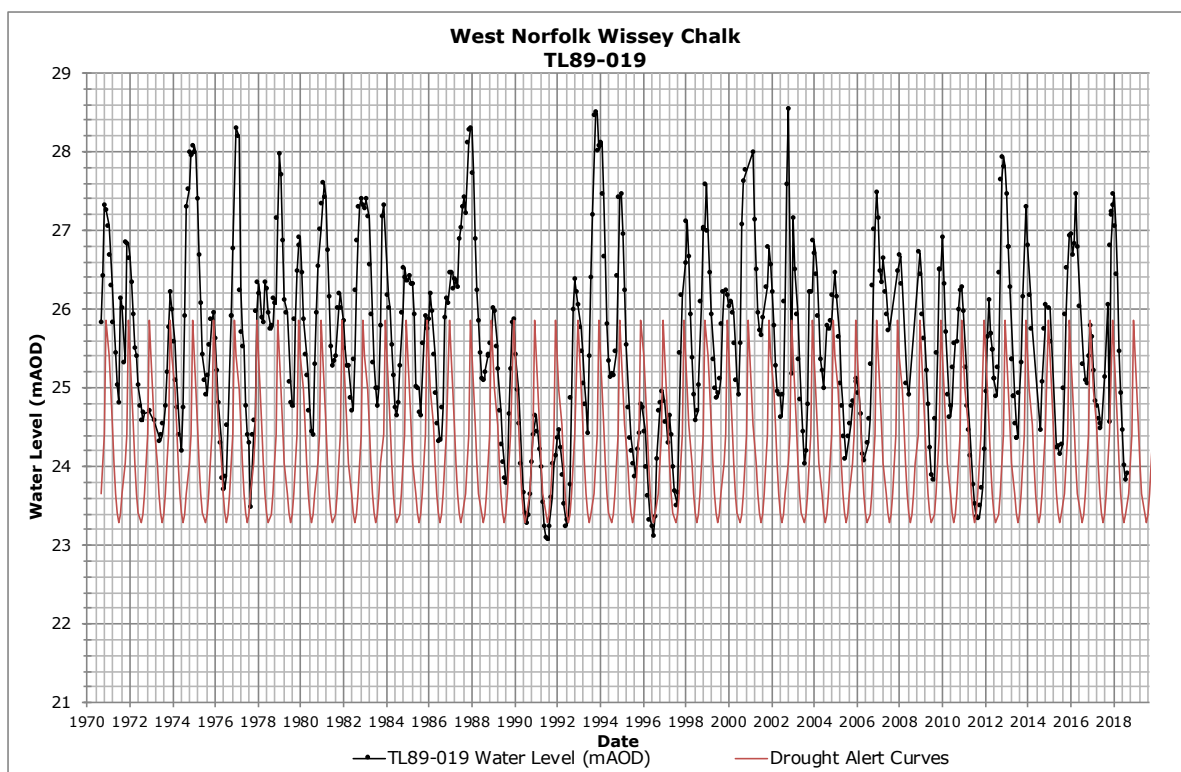


Figure 11: Drought alert curve used for Eriswell 1 and Isleham

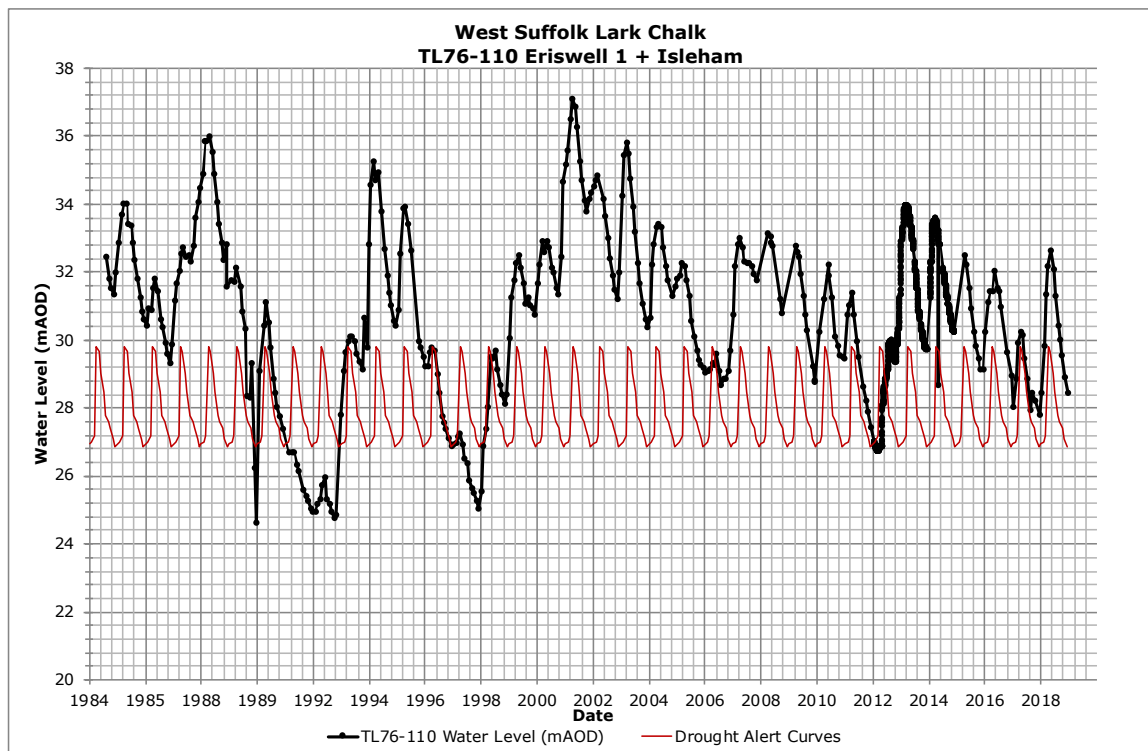


Figure 12: Drought alert curve used for Goxhill 2

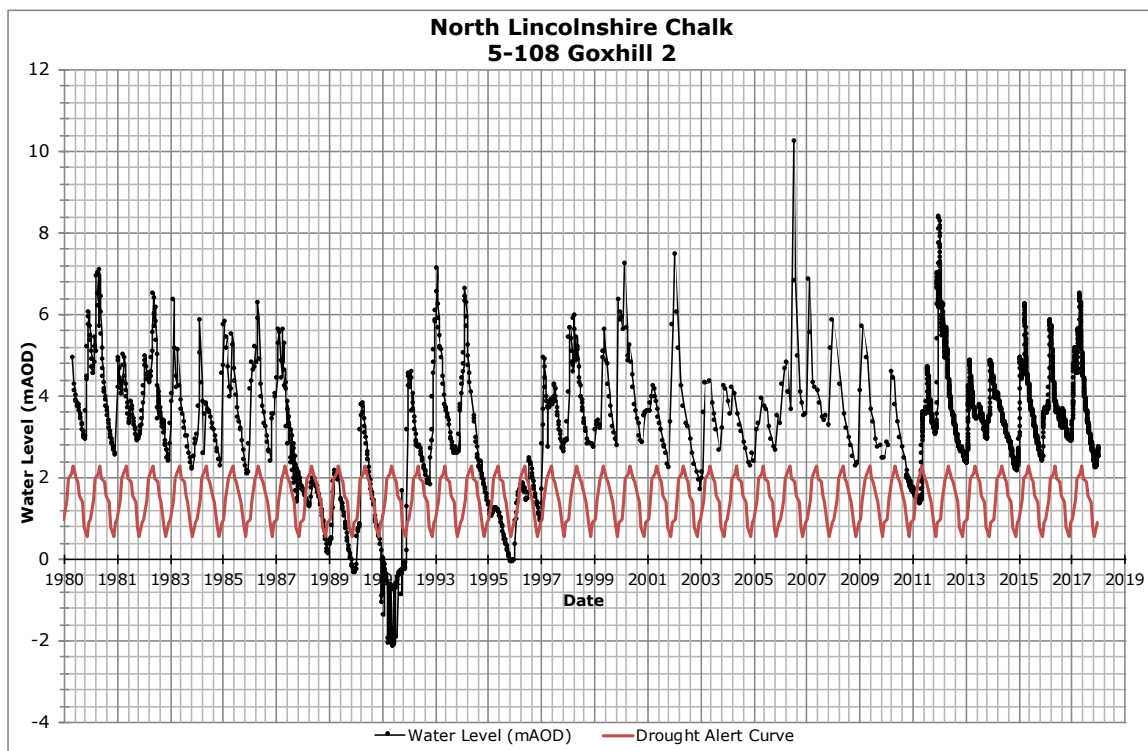


Figure 13: Drought alert curve used for Long Hill

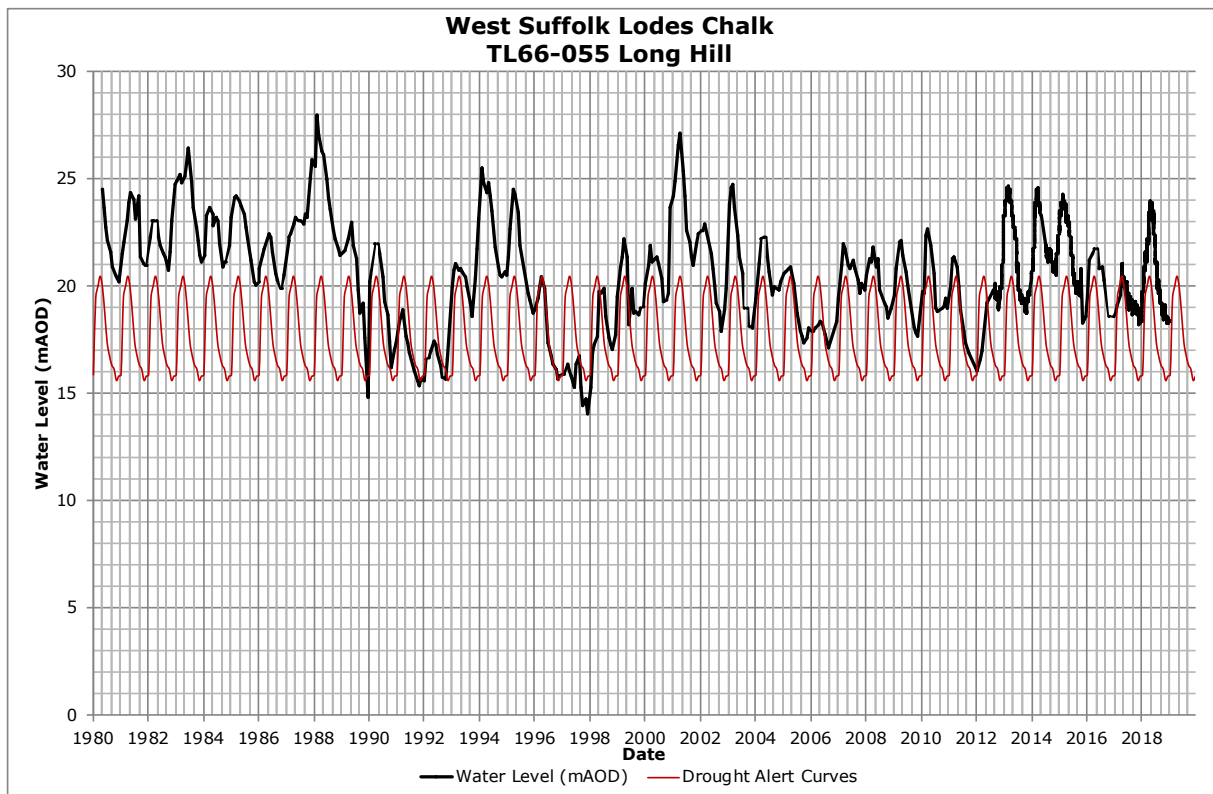


Figure 14: Drought alert curve used for Marham

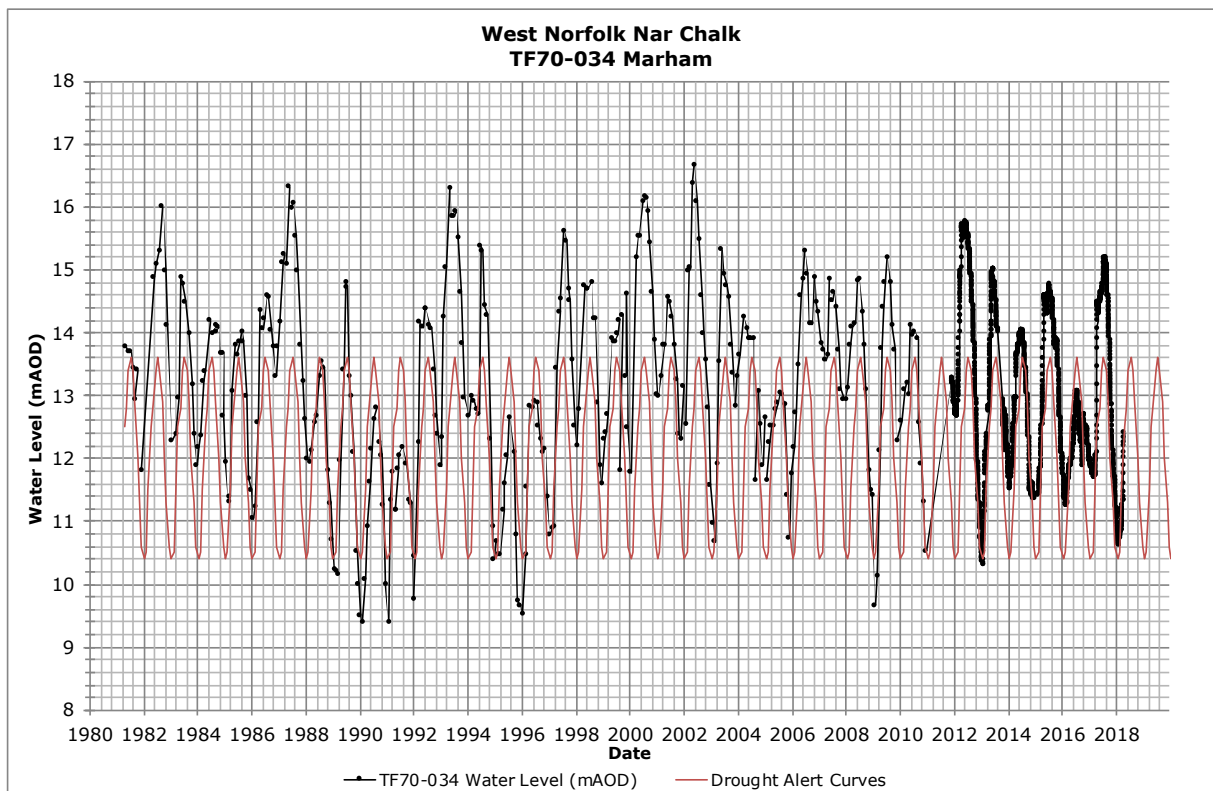


Figure 15: Drought alert curve used for Metton

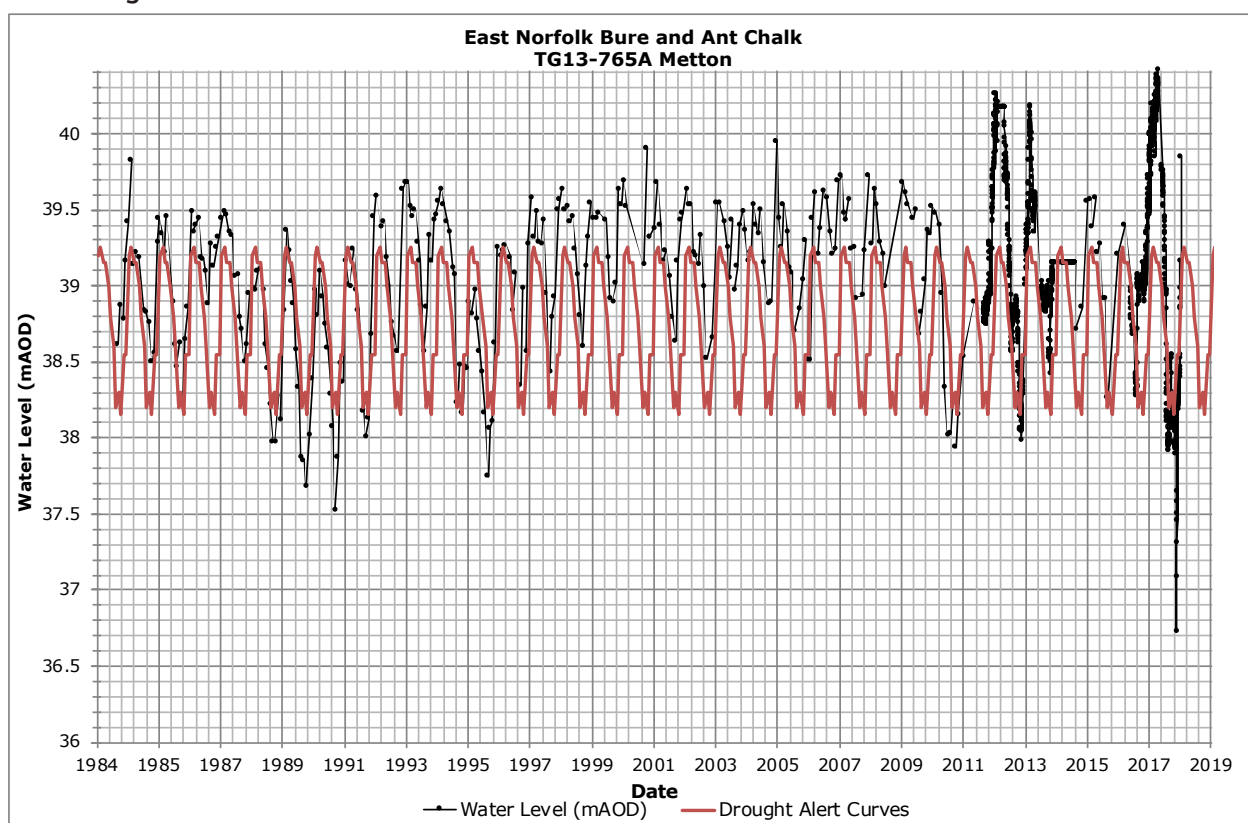


Figure 16: Drought alert curve used for Southfields

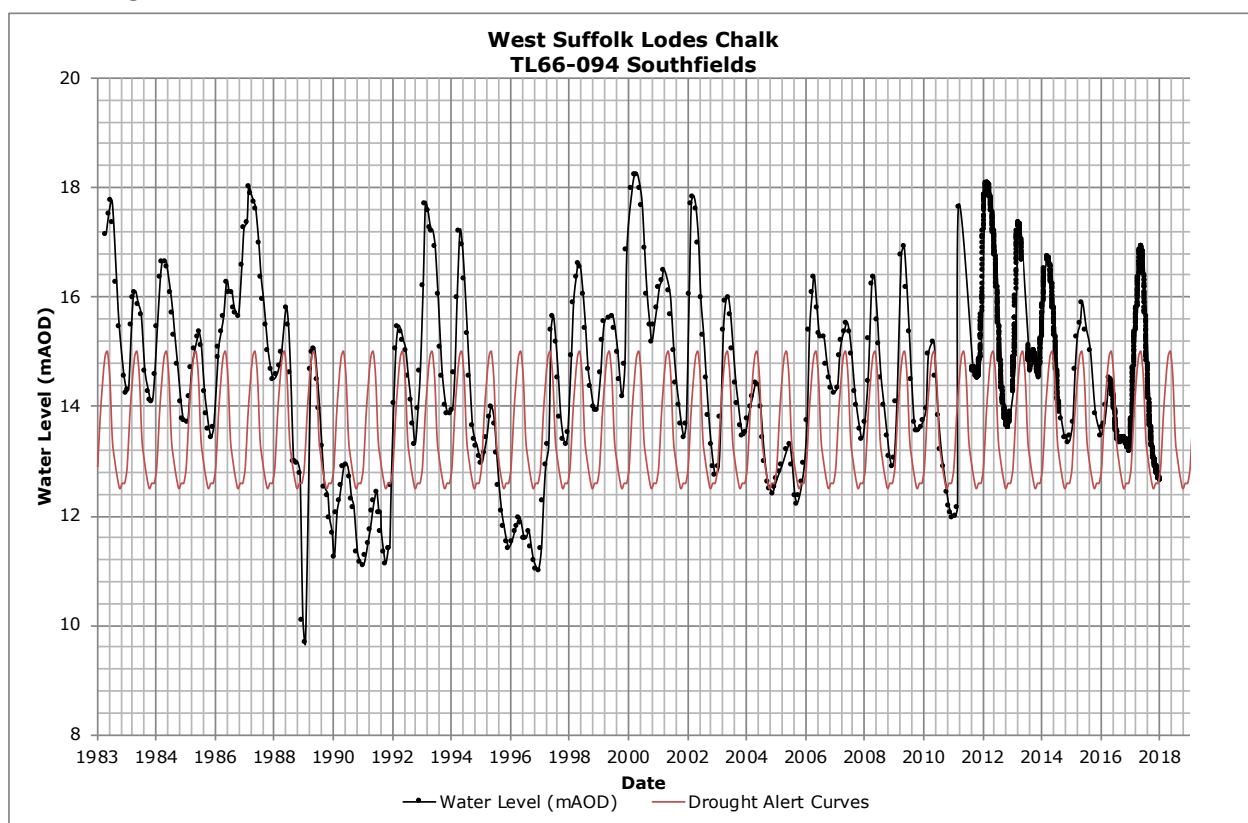


Figure 17: Drought alert curve used for Waneham Bridge

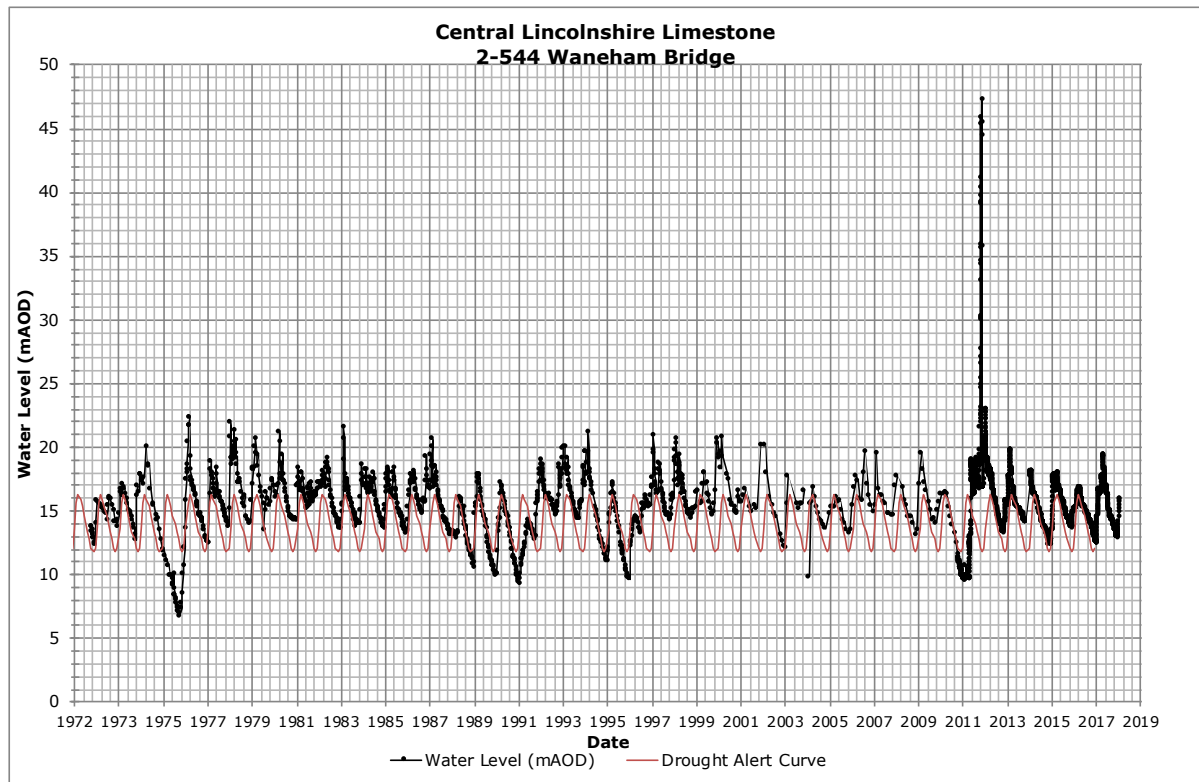


Figure 18: Drought alert curve used for Welton

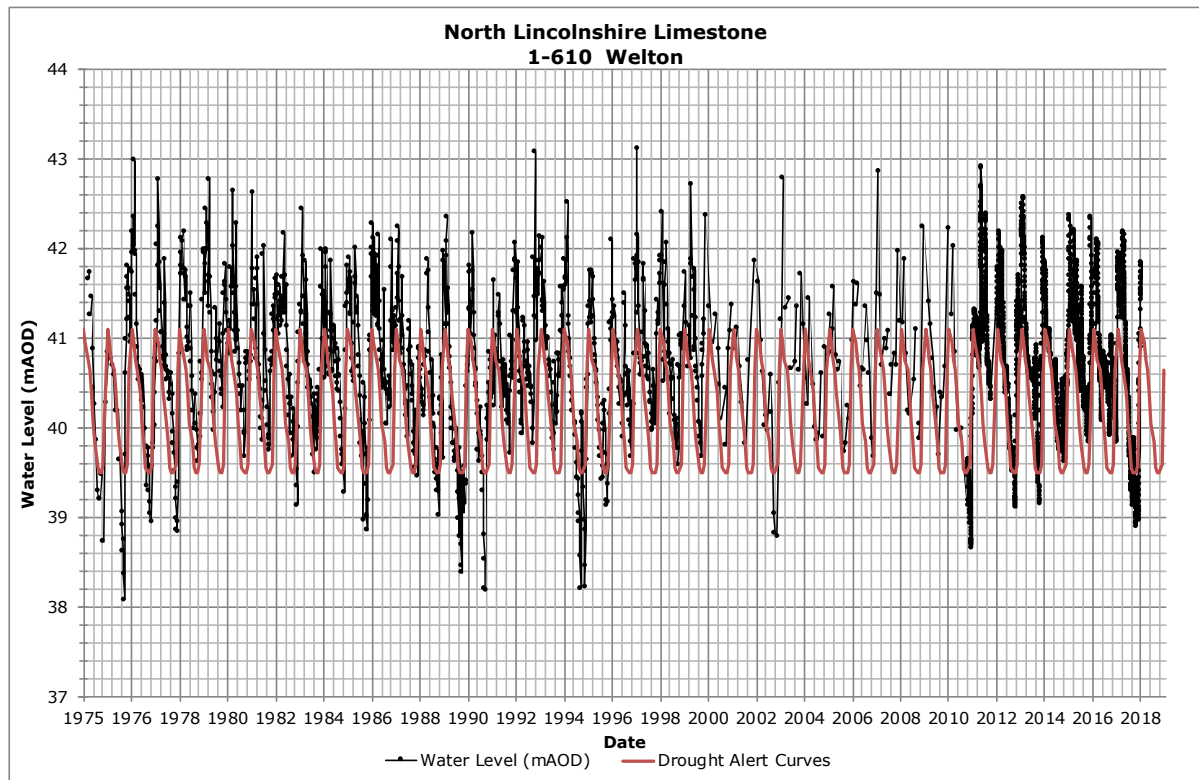


Figure 19: Drought alert curve used for Winterton Carrs 1 and Winterton Holmes

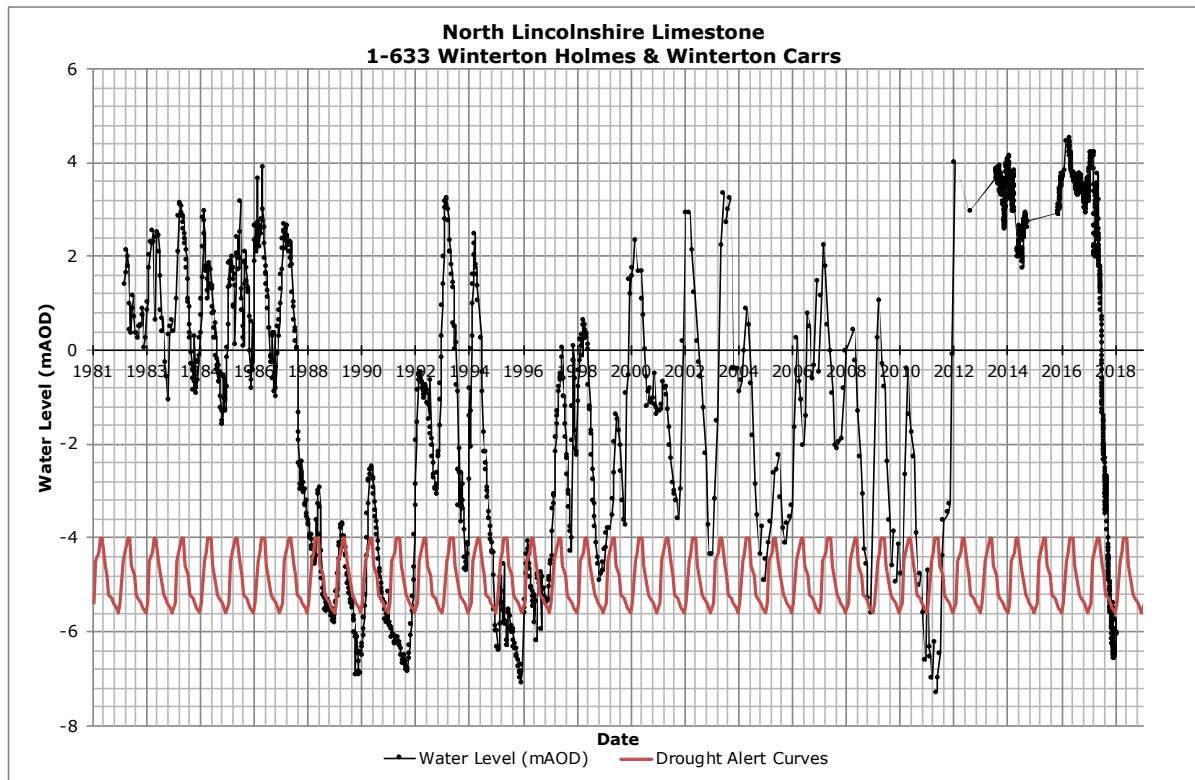
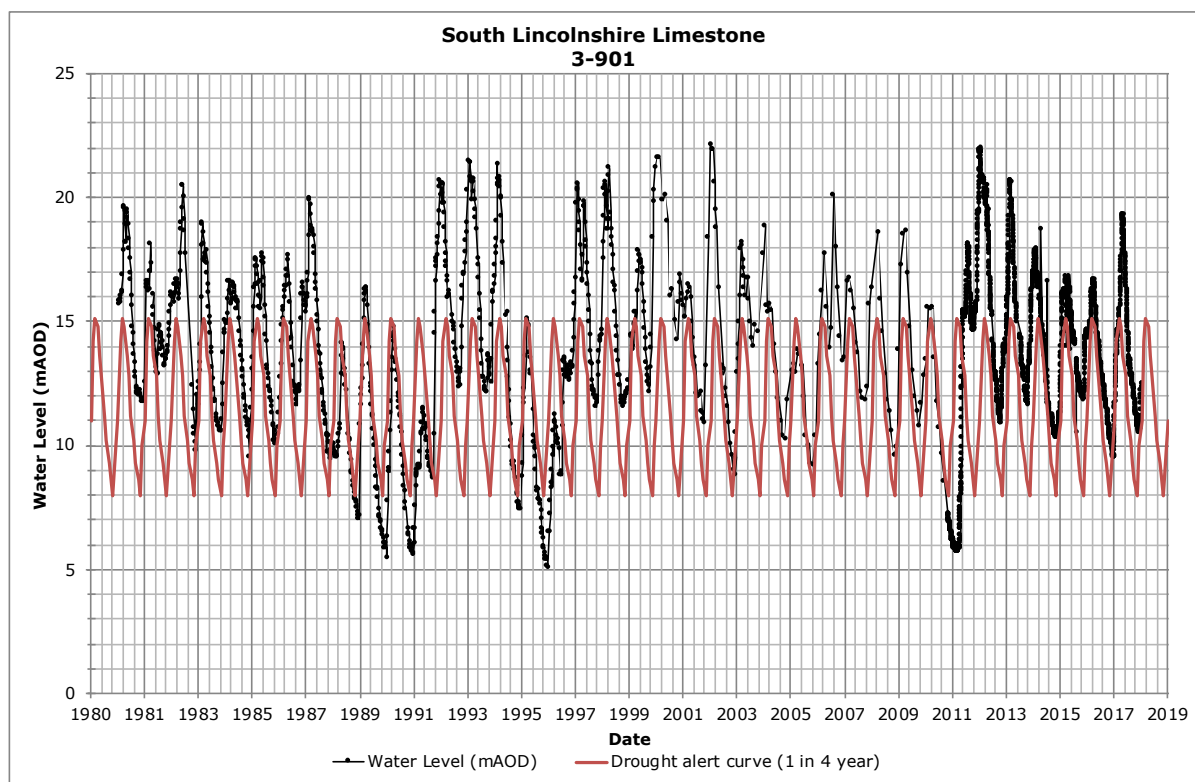


Figure 20: Drought alert curve used for South Lincolnshire Limestone borehole conditions





Cover photo - Anglian Water's Grafham Water reservoir, an 806-hectare biological Site of Special Scientific Interest, southwest of Huntingdon in Cambridgeshire. It was designated an SSSI in 1986.