Draft Drought Plan 2027

Annex 4 – Appendix B: Groundwater Triggers

May 2026

from Southern Water

Table of Contents

IMPORTANT NOTE:

This Annex is incomplete and the table below describes progress, along with work still to be completed.

Annex 4 Appendix B Groundwater Triggers	Description
Annex % Complete	70%
Work Completed	• Suitability assessment of boreholes used in Drought Plan 2022 • Identification of new proposed indicator boreholes • Development of borehole Standardised Groundwater Indices (SGI) trend app • Completed draft derivation of new groundwater drought triggers ***This Annex is in draft form only. As indicated below, the content remains subject to further analysis, regulatory input and evidence and may be amended prior to finalisation of the Drought Plan. Southern Water does not invite reliance on this section in its current form.***
Work Remaining	• Testing of triggers and development of worked examples
External Deliverables	**Consultancy support** • None **Regulatory support** • Environment Agency (EA) to review the draft groundwater triggers by the end of July 2026
Dependencies	None
Critical Path	Regulatory review of the triggers is needed before these triggers are finalised. A review call with regulators will be completed by the end July 2026
Timeline	• Testing of triggers by of May 2026 • EA review and call by End of July 2026
Decision points, meetings and workshops	Meeting/Call with regulators will be arranged for the review of groundwater triggers.

1 Introduction

Groundwater provides a substantial proportion of public water supply in the areas supplied by Southern Water. 70 % of water comes from groundwater. To help SWS anticipate and mobilize a response to the groundwater drought, groundwater drought triggers are necessary. In UK drought planning, groundwater triggers are predefined groundwater level thresholds that signal when water companies and regulators should take specific drought management actions.

In support of Drought Plan 2027 a review of the groundwater drought triggers was undertaken under the following terms of reference:

- Review current (Drought Plan 2022) drought trigger indicator boreholes.
- Assess potential locations that can improve the drought triggers.
- Following the SGI DP22 methodology, derive updated groundwater drought triggers and assess them against past drought occurrences and frequency of crossing using historical data.
- Test the groundwater triggers against past events.
- Develop worked examples, one for a single location in the three regions.

2 Groundwater Triggers

A review of EA regional observation boreholes (OBH) was undertaken. Boreholes were initially reviewed based on location, aquifer, data trends and data availability. The OBH shown below (Table 1) are those that were then taken forward and considered suitable for a more thorough technical review.

Table 1 – list of regional observation wells, that underwent technical review and those accepted

Observation borehole	Aquifer block	Respective WRZs
Accepted:		
Carrsibrooke Castle	IoW Central Downs Chalk	IOW
Calbourne Newbarn Farm	IoW Central Downs Chalk	IOW
Clanville Gate	River Test Chalk	HKZ,HAZ, HRZ
West Meon	River Itchen Chalk	HSE, HWZ
Chilgrove House	East Hampshire and Chichester Chalk	SWZ
Whitelot Bottom	Brighton Chalk Block	SWZ, SBZ
Houndean Bottom	Brighton Chalk Block	SBZ
Parsonage Farm	East Kent Chalk	KTZ
Little Bucket	East Kent Chalk	KTZ
Potential:		
Myrtle Grove	Worthing Chalk Block	SWZ
Rejected:		
Ladies Mile	Brighton Chalk Block	SBZ
Riddles Lane	North Kent Chalk	KMW, KME
Wilgate Green	North Kent Chalk	KMW, KME

3 Methodology

3.1 The use of standardised groundwater indices

For our 2019 Drought Plan (DP19), groundwater drought triggers were based on month-by-month frequency (percentile) groundwater level analysis, with the Level 1 and Level 2 triggers assigned at groundwater elevations equivalent to a 1-in-10 years and 1-in-20 years return periods respectively. For the 2022 Drought Plan (DP22), we proposed to replace the previous percentile-based approach with triggers based on Standardised Groundwater Indices (SGI). We have continued with the SGI approach within this plan.

The SGI method was developed by the British Geological Survey (BGS)[1] , and the approach has subsequently been applied in several follow up studies[2] [3] [4] [5]. The methodology and papers were reviewed, and an 'in-house' python app developed to calculate SGI trends, and to also back calculate equivalent percentile curves.

The SGI approach follows similar principles to existing meteorological drought indicators such as the standardised precipitation index (SPI). The SGI are effectively the groundwater level normalised index (i.e. the normal score) for all groundwater level values within a specific calendar month. And so, the monthly groundwater levels are represented as a series of individual monthly 'standard normal scores' (i.e. z-scores), with values between -3 and +3.

The sample sets of all groundwater level values for a specific month typically have a skewed distribution (i.e. non-normal and so 'non-parametric'). The app checks for skewness, and the monthly sample sets are transformed to a standard normal distribution using a 'Normal Scores Transform' method. The 'forced normalisation' of the monthly sample sets allows the standard scores (z-scores) to be calculated for each individual month, and so a time series of monthly groundwater level 'normal scores' can be constructed.

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[1] Bloomfield, J. P. and Marchant, B. P., 2013. Analysis of groundwater drought building on the standardised precipitation index approach, Hydrol. Earth Syst. Sci., 17, 4769–4787. https://doi.org/10.5194/hess-17-4769-2013

[2] Bloomfield, J. P., Marchant, B. P. and McKenzie, A. A., 2019. Changes in groundwater drought associated with anthropogenic warming, Hydrol. Earth Syst. Sci., 23, 1393–1408. https://doi.org/10.5194/hess-23-1393-2019.

[3] Bloomfield, J.P., Marchant, B.P. and Wang, L., 2018. Historic Standardised Groundwater level Index (SGI) for 54 UK boreholes (1891-2015). NERC Environmental Information Data Centre. (Dataset). https://doi.org/10.5285/d92c91ec-2f96-4ab2-8549-37d520dbd5fc

[4] Brauns, B., Cuba, D., Bloomfield, J. P., Hannah, D. M., Jackson, C., Marchant, B. P., Heudorfer, B., Van Loon, A. F., Bessière, H., Thunholm, B. and Schubert, G., 2020. The Groundwater Drought Initiative (GDI): Analysing and understanding groundwater drought across Europe, Proc. IAHS, 383, 297–305. https://doi.org/10.5194/piahs-383-297-2020

[5] Wendt, D. E., Van Loon, A. F., Bloomfield, J. P. and Hannah, D. M., 2020. Asymmetric impact of groundwater use on groundwater droughts, Hydrol. Earth Syst. Sci., 24, 4853–4868. https://doi.org/10.5194/hess-24-4853-2020

SGI drought triggers representing appropriate normal score values (i.e. probabilities) are selected for these trends. Negative (i.e. below average) monthly standard scores ('z-scores') represent differing extremes of drought, or lower than average monthly groundwater levels.

A directly corresponding groundwater level trigger curve hydrograph can also still be produced by back calculation (by expressing the SGI triggers as their corresponding monthly groundwater level).

We believe the SGI approach offers several advantages compared with groundwater hydrographs:

- SGI can be readily compared and correlated to rainfall SPIs and Standardized Precipitation-Evapotranspiration Indices (SPEIs) on the same scale and conventional drought threshold classifications used for SPIs could be applied (e.g. SGI of -1 to -1.5 = Moderate drought, SGI of -1.5 to -2 = severe drought, SGI of < -2.0 = extreme drought)[3,6]

- Direct correlation with SPI and SPEI series is possible.

- Table 2 can be used to identify critical rainfall and recharge accumulations associated with groundwater drought that is an important consideration for our Drought Plan and WRMP drought vulnerability assessment.

- A standardisation approach allows easier site-to-site comparison of groundwater hydrograph responses to drought events where individual borehole hydrographs may have very different groundwater ranges and shapes across the various aquifer blocks from which we abstract.

- An SGI trend can help to highlight the onset of droughts more clearly.

- The approach has been validated by several peer-reviewed studies across major UK and European aquifers, including the chalk.

- Published studies show a good correlation of SGI with independently established historical droughts and hence we consider the SGI is a robust indicator of groundwater drought.

- The approach has also been used to identify potential long-term trends of anthropogenic warming.

The SGI approach has been applied to assist in selecting the groundwater drought indicator observation boreholes for use within this plan.

Table 2 – Proposed drought thresholds for SGI (linked levels of service percentiles).

SGI range	Level percentile range	Drought definition	Drought level
-1.00 < SGI < 0.00	level < 50th %	Below average	0
-1.50 < SGI < -1.00	10th % < level < 20th %	Impending drought (1 in 5)	1
-2.00 < SGI < -1.50	5th % < level < 10th %	Moderate Drought (1 in 10)	2
-2.50 < SGI < -2.00	0.2 % < level < 5th %	Severe drought (1 in 20)	3
SGI < -2.50	level < 0.5%	Extreme drought (1 in 200)	4

3.2 SGI Methodology

The calculation of SGI values and derivation of triggers followed these steps:

- ‘Resampling’ of the observed groundwater level data series {xn} is conducted to obtain regular sample values, for the first day of each month (or weekly). How:
  - An ‘up-sampled’ hourly time series is first created, based on the available original data.
  - Missing hourly values (within the measured data) are interpolated from adjacent values.
  - The time-series frequency is re-adjusted to match the users selected frequency (e.g. weekly or start of month). This creates a ‘down-sampled’ set of regular and equally spaced values.
  - Monthly frequency is advised, to reduce shorter period voliatilty and statistical error.

- ‘A **Rank-Based Inverse Normal Transformation’ (**or ‘Normal Scores Transformation’) was conducted upon ‘sample sets of monthly data’. How:
  - The level data, for each specific month across all recorded years, is collated. The values within each monthly sample set are ordered into an ascending series.
  - A monthly sample set is ordered, to produce a sequence of increasing values $\{x_n\}$.
  - The ‘equivalent’ relative rank/position of each value within a monthly sample set is estimated. Using Python code used:
  - *rankdata*(x_i).
  - Each value’s ‘relative rank’ is converted into a ‘probability’ $\boldsymbol{p_i}$ (between 0 and 1). This is the probability that any value drawn at random from the monthly distribution, will be less than or equal to the selected rank value. This ‘forces’ the data into the required normal probability distribution. Python code used:
  - p_i = *rankdata*(x_i)/(*len*(x_n) + 1).
  - Van der Waerden’s method is used to derive probabilities from ranks.

- The respective ‘standard score’ (i.e. ‘z-score’) for each individual monthly value is then calculated, equivalent to the level values probability, within the monthly sample set. How:
  - The Inverse Cumulative Distribution Function is applied to the equally spaced monthly probability values, to convert the series of probabilities for a specific month into equivalent monthly z-scores. Python code used:
    - *norm.ppf* (p_i).

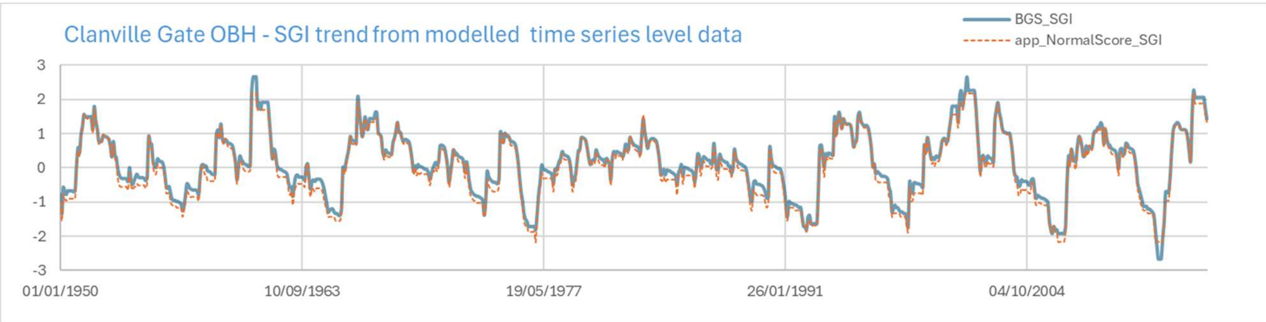
- A series of corresponding sequential/increasing monthly groundwater level standard scores (z-scores), or SGI values, is similarly produced.

- A directly equivalent groundwater hydrograph of drought trigger levels is constructed. The SGI method is applied in reverse to back calculate the groundwater level associated with a monthly trigger SGI value (trigger z-scores). How:
  - Monthly groundwater level sample sets are used to create two distinct and separate series of data.
    - An ascending series of level values, and the corresponding (ascending) series of standard scores.
  - A linear interpolation function is set to represent the 2 series of data. Python code:
    - *interpolation_function = interp1d(sortedMonthlyZScores , sortedMonthlyLevels], kind='linear', fill_value="extrapolate").*
  - The SGI trigger values (e.g. -1, -1.5, -2.0 ..etc), are used within the interpolation function, to back calculate an equivalent groundwater level. This is done for each specific monthly sample set, and for each trigger value. Python code:
    - *back_transformed_level_trigger = interpolation_function(-1.5).*
  - The set of recurring annual trigger curves are constructed.

3.3 Method Quality Assurance Checks

QA#1 - comparing in-house app SGI outputs, against BGS study SGI outputs

SGI trends produced by the in-house SGI app, are compared directly against published BGS SGI output trends for the same observation wells (and using the same modelled groundwater level data as input) [2]. The Southern Water app appears to closely match the SGI trends produced within the BGS study and reports (Figure 1).



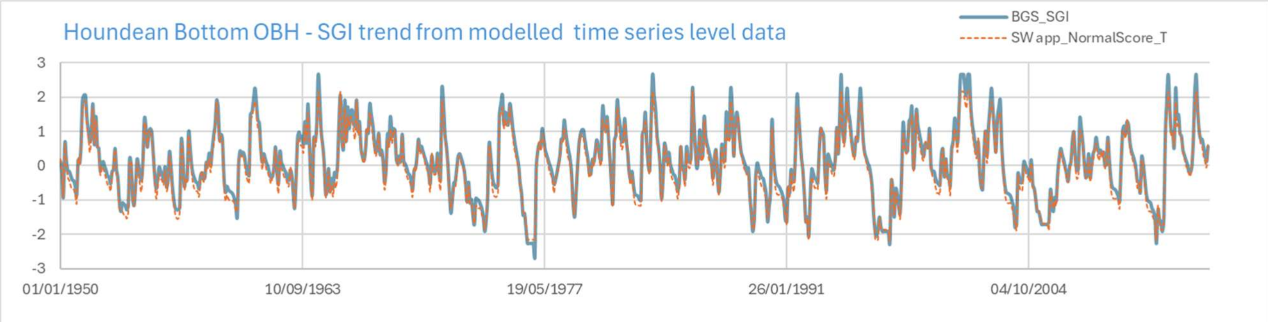


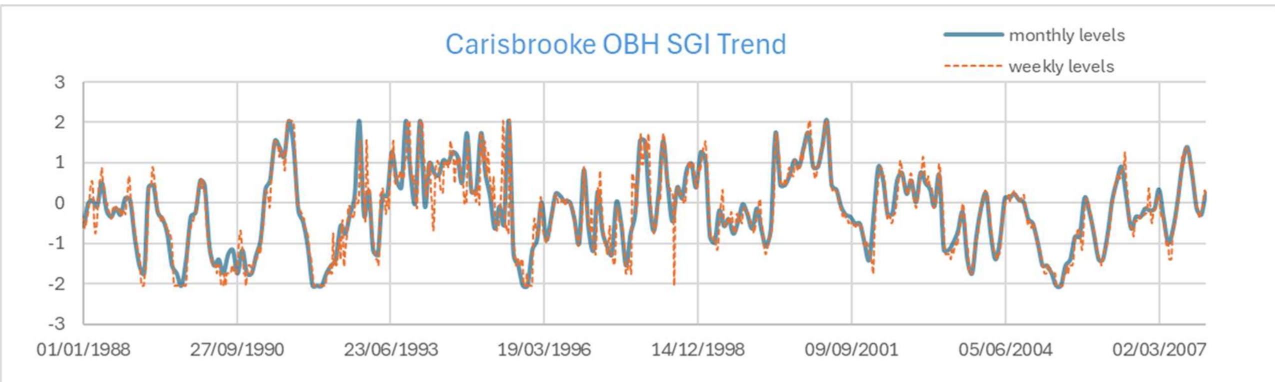
Figure 1- Southern Water vs BGS SGI trends at 2 OBH – assessed using the same input data

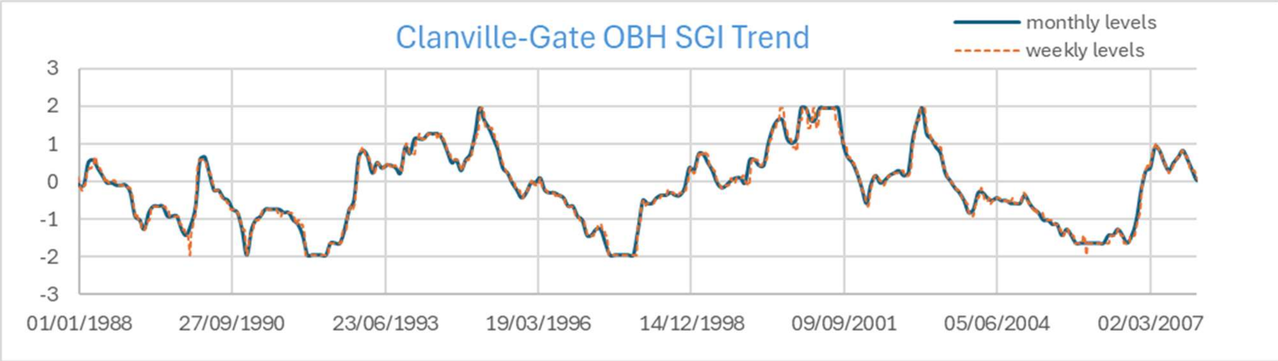
QA #2– comparing monthly or weekly data frequencies to produce SGI trends

Rainfall SPI are often calculated using a minimum 3 monthly (rainfall totals) sample frequency. Higher frequency (e.g. weekly, daily, hourly) hydrometric data sampling generally becomes prone to increasingly greater natural 'sudden variability' over the shorter time intervals (e.g. rainfall totals may vary considerably over days or weeks).

Groundwater level variations tend to be less 'flashy, erratic or variable', and reviewed SGI literature tends to use monthly groundwater level data intervals for producing SGI trends. While the use of monthly intervals is recommended, we have also reviewed the potential robustness of using weekly groundwater level intervals, for creating SGI trends. A shorter frequency interval would better meet the dynamic demands of business/regulatory reporting and might allow for faster decision making regarding the implementation of drought measures. SGI trends using both monthly and weekly sample frequencies are produced and compared. It's noted that the weekly SGI trends generally match the monthly SGI trends well (Figure 2), though the 'increased noise' and the occasional 'anomalous values' (outside of monthly SGI trends) are evident within the weekly trends. And unsurprisingly, more so for Carisbrooke OBH which is known to have a 'flashy' groundwater level record. So, while the use of weekly level frequency SGI appears possible, a cautious approach is still advised, to consider sudden 'anomalous deviation' from the monthly trend.

Using a sample frequency of any less than a week is not advised, as the data is likely to become increasingly noisier, as short-term influences (e.g. rapid recharge, pumping interference) will become increasingly significant between individual data points. But critically, it just becomes increasingly difficult to justify that individual data points are 'independent with respect to each other', a key assumption within the Central Limit theorem (and probability theory).





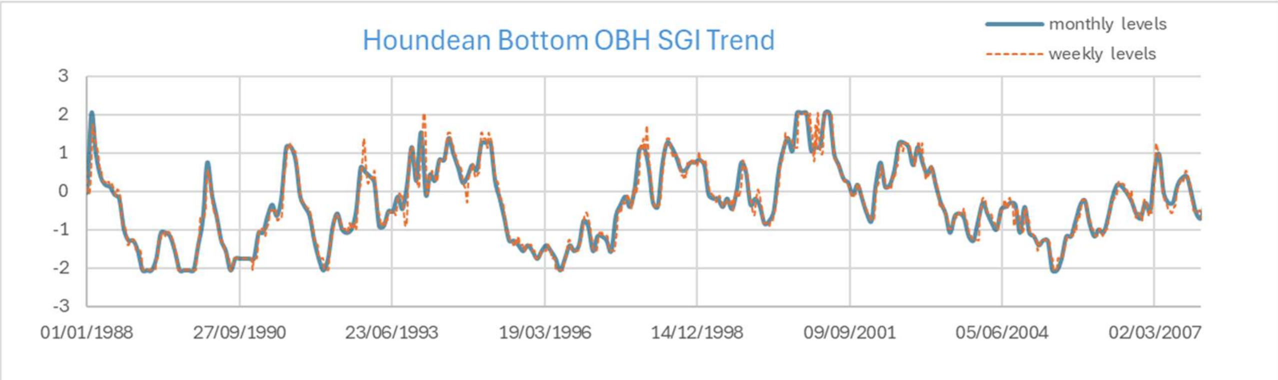
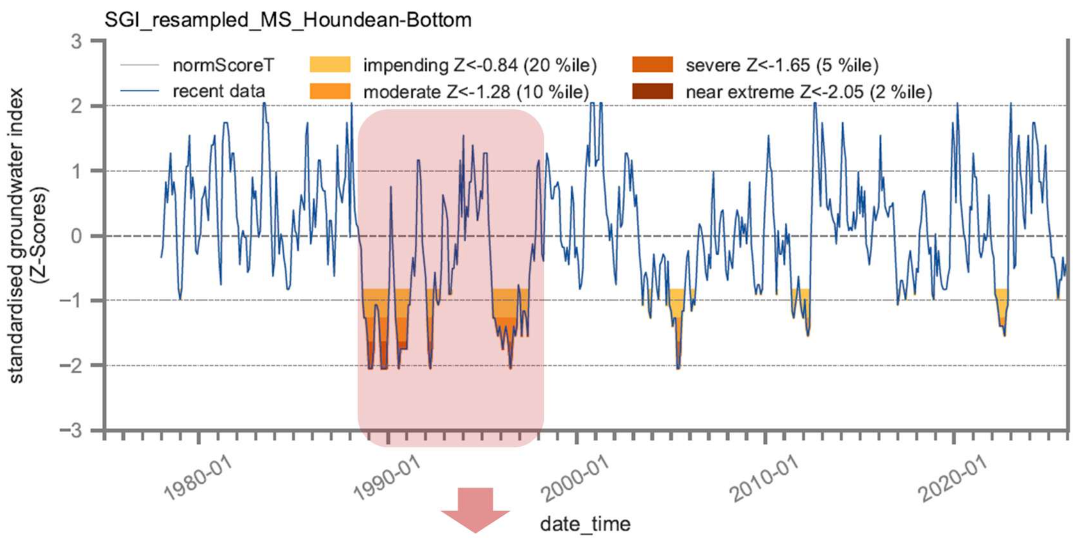


Figure 2 - comparison of the use of either monthly or weekly frequency data

QA#3 – check the back calculated hydrograph trigger curves correspond with SGI trends

Back calculated trigger curves and trends, correlate directly with (or 'reflect') their corresponding SGI trend. Allowing dual use or alternative representations of the same data within dashboards. Though SGI trends can often highlight the onset of droughts more clearly, especially in situations where hydrograph trigger bands are compressed, or where groundwater levels track parallel with trigger curves (Figure 3).



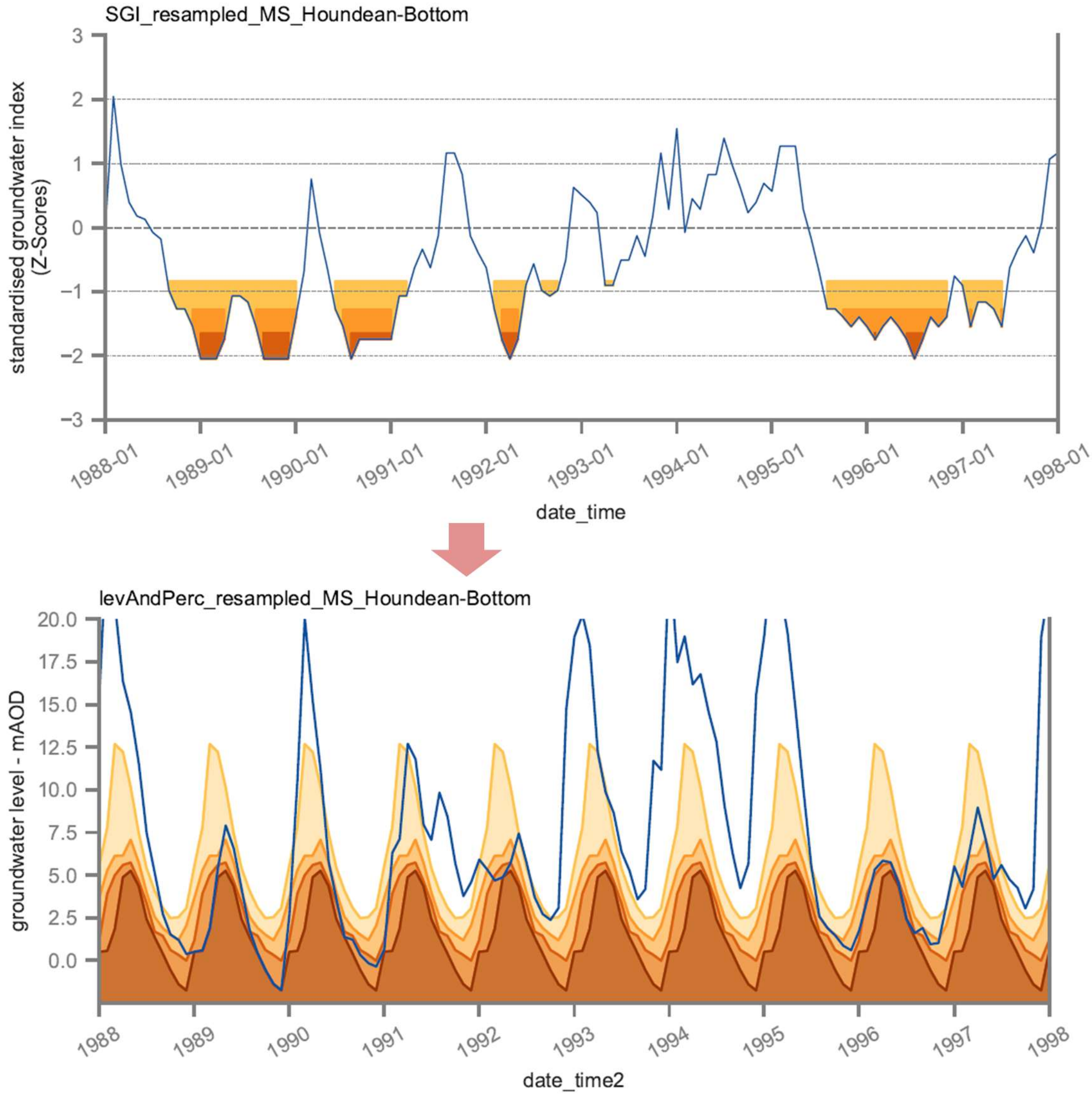


Figure 3 - back calculated trigger curves directly match ('reflect') corresponding SGI trends

QA#4 - Expressing errors and uncertainty (in groundwater levels)

It should be noted that 'uncorrected' original OBH level data has been used when generating SGI trends, and the application of an appropriate error band is advised to represent the uncertainty in level data on hydrograph curve charts (when appropriate). Though it should also be noted that the act of 'down-sampling' and a reduction (of original higher frequency raw data) down to monthly data intervals acts to smooth or average out any higher frequency variations/noise (i.e. hourly/daily variations). The reasoning for not attempting to correct historic and/or current raw OBH data (e.g. to attempt to remove minor daily pumping influence) is explained further here:

- The act of 'down sampling' higher frequency data sets, to produce regular monthly or weekly data sets, effectively acts to average out higher frequency (daily or hourly) variations. Many telemetered monitored OBH provide relatively high frequency groundwater observation data (i.e. daily or less sampling intervals).

- Corrections to remove historic pumping influence using recession analysis or using a groundwater hydraulic approach (e.g. Thies or Jacob) simply cannot be applied with accuracy or confidence. As historic sub-daily pumping states (on/off), the instantaneous abstraction flow rates, and/or the duration of pumping are not known. So, applying such corrections may be misleading or contribute to further (hidden) error.

- Approaches which offer a broad, averaged and general wholesale correction of date sets (e.g. shifting data sets up/down by a set amount) are unlikely to significantly influence a standardised normal SGI trigger (i.e. standard scores). As SGI triggers are described by the degree of variation from the mean and are not absolute level values.

- When compared to seasonal ranges (c.20m), the observed error ranges ('noise') at some boreholes under low groundwater conditions are generally small (c. 0.2m-0.5m maximum), equivalent to c. 1% to 2.5 % of that range.

- It's appreciated that uncertainty could influence back calculated groundwater level triggers (i.e. absolute level values), and the associated groundwater level trigger curves plotted on hydrographs. But a simpler appropriate 'error band' approach is advised for these hydrograph trigger curves, to best openly and clearly communicate any such uncertainty, and aid decision making.

The range of the 'uncertainty/error' is derived by reviewing the typical range of observed daily or hourly groundwater level variations (e.g. apparent 'noise'), under lowest groundwater conditions.

3.4 Review and selection of the initial level 1 trigger - the onset of droughts

Drought trigger values need to reflect known historic droughts, their onset, and their intensity. Though additionally the initial level 1 drought triggers also need to provide sufficient warning to allow the completion of the regulatory drought permit/order application process (in time for actions to take effect)

Literature reviews typically return a range of advised SGI drought intensity values of -1.0 (moderate), -1.5 (severe), -2.0 (extreme)[1 2 3 4 5] . With values between 0 and -1.0 representing a minor drought, or the period leading up to an impending harsher drought.

Confidence in the initial level 1 drought trigger appears key though. The potential use of an SGI value of -1.0 as the initial (level 1) drought 'trigger' was reviewed and compared against other similar potential level 1 trigger values. A simple (semi-quantitative) sensitivity analysis or sense check was undertaken with regards to the perceived initial onset of droughts. The initial onset of historic droughts and the frequency of these historic drought events were compared, using 3 separate and distinct 'onset of drought' level 1 triggers.

The 3 scenarios looked at for defining the initial onset (level 1) of a drought are:

1. SGI = -0.84 (equivalent to the 20th percentile of level data).
2. SGI = -1.03 (equivalent to the 15th percentile of level data).
3. SGI = -1.28 (equivalent to the 10th percentile of level data).

Onset of drought (horizontal) trigger lines are plotted against historic SGI trends for selected observation boreholes in each water supply area (West, Central and East). Crossing events and crossing frequency were reviewed for this level 1 trigger, against know recent historic droughts. The purpose of the validation exercise was to compare the different level 1 trigger values, and to broadly sense check that minor droughts are not triggered too frequently, but that the key historic droughts are still captured, and to review this against 'local' data.

Examples for Clanville Gate (Western area) and Little Bucket (Eastern area) are shown below (Figure 4 and Figure 5 respectively).

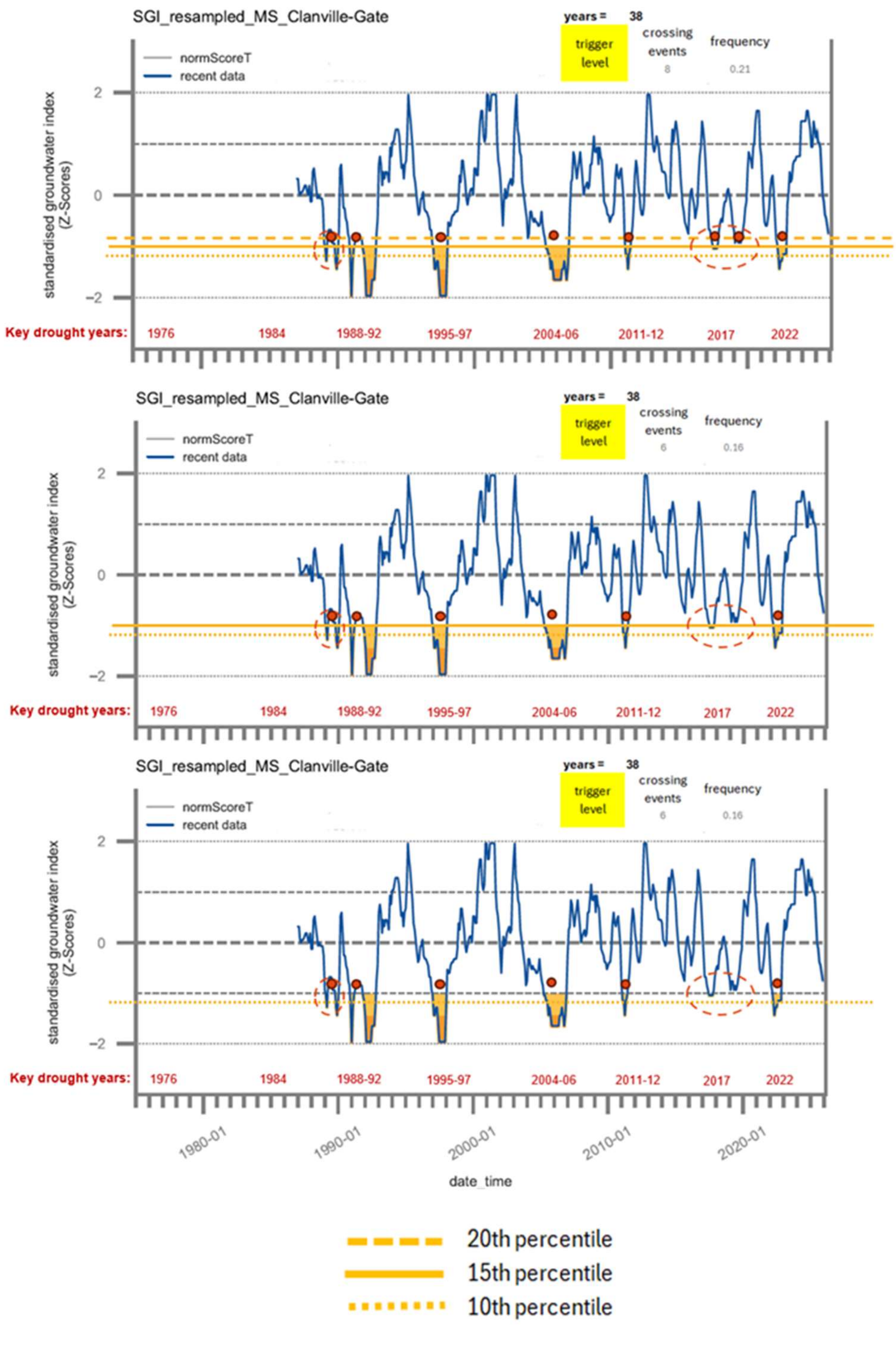


Figure 4: Clanville Gate (Western area) SGI trace with annotated drought years

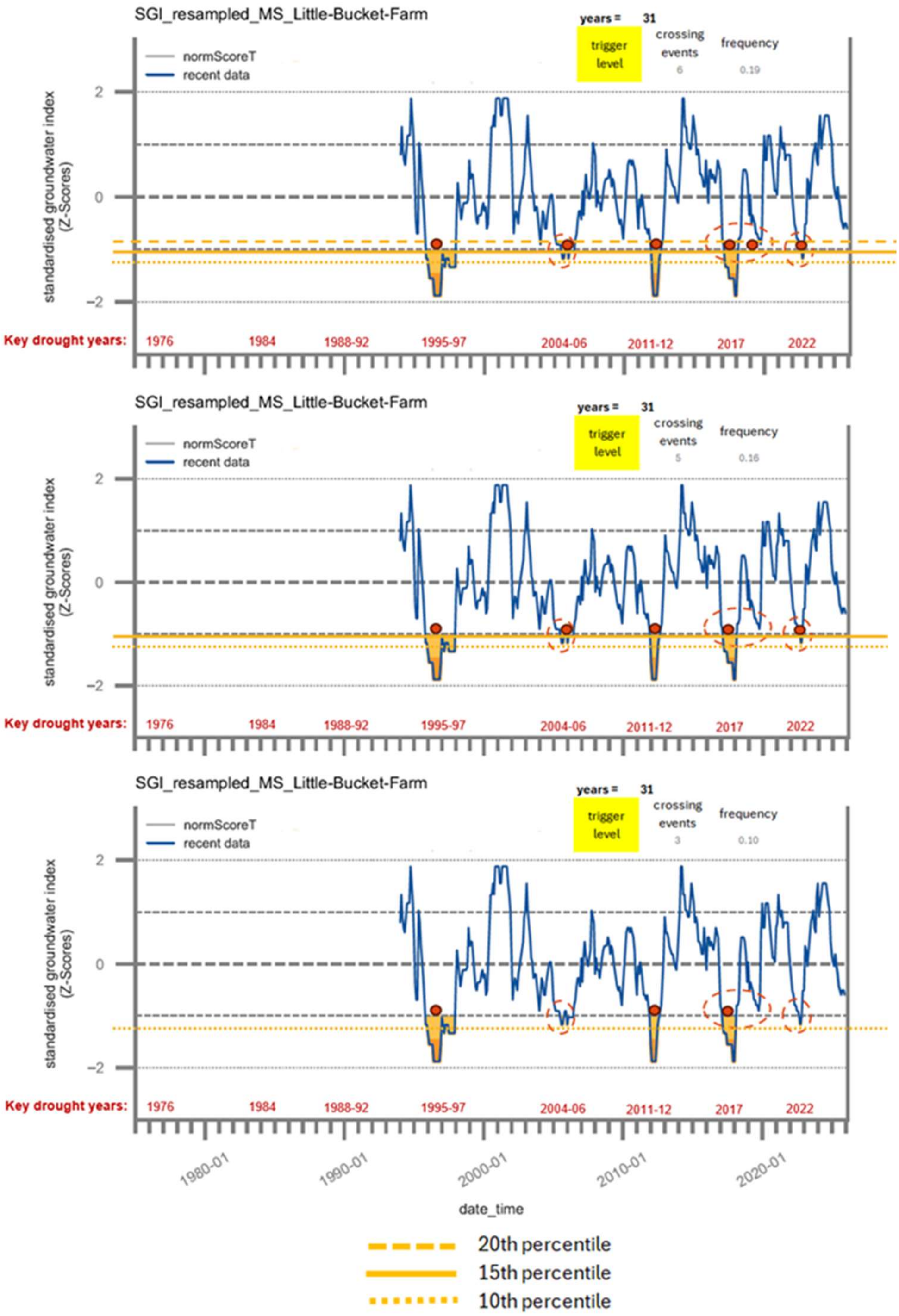


Figure 5: Little Bucket (Eastern area) SGI trace and annotation of drought years

An initial (level 1) trigger value set at SGI = -0.84 (the 20th percentile) tended to capture the onset of all historic minor and major droughts, though the resulting higher trigger frequency could be viewed as being too frequent, and over precautionary. While precautionary, it perhaps better fills the role of an internal early warning or alarm'.

An initial (level 1) trigger value set at SGI = -1.03 (the 15th percentile) tended to capture all historic major/significant droughts, though some minor droughts are not triggered. Sufficient warning or forecasting of the situation prior to this trigger (so required actions can be more quickly implemented) would be advised.

An initial (level 1) trigger value set at SGI = -1.28 (the 10th percentile) tended to capture most, but not all, historic major/significant droughts. With major droughts being triggered notably later. For example, the 2022 drought and the more notable 2004-06 drought would not have been triggered at Little Bucket using this initial trigger value. The value would appear to be too low for use as an initial trigger level.

This initial 'sense check' provides local evidence to support the use of an SGI value of -1.0, as the initial level 1 drought trigger value.

3.5 Reviewing potential drought monitoring locations

Potential observation boreholes (for use as drought triggers) were initially reviewed by a stage 1 high level screening stage (of DEFRA hydrometric data). The screening process considered these factors:

- **Aquifer type** – matches that of abstractions
- **Length of record** – adequate historic data length
- **Data frequency, consistency, and data availability** – readily available and current data
- **Proximity to external influence** (abstractions, sea tides etc) – minimal influence preferred
- **Seasonal range** – more 'notable' seasonal ranges aids trigger bands and decision making

The individual boreholes successfully selected from the initial screening then underwent a second stage assessment, consisting of a more thorough technical review (Figure 6). For the second stage review the groundwater level and SGI trends were plotted and the level 1, level 2 and level 3 'annual drought event' frequencies were assessed for each borehole. The purpose was to confirm if these selected boreholes, and the generated range of trigger levels, reflects past known moderate and severe drought events.

The SGI trigger values used are:

- -1.0 (level 1 drought - moderate).
- -1.5 (level 2 drought - severe).
- -2.0 (level 3 drought - extreme).
- -2.5 (level 4 drought – very extreme).

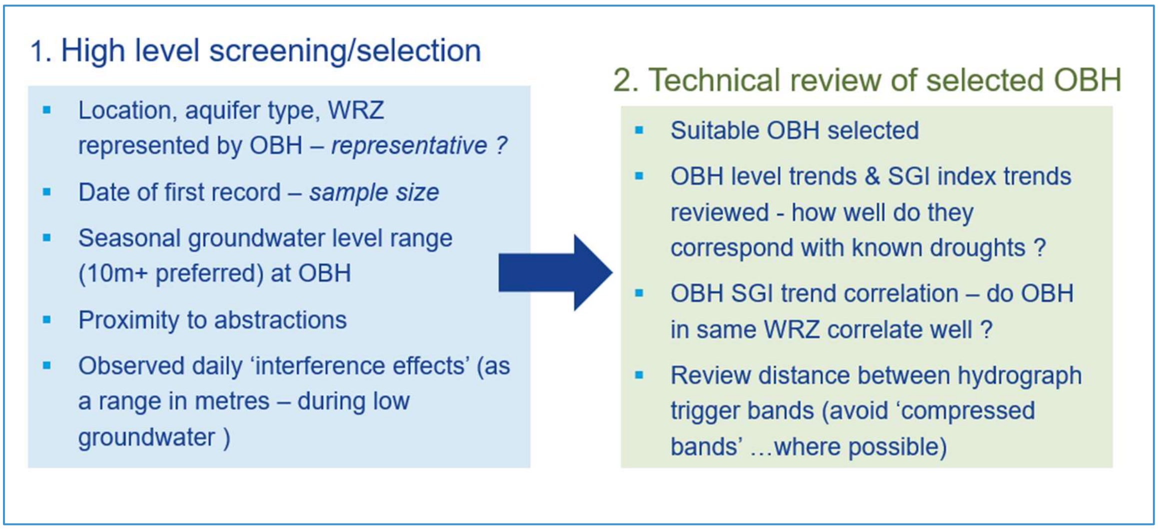


Figure 6: Summary of the review methodology

Drought frequency crossing events were noted. These are defined by SGI values first falling below the set trigger level, and the event ends once the SGI recovers to values of 0 or greater. The number of crossing events at each trigger level are summed and then divided by the number of years within the whole trend. Though 2 or more consecutive historic values below a trigger level are required for an event to be considered as real and not anomalous. The summary of these results is shown below in Table 3.

Table 3: Comparison of SGI triggering frequency between boreholes

SGI Triggers - Percentage of Crossing Events			
SGI trigger boundary: Equivalent percentile: Approx annual frequency:	Z < -1.00 c. 15th percentile 1-in-7 years	Z < -1.50 c. 7th percentile 1-in-14 years	Z < -2.00 c. 2nd percentile 1-in-50 years
Carrsibrooke Castle	21%	13%	0%
Calbourne Newbarn Farm	21%	15%	0%
Clanville Gate	15%	8%	0%
West Meon	13%	8%	0%
Chilgrove House	24%	18%	4%
Whitelot Bottom	14%	8%	0%
Houndean Bottom	15%	10%	0%
Parsonage Farm	12%	8%	0%
Little Bucket	13%	10%	0%
Myrtle Grove	13%	6%	0%
Ladies Mile	13%	9%	0%
Riddles Lane	7%	5%	0%
Wilgate Green	12%	4%	0%

The following annotation (Figure 7) is shown on each SGI trend, which summarises the results this frequency assessment:

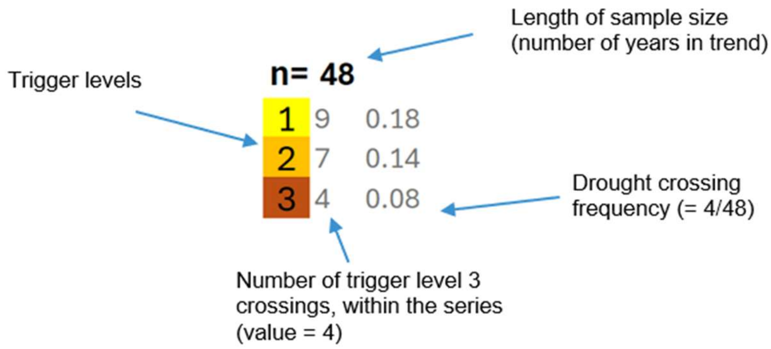


Figure 7: SCI trace annotation used in the presentation of results

4 Reviews of observation borehole suitability

The following sections contains the stage 2 review of the observation boreholes that passed through initial screening/selection (Fig 6 and Table 4) across the Western, Central and Eastern areas.

- The OBH groundwater levels and trends are individually reviewed to consider:
- That groundwater level and SGI trends are representative of known historic drought periods
- That SGI trends broadly 'correlate' with each other (consistency within a water resource zone/area).
- That hydrograph trigger curves, back calculated from the SGI trends, correspond with SGI trends
- The representation of seasonality within percentile trigger curve shapes and width of trigger bands.

The 'down-sampling' (i.e. reduction of sample frequency) of the time series borehole level data, into a consistant and regular monthly frequency, also enables easier direct assessments between different SGI trends using Pearson correlation analysis. However,although this is a useful addition, correlation assessments alone by can be misleading, and should be used as part of the range of approaches for considering borehole suitabilty.

4.1 Western Area Review – obsevation borehole review

The groundwater level records for the two boreholes used as drought triggers within Hampshire (Clanville Gate and West Meon) both have medium-length high frequency time series records dating back to the 1980s. They provide good indicator boreholes for the West Hampshire Chalk and River Test catchment, and the East Hampshire Chalk and River Itchen catchment. Both boreholes are also featured within EA Water Situation Reporting, and Clanville Gate is included with the BGS SGI study and report[5].

Daily/weekly interference pumping impacts are not visually discernible within the groundwater level data at Claville Gate or West Meon.

The generated SGI trends are also noted to correspond well with known historic drought events (Figure 9), and a strong correlation is noted between the two observation boreholes themselves (Figure 8).

The proposed groundwater monitoring boreholes for the Hampshire area remain unchanged and are Clanville Gate and West Meon observation wells.

For the Isle of Wight, the triggers are based upon levels and trends at the observation borehole at Carisbrook Castle and a proposed new/additional trigger borehole at Calbourne Newbarn Farm. Both have a medium length record (back to the 1980's). The level trends appear representative of the Chalk aquifer and the SGI trends are noted to reflect historic droughts well (Figure 9).

Both the Isle of Wight boreholes correlate well with each other, though only Calbourne Newbarn Farm correlates well with the mainland Hampshire observation boreholes (Figure 8). The Isle of Wight chalk aquifer is characteristically very flashy, responding more quickly to recharge and/or to periods of dry weather alike. A sudden increased groundwater recession trend is also noted under lower groundwater levels. This may reflect a greater nearby pumping influence (increased abstractions or reducing transmissivity), the onset of aquifer barrier boundary effects or reduced groundwater seepages from other adjacent aquifers. But although this increase in general recession is noted within droughts, direct daily scale abstraction fluctuations at the monitored observation boreholes are not apparent.

The proposed groundwater trigger boreholes for the Isle of Wight are Carrisbook Castle observation borehole, and the new additional monitoring point at Calbourne Newbarn Farm.

The groundwater level percentile hydrographs that directly correspond with the generated SGI trends at the observation wells are also shown (Figure 10)

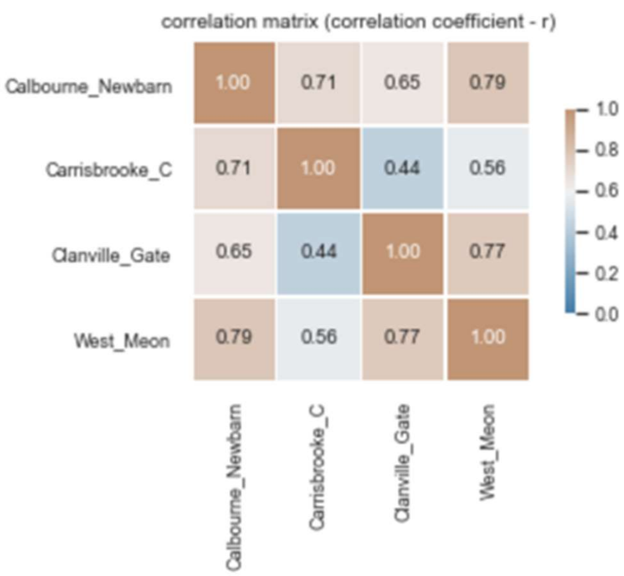


Figure 8: Western Area– Pearson correlation matrix for reviewed OBH (SGI trends: 2001 – 2025)

Figure 9: Western Area - OBH groundwater level and SGI trends (based on -1.0, -1.5, -2.0 SGI values)

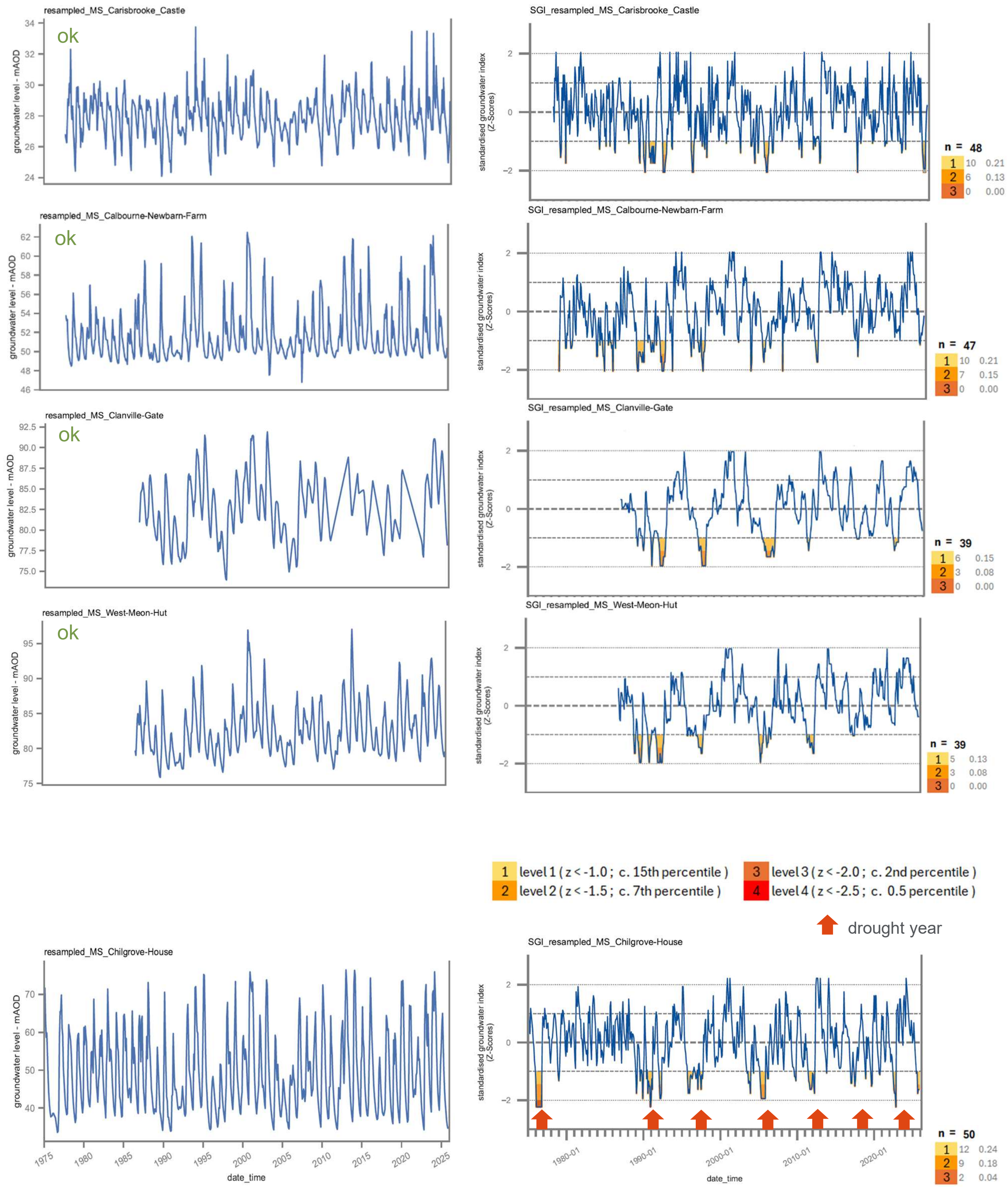
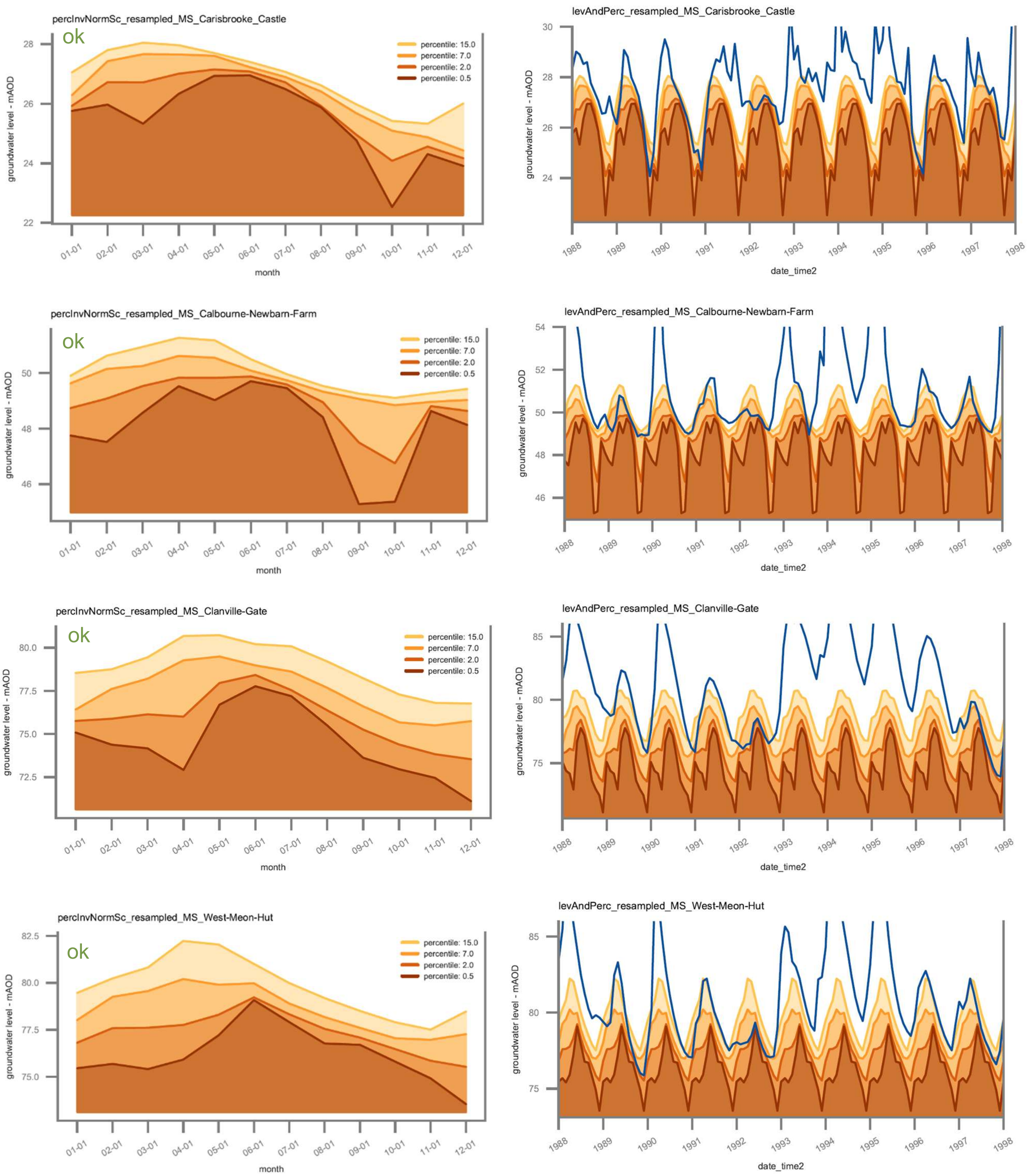


Figure 10: Western Area - corresponding percentile hydrographs for groundwater triggers



4.2 Central Area Review – observation borehole review

Three indicator boreholes are included within the Central area covering the Chalk aquifer of the Worthing and Brighton Chalk blocks. The boreholes are associated with SWZ and SBZ water resource zones, which are completely reliant on groundwater resources.

Ladies Mile and Myrtle Grove were considered as potential additional or replacement trigger boreholes. Myrtle Grove being more representative of the Worthing block, and Ladies Mile as a potential replacement to Houndean Bottom.

Myrtle Grove correlated very well with known droughts and with the other observation boreholes, but the frequency of online data updates appears slow, and a direct API data link is not available making it currently unsuitable for use as a drought trigger borehole. Ladies Mile showed no notable advantage over Houndean Bottom and has more closely spaced/packed trigger curves (Figure 13). For these reasons, both Myrtle Grove and Houndean Bottom are currently discounted.

The three selected (and retained) trigger boreholes (Chilgrove House, Whitelot Bottom, and Houndean Bottom) have good, long-term groundwater level records back to the 1970’s and provide a good spatial spread of coverage from west to east across the relatively narrow coastal aquifer blocks. These SGI trends represent historic droughts well (Figure 12) and correlate well with each other. Though Chilgrove House and Whitelot Bottom OBH do show a less strong correlation (Figure 11).

Chilgrove House was one of the pilot sites within the BGS SGI studies and paper[28], adding confidence to its continued selection, and the monitored level data shows no apparent interference pumping effects. Even though it is not best representative of Southern Water operational areas, it still represents the general aquifer well and provides a greater east-west spread to the understanding of groundwater resource situations.

Both Whitelot Bottom and Houndean Bottom groundwater levels show influence from nearby abstractions, with maximum daily variations or ranges of c. 0.5m noted. Uncertainty is recommended to be handled with error bands on the hydrograph. But overall, these boreholes provide a good representation of the central and western part of the Brighton Chalk block and the eastern part of the Worthing Chalk block.

The proposed groundwater monitoring boreholes for the central area remain unchanged and are Chilgrove House, Whitelot Bottom and Houndean Bottom. The groundwater level percentile hydrographs that directly correspond with the generated SGI trends at the observation wells are also shown (Figure 13).

Figure 11: Central - correlation matrix for reviewed OBH (SGI trends: 2001 – 2025)

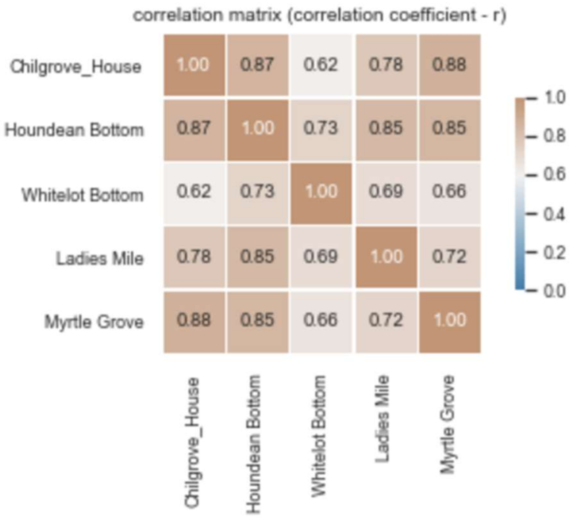


Figure 12: Central Area - OBH groundwater level and SGI trends (based on -1.0, -1.5, -2.0 SGI values)

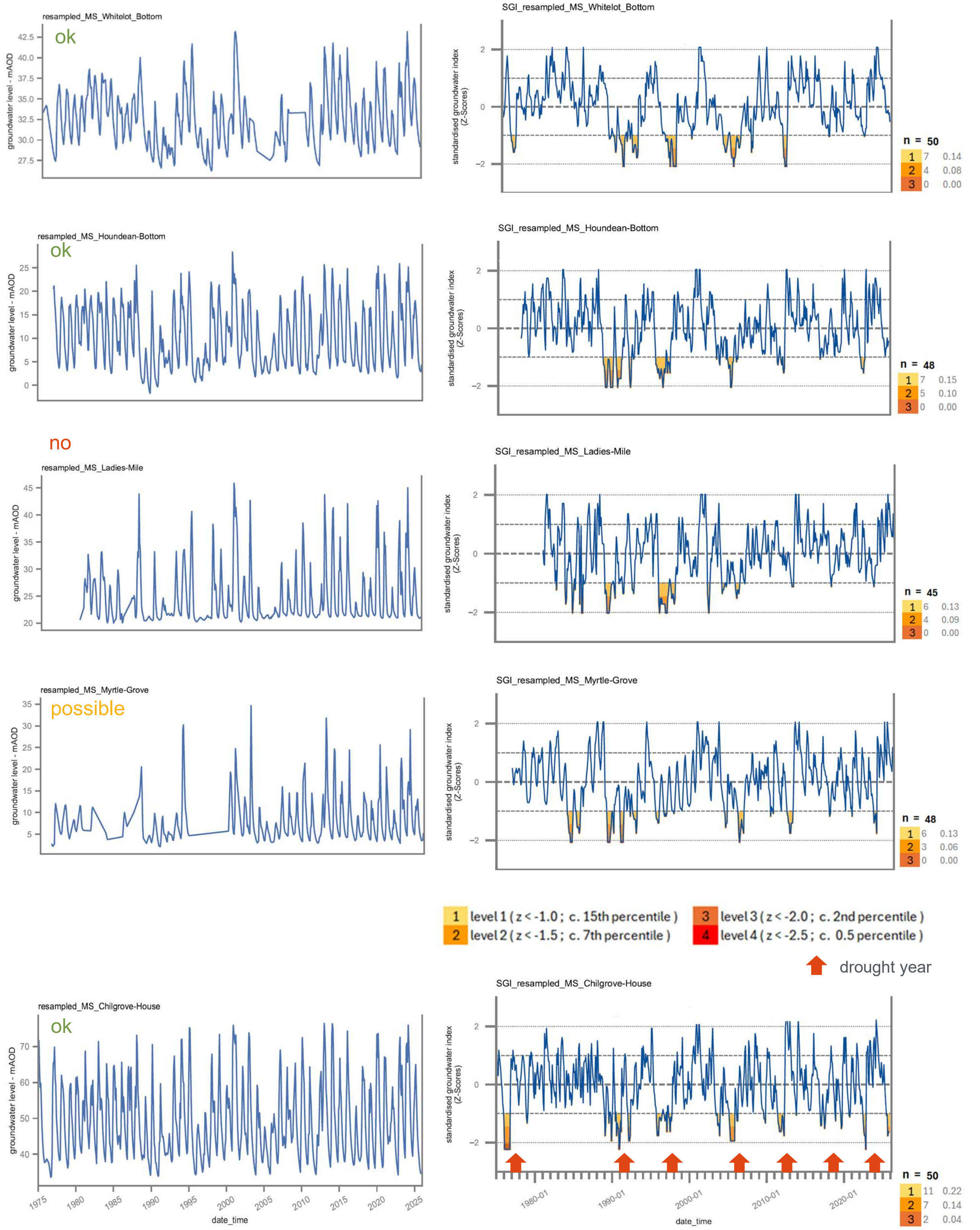
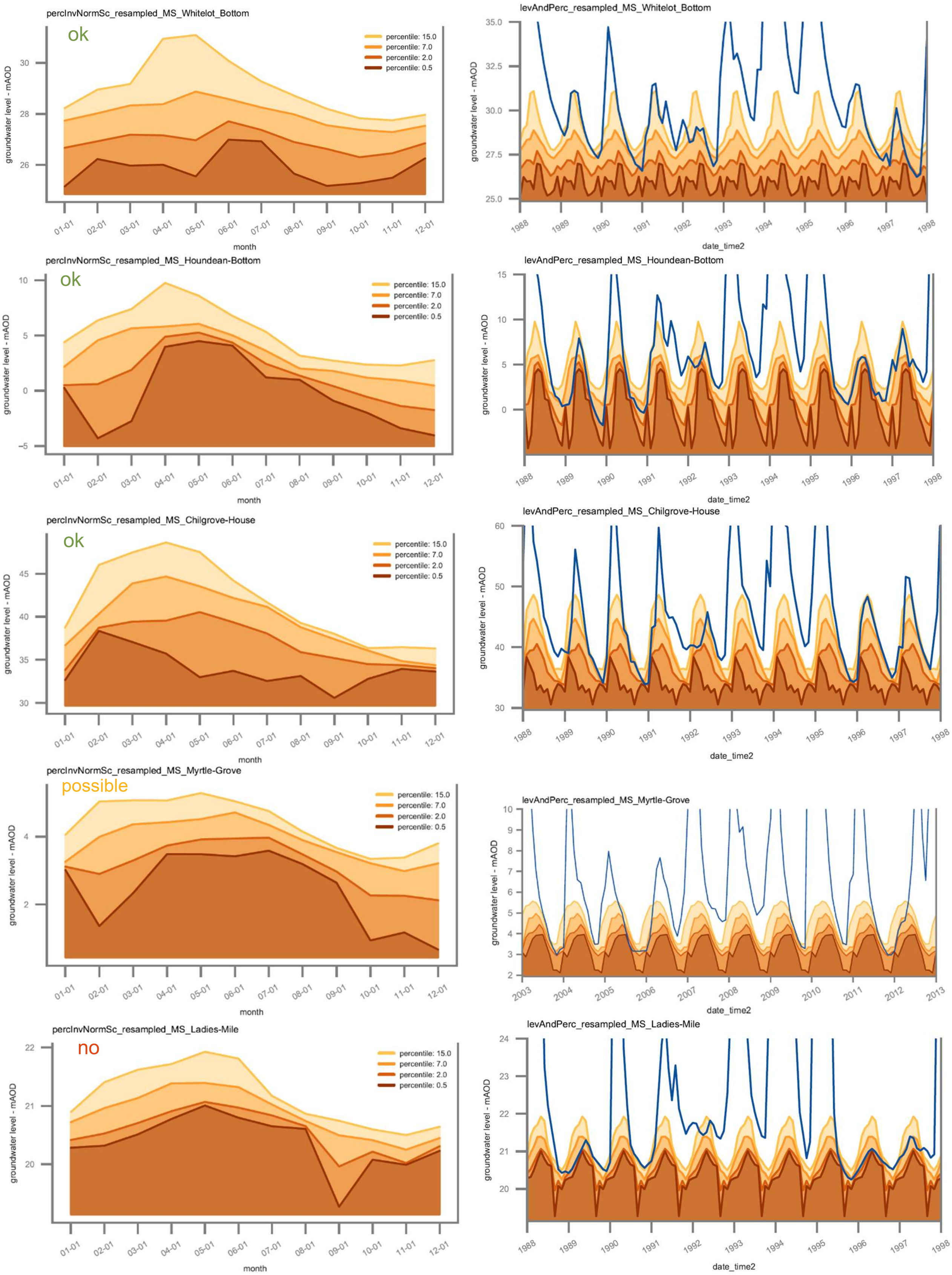


Figure 13: Central Area - corresponding hydrographs for groundwater triggers



4.3 Eastern Area Review– observation borehole review

Two boreholes have been selected in the Eastern area, and one dropped. One of the selected boreholes is also included in monthly water situation monitoring by the EA.

Little bucket observation borehole is retained. It has a medium length record to the 1990's, it is included with EA water situation reports and was included with the BGS SGI study. There are no visually discernible pumping influences, and the SGI groundwater trend aligns well with the known historic droughts throughout its record. Though level 2 and level 3 trigger bands become relatively compressed towards the end of the year (Figure 16).

Riddles Lane observation well is dropped as a drought trigger. Recent SGI trends do not correspond with most recent known 'drought' periods and the calculated annual hydrograph trigger curves lack typical clear seasonality (Figure 16). The groundwater levels themselves show a steady underlying increasing baseline trend since c. 2010, which effectively acts to flatten long term monthly percentile estimates. It is no longer best representative of current droughts and not best suited for use as a drought indicator borehole.

Wilgate Green was considered as a possible alternative within stage 1 screening. However, it has a short data set (Figure 15), and the SGI trend does not clearly pick out the key 2005/2006 drought (towards the start of the record). The SGI trend is noted to correlate moderately to weakly with other observation boreholes (Figure 14). This location has the potential to be a drought trigger location but would benefit from a longer data set. This borehole should be re-considered in future drought plans as a possible replacement for the Riddles Lane OBH (as it would also support observations in resource zones KME/KMW)

Other reviewed (high level screening) observation boreholes for the KME/KMW area have records that are close to abstractions and show significant abstraction interference, and/or are not frequently updated. These have not been progressed/selected through early screening.

Parsonage Green has been selected as replacement to Riddles Lane, and to provide support/resilience to Little Bucket observation borehole. But its location is close to Little Bucket and is not best representative KMW. It also has a relatively short data set. But there are no visually discernible pumping influences, it represents historic droughts well, and the SGI trend generally correlates well with Little Bucket (Figure 14). The hydrograph groundwater level trigger bands do become compressed towards the end of the year (like Little Bucket), though this may not be such a concern for typical drought action decisions are taken in summer/autumn (Figure 16).

We will continue to keep the performance of our North Kent indicator boreholes under review and, if necessary, update our triggers or incorporate alternative sites.

The absence of a Kent Medway area observation borehole is not preferred. Though it is worth noting, that for our Kent Medway Zones (KMW/KME) most of our groundwater sources are not especially vulnerable to groundwater drought (i.e. many do not have significant groundwater level constraints on Deployable Output) and hence our primary drought triggers for those WRZs are still linked to rainfall, effective rainfall and the reservoir storage and we would typically expect those to trigger drought actions in advance of groundwater drought.

The proposed groundwater monitoring boreholes for the eastern area are Little Bucket and Parsonage Green.

Figure 14: Kent - correlation matrix for reviewed OBH (SGI trends: 2001 – 2025)

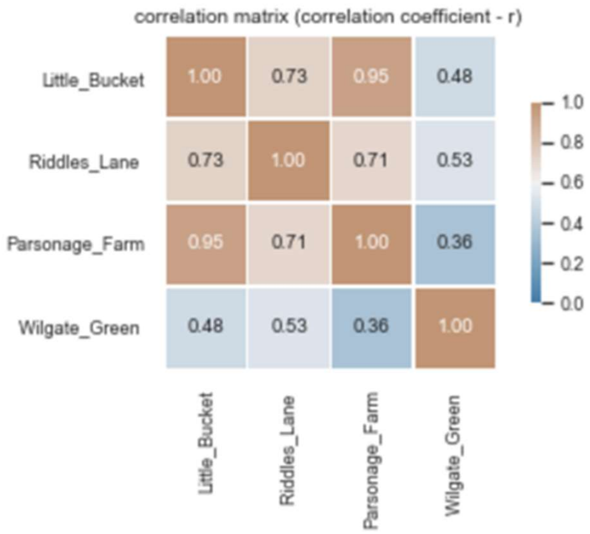


Figure 15: Kent - OBH groundwater level and SGI trends (based on -1.0, -1.5, -2.0 SGI values)

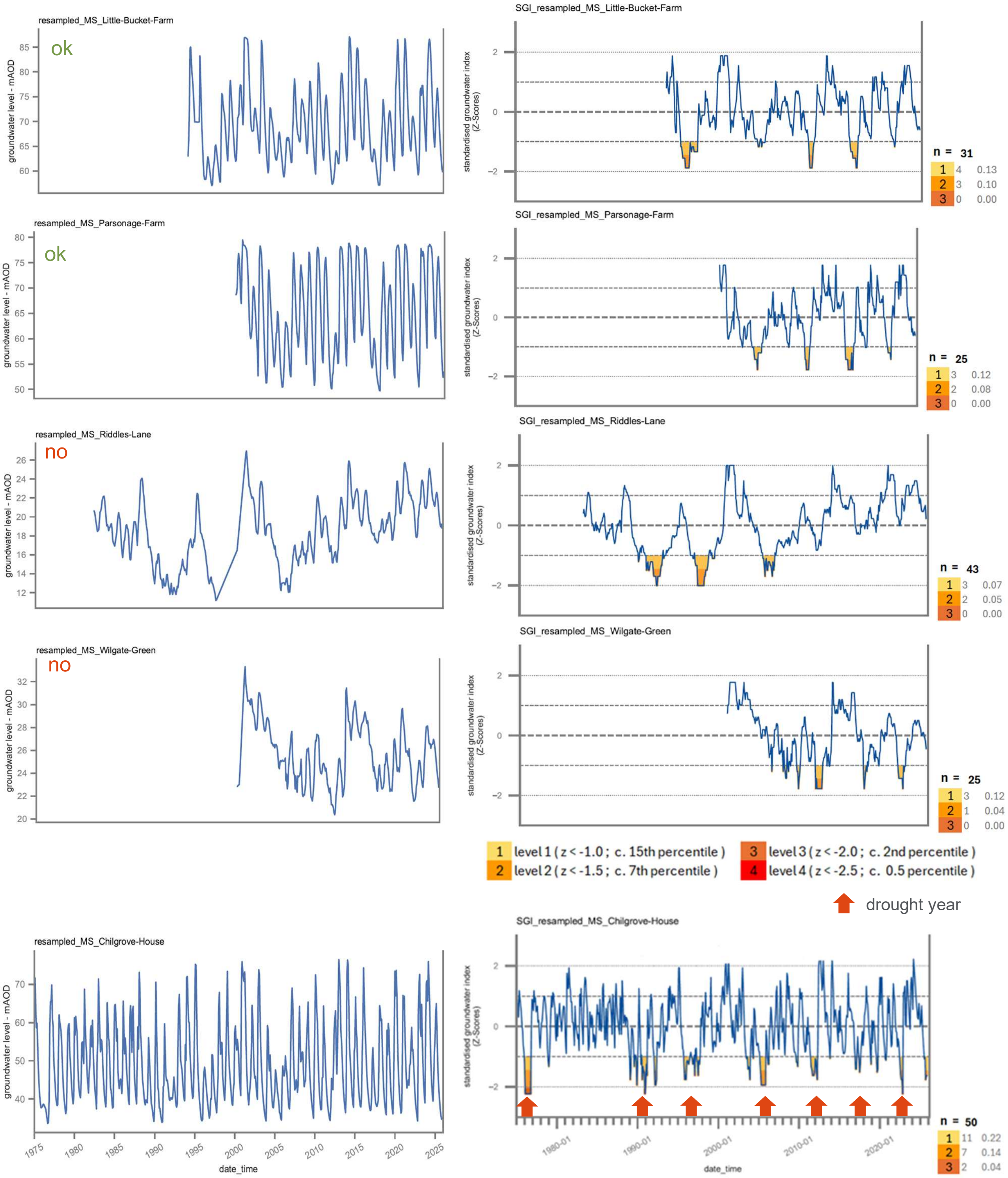


Figure 16: Kent - percentile hydrographs for groundwater level triggers

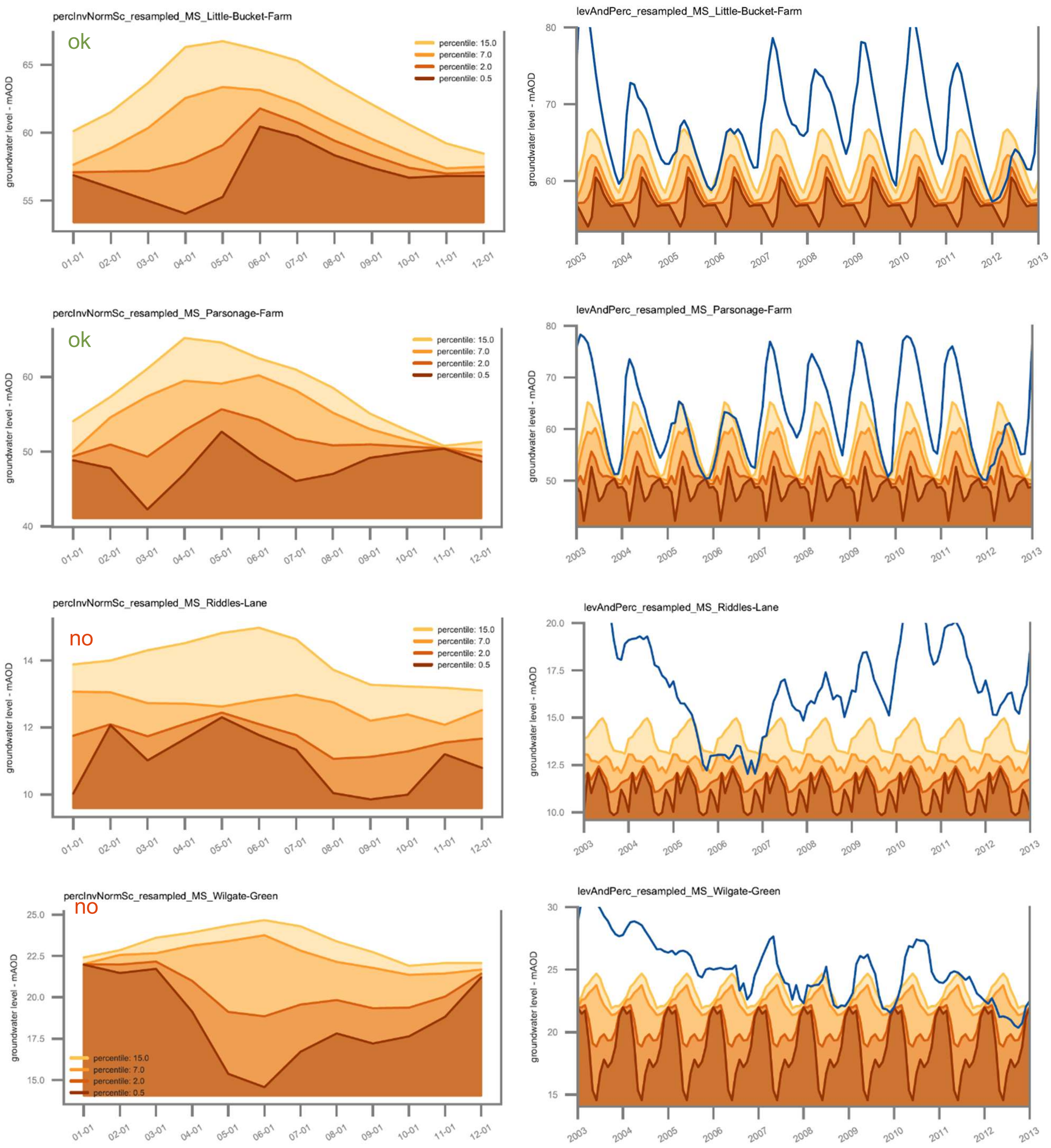


Table 4 - Boreholes that passed initial screening, and then reviewed further after SGI trends and trigger curves were created and reviewed

	1. Selected after 1st screening of available OBH's												2. Subsequent review of levels, SGI trends and trigger curves				
	OBH	Aquifer block	Relevant WRZ	Monitored by EA (y/n)	real-time data	Chalk aquifer (y/n)	1st record date	Seasonal groundwater range (approx. m)	Distance to closest abstraction (m)	Within an SPZ?	trend visually influeneced by pumping (y/n)	visually inferered max pumping interference (m)	SGI index corresponds with known drought periods	SGI trend correlates well with other OBH in area	Distance between hydrograph trigger bands	Comments	suitable y/n
Current Drought Plan OBHs	Carisbrooke Castle	IoW Central Downs Chalk	IOW	y	y	y	01/01/1977	8	440	SPZ1 Southern Water abstraction	y	n/a	yes	yes	average	Level trends appear representative of the Chalk aquifer and historic droughts. But responds rapidly to recharge, and receeds quickly in summer (i.e. flashy). Likely a result of the small aquifer extent, and abstraction or local drainage influences. A sudden greater groundwater recession rate under the lowest drought groundwater levels is noted. It might reflect a gradual greater pumping influence, under lower groundwater. Or may represent the onset of aquifer barrier bourndry effects, or reduced groundwater seepages from other adjacent aquifers during droughts. But although increased recession is noted, direct daily abstraction influences on the monitored observation borehole levels are not apparent.	y
	Clanville Gate	River Test Chalk	HKZ,HAZ,HRZ	y	y	y	10/11/1986	15	5550	SPZ3 third party abstraction	n	n/a	yes	yes	good	Within the SPZ3 of a third party natural spring/abstraction. No visually descernible pumping influence. SGI index reflects known droughts, and correlates strongly West Meon Hut (within Hampshire R. Itchen catchemnet)	y
	West Meon Hut	River Itchen Chalk	HSE, HWZ	y	y	y	11/09/1986	14	0	No	n	n/a	yes	yes	good	No nearby abstraction or visually discernible pumping influnece. SGI trend reflects historic drought events, and the borehole correlates strongly with Clanville Gate (within Hampshire R. Test catchment). As might be expected, correlation with Isle of Wight Carrisbrooke chalk BH is moderate to weak, though the correlation appears beter with Calbourne Newbarn-Farm Isle of Wight BH.	y
	Chilgrove House	East Hants and Chichester Chalk	SWZ	y	y	y	31/12/1835	40	2006	SPZ2 Portsmouth Water abstraction	n	n/a	yes	yes	average	Within the SPZ2 of a third party natural spring/abstraction. No visually discernible abstraction influence, and has a long historic data set. Provides a good regional historic drought indicator, though not specific to a Southern Water WRZ. Thought a useful indicator for East Hampshire and Sussex Worthing Chalk areas. Has a moderate positive correlation with Whitelot Bottom, and a strong positive correlation with all other area boreholes.	y
	Whitelot Bottom	Brighton Chalk Block	SWZ,SBZ	y	y	y	16/05/1973	12	1000	SPZ3 2x Southern Water abstraction	y	0.5	yes	yes	good	Within the SPZ2 of 2 x Southern water abstraction.Visually discernible abstraction influence under drought minimums. Provides a good long historic drought indicator, specific to the Brighton WRZ . Thought a useful indicator for adjacent Worthing WRZ. Has a strong positive correlation with Houndean Bottom.	y
	Houndean Bottom	Brighton Chalk Block	SBZ	y	y	y	13/07/1999	25	964	SPZ3 Southern Water abstraction	y	0.5	yes	yes	average	Within the area of influence of multiple Southern Water abstractions in Newmarkey Valley. But it has good historic data, the SGI trend represents historic droughts well, and it also creates distinct and clear hydrograph trigger curves. It additionally has a strong positive correlation with all other area observation boreholes	y
	Riddles Lane	North Kent Chalk	KMW,KME	y	y	y	15/04/1982	6	2563	SPZ2 Southern Water abstraction	n	n/a	no	yes	good	Recent SGI trends do not correspond with most recent 'drought' periods, and calculated annual hydrograph trigger curves lack a typical clear seasonality. The groundwater levels show an underlying steady increasing trend since c. 2010, which influences and flattens monthly percentile calculations. Though the borehole appears to correlate well with other monitoring wells (within the Persons correlation matrix) with regrds seaonality, its underlying increasing trend suggests its not best representive of droughts or a good drought indicator borehole	n
	Little Bucket	East Kent Chalk	KTZ	y	y	y	13/10/1993	20	6663	SPZ3 third party abstraction	n	n/a	yes	yes	average	No visually discernible pumping influence and SGI groundwater drought trend aligns well with known historic droughts. The hydrograph trigger band is relativel small and compressed, for the severe drought range of water levels. The SGI trend correlates well with Little Bucket and Riddles Lane BH's	y
Potential OBHs	Calbourne Newbarn Farm	IoW Central Downs Chalk	IOW	y	y	y	21/09/1990	10	1200 (Calbourne)	Outside all SPZs	y	<0.1	yes	yes	average	1200m from Calbourne WSW. The data set is short , but it reflects recent droughts well, and correlates better with the mainland Hampshire monitoring wells (than Carrisbrooke Castle does). Though it also correlates well with Isle of Wight Carrisbrooke Castle BH . Though trigger curves are closely spaced within middle of year, similar to Carrisbrooke Castle	y
	Parsonage Farm North Elham	East Kent Chalk	KTZ	y	y	y	17/01/2000	25	?	SPZ1 (Outside SW)	n		yes	yes	average	Relatively short data set, but represents historic droughts well. SGI trend correlates well with Little Bucket and Riddles lane. But the BH is located close to the existing Little Bucket regional observation borehole. Hydrograph groundwater level trigger bands become compressed towards the end of the year	y
	Wilgate Green	North Kent Chalk	KMW,KME	y	y	y	23/05/2001	6	1,097	SPZ2 Throwley	n		no	no	good	The SGI trend does not clealry pick out the 2005/2006 drought (towards the start of the record), and the SGI trend correlates moderatley to weakly with other BH in the same area. But has potential. Reconsider in future drought plans when it has longer data set.	n
	Myrtle Grove	Brighton Chalk Block	SWZ	y	n	y	11/05/2002	25	1,830	TCZ Patching WSW	n		yes	yes	average	Apparent infrequent online data updates, and may not provide real time data. The SGI trend matches known drought periods and the BH corrolates well with other Sussex monitoring wells. Has potential as a Worthing Block monitoring well, reconsider in future droughht plans, or if online access to data and frequency of updates improves?	maybe
	Ladies Mile	Brighton Chalk Block	SBZ	y	y	y	22/03/2002	20	1,379	TCZ Surrenden	y	0.05	yes	yes	poor	Within the area of influence of a Southern Water abstractions . But has good historic data, and SGI trend represents historic droughts well. It additionally has a strong positive correlation with all other area observation boreholes similar to Houndean bottom. However the hydrograph drought trigger bands are very compressed and close together, and so less favourable for use (compared to the existing Houndean Bottom BH)	n

5 Summary of the old and new trigger boreholes by Water Resource Zone (WRZ)

A summary of the newly proposed drought monitoring boreholes (Table 5), and the previous drought plan monitoring boreholes (Table 6) is shown below. A suitable replacement monitoring borehole for Riddles Lane could not be found for North Kent Chalk (Wilgate Green should be reviewed within future plans, when its record is longer).

Table 5 – newly proposed drought monitoring boreholes

Observation borehole	Aquifer block	Respective WRZs
New drought plan:		
Carrsibrooke Castle	IoW Central Downs Chalk	IOW
Calbourne Newbarn Farm	IoW Central Downs Chalk	IOW
Clanville Gate	River Test Chalk	HKZ,HAZ, HRZ
West Meon	River Itchen Chalk	HSE, HWZ
Chilgrove House	East Hampshire and Chichester Chalk	SWZ
Whitelot Bottom	Brighton Chalk Block	SWZ, SBZ
Houndean Bottom	Brighton Chalk Block	SBZ
Parsonage Farm	East Kent Chalk	KTZ
Little Bucket	East Kent Chalk	KTZ
No Suitable OBH	North Kent Chalk	KME/KMW

Table 6 - previous drought monitoring and additional reviewed boreholes

Observation borehole	Aquifer block	Respective WRZs
Previous drought plan:		
Carrsibrooke Castle	IoW Central Downs Chalk	IOW
Clanville Gate	River Test Chalk	HKZ,HAZ, HRZ
West Meon	River Itchen Chalk	HSE, HWZ
Chilgrove House	East Hampshire and Chichester Chalk	SWZ
Whitelot Bottom	Brighton Chalk Block	SWZ, SBZ
Houndean Bottom	Brighton Chalk Block	SBZ
Little Bucket	East Kent Chalk	KTZ
Riddles Lane	North Kent Chalk	KMW, KME
+ Additionally Reviewed		
Ladies Mile	Brighton Chalk Block	SBZ
Myrtle Grove	Worthing Chalk Block	SWZ
Wilgate Green	North Kent Chalk	KMW, KME

Observation borehole	Aquifer block	Respective WRZs
Parsonage Farm	East Kent Chalk	KTZ
Calbourne Newbarn Farm	IoW Central Downs Chalk	IOW

6 Monthly Groundwater Triggers

The SGI groundwater triggers, by definition, remain consistent across a whole year, and are represented by the normal score values of –1.0, -1.5, -2.0, and -2.5. The directly related groundwater level percentiles for each month (for the 1st of each month) have also been back-calculated, to enable the production of groundwater level percentile hydrographs (Table 7).

Calbourne Newbarn

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	49.91	49.61	48.83	47.85
1/2	50.79	50.13	49.22	47.67
1/3	51.08	50.22	49.62	48.67
1/4	51.27	50.58	49.86	49.56
1/5	51.20	50.52	49.90	49.11
1/6	50.51	50.08	49.89	49.72
1/7	49.96	49.73	49.60	49.47
1/8	49.55	49.33	49.00	48.47
1/9	49.30	49.05	47.70	45.50
1/10	49.16	48.81	46.88	45.50
1/11	49.30	48.95	48.83	48.65
1/12	49.43	49.00	48.68	48.19

Carrisbrooke Castle

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	27.06	26.24	25.95	25.78
1/2	27.86	27.39	26.79	26.04
1/3	28.08	27.63	26.84	25.47
1/4	27.99	27.64	27.07	26.40
1/5	27.71	27.60	27.17	26.96
1/6	27.41	27.22	27.09	26.96
1/7	27.08	26.88	26.74	26.51
1/8	26.62	26.41	25.93	25.88
1/9	26.00	25.66	24.97	24.79
1/10	25.42	25.08	24.22	22.68
1/11	25.37	24.83	24.58	24.33
1/12	26.07	24.42	24.19	23.94

West Meon Hut

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	79.55	78.00	76.94	75.59
1/2	80.27	79.23	77.76	75.87
1/3	81.11	79.53	77.81	75.62
1/4	82.32	80.06	77.92	76.10
1/5	82.08	79.80	78.40	77.31
1/6	81.03	79.89	79.24	79.10
1/7	80.02	78.87	78.36	77.95
1/8	79.21	78.18	77.62	76.85
1/9	78.51	77.57	77.12	76.74
1/10	77.92	77.04	76.53	75.87
1/11	77.51	76.91	75.94	75.01
1/12	78.64	77.24	75.70	73.74

Clanville Gate

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	78.73	76.40	75.82	75.15
1/2	79.30	77.53	76.02	74.53
1/3	79.71	78.13	76.31	74.36
1/4	80.82	79.15	76.28	73.22
1/5	80.81	79.41	78.07	76.82
1/6	80.32	78.97	78.48	77.83
1/7	80.16	78.50	77.57	77.23
1/8	79.45	77.59	76.45	75.58
1/9	78.30	76.60	75.40	73.78
1/10	77.32	75.65	74.52	73.10
1/11	76.85	75.41	73.95	72.59
1/12	77.01	75.70	73.75	71.35

Whitelot Bottom

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	28.38	27.70	26.81	25.30
1/2	29.57	27.99	26.99	26.30
1/3	29.64	28.30	27.29	26.09
1/4	31.15	28.36	27.26	26.12
1/5	31.25	28.76	27.09	25.69
1/6	30.11	28.52	27.77	27.06
1/7	29.37	28.25	27.41	26.97
1/8	28.77	27.95	27.01	25.78
1/9	28.34	27.55	26.76	25.32
1/10	27.94	27.36	26.39	25.38
1/11	27.87	27.26	26.54	25.59
1/12	27.97	27.48	26.90	26.32

Chilgrove House

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	39.32	36.47	33.91	32.76
1/2	46.54	40.30	38.75	38.38
1/3	48.00	43.71	39.64	37.29
1/4	48.81	44.27	39.88	36.10
1/5	47.74	43.51	41.21	33.72
1/6	44.37	42.09	39.85	34.27
1/7	41.71	41.14	38.55	33.08
1/8	39.33	38.76	36.13	33.39
1/9	38.03	37.34	35.60	31.03
1/10	36.39	36.06	34.64	32.95
1/11	36.55	34.82	34.42	33.97
1/12	36.47	34.36	34.06	33.67

Houndean Bottom

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	4.68	2.03	0.53	0.29
1/2	6.42	4.48	1.04	-3.81
1/3	7.67	5.53	2.30	-2.29
1/4	9.98	5.79	4.96	4.06
1/5	9.32	5.94	5.33	4.56
1/6	7.02	4.93	4.38	4.11
1/7	5.34	3.60	2.55	1.33
1/8	3.52	1.94	1.40	1.03
1/9	2.73	1.76	0.54	-0.77
1/10	2.37	1.10	-0.42	-1.84
1/11	2.35	0.91	-1.19	-3.18
1/12	2.78	0.44	-1.53	-3.80

Parsonage Farm

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	54.26	50.01	49.45	48.89
1/2	57.95	54.43	51.26	48.09
1/3	61.59	57.08	50.02	42.96
1/4	65.65	59.22	53.41	47.61
1/5	64.90	58.97	55.97	52.97
1/6	62.55	59.98	54.78	49.57
1/7	61.28	57.94	52.28	46.62
1/8	58.92	55.03	51.21	47.39
1/9	55.33	52.93	51.14	49.35
1/10	52.95	51.57	50.75	49.94
1/11	50.86	50.46	50.43	50.39
1/12	51.42	50.21	49.47	48.73

Little Bucket

month	SGI = -1 percentile: 15.9	SGI = -1.5 percentile: 6.7	SGI = 2.0 percentile: 2.3	SGI = -2.5 percentile: 0.6
1/1	60.22	57.55	57.11	56.89
1/2	61.60	58.70	57.26	56.06
1/3	63.72	60.04	57.40	55.22
1/4	66.54	62.25	58.20	54.43
1/5	67.05	63.21	59.46	55.65
1/6	66.32	63.12	61.91	60.58
1/7	65.44	62.05	60.86	59.83
1/8	63.66	60.71	59.52	58.44
1/9	62.23	59.45	58.43	57.51
1/10	60.78	58.31	57.49	56.76
1/11	59.24	57.31	57.01	56.84
1/12	58.55	57.44	57.11	56.85

Table 7 – monthly groundwater level percentiles at drought monitoring boreholes