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*Supplement of*

## **Asymmetric impact of groundwater use on groundwater droughts**

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## Supplementary material

### 5 S1: Location and purpose of groundwater abstraction wells in the four water management units in the UK

#### S2: Example of near-natural, uninfluenced and influenced sites in Lincolnshire

S2 shows an illustrated example of four sites that include a documented near-natural site (first panel), and three groundwater monitoring sites in the paired water management unit. The reference groundwater site (Aylesbury) is an Index well of the Hydrologic Register and is representing near-natural conditions. This Index well is included in the reference cluster for Lincolnshire water management unit (see Figure 1 in manuscript). For this reference cluster the lowest  $SPI_Q$ -SGI correlation is 0.75 [L266], hence monitoring sites with a similar or higher correlation are considered relatively uninfluenced over the 30-year time period. The monitoring site in the second panel is thus considered uninfluenced, as the  $SPI_Q$ -SGI correlation is 0.831 using the site-specific optimal precipitation accumulation period (17 months). The other two sites are considered to be influenced, as correlations are lower than the lowest correlation of the reference cluster: 0.561 and 0.566 (third and fourth panel respectively). The SGI of both wells is remarkably different (flashier) compared to the first two SGI time series, but more importantly despite different precipitation accumulation periods SGI variation don't synchronise well with either short-term or long-term  $SPI_Q$  (dotted blue line in Figure S2).

#### S3: Cluster composition of three clustering techniques applied to near-natural standardised time series

#### S4: Accumulation period of monitoring wells in the four water management units in the UK

20 S5: Distributions of recorded drought frequency of all four water management units for categorised influenced and uninfluenced sites.

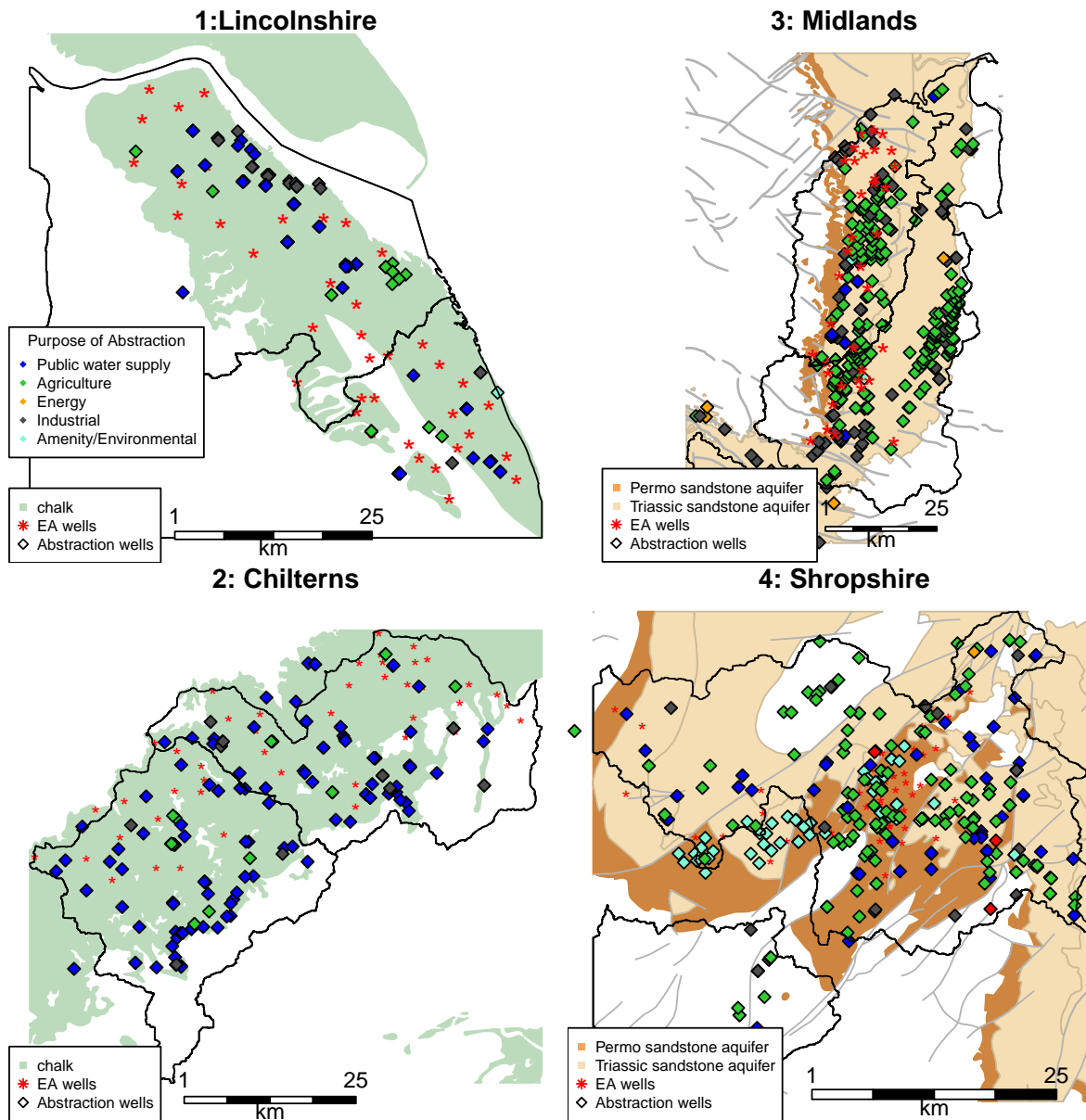
S6: Distributions of recorded drought duration of all four water management units for categorised influenced and uninfluenced sites.

25 S7: Distributions of recorded drought deficit of all four water management units for categorised influenced and uninfluenced sites.

#### S8: Duration and occurrence of minor droughts in Lincolnshire, Chilterns, and Shropshire.

Water management units	Average duration of minor droughts (in months)	Average autocorrelation (in months)	Occurrence of minor droughts 24 months before reference droughts (%)	Occurrence of minor droughts during reference droughts (%)
1: Lincolnshire	3.1	11.6	27	60
2: Chilterns	3.7	17.3	34	27
4: Shropshire	5.0	15.1	43	23

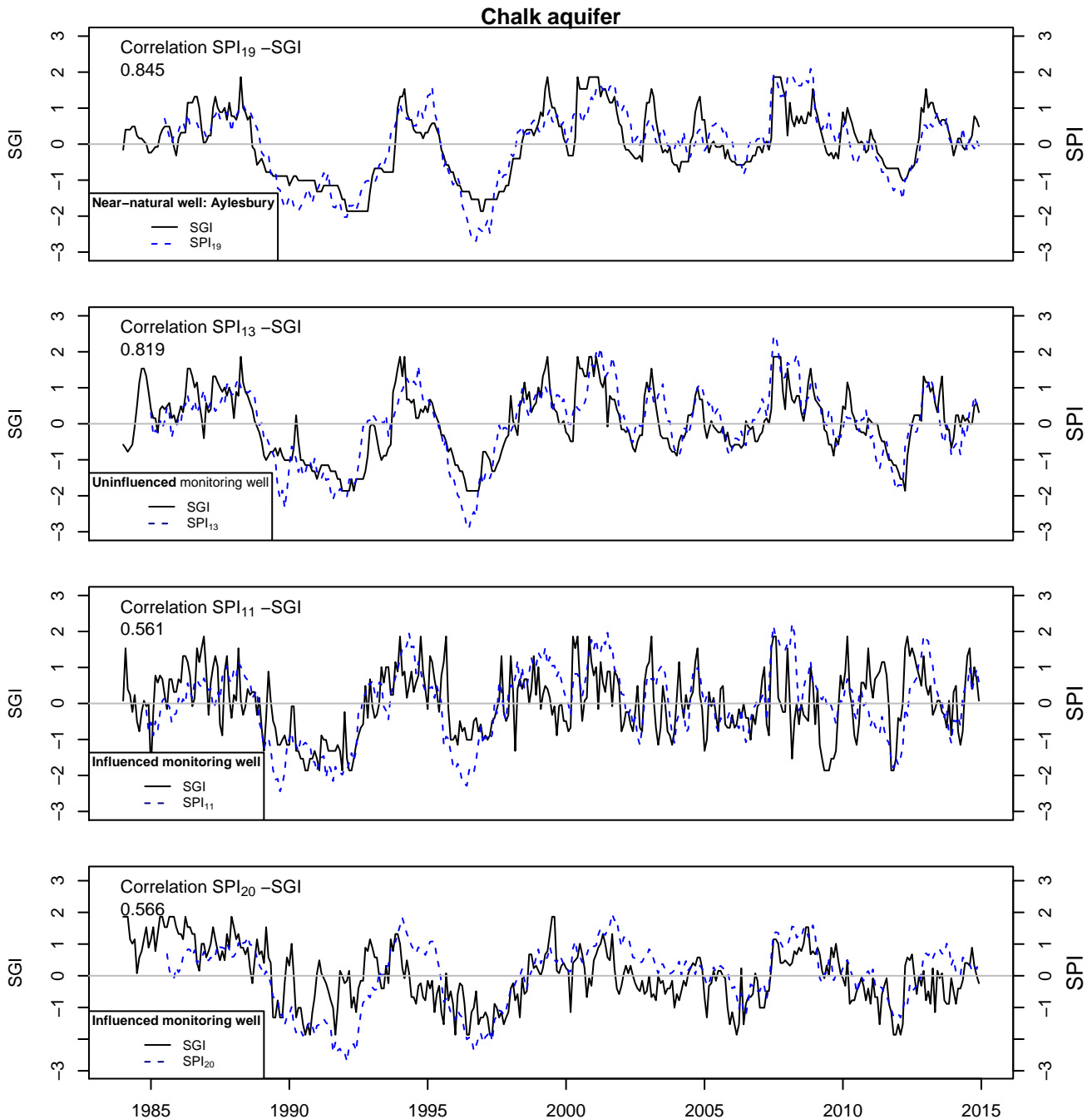
**Table S8.** Duration and occurrence of minor droughts in influenced sites in Lincolnshire, Chilterns, and Shropshire. Results show that the average duration is shorter than the average auto-correlation (calculated from groundwater level observations).



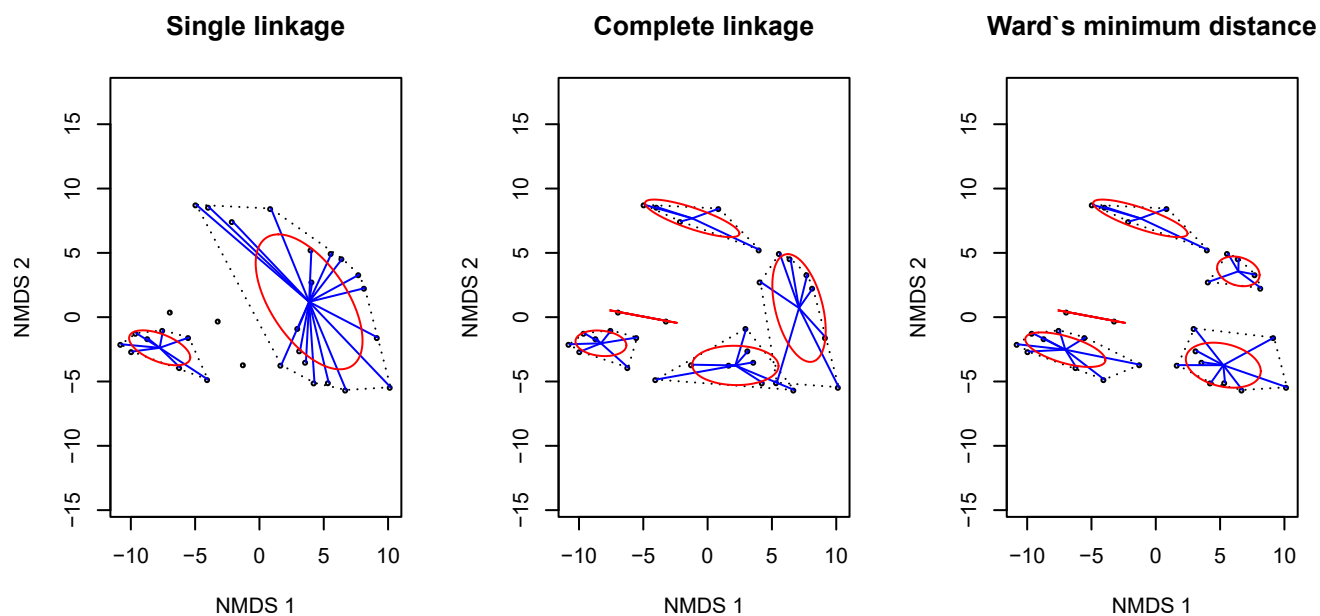
**Figure S1.** The location and purpose of groundwater abstraction wells in the four water management units. The coloured diamonds indicate locations of abstraction wells and the colours represent the purpose of a provided abstraction licence. Please note that some wells overlap.

## References

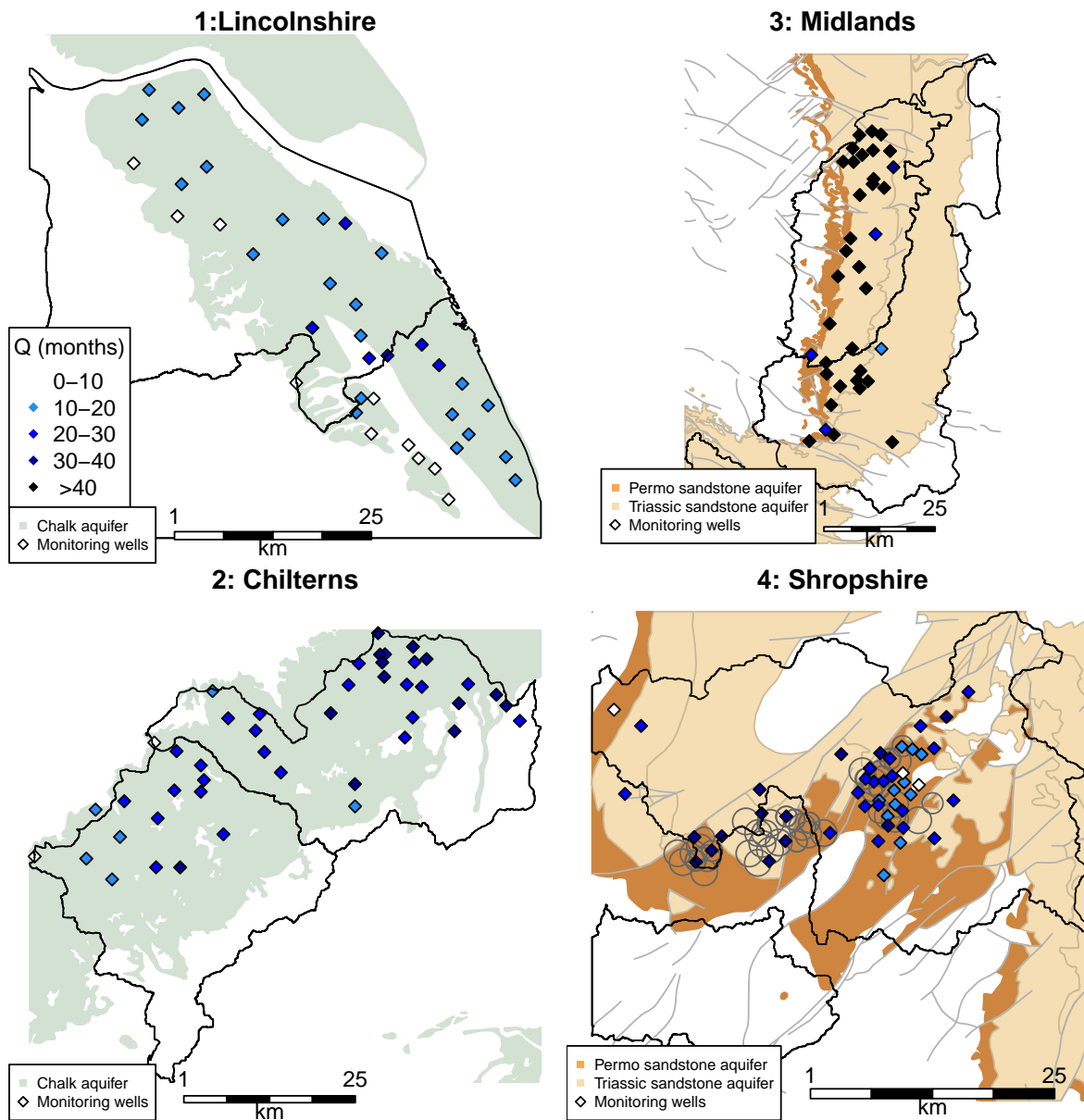
Dixon, P.: VEGAN, a package of R functions for community ecology, *Journal of Vegetation Science*, 14, 927–930, <https://doi.org/10.1111/j.1654-1103.2003.tb02228.x>, 2003.



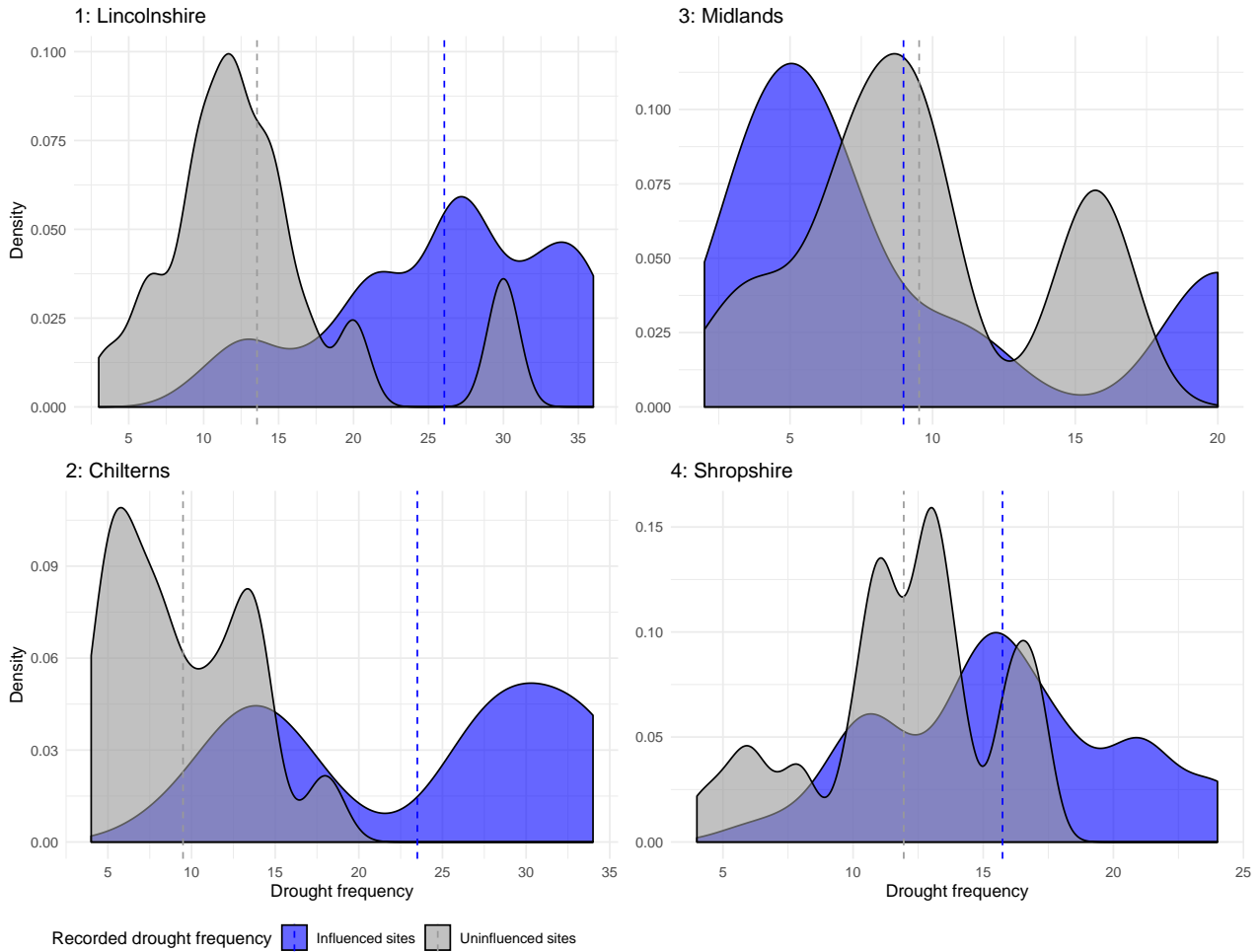
**Figure S2.**  $SPI_Q$ -SGI comparison for a near-natural Index site (top panel), an uninfluenced monitoring site (second panel), and two influenced monitoring sites in Lincolnshire (third and fourth panel). The SGI and  $SPI_Q$  are shown in black and blue (dashed). The correlation between the  $SPI_Q$ -SGI is shown in the top left corner of the hydrograph.



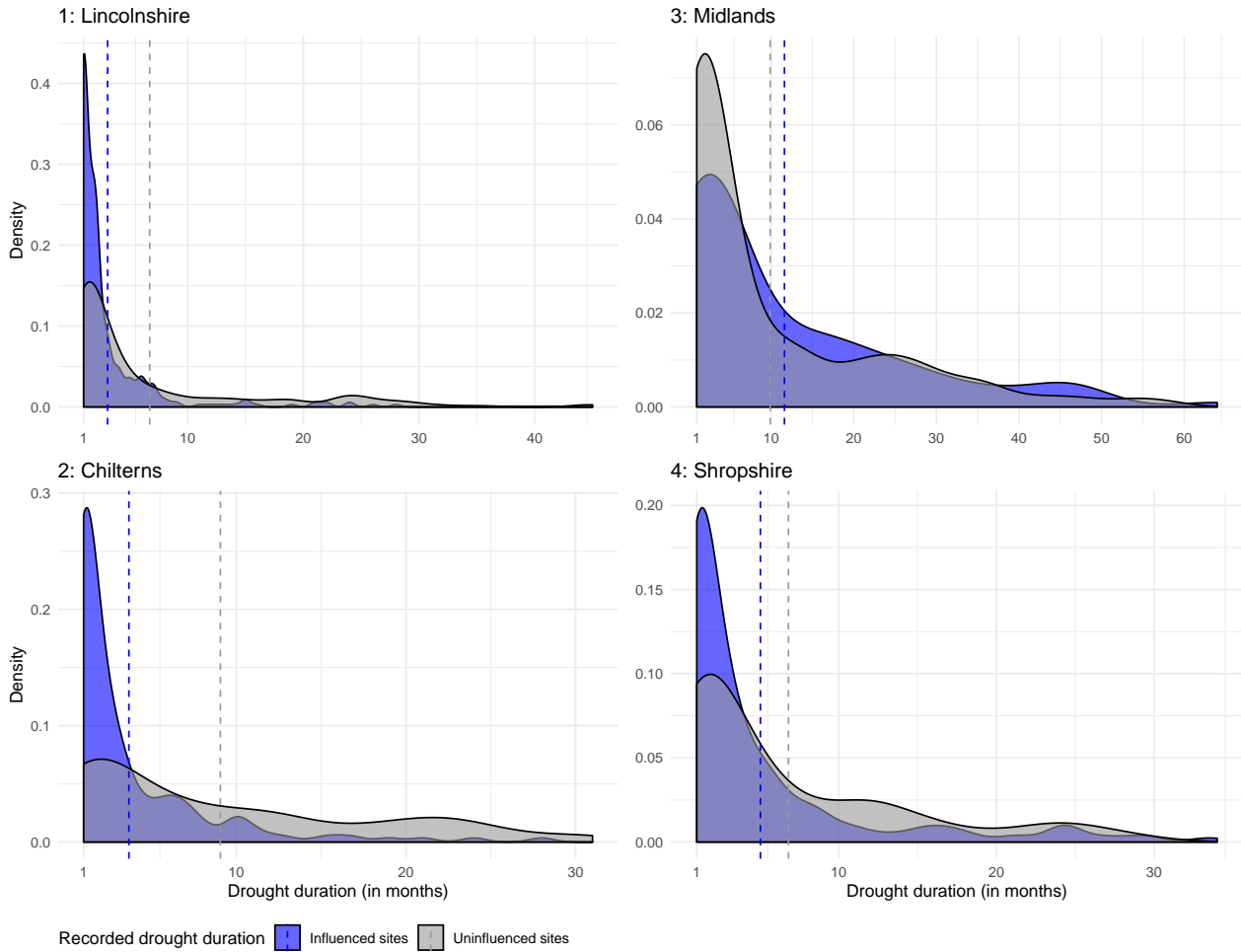
**Figure S3.** Cluster composition of three clustering techniques (single linkage, complete linkage, and Ward's minimum) shown for the five Chalk clusters using the matrix non-metric multidimensional scaling plot (NMDS) of the vegan package (Dixon, 2003). The clusters in Ward's minimum technique show the least overlap and are therefore selected in further analysis.



**Figure S4.** Accumulation period (in months) for monitoring wells in the four water management units.

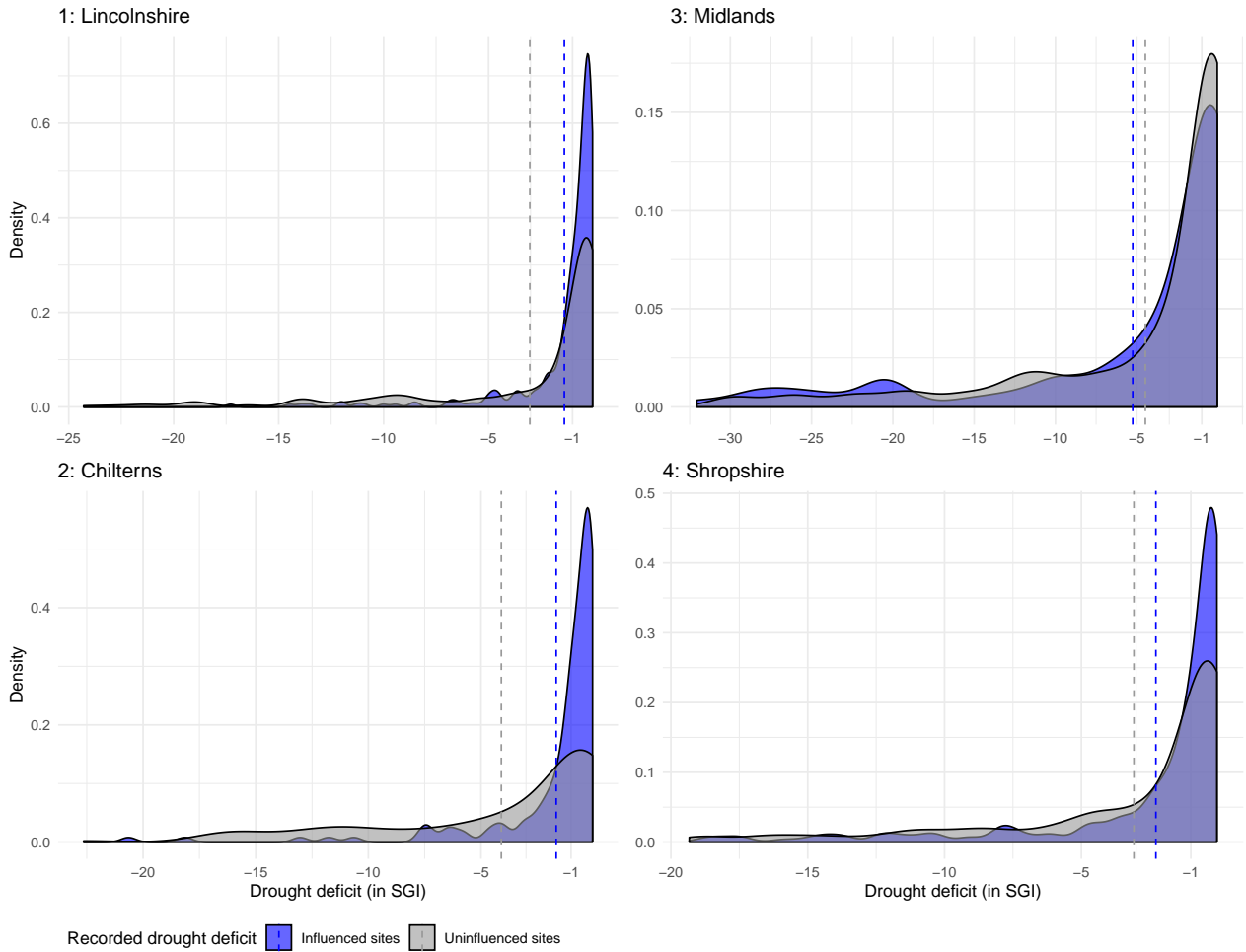


**Figure S5.** Drought frequency distribution of the four water management units for uninfluenced sites (grey) and influenced (blue). The mean drought frequency is indicated with the dotted vertical line (also in Table 2 in the manuscript).



**Figure S6.** Drought duration distribution of the four water management units for uninfluenced sites (grey) and influenced (blue). The mean drought duration is indicated with the dotted vertical line (also in Table 2 in the manuscript).





**Figure S7.** Drought deficit distribution of the four water management units for uninfluenced sites (grey) and influenced (blue). The mean drought deficit is indicated with the dotted vertical line (also in Table 2 in the manuscript).