Spatial Variations in the Relationship between Precipitation & Streamflow in Great Britain

Harry West, Nevil Quinn & Michael Horswell - Centre for Water, Communities and Resilience - University of the West of England, UK

Email: Harry.West@uwe.ac.uk

Background

- Standardised indicators (SI's) such as the Standardised Precipitation Index (SPI) [1] and Standardised Streamflow Index (SSI) are increasingly used as monitoring tools, especially for hydrological extremes.
- They are useful for this purpose because they represent wetness/dryness relative to a baseline period (1961-2010).
- They can be calculated over a number of months (the accumulation period) (e.g. 1,3,6… 24) and are spatially and temporally standardised enabling comparison across scales.
- In Great Britain SPI is now nationally available at near-real time through the CEH Drought Portal.

- Despite their utility, there are challenges in developing public understanding of SI's and in their practical application in management, for example, the SPI has been used as a proxy for streamflow and groundwater [2].
- However relationships between precipitation and runoff are mediated by spatially varying catchment characteristics [3].

- Our research seeks to extend SI's practical value by exploring whether readily available standardised precipitation indices can be used to infer current or near-future flows.

Research Questions

1. Can the SPI be used to infer streamflow (quantified by the SSI - Standardised Streamflow Index)?
2. Can current or preceding SPI be used to infer future SSI (1-3 months ahead)?
3. What catchment characteristics may influence the the utility of different SPI accumulation periods for inferring SSI?

Methods

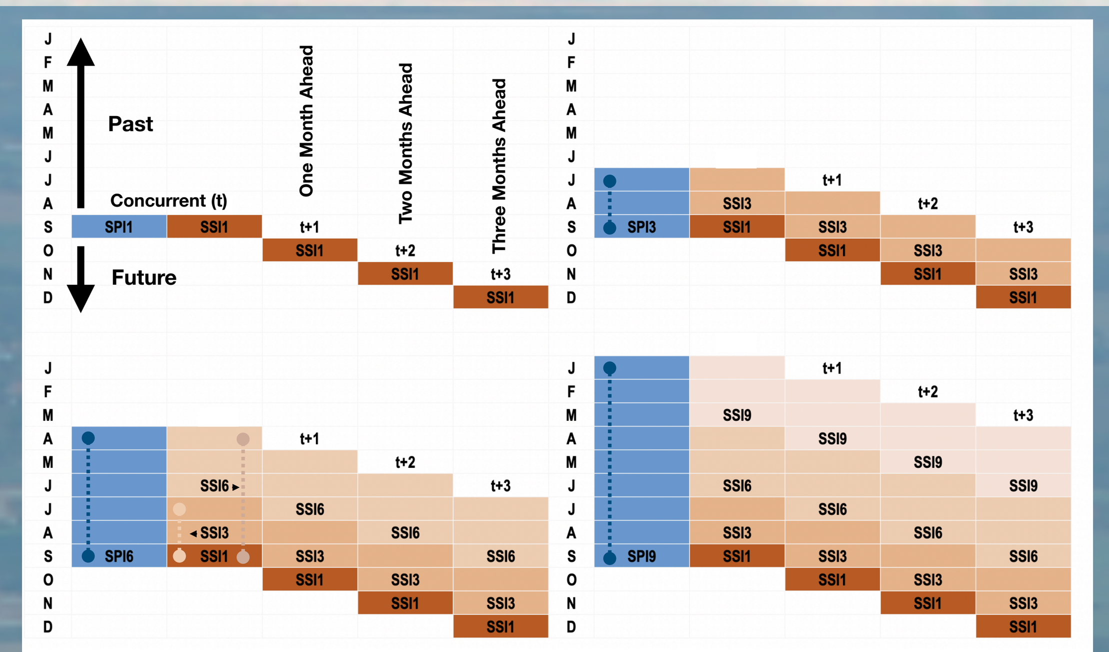
4 SPI accumulation periods calculated from 1900-2015 rainfall: SPI1, SPI3, SPI6, SPI9 [4]

SSI1, SSI3, SSI6, SSI9 [5] *4 SSI accumulation periods calculated from simulated daily flows (1900-2015)*

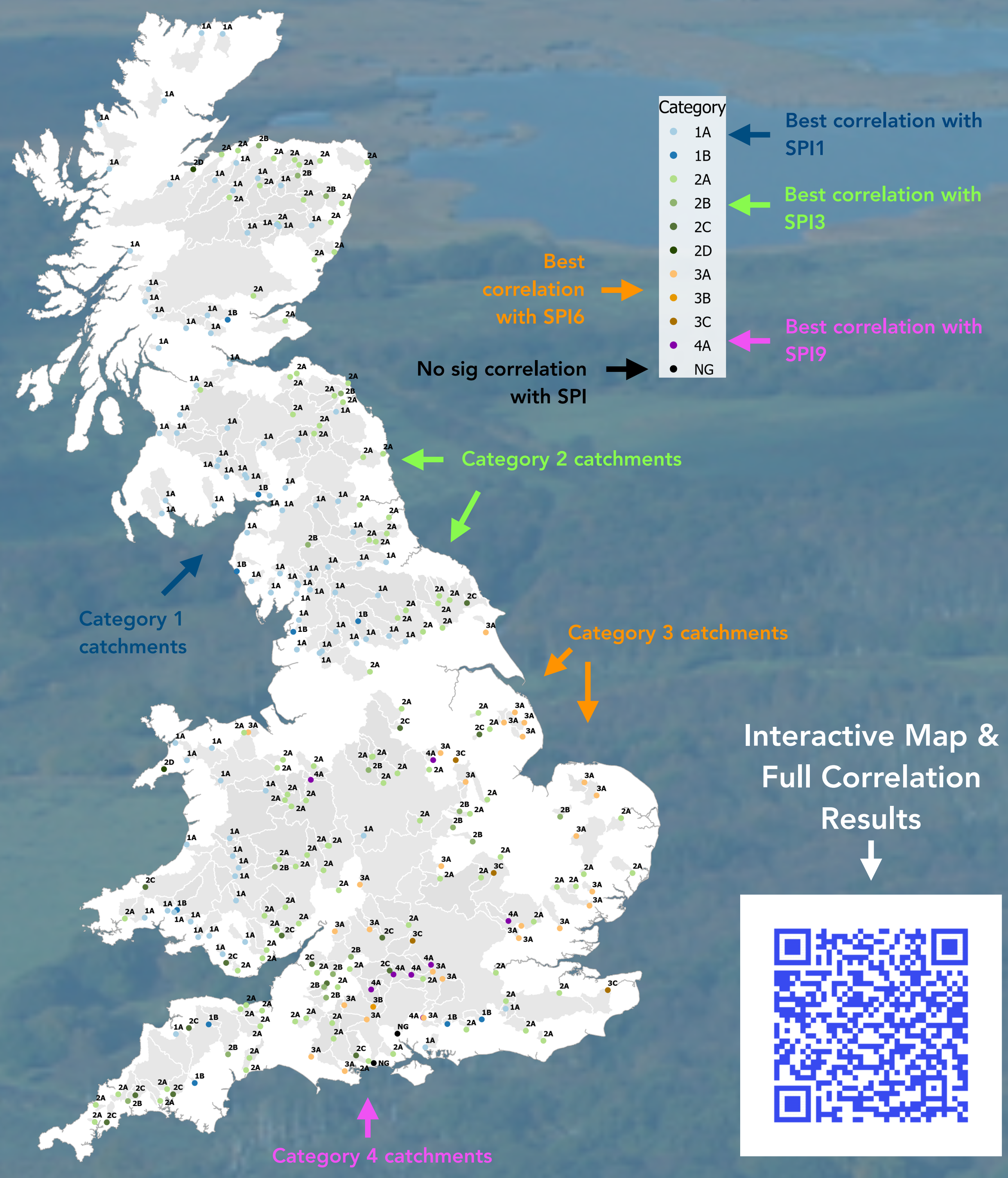
All catchment data from the National River Flow Archive →

Which SPI, if any, allows us to best infer streamflow? → Spearman's correlation between concurrent and lagged SPI-SSI → Regression between SPI-SSI correlation and the Base Flow Index (BFI) → Multivariate Clustering Analyses on additional catchment characteristics → Iterative exploratory and OLS regression analyses → Catchments assigned to classes

What catchment characteristics affect the SPI-SSI relationship? → Multivariate Clustering Analyses on additional catchment characteristics



Results - Catchment Classification Map



Interactive Map & Full Correlation Results ↓

Results - Catchment Classification Key Characteristics

Optimum SPI	Category	OLS Regression with BFI (R^2)	Sub-Category	Number of Catchments	Optimum Catchment Characteristics – brackets indicate the direction of the relationship (Positive + / Negative -)	Catchment Characteristics OLS Regression (R^2)
SPI1	1	0.41	1A	92	• BFI (-) • Grassland (+) • BFIHOST (-) • SAAR 1961-1990 (+) • PROPWET (-) • DPSBAR (+)	0.72
			1B	10	There were too few catchments for a defensible OLS analysis. However these catchments have notably high coverage of low or moderate permeable bedrock geology.	
SPI3	2	0.04	2A	113	• SAAR 1961-1990 (-) • BFI (+) • Moderate Permeability Geology (+) • Low Permeability Geology (-) • Grassland (-) • Arable (+)	0.66
			2B	17	There were too few catchments for a defensible OLS analysis. However these catchments have notably high coverage of grassland and low permeability bedrock geology.	
			2C	15	• Woodland (+) • Maximum Altitude (-) • BFI (+)	0.64
			2D	2	There were too few catchments for a defensible OLS analysis. However these catchments have notably high PROPWET values and low permeability bedrock geology coverage.	
SPI6	3	0.16	3A	27	• Arable (+) • BFI (+)	0.79
			3B	1	There were too few catchments for a defensible OLS analysis. This catchment has high amounts of highly permeability bedrock geology and is flat (low DPSBAR).	
			3C	4	There were too few catchments for a defensible OLS analysis. These catchments have varied geology. But are generally flat and have high arable land coverage.	
SPI9	4	0.52	4A	8	• High Permeability Geology (+) • Low Permeability Deposits (+) • BFI (+)	0.81
Uncategorised (NA in map opposite)				2	There were too few catchments for a defensible OLS analysis. These catchments have high amounts of highly permeable geology and no low permeable superficial deposits.	

Key Findings

- Conventional understanding frames lags between rainfall and flow as catchment memory, a function of catchment storage often represented by the BFI.
- **Our results demonstrate that there are other significant catchment factors relevant beyond the BFI.**
- Characteristics affecting the 'quicker' **Category 1** catchments for example largely relate to general **catchment wetness** (soils and rainfall) and **slope**.
- While those determining the 'slower' **Category 3** and **4** catchments generally relate to **geology**.

- Our results also revealed spatio-temporal variations in the utility of the different SPI accumulation periods in inferring current and future SSI. These can be fully explored using the QR code on the left.
- Generally, SPI correlations with future (1-3 months ahead) SSI1 and SSI3 were poor, suggesting limited value for SPI in inferring quick response events. This usually relates to floods, but 'quick' (rapid onset) droughts have also been noted in historic records [6].
- SPI-SSI correlations based on longer accumulation periods were good, and suggest current and preceding rainfall can be used to infer hydrological drought conditions in the near future - research corroborates reported drought impacts are most strongly related with longer accumulation periods [7].

- An interactive map (accessed via the QR code) provides 40 correlation coefficients for each catchment that enables resource managers to explore which SPI accumulation is most appropriate for their needs.

References

1.McKee, T.B. et al (1993), The relationship of drought frequency and duration to time scales, 8th Conference on Applied Climatology, American Meteorological Society, Boston, 179-184
2. Van Loon, A.F. et al (2017), Testing the use of standardised indices and GRACE satellite data to estimate the European 2015 groundwater drought in near-real time, Hydrology & Earth System Sciences, Vol.21, 1697-1718.
3. Barker, L.J. et al. (2016), From meteorological to hydrological drought using standardised indices, Hydrology & Earth System Sciences, Vol.20, 2483-2505.
4. Tanguy, M. et al (2017), Historic gridded Standardised Precipitation Index for the United Kingdom 1862-2015 (generated using gamma distribution with standard period 1961-2010) v4, *NERC Environmental Information Data Centre*, https://doi.org/10.5285/233090b2-1d14-4eb9-9f9c-3923ea2350ff.
5. Barker, L.J. et al. (2018), Historic Standardised Streamflow Index (SSI) using Tweedie distribution with standard period 1961-2010 for 303 UK catchments (1891-2015), *NERC Environmental Information Data Centre*, https://doi.org/10.5285/58ef13a9-539f-46e5-88ad-c89274191ff9.
6. Barker, L.J. et al. (2019), Historic hydrological droughts 1891-2015: A systematic characterisation for a diverse set of catchments across the UK, Hydrology & Earth System Sciences Discussions.
7. Parsons, D.J. et al. (2019), Regional variation in the link between drought indices and reported agricultural impacts of drought, Agricultural Systems, Vol.172, 119-129.

*** Manuscript in Preparation for the Hydrological Sciences Journal ***