'FUTURE FLOWS' AND FUTURE FLOODS:

An exploration of the implications of climate change for high flows in the UK

Nevil QUINN and Michael HORSWELL, University of the West of England, Bristol

1. INTRODUCTION

'Future Flows Hydrology' comprises an 11-member ensemble of equally probable hydrological outcomes using a nationally consistent method based on the Medium emission scenario (A1B), and the Hadley Centre's HadRM3-PPE-UK climate projections (Prudhomme et al. 2013). Daily mean simulated flow is available for representative catchments in the UK, covering the period January 1951-December 2098, representing the best nationally consistent expression of potential flows over the medium to long term (146 water years).

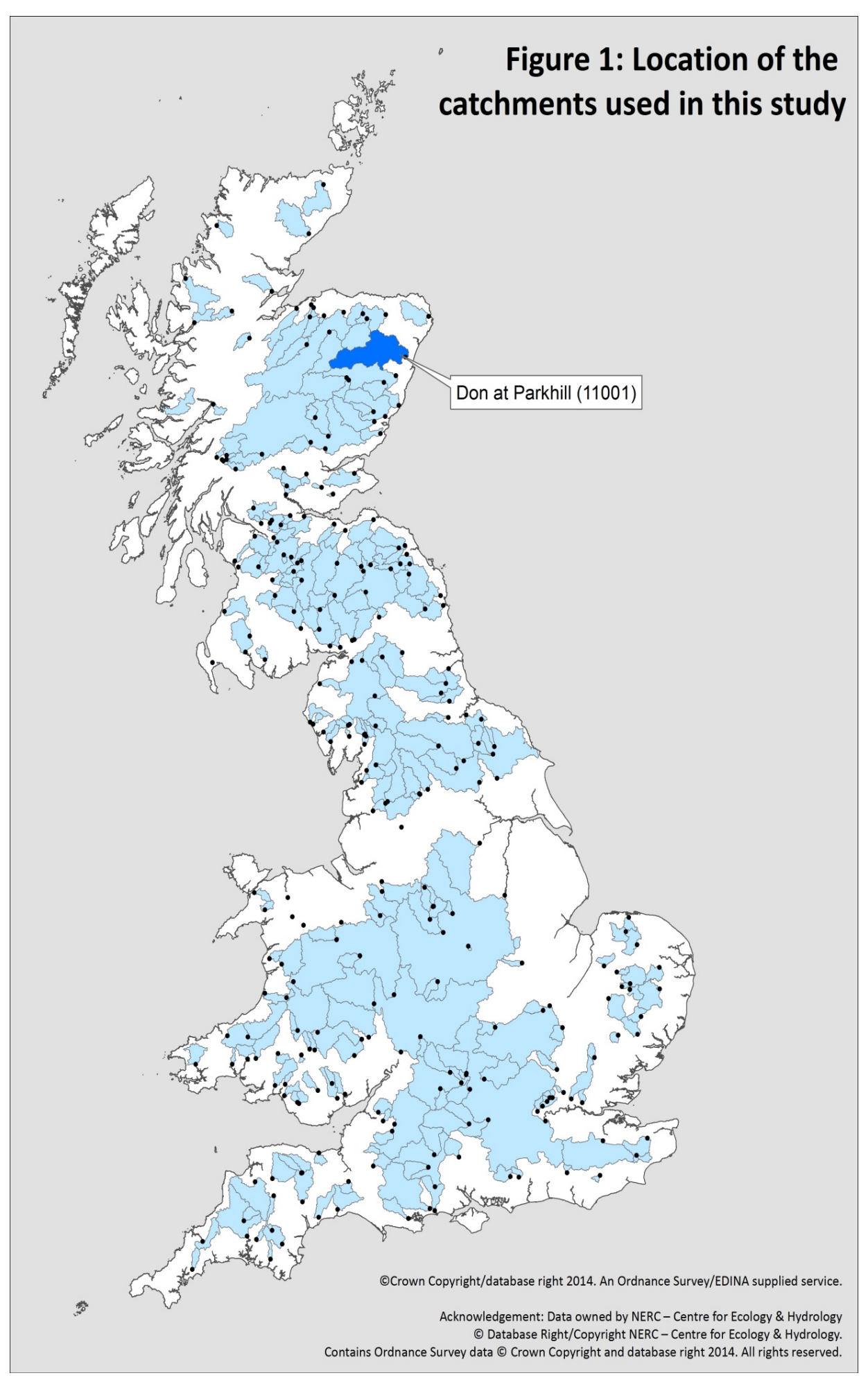


Figure 1: Location of the catchments used in this study

2. PURPOSE

- To assess potential for regional changes in future peak flows using flood indices based on daily mean simulated flow as a proxy
- To consider implications for design flood estimate and engineering practice

3. METHODOLOGY

- Future Flows data for 275 stations were obtained from the National River Flow Archive (http://www.ceh.ac.uk/data/nrfa/)
- For each station and each of the 11 ensemble members:
  - the water year annual maximum (AMAX) of the modelled daily mean flow (m³/s) was abstracted
  - the standard meteorological seasonal average of the Richards-Baker Flashiness Index (RBI) (Baker *et al*. 2004) was calculated for 272 stations. The RBI is a good indicator of hydrological intensification because it integrates several flow regime characteristics (e.g. rate of change of flow, peak magnitude, peak frequency). The concept of flashiness is also broadly and intuitively understood.

$$RBI = \frac{\sum_{i=1}^{n}|q_i - q_{i-1}|}{\sum_{i=1}^{n} q_i}$$

  - trend in both was assessed using the Mann-Kendall Test (Kendall 1975) in XLSTAT.
- To illustrate potential changes in flood magnitude/frequency:
  - one catchment showing a high number of significant upward trends was selected for further investigation (11001 Don at Parkhill, shaded dark blue in Fig. 1)
  - for each ensemble member, the annual maximum was split into two periods (1951-2024 and 2025-2098). Flood frequencies for typical recurrence intervals were calculated for both periods using the Generalised Logistic distribution and L-moments fitting in HydroTools (Wallingford HydroSolutions).

4. RESULTS

4.1 Changes in the annual maximum of simulated daily flow

- ✓ Of the 3025 simulations only a small proportion (6%) showed a decreasing trend in AMAX, although none were significant (at even p<0.1).
- ✓ A majority of simulations (62%) showed a significant increasing trend (p<0.05), 40% of which were at a higher level of significance (p<0.01) (Fig. 2a).

Figure 2a: Occurence of trends in AMAX across all simulations (n=3025)

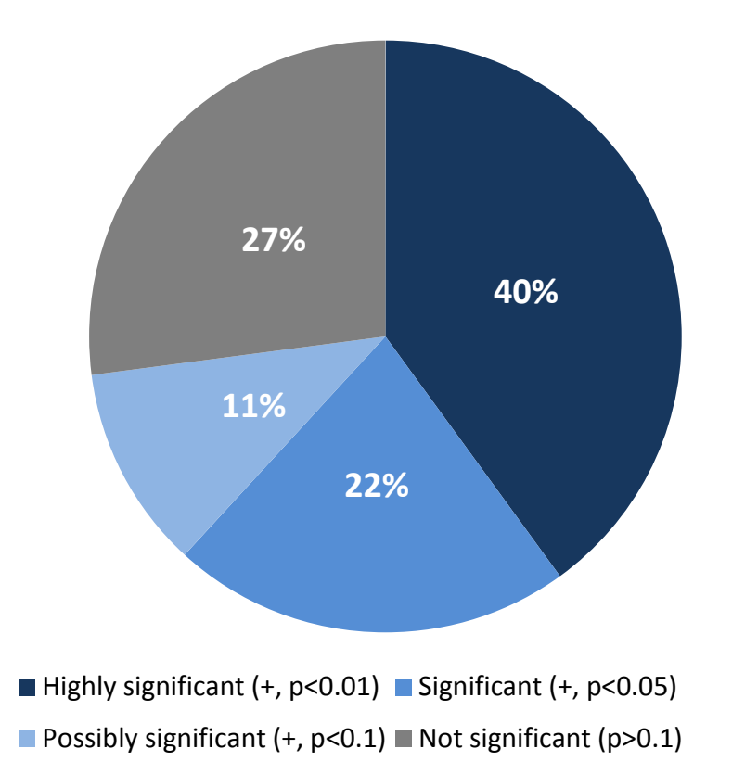
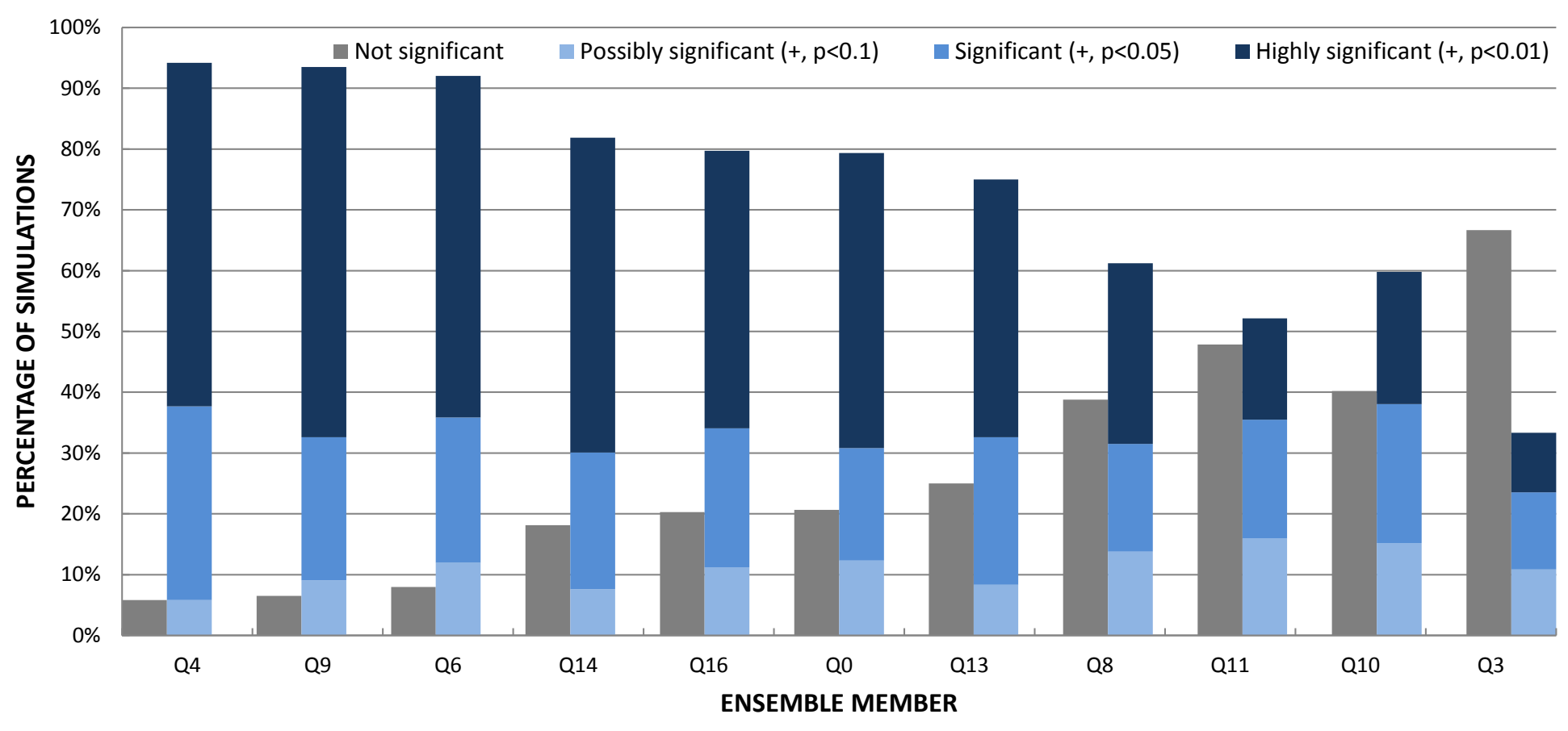


Figure 2b: Trends in AMAX per ensemble member



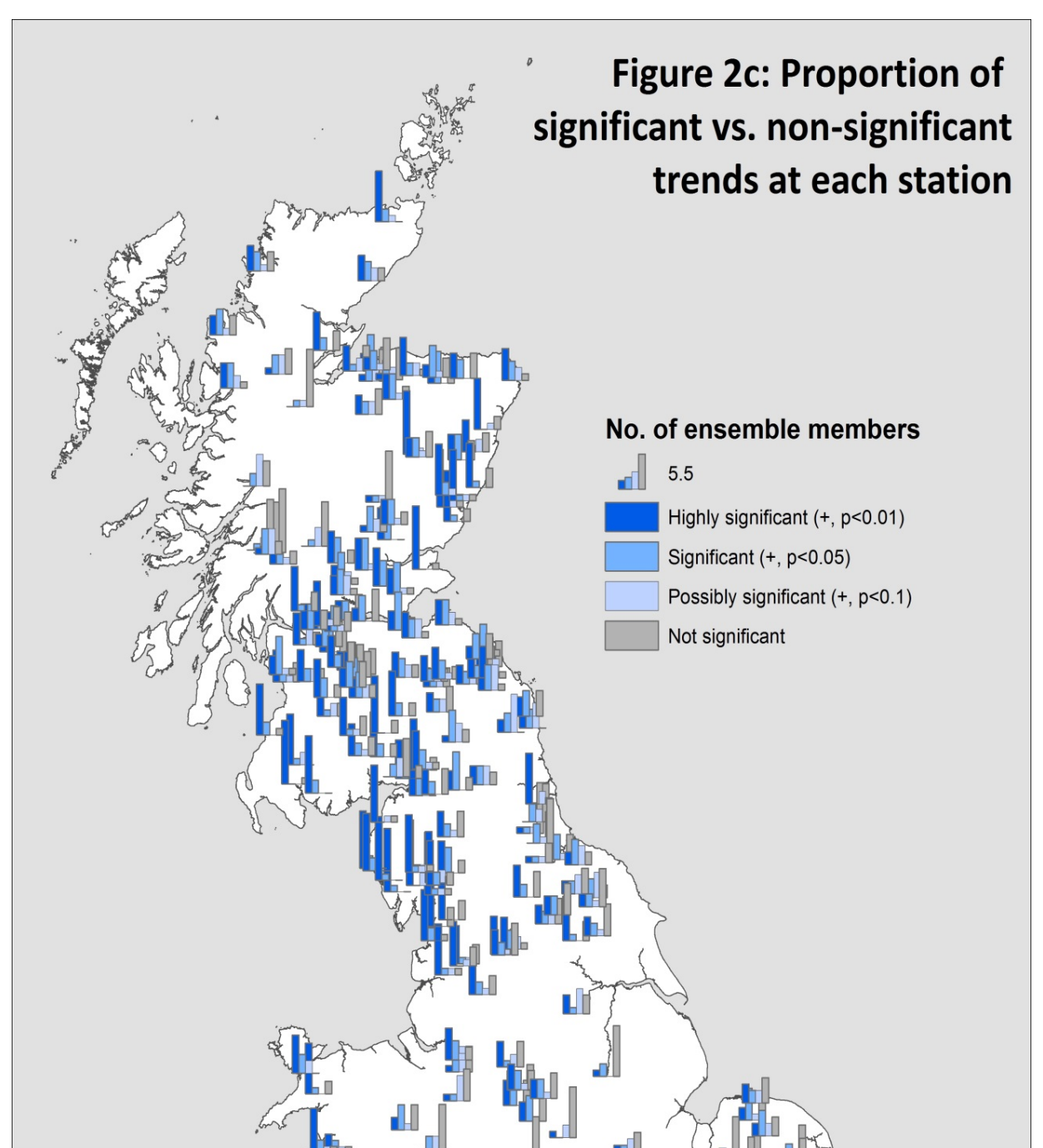


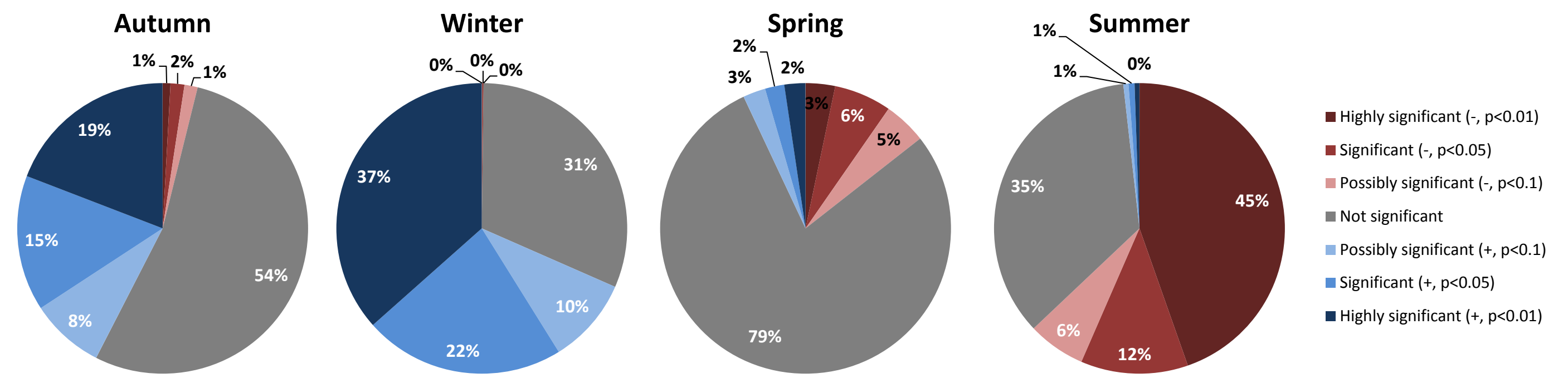
Figure 2c: Proportion of significant vs. non-significant trends at each station

- ✓ Trends were more evident for some ensemble members (e.g. Q4 and Q9) than for others (e.g. Q3) (Fig. 2b). Only one ensemble member (Q3) showed significant trends in less than half of stations.
- ✓ Trends show a clear geographic pattern, with a high proportion of significant trends being reported in the south and south west of England, west Wales, north west England and north east of Scotland (Fig. 2c). East Anglia, the Midlands and south west Scotland show the lowest occurrence of trends.

4.2 Changes in the Richards-Baker Flashiness Index

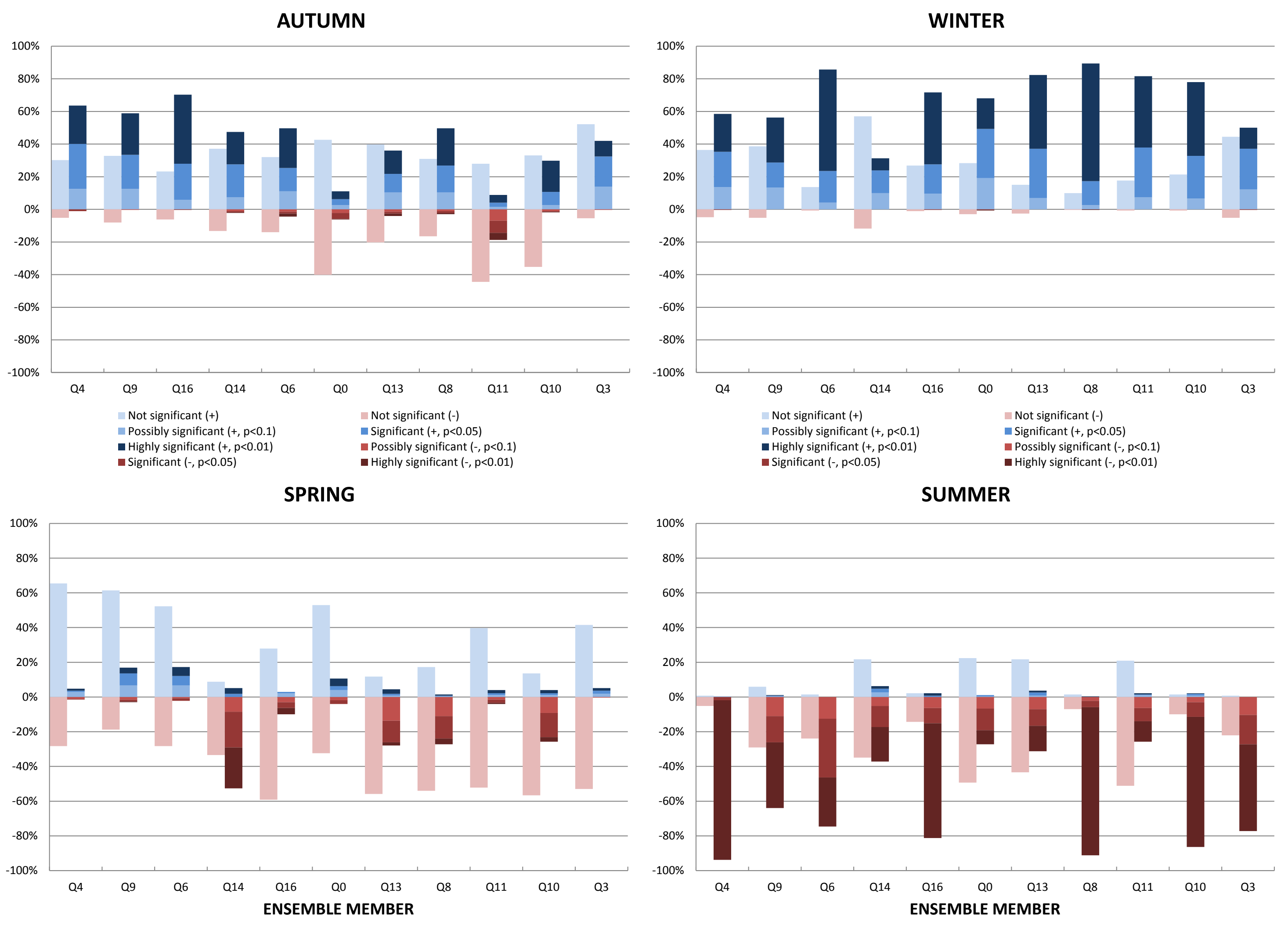
- ✓ 59% of simulations showed a significant increase in winter flashiness, in contrast to spring where very few trends are evident (Fig. 3a). In summer, significant decreasing trends in flashiness dominate.

Figure 3a: Seasonal variation in trends in the Richards-Baker Flashiness Index (n=2992)



- ✓ Increasing trends for winter and decreasing trends for summer are relatively consistent across all ensemble members (Fig. 3b). Patterns for autumn and spring are much more mixed.

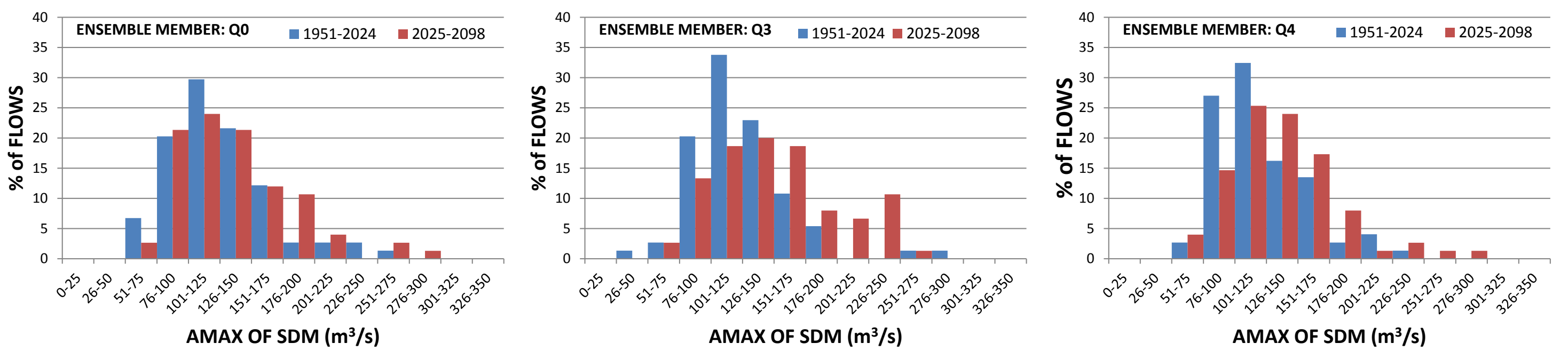
Figure 3b: Seasonal variation in trends in the Richards-Baker Flashiness Index per ensemble member



4.3 Implications for flood risk management

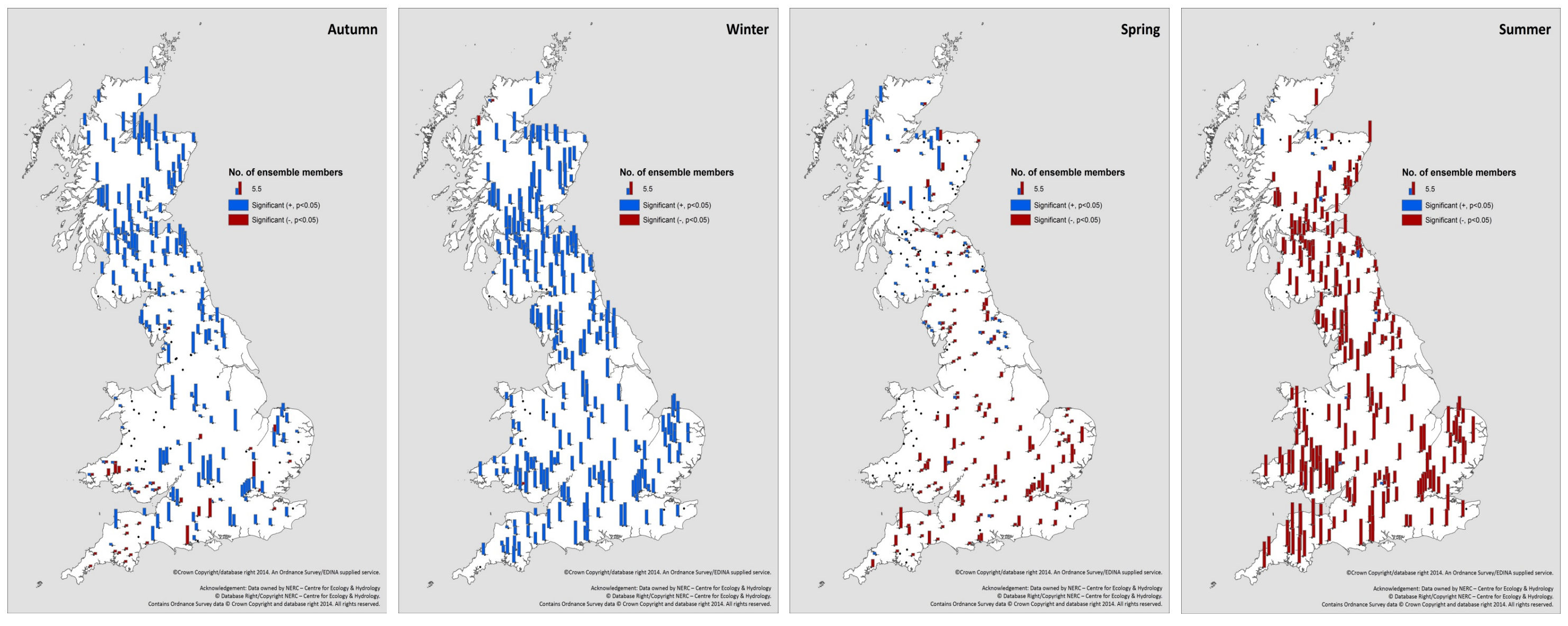
- For the Don at Parkhill (11001), comparative frequency distributions for three of the ensembles (Q4 – highest proportion of trends, Q3 – lowest proportion of trends, Q0 - intermediate) for the two periods show an upward shift in the annual maximum of the simulated daily mean (SDM) flow (Fig. 4a).

Figure 4a: Shift in the frequency distribution of annual maxima for the Don at Parkhill (11001)



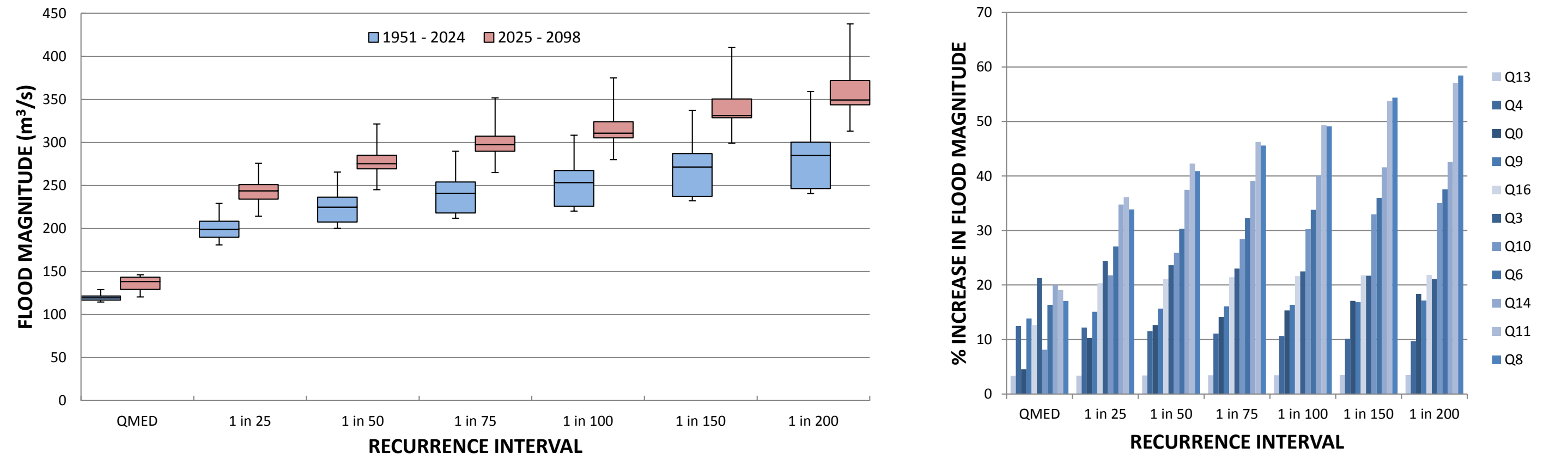
- Flashiness increases in winter and decreases in summer (Fig. 4b). Apart from Scotland, in spring the majority of ensemble members do not show significant trends at most stations. In autumn positive trends dominate in the north but are less evident in the south.

Figure 4b: Numbers of ensemble members per station showing significant trends (p<0.05)



- The magnitude of the 1 in 100 event rises from an average across ensemble members of 251m³/s (1951-2025) to 315m³/s (2026-2098) (25%). Figure 4c shows the range in flood magnitudes across all ensemble members.
- Increases for the 1 in 100 event averaged 26% across the ensemble members, but 3 scenarios showed higher increases in the range 40 to 49%. Earlier estimates suggested a 20 to 30% increase in the 1 in 100 year event in north east Scotland by the 2080s (Price & McKenna 2003).
- Higher recurrence intervals (1:150, 1:200) for some ensemble members showed increases in the region of 50 to 60%. This is despite this catchment being categorized as 'damped-high' in Reynard *et al*. (2009), meaning a catchment of lower vulnerability because for lower recurrence intervals, flood changes are smaller than maximum rainfall changes.

Figure 4c: The variation in flood magnitude across all ensembles calculated for two periods for the Don at Parkhill (11001) (left) and corresponding % increase for each ensemble member (right)



5. CONCLUSIONS

Using the annual maximum of simulated daily mean flows as proxy, Future Flows data suggest a statistically significant and widespread trend of increasing flood magnitude for the period (1951-2098) in the south, west, and north east of the United Kingdom. Trends are less evident in the Midlands and East Anglia.

For the Don at Parkhill, increases in flood magnitude between 1951-2025 and 2026-2098 vary across ensemble members but, can be as high as 58% for the 1:200 event. This is higher than the current SEPA guidance suggesting a 20% climate change factor for the 1 in 200 year event in north east Scotland (SEPA 2014).

However SEPA (2014:8) do recommend that 'best estimates based on the most up-to-date findings' should be used in peak flow estimation. By repeating the type of analysis undertaken for the Don at Parkhill for other catchments, the potential effects of climate change on Future Floods can be contextualized locally for design purposes.

REFERENCES

Baker, D.B. et al. 2004. A new flashiness index: characteristics and applications to Midwestern rivers and streams. *Journal of the American Water Resources Association* 40(2):503-522.
Kendall, M.G. 1975. *Rank Correlation Methods*. Griffin, London.
Price, D.J. and J.E. McKenna. 2003. *Climate change: Review of levels of protection offered by flood prevention schemes UKCIP02 update*. Environment Group Research Report, Scottish Executive. Available online: http://www.scotland.gov.uk/Publications/2004/02/18789/32039.
Prudhomme, C. et al. (2013) Future Flows Hydrology: an ensemble of daily river flow and monthly groundwater levels for use for climate change impact assessment across Great Britain. *Earth System Science Data* 5:101-107.
Reynard, N.S. et al. (2009) *Regionalised impacts of climate change on flood flows*. R&D Technical report FD2020/TR. London: Defra.
SEPA. 2014. *Technical Flood Risk Guidance for Stakeholders Version 8* (February 2014). Available online: http://www.sepa.org.uk/planning/flood_risk/policies_and_guidance.aspx.

ACKNOWLEDGEMENTS

The financial support of the Department of Geography and Environmental Management, UWE, Bristol is gratefully acknowledged. Special thanks to Nick Jones for programming work, Sarah Lupton for undertaking considerable data processing and Paul Satchell for GIS assistance. Staff at the National River Flow Archive for providing an excellent service.

British Hydrological Society National Symposium
Birmingham, 2-4 September 2014

Centre for Floods, Communities and Resilience