26th International Congress on Modelling and Simulation, Adelaide, SA, Australia, 30 Nov–4 Dec 2025
mssanz.org.au/modsim2025

Ahead of the curve: Data-driven identification of hydrological state shifts

E Kajubi [a, b, c], **TJ Peterson** [c], **A Mondal** [b, d] **and S Zahedi** [c]

[a] *IITB Monash Research Academy, IIT Bombay, Mumbai, India*
[b] *Department of Civil Engineering, Indian Institute of Technology Bombay, Mumbai, India*
[c] *Department of Civil and Environmental Engineering, Monash University, Clayton, Victoria*
[d] *Interdisciplinary Program in Climate Studies, Indian Institute of Technology Bombay, Mumbai, India*
Email: enock.kajubi@monash.edu

Abstract: Runoff at many catchments has recently been shown to shift during and after meteorological droughts, leading to fundamental changes in rainfall-runoff relationships (Saft et al., 2015). However, while some catchments recover to their pre-drought state, others persist in the shifted state even after the meteorological drought, providing evidence for the coexistence of two alternative steady states (Peterson et al., 2021). These hydrological shifts may be reversible or irreversible depending on catchment-specific resilience to climatic disturbances though the cause of non-recover remains an open question (Peterson et al., 2021; Saft et al., 2015). Although many types of shifts are plausible (Pamminger et al., 2025), (Saft et al., 2015) only looked at annual rainfall–runoff intercept shifts while (Peterson et al., 2021) focused only at annual and seasonal intercept and uncertainty shifts. To explore such shifts does however require detailed timeseries modelling using say, hidden Markov models. This paper proposes model-independent statistical techniques to identify any type of runoff shift.

Here we present a data-driven method to probabilistically detect any type of runoff shift directly from observed P and Q data. Our approach employs univariate and multivariate statistical metrics to identify runoff shifts before or as soon as they happen. Rising variance and autocorrelation are among the univariate metrics while the dominant eigenvalue of the covariance matrix of P and Q as shown in **Error! Reference source not found.** is among the multivariate metrics used. As shown in **Error! Reference source not found.**, covariance and the dominant eigenvalue increase significantly towards the shift year of 1985 and recovery year of 2005 suggesting a change in stable state and increased variability in runoff signalling temporal zones when rainfall does not explain runoff changes. However, the findings from all studied metrics offer subjective interpretations of when and where shifts occur. To address this limitation, we apply both a window-based and a temporally random (non-sequential) bootstrapping approach to reduce subjectivity and improve robustness. We then use probabilistic tests to identify differences in the distributions of the two bootstrap approaches in each year. Using these distributions, fig 1C-D show that the distribution of the moving window statistics clearly differs from the long-term distribution (red lines) during the years of shift in 1985 and 2005. Ongoing work is now applying this approach to 161 Victorian catchments and verify its robustness using the Millennium Drought (MD) using the shift and recovery years identified by (Peterson et al., 2021; Saft et al., 2015). Our approach shall provide a more simplistic model-free approach to identify all plausible types of shifts before or as soon as they occur. We anticipate this will provide early warnings of hydrological shifts.

REFERENCES

Pamminger LW, Peterson TJ & Peel MC (2025) Climate Change May Alter Rainfall-Partitioning in Ways Unlikely To Be Detected in the Coming Decades. *Water Resources Research*, *61*(7). https://doi.org/10.1029/2024WR039102

Peterson TJ, Saft M, Peel MC & John A (2021) Watersheds may not recover from drought. *Science*, *372*(6543), 745–749. https://doi.org/10.1126/science.abd5085

Saft M, Western AW, Zhang L, Peel MC & Potter NJ (2015) The influence of multiyear drought on the annual rainfall-runoff relationship: An Australian perspective. *Water Resources Research*, *51*(4), 2444–2463. https://doi.org/10.1002/2014WR015348

Keywords: *Rainfall-runoff relationships, model-free statistical indicators, stable state shifts, catchment resilience*

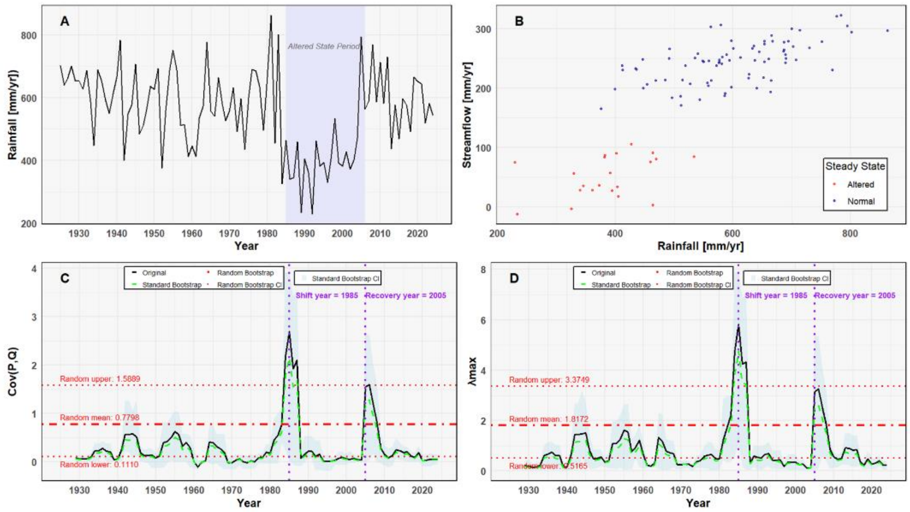

Figure 1: Demonstration of the shifts detection approach using a synthetic shift and multivariate statistics: A) Rainfall timeseries, B) Scatter plots for rainfall and streamflow data used, C) Covariance behaviour towards 1985 and 2005 and D) Dominant Eigenvalue behaviour towards 1985 and 2005.