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Identifying mechanisms influencing non-stationarity in rainfall-runoff relationships in southeast Australia

Proloy Deb (1), Anthony S. Kiem (1), and Garry Willgoose (2)

(1) School of Environmental and Life Sciences, Faculty of Science, University of Newcastle, Callaghan, NSW, 2308, Australia, (2) School of Engineering, Faculty of Engineering and Built Environment, University of Newcastle, Callaghan, NSW, 2308, Australia

Southeast Australia (SEA) experiences severe droughts. During drought, reduced rainfall alters bio-physical catchment properties resulting in non-stationarity of rainfall-runoff (R-R) relationships. Various processes have been identified which potentially influence non-stationarity in the R-R relationship at annual scale, however, numerous knowledge gaps remain, especially at the seasonal scale.

This study analyses various endogenous and exogenous mechanisms which can possibly influence R-R relationships. Two case study catchments with contrasting biophysical characteristics were used: Coolac in New South Wales (410044) and Ancona in Victoria (405251). The endogenous mechanisms evaluated were: monthly ground water table (GW), daily baseflow, bi-monthly leaf area index (LAI) and daily Horton Index (HI). The exogenous mechanisms evaluated were: daily reference evapotranspiration (ET0), daily rainfall totals, daily maximum (Tmax) and daily minimum (Tmin) temperatures. Average annual and seasonal values were used for endogenous mechanisms. For exogenous mechanisms, seasonal and annual totals (averages) were used for ET0 and rainfall (Tmax and Tmin).

Linear models at annual and seasonal scales were generated with Box-Cox transformed runoff and rainfall as the dependent and independent variables respectively. This was done for both drought and non-dry periods. In order to identify shifts in R-R relationship, one-way analysis of variance (ANOVA) was performed for intercepts of the linear models for drought and non-dry periods with the null hypothesis that the variance of the intercepts is equal. In addition, Student's t-tests and Kolmogorov-Smirnov (KS) tests were also performed for R-R ratios during drought and non-dry periods at annual and seasonal scales and to test the influence of individual endogenous and exogenous mechanisms on non-stationarity.

The results reconfirm previous findings that non-stationarity in R-R relationships exists at annual scale for both catchments. In addition, for catchment 405251, non-stationarity is observed for all seasons when Millennium drought conditions are compared with non-dry conditions. For 410044, non-stationarity is observed during summer/spring when WWII drought conditions are compared with non-dry periods whereas non-stationarity is observed during autumn/winter/spring when Millennium drought conditions are compared with non-dry conditions. Interestingly, higher runoff per unit rainfall is observed during the WWII drought relative to non-dry periods. The KS tests reveal baseflow contribution to runoff as the most likely reason for this counter-intuitive result.

The KS test also shows that GW and HI are major endogenous influences on R-R relationships. Exogenous mechanisms that significantly influence annual and seasonal R-R relationships are Tmin for 405251 and Tmax for 410044. The influence of rainfall on non-stationarity is significant (i) at the annual scale and all seasons during the WWII drought for 410044 and (ii) during summer/autumn for the Millennium drought for the corresponding catchment.

These results highlight the importance of understanding, and realistically modelling, interactions between endogenous and exogenous mechanisms in order to properly capture the (a) interactions between surface water and groundwater and (b) non-stationarity in R-R relationships that occur as a result of changing catchment or hydroclimatic conditions. The results will help the hydrological modelling community develop more robust models that will guide water managers to adapt changing catchment or hydroclimatic conditions.