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An aridity index (ϕ) based formulation for baseflow and direct-runoff.

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Introduction

- Baseflow and direct-runoff represent distinct catchments responses to rainfall[1] and their individual estimation is of interest for different fields such as flood estimation, water resources management, ecosystem functioning and groundwater recharge estimation.
- Even though a theoretical framework has been proposed for the prediction of these two fluxes at the catchment scale[1], there isn't yet a proper formulation for their prediction based on physical principles.
- This work proposes an aridity index (ϕ) solution for the long-term direct runoff (Q_D) and baseflow (Q_B) prediction based on a similar reasoning[2] of the effects of ϕ on the long-term streamflow (Q)

Methods and Catchment selection

The study catchments are located in the conterminous United States and are a subset of the CAMELS[3] dataset:

- 486 catchments.
- 30 hydrologic years continuous daily streamflow (1983-2013
- Threshold of less than 1% missing streamflow records
- Non-snow dominated (fraction of precipitation falling as snow < 30%
- PET estimated as in Penman[4] – Open water equation.
  - Solar radiation from Gridmet[5]
  - All other variables from the CAMELS[3] dataset.
- Baseflow separation using the Lyne and Holick[6] method.

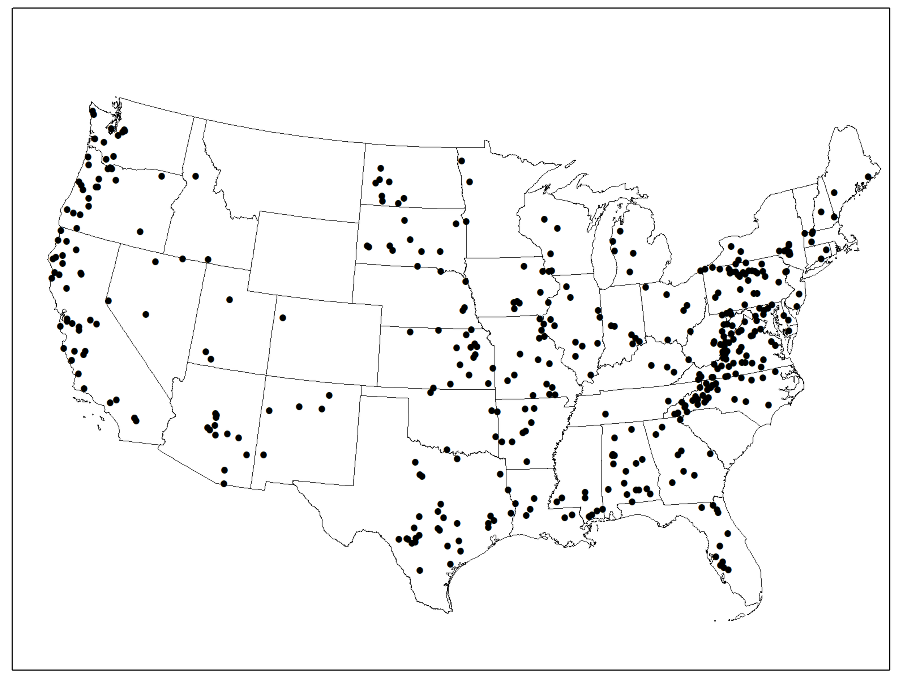


Figure 1. Locations of catchments used in this study.

Background: The Budyko(1974) and L'vovich (1979) water balance frameworks:

Budyko (1974)

$$P = Q + E$$

$$\frac{E}{P} = 1 - \frac{Q}{P} = f_E(\phi)$$

Limiting conditions:

$$\phi \to \infty \therefore\ E/P \to 1, and\ Q/P \to 0,$$

$$\phi \to 0 \therefore\ E/P \to 0, and\ Q/P \to 1,$$

Resulting formulation:

$$f_E(\phi) = E/P = [\phi \times (1 - \exp\phi) \times \tanh\phi^{-1}]^{0.5},$$

$$f_R(\phi) = Q/P = 1 - E/P = 1 - f_E(\phi)$$

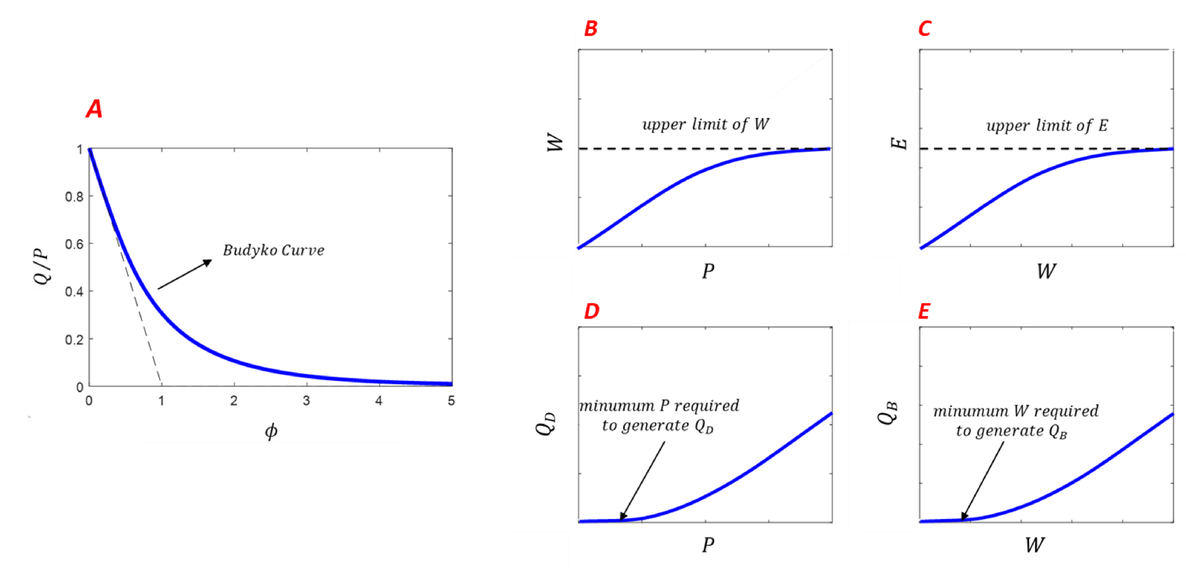
L'vovich (1979)

$$P = Q_D + W$$

$$W = Q_B + E$$

$$P = Q_D + Q_B + E$$

What controls the water balance partitioning within the L'vovich (1979) framework at mean-annual time-scales?



Proposed derivation:

Water balance according to L'vovich (1979)

$$P = Q_D + Q_B + E$$

Runoff coefficient:

$$\frac{Q}{P} = \frac{Q_D}{P} + \frac{Q_B}{P}$$

We can write:

$$f_R(\phi) = f_D(\phi) + f_B(\phi)$$

where:

$$\frac{Q_D}{P} = f_D(\phi)$$

$$\frac{Q_B}{P} = f_B(\phi)$$

Applying limiting conditions:

$$\phi \to \infty, : \frac{Q}{P} = \frac{Q_D}{P} + \frac{Q_B}{P} \to 0$$

thus, $f_D \to 0\ ;\ f_B \to 0$

$$\phi \to 0, \quad \frac{Q}{P} = \frac{Q_D}{P} + \frac{Q_B}{P} \to 1,$$

therefore, $f_D \to \left[\frac{Q_D}{P}\right]_{max}$

and, $f_B \to \left[\frac{Q_B}{P}\right]_{max} = 1 - \left[\frac{Q_D}{P}\right]_{max}$

Resulting formulation:

$$Q_D = P.f_D$$

$$W = P - Q_D = P - P.f_D = P.(1 - f_D)$$

$$Q_B = P.f_B$$

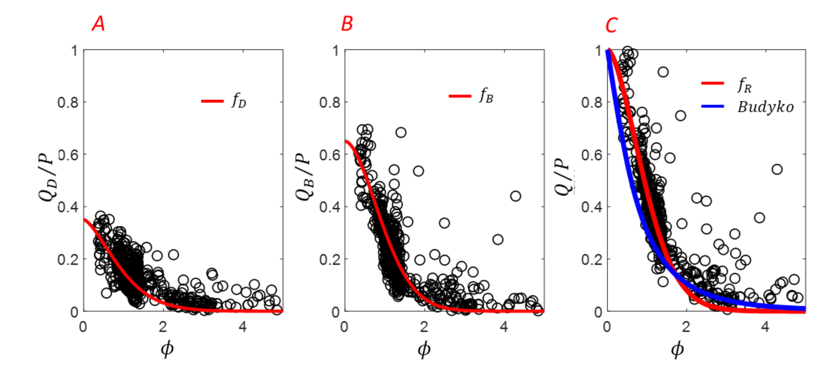
$$E = P - Q_b - Q_D = P - P(f_D + f_B)$$

Results:

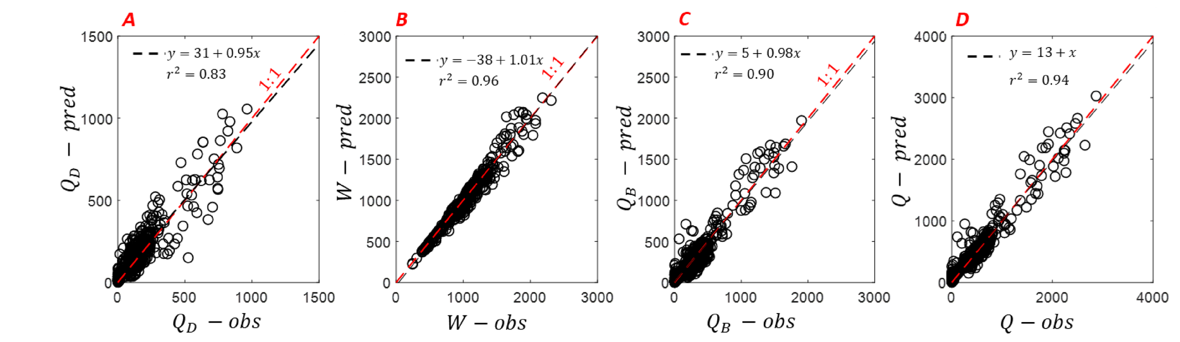
Derived equations

$$f_D(\phi) = \exp\left(\phi^{1.5} - \frac{\ln(0.35)}{1.14}\right)^{0.85}$$

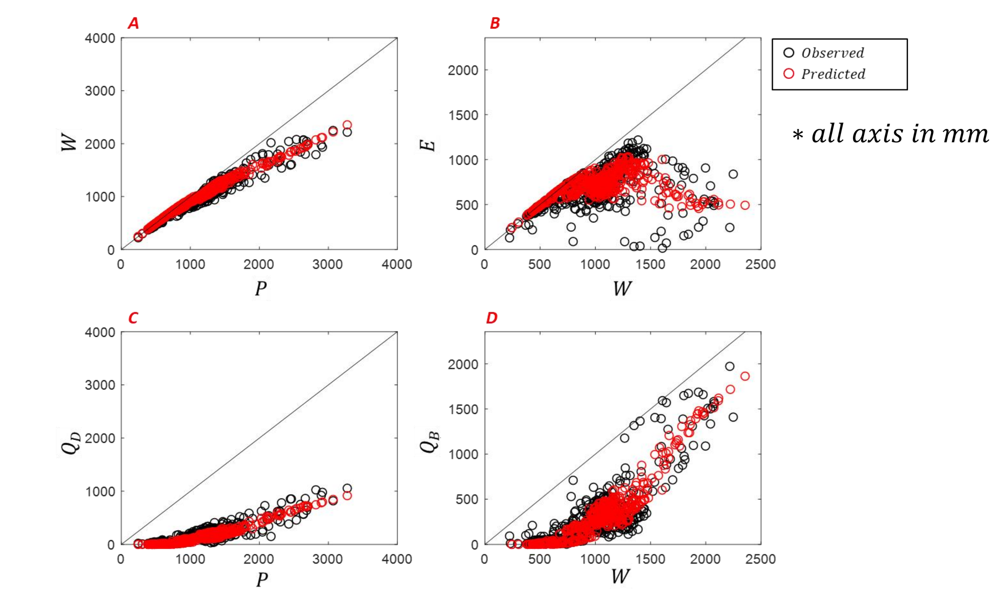
$$f_B(\phi) = \exp\left(\phi^{1.8} - \frac{\ln(0.65)}{1.15}\right)^{0.75}$$



Predictive performance



L'vovich framework under a ϕ − based formulation



∗ *all axis in mm*

Discussion and conclusion

- The aridity index (ϕ) largely controls the mean-annual fluxes, explaining 84% and 90% of the spatial (between-catchment) variability of Q_D and Q_B, respectively.
- To our knowledge, the only reported method for the prediction of Q_D at the catchment scale[7] require either knowledge of in-situ calibration of land-surface parameters, or its inference through calibration. Our results suggest an interesting venue for the advancement of prediction of Q_D at ungauged sites.
- When combined, our solutions produce a similar type of curve as it is traditionally applied for the prediction of long-term streamflow[2]. This suggests an interesting venue for prediction of both long-term catchment fluxes at large-scale applications, such as the derivation climate-change effects on Q based on its individual components.
- Our approach for the solution of the L'vovich[1] water balance framework differs from the ones recently introduced in the literature[8,9] where a conceptual model of the partitioning was assumed, which lead to formulations requiring site-specific calibration.
- An interesting venue for research is the assessment of the other factors controlling Q_B / P and Q_D / P at the mean-annual scale, to extend the formulations presented here and include additional landscape and climate properties to further investigate the controls on baseflow and direct-runoff coefficient. At the same time, it would be interesting to understand how the already understood climatic and landscape features that are known to provide further insight into the controls on Q are translated into the control of its complementary components Q_B and Q_D.

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