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Discussion

Comment on the paper: "Basin hydrologic response relations to distributed physiographic descriptors and climate" by Karen Plaut Berger, Dara Entekhabi, 2001. Journal of Hydrology 247, 169–182

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1. Introduction

A basic problem relating to the long-term water balance involves splitting precipitation P, into runoff R, and actual evapotranspiration E. Berger and Entekhabi (2001) showed that the evapotranspiration efficiency E/E_p (E_p denotes potential evapotranspiration) and the runoff ratio R/P, are related to physiographic basin features and regional climate information. Berger and Entekhabi (2001) estimated actual watershed evapotranspiration E, and runoff R, at 10 basins across the US, using an equilibrium distributed hydrologic model. They argue that their results are preliminary because they are only based on modeled values of E and R. They suggest that the next step is to assemble observed evapotranspiration and runoff data for a number of basins to test their modeled results. We describe the results of such experiments here. We develop basin hydrologic response relations using observed (instead of modeled) fluxes of runoff from 1305 basins in the continental US. Analogous to their study which employed six basin descriptors, this study uses the following four basin characteristics: wetness ratio P/E_p, relative infiltration capacity i_r/K_s, average slope S, and drainage density D_d. A linear regression model is developed which relates the runoff ratio to those basin descriptors, and our model is compared with an analogous model developed by Berger and Entekhabi.

2. National databases of climate and streamflow

2.1. Streamflow database

Daily streamflow records were obtained from a national Hydro-Climatic Data Network (HCDN) for 1305 basins within the 18 water resources regions of the continental US (Slack et al., 1993). Fig. 1 shows the location of those 1305 basins within the continental US. A unique aspect of this database is that it is relatively free from anthropogenic influences.

2.2. Climate database

The climate database consists of 37-year monthly time-series of monthly precipitation, average maximum daily temperature and average minimum daily temperature derived from 0.5° time-series grids based on the precipitation–elevation regressions on independent slopes model (PRISM) climate interpolation

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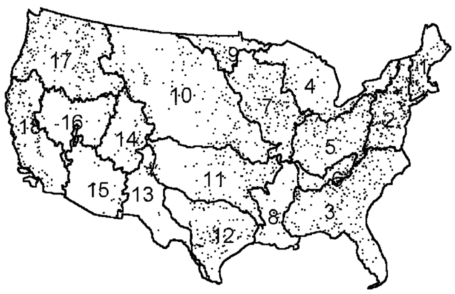

Fig. 1. Location of 1305 watersheds in the 18 water resources regions in the continental US.

modeling system (Daly et al., 1994). PRISM uses a precipitation–elevation regression relationship to distribute point measurements to evenly spaced grid cells by accounting for orographic effects in mountainous regions (Daly et al., 1994). The climatic monthly time-series grids obtained from the PRISM modeling system were spatially averaged over each HCDN basin using a geographic information system. To accomplish this task, the 1305 watershed boundaries are outlined using a 1 km digital elevation map of the US. Using the monthly temperature time-series data along with extraterrestrial solar radiation, monthly time-series of potential evapotranspiration were obtained using the method introduced by Hargreaves and Samani (1982). Extraterrestrial solar radiation was estimated for each HCDN basin by computing the solar radiation over 0.1° grids using the method introduced by Duffie and Beckman (1980), and then summing those estimates over the entire basin. The result is a unique set of time-series of monthly precipitation, potential evapotranspiration and streamflow over the period 1951–1988 for 1305 basins distributed across the US.

3. Descriptors of basin climate and physiography

Berger and Entekhabi (2001) used six variables representing a basin's climate, geomorphology and lithology to develop a regression model for the runoff ratio. In this study, we use the following four variables, which are a subset of their six variables.

3.1. Wetness index (P/E_p)

The wetness index (or humidity index) is the ratio of mean annual precipitation P to mean annual potential evapotranspiration E_p. Wetness indices for the 1305 basins were obtained from the 37-year monthly time-series of precipitation and potential evapotranspiration described earlier.

3.2. Drainage density (D_d)

In this discussion, drainage density is defined as the ratio of main channel stream length to the basin area. Normally drainage density is defined using the total length of all stream segments, however, that was unavailable here. The main channel stream length and the drainage area for each basin are obtained from the HCDN database (Slack et al., 1993). The main channel stream length is measured as the length of the main channel from the gage to the basin divide. The average drainage area of the 1305 basins is 2485 km^2 and the average stream length is 104 km.

3.3. Average basin slope (S)

The average basin slope for each basin is computed in Arc-View, a geographic information system, using a 1-km digital elevation model (DEM). The average basin slope is expressed as the average of the slope of each cell in the DEM, which is computed using the 'derive slope' function in Arc-View.

3.4. Relative infiltration capacity (i_r/K_s)

Berger and Entekhabi (2001) define the relative infiltration capacity as the ratio of mean precipitation intensity to saturated hydraulic conductivity. The mean precipitation intensity of 24-h rainfall is obtained for each basin from the HCDN database (Slack et al., 1993). The average permeability, a surrogate for saturated hydraulic conductivity, is obtained from the 1 km grid developed by the USGS (Wolock, 1997).

3.5. The runoff ratio (R/P)

The runoff ratio (R/P), a measure of overall basin hydrologic response, is obtained for each of the 1305 basins using the national databases of climate and streamflow described earlier. Table 1 illustrates the correlation coefficients between the four basin

Table 1
Correlation matrix of basin descriptors and hydrologic response

Variables	Wetness index (P/E_p)	Average basin slope (S)	Relative infiltration capacity (i_r/K_s)	Drainage density (D_d)	Runoff ratio (R/P)
P/E_p	1.000				
S	0.235	1.000			
i_r/K_s	−0.052	−0.318	1.000		
D_d	0.137	0.142	0.020	1.000	
R/P	0.712	0.572	−0.239	0.280	1.000

descriptors and the runoff ratio. Using a 95% level F-test, nearly all variables are significantly inter-correlated except the correlation between the wetness index and the relative infiltration capacity and the correlation between the drainage density and relative infiltration capacity which are not significantly different from zero.

4. Data-based hydrologic response relations for the continental US

The point of this discussion is to test and compare hydrologic response relations derived here from observed runoff-ratios with analogous hydrologic response relations based on modeled runoff ratios which were estimated by Berger and Entekhabi. Analogous to their study, stepwise regressions are performed between the runoff ratio and the four variables: wetness index, average basin slope, drainage density and relative infiltration capacity.

The results of the stepwise regressions are reported in Table 2. All four variables are significantly different from zero using a 5% level t-test. Tables 1 and 2 indicate that among all basin variables, the wetness index P/E_p, explains most of the variability in the observed runoff ratio ($R^2 = 0.51$) over the continental US. The coefficient of determination R^2 increases to 68% when both average basin slope and the wetness index are used to predict the runoff ratio. The remaining two variables, drainage density and relative infiltration capacity provide only a marginal improvement by increasing the overall R^2 to 71% when all four basin variables are included.

Fig. 2 compares the observed runoff ratios with values obtained from our four variable linear regression model summarized in Table 2. The overall agreement is good; however, our regression model overestimates runoff ratios for arid basins (low runoff ratios) in the midwestern and southwestern US. In arid regions, the runoff ratio is low, in part because the soil moisture-holding capacity of arid basins is high (Sankarasubramanian and Vogel, 2002).

The basin hydrologic response relation for evaporation efficiency (E/E_p) is not developed here because it can be derived from the runoff ratio relationship. Assuming net changes in basin storage are negligible over the long-term and assuming net seepage is also negligible, long-term evapotranspiration E is given by

$$E = P - R \tag{1}$$

Many investigators have used these assumptions for modeling the long-term hydroclimatology of a basin or region (Milly, 1994; Roads et al., 1994). Dividing Eq. (1) by E_p and rearranging leads to

$$E/E_p = P/E_p(1 - R/P) \tag{2}$$

Since evapotranspiration efficiency is simply a function of the runoff ratio R/P and the wetness index P/E_p, we did not develop associated regressions for E/E_p.

5. Summary and conclusions

Berger and Entekhabi (2001) developed the following multivariate relationship between modeled runoff ratio and four basin descriptors using 10 basins

Table 2
Stepwise regression results for runoff ratio fitted with an intercept. Model coefficients are listed in the same order as given under the 'variable' column

Variable(s)	R^2	Coefficients				Constant
P/E_p	0.507	0.432				−0.012
P/E_p, S	0.681	0.370	0.036			−0.038
P/E_p, S, D_d	0.699	0.361	0.035	0.436		−0.069
P/E_p, S, D_d, i_r/K_s	0.706	0.362	0.032	0.454	−0.138	−0.045

in the US:

$$\frac{R}{P} = -0.27 + 0.13\frac{P}{E_p} - 0.46S_{50} - 0.07D_d - 0.75\frac{i_r}{K_s}, \qquad R^2 = 0.87$$

Similarly, we developed the following relationship based on observed runoff ratios at 1305 basins across the US:

$$\frac{R}{P} = -0.045 + 0.362\frac{P}{E_p} - 0.032S - 0.454D_d - 0.138\frac{i_r}{K_s}, \qquad R^2 = 0.71$$

Different definitions of the basin characteristics were employed as well as different databases, so that one cannot really compare the coefficients in these two equations. Nevertheless, it is interesting to note that most of the variability in observed runoff ratios is explained by the same types of basin characteristics used by Berger and Entekhabi, to explain the variability in modeled runoff ratios. This lends support to their approach which employs hydrologic model output in combination with basin descriptors, to determine those aspects of basin lithology, climate and topography which govern the overall hydrologic response of a basin. Furthermore, it is interesting to note that in both studies, the wetness index explained most of the variability in the runoff ratio. In their study, the wetness index explained 70% of the variability in modeled runoff ratios, whereas in this discussion, the wetness index explained only 51% of the variability in observed runoff ratios. The two studies differed in terms of the degree to which

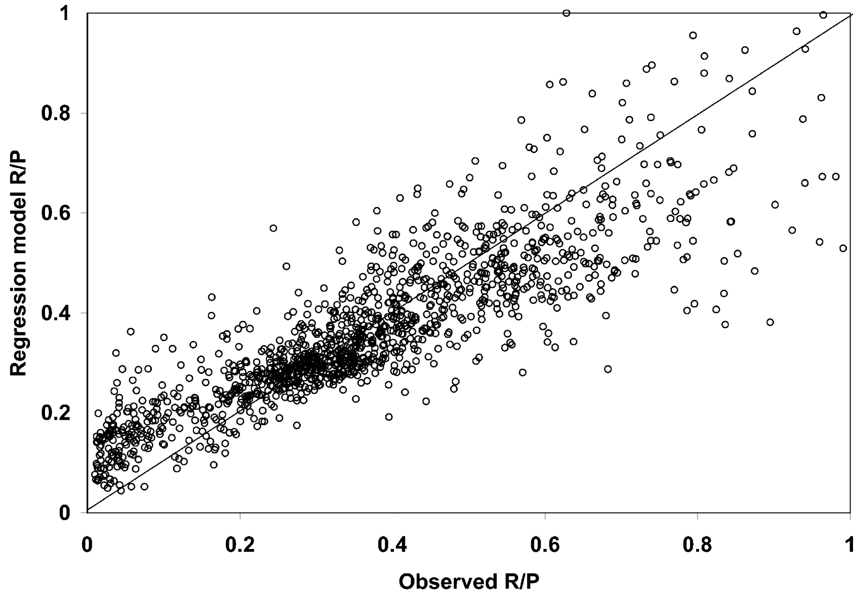

Fig. 2. Comparison between the observed runoff ratio and the regression model fitted runoff ratio using all the four basin descriptors.

information on the lithology and topography were able to improve estimates of the runoff ratio over and above the use of the wetness index alone.

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References

Daly, C., Neilson, R.P., Philips, D.L., 1994. A statistical-topographic model for mapping climatological precipitation over mountainous terrain. Journal of Applied Meteorology 33 (2), 140–158.

Duffie, J.A., Beckman, W.A., 1980. Solar Engineering of Thermal Processes, Wiley, New York, pp. 1–109.

Hargreaves, G.H., Samani, Z.A., 1982. Estimating potential evapotranspiration. Journal of Irrigation and Drainage Engineering 108 (3), 225–230.

Milly, P.C.D., 1994. Climate, interseasonal storage of soil water and the annual water balance. Advances in Water Resources 17, 19–24.

Roads, J.O., Chen, S.C., Guetter, A.K., Georgakakos, K.P., 1994. Large scale aspects of the United States hydrologic cycle. Bulletin of the American Meteorological Society 75 (9), 1589–1610.

Sankarasubramanian, A., Vogel, R.M., 2002. Annual hydroclimatology of the continental United States. Water Resources Research, Volume 38, (in press).

Slack, J.R., Lumb, A.M., Landwehr, J.M., 1993. Hydroclimatic data network (HCDN): a U.S. geological survey streamflow data set for the United States for the study of climate variation, 1874–1988. Water-Resource Investigations Report 93-4076, US Geological Survey, Washington, DC.

Wolock, D.M., 1997. STATSGO soil characteristics for the conterminous United States. USGS Open-File Report 97-656.