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Regional estimation of base flow for the conterminous United States by hydrologic landscape regions

C. Santhi [a,*], P.M. Allen [b], R.S. Muttiah [c], J.G. Arnold [d], P. Tuppad [a]

[a] *Backland Research and Extension Center, Texas A&M University System, 720 East Blackland Road, Temple, TX 76502, USA*
[b] *Department of Geology, Baylor University, One Bear Place #97354, Waco, TX 76798-7354, USA*
[c] *Department of Geology, Box 298830, Texas Christian University, Fort Worth, TX 76129, USA*
[d] *Grassland Soil and Water Research Laboratory, United States Department of Agriculture — Agricultural Research Service, 808 East Blackland Road, Temple, TX 76502, USA*

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Summary Information on base flow availability and/or contributions is needed to develop water quantity and water quality management strategies. Base flow availability varies over space and time in a region due to climate, topography, landscape, and geological characteristics. In this study, base flow index (BFI) (base flow/total stream flow) was estimated from daily streamflow records using a recursive digital filter method and interpolated to produce a raster grid map for the conterminous United States. When compared for validation, BFI estimated by recursive digital filter method showed good agreement overall with the USGS smoothed minima BFI method. Estimated base flow index and volume were analyzed, with Hydrological Landscape Regions (HLRs) developed for the United States to identify the mean hydrologic flow response within HLR. They were also used to determine relationships with hydro-geologic descriptive variables and used for defining the HLRs based on Pearson's correlation table and a stepwise multiple regression. These descriptive variables used in defining the HLRs include relief, effective rainfall, potential evapotranspiration and percentage of sand. The regression results indicated that relief and percentage of sand were highly correlated to base flow index, and the amount of base flow volume can be related to gradient and the amount of effective rainfall. The regression results also suggested that the descriptive variables used in constructing the HLR can be used to define mean values of shallow ground water flow within the regions. Further testing is needed to ascertain if such relationships could be used to define flow within an HLR.

* Corresponding author. Tel.: +1 254 774 6141; fax: +1 254 774 6001.
E-mail addresses: csanthi@brc.tamus.edu (C. Santhi), Peter_Allen@baylor.edu (P.M. Allen), R.Muttiah@tcu.edu (R.S. Muttiah), Jeff.Arnold@ARS.USDA.GOV (J.G. Arnold), ptuppad@brc.tamus.edu (P. Tuppad).

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Introduction

A new concept — based on a regional framework — is needed to assess water quality and quantity at continental scales (Wolock, 2003a). Regional frameworks such as ''Ecoregions'' (Omernik and Bailey, 1997) and ''hydrologic landscape regions'' (HLR) (Wolock et al., 2004) have gained importance among government and other agencies. These agencies are interested in addressing water quality and quantity issues across local, state, and federal boundaries with a regional framework in a holistic perspective (Simon et al., 2004). A regional framework considers aggregation of spatial patterns of hydrological, geological, biotic and abiotic characteristics, and any other factors considered being useful to broaden the approach for management of resources. Several studies focused on the regionalization concept. Regionalization of streamflow characteristics is based on the premise that catchments with similar geology, topography, climate, vegetation, and soils would have similar streamflow responses (Smakhtin, 2001; Winter, 2001; Wolock, 2003a). The concept of hydrological landscape regions (HLRs) is based on the idea that a single, simple physical feature of the land, termed a fundamental hydrologic landscape unit, controls the hydrologic response of an area (Winter, 2001; Wolock et al., 2004). While HLR and similar concepts appear sound, they have neither been tested against regional hydrologic variables, nor for integrity of the delineated regions especially at 'continental scale'. Wolock et al. (2004) and Winter's (2001) hypothesis is that the watershed areas can be separated with reference to physical attributes and these can be correlated to ground water flow. This hypothesis has been attempted by several studies. Lacey and Grayson (1998) have attempted to relate the base flow to catchment properties in southern part of Australia. Neff et al. (2005) used base flow separation coupled with surficial geology classes and percentage of surface water to predict base flow at ungaged sites within the Great Lakes basin using regression models. Their model predicted the observed base flow at individual gages up to 89 and 94% of the time. These studies indicate the usefulness of regional base flow separation for prediction of general ground water contribution to streams in ungaged areas. In the present study, the authors have related landscape regions and the hydro-geologic variables within them to base flow at 'continental scale' in the United States.

Base flow is an important component of the ground water system. It is the component of streamflow that is attributed to ground water discharge and other delayed sources such as snow melt into streams. Reay et al. (1992) found that neglecting base flow (shallow ground water discharge) as a nutrient source to streams leads to misinterpretation of data and mismanagement. Knowledge on base flow availability is important in: development of water management strategies, especially for drought conditions; establishment of relationships between aquatic organisms and their environment; estimation of small to medium water supplies; and management of salinity, water quality, and algal blooms. In addition, base flow maintains flow for navigation, water supply, hydroelectric power and recreational uses in reservoirs (McMahon and Mein, 1986). Stuckey (2006) infers that studies estimating base flow contributions to streams are useful for watershed planners to determine water availability, water use allocations, assimilative capacity of streams and aquatic habitat needs.

Base flow displays spatial and temporal variability due to climate, land use, soils, frequency and amount of recharge, vegetation, topography, and geology (Stuckey, 2006; Delin et al., 2007). At the continental scale, Heath (1984) divided the United States into ground water regions based on rock units; however, he neither addressed topography nor climate. Vogel and Kroll (1992) statistically categorized regions and assessed many geomorphic variables, but did not incorporate findings into definable landscape regions.

This study substantiates the relationship between base flow and hydrologic landscape regions. As the variability of base flow is key to the understanding of the ground water system, and hydrologic landscape regions have defined the spatial variations in hydrologic characteristics, this study will test their degree of interrelationship and thus their potential as a tool in water resources management. The specific objectives of the study were to:

(1) estimate base flow index using the recursive digital filter method for the conterminous United States;
(2) analyze the hydrologic response (base flow and surface runoff) of hydrologic landscape regions of the United States using the estimated base flow index and base flow volume, and
(3) determine the relationship between the base flow index or base flow volume and the hydro-geological characteristics (descriptive variables) of the hydrologic landscape regions.

The first part (''Methodology'' section) of the methodology describes the estimation of the base flow index and the volume for the conterminous United States and the second part (''Base flow analyses with relevance to hydrological landscape regions'' section) describes how the hydrologic landscape regions are related to base flow index and base flow volume in the conterminous United States. Results and inferences made from both of these parts are discussed in ''Results and discussion'' section.

Methodology

Estimation of base flow index for the conterminous United States

In general, base flow is estimated through hydrograph analysis by separating streamflow into surface runoff and base flow. The separation is often estimated by using standard analytical methodologies or tracer techniques or a mass balance approach (Pinder and Jones, 1968; McCuen, 1989). Several analytical methods have been developed to separate base flow from streamflow. Neff et al. (2005), Scanlon et al. (2006) and Nolan et al. (2007) reviewed the relative merits of several base flow separation methods including recursive digital filter methods. Although, most of these methods are based on physical reasoning, exact separation of the streamflow hydrograph into surface flow and ground water flow is difficult and time consuming, especially, if