Regression models for estimating mean annual and low flows from Skagit tributaries

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Context and Objectives

Mean annual and low flows (2-year 7-day) for Skagit River tributaries are useful for a variety of applications, including the establishment of in-stream flow requirements. This brief report documents the development of two relatively simple regression equations that may be useful for such purposes.

Because runoff characteristics are known to vary considerably between basins, we focused on methods that would be well suited to small to moderate-sized Skagit tributaries with basins less than 100 mi^2. We determined initially that an ideal method would utilize empirical regression models based on local flow data. For ease of implementation, we judged that such a method should not require more than a small number of basin attributes that could be easily determined from topographic maps and/or GIS information. These limitations eliminated from consideration any physically-based hydrologic models, which would be prohibitively data intensive, or annual or shorter time-steps models.

Methods

Our analysis began with compiling all historical flow data (Williams et al. 1985 and USGS web-site) from suitable USGS stations. All selected gages are within the Skagit or Samish River basins except for Deer Creek, which is adjacent to the Skagit basin. We identified 20 gages with a sufficient flow record for analyzing mean annual runoff ("MAR"), and 12 with published 2-year 7-day low flow values ("Q7L2"). All MAR and Q7L2 values were normalized by basin area (i.e. cfs divided by basin area) for analysis. The considerable differences in both values across the gaged basins precluded use of a single average value for the Skagit basin or for hydrologic regions (Beechie 1992). We did notice differences in runoff between basins with glacier runoff (about half of the gaged basins) and those without glaciers, however.

A handful of potential predictive variables were evaluated using regression analysis. We evaluated multiple-variable models using a "step-forward" selection approach. Predictive variables included: 1. Basin area, 2. Mean elevation, and 3. Mean annual precipitation ("MAP"), as determined from: a. PRISM data (Daly et al. 1998) and 2. the US Weather Service map (1965). We also considered whether or not basins have any glacial runoff.

Results

<u>Mean Annual Runoff Model</u>

Because we had minimal success predicting runoff for all basins, we analyzed glacial ($n = 9$) and non-glacial basins ($n = 11$) separately. Although we found no suitable model (all $r^2 < 0.10$) for the glacial basins, we did identify a good predictive model (adjusted $r^2 = 0.82$) for non-glacial basins (see Figure 1). Mean annual precipitation (PRISM version), the single predictive variable, was highly significant ($p<0.001$). No other basin attributes were significant (i.e. $p>0.10$).

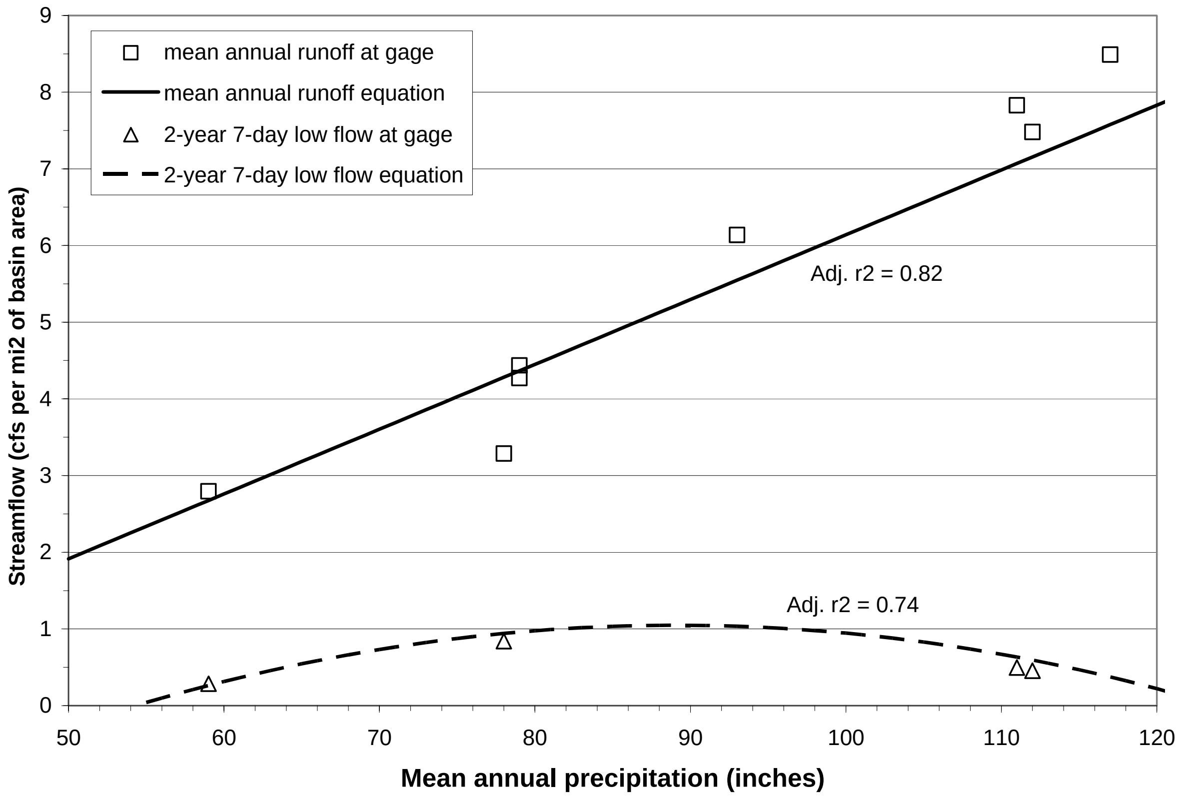

Figure 1. Plot showing gage values vs. model predictions of mean annual runoff and low flows for non-glacial Skagit tributaries.

The resulting regression equation for basins without glacial runoff is:

$$MAR = BA * ((0.0845 * MAP) - 2.31)$$

Where: MAR is mean annual runoff in cubic feet per second,
BA is basin areas in square miles, and
MAP is the mean annual precipitation (area-weighted over basin) in inches.

Low Flow Model

We developed a useful regression model (adjusted $r^2 = 0.74$) that predicts 2-year 7-day low flows reasonably for both glacial and non-glacial basins. The presence/absence of glacial inflow determines the value of the constant used, as shown below. The resulting model also incorporates mean annual precipitation, in both simple and quadratic forms, as a significant predictor ($p<0.01$):

$$Q7L2 = BA * ((0.154 * MAP) – (0.000867 * MAP^2) - C)$$

Where: Q7L2 is 2-year 7-day low flow in cubic feet per second,
BA is basin areas in square miles,
C is a constant = 5.83 for non-glacial basins or 5.36 for glacial basins, and
MAP is the mean annual precipitation (area-weighted over basin) in inches.

Users should be aware that application of the low flow model above for basins with mean annual precipitation outside the range of data (59 – 125”) will produce unrealistic results, as discussed further in the following section.

Application of Regression Models

Proper application of these models depends on accurate input information. Basin areas can be determined with adequate precision using topographic maps or a GIS (with digital elevation model). Similarly, determining the presence of glaciers in any portion of the basin can be determined from a USGS topo map (7.5 minute). An accurate determination of mean annual precipitation for the ungaged basin involves two key considerations. First, the models were based upon precipitation amounts generated using the PRISM model (Daly et al. 1998). Annual precipitation values from the widely-used US Weather Service (1965) map should not be used within either the above equations. Secondly, because annual precipitation varies within any given basin, an area-weighted composite value should be determined for each basin.

As for any empirical model, it is critical that the above regression models be applied to basins within the range of source data. All source data were from basins of less than 100 mi^2 with mean annual precipitation ranging from 59 to 125 inches. In particular, applying the Q7L2 model outside this precipitation range is problematic because it will likely produce negative flow estimates, which are physically nonsensical. For portions of the Skagit and Samish basin that are outside this precipitation range, other estimation methods will be necessary. In contrast, because the mean annual runoff model gives physically reasonable results somewhat outside the source precipitation range, slightly broader use may be justifiable so long as the greater uncertainty levels are recognized.

References

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