Closer Look at the Baseflow Correlation Method

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Abstract: In 2003, Reilly and Kroll examined the baseflow correlation method at river sites throughout the United States. The current study reexamines Reilly and Kroll's baseflow correlation experiment by investigating the use of different performance metrics, experimental parameters, and model assumptions that were not investigated by Reilly and Kroll. The goal of this study is to provide additional guidance on how to implement the baseflow correlation method in practice. The results confirm that baseflow measurements should be obtained during low flow seasons and as far as possible from runoff events. When one has only five baseflow measurements at the low-flow partial-record site, the correlation coefficient between baseflows at gauged and low-flow partial-record sites should be at least 0.9; when the number of baseflow measurements is 10 or more, the method performs adequately if the correlation coefficient is greater than 0.6. The performance of the baseflow correlation method improves as the number of baseflow measurements increases, but levels off dramatically when one has more than 10 measurements.

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Introduction

The estimation of low-flow statistics at low-flow partial-record sites is a common problem faced by hydrologists and engineers. Low-flow statistics are widely used in water quality management and water supply planning (Smakhtin 2001). The most widely employed low-flow quantile in the United States is the 7-day, 10-year low flow ($Q_{7,10}$), which by definition is the tenth percentile of the distribution of annual minimum 7-day average flows (Riggs 1980).

Regional regression is a common method used for estimating low-flow statistics at ungauged river sites (Smakhtin 2001; Kroll et al. 2004). However, this method often performs poorly in practice to estimate low flows (Thomas and Benson 1970; Barnes 1985; Hammett 1985; Arihood and Glatfelter 1986; Vogel and Kroll 1992; Ries 1994; Kroll et al. 2004). Riggs (1965, 1972) proposed correlating baseflow measurements obtained at the low-flow partial-record site with concurrent daily flows at a nearby gauged site as an alternative. Stedinger and Thomas (1985) proposed an improved *d*-day, *T*-year low-flow estimator and developed a first-order estimator of its variance. This technique is often referred to as the baseflow correlation method (Reilly and Kroll 2003).

Stedinger and Thomas (1985) examined the performance of the baseflow correlation method with 20 pairs of stream sites. Reilly and Kroll (2003) expanded this experiment to investigate its performance to estimate the $Q_{7,10}$ at more than 1,300 river sites across the United States. In the experiment by Reilly and Kroll, they employed streamflow sites from the USGS's Hydro-Climatic Data Network (HCDN) (Slack and Landwehr 1992); these streamflow sites are also employed in the current study. Reilly and Kroll concluded that the baseflow correlation method performs well in the United States when baseflow measurements are obtained by randomly choosing one baseflow measurement from consecutive recessions (referred to as the "recession" method) and the potential candidate gauged sites are restricted within 200 km. They also suggested using at least ten baseflow measurements. Their experiment supported the suggestion by Stedinger and Thomas (1985) that the correlation coefficient of concurrent baseflows between the gauged and low-flow partial-record sites should be at least 0.70.

The experiment performed by Reilly and Kroll (2003) required a number of experimental parameters. The current study revisits this baseflow correlation experiment and investigates the following experimental parameters and model assumptions:

- The impact of different performance metrics on the results of the experiment;
- When to take baseflow measurements at low-flow partial-record sites;
- How to designate streamflows as under baseflow conditions;
- The impact of the correlation coefficient between concurrent baseflows at the gauged and low-flow partial-record sites (ρ) and segment length;
- The assumption that the frequency factor at the low-flow partial-record site is equivalent to the frequency factor at the gauged site; and
- The assumption that the log-linear relationship between the annual minimums at the low-flow partial-record site and those at the gauged site is the same as the log-linear relationship between the concurrent baseflows at the two sites.

The results provide details as to the tradeoffs between the correlation coefficient and the number of required baseflow mea-

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surements in the baseflow correlation method. The results also provide additional guidance on how to implement the baseflow correlation method in practice.

Methodology

The baseflow correlation method proposed by Stedinger and Thomas (1985) is summarized in the following. This method has several basic assumptions. The first assumption of the baseflow correlation method is a linear relationship between y_i, the logarithm of the d-day annual minimum flows at a low-flow partial-record site, and those at a gauged site, x_i

$$y_i = \alpha + \beta x_i + \varepsilon_i, \quad \varepsilon_i \sim N(0,\sigma_\varepsilon^2) \tag{1}$$

where α and β=model parameters; and ε_i=independent normal error terms with a mean of zero and a constant variance, σ_ε^2.

Second, since annual minimum flows are not available for the low-flow partial-record site, it is assumed that the relationship between d-day annual minimum flows is similar to the relationship between instantaneous baseflows. This assumption is examined in this paper. Thus the linear relationship between the logarithm of baseflow measurements at the low-flow partial-record site, $\tilde{y}_i$, and the logarithm of corresponding baseflows at the gauged site, $\tilde{x}_i$, is given by

$$\tilde{y}_i = \alpha + \beta \tilde{x}_i + \varepsilon_i, \quad \varepsilon_i \sim N(0,\sigma_\varepsilon^2) \tag{2}$$

The third assumption is that the annual minimum streamflows are described by a log Pearson Type 3 (LP3) distribution. The LP3 distribution has been used by USGS for describing annual minimum streamflow series in the United States (Rumenik and Grubbs 1996; Wandle and Randall 1993; Barnes 1985). By this assumption, the logarithm of $Q_{7,10}$ at the low-flow partial-record site can be estimated by (Stedinger and Thomas 1985)

$$\ln(\hat{Q}_{7,10}) = \hat{\mu}_y + K_y \hat{\sigma}_y \tag{3}$$

where $\hat{\mu}_y$=estimator of the log-space mean; $\hat{\sigma}_y$=estimator of the log-space variance; and K_y=associated frequency factor for the LP3 distribution. The frequency factor is a function of the log-space skew of the 7-day annual minimum flows and the percentile of interest. In the baseflow correlation method, the frequency factor for the low-flow partial-record site, K_y, is assumed equal to the frequency factor for the gauged site, K_x, an assumption that is explored in this paper. Thus only estimators of $\hat{\mu}_y$ and $\hat{\sigma}_y$ are required; Stedinger and Thomas (1985) suggested the unbiased estimators

$$\hat{\mu}_y = a + b m_x \tag{4}$$

$$\hat{\sigma}_y^2 = b^2 s_x^2 + s_e^2\left(1 - \frac{s_x^2}{(L-1)s_{\tilde{x}}^2}\right) \tag{5}$$

where m_x and s_x^2=log-space mean and variance of the 7-day annual minimum flows at the gauged site, respectively; $s_{\tilde{x}}^2$=sample variance of the logarithms of the baseflows at the gauged site; L=number of concurrent baseflow measurements; and a, b, and s_e^2=ordinary least-squares estimators of the parameters α, β, and σ_ε^2 (Draper and Smith 1966) estimated using concurrent baseflow measurements. Stedinger and Thomas (1985) derived the variance of the $Q_{7,10}$ estimator as

$$\mathrm{Var}[\ln(\hat{Q}_{7,10})] \cong \frac{s_e^2}{L} + \frac{(m_x - m_{\tilde{x}})^2 s_e^2}{(L-1)s_{\tilde{x}}^2} + \frac{b^2 s_x^2}{n} + \frac{K_y^2}{4\hat{\sigma}_y^2}\left(\frac{4b^2 s_x^4 s_e^2}{L s_{\tilde{x}}^2} + \frac{2b^4 s_x^4}{n} + \frac{2s_e^4}{L}\right) + \frac{2b s_x^2 (m_x - m_{\tilde{x}}) K_y s_e^2}{L \hat{\sigma}_y s_{\tilde{x}}^2} \tag{6}$$

where n=number of years record at the gauged site.

Jackknife Simulation Experiment

The jackknife simulation experiment performed by Reilly and Kroll (2003) is outlined in the following. To assess the performance of the baseflow correlation method for estimating $Q_{7,10}$ at low-flow partial-record sites, this experiment is performed at gauged sites using the at-site $Q_{7,10}$ estimators derived from the historic record as "true" values. Each gauged site is sequentially selected as the site where the $Q_{7,10}$ is estimated using the baseflow correlation method. This site is referred to as the low-flow partial-record site hereafter. The sites with "true" $Q_{7,10}$ of zero (i.e., 10% or more historic 7-day annual minimums are zero) are excluded from this experiment. After D days of continuously decreasing streamflow, the streamflow at the low-flow partial-record site is designated as under baseflow conditions. Reilly and Kroll used D of 5 days; D of 3, 5, and 7 days is investigated in this study. A baseflow segment, which is a series of streamflows measured during baseflow conditions, is constructed at the low-flow partial-record river site. Reilly and Kroll employed streamflows during typical low flow months (July through October); here streamflows across a whole year are also considered. The number of streamflow measurements in the series is called the segment length. Segment lengths of 5, 10, 15, and 20 days were employed by Reilly and Kroll. Reilly and Kroll employed three methods for constructing baseflow segments: the "consecutive" method, which uses consecutive baseflow days; the "random" method using randomly selected baseflow days from consecutive years; and the "recession" method that employs one random baseflow day from consecutive baseflow recessions.

Potential candidate gauged sites are searched to find those that have baseflow conditions on the same days that comprise the baseflow segment. To investigate how to select a gauged site based on a simple criterion, i.e., the distance between the gauged site and low-flow partial-record site, three potential candidate gauged site selection methods are investigated: (1) sites within the same USGS water resources region; (2) sites within 100 km; and (3) sites within 200 km. The three methods are necessitated by the low density of HCDN sites in some regions; in practice one might find gauged sites much closer than 100 km. The number of candidate gauged sites for each segment is denoted as N. If the number of candidate gauged sites for the segment is greater than or equal to a specified value, the segment is designated as a valid segment. The baseflow correlation method is then used to estimate the $Q_{7,10}$ and its variance using each candidate gauged site. The estimator with the smallest variance is chosen as the best $Q_{7,10}$ estimate for the baseflow segment and compared to the at-site $Q_{7,10}$ estimate at the low-flow partial-record site. This process is repeated for all baseflow segments at the low-flow partial-record site. All other gauged sites are then sequentially designated as low-flow partial-record sites. The low-flow partial-record sites with at least one valid segment are designated as valid low-flow partial-record sites, which represent the subset of all sites used to assess the baseflow correlation method.

Performance Metrics

The performance metrics examined by Reilly and Kroll (2003) were average relative absolute difference (ARAD), relative bias, and root of relative mean-square error. The ARAD was primarily used in their analysis since it is easily interpretable as the average percent deviation from the "true value," where the true value is the at-site $Q_{7,10}$ estimate obtained using the historic record. The ARAD is calculated as

$$\mathrm{ARAD}=\frac{\sum_{i=1}^{M}\left(\frac{|\hat{Q}_{7,10i}-Q_{7,10}|}{Q_{7,10}}\right)}{M} \tag{7}$$

where $\hat{Q}_{7,10i}=i$th baseflow correlation estimate of the $Q_{7,10}$ at the low-flow partial-record site; $Q_{7,10}$=at-site $Q_{7,10}$ estimate obtained via a LP3 frequency analysis using the historic record; and M=number of valid segments. All of the metrics used by Reilly and Kroll consider relative errors, which reduce the influence of sites with large $Q_{7,10}$ values on the performance metrics. The problem with these metrics is that they can instead amplify the impact of sites with small $Q_{7,10}$ values at the expense of sites with large $Q_{7,10}$ values. To investigate the impact of the metric, results are stratified based on the magnitude of the at-site $Q_{7,10}$ estimates. The results of ARAD across the United States, with a segment length of 10 days, minimum N of 3, $\rho \geqslant 0.7$, D=5, low-flow months, and sites within 200 km, are shown in Fig. 1(a). It can be seen that the ARAD increases dramatically as the at-site $Q_{7,10}$ decreases, causing sites with small $Q_{7,10}$ values to dominate the results. The relative bias and root of relative mean square error have similar patterns as ARAD.

To create a more consistent performance metric that is less influenced by the magnitude of the observations, a number of additional performance metrics are investigated. This includes the absolute difference (AD) and unit area absolute difference (UAAD), which are computed at each low-flow partial-record site as

$$\mathrm{AD}=\frac{\sum_{i=1}^{M}|\hat{Q}_{7,10i}-Q_{7,10}|}{M} \tag{8}$$

$$\mathrm{UAAD}=\frac{\sum_{i=1}^{M}\left(\frac{|\hat{Q}_{7,10i}-Q_{7,10}|}{A}\right)}{M} \tag{9}$$

where A=drainage area of the low-flow partial-record site. These metrics are then aggregated across the conterminous United States as was explained in Reilly and Kroll (2003).

The results of AD across the United States, with a segment length of 10 days, minimum N of 3, $\rho \geqslant 0.7$, D=5, low-flow months, and sites within 200 km, are shown in Fig. 1(b). As expected, the sites with large $Q_{7,10}$ values dominate the AD results. If UAAD is instead used as the performance metric, Fig. 1(c) is obtained. While UAAD increases as the at-site $Q_{7,10}$ values increases, the trend is much less dramatic than when using AD. Though a unique best performance metric is not identified here, it is informative to investigate how conclusions vary as performance metrics vary. One should be particularly sensitive to performance metrics when a large range of true values is present, or the values are bounded (e.g., Kroll and Stedinger 1996). Here, the UAAD appears more consistent compared to the other two metrics examined, since it is not as dramatically impacted by the magnitude of $Q_{7,10}$ values and is thus better to assess method performance at river sites with a large range of streamflow discharges.

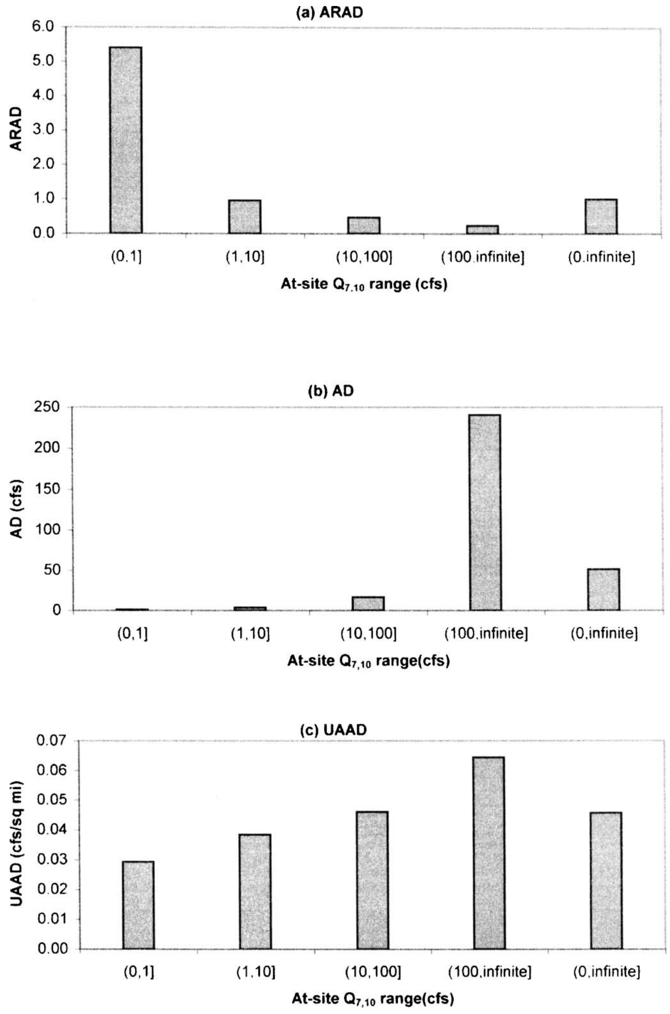

Fig. 1. The performance metrics for the United States with different $Q_{7,10}$ ranges for segment length of 10 days, minimum N of 3, $\rho \geqslant 0.7$, D=5, and sites within 200 km for: (a) ARAD; (b) AD; and (c) UAAD. The x-axis is the ranges of $Q_{7,10}$, i.e., $Q_{7,10}$ from 0 to 1 cfs, from 1 to 10 cfs, etc.

New Results for the United States

In this section, the original results of Reilly and Kroll (2003) are presented employing the UAAD. Of interest is whether conclusions change using this new metric. Though not presented here, the results indicate that the random and recession methods for compiling a baseflow segment perform much better than the consecutive method. These results, which are the same as those found by Reilly and Kroll, indicate the need for nearly independent baseflow measurements. Since one would typically not have the time to employ the random method, all results shown here are for the recession method, which one could employ in practice. Reilly and Kroll found that the gauged site selection methods had minimal impact on the method performance, and that sites within 200 km of each other generally performed as well as sites within

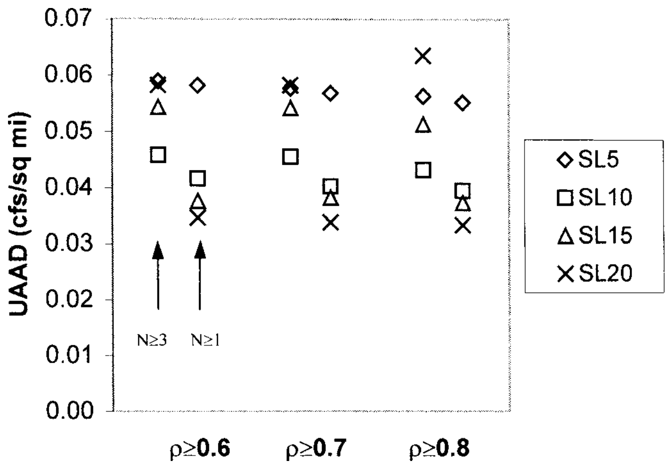

Fig. 2. UAAD for the United States with the recession method, $D=5$, and sites within 200 km, for $\rho \geqslant 0.6$, $\rho \geqslant 0.7$, and $\rho \geqslant 0.8$ and segment lengths of 5, 10, 15, and 20 days. The first, third, and fifth columns are for $N \geqslant 3$, whereas the second, fourth, and sixth columns are for $N \geqslant 1$.

100 km. We also found this result, and thus only results for sites within 200 km are presented.

The results for the recession method are shown in Fig. 2. The first, third, and fifth columns in Fig. 2 are the UAAD for $N \geqslant 3$, $D=5$, and $\rho \geqslant 0.6$, 0.7, and 0.8, respectively. Surprisingly, the conclusion that longer segment lengths (SLs) improve performance is not reached for SLs of 15 and 20 days when $N \geqslant 3$. In addition, contrary to Reilly and Kroll (2003), the results do not clearly show the pattern that the performance is improved by increasing the correlation coefficient when $N \geqslant 3$. The reason for these results may be due to the fact that the number of valid segments is very small for long segment lengths when the minimum N is equal to 3. Table 1 contains the percentage of valid sites and average valid segments per site for gauged sites within 200 km, $\rho \geqslant 0.6$, $D=5$, and $N \geqslant 3$. It can be seen that there are only 20 valid sites for a segment length of 20 days with 1.3 valid segments per site when $N \geqslant 3$.

To address this issue, the minimum N was instead set to 1. Thus only one candidate gauged site was necessary in order to have a valid baseflow segment. Table 2 contains the percentage of valid sites and average valid segments per site for gauged sites within 200 km, $\rho \geqslant 0.6$, $D=5$, and $N \geqslant 1$. For a segment length of 20 days, there are now 363 valid sites, and the average number of valid baseflow segments per site is 3.7. Using a minimum N of 1 greatly increases the number of valid segments employed in the jackknife experiment.

Table 1. Impact of Segment Lengths on Valid Sites Used for the Analysis of the Recession Method, Using Gauged Sites within 200 km, $\rho \geqslant 0.6$, $D=5$, and $N \geqslant 3$

Segment length (days)	Valid sites	Percentage of valid sites	Average valid segments per site
5	1,249	90.2	53.7
10	689	49.7	7.3
15	213	15.4	2.5
20	20	1.4	1.3

Table 2. Impact of Segment Lengths on Valid Sites Used for the Analysis of the Recession Method, Using Gauged Sites within 200 km, $\rho \geqslant 0.6$, $D=5$, and $N \geqslant 1$

Segment length (days)	Valid sites	Percentage of valid sites	Average valid segments per site
5	1,338	96.6	95.7
10	1,198	86.5	19.6
15	823	59.4	7.6
20	363	26.2	3.7

The second, fourth, and sixth columns in Fig. 2 are the UAAD across the entire United States for $N \geqslant 1$, $D=5$, $\rho \geqslant 0.6$, 0.7, and 0.8, respectively. The surprising results observed with $N \geqslant 3$ are no longer present. For instance, as the segment length increases, the performance of the baseflow correlation method improves for all ρ. In addition, as the ρ increases, the method performance also increases, as one would expect. The results show that the minimum N value had a large impact on the performance of the baseflow correlation method for large segment lengths as the number of valid segments is increased considerably by using a minimum N of 1. Therefore, the minimum N is taken as 1 for subsequent results in this paper.

Based on the new results using UAAD, it appears that having $\rho \geqslant 0.6$ performs nearly as well as when $\rho \geqslant 0.7$ and 0.8, regardless of the segment length. One reason for this may be due to the fact that sites with $\rho \geqslant 0.7$ and 0.8 are included in the results for $\rho \geqslant 0.6$, and thus there is duplicate information in these results. The impact of ρ on the baseflow correlation method is further investigated in this paper in the section entitled "The Impact of Correlation Coefficient (ρ)."

When to Take Baseflow Measurements

Reilly and Kroll (2003) only employed flow records during the typical low flow months of July through October as annual low flows occur in most regions of the United States during this period. As most streamflow sites annually have only 5–10 streamflow recessions of adequate length during the low flow months, it will take a number of years to gather enough baseflow measurements to implement the baseflow correlation method. One way to reduce this time is to take baseflow measurements throughout the entire year, an issue not investigated by Reilly and Kroll. The impact of using all the flow records across the entire year is investigated in this section. The results are shown in Fig. 3. It is

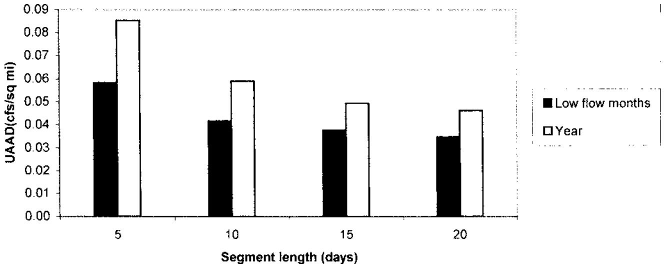

Fig. 3. The impact of using flow record of an entire year ("Year") and low-flow months for the recession method, gauged sites within 200 km, $\rho \geqslant 0.6$, $D=5$, and $N \geqslant 1$

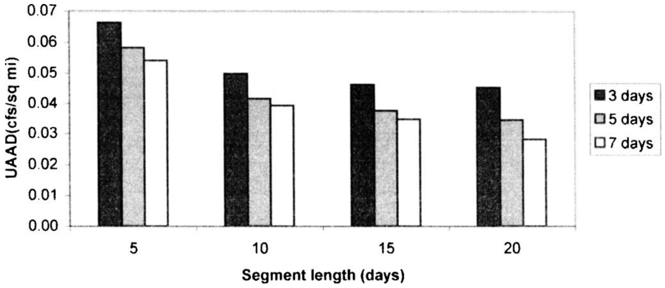

Fig. 4. The impact on UAAD of D, the number of days of continuously decreasing flows to designate baseflow conditions, for the recession method, using gauged sites within 200 km, $\rho \geqslant 0.6$, and $N \geqslant 1$

easy to see that the baseflow correlation method performs much worse when the flow records across an entire year are used than when the flow records during low flow months are employed. These results confirm that the baseflow measurements should be taken during the low flow months, from July through October, in the United States. All subsequent results in this paper are for the low flow months.

How to Designate Baseflows

Reilly and Kroll (2003) designated streamflows at a low-flow partial-record site as baseflows after 5 days of continuously decreasing streamflow ($D=5$). The impact of the number of days of continuous decreasing streamflow (D) is investigated in this section. The experiment is repeated for D of 3, 5, and 7. The results are shown in Fig. 4. The method performance is improved as the number of days of continuous decreasing streamflow increases. This result indicates that the method performs better as the baseflow measurements are obtained further away from runoff events, though results are more similar when D is 5 and 7 than when D is 3 and 5.

Impact of Correlation Coefficient (ρ) and Segment Length

To examine the impact of ρ, the UAAD is computed based on stratifying ρ. The results are shown in Fig. 5, where UAAD has ranges of ρ of 0.6–0.7, 0.7–0.8, 0.8–0.9, and 0.9–1.0. This result shows the pattern that the UAAD decreases as ρ increases. Fig. 5 allows one to examine the trade-off between segment length and ρ. For instance, if a segment length is 5 days and $\rho \geqslant 0.9$, the baseflow correlation estimator is nearly as good as when the segment length is 10 days and ρ is between 0.6 and 0.7. These results indicate a large improvement when the segment length increases from 5 to 10 days, but only minimal improvement when the segment length is greater than 10 days. It also shows that the method performance is more sensitive to ρ when the segment length is small. Although having a large ρ produces a better baseflow correlation estimator, these results indicate that only a slight increase in performance is observed when ρ is greater than 0.6 for a segment length of 10 days or more.

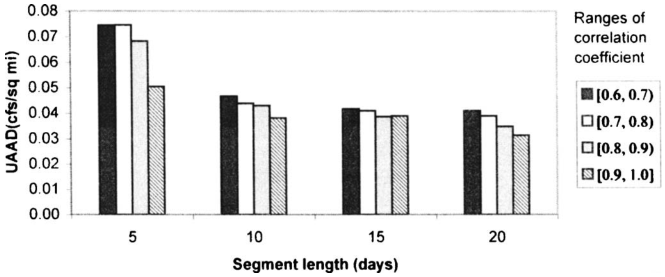

Fig. 5. The impact on UAAD of magnitude of correlation coefficient (ρ) and segment length for recession method, using gauged sites within 200 km, $D=5$, and $N \geqslant 1$.

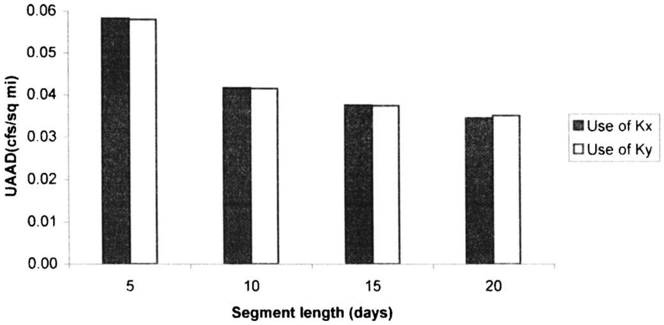

Fig. 6. The impact on UAAD of frequency factor for the recession method, using gauged sites within 200 km, $\rho \geqslant 0.6$, $D=5$, and $N \geqslant 1$

Assumption of Equivalent Frequency Factor

One assumption of the baseflow correlation method is that the frequency factor for the low-flow partial-record site, K_y, is equal to the frequency factor for the gauged site, K_x. To investigate this assumption, the jackknife experiment is repeated, but instead of using the frequency factor from the gauged site in Eq. (3), the at-site frequency factor from the low-flow partial-record site (K_y) is employed. Although K_y is not available in practice, this experiment allows us to examine the impact of employing K_x in the baseflow correlation method. The results are shown in Fig. 6, which shows that the assumption of equivalent frequency factors for the gauged site and low-flow partial-record site turns out to be a good one. This result may be due to the log-skew being relatively constant at HCDN sites that are within 200 km of each other.

Assumption of Same Log-Linear Relationships

An additional assumption investigated here is that the log-linear relationship between the 7 day annual minimum flows of the low-flow partial-record site and the gauged site is the same as the log-linear relationship between the baseflow measurements at the low-flow partial-record site and the concurrent baseflows at the gauged site. To investigate this assumption, the estimators of α and β in Eqs. (1) and (2) (a and b) are estimated using all annual minimums and all concurrent baseflow measurements at pairs of sites across the United States. Only sites with at least 40 years of concurrent record within 200 km of each other are employed. The results are shown in Figs. 7 and 8, for a and b, respectively. The x-axis is the estimate using the concurrent baseflow measurements and the y-axis is the estimate using the annual minimums. There is indeed a cloud of points in Figs. 7 and 8. Though some estimates using the annual minimums are different from the esti-

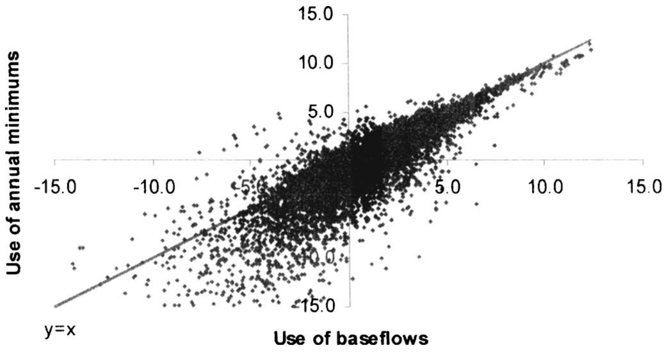

Fig. 7. Estimates of *a* using annual minimums and concurrent baseflows

mates using the concurrent baseflow measurements, most estimates are similar. An investigation (not presented here) shows that this relationship is not impacted by the strength of correlation of the baseflows, or by the ratio of watershed characteristics at the gauged and low-flow partial-record sites, such as the magnitude of the flows, drainage area, and stream length. In addition, a linear model was fit in Figs. 7 and 8 by line of organic correlation (Hirsch and Gilroy 1984). The resulting models were then employed to estimate *a* and *b* for the annual minimums as a function of *a* and *b* from baseflow measurements, and these values were then used in the baseflow correlation method. Unfortunately, the baseflow correlation method performed worse using this technique. This may be due to the fact that the regression line adjusts the estimates of *a* too much when the original estimates of *a* are close 0, which occurs at many sites. In addition, *a* and *b* are in log-space, and thus the impact of this model adjustment is amplified when transforming the data back to real space. Further investigations of this assumption are warranted.

Conclusions

On the basis of this experiment, the following conclusions of Reilly and Kroll (2003) are supported:

- Nearly independent baseflow measurements are needed, as the consecutive method to obtain baseflow measurements performs much worse than the random and recession methods. The recession method of picking one baseflow measurement from consecutive recessions represents a reasonable and practical way to obtain baseflow measurements.
- The gauged site selection methods did not have an impact on method performance in this experiment. This may be due to the sparseness of HCDN gauges in many portions of the country.
- The performance of the baseflow correlation method improves as the number of baseflow measurements increases. However, some leveling off of performance is observed with more than ten baseflow measurements.

In addition, this experiment provides guidance on how and when to take baseflow measurements at low-flow partial-record sites. The following new conclusions are reached in this investigation.

- Unit area performance metrics are less impacted by the magnitude of $Q_{7,10}$ values compared with metrics measuring relative or absolute errors.
- The method performance is most sensitive to the correlation coefficient between the baseflows when only five baseflow measurements are employed; with more baseflow measurements the correlation coefficient has less impact on the method performance.
- The method performs well if the correlation coefficient is greater than or equal to 0.6 for 10 or more baseflow measurements. With five baseflow measurements, a correlation coefficient of at least 0.9 is needed to obtain similar results.
- The baseflow measurements should be obtained during the low flow season, defined as July through October in this study.
- Ideally baseflow measurements should be taken as far as possible from runoff events, though in general the stream should have at least 5 days of continuously decreasing streamflow.
- The assumption of equivalent frequency factors between the gauged and low-flow partial-record sites has little impact on the baseflow correlation method.
- The assumption of the same log-linear relationship between annual minimums and baseflows generally appears reasonable, though in some cases wide variations are observed.

One problem with this analysis is that the HCDN river sites are sparsely distributed across the United States. Further evaluation of the baseflow correlation method is warranted for regions with a denser network of river sites. As the metrics used in the current research are always averaged across the United States and the baseflow correlation method performance varies in different regions, further regional investigations of the baseflow correlation method may be valuable. In addition, information from simultaneously employing multiple gauged sites may improve the baseflow correlation method. These issues are being explored by the writers in further analyses of the baseflow correlation method.

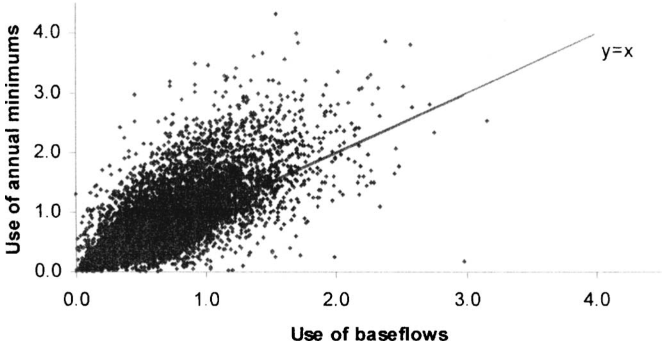

Fig. 8. Estimates of *b* using annual minimums and concurrent baseflows

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