Quantifying the Variability of Baseflow of Watersheds For The Chesapeake Bay

UMBC REU Site: Interdisciplinary Program in High Performance Computing
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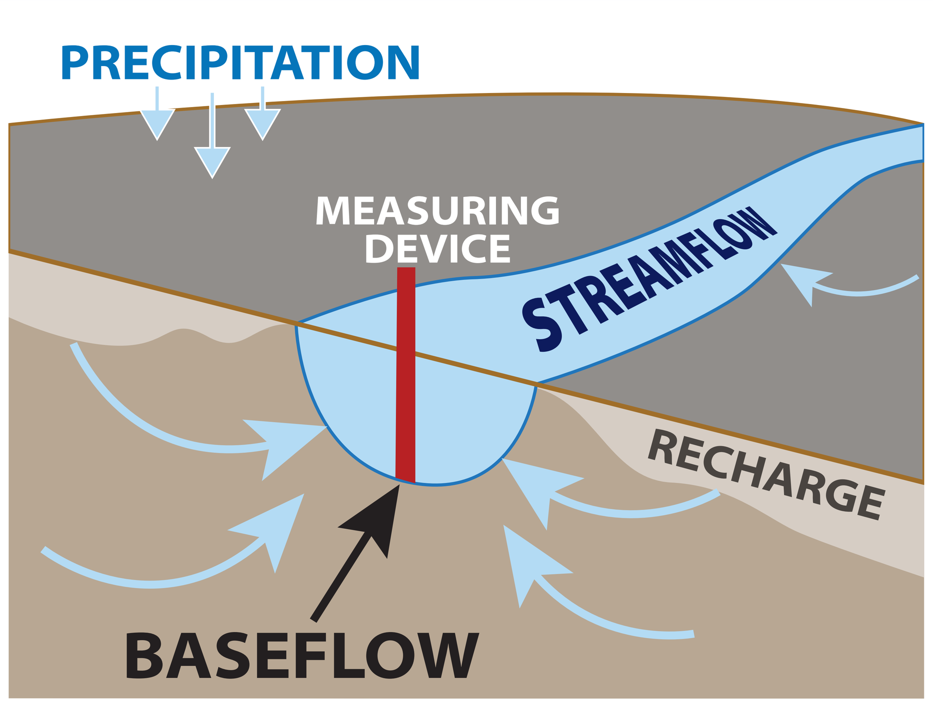
Introduction

The U.S. Geological Survey National Water-Quality Assessment Project conducted a study to estimate base flow. Baseflow is the estimated volumetric discharge of water, primarily from groundwater sources, that is relayed to the measurement sites. We explore the estimation of variability of the baseflow using two methods: the bootstrap method and the delta method.

Baseflow



Purpose

Calculating the variability of baseflow is important:

- make informed decisions about water regulation
- address question of aquatic ecosystems to environmental changes

Data

USGS National Water-Quality Assessment Project

- Conducted a study of 225 sites in the Chesapeake Bay watershed
- Data ranges from 1913 to 2016
  - Collected daily-mean streamflow per site
  - Estimated baseflow per site
- Goal was to evaluate and improve baseflow estimation methods

Recursive Digital Filter

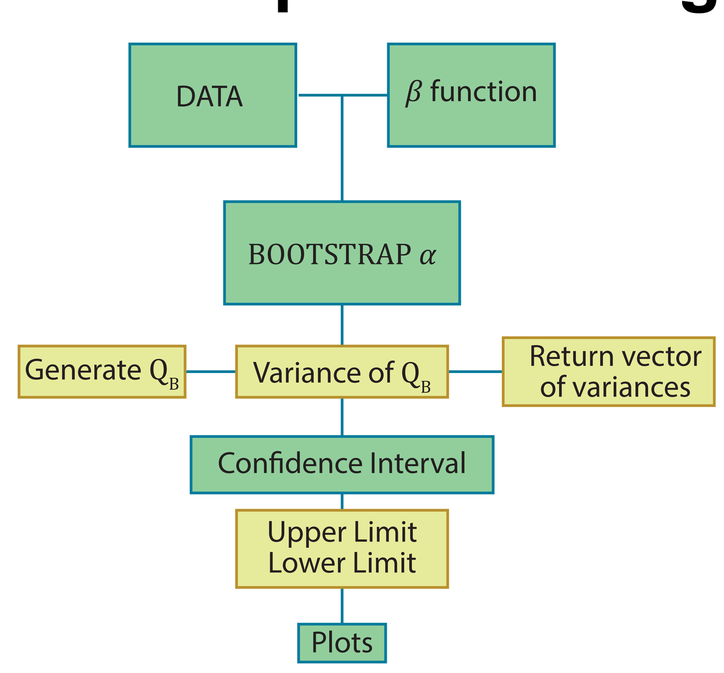
$$Q_{Bj} = \frac{[(1-\beta)\alpha Q_{Bj-1} + (1-\alpha)\beta Q_j]}{(1-\alpha\beta)}$$

$\alpha :=$ recession constant,
$\beta :=$ maximum base-flow index,
$Q_j :=$ streamflow (L^3/t),
$Q_{Bj} :=$ baseflow (L^3/t),
$j :=$ index of time step (day).

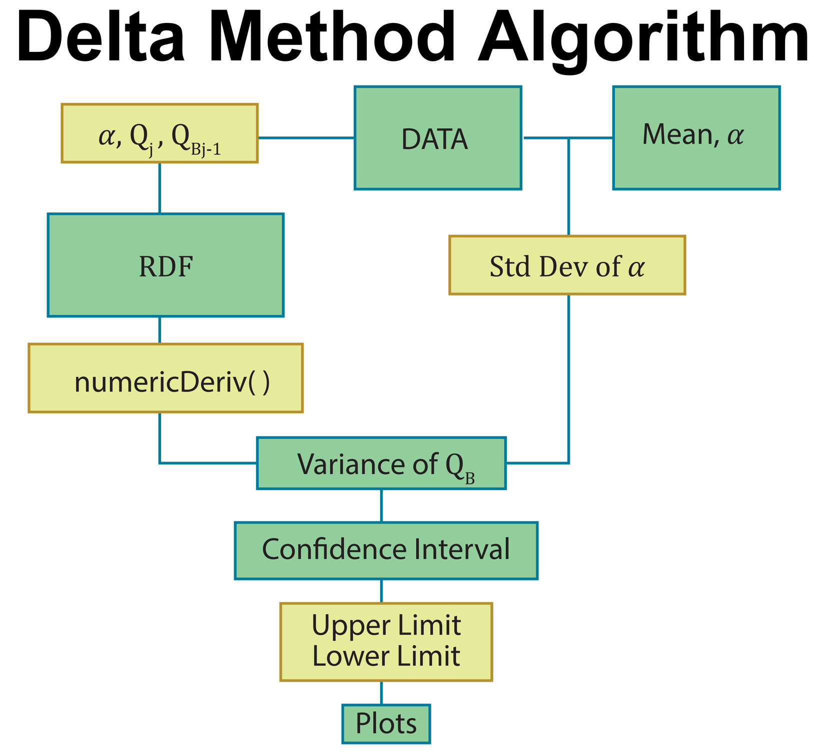
GOAL: Assume Q_J is constant, Quantify variance of α and Q_B.

Statistical Methods

Bootstrap Method Algorithm



Delta Method Algorithm



Explicit Function

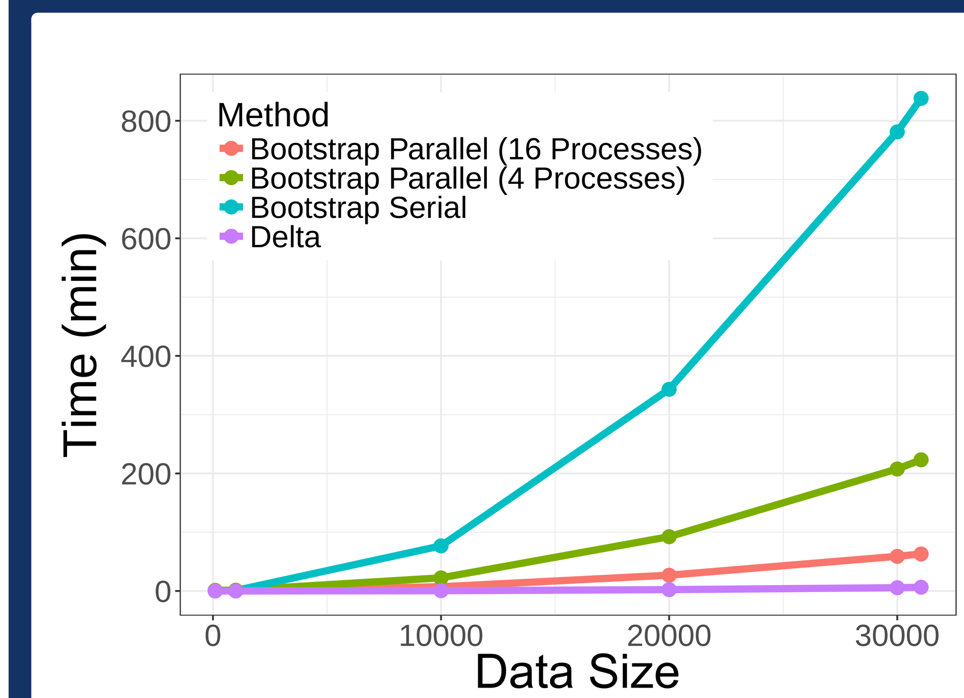
$$Q_{Bj} = \tau_1^j Q_{B0} + \sum_{i=1}^{j} \tau_1^{j-i}\tau_2 Q_j$$

where,

$$\tau_1 = \left[\frac{(1-\beta)\alpha}{1-\alpha\beta}\right]$$

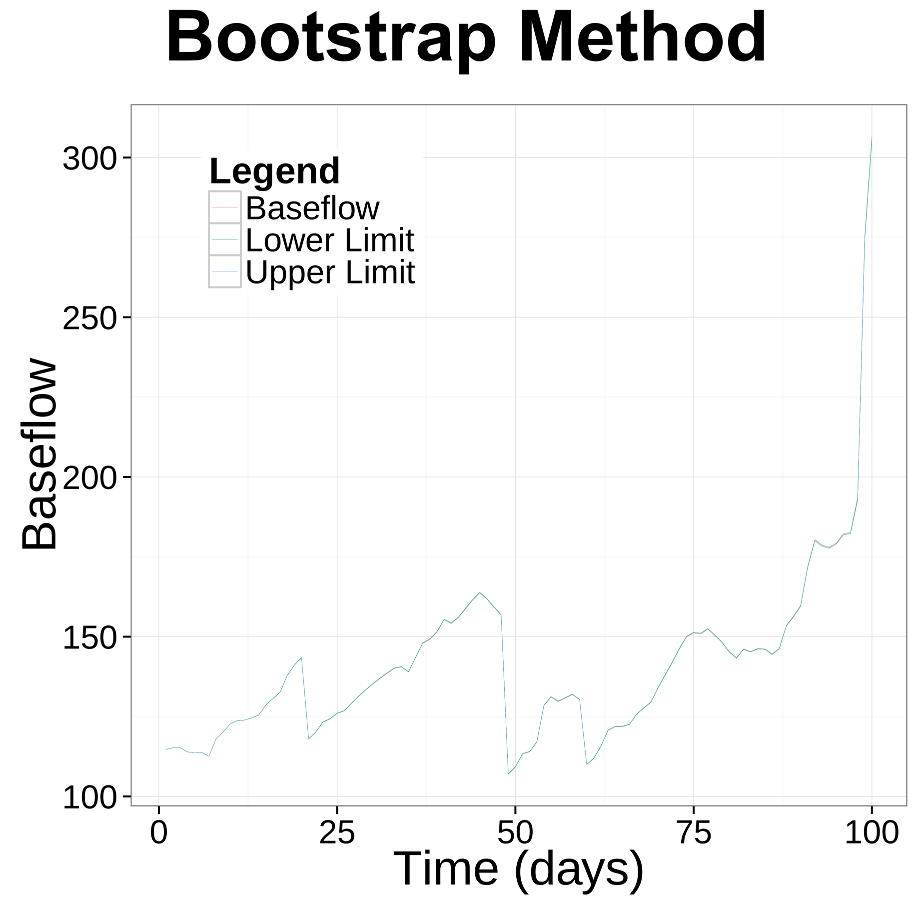
$$\tau_2 = \left[\frac{(1-\alpha)\beta}{1-\alpha\beta}\right].$$

Performance Study



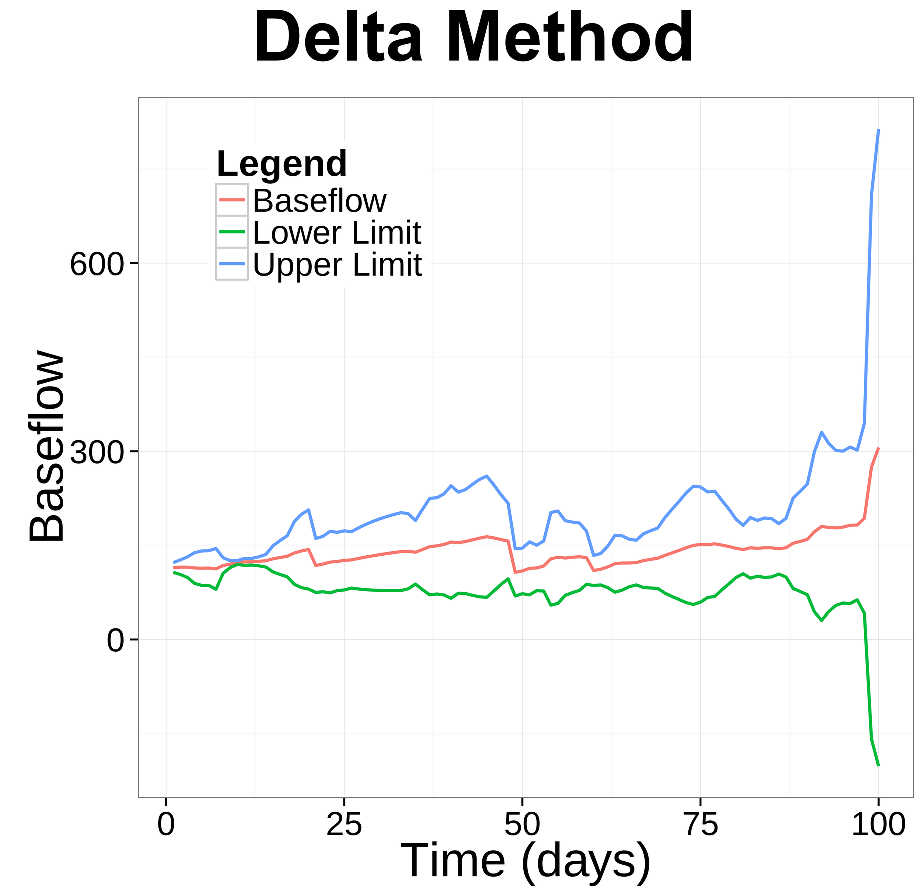
Variability of Baseflow for 100 days

Bootstrap Method



The three lines are not discernible.

Delta Method



Large variances are produced.

Results & Discussion

95% confidence interval

- Delta method has greater margin of error
- Averages:
  - Bootstrap Method: 538.8 $(L^3/t)^2$
  - Delta Method: 447,326.7 $(L^3/t)^2$

Bootstrap Method

- Variability using median of α values is negligible.
- Small margin of error implies variability around baseflow is negligible.

Delta Method:

- Results show larger variance.
- Q_{Bj} is non-continuous function.
  - Denominator $(1-\alpha\beta)$ produces zero when $\alpha\beta \to 1$.
- Method not recommended.

Random Streamflow

- Measuring method of streamflow is unknown.
  - Contributes to baseflow variability

$$Var(Y) = Xcov(\underset{\sim}{\epsilon})X^{\mathsf{T}} + \gamma^{\mathsf{T}}cov(X)\gamma$$

$$X = [\tau_1^j,\ \tau_1^{j-1}\tau_2,\ \cdots,\ \tau_1\tau_2,\ \tau_2]$$
$$\gamma = [\mu_0,\ \mu_1,\ \cdots,\ \mu_{j-1},\ \mu_j]^{\mathsf{T}}$$
$$\underset{\sim}{\epsilon} = [e_0,\ \epsilon_1,\ \cdots,\ \epsilon_{j-1},\ \epsilon_j]^{\mathsf{T}}$$

$cov(X)$ & $cov(\underset{\sim}{\epsilon})$ are covariance matrix of X and $\underset{\sim}{\epsilon}$ with size $(j+1)\times(j+1)$. (See Ref. 3)

References

[1] Raffensperger J.P. et al. Technical Report 5034, USGS, 2017.

[2] K. Eckhardt. *Wiley InterScience*, 2005.

[3] Technical Report HPCF–2017–12, hpcf.umbc.edu > Publications.

Acknowledgements

- REU Site: `hpcreu.umbc.edu`
- NSF, NSA, DOD, UMBC, HPCF, CIRC, USGS