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baseflow: a MATLAB and GNU Octave package for baseflow recession analysis

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Summary

`baseflow` is a MATLAB® (MATLAB, 2020) toolbox that facilitates baseflow recession analysis, a set of methods used in hydrologic science to infer aquifer properties that cannot be measured directly (Brutsaert & Nieber, 1977). The widespread availability of streamflow measurements means that baseflow recession analysis can be used to estimate aquifer properties and their variations globally over the modern instrumental stream gage record. This toolbox offers easy-to-use functions for baseflow recession analysis using measured values of streamflow recorded on a daily timestep. It is primarily designed for shallow (depth « breadth) unconfined riparian aquifers that discharge groundwater laterally into adjacent stream channels, rather than confined aquifers or complex geologic structures which require specialized numerical groundwater models. The toolbox can also be used to study the collective behavior of individual hillslope aquifers that constitute hydrologic catchments, known as "watersheds," using a non-linear dynamical systems perspective (Kirchner, 2009). By leveraging recent advancements in the baseflow recession analysis literature (Dralle et al., 2017; Roques et al., 2017), `baseflow` enables consistent, objective estimation of unconfined hillslope aquifer properties and conceptual catchment-scale aquifer properties.

Statement of need

Baseflow is a vital component of streamflow that originates from groundwater sources rather than rainfall, surface water, or managed reservoir release (Hall, 1968). Baseflow plays a crucial role in sustaining water availability during dry seasons, particularly in systems lacking surface water storage (Cooper et al., 2018). The shape of the baseflow recession curve can provide insights into the physical properties of aquifers, which are geological structures that store and release groundwater to rivers (Brutsaert & Lopez, 1998; Troch et al., 2013). However, inferring the presence and amount of baseflow is a challenging task as it requires specialized algorithms involving signal processing, curve-fitting, and parameter estimation, using measured values of streamflow that are often contaminated by measurement error (Dralle et al., 2017).

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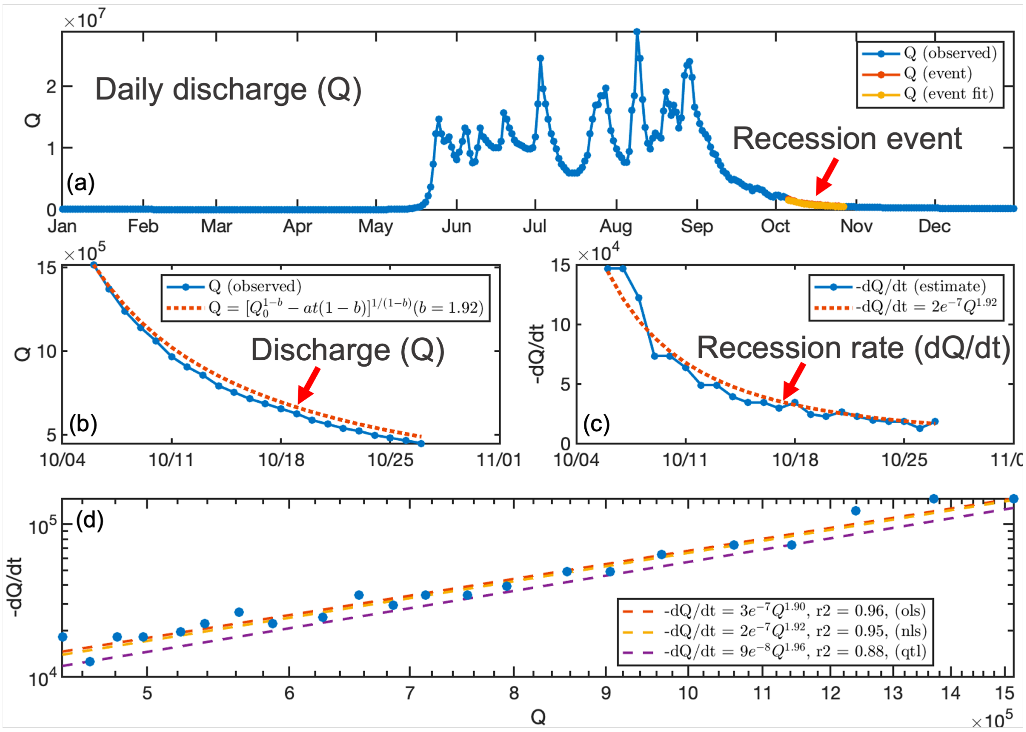

Figure 1: Example of baseflow recession analysis, the core functionality of the 'baseflow' toolbox.

The `baseflow` API was designed to provide a user-friendly interface for common baseflow recession analysis tasks such as event detection, parameter fitting, probability-distribution fitting, and visualization (Figure 1). The toolbox emphasizes the non-linear nature of streamflow, which can arise from rate-dependent hydraulic properties (Rupp & Selker, 2006), or the nonlinear collective behavior of hillslope aquifer units that comprise hydrologic catchments (Harman et al., 2009). `baseflow` is intended for use by researchers in the hydrologic sciences (Cooper et al., 2023) and serves as the foundation for ongoing investigations into changing groundwater storage capacity in Arctic and Subarctic catchments resulting from permafrost thaw.

State of the field

Recent developments in publicly available software packages for baseflow recession analysis have provided hydrologists with objective and repeatable methods for estimating baseflow parameters (Arciniega-Esparza, 2018; Dralle et al., 2017; Gnann et al., 2021). This is important because baseflow recession analysis is sensitive to methodological decisions that are often poorly documented. Among the reviewed packages, there is a shared focus on estimating the canonical parameters of the event-scale recession equation:

$$-\frac{\mathrm{d}Q}{\mathrm{d}t} = aQ^b \tag{1}$$

where Q is streamflow, t is time, and recession parameters a and b determine the shape of the recession curve (Figure 1). This equation, which is used to determine the shape of the recession curve, relates the rate of change of streamflow to streamflow itself.

Two packages for baseflow recession analysis are available within the MATLAB ecosystem. `HYDRORECESSION` (Arciniega-Esparza et al., 2017; Arciniega-Esparza, 2018) is a MATLAB toolbox organized around a graphical user interface that provides methods to detect recession events and fit Equation 1. Relative to HYDRORECESSION, the baseflow toolbox offers additional features for aquifer property estimation, such as saturated aquifer thickness, saturated hydraulic conductivity, and drainable porosity. HYDRORECESSION and baseflow both provide methods libraries for fitting alternative forms of Equation 1 based on solutions to the one-dimensional lateral groundwater flow equation. baseflow could benefit from incorporating two of the four forms available in HYDRORECESSION and a graphical user interface for data exploration.

The Toolbox for Streamflow Signatures in Hydrology (TOSSH) (Gnann et al., 2021) provides recession event-detection and curve-fitting algorithms but is broader in scope than baseflow and HYDRORECESSION. For example, TOSSH provides automated estimation of several dozen quantitative metrics of streamflow known as "hydrologic signatures" including recession parameters a and b. It provides a narrower toolkit for estimating a and b, and limited options for interpreting their values in terms of hydraulic groundwater theory. However, TOSSH provides a unique capability for interpreting a and b empirically in terms of hydrologic signatures. Although baseflow is designed for hillslope- and catchment-scale aquifer characterization, it could benefit from a broader scope that includes methods for quantifying evapotranspiration, which significantly affects estimates of a and b (Jachens et al., 2020).

Unique functionality: power-law scaling of recession parameters

Development of the baseflow toolbox was motivated by the need to automate Pareto distribution fits to large-sample recession parameter ensembles, based on recent research (Cooper et al., 2023) that derived the Pareto transformation of Equation 1. baseflow provides the only automated Pareto distribution parameter fitting module for aquifer characterization that we know of. The toolbox accomplishes this by wrapping the function plfit, a Matlab function for fitting Pareto distributions which has been cited over 10,000 times (Clauset et al., 2009). This wrapper serves as a translator from the notation and functional forms of plfit to those of hydraulic groundwater theory. The Pareto-fitting method implemented in baseflow is especially important because it provides theoretically unbiased estimates of a and b for late-time aquifer drainage, which are necessary for obtaining meaningful estimates of aquifer properties from baseflow recession analysis.

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