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Research paper

HYDRORECESSION: A Matlab toolbox for streamflow recession analysis

Saúl Arciniega-Esparza[a], José Agustín Breña-Naranjo[a,*], Adrián Pedrozo-Acuña[a], Christian Mario Appendini[b]

[a] Instituto de Ingeniería, Universidad Nacional Autónoma de México, Cd. Universitaria, 04510 Coyoacán, Ciudad de Mexico, Mexico
[b] Instituto de Ingeniería, Universidad Nacional Autónoma de México, Sisal, Mexico

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ABSTRACT

Streamflow recession analysis from observed hydrographs allows to extract information about the storage-discharge relationship of a catchment and some of their groundwater hydraulic properties. The HYDRORECESSION toolbox, presented in this paper, is a graphical user interface for Matlab and it was developed to analyse streamflow recession curves with the support of different tools. The software extracts hydrograph recessions segments with three different methods (Vogel, Brutsaert and Aksoy) that are later analysed with four of the most common models to simulate recession curves (Maillet, Boussinesq, Coutagne and Wittenberg) and it includes four parameter-fitting techniques (linear regression, lower envelope, data binning and mean squared error). HYDRORECESSION offers tools to parameterize linear and nonlinear storage-outflow relationships and it is useful for regionalization purposes, catchment classification, baseflow separation, hydrological modeling and low flows prediction. HYDRORECESSION is freely available for non-commercial and academic purposes and is available at Matlab File Exchange (http://www.mathworks.com/matlabcentral/fileexchange/51332-hydroecession).

1. Introduction

Streamflow recession curves (SRCs) from hydrographs contain information about the dynamical behavior of the interaction between groundwater and surface water and the hydraulic properties of unconfined aquifers (e.g. Brutsaert and Nieber, 1977; Wittenberg, 1999; Dewandel et al., 2003). SRCs describe the rate at which the observed discharge in a stream declines between storm events, and for practical purposes they can be considered as a proxy for streamflow storage delay in catchments.

Analysing streamflow recession time series can be a complex task because of its common quasi-uniqueness nature. Indeed, after a storm event, the descending curve of a hydrographs is characterized by steep slopes due to the effect of surface and subsurface flow, and when such contributions become negligible the recession curve usually consists of milder recession rates that indicate the attenuation of outflow coming from shallow aquifers to the stream. However, in reality, different initial conditions of groundwater storage and spatial-temporal states of soil moisture wetness prior to a storm imply a wide array of recessions curves with multiple slopes. Nevertheless, when sufficient streamflow records are available, they provide useful information to characterize the storage-discharge relationship of a particular catchment (Aksoy and Wittenberg, 2011).

Several recession analysis methods (RAMs) based on analytical solutions and conceptual models have been established (e.g. Boussinesq, 1904; Maillet, 1905; Coutagne, 1948; Wittenberg, 1994) with the principal aim to study the storage-discharge relationship of catchments. Earlier studies of SRCs managed to isolate the variability of the recession shape by extracting a master recession curve out of the multiple observed curves (Barnes, 1939). However, Jones and Mcgilchrist (1978) and Anderson and Burt (1980) found that graphical techniques such as the master recession curve ignore the variability of storage depletion and obstruct the estimation of the transition point between direct runoff and baseflow. In order to avoid such issues, a parameterized methodology based on the relationship between streamflow (Q) and its decline rate (-dQ/dt) was proposed by Brutsaert and Nieber (1977) and widely used afterwards (Vogel and Kroll, 1992; Szilagyi et al., 1998; Kirchner, 2009; Wang and Cai, 2010; Beck et al., 2013).

To exclude the storm-runoff effect in the storage-discharge relationship, different techniques were developed to extract recession segments (Recession Extraction Methods or REMs) that primarily correspond to baseflow, such as the Vogel and Kroll (1992) method that uses segments from 3-d moving average decreasing streamflow time series and that removes when the difference between two consecutive daily values are higher than 30%; or Kirchner (2009) that used the complete

* Correspondence to: Instituto de Ingeniería, UNAM, Mexico City, Mexico.
E-mail addresses: sarciniegae@iingen.unam.mx (S. Arciniega-Esparza), jbrenan@ii.unam.mx (J.A. Breña-Naranjo).

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streamflow dataset with negative values of dQ/dt; meanwhile Aksoy and Wittenberg (2011) applied a model to find which decreasing segments of a given hydrograph correspond to groundwater outflow.

Established RAMs have been used for different purposes, such as: long-term seasonal changes and man-made effects in low flows (Wittenberg, 2003; Wang and Cai, 2010), drought detection (Kienzle, 2006; Stoelzle et al., 2012, 2014), groundwater hydraulic properties estimation (Szilagyi et al., 1998; Aksoy et al., 2001; Mendoza et al., 2003; Dewandel et al., 2003), trends in groundwater storage (Brutsaert, 2008; Sawaske and Freyberg, 2014), baseflow separation (Szilagyi and Parlange, 1998; Wittenberg, 1999; Brodie and Hostetler, 2005), low flows prediction (Aksoy and Bayazit, 2000; Aksoy et al., 2001) and baseflow regionalization (Peña-Arancibia et al., 2010; van Dijk, 2010; Beck et al., 2013). But as suggested by Stoelzle et al. (2013), streamflow recession analysis can be quite sensitive to the conceptual model applied, the criteria to extract the recession curve in a hydrograph and the parameter estimation technique (PET). Therefore, combining different methodologies can yield contrasting model results for hydrological modeling purposes (e.g. Stoelzle et al., 2012). For this reason, a software toolbox aimed at analysing streamflow recession curves under different criteria (type of model, best fit technique and initial conditions) was developed so it can be tested across a wide range of climates, landscapes and hydrogeological settings.

The HYDRORECESSION toolbox promotes the analysis of streamflow recession curves through a friendly-user platform composed of several recession extraction techniques, conceptual models and parameterization tools so a sensitivity analysis for a multiple variety of combinations can be performed. Also, for trends analysis purposes, the software allows to investigate the seasonality and long term temporal fluctuations of SRCs and its model parameters.

2. HYDRORECESSION: general aspects

The HYDRORECESSION toolbox is a Graphic User Interface written in Matlab version 2010b. This is a first version developed at the Institute of Engineering from the National University of Mexico (II-UNAM). The software consists of a group of functions that run through the GUI, and the code is open source for modifications. The friendly interface allows to make intuitive analysis for long datasets and its graphical library provides a large array of figure options. The software can read streamflow data stored in Excel compatible files (.xls,.xlsx,.csv) with a [day month year streamflow] structure. The current version of HYDRORECESSION can only handle daily streamflow files, but the possibility to read and analyse sub-daily information will be incorporated in the future (Table 1 and 2).

The main graphical user interface displayed by default when executing the toolbox is shown in Fig. 1 and it is composed of the following tabs, sub-windows and sub-figures:

Table 1
Recession Analysis Methods (RAMs) included in HYDRORECESSION.

Method	Storage-discharge relationship	Recession curve equation	Parameter estimation technique
Maillet (1905)	$S = Q/\alpha$	$Q_t = Q_0 e^{-\alpha t}$	Mean square error
Boussinesq (1905)	$S = \int f(Q)dt$	$Q_t = Q_0 (1 + n\, t)^{-2}$	Least squares
Coutagne (1978)	$\frac{dQ}{dt} = -aQ^b$	$Q_t = [Q_0^{1-b} - (1 - b)at]^{1/1-b}$	Lineal regression Lower envelope Data Binning
Wittenberg (1999)	$S = cQ^d$	$Q_t = Q_0 \left[1 + \frac{(1-d)Q_0^{1-d}}{cd} t\right]^{1/d-1}$	Mean square error

Table 2
Recession Extraction Methods (REMs) included in HYDRORECESSION. *editable features.

Method	Criterion	Minimum duration (days)*	Filter criterion (removed days)*	Exclusion of anomalous recession decline*
Vogel and Kroll (1992)	Decreasing 3-d moving average	10	First 30%	$\frac{Q_i - Q_{i+1}}{Q_{i+1}} > 30\%$
Brutsaert and Nieber (1977)	$dQ/dt<0$	6–7	First 3–4, last 2	$\frac{dQ_{t+1}}{dt} > \frac{dQ_t}{dt}$
Kirchner (2009)	$dQ/dt<0$	1	–	–
Aksoy and Wittenberg (2011)	$dQ/dt<0$	5	First 2	$CV > 0.20$

A) Data files: this sub-window shows all the datasets being loaded using the Graph tab.
B) Type of Analysis: this sub-window allows to perform the recession analysis throughout a combination of multiple, REMs (Vogel, Brutsaert, Aksoy-Wittenberg), RAMs (Maillet, Boussinesq, Coutagne, Wittenberg) and MPEs (Linear regression, Least Squares, Binning, Lower envelope). For non-linear models (Coutagne, Wittenberg), the toolbox includes the option to fix the power exponent in order to simplify the analysis as suggested by Wittenberg (1999). Model parameter estimation for the Coutagne model can be performed either using linear regression (Vogel and Kroll, 1992), lower envelope (quantile regression with 5% of the data under the envelope, see Brutsaert and Nieber, 1977) or data binning (Kirchner, 2009). Meanwhile, the parameters from the Maillet, Boussinesq and Wittenberg models can be fitted through the minimization of the mean square error with the Matlab global optimization toolbox. Finally, for model behavior and hydrological comparison purposes, time series units can be converted from m^3/s to mm/day.
C) Plot of the observed streamflow time series (in blue), with the extracted segments during every recession period highlighted (in black).
D) Plot of the results of the recession analysis (in a log-log scatter plot). Black dots correspond to streamflow recession data, red dots are the extracted segments (using any of the REMs) from the whole dataset, and the blue line is the fitted model.
E) Plot of quantitative comparison of the observed against the simulated recession curve under different REMs, RAMs and PETs. The black line is a 1:1 relationship.
F) Model parameters and performance: this sub-window shows the fitted parameters for the MAR. Three criteria can be used to assess the model performance (Table 3): determination coefficient, Willmott Index (Willmott, 1981) and the modified Nash-Sutcliffe coefficient (Krause and Boyle, 2005).
G) Master Curve: this sub-window generates a plot of the master recession curve extracted from the simulated recession curves using different RAMs and REMs.

3. HYDRORECESSION: description of the main tools

3.1. Data

This tab loads the data files and saves them in a Matlab database with the support of the following commands (highlighted in bold):

3.1.1. Load data files

Load data files loads the data files (in the following EXCEL format: