ground water

Computer Note/

A Visual Basic Spreadsheet Macro for Recession Curve Analysis

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Abstract

A Visual Basic program for an Excel spreadsheet was written to construct a master recession curve (MRC), using the adapted matching strip method, for recession analysis of ground water level time series. The program uses five different linear/nonlinear regression models to adjust individual recession segments to their proper positions in the MRC. The program can also be used to analyze the recession segments of other time series, such as daily stream discharge or stage. Some examples of field data from Croatia are used to illustrate the usefulness of its application.

Introduction

Recession analysis can be traced back to Boussinesq (1877) and Maillet (1905) who presented quantitative analysis of hydrograph recession and demonstrated the applicability of an exponential decay function. The simple exponential equation has also been used in many empirical studies and is today the most widely used equation for recession analysis (Tallaksen 1995).

The recession curve analysis extracts valuable information concerning storage properties and aquifer characteristics. Brutsaert and Lopez (1998) presented a recession slope analysis of low-streamflow hydrographs for estimating effective basin-scale hydrogeological parameters. Tallaksen (1995) presented a detailed review of recession analysis and its application. Recession analysis has proven useful in many areas of water resource planning and management, such as low-flow forecasting for the management of irrigation, water supply, hydroelectric powerplants, and waste dilution.

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In any given system, such as an aquifer or stream, individual recession segments recorded at different times may have different slopes depending on the variability in storage, evaporation loss, and recharge rates. In many cases, however, it is possible to compile individual recessions into a single recession curve that provides an average characterization of head, flow, or other observed variable response: the resulting construction is termed a master recession curve (MRC). Recession rates are strongly influenced by the antecedent conditions of the system, and thus the MRC represents the most probable recession scenario under a given situation (Nathan and McMahon 1990).

Traditionally, graphical methods have been used to construct an MRC (Toebes et al. 1969). The two most commonly used methods are the matching strip method (Snyder 1939) and the correlation method (Langbein 1938). In the matching strip method, which is based upon the simple exponential model, individual recession segments are plotted and adjusted horizontally until they overlap in the main parts (Toebes and Strang 1964). The MRC is constructed by visually fitting a model function to the set of individual recession segments to achieve the best fit. Nathan and McMahon (1990) presented a procedure adapted for semiautomated processing on a computer that extracts variable-length recession periods from the streamflow record and plots them in descending order on semilogarithmic scales. The operator then interactively shifts individual recessions along the ordinate axis until all the base flow recessions overlap in the desired fashion.

Arnold et al. (1995) presented a completely automated technique for constructing the MRC. The procedure was designed to automate a method to predict the slope of the base flow recessions using linear regression to adjust streamflow segments to their proper position in the MRC.

The adapted matching strip procedure presented in this paper uses five different linear/nonlinear regression models to adjust the segments to their proper position in the MRC. The historical acceptance and a wide use of a single exponential recession function in recession analysis can perhaps be partly attributed to the ease of construction and interpretation of semilogarithmic plots, since the recessions that obey the exponential decay function plot as a straight line on semilogarithmic graph paper (Nathan and McMahon 1990). As the simple exponential equation generally does not satisfactorily represent recession over a wide range of conditions, a Visual Basic (VB) spreadsheet macro was constructed using algorithms that offer four additional regression models, i.e., linear, logarithmic, second-order polynomial, and power in order to obtain the most appropriate quantitative expression for the MRC. The VB macro, with the automatic and objective methods, eliminates some of the subjective elements of recession analysis and encourages wider use. The platform chosen for the program (i.e., MS Excel) is widely accessible, and the user-friendly concept of the VB spreadsheet macro makes it easy to use.

Program Design

The VB macro simulates a graphical method of superimposing recession segments into overlapping positions using the adapted matching strip method. After defining the data-processing period and storing the data set in a new spreadsheet, the first computational step is time series segmentation (Figure 1), in which the continuous time series is divided into short segments corresponding to individual recession events. Recession segments are then rank sorted from the highest to the lowest according to the initial value of each recession segment. Segments' sorting is followed by date conversion that converts absolute time into relative time equal to zero at the beginning of each segment. The recession segment with the highest initial value, hereafter referred to as the first recession segment, is tested with five different regression models (trend lines) available in Excel ("Calculate A" in Figure 1), i.e., linear ($y = ax + b$), logarithmic ($y = a\ln x + b$), second-order polynomial ($x = ay^2 + by + c$), power ($y = bx^a$), and exponential ($y = be^{ax}$). Note that y designates ground water level, and x designates time. The second-order polynomial regression model takes the form $x = f(y)$ because $y = f(x)$ has a tendency to bend upward at the lowest values of recession segments, which is not desirable in predicting the lowest or extrapolated values. The model that best fits the first recession segment is selected and referred to as the first regression curve. A criterion used by computer programs to select the most appropriate model is coefficient of determination R^2 (Kirkup 2002; Montgomery and Runger 2003). Some authors refer to this coefficient as "goodness of fit" (Davis 2002). Values of R^2 range between 0 and 1

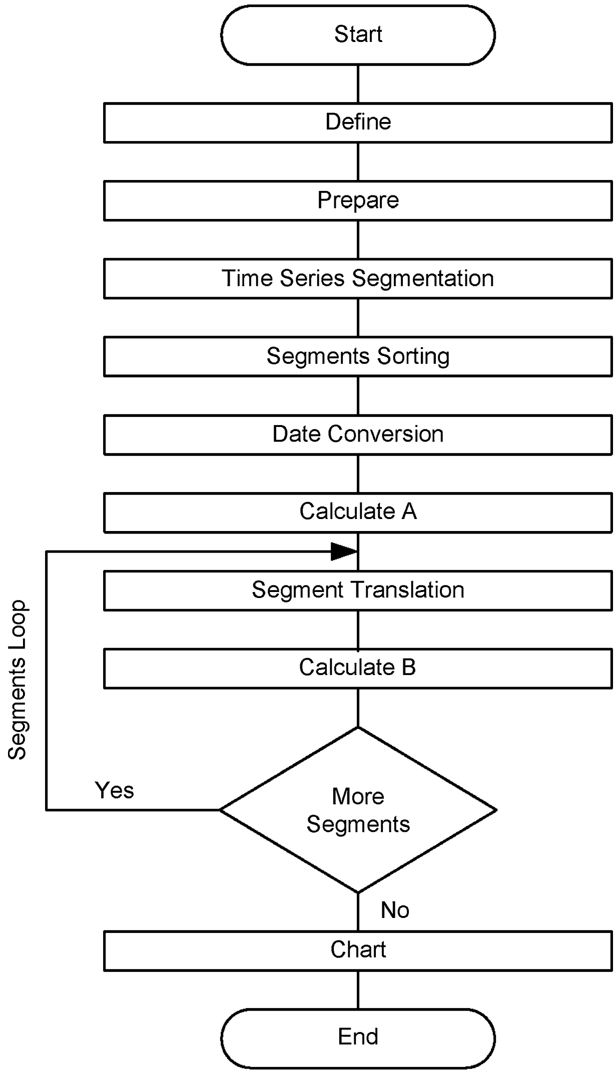

Figure 1. Program structure.

and indicate how well the trend line describes the data. The trend line is most reliable when R^2 is near 1.

After defining the first regression curve, the recession segment that has the second highest initial value (the second recession segment) is translated to its proper position in the first regression curve ("Segment Translation" in Figure 1) in the following manner: (1) program calculates the time shift required to place the initial point of the second recession segment on the first regression curve; for example, if the first regression curve is a logarithmic function ($y = a\ln x + b$), the time shift (x_2) is given by $x_2 = e^{(y_2-b)/a}$, where y_2 is the initial value of the second recession segment; (2) the matching relative times for the rest of the second recession segment are calculated by adding x_2 to relative times of the remaining values.

In the next step ("Calculate B" in Figure 1), the regression analysis is applied to the composite of the first and second segments using all five models, and the most appropriate regression model (the second regression curve) is selected. The third recession segment is adjusted to its proper position in the second regression curve in the same manner as described previously in steps 1 and 2 to generate the composite time series of the three segments.

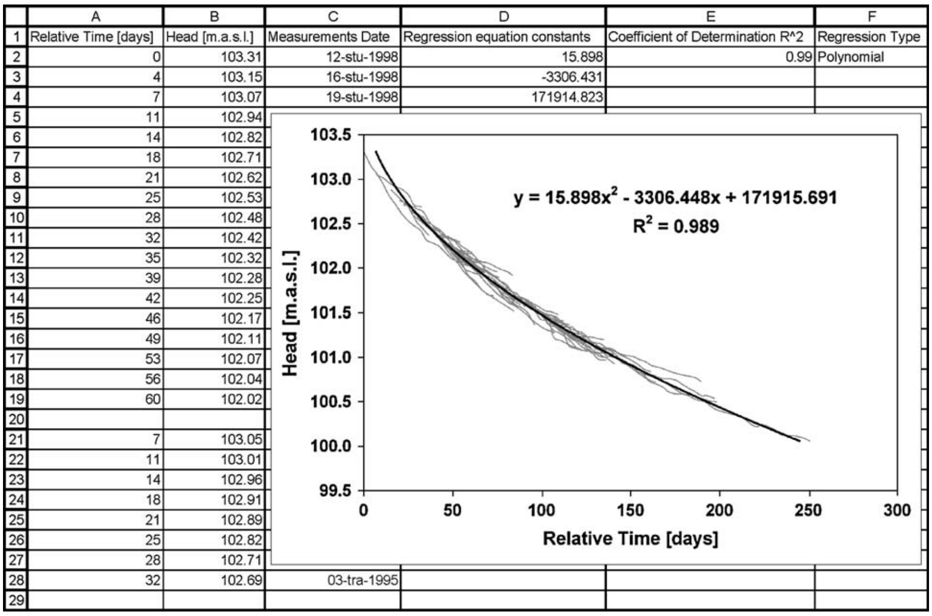

Figure 2. A spreadsheet example of the MRC of the ground water hydrograph for an observation well located in an unconfined alluvial aquifer, Zagreb, Croatia.

These steps are repeated ("Segments Loop" in Figure 1) until all recession segments are processed. Finally, the composite of all recession segments is described by the most appropriate regression model, which is the MRC.

The program produces a graph with all overlapping recession segments and an MRC at the end of the processing ("Chart" in Figure 1). Such a graph enables a visual check as to whether the selected regression model used to generate the MRC is appropriate. This is an effective way to examine the goodness of fit because the coefficient of determination R^2 can be large even when the linear/nonlinear approximation is poor (Montgomery and Runger 2003).

Examples

The first example (Figure 2) illustrates an MRC of an observation well located in an alluvial aquifer in the area of Zagreb, the Croatian capital. Columns A and B contain recession segments data with calculated matching relative times. Column C contains absolute times, i.e., measurement dates. Columns D, E, and F are constants of

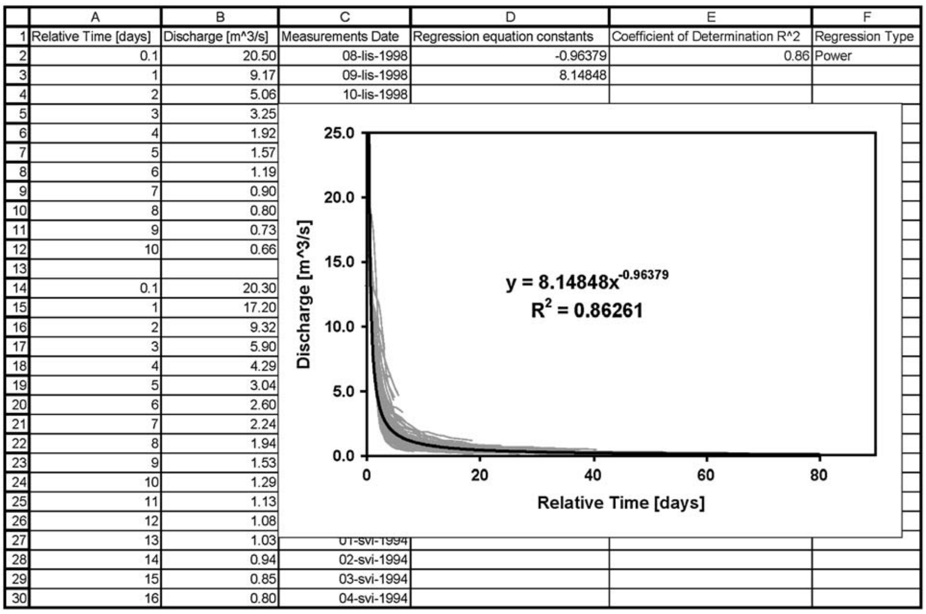

Figure 3. A spreadsheet example of the MRC of the hydrograph of Bulaž spring, Istria, Croatia.

the regression equation, the coefficient of determination, R^2, and type of regression model. The MRC was obtained by processing a 10-year (1994 to 2003) time series of ground water level.

The second example (Figure 3) illustrates an MRC of the Bulaž karst spring, located in Croatia. The recession curve was obtained by processing an 8-year time series (1994 to 2001) of daily discharge.

Conclusions

A VB program for spreadsheet analysis of an MRC is described and applied to two examples. The first example shows the MRC of an observation well located in an unconfined alluvial aquifer, while the second shows creation of the MRC of a karst spring.

In addition to its use for processing the time series of individual objects, after minor modifications the program can also be used for automated processing of time series measured at a set of *n* objects, which enables automated generation of MRCs for a large number of records.

The adapted matching strip method presented in this paper uses five different linear/nonlinear regression models in order to adjust the segments to their proper position in the MRC. The method is fast, reliable, and objective. This ensures consistency in the derivation and applicability for larger data sets.

Software Availability

The Excel spreadsheet with its open-access VB macro may be requested without charge via e-mail to the corresponding author.

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