

PROGRAM USER GUIDE FOR RECESS

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The program user should have these files....

curv.exe
Holiday.txt
index.txt
ranges.txt
recess.exe
recplot.exe
recsum.txt
screen.exe
station.txt
winter.ico

INTRODUCTION

PURPOSE

The RECESS program is used to determine the recession index and to define the master recession curve (MRC) from analysis of streamflow records. This manual describes a version of the program that reads data in a format that is available from USGS Web sites. This manual also describes the use of a graphics application RECPlot which can be used to view recession segments while the user is executing RECESS. RECESS can be used independently of this application which requires the windows operating system. This manual does not include complete explanation of the computer program; the reader is referred to an earlier report (Rutledge, 1998, pages 9-32).

BACKGROUND ABOUT RECESSION CHARACTERISTICS

The method described in this manual is intended for analysis of streamflow recession during times when no ground-water recharge is occurring, when all flow is from ground-water discharge, and when the profile of the ground-water head distribution is nearly stable. According to a model developed by Rorabaugh (1964), recession will be linear on a graph of the logarithm of flow as a function of time. The rate of recession can be expressed as the recession index, in days per log cycle. This variable is needed when the "Rorabaugh Method" is used to estimate recharge (Wilder and Simmons, 1978; Bevans, 1986; Gerhart and Lazorchick, 1988; Hoos, 1990).

Although the linear model of recession can be a reasonable approximation, there are a number of processes that will effect recession-curve shape, some causing departures from linearity (Horton, 1933; Werner and Sundquist, 1951; Riggs, 1964; Ineson and Downing, 1964; Toebes and Strang, 1964; Ibrahim and Brutsaert, 1965; Singh, 1969; Hornberger and others, 1970; Singh and Stall, 1971; Trainer and Watkins, 1974; Daniel, 1976; Nutbrown and Downing, 1976; Anderson and Burt, 1980; Petras, 1986; Szilagyi, 1999, Rutledge, 2002). Wood and others (1972) developed nonlinear master recession curves (MRC's) for several streams in eastern Pennsylvania, and Rutledge and Mesko (1996) used the RECESS program to derive a variety of MRC shapes in the Appalachian and Piedmont regions of the eastern United States. The description of recession can have a variety of applications in hydrologic studies, including the evaluation of aquifer properties and the sustainability of ground-water discharge.

Theoretically, characteristics of flow recession can be evaluated on the basis of ground-water-level information. This may require designation of the altitude of the outflow boundary. Because this altitude can vary along the length of the boundary (the stream), ground-water-level recession analysis may lead to a variety of results (Rutledge, 2002; 2003).

GENERAL DESCRIPTION OF THE METHOD

The RECESS program is an empirical method for describing recession characteristics. A general description follows. The program scans the streamflow dataset, finding periods of continuous recession; such as the period from day 93 to day 121 in figure 1. When a segment is found, the program user can decide whether it should be analyzed and, if so, which parts represent near-linear conditions (on the semi-log plot) that can be used to quantify the recession index. In this case (fig. 1), the selection might be the period from day 100 to day 121, as prior data indicate the effects of direct-surface runoff or instability of the ground-water-head profile, or both. After the user has selected a segment, the program will calculate a mathematical expression in this form:

$$t = K_1 \times \text{Log}Q + K_2 \quad (1)$$

where t is time in days, $\text{Log}Q$ is the logarithm of the flow in ft^3/s , and K_1 and K_2 are coefficients that are determined by linear regression. This expression is used to derive the recession index (days/log cycle), which is the absolute value of K_1 . After this solution is obtained the program proceeds to the next period of continuous recession, and repeats this process until a number of segments have been analyzed.

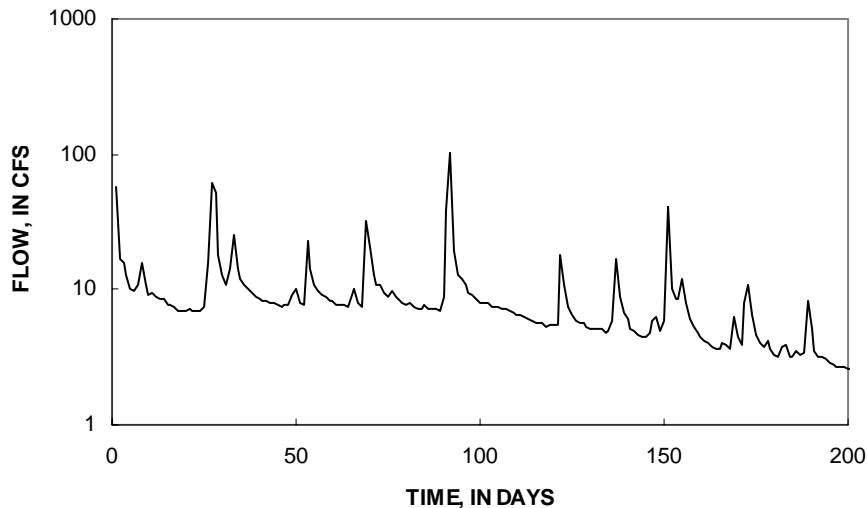


Figure 1. Example period of continuous recession (day 93 to day 121) that RECESS might detect depending on program-user options. (The streamflow-gaging station is Holiday Creek near Andersonville, Virginia. The time scale represents days in the 1996 calendar-year.)

After the program has found all recession segments in the period of interest, it can perform calculations to determine the expression for the MRC. These calculations are illustrated in figure 2. Frame A represents the near-linear segments that were selected. The program uses equation 1 to derive the recession index (K) for each, represented by the dots in frame B. The program determines the best-fit linear equation for K as a function of LogQ, represented by the straight line in frame B. Coefficients of this equation are used to obtain the MRC (frame C), which is a polynomial expression of time as a function of LogQ:

$$t = A \times (\text{Log}Q)^2 + B \times (\text{Log}Q) + C \quad (2)$$

where t is time and A, B, and C are coefficients. The MRC (frame C) is the result of integration of the best-fit linear equation for K as a function of LogQ (frame B). It is unique because at time=0, LogQ is the maximum value of the LogQ from all selected recession segments. In this example (frame C) the MRC is concave, but one regional application of RECESS demonstrated a variety of MRC shapes among basins (Rutledge and Mesko, 1996, p. 7-15). This empirical expression requires the assumption of a linear relation between K and LogQ. If this assumption is not valid for a particular dataset, the user should exercise caution or consider other methods for deriving the MRC from data displayed in frame B.

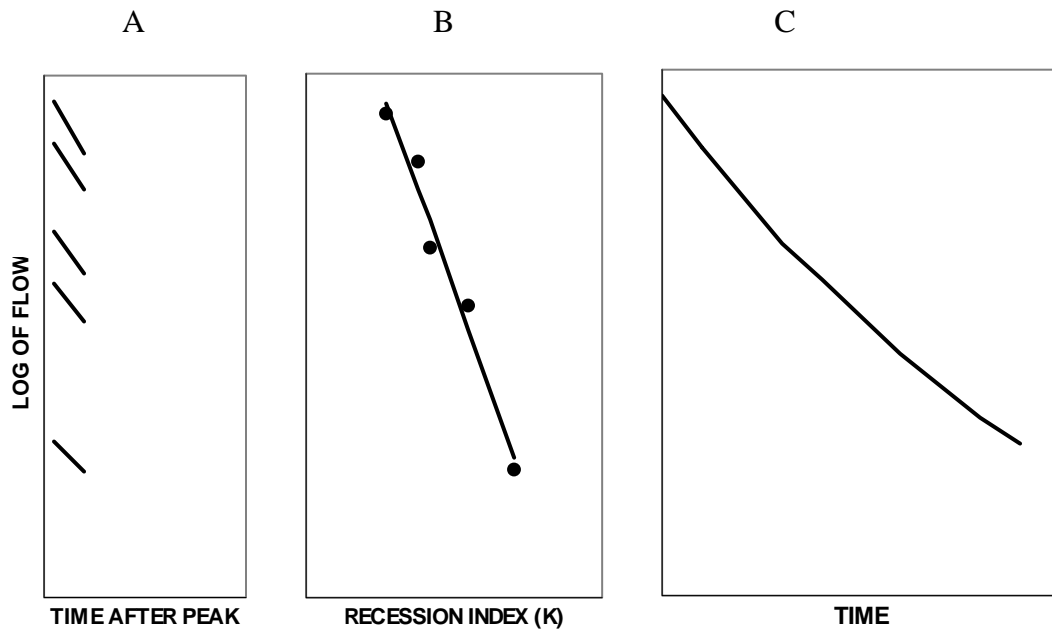


Figure 2. Schematic representation of the method used to determine the master recession curve: (A) selected recession segments, (B) recession index (K) (days per log cycle of recession), and best-fit line, and (C) the master recession curve, obtained from coefficients in B.

QUANTITATIVE SIGNIFICANCE OF VARIATIONS

The recession index, quantified in days per log cycle, is a convenient way of describing recession characteristics. Its disadvantage arises from the way it can exaggerate slight variations that may not be quantitatively significant. To illustrate, consider two hypothetical streamflow-gaging stations representing two basins, and a period of recession that is preceded by identical flow (10.0 cfs). In both cases the recession is linear (on the log scale), but occurs at slightly different rates. After 10 days, the flow in basin A is 7.9 cfs and the flow in basin B is 7.5 cfs. These correspond to recession indexes of 98 (A) and 80 (B), in days per log cycle. Slight variations, which can be close to the level of uncertainty of streamflow data, may relate to differences in the recession index that appear significant. Similar results were found when the Rorabaugh Method was used to estimate recharge using the RORA program, demonstrating slight sensitivity to variation in the recession index (Rutledge, 1998, p. 29).

PREPARING TO USE THE PROGRAM

This section describes things the program user may need to do before using the RECESS program to analyze streamflow data files of interest. The first-time user who is experimenting with the data files included with this report can skip this section and proceed to the instructions for running the program. The section about the SCREEN program may be helpful to the first-time user.

OBTAINING STREAMFLOW DATA FILES

A streamflow data file can be obtained from the following USGS web site: <http://water.usgs.gov/nwis/discharge>. From this site, the user will need to select site selection criteria. For example, if the site of interest is Holiday Creek in Virginia, yet the site identification number is not known, the selection criteria might be *State* and *Site Name*. After proceeding to the option to select a site, the user would then enter *Holiday* under site name, then the state of Virginia. After these options, the user selects the particular station of interest. Under *Choose Output Format* a range of dates is selected and the user should select *Tab-separated data*. Then the user should select to save as a file, designate the directory where the data are to be written on the user's computer, and specify a file name. File names should be in the format *xxxxx.txt*, where *xxxxx* is an abbreviated station name. In this case the file name might be designated as *Holiday.txt*. (Note: the length of the file name, including *.txt*, should be 12 characters or less.) Under *save as file type* the user should specify *plain text*. An example streamflow data file, obtained as described above, is illustrated in figure 3.

THE “SCREEN” PROGRAM

Before analyzing a streamflow data file the user might execute the SCREEN program to display the period of record. To demonstrate, execute the program by clicking on the application in windows or by entering the command “screen” in the MS-DOS command window. Designate the streamflow data file *Holiday.txt*. The output file *screenout.txt* should look like figure 4. This illustrates data are available from 1970 to 2000.

THE “STATION.TXT” FILE

An input data file “*station.txt*” includes drainage area of the stations of interest. This file includes an entry for the streamflow data file that is provided with this report (*Holiday.txt*). The user should place additional entries in this file for each station analyzed. The RECESS program does not use the drainage area, but an auxiliary program CURV uses this variable in calculations of the MRC.

```

#
# U.S. Geological Survey
# National Water Information System
# Retrieved: 2001-08-29 13:12:17 EDT
#
# -----WARNING-----
# The data you have obtained from this automated
# U.S. Geological Survey database have not received
# Director's approval and as such are provisional
# and subject to revision. The data are released
# on the condition that neither the USGS nor the
# United States Government may be held liable for
# any damages resulting from its use.
#
# This file contains published daily mean streamflow data.
#
# This information includes the following fields:
#
# agency_cd   Agency Code
# site_no     USGS station number
# dv_dt       date of daily mean streamflow
# dv_va       daily mean streamflow value, in cubic-feet per-second
# dv_cd       daily mean streamflow value qualification code
#
# Sites in this file include:
# USGS 02038850 HOLIDAY CREEK NEAR ANDERSONVILLE, VA
#
#
agency_cd   site_no     dv_dt dv_va dv_cd
5s      15s      10d      12n      3s
USGS    02038850    1970-01-01    17
USGS    02038850    1970-01-02    8.4
USGS    02038850    1970-01-03    6.8
USGS    02038850    1970-01-04    6.2
USGS    02038850    1970-01-05    7.3
USGS    02038850    1970-01-06    4.9
USGS    02038850    1970-01-07    5.1
USGS    02038850    1970-01-08    6.5
USGS    02038850    1970-01-09    4.0
USGS    02038850    1970-01-10    3.2
USGS    02038850    1970-01-11    3.3
USGS    02038850    1970-01-12    3.7
USGS    02038850    1970-01-13    3.4
USGS    02038850    1970-01-14    3.5
USGS    02038850    1970-01-15    3.7
USGS    02038850    1970-01-16    3.8
USGS    02038850    1970-01-17    4.0
USGS    02038850    1970-01-18    13
USGS    02038850    1970-01-19    18
USGS    02038850    1970-01-20    11

```

Figure 3. Example streamflow data file obtained from a USGS web site. (This is truncated from the data file *Holiday.txt*, which is available with this manual.)

```

READING FILE NAMED Holiday.txt
FIRST YEAR IN RECORD = 1970
LAST YEAR IN RECORD = 2000
      MONTH
YEAR  J F M A M J J A S O N D
1970  . . . . . . . . . . .
1971  . . . . . . . . . . .
1972  . . . . . . . . . . .
1973  . . . . . . . . . . .
1974  . . . . . . . . . . .
1975  . . . . . . . . . . .
1976  . . . . . . . . . . .
1977  . . . . . . . . . . .
1978  . . . . . . . . . . .
1979  . . . . . . . . . . .
1980  . . . . . . . . . . .
1981  . . . . . . . . . . .
1982  . . . . . . . . . . .
1983  . . . . . . . . . . .
1984  . . . . . . . . . . .
1985  . . . . . . . . . . .
1986  . . . . . . . . . . .
1987  . . . . . . . . . . .
1988  . . . . . . . . . . .
1989  . . . . . . . . . . .
1990  . . . . . . . . . . .
1991  . . . . . . . . . . .
1992  . . . . . . . . . . .
1993  . . . . . . . . . . .
1994  . . . . . . . . . . .
1995  . . . . . . . . . . .
1996  . . . . . . . . . . .
1997  . . . . . . . . . . .
1998  . . . . . . . . . . .
1999  . . . . . . . . . . .
2000  . . . . . . . . X X X

COMPLETE RECORD = .      INCOMPLETE = X

```

Figure 4. Example tabular display of a streamflow record, showing periods of complete record (a number for each day in the month) and periods of incomplete record. (This display is generated onto a file by the program SCREEN, and on the monitor by RECESS. Streamflow data file is *Holiday.txt*.)

RUNNING THE RECESS PROGRAM

This section gives specific instructions for running RECESS for the streamflow data file that is included with this report. The first sub-section describes the use of RECESS in conjunction with the RECPLLOT application to generate a graph of all recession segments that are detected by the program. This exercise is performed without mathematical analysis. The first-time program user should try these steps as a way of gaining familiarity with the program. The second sub-section describes the determination of the median recession index. The operations in the second sub-section require user designation of segments to be analyzed based upon near-linear recession and demonstrate calculations performed by the program. The third sub-section describes the derivation of the master recession curve (MRC). These three sub-sections describe specific use of the program for a specific dataset. The fourth sub-section includes considerations for program use in hydrologic studies that involve other datasets.

GRAPHICAL DISPLAY OF RECESSION SEGMENTS WITHOUT MATHEMATICAL ANALYSIS

The program can be executed by clicking on the RECESS application in Windows, or by opening the MS-DOS window and entering the command "recess". In either case, a command window is displayed. Expand this window downward so that more than 40 lines are displayed. Enter *Holiday.txt* as the streamflow data file. The program generates a tabular display of the completeness of the record. Designate the starting year as 1970 and the ending year as 2000, to analyze the entire period available. At this point the program will ask the number of months of interest; enter 12, then enter "n" to designate that no particular season is being analyzed. The program asks how many days of recession are required in order to detect a recession period; enter 15.

After the operations described above, the program will detect the first period of recession. At this point the program should indicate the "date of new peak" to be 1970-11-20 (year, month, day). The "peak" is the day that precedes the period of recession. The program displays, within the command window, a number of possible operations, most of which will not be needed during this exercise. Before responding to these, move the command window to the left side of the monitor. Click on the RECPLLOT application in Windows. This should generate a new window entitled RECPLLOT, which includes a graph of the period of recession that has been detected. The X-axis is days since the peak and the Y-axis shows the logarithm of flow (Log-10 of ft³/s). The plot should be similar to the bottom curve in figure 5A. Leaving the new window open, return to the command window and respond "a" to advance to the next period of recession. Then, in the RECPLLOT window, click on "open" then the file name "*recdata.txt*", and another recession segment should be generated. When these operations are repeated two more times there should be four recession segments in the RECPLLOT window, similar to figure

5A. The program user might repeat these operations until RECESS has reached the end of the period of record. When all segments have been illustrated, the RECPLOT window should appear similar to figure 5B. At this point the program displays the following question at the bottom of the command window: “Do you want to analyze the recessions selected?” Enter “n” then click “enter” one more time to terminate the RECESS program.

No mathematical analysis has been performed at this point. Most of these segments include departures from the linear model of recession at early time. These departures may be caused by direct surface runoff or instability of the ground-water-head profile. The magnitude of these departures depends on the magnitude of the storm event (and the amount of recharge) that occurred during or near the time of the peak. The mathematical analysis should take place only after these early-time sections have been removed. The following section explains this process. Click “Exit” in the RECPLOT window when ready to go to the next exercise.

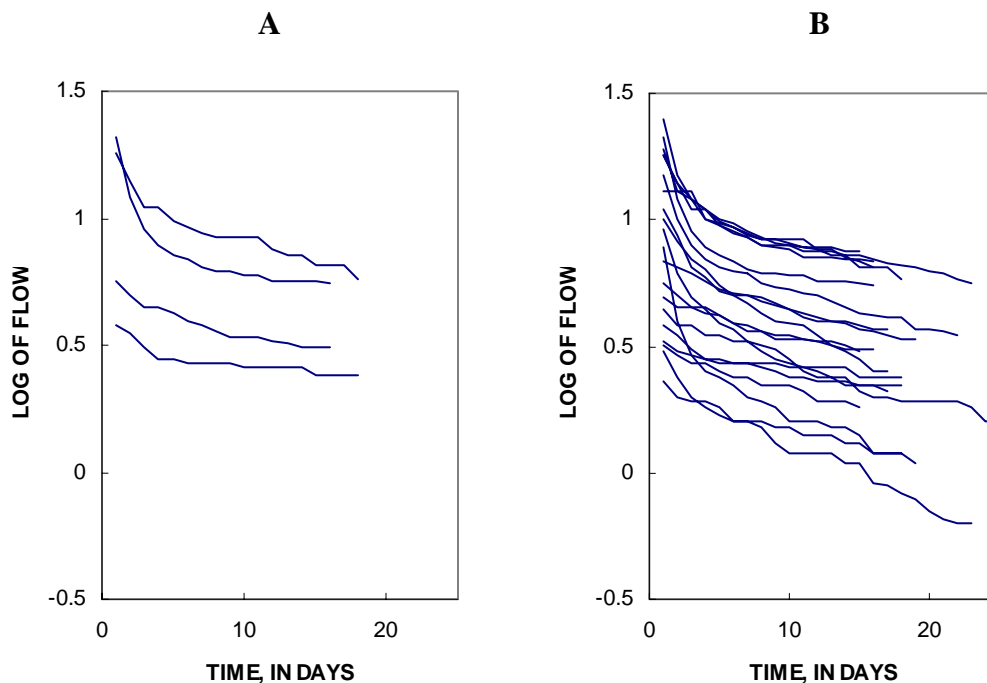


Figure 5. Example graphical display of recession segments without mathematical analysis, similar to a graph that can be generated with the RECPLOT application. (Frame A shows the plot after 4 segments have been illustrated. Frame B shows the plot after all segments have been illustrated.)

DETERMINATION OF THE RECESSION INDEX

The use of the program for this purpose begins with steps that are similar to the previous section. Execute the program by clicking on the RECESS application in Windows Explorer, or by opening the MS-DOS window and entering the command “recess”. In either case, a command window is displayed. Expand this window downward so that more than 40 lines are displayed. Enter *Holiday.txt* as the streamflow data file. The program generates a tabular display of the completeness of the record. Designate the starting year as 1970 and the ending year as 2000, to analyze the entire period available. At this point the program will ask the number of months of interest; enter 12, then enter “n” to designate that no particular season is being analyzed. The program asks how many days of recession are required in order to detect a recession period; enter 15.

At this point the program will require user selection of the recession periods, and designation of the segment for analysis. For the sake of this exercise, all recession periods will be selected and it is noted that most departures from linearity occur within the first 6 days of each period of recession (fig. 5). To simplify this exercise, given all recession periods are at least 15 days long, the following options are selected whenever RECESS detects a new recession period:

```
g(return)..... c(return).....7(return).....15(return).....r(return)
```

The option “g” will generate a graphic of the period of recession, and is optional for this exercise. The option “c” will designate the user is to choose limits of the segment, and the next two entries, “7” and “15” are the limits. The option “r” will instruct the program to perform linear regression to solve equation 1, and thus determine the recession index. The five entries are given 20 times (the number of recession periods that are detected by RECESS).

After operations on the last recession segment, the program asks whether you want to analyze the recessions selected. Enter “y.” Then the program displays the recession indexes (K) for each segment selected. The value of K is shown numerically and by the position of the asterisk. At this point the program user could eliminate outliers, but enter “0” to indicate no recession segments are to be eliminated. Then enter “2” to indicate you want to describe the MRC (this will be discussed in the next section). Then, when prompted, “enter” one more time to terminate the program.

If the RECESS program has been executed as described above, there should be a new line at the bottom of file “*index.txt*”, giving the recession index = 67.43 days per log cycle. This represents the median value among all segments analyzed. In hydrologic studies it is advised that the recession index should be reported with viewer significant figures (for example, 67). As previously noted, the user should specify input to the RECESS program as specifically described, for the sake of this exercise. This will be helpful for discussion of additional program output in the next section. Later, the user should read the section “Additional Considerations for Program Use.”

THE MASTER RECESSION CURVE

To describe the MRC, the user should execute the RECESS program as described in the previous page, then proceed with the use of data files and the CURV program, as described below. It is noteworthy that near the end of the previous sub-section, the user elected to derive the MRC, with the number “2”. If the number “1” was designated, then the program would not have generated output as described below. If the “1” were entered the program would only write to file “*index.txt*”.

Output Files for the RECESS Program

When the RECESS program is executed as described above, results are written to three output files, as described below.

recsum.txt -- Each time RECESS is executed, one new line is written to the bottom of *recsum.txt*. This line gives a summary of results of the session: name of the streamflow datafile; single-letter designation of the season; time period of analysis; number of recession segments used; the minimum, median, and maximum LogQ of all segments used; and the three coefficients of the MRC (eq. 2). The auxiliary program CURV will read *recsum.txt* for the purpose of generating an x-y file which can be used to generate the MRC.

X-file – A new x-file gives details about one execution of RECESS. The x-file is assigned a name equal to the name of the original streamflow datafile, except two letters are added to the beginning of the name. The first is the letter “x” and the second is the letter that designates the season. If RECESS has been executed as described above, the file name is *xn.Holiday.txt*. The x-file includes detailed information about each recession segment that was initially selected—date of the peak and designation of the starting and ending of the recession segment (days after the peak). Also included is a listing of each data pair of LogQ and K for each recession segment and a graphical representation of K for each segment. This listing is shown twice: once before and once after the user eliminates segments not wanted. The x-file also shows the best-fit linear equation for K as a function of LogQ and the resulting second-order polynomial that is the MRC. Because of the file name, if RECESS is executed twice for the same streamflow data file and season, the first x-file will be overwritten.

Y-file – A new y-file gives detailed information about the time and flow for each day of each selected recession segment. The y-file is assigned a name equal to the name of the streamflow datafile, except two letters have been added to the beginning of the name. The first is the letter “y” and the second is the letter that designates the season. If RECESS has been executed as described above the file name is *yn.Holiday.txt*. The y-file can be used to generate a graph of each recession segment. One such graph could be the flow as a function of the time since the last peak (fig. 6). Another could be the flow as a function of time, where the time has been adjusted so that all recession segments are

drawn on the same MRC (fig. 7). Because of the file name, if RECESS is executed twice for the same streamflow data file and season, the first y-file will be overwritten.

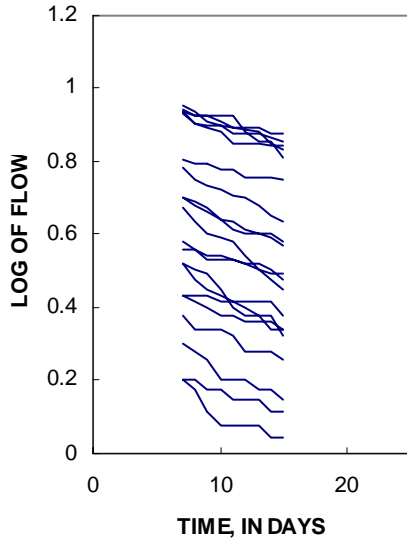


Figure 6. Recession segments generated from the Y-file, as described in the text. (The x-axis is the time since the last peak.)

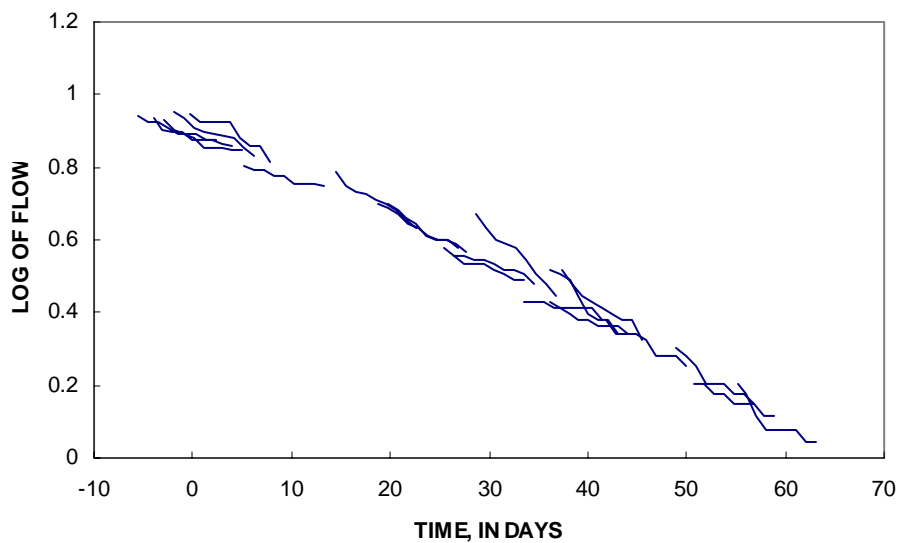


Figure 7. Recession segments generated from the Y-file, as described in the text. (The x-axis is the time adjusted so that all segments will appear roughly on the same master recession curve.)

The CURV Program

CURV is an auxiliary program which can be used to display multiple MRC's on the same graph. These can represent a number of streamflow gaging stations (basins), such as the example in figure 8, or they may represent various seasons for the same streamflow gaging station. The CURV program is used to illustrate the exact solution of the MRC equation, without showing each segment (unlike the Y-file).

To generate the MRC for the streamflow dataset analyzed in previous pages, execute the CURV program by clicking on the application in windows or by entering the command "curv" in the MS-DOS command window. Designate the streamflow data file as "*Holiday.txt*", then specify with the letter "n" there is no particular season of interest, to be consistent with the application of RECESS described earlier. Then designate no additional MRC's are to be drawn (with the letter "n"). Exit the CURV program, then generate the MRC using a graphics application such as MS Excel, reading file *curvout.txt*. It may be necessary to remove some of the header lines at the beginning of the file before plotting. The plot should be similar to figure 9.

If this method is used to generate multiple MRCs, such as figure 8, the recess program should be executed for each dataset and/or season. Each application of RECESS should be represented by one line in *recsum.txt*. For example, if the user is generating MRC's for summer and winter for the same streamflow datafile, the user should execute RECESS twice. In one application of RECESS, summer months are selected for analysis, and the season should be designated as "s", and in the other application winter months are selected and "w" is designated. When CURV is executed, designate the station name and season "s", then when asked if additional MRC's are to be drawn, answer "y" then the station name again, and season "w".

The CURV program scans *recsum.txt* and finds the first entry that satisfies the user-designated combination of streamflow data file and season. For each combination, the program determines 50 evenly-spaced values of LogQ—from the maximum to the minimum values of LogQ for all recession segments that were selected in the execution of RECESS (these limits are read from *recsum.txt*). For each LogQ, the time is calculated according to equation 2, using coefficients in *recsum.txt*. The program writes 50 lines to *curvout.txt*.

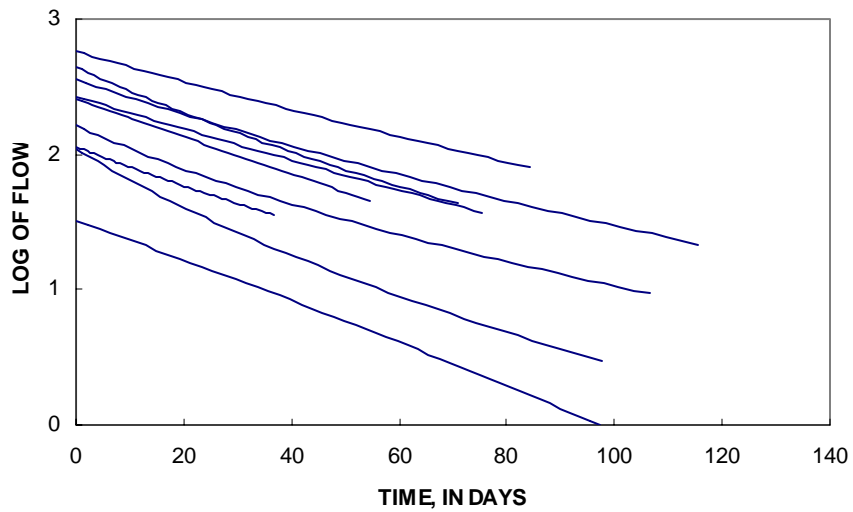


Figure 8. Example plot of multiple master recession curves, which can be generated from output of the CURV program. (from Rutledge and Mesko, figure 6).

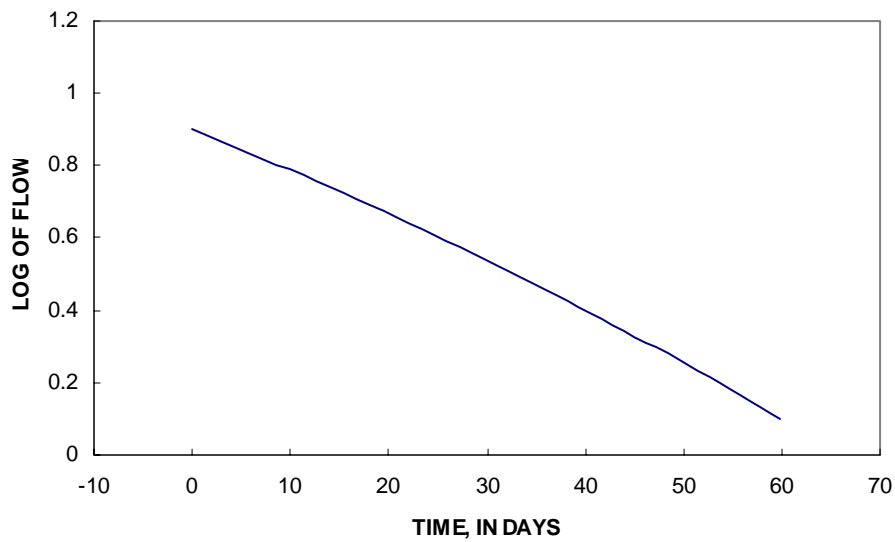


Figure 9. The master recession curve, generated from the file *curvout.txt*, as described in the text.

ADDITIONAL CONSIDERATIONS FOR PROGRAM USE

The exercises described above are provided so the user can gain familiarity with the program. These include the use of one streamflow dataset and specific user options, so results described here can be compared with results generated by the user. When conducting a hydrologic study the program user may consider variations as described below.

The user might select certain months for analysis. For example periods of ground-water evapotranspiration (GWET) might be eliminated because this process will affect recession characteristics. If GWET is considered to be significant in the four months April, May, June, and July, elect to analyze 8 months, then designate them using these numbers: 1, 2, 3, 8, 9, 10, 11, and 12 (each followed by a “return”).

The user will find it necessary to modify the limits for plotting, by editing the file *ranges.txt*. The version of this file that is provided with this manual includes ranges of LogQ that are conducive to the analysis of the streamflow datafile *Holiday.txt*.

The RECPLOT application might be used as a guide in selecting near-linear segments. When a new recession interval has been found by the program, the user clicks on the application outside the command window. Before proceeding to the next recession interval, the user should close the RECPLOT window.

When recession data are displayed (using “g” in the command window, or using the RECPLOT application), the data may exhibit “stepping” which is caused by rounding of daily streamflow in the USGS database. The “t” option can also be used to view recession data.

The exercise described earlier includes selection of all recession intervals, and the same time limits for each: 7 to 15 days (p. 11). When the RECESS program is applied in a hydrologic study the user can apply considerable judgment. For example the author suggests this input for data file *Holiday.txt* (tabulation below). This includes selection of longer periods of recession, where such data are available, and the selection “a” to advance without analysis of a segment, given some recession intervals may show anomalous recession characteristics.


```

1970-11-20  g  c  4  18  r
1971-04-07  g  c  7  16  r
1973-05-28  g  c  6  18  r
1974-07-07  g  c  6  16  r
1976-04-01  g  c  6  23  r
1976-08-09  g  c  3  18  r
1977-05-04  g  c  7  19  r
1977-06-25  g  c  3  15  r
1978-03-26  g  c  8  15  r
1978-08-07  g  c  10  17  r
1981-06-07  g  a
1982-04-26  g  c  9  22  r
1984-05-06  g  c  7  16  r
1984-05-30  g  c  7  17  r
1985-08-27  g  c  15  25  r
1986-06-12  g  r
1993-01-22  g  a
1994-09-01  g  c  6  15  r
1997-08-20  g  a
2000-04-25  g  a

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..... after this, program options described on p. 11 (paragraph 4) can be repeated. The program displays recession index (K) numerically and by the position of an asterisk. This is given in order of the value of LogQ, so the relation between K and LogQ might be viewed at this point. The user has the option of deleting segments if a value of K is considered to be an outlier. To eliminate one outlier, enter "1" then enter the number that identifies the recession segment to be deleted.

The RECESS program is designed for determination of the recession index and the master recession curve. Depending on the needs of hydrologic studies, the program might be used for other purposes. For example non-quantitative description of recession curves, without editing, may be useful in some studies. (Fig. 5).

A graphic is generated to the monitor near the end of program execution, and is repeated in the "X-file," showing the relation between K and LogQ. This could be used to evaluate the assumed linear relation. (See General Description of the Method, and Figure 2.) Data pairs could be extracted from the X-file, then plotting using separate graphics software. If the assumed linear relation is not valid, the user might decide not to use equation 2 to describe the MRC.

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