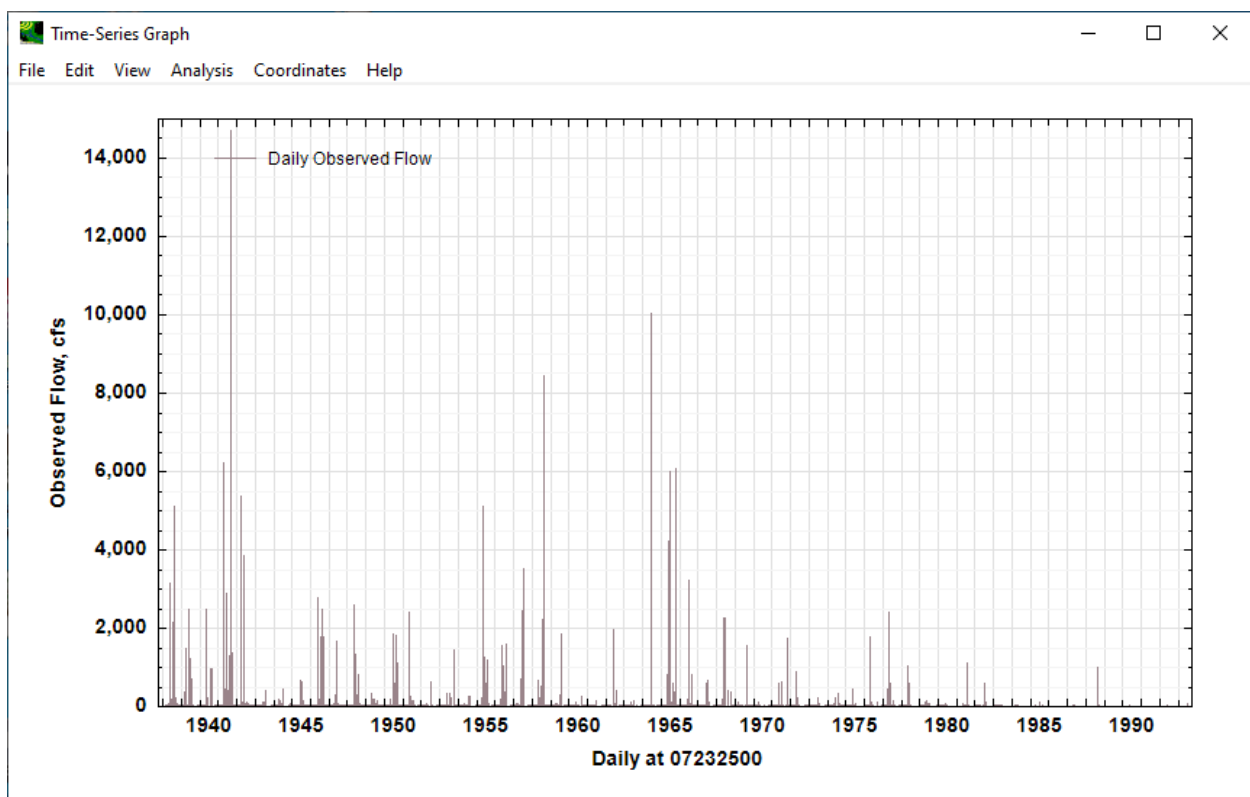


# Analysis of Base Flow with the Hydrologic Toolbox

## Version 1.0 Release

This document describes functionality in the Hydrologic Toolbox to analyze time-series data. The functionality (1) allows users to work with base-flow and runoff time series generated by use of the “Interactive” mode of hydrograph separation; (2) includes the Mann-Kendall approach to test for monotonic trends in streamflow, base-flow, and runoff time series; and (3) allows subsetting, splitting, filtering, and other manipulations of a time series. The functionality is described using streamflow data available for the USGS Beaver River near Guymon, Oklahoma, streamgage (07232500). Streamflow was monitored at the site between October 1, 1937, and September 30, 1993. Wahl and Tortorelli (1997, U.S. Geological Survey Water-Resources Investigations Report 96-4303) have shown that streamflow and base flow at the site sharply decreased during the monitoring period in response to groundwater development in the basin. The declines are illustrated by the following streamflow hydrograph for the period of record:



## Working with Calculated Base-Flow and Runoff Time Series

The Hydrologic Toolbox was used to calculate daily time series of base flow and runoff at the Beaver River streamgage for the period of record using the PART, HYSEP-FIXED, and BFI Standard approaches (see USGS Techniques and Methods 3-B10, which is distributed with the Hydrologic Toolbox, for a description of the hydrograph-separation methods, as well as the tutorial on “Hydrograph Separation”). Three time series were generated for each of the hydrograph-separation methods: daily base flow (‘BF\_’), base-flow percentage (‘BFPct\_’), and runoff (‘RO\_’). These time series are now available for graphing and other analyses within the Toolbox, as illustrated by the following data-selection dialog box and the examples in the remainder of this tutorial:

Select Data To Graph

File Attributes Select Help

Select Attribute Values to Filter Available Data

StaNam	Location	Constituent	SeasonName
Beaver River near Felt, OK	07154000	BFPct_BFIStandard	~Missing~
Beaver River near Goodwe	07154500	BFPct_HySEPFixed	
Beaver River near Guymon	07155000	BFPct_Part	
CIMARRON R NR FOLSO	07155500	BF_BFIStandard	
Cimarron River ab Ute Crei	07232250	BF_HySEPFixed	
Cimarron River near Guymon	07232500	BF_Part	

Matching Data (16 of 16)

Station	Location	Constituent	SeasonName
Beaver River near Guymon, +	07232500	FLOW	
	07232500	BF_Part	
	07232500	BFPct_Part	
Beaver River near Guymon, +	07232500	RO_Part	
	07232500	BF_HySEPFixed	
	07232500	BFPct_HySEPFixed	
Beaver River near Guymon, +	07232500	RO_HySEPFixed	
	07232500	BF_BFIStandard	

Selected Data (0)

Date Range of Selected Data

All Common

Start none none

End none none

☒ Include Provisional Data

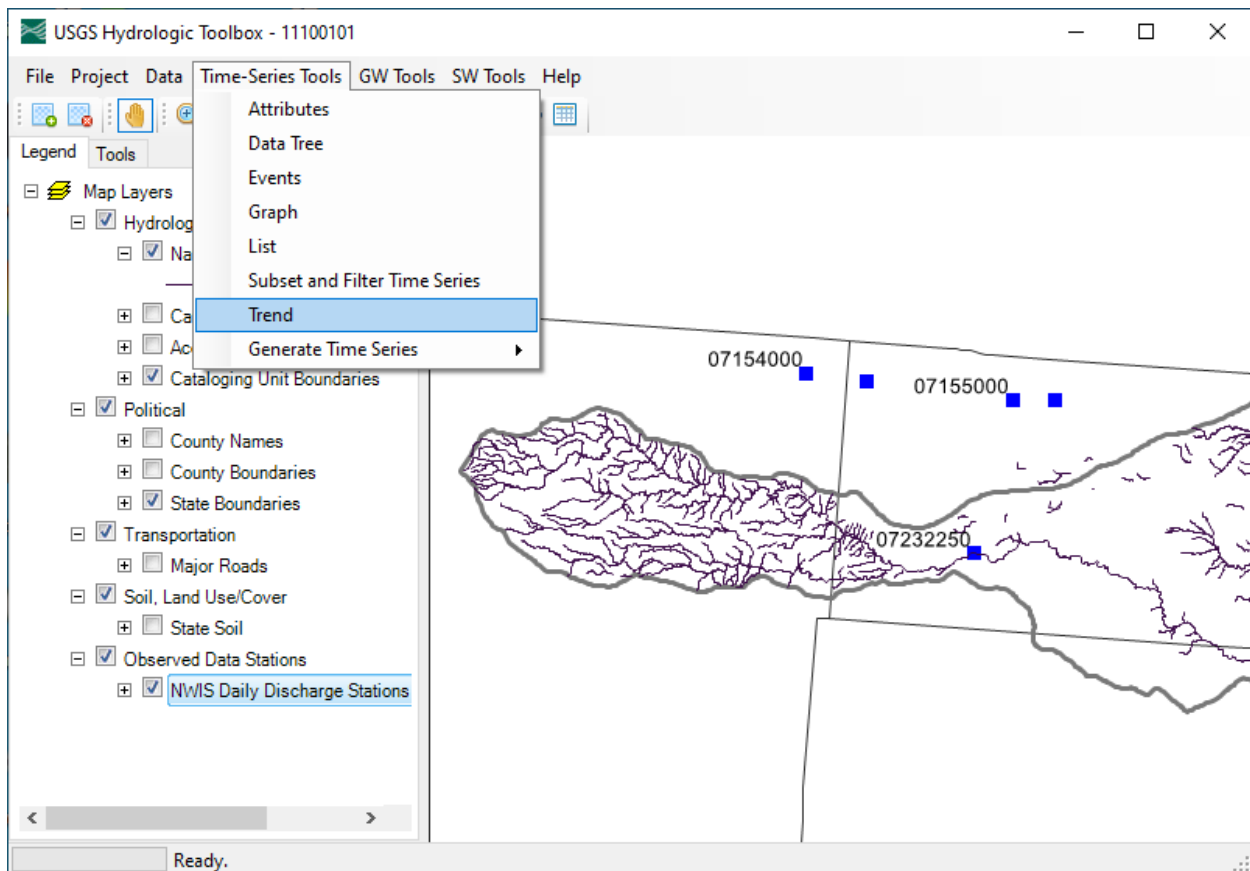
☐ Subset and Filter Time Series

Ok Cancel

Note that after closing the current Toolbox session, the generated time series are saved with the project, as is done for the streamflow data.

## Kendall Tau Trends Functionality

The Hydrologic Toolbox includes the Mann-Kendall method to test for monotonic trends in an annual time-series data set. Kendall's tau statistic is computed for the n-day time series, which is used to test for monotonic trends in time. The Kendall tau test statistic is reported along with the p-value and the Sen slope of the trend line. A site should be flagged for further screening when the test results in a p-value of 0.05 or less. The functionality is available within the **"Time-Series Tools>Trend"** option:



In this example, annual trends in observed streamflow and base flow calculated by the BFI Standard method will be analyzed for several user defined N-day periods. The first step is to select the streamflow and BFI base-flow records:

**Select Data For Trend Analysis**

File   Attributes   **Select**   Help

Select Attribute Values to Filter Available Data

StaNam	Location	Constituent	SeasonName
Beaver River near Felt, OK	07154000	BFPct_BFIStandard	~Missing~
Beaver River near Goodwe	07154500	BFPct_HySEPFixed	
Beaver River near Guymon	07155000	BFPct_Part	
CIMARRON R NR FOLSO	07155500	BF_BFIStandard	
Cimarron River ab Ute Crea	07232250	BF_HySEPFixed	
Cimarron River near Boise	07232470	BF_Part	

Matching Data (16 of 16)

Location	Constituent	SeasonName
07232500	BFPct_Part	
Beaver River near Guymon, +	07232500	RO_Part
	07232500	BF_HySEPFixed
	07232500	BFPct_HySEPFixed
Beaver River near Guymon, +	07232500	RO_HySEPFixed
	07232500	BF_BFIStandard
	07232500	BFPct_BFIStandard
Beaver River near Guymon, +	07232500	RO_BFIStandard

Selected Data (2 of 16)

Location	Constituent	SeasonName
Beaver River near Guymon, +	07232500	FLOW
	07232500	BF_BFIStandard

Date Range of Selected Data

	All	Common
Start	1937/10/01	1937/10/01
End	1993/09/30	1993/09/30

☒ Include Provisional Data  
☐ Subset and Filter Time Series

Ok

Cancel

Hitting “Ok,” brings up the Trend dialog box:

**Trend**

File Analysis Help

**Flow Condition**

☐ High

☒ Low

**Year / Season Boundaries**

Start: April 1

End: March 31

**Years to Include in Analysis**

All: 1937/10/01 to 1993/09/30

Start Year: Data Starts 1937/10/01

End Year: Data Ends 1993/09/30

**Annual Value Limits**

☐ Ignore Values Below

☐ Ignore Values Above

**Number of Days**

1  
2  
3  
7  
10  
30  
60  
90  
183  
365

+

-

Default

All

None

Display Basic Statistics

N-Day Timeseries List

Trend List

As shown on the dialog box, the user can choose to analyze annual trends for either high-flow or low-flow conditions for defined numbers of days (N-day). The default N-day options can be modified by adding (+ button) or subtracting (- button) values in the entry box. For this analysis, trends in high flows for all of the default days will be determined; the Year/Season Boundaries are specified as October 1 through September 30 for consistency with the two time series:

**Trend** [Minimize] [Maximize] [Close]

File Analysis Help

Flow Condition

☒ High

☐ Low

Year / Season Boundaries

Start: October 1

End: September 30

Years to Include in Analysis

All: 1937/10/01 to 1993/09/30

Start Year:  Data Starts 1937/10/01

End Year:  Data Ends 1993/09/30

Annual Value Limits

☐ Ignore Values Below

☐ Ignore Values Above

Number of Days

1  
2  
3  
7  
10  
30  
60  
90  
183  
365

+ - Default

All None

Display Basic Statistics N-Day Timeseries List Trend List

After hitting 'Trend List' the following results display the Kendall Tau calculations, including the Kendall Tau statistic ('KENTAU'), p-level ('KENPLV'), and median slope ('KENSPL') for the streamflow and base-flow time series:

Trend of High Annual Time Series and Statistics												
File Edit View Analysis Help												
STAID	WhatData	KENTAU	KENPLV	KENSPL	From	To	Count	Not Used	Min	Max	Constituent	
07232500	FLOW	-0.45844	0.00000065592	-43.421	1937/10/01	1993/09/30	56	0	0.01	14,700	H001	
07232500	FLOW	-0.45974	0.00000061041	-26.969	1937/10/01	1993/09/30	56	0	0.005	9,865	H002	
07232500	FLOW	-0.46104	0.00000056796	-19.129	1937/10/01	1993/09/30	56	0	0.00333333	7,536.7	H003	
07232500	FLOW	-0.45584	0.00000075701	-8.8997	1937/10/01	1993/09/30	56	0	0.0014286	3,485	H007	
07232500	FLOW	-0.45844	0.00000065592	-6.6576	1937/10/01	1993/09/30	56	0	0.001	2,458.2	H010	
07232500	FLOW	-0.47403	0.00000027375	-3.0647	1937/10/01	1993/09/30	56	0	0.000333333	825.6	H030	
07232500	FLOW	-0.5013	0.000000056132	-1.9064	1937/10/01	1993/09/30	56	0	0.00016667	456.82	H060	
07232500	FLOW	-0.51429	0.000000025778	-1.4108	1937/10/01	1993/09/30	56	0	0.000111111	395.52	H090	
07232500	FLOW	-0.55065	0.0000000027053	-0.91871	1937/10/01	1993/09/30	56	0	0.000054645	269.09	H183	
07232500	FLOW	-0.57922	0	-0.57764	1937/10/01	1993/09/30	56	0	0.000027397	138.04	H365	
07232500	BF_BFIStandard	-0.46299	0.00000048822	-0.21739	1937/10/01	1993/09/30	56	0	0	33	H001	
07232500	BF_BFIStandard	-0.46039	0.00000058744	-0.21698	1937/10/01	1993/09/30	56	0	0	31.755	H002	
07232500	BF_BFIStandard	-0.45909	0.0000006313	-0.21602	1937/10/01	1993/09/30	56	0	0	31.17	H003	
07232500	BF_BFIStandard	-0.47208	0.00000030499	-0.20763	1937/10/01	1993/09/30	56	0	0	28.554	H007	
07232500	BF_BFIStandard	-0.47727	0.00000022695	-0.20053	1937/10/01	1993/09/30	56	0	0	26.882	H010	
07232500	BF_BFIStandard	-0.47078	0.00000032824	-0.17957	1937/10/01	1993/09/30	56	0	0	19.266	H030	
07232500	BF_BFIStandard	-0.4539	0.00000084064	-0.15072	1937/10/01	1993/09/30	56	0	0	15.552	H060	
07232500	BF_BFIStandard	-0.44481	0.0000013787	-0.13963	1937/10/01	1993/09/30	56	0	0	13.335	H090	
07232500	BF_BFIStandard	-0.46299	0.00000050839	-0.12121	1937/10/01	1993/09/30	56	0	0	10.157	H183	
07232500	BF_BFIStandard	-0.51364	0.000000026735	-0.082857	1937/10/01	1993/09/30	56	0	0	6.7003	H365	

As shown by the results, there are statistically significant declines in streamflow and base flow for all of the N-day periods, which is consistent with the findings of Wahl and Tortorelli (1997). The 365-day ('H365') results calculated by the program for streamflow are nearly identical to those given in Wahl and Tortorelli (1997, p. 28); the results for base flow are slightly different from those presented in Wahl and Tortorelli (1997), most likely due to the modification made to the BFI algorithm for implementation in the Hydrologic Toolbox (see USGS TM 3-B10, p. 3).

Statistically significant declines in streamflow and base flow also are evident for the low-flow N-day calculations (see below). Also note that the trend calculations for the 365-day low flows ('L365') are equivalent to those for the 365-day high flows because of the use of the same flow statistics for both computations.

Trend of Low Annual Time Series and Statistics													
File	Edit	View	Analysis	Help									
STAID	WhatData	KENTAU	KENPLV	KENSLP	From	To	Count	Not Used	Min	Max	Constituent		
07232500	FLOW	-0.27338	0.000090023	0.000099981	1937/10/01	1993/09/30	56	0	0	1.2	L001		
07232500	FLOW	-0.29221	0.000044686	0.000099981	1937/10/01	1993/09/30	56	0	0	1.25	L002		
07232500	FLOW	-0.31429	0.000026104	0.000099981	1937/10/01	1993/09/30	56	0	0	1.3333	L003		
07232500	FLOW	-0.37143	0.0000024109	0.000099981	1937/10/01	1993/09/30	56	0	0	1.4429	L007		
07232500	FLOW	-0.41818	0.0000003465	-0.0022566	1937/10/01	1993/09/30	56	0	0	2.16	L010		
07232500	FLOW	-0.54935	0	-0.016057	1937/10/01	1993/09/30	56	0	0	5.7667	L030		
07232500	FLOW	-0.58117	0	-0.063364	1937/10/01	1993/09/30	56	0	0	6.6667	L060		
07232500	FLOW	-0.58701	0	-0.10544	1937/10/01	1993/09/30	56	0	0	10.481	L090		
07232500	FLOW	-0.54286	0.0000000043923	-0.1557	1937/10/01	1993/09/30	56	0	0	33.333	L183		
07232500	FLOW	-0.57922	0	-0.57764	1937/10/01	1993/09/30	56	0	0.000027397	138.04	L365		
07232500	BF_BFIStandard	-0.27597	0.000077213	0.000099981	1937/10/01	1993/09/30	56	0	0	1.2	L001		
07232500	BF_BFIStandard	-0.27532	0.000080482	0.000099981	1937/10/01	1993/09/30	56	0	0	1.215	L002		
07232500	BF_BFIStandard	-0.2974	0.000048576	0.000099981	1937/10/01	1993/09/30	56	0	0	1.22	L003		
07232500	BF_BFIStandard	-0.34156	0.000010478	0.000099981	1937/10/01	1993/09/30	56	0	0	1.2571	L007		
07232500	BF_BFIStandard	-0.34351	0.0000093249	0.000099981	1937/10/01	1993/09/30	56	0	0	1.283	L010		
07232500	BF_BFIStandard	-0.46948	0.000000023008	-0.0041098	1937/10/01	1993/09/30	56	0	0	1.4493	L030		
07232500	BF_BFIStandard	-0.5474	0	-0.0077729	1937/10/01	1993/09/30	56	0	0	2.3115	L060		
07232500	BF_BFIStandard	-0.58896	0	-0.013368	1937/10/01	1993/09/30	56	0	0	2.7954	L090		
07232500	BF_BFIStandard	-0.52597	0.00000001255	-0.053941	1937/10/01	1993/09/30	56	0	0	5.982	L183		
07232500	BF_BFIStandard	-0.51364	0.000000026735	-0.082844	1937/10/01	1993/09/30	56	0	0	6.7003	L365		

One final note concerning trends functionality in the Toolbox: The “Data Tree” option under “Analysis” includes 1-day high-flow (H001) and 7-day low-flow (L007) calculations for the selected time series, as illustrated for the streamflow data for the Beaver River streamgage:

Data Tree	
File	Edit View Analysis Help
.....	Hammonic Mean Adj : 0.88411
.....	KenTau1-DayHighProbLevel : 0.00000065592
.....	KenTau1-DayHighSlope : -43.421
.....	KenTau1-DayHighValue : -0.45844
.....	KenTau7-DayLowProbLevel : 0.000008525
.....	KenTau7-DayLowSlope : -0.0000020796
.....	KenTau7-DayLowValue : -0.36094
.....	Last : 0
.....	Max : 14,700
.....	MaxDate : 1941/09/23 24:00

The 1-day high-flow values are exactly equal to those calculated by the “**Trends**” functionality because the annual analysis period is the same (October 1 through September 30). Note, however, that the “**Data Tree**” calculations for the 7-day low-flow values use an annual date range of April 1 through March 31, which results in different calculations for the 7-day low-flow values from those made with the “**Trends**” functionality above.

### **“Subset and Filter Time Series” Functionality**

The **Subset and Filter Time Series** submenu item allows the user to transform the selected data in a variety of ways, such as subsetting datasets by date or season or filtering the data by specific ranges of values. There are two ways to access the functionality, the first through the **Time-Series Tools** menu option and the second through the "Select Data" form, which is available through selection of any of the **Time-Series Tools**. The approaches differ in how the subsetting or filtered data are used and temporarily saved during the current working session. If the functionality has been selected through any of the tools under the **Time-Series Tools** menu, then the subsetting or filtered data are temporarily available through the "Select Data" form for one or more analyses without having to subset or filter the data multiple times; alternatively, if the functionality has been selected through the **Time-Series Tools** option, the subsetting or filtered data are not temporarily saved. Each of the two approaches for accessing the functionality is described below. In this example, a streamflow dataset is selected for graphing through the **Time-Series Tools > Graph** submenu:



**Select Data To Graph**

File   Attributes   Select   Help

Select Attribute Values to Filter Available Data

Scenario	Location	Constituent
OBSERVED	07154000	BFPCT_BFISStandard
~Missing~	07154500	BFPCT_HySEPFixed
	07155000	BFPCT_PART
	07155500	BF_BFISStandard
	07232250	BF_HySEPFixed
	07232470	BF_PART
Matching Data (16 of 16)		
OBSERVED	07154500	FLOW
OBSERVED	07155000	FLOW
OBSERVED	07155500	FLOW
OBSERVED	07232250	FLOW
OBSERVED	07232470	FLOW
<b>OBSERVED</b>	<b>07232500</b>	<b>FLOW</b>
	07232500	BF_PART
	07232500	RO_PART
Selected Data (1 of 16)		
OBSERVED	07232500	FLOW
Date Range of Selected Data		
	All	Common
Start	1937/10/01	1937/10/01
End	1993/09/30	1993/09/30
		<input checked="" type="checkbox"/> Include Provisional Data <input checked="" type="checkbox"/> Subset and Filter Time Series
		<div>Ok</div> <div>Cancel</div>

which results in the following dialog box:

**Filter Data**

Subset By Date | Split Into Time Periods | Filter By Value | Change Time Step | Timeseries Math

	All	Common	
Start	1937/10/01	1937/10/01	1937/10/01
End	1993/09/30	1993/09/30	1993/09/30

☐ Apply month/day range to each year

Ok Cancel

Two examples are provided to illustrate how the functionality can be used.

In the first example, streamflow data for the Beaver River are subsetted by a particular month, in this case, October, for graphing. This is done in the 'Subset By Date' tab, in which the user checks the 'Apply month/day range to each year' button and modifies the data ranges to include only days in October:

**Filter Data**

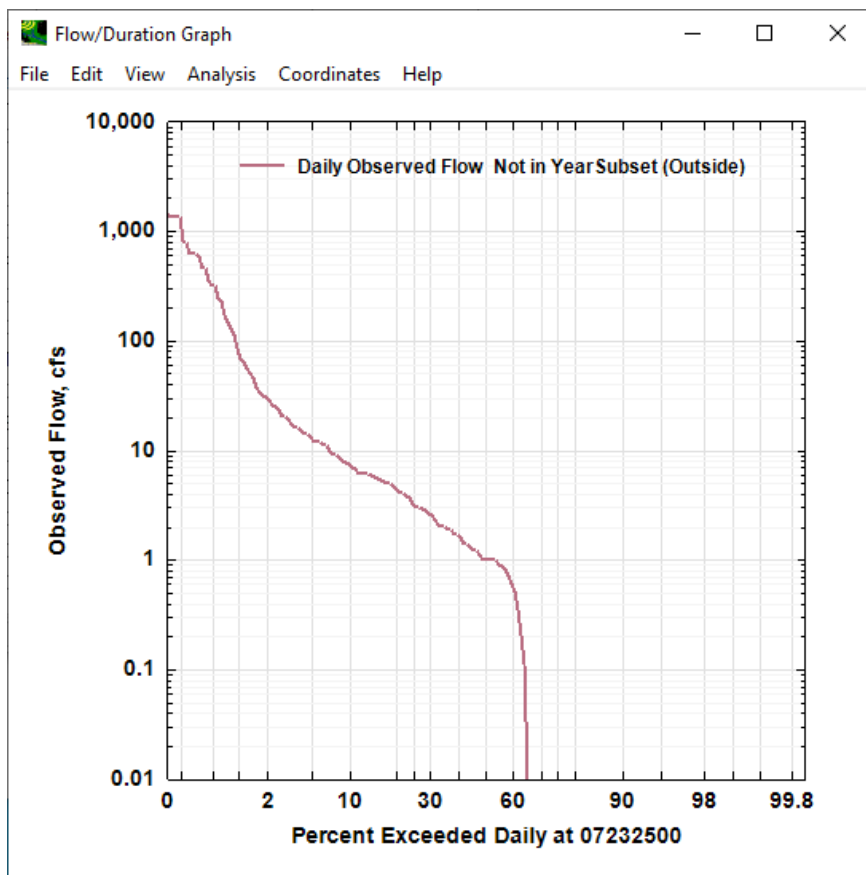
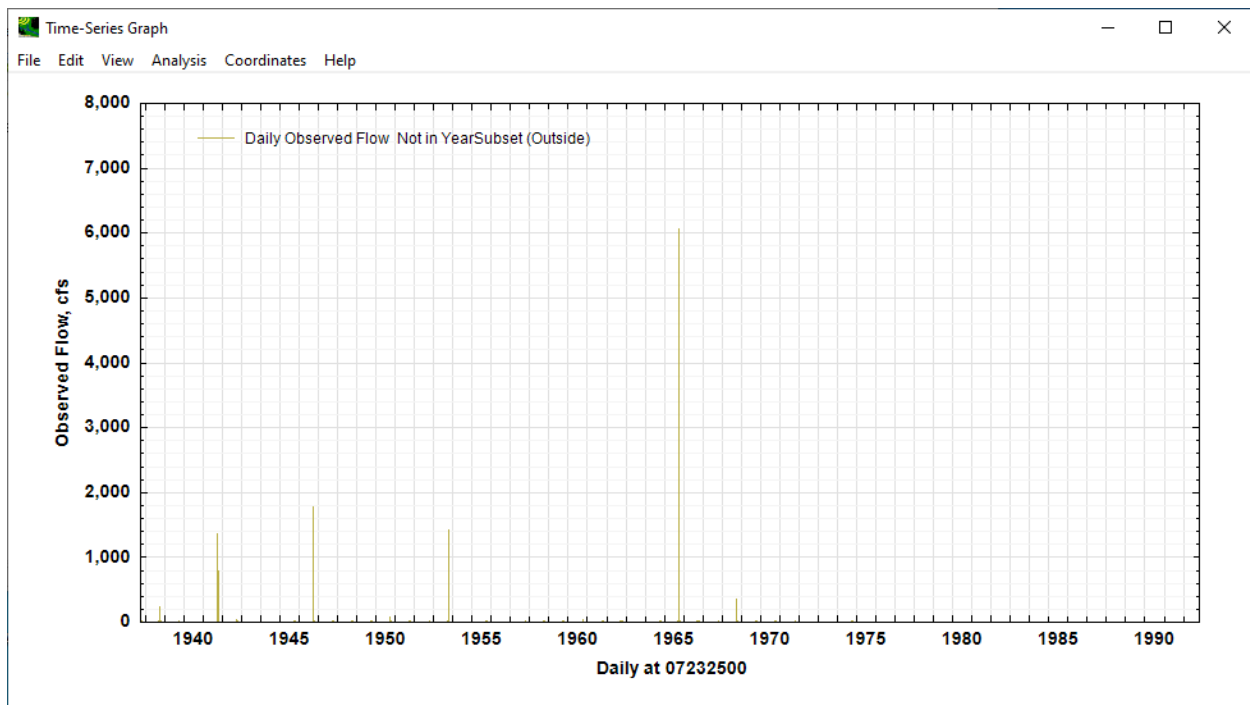
Subset By Date | Split Into Time Periods | Filter By Value | Change Time Step | Timeseries Math

	All	Common	
Start	1937/10/01	1937/10/01	1937/10/01
End	1993/09/30	1993/09/30	1992/10/31

☒ Apply month/day range to each year

Ok Cancel

After then choosing the 'Time Series' and 'Flow/Duration' graphing options, the following two plots are generated:



The next example illustrates how the streamflow data can be split into 5-year increments to evaluate how flow-duration conditions changed at the streamgauge over the period January 1, 1938, through December 31, 1992. First, after selecting the 'Subset and Filter Time Series' option within the graphing dialog box, the user specifies the date range of the analysis within the 'Subset By Date' tab:

The screenshot shows a software window titled 'Filter Data' with standard Windows window controls (minimize, maximize, close). The window contains five tabs: 'Subset By Date', 'Split Into Time Periods', 'Filter By Value', 'Change Time Step', and 'Timeseries Math'. The 'Subset By Date' tab is currently selected. Inside this tab, there are two sub-tabs: 'All' and 'Common'. The 'Common' sub-tab is active. Below the sub-tabs, there are date selection fields. The 'Start' row shows '1937/10/01' for 'All' and '1937/10/01' for 'Common', with a text box to the right containing '1938/01/01'. The 'End' row shows '1993/09/30' for 'All' and '1993/09/30' for 'Common', with a text box to the right containing '1992/12/31'. Below these fields is a checkbox labeled 'Apply month/day range to each year', which is currently unchecked. At the bottom right of the dialog are 'Ok' and 'Cancel' buttons.

	All	Common	
Start	1937/10/01	1937/10/01	1938/01/01
End	1993/09/30	1993/09/30	1992/12/31

☐ Apply month/day range to each year

Ok Cancel

and then selects the 'Split Into Time Periods' tab, which results in the following dialog box:

**Filter Data**

Subset By Date | Split Into Time Periods | Filter By Value | Change Time Step | Timeseries Math

☒ Split Into Time Periods

Time Periods  
 Month

Time periods to include:

Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep

All None

☒ One time series containing all values from selected time periods  
☐ Separate time series for each selected time period  
☐ Separate time series for each group of  time periods

Ok Cancel

For this analysis, the user checks the 'Split Into Time Periods' button, selects 'Calendar Year' under 'Time Periods', highlights the years of interest in blue (which in this case have been pre-loaded for 1938-1992), checks the 'Separate time series for each group of \_\_\_ time periods' button, and then specifies '5' for the number of time periods:

**Filter Data**

Subset By Date   Split Into Time Periods   Filter By Value   Change Time Step   Timeseries Math

☒ Split Into Time Periods

Time Periods  
Calendar Year

Time periods to include:

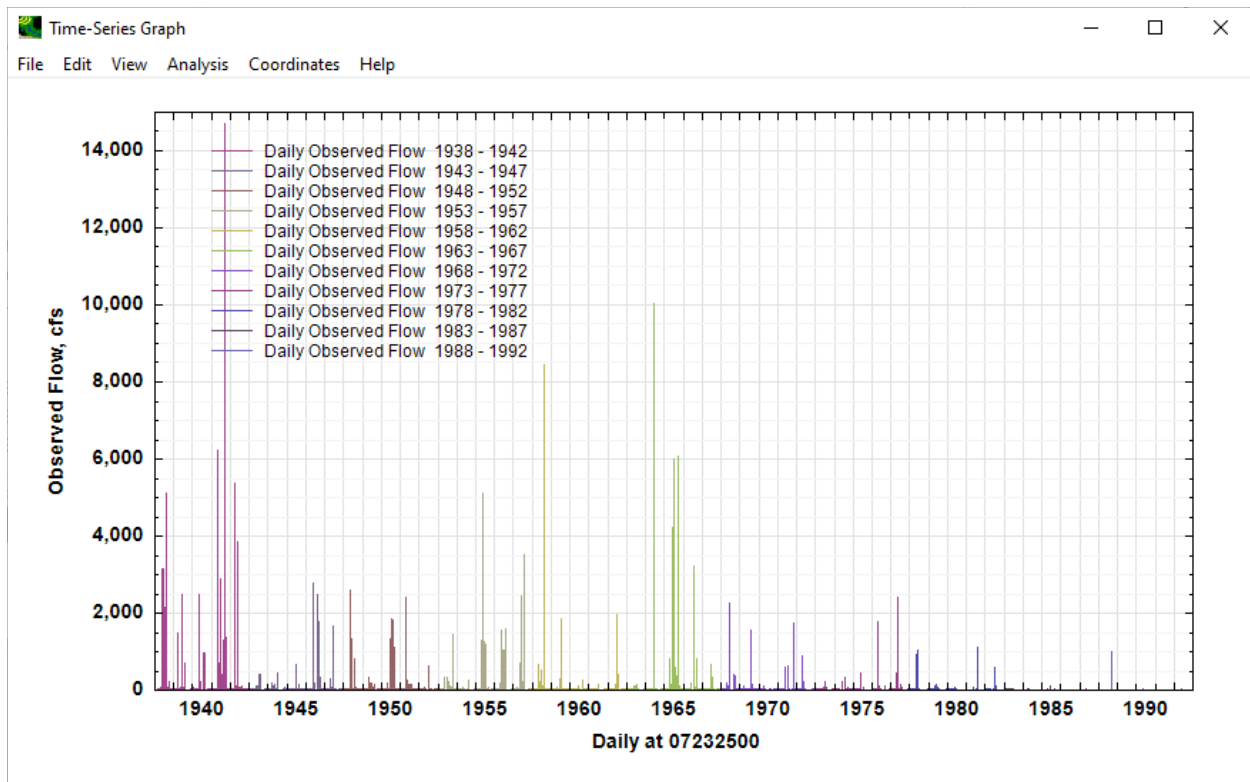
1970  
1971  
1972  
1973  
1974  
1975  
1976  
1977  
1978  
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1980  
1981  
1982  
1983  
1984  
1985  
1986  
1987  
1988  
1989  
1990  
1991  
1992  
1993

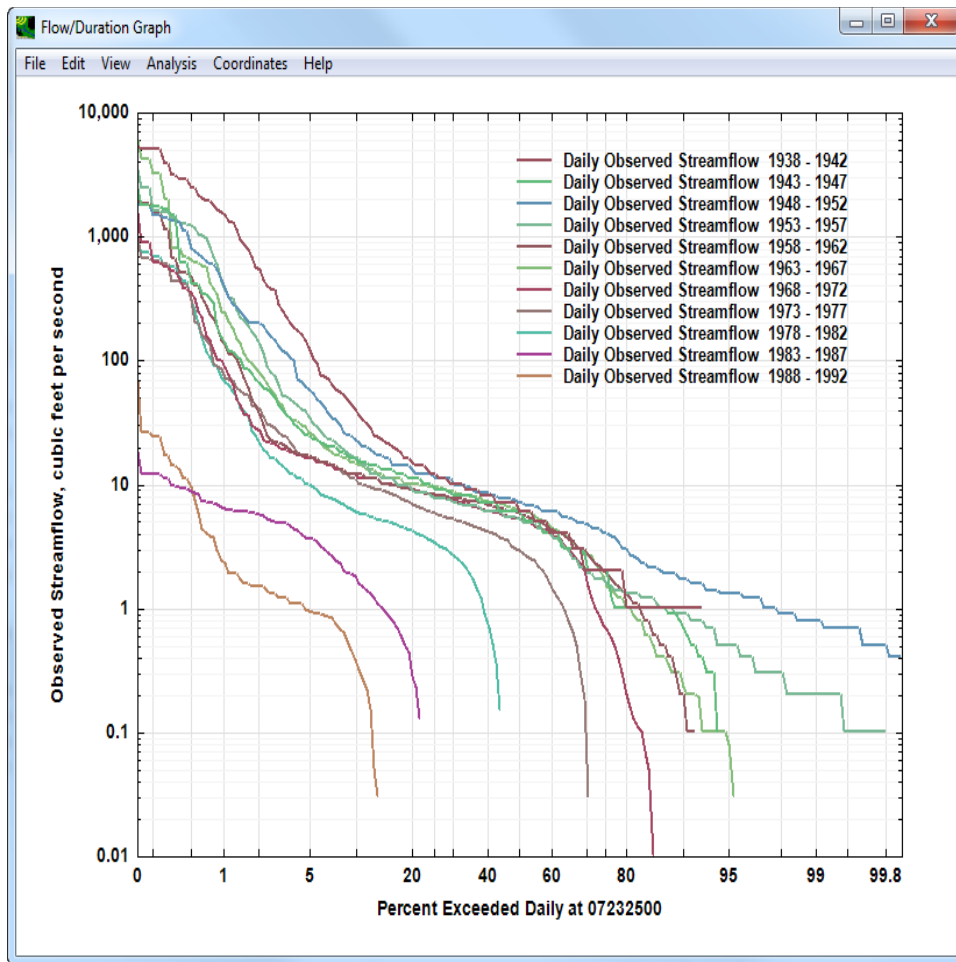
All   None

☐ One time series containing all values from selected time periods  
☐ Separate time series for each selected time period  
☒ Separate time series for each group of 5 time periods

Ok   Cancel

The resulting 'Time Series' and 'Flow/Duration' graphs for these selection criteria are:





The flow-duration curves for the 5-year intervals clearly demonstrate a decline in streamflow over the 55-year period, with those for the earliest time periods showing streamflows greater than 0.1 cubic feet per second more than approximately 95-percent of the time and those for the last two time periods (1983-1987; 1988-1992) showing flows below 0.2 cubic feet per second at the streamgauge more than 75 percent of the time.