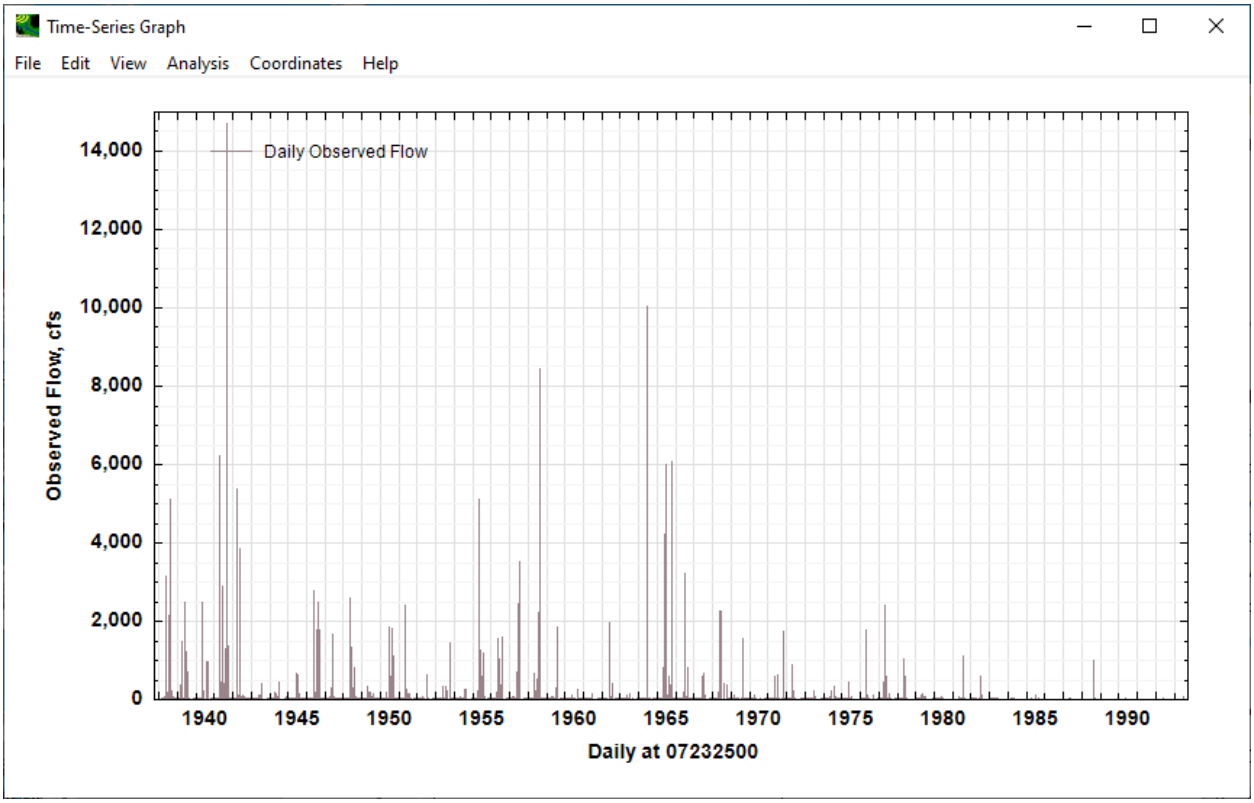
Analysis of Base Flow with the Hydrologic Toolbox

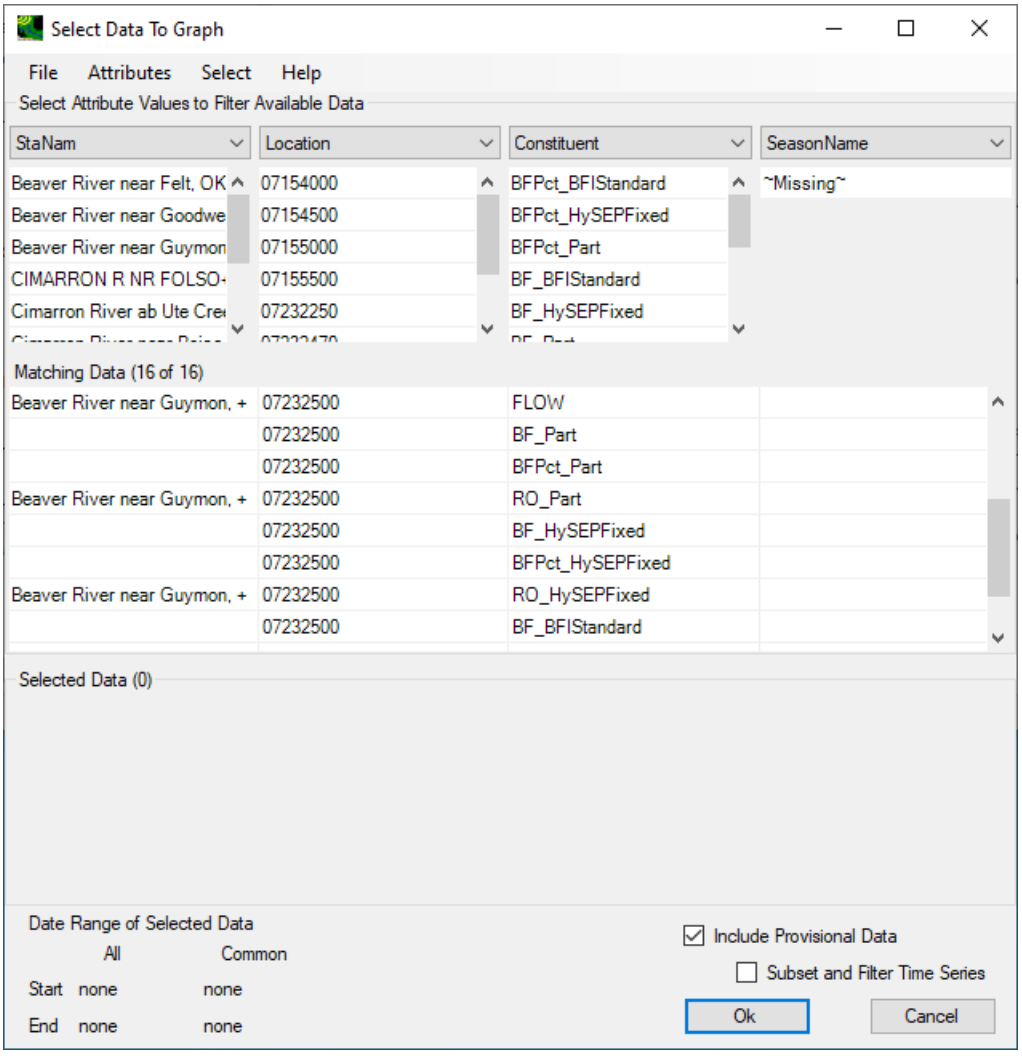
Version 1.0 Release

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

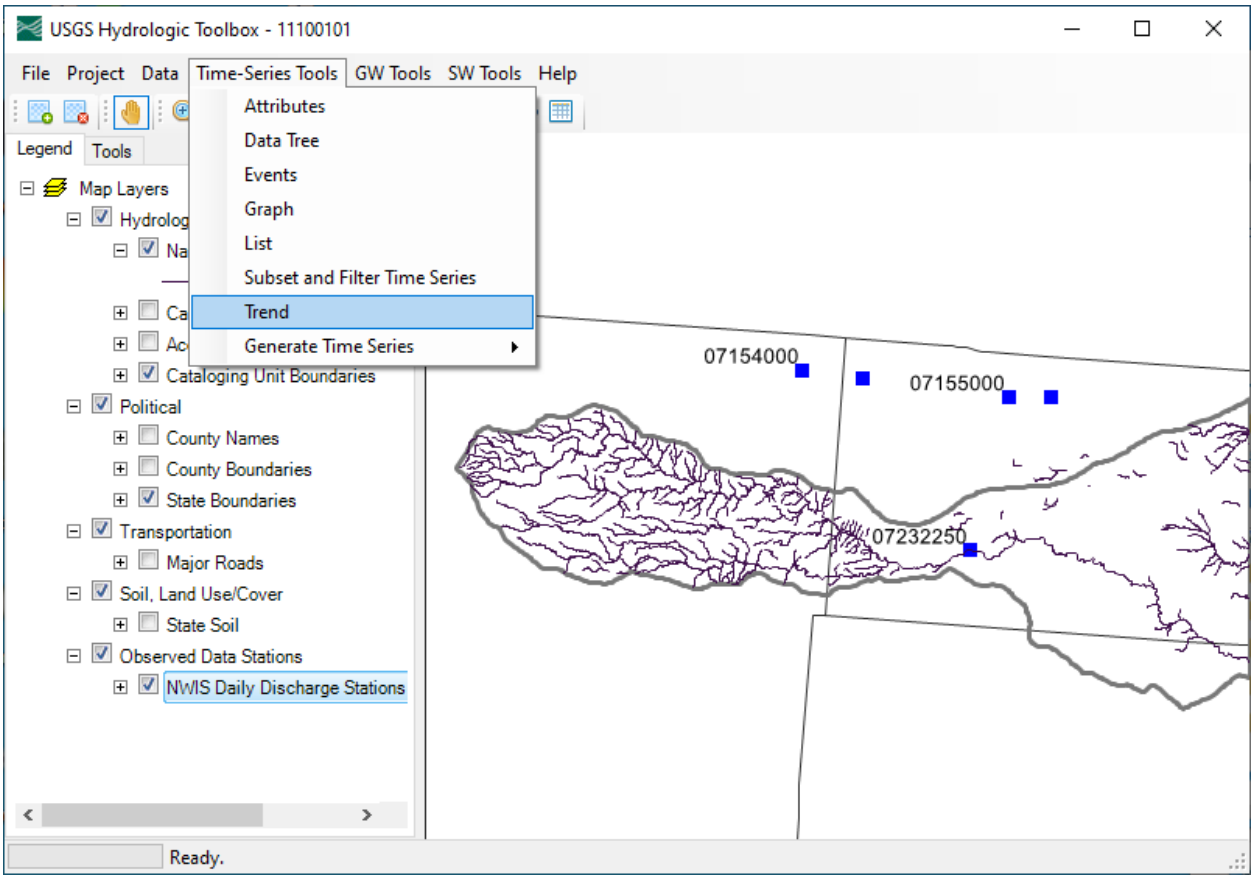
The Hydrologic Toolbox was used to calculate daily time series of base flow and runoff at the Beaver River streamgage for the period of record using the PART, HYSEP-FIXED, and BFI Standard approaches (see USGS Techniques and Methods 3-B10, which is distributed with the Hydrologic Toolbox, for a description 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:



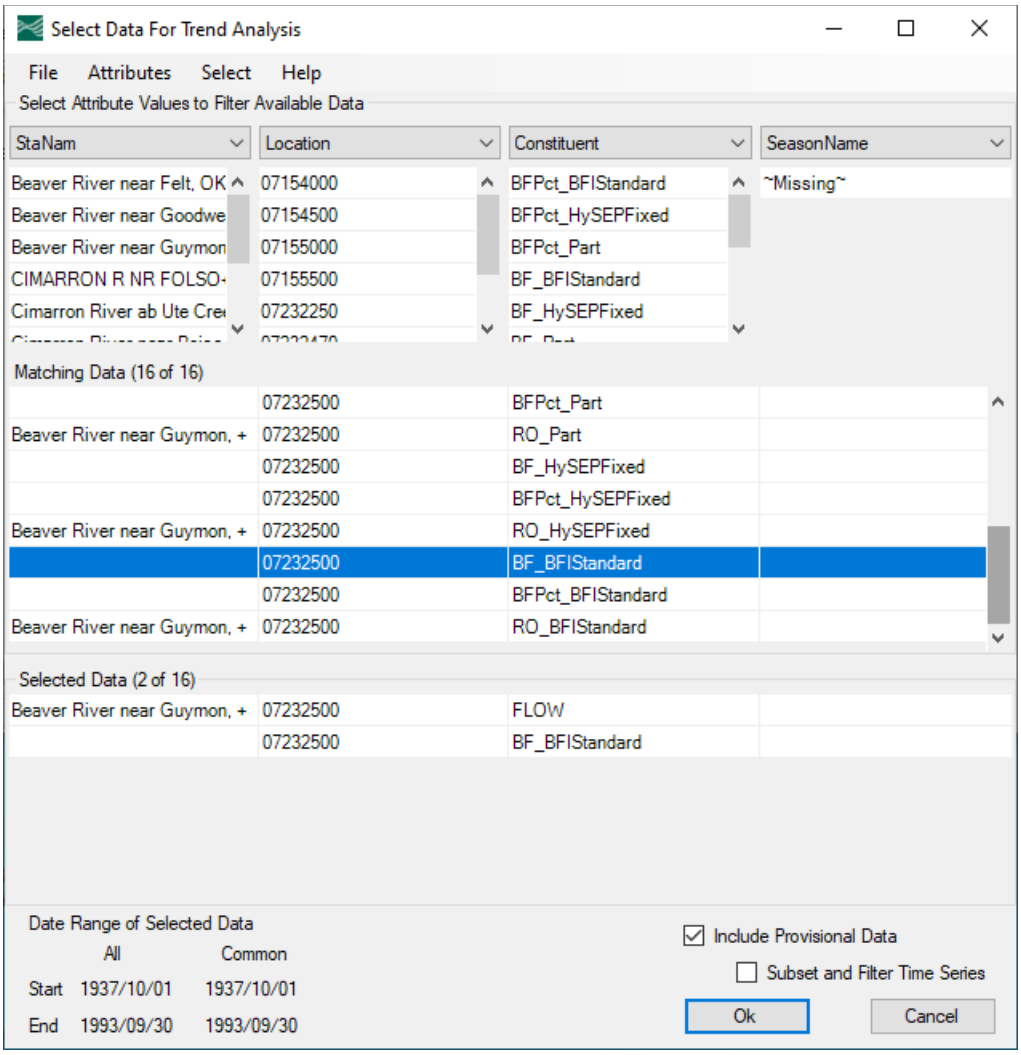
Note that after closing the current Toolbox session, the generated time series are saved with the project, as is done for the streamflow data.

Kendall Tau Trends Functionality

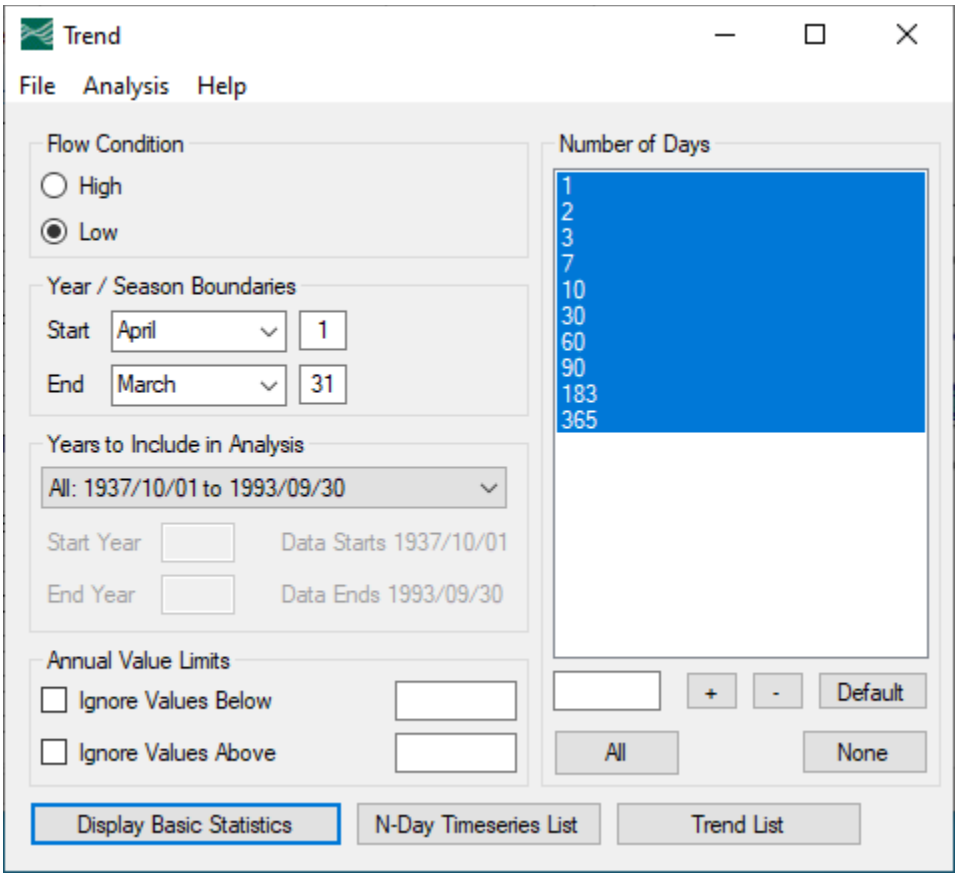
The Hydrologic Toolbox includes the Mann-Kendall method to test for monotonic trends in an annual time-series data set. Kendall's tau statistic is computed for the n-day time series, which is used to test for monotonic trends in time. The Kendall tau test statistic is reported along with the p-value 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:



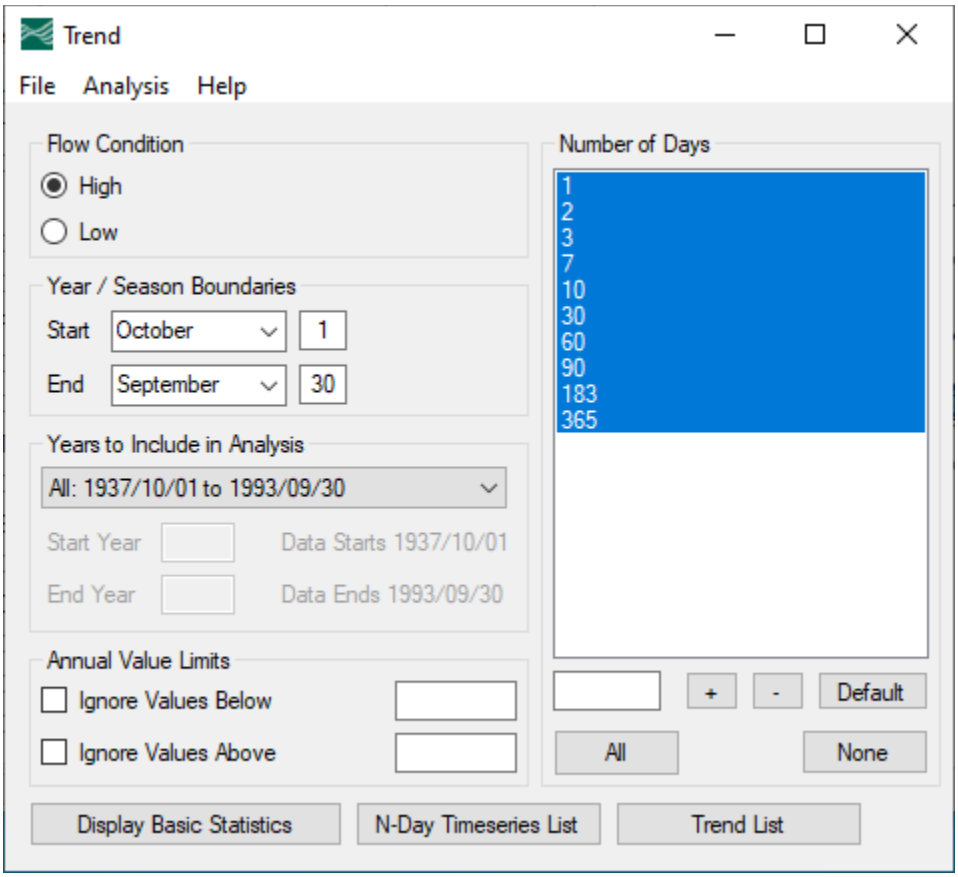
In this example, annual trends in observed streamflow and base flow calculated by the BFI Standard method will be analyzed for several user defined N-day periods. The first step is to select the streamflow and BFI base-flow records:



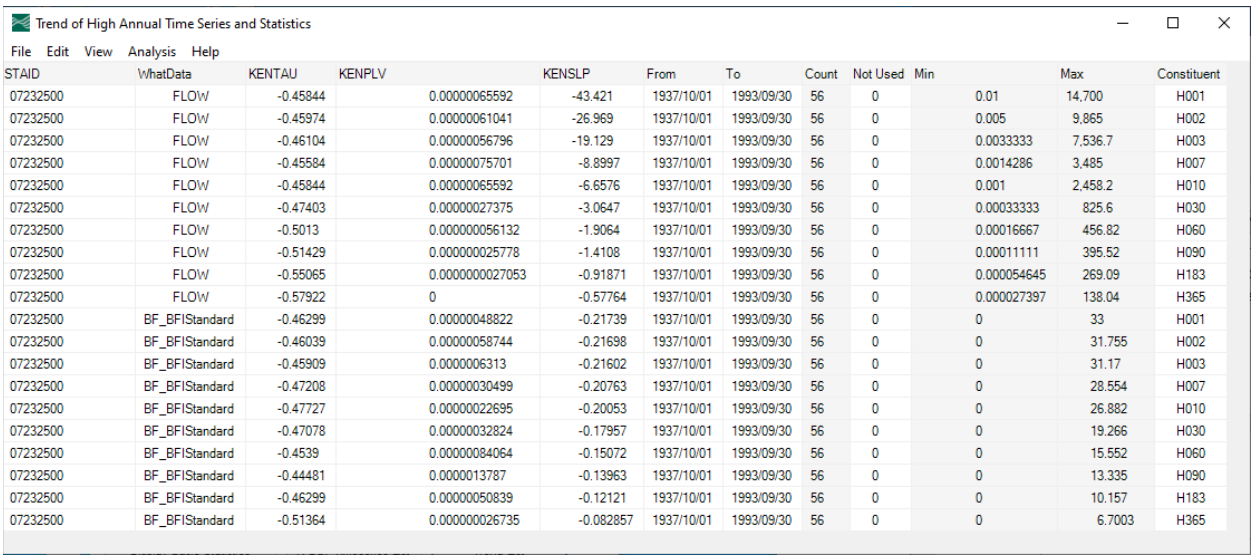
Hitting “Ok,” brings up the Trend dialog box:



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:



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



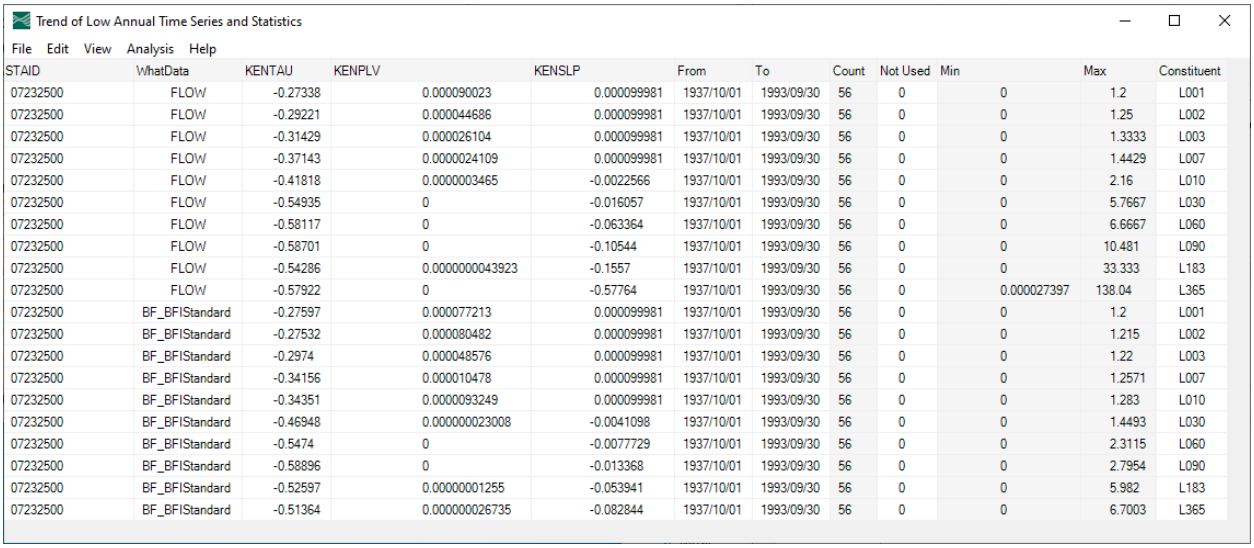
Trend of High Annual Time Series and Statistics

File Edit View Analysis Help

STAID	WhatData	KENTAU	KENPLV	KENSLP	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	0.0033333	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	0.00033333	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	0.00011111	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).

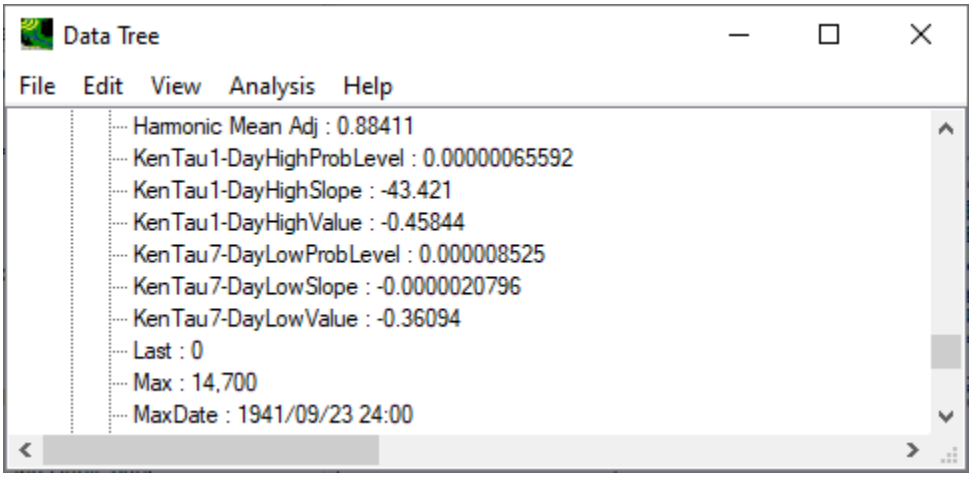
Statistically significant declines in streamflow and base flow also are evident for the low-flow N-day calculations (see below). Also note that the trend calculations for the 365-day low flows ('L365') are equivalent to those for the 365-day high flows because of the use of the same flow statistics for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

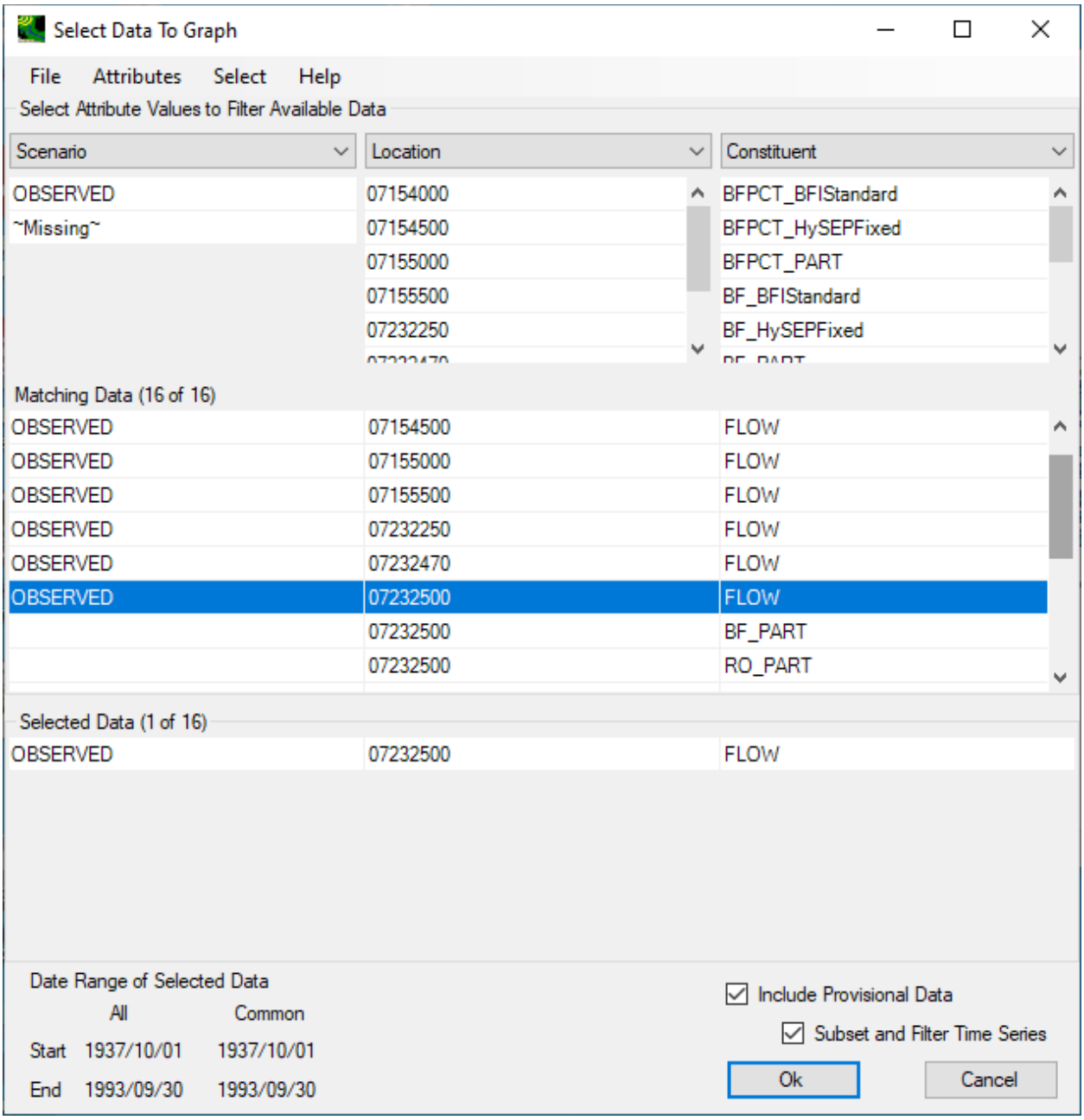
One final note concerning trends functionality in the Toolbox: The "**Data Tree**" option under "**Analysis**" includes 1-day high-flow (H001) and 7-day low-flow (L007) calculations for the selected time series, as illustrated for the streamflow data for the Beaver River streamgage:



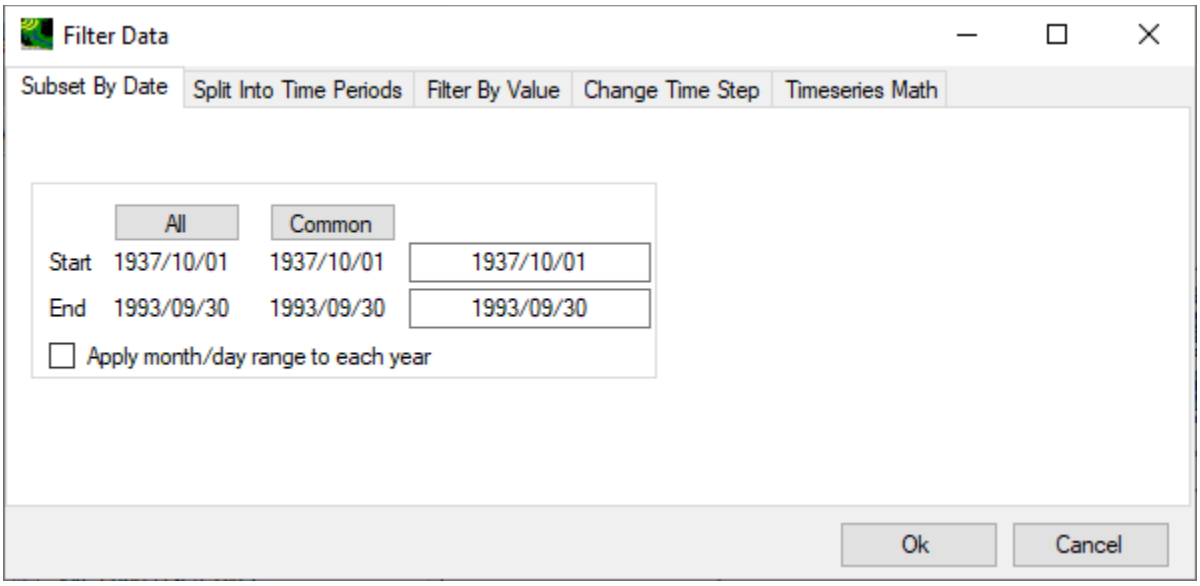
The 1-day high-flow values are exactly equal to those calculated by the "**Trends**" functionality because the annual analysis period is the same (October 1 through September 30). Note, however, that the "**Data Tree**" calculations for the 7-day low-flow values use an annual date range of April 1 through 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 subsetted 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 subsetted 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 subsetted 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:

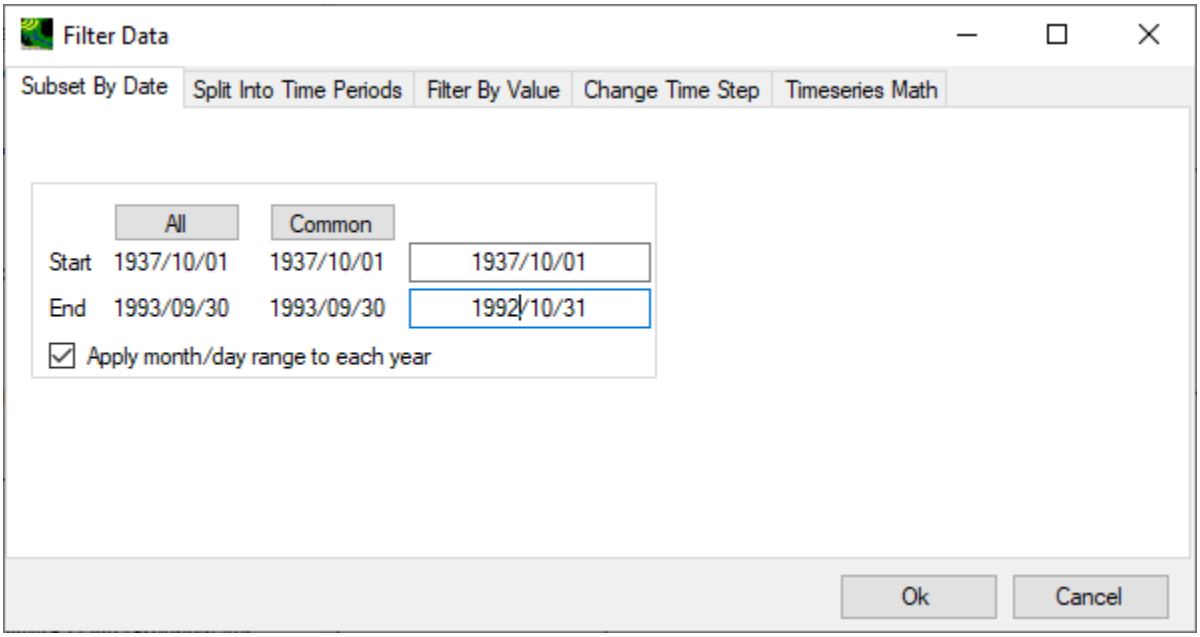


which results in the following dialog box:

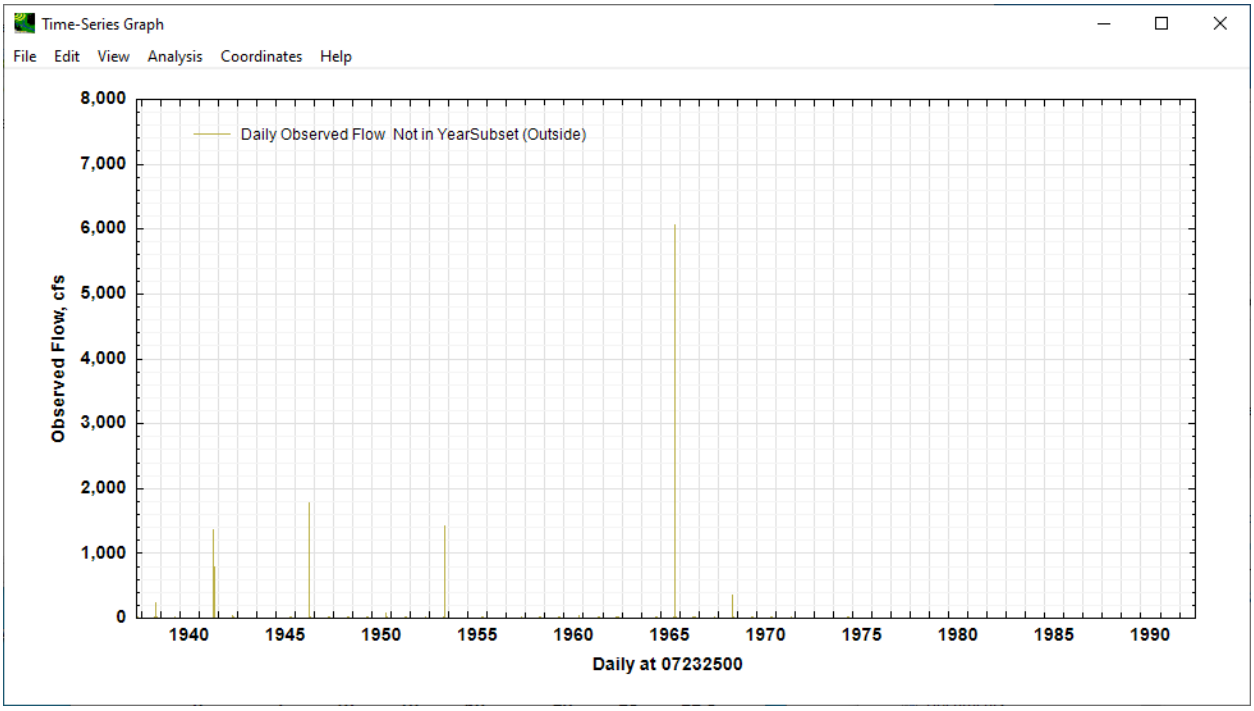


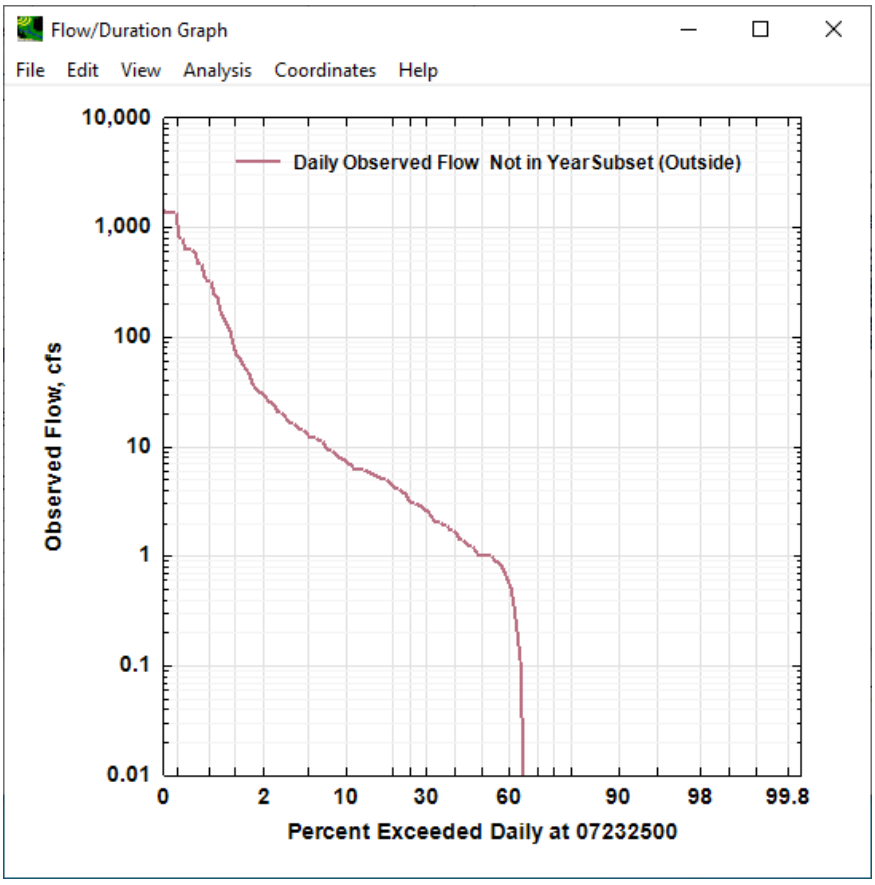
Two examples are provided to illustrate how the functionality can be used.

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:

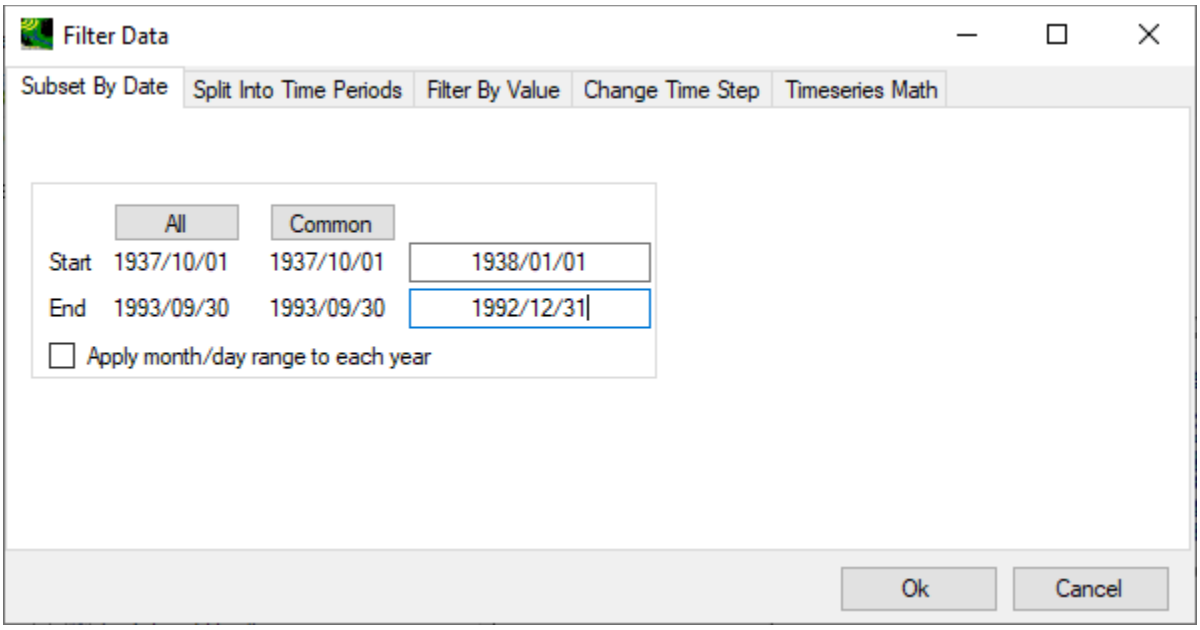


After then choosing the 'Time Series' and 'Flow/Duration' graphing options, the following two plots are generated:

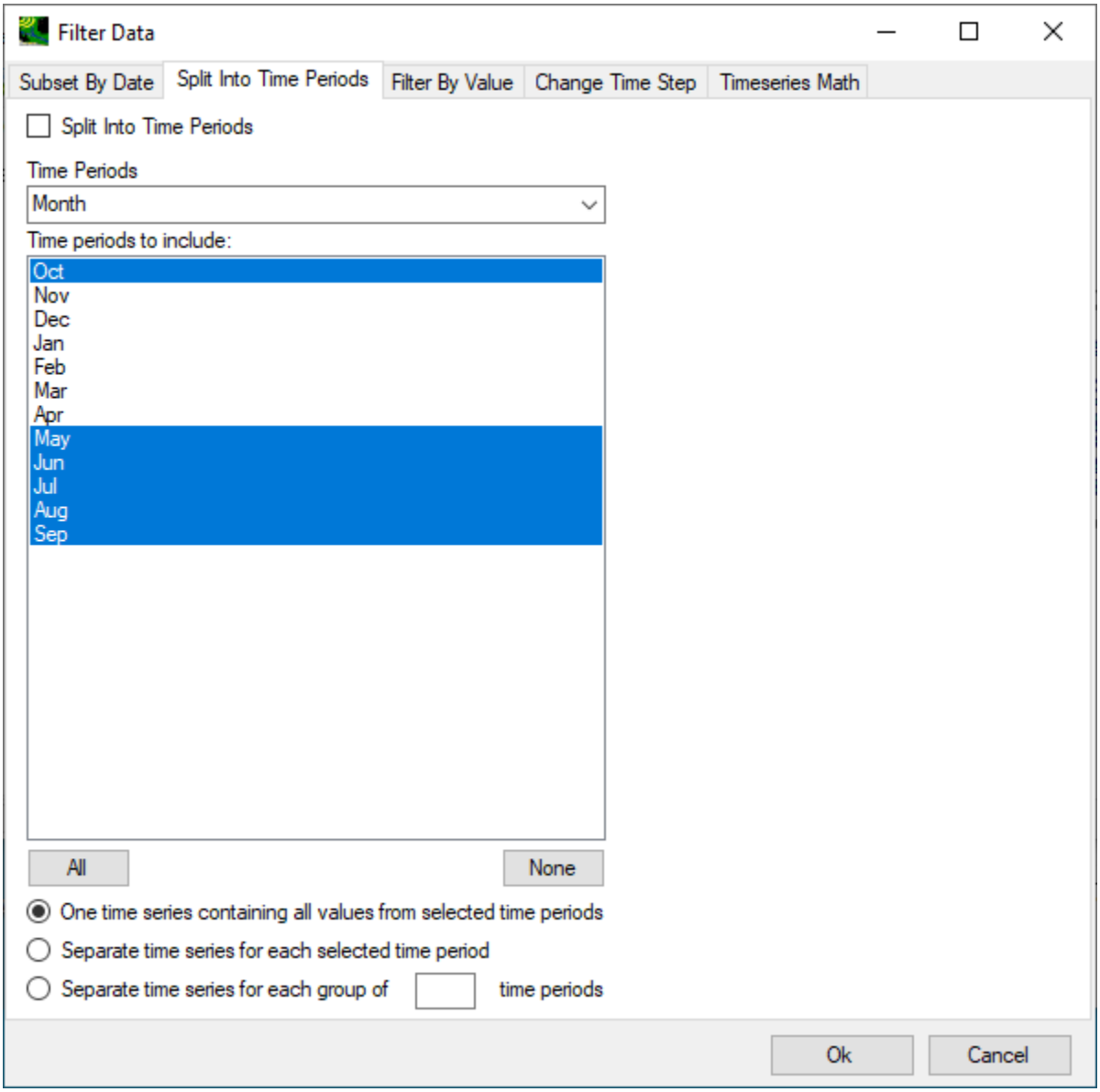

Time-Series Graph
File Edit View Analysis Coordinates Help
Daily Observed Flow Not in YearSubset (Outside)
Observed Flow, cfs
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
Daily at 07232500


Flow/Duration Graph
File Edit View Analysis Coordinates Help
Daily Observed Flow Not in YearSubset (Outside)
Observed Flow, cfs
10,000
1,000
100
10
1
0.1
0.01
0
2
10
30
60
90
98
99.8
Percent Exceeded Daily at 07232500

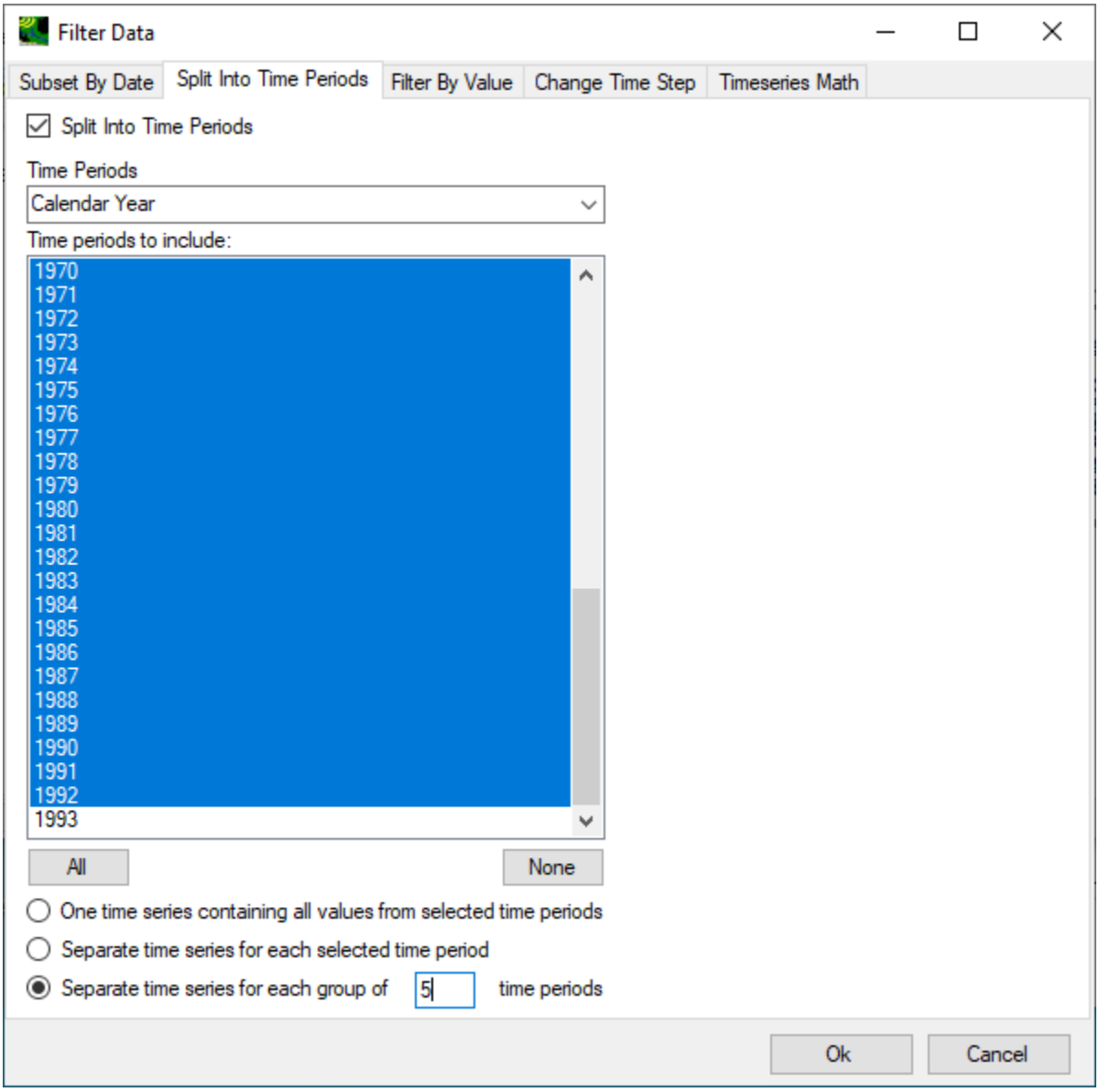
The next example illustrates how the streamflow data can be split into 5-year increments to evaluate how flow-duration conditions changed at the streamgage over the period January 1, 1938, through December 31, 1992. First, after selecting the 'Subset and Filter Time Series' option within the graphing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



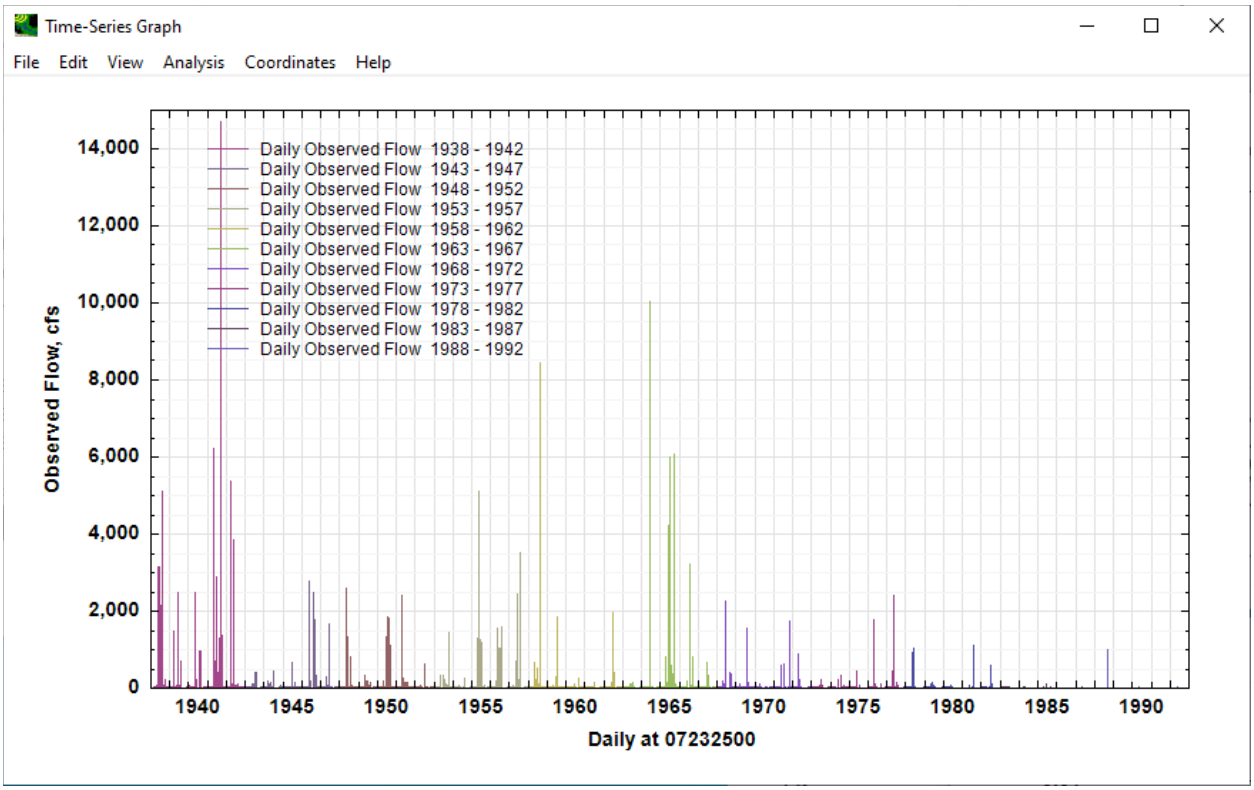
and then selects the 'Split Into Time Periods' tab, which results in the following dialog box:

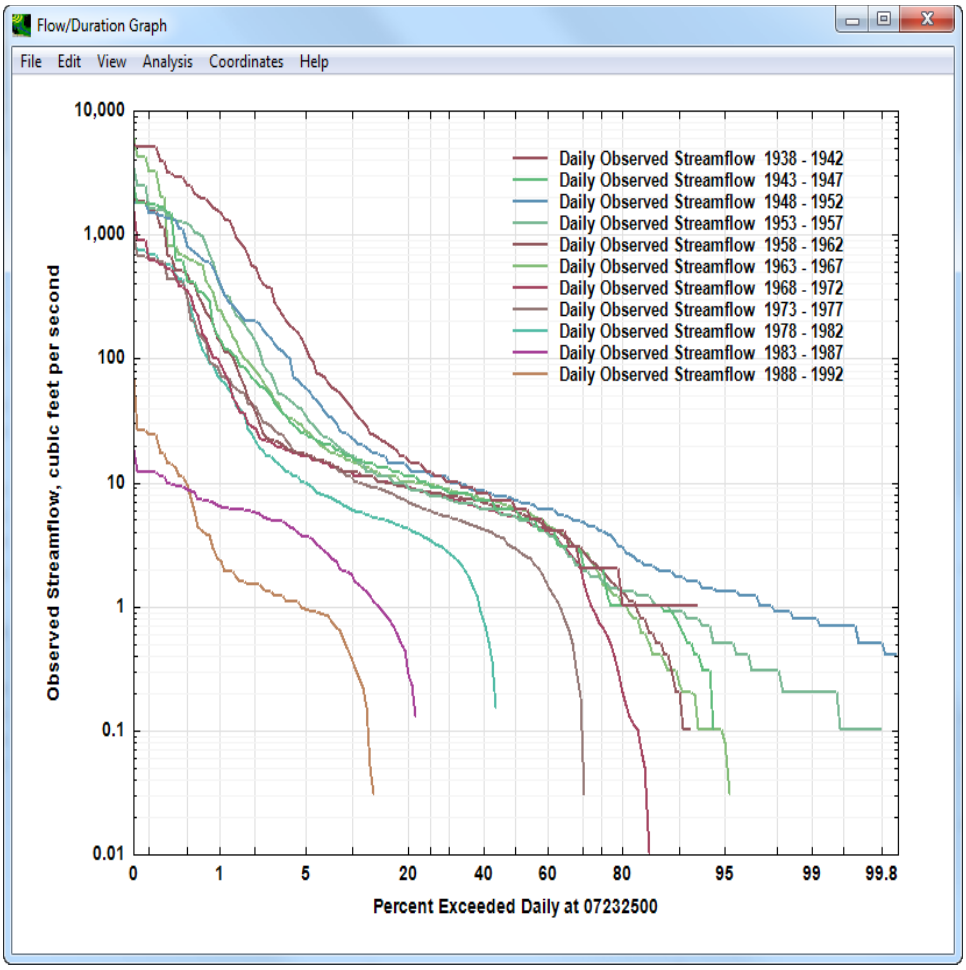


For this analysis, the user checks the 'Split Into Time Periods' button, selects 'Calendar Year' under 'Time Periods', highlights the years of interest in blue (which in this case have been pre-loaded for 1938-1992), checks the 'Separate time series for each group of __ time periods' button, and then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



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


Time-Series Graph
File Edit View Analysis Coordinates Help
Daily Observed Flow 1938 - 1942
Daily Observed Flow 1943 - 1947
Daily Observed Flow 1948 - 1952
Daily Observed Flow 1953 - 1957
Daily Observed Flow 1958 - 1962
Daily Observed Flow 1963 - 1967
Daily Observed Flow 1968 - 1972
Daily Observed Flow 1973 - 1977
Daily Observed Flow 1978 - 1982
Daily Observed Flow 1983 - 1987
Daily Observed Flow 1988 - 1992
Observed Flow, cfs
14,000
12,000
10,000
8,000
6,000
4,000
2,000
0
1940
1945
1950
1955
1960
1965
1970
1975
1980
1985
1990
Daily at 07232500



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 streamgage more than 75 percent of the time.