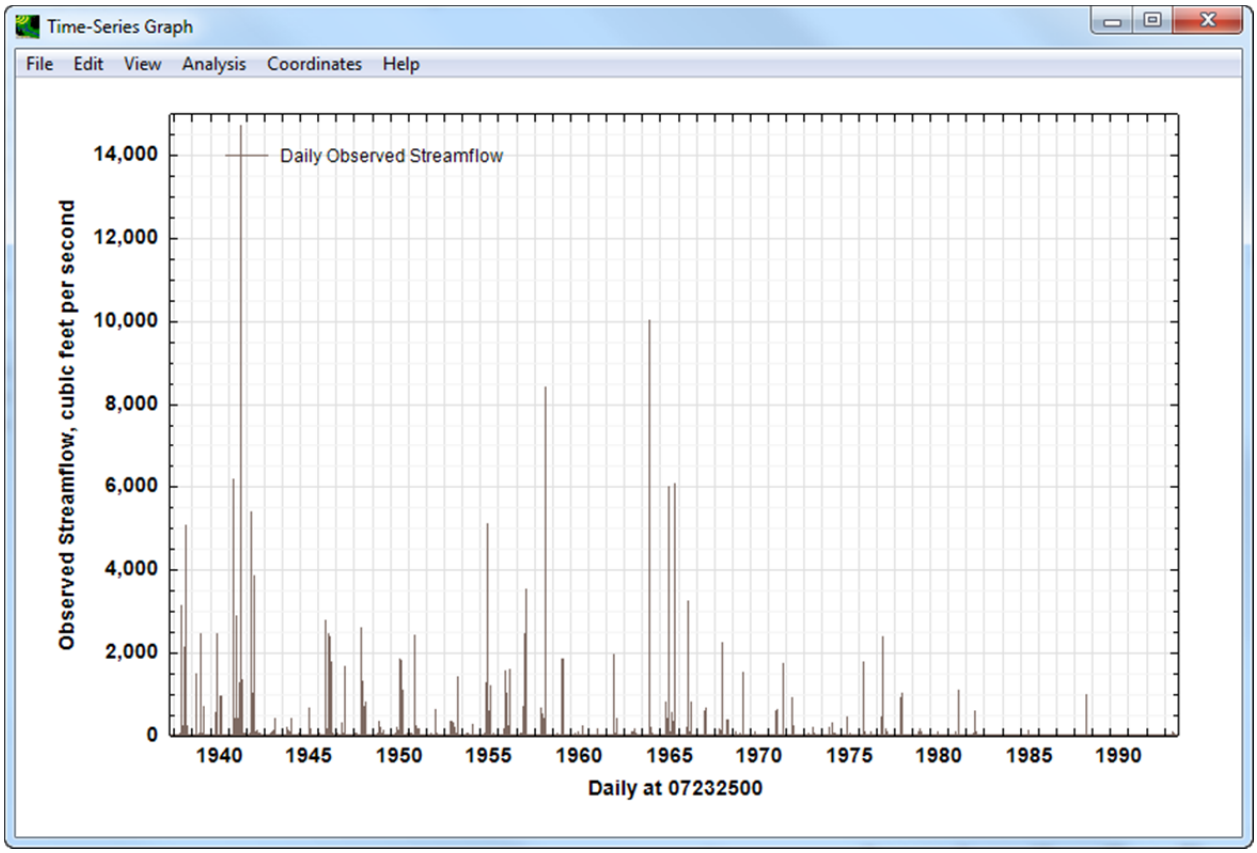
Groundwater Toolbox Tutorial

Updated Functionality for Analysis of Time-Series Data

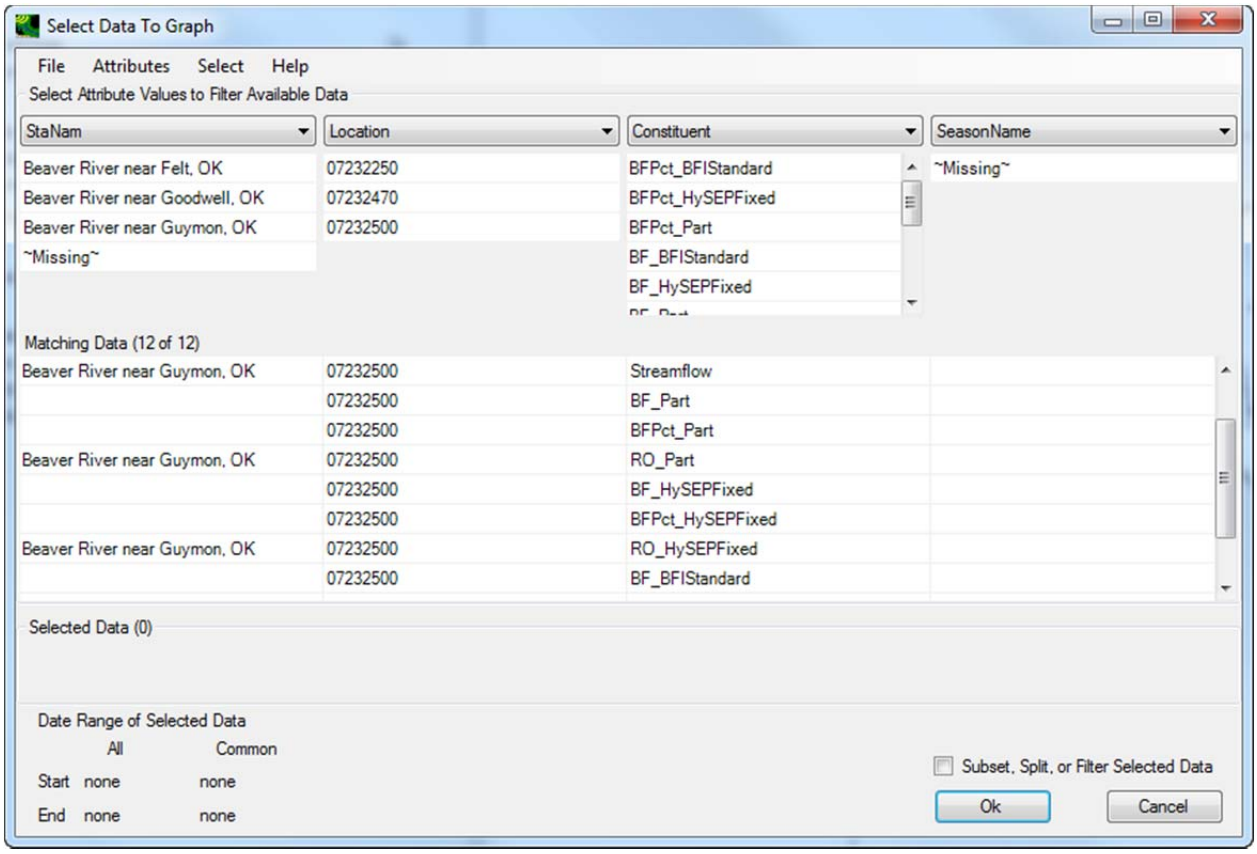
October 1, 2016 (Version 1.2 release)

This document describes updated functionality for the Groundwater (GW) Toolbox to analyze time-series data. The updates (1) allow users to work with base-flow and runoff time series generated by use of the "Interactive" mode of hydrograph separation, (2) provide enhancements to the existing Kendall Tau trends functionality, and (3) allow subsetting, splitting, filtering, and other manipulations of a time series. Each of the updates 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

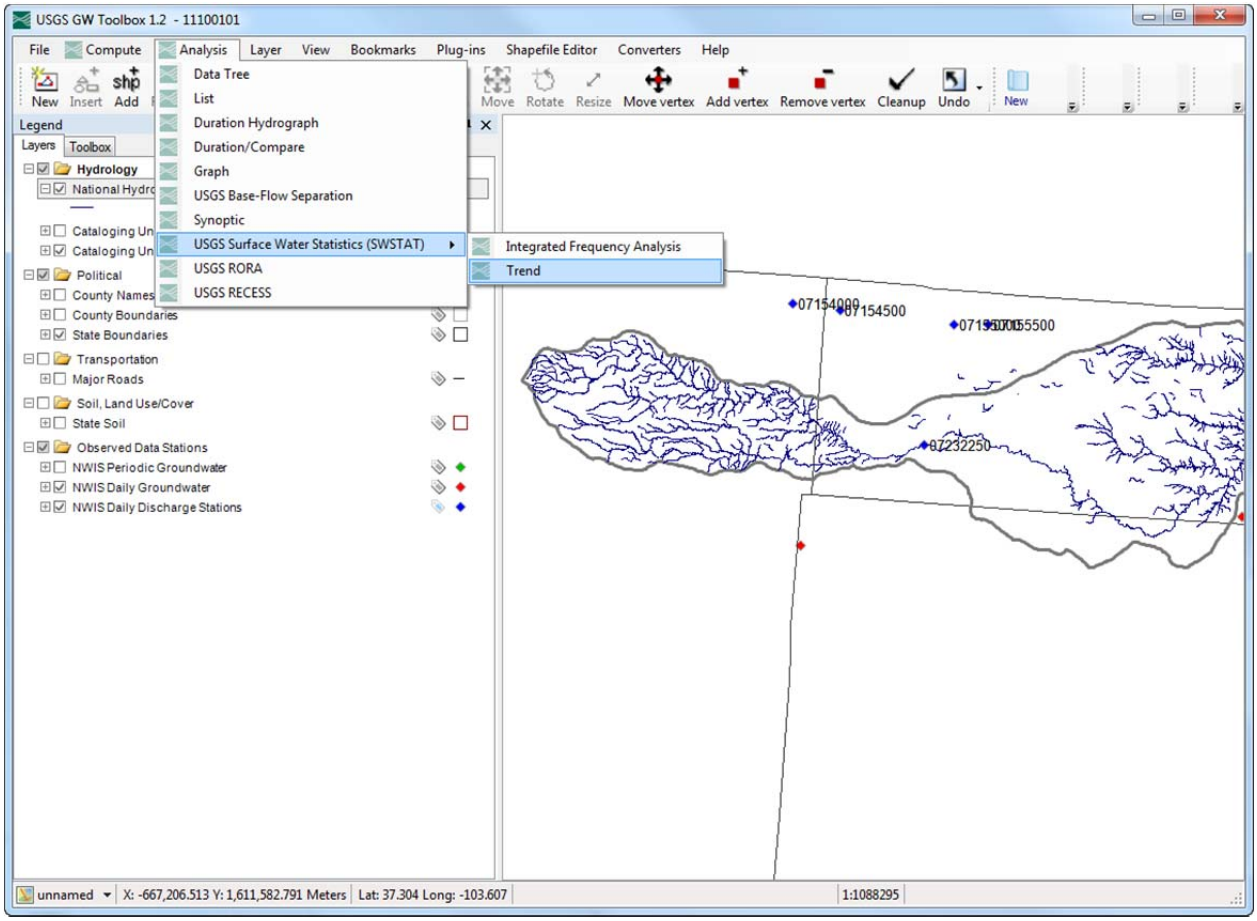
The GW Toolbox was used to calculate daily time series of base flow and runoff at the Beaver River streamgage for the period of record using the PART, HYSEP-FIXED, and BFI Standard approaches (see USGS Techniques and Methods 3-B10, which is distributed with the GW Toolbox, for a description of the hydrograph-separation methods, as well as the tutorial on "New and Updated Functionality for Hydrograph Separation with the Groundwater Toolbox"). 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:



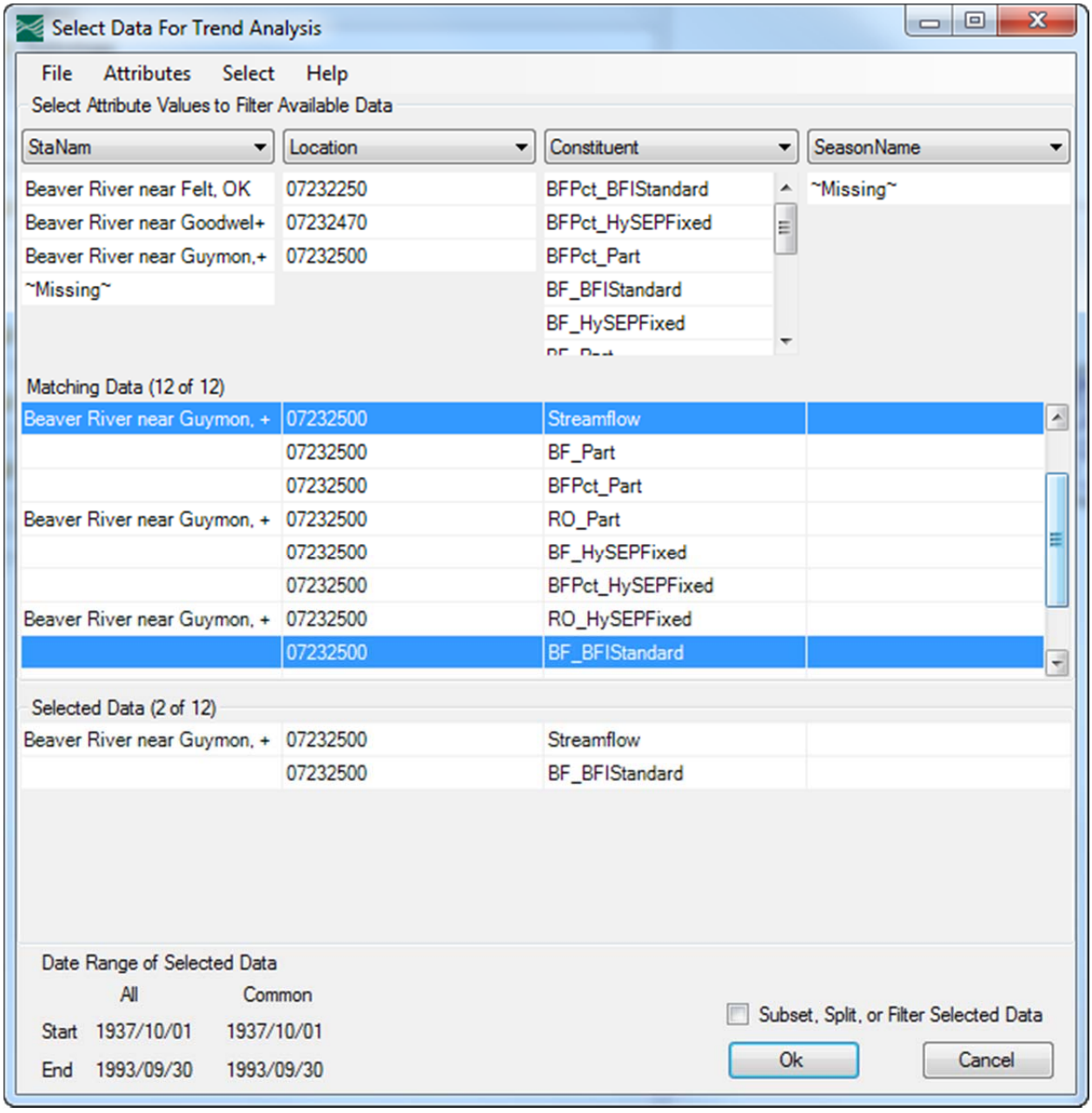
Note that after closing the current Toolbox session, the generated time series are not saved with the project, as is done for the streamflow data. However, the base-flow and runoff time series are available in the Daily.csv files that are generated as part of the hydrograph-separation process, and can be imported back into the Toolbox from the csv files (see the tutorial on 'Scripting_to_import_Excel_data.pdf').

Kendall Tau Trends Functionality

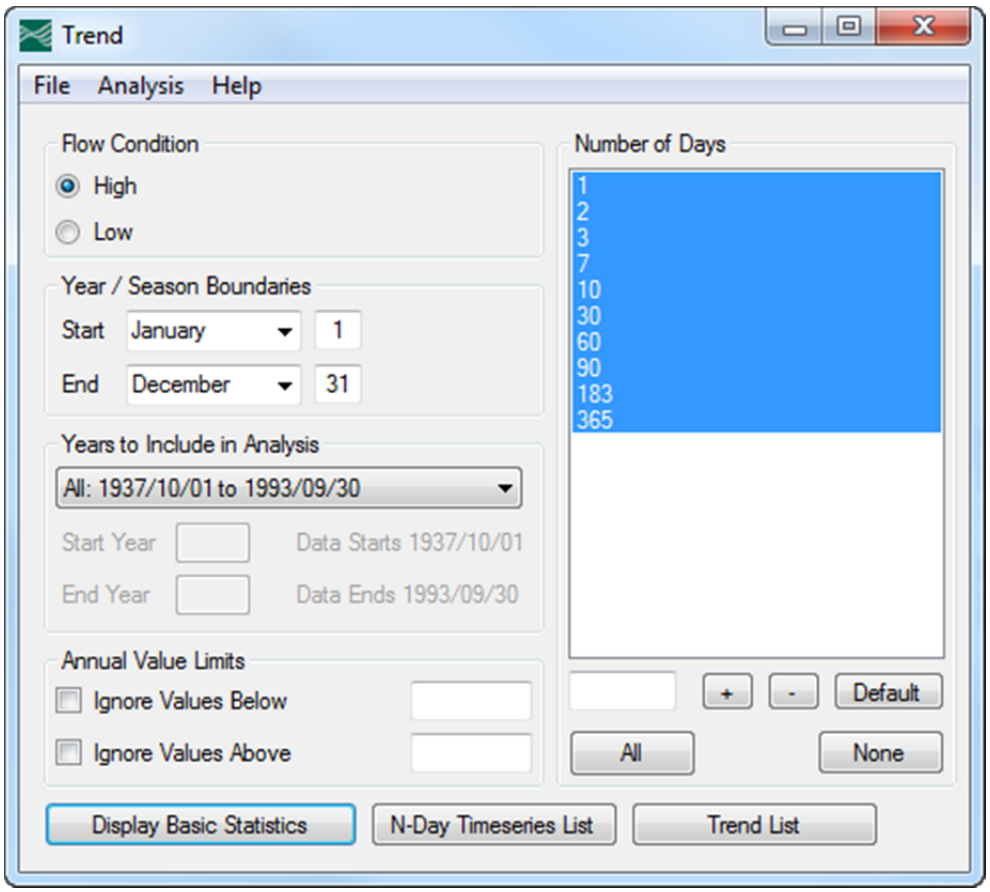
The GW Toolbox includes the Kendall Tau statistic to test for trends in an annual time-series data set. The functionality is available within the "**Analysis>USGS Surface Water Statistics (SWSTAT)>Trend**" option:



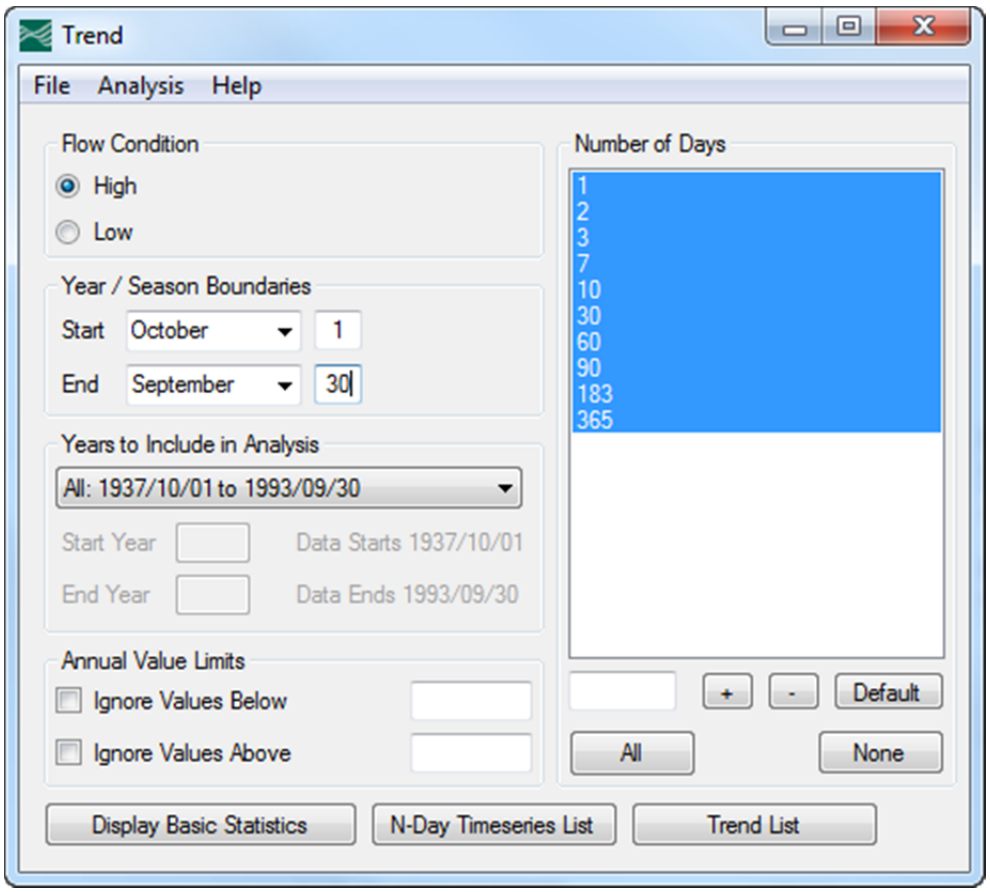
In this example, annual trends in observed streamflow and base flow calculated by the BFI Standard method will be analyzed for several user defined N-day periods. The first step is to select the streamflow and BFI base-flow records:



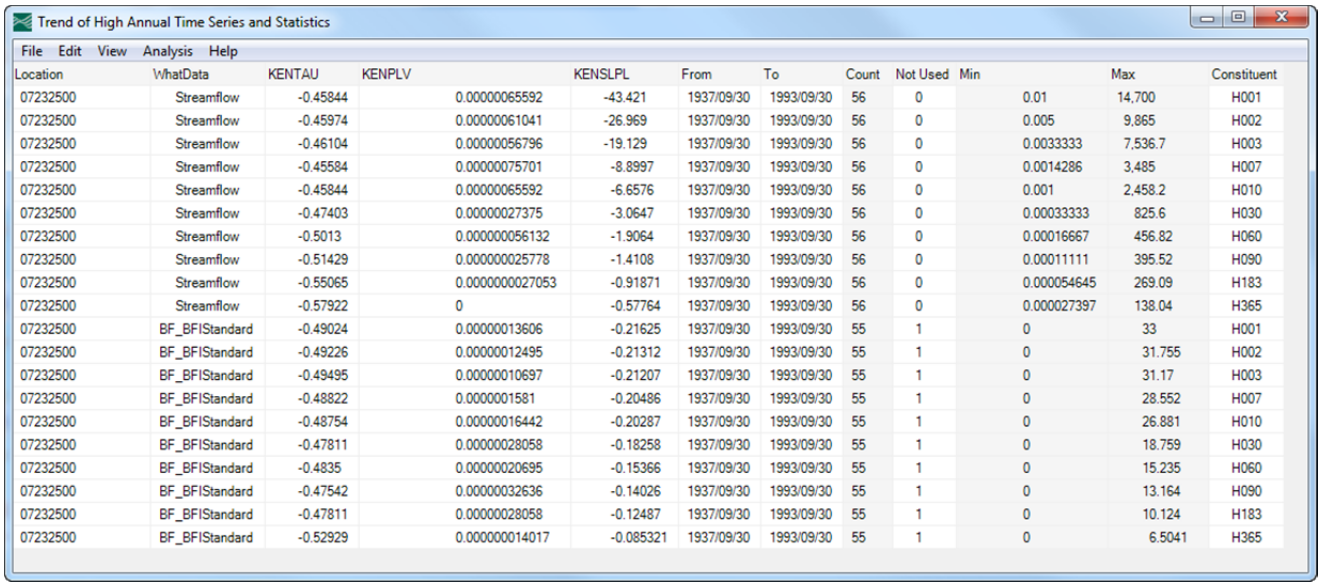
Hitting “Ok,” brings up the Trends dialog box:



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, we'll determine trends in high flows for all of the default days, and modify the Year/Season Boundaries to 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:



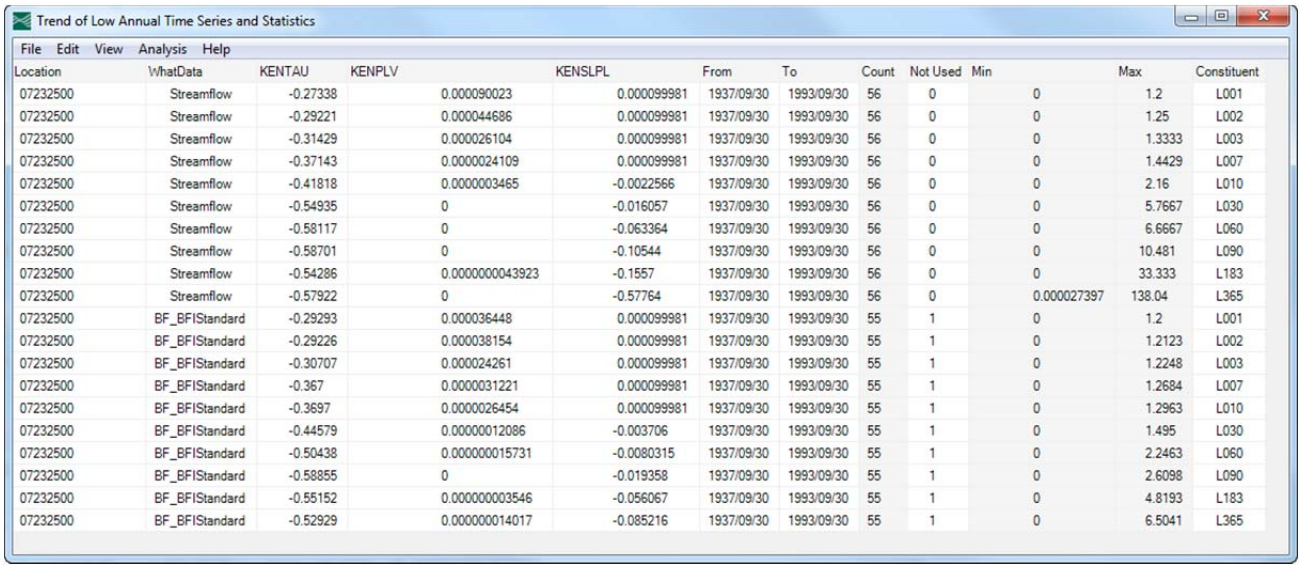
Trend of High Annual Time Series and Statistics

File Edit View Analysis Help

Location	WhatData	KENTAU	KENPLV	KENSLPL	From	To	Count	Not Used	Min	Max	Constituent
07232500	Streamflow	-0.45844	0.00000065592	-43.421	1937/09/30	1993/09/30	56	0	0.01	14,700	H001
07232500	Streamflow	-0.45974	0.00000061041	-26.969	1937/09/30	1993/09/30	56	0	0.005	9,865	H002
07232500	Streamflow	-0.46104	0.00000056796	-19.129	1937/09/30	1993/09/30	56	0	0.0033333	7,536.7	H003
07232500	Streamflow	-0.45584	0.00000075701	-8.8997	1937/09/30	1993/09/30	56	0	0.0014286	3,485	H007
07232500	Streamflow	-0.45844	0.00000065592	-6.6576	1937/09/30	1993/09/30	56	0	0.001	2,458.2	H010
07232500	Streamflow	-0.47403	0.00000027375	-3.0647	1937/09/30	1993/09/30	56	0	0.00033333	825.6	H030
07232500	Streamflow	-0.5013	0.00000056132	-1.9064	1937/09/30	1993/09/30	56	0	0.00016667	456.82	H060
07232500	Streamflow	-0.51429	0.00000025778	-1.4108	1937/09/30	1993/09/30	56	0	0.00011111	395.52	H090
07232500	Streamflow	-0.55065	0.0000000027053	-0.91871	1937/09/30	1993/09/30	56	0	0.000054645	269.09	H183
07232500	Streamflow	-0.57922	0	-0.57764	1937/09/30	1993/09/30	56	0	0.000027397	138.04	H365
07232500	BF_BFIStandard	-0.49024	0.00000013606	-0.21625	1937/09/30	1993/09/30	55	1	0	33	H001
07232500	BF_BFIStandard	-0.49226	0.00000012495	-0.21312	1937/09/30	1993/09/30	55	1	0	31.755	H002
07232500	BF_BFIStandard	-0.49495	0.0000010697	-0.21207	1937/09/30	1993/09/30	55	1	0	31.17	H003
07232500	BF_BFIStandard	-0.48822	0.0000001581	-0.20486	1937/09/30	1993/09/30	55	1	0	28.552	H007
07232500	BF_BFIStandard	-0.48754	0.00000016442	-0.20287	1937/09/30	1993/09/30	55	1	0	26.881	H010
07232500	BF_BFIStandard	-0.47811	0.00000028058	-0.18258	1937/09/30	1993/09/30	55	1	0	18.759	H030
07232500	BF_BFIStandard	-0.4835	0.00000020695	-0.15366	1937/09/30	1993/09/30	55	1	0	15.235	H060
07232500	BF_BFIStandard	-0.47542	0.00000032636	-0.14026	1937/09/30	1993/09/30	55	1	0	13.164	H090
07232500	BF_BFIStandard	-0.47811	0.00000028058	-0.12487	1937/09/30	1993/09/30	55	1	0	10.124	H183
07232500	BF_BFIStandard	-0.52929	0.000000014017	-0.085321	1937/09/30	1993/09/30	55	1	0	6.5041	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 GW Toolbox (see USGS TM 3-B10, p. 3).

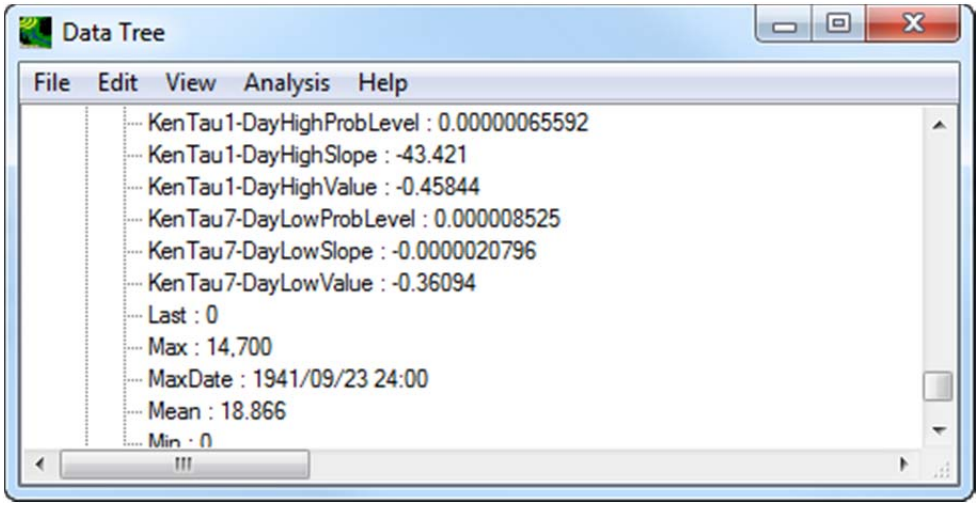
Statistically significant declines in streamflow and base flow also are evident for the low-flow N-day calculations (see below). Also note that the trend calculations for the 365-day low flows ('L365') are equivalent to those for the 365-day high flows because of the use of the same flow statistics for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


Trend of Low Annual Time Series and Statistics

File Edit View Analysis Help

Location	WhatData	KENTAU	KENPLV	KENSLPL	From	To	Count	Not Used	Min	Max	Constituent
07232500	Streamflow	-0.27338	0.000090023	0.000099981	1937/09/30	1993/09/30	56	0	0	1.2	L001
07232500	Streamflow	-0.29221	0.000044686	0.000099981	1937/09/30	1993/09/30	56	0	0	1.25	L002
07232500	Streamflow	-0.31429	0.000026104	0.000099981	1937/09/30	1993/09/30	56	0	0	1.3333	L003
07232500	Streamflow	-0.37143	0.0000024109	0.000099981	1937/09/30	1993/09/30	56	0	0	1.4429	L007
07232500	Streamflow	-0.41818	0.0000003465	-0.0022566	1937/09/30	1993/09/30	56	0	0	2.16	L010
07232500	Streamflow	-0.54935	0	-0.016057	1937/09/30	1993/09/30	56	0	0	5.7667	L030
07232500	Streamflow	-0.58117	0	-0.063364	1937/09/30	1993/09/30	56	0	0	6.6667	L060
07232500	Streamflow	-0.58701	0	-0.10544	1937/09/30	1993/09/30	56	0	0	10.481	L090
07232500	Streamflow	-0.54286	0.0000000043923	-0.1557	1937/09/30	1993/09/30	56	0	0	33.333	L183
07232500	Streamflow	-0.57922	0	-0.57764	1937/09/30	1993/09/30	56	0	0.000027397	138.04	L365
07232500	BF_BFIStandard	-0.29293	0.000036448	0.000099981	1937/09/30	1993/09/30	55	1	0	1.2	L001
07232500	BF_BFIStandard	-0.29226	0.000038154	0.000099981	1937/09/30	1993/09/30	55	1	0	1.2123	L002
07232500	BF_BFIStandard	-0.30707	0.000024261	0.000099981	1937/09/30	1993/09/30	55	1	0	1.2248	L003
07232500	BF_BFIStandard	-0.367	0.0000031221	0.000099981	1937/09/30	1993/09/30	55	1	0	1.2684	L007
07232500	BF_BFIStandard	-0.3697	0.0000026454	0.000099981	1937/09/30	1993/09/30	55	1	0	1.2963	L010
07232500	BF_BFIStandard	-0.44579	0.00000012086	-0.003706	1937/09/30	1993/09/30	55	1	0	1.495	L030
07232500	BF_BFIStandard	-0.50438	0.000000015731	-0.0080315	1937/09/30	1993/09/30	55	1	0	2.2463	L060
07232500	BF_BFIStandard	-0.58855	0	-0.019358	1937/09/30	1993/09/30	55	1	0	2.6098	L090
07232500	BF_BFIStandard	-0.55152	0.000000003546	-0.056067	1937/09/30	1993/09/30	55	1	0	4.8193	L183
07232500	BF_BFIStandard	-0.52929	0.000000014017	-0.085216	1937/09/30	1993/09/30	55	1	0	6.5041	L365

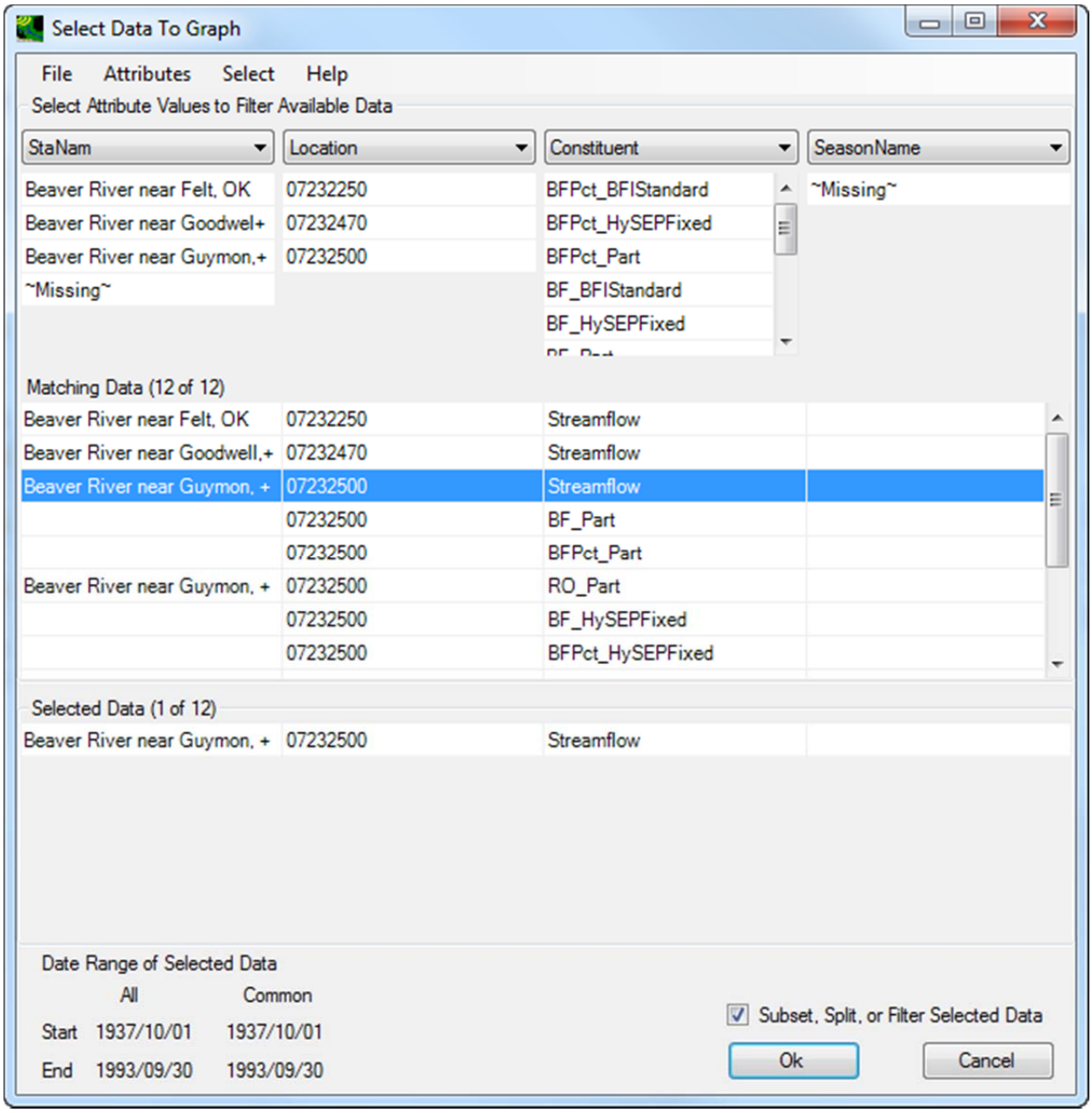
One final note concerning trends functionality in the Toolbox: The "**Data Tree**" option under "**Analysis**" includes 1-day high-flow (H001) and 7-day low-flow (L007) calculations for the selected time series, as illustrated for the streamflow data for the Beaver River streamgage:



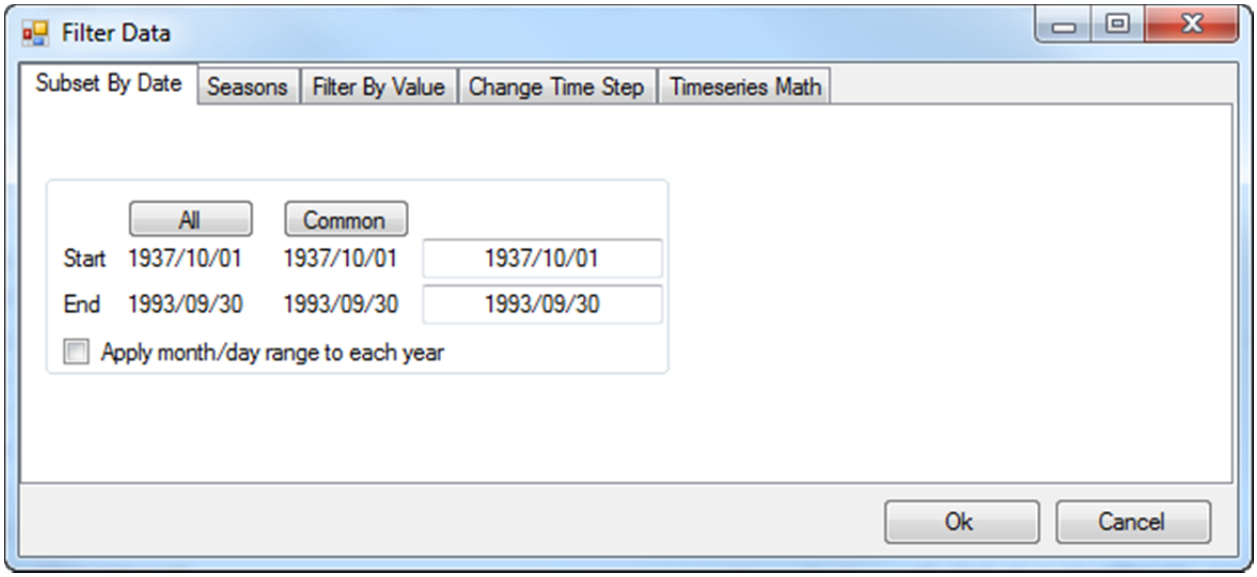
The 1-day high-flow values are exactly equal to those calculated by the "**Trends**" functionality because the annual analysis period is the same (October 1 through September 30). Note, however, that the "**Data Tree**" calculations for the 7-day low-flow values use an annual date range of April 1 through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

"Subset, Split, or Filter Selected Data" Functionality

A new functionality has been developed to subset, split, or filter time-series data that have been selected for graphing or analysis. The functionality is implemented by checking the subsetting option in the 'Select Data' dialog boxes, such as for graphing:

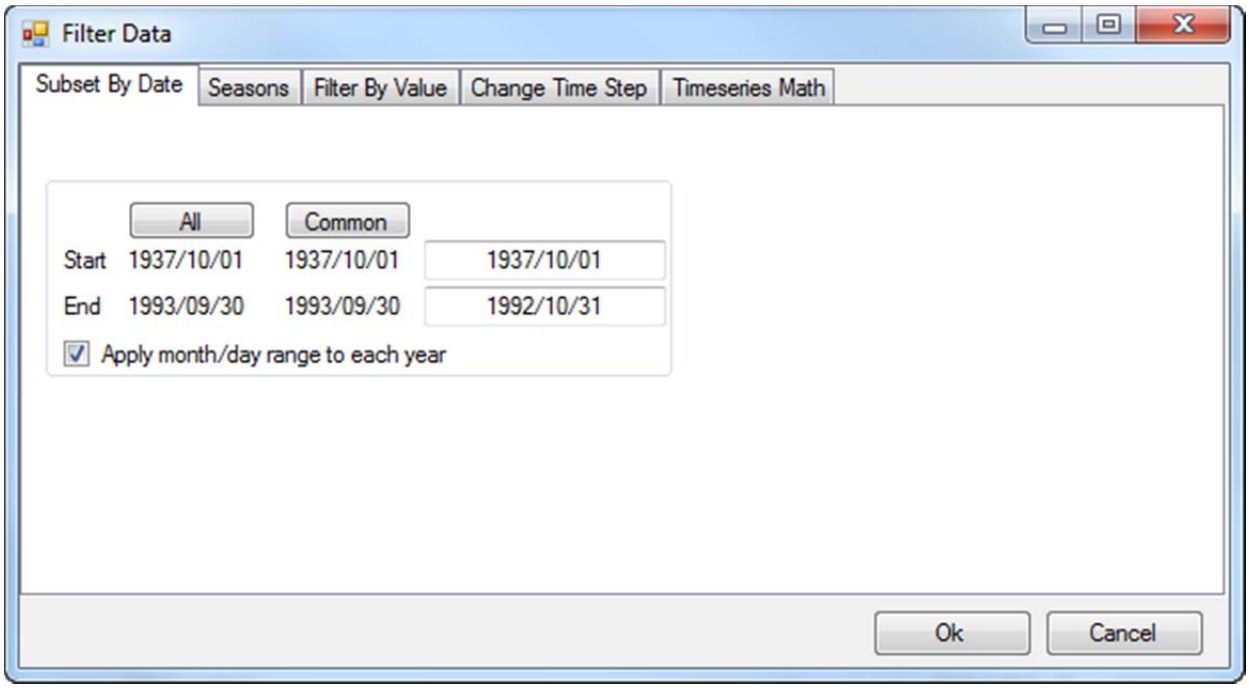


which results in the following dialog box:

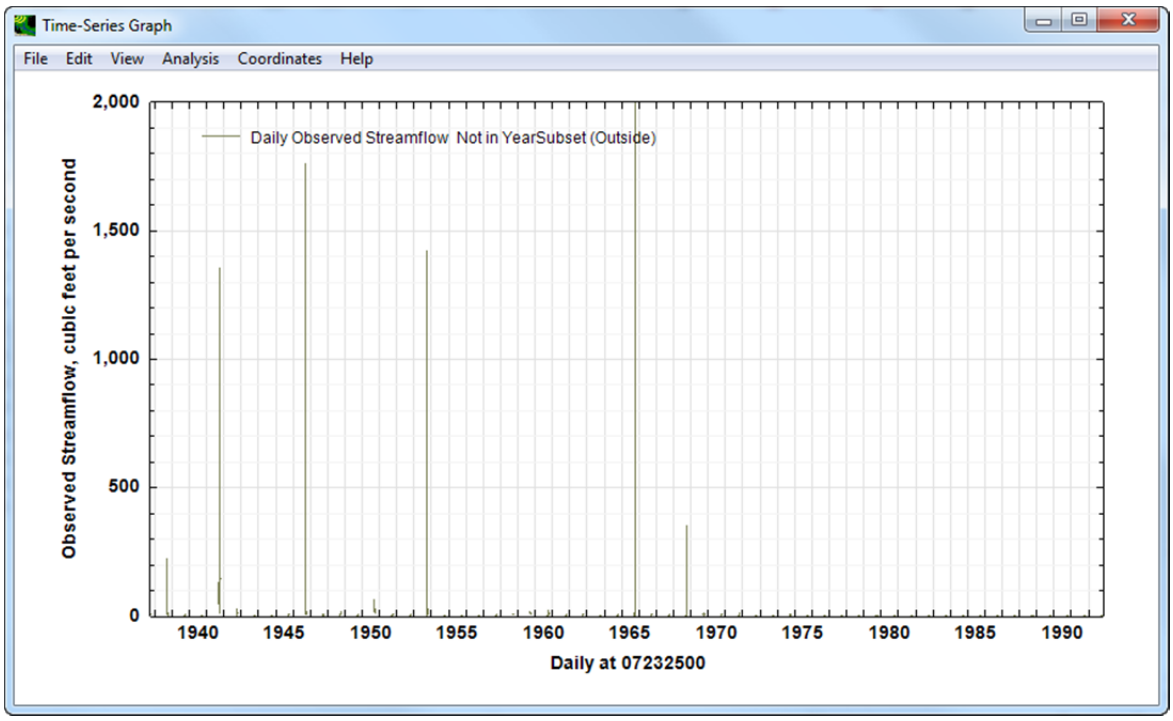


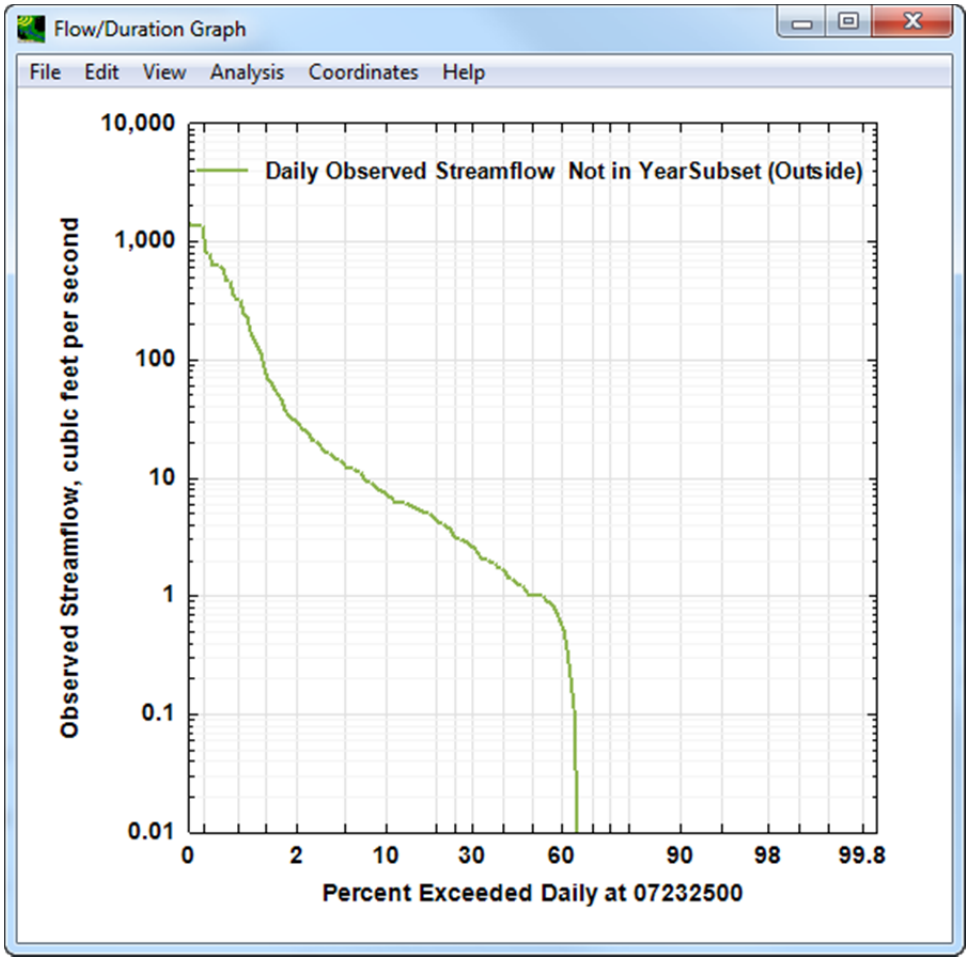
A few examples are provided to illustrate how the functionality can be used.

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:

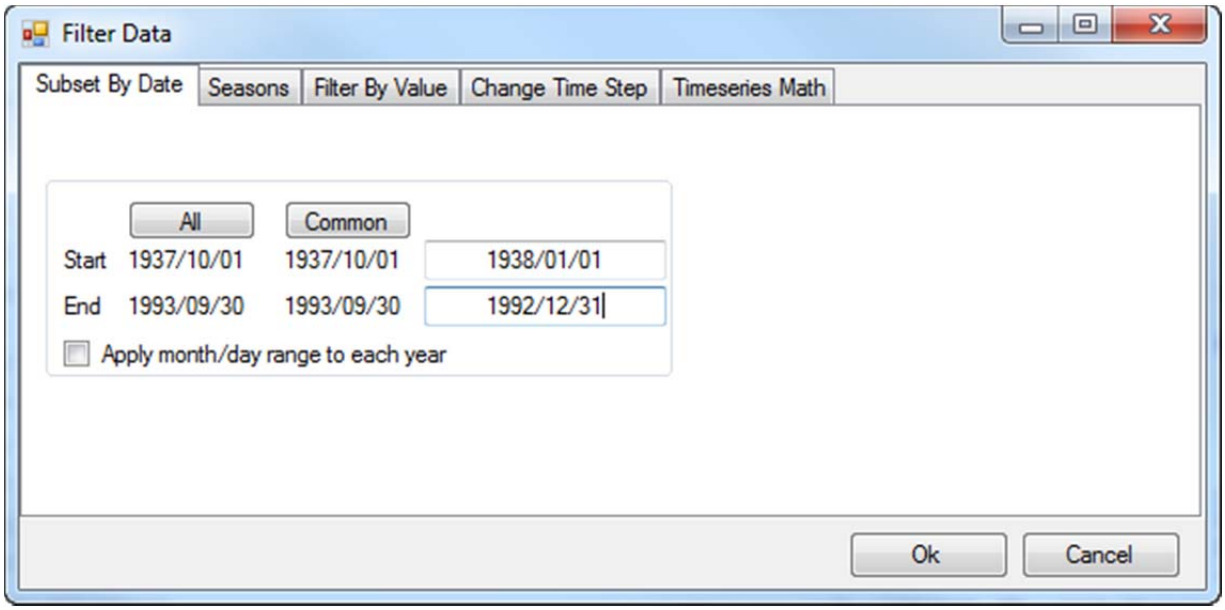


After then choosing the 'Time Series' and 'Flow/Duration' graphing options, the following two plots are generated:

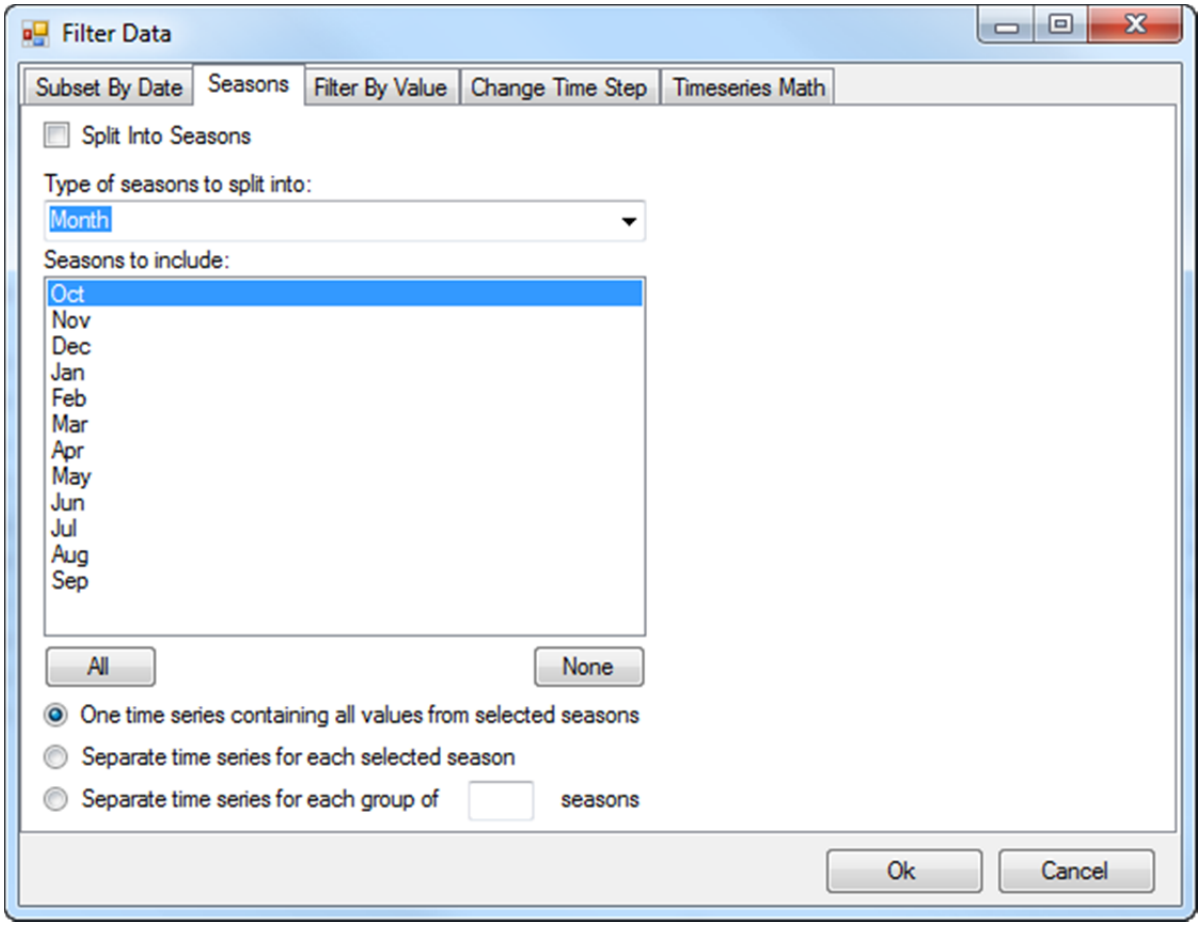

Time-Series Graph
File Edit View Analysis Coordinates Help
Daily Observed Streamflow Not in YearSubset (Outside)
Observed Streamflow, cubic feet per second
2,000
1,500
1,000
500
0
1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990
Daily at 07232500


Flow/Duration Graph
File Edit View Analysis Coordinates Help
Daily Observed Streamflow Not in YearSubset (Outside)
Observed Streamflow, cubic feet per second
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

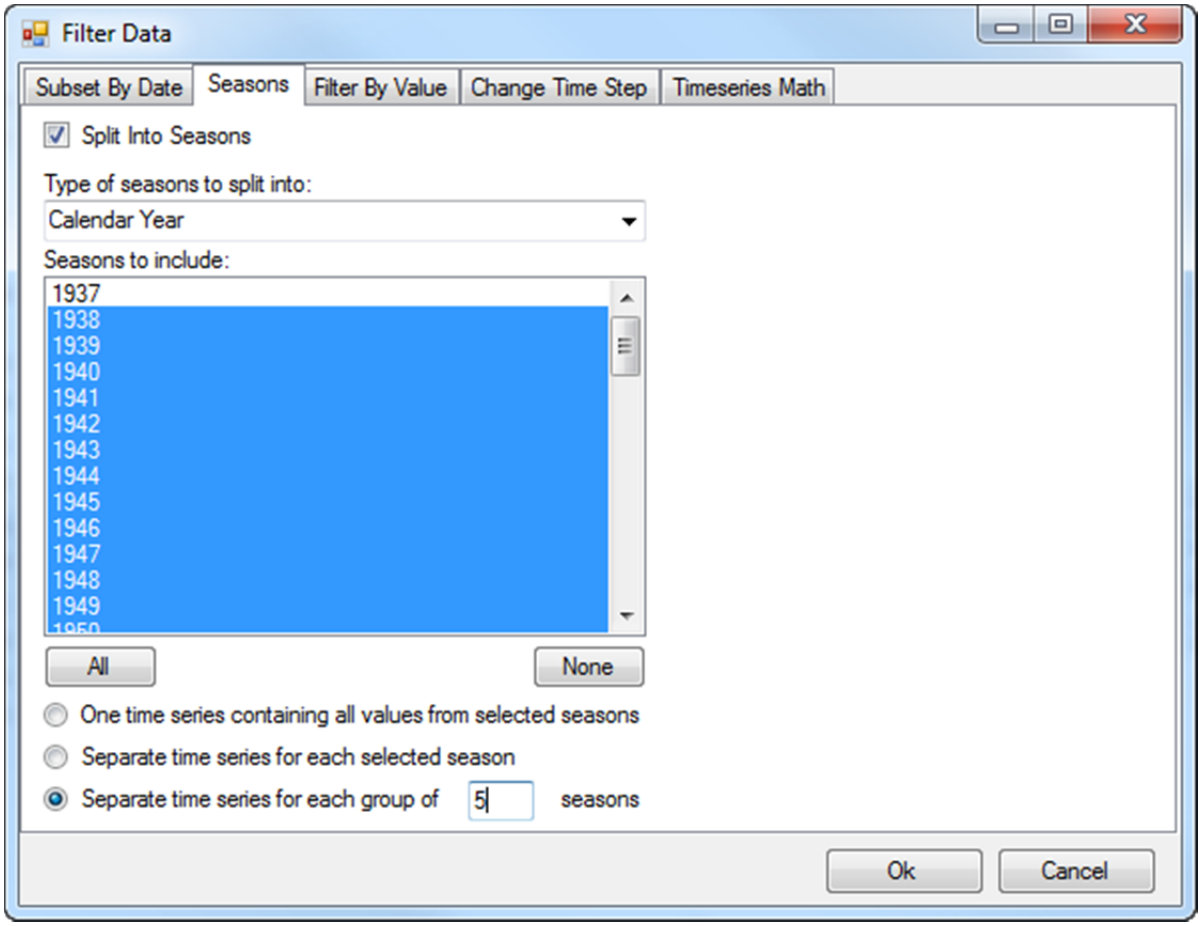
The next example illustrates how the streamflow data can be split into 5-year increments to evaluate how flow-duration conditions changed at the streamgage over the period January 1, 1938, through December 31, 1992. First, after selecting the 'Subset, Split, or Filter Selected Data' option within the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



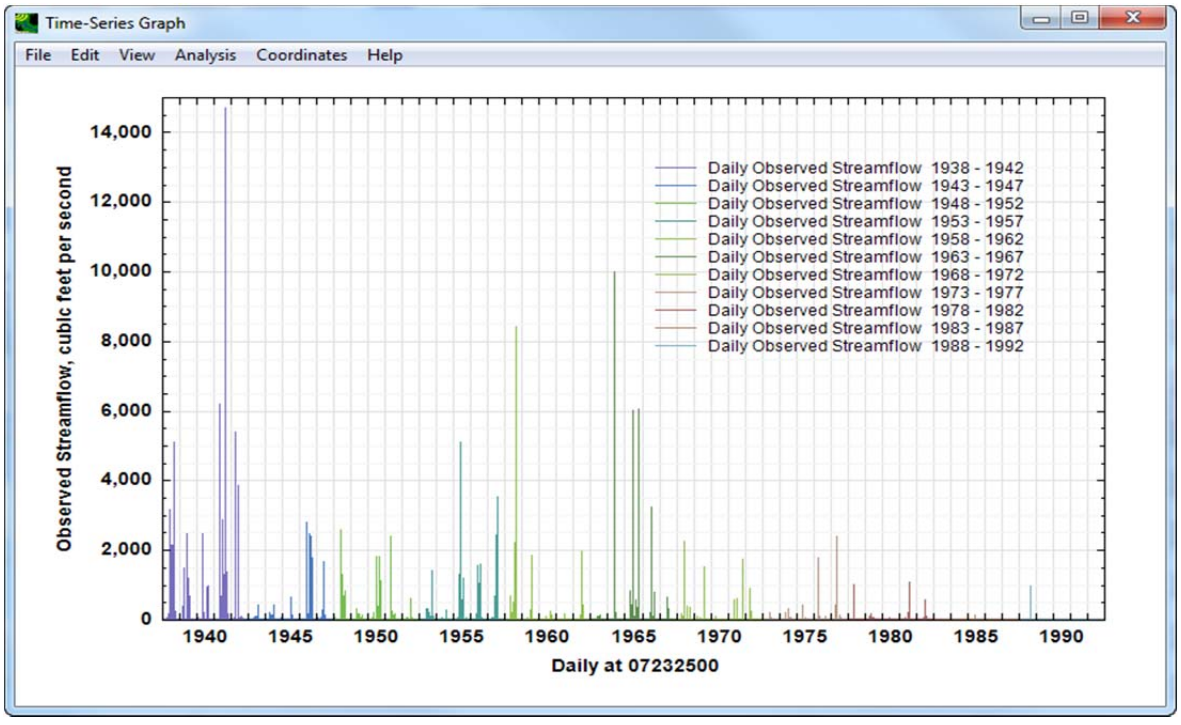
and then selects the 'Seasons' tab, which results in the following dialog box:

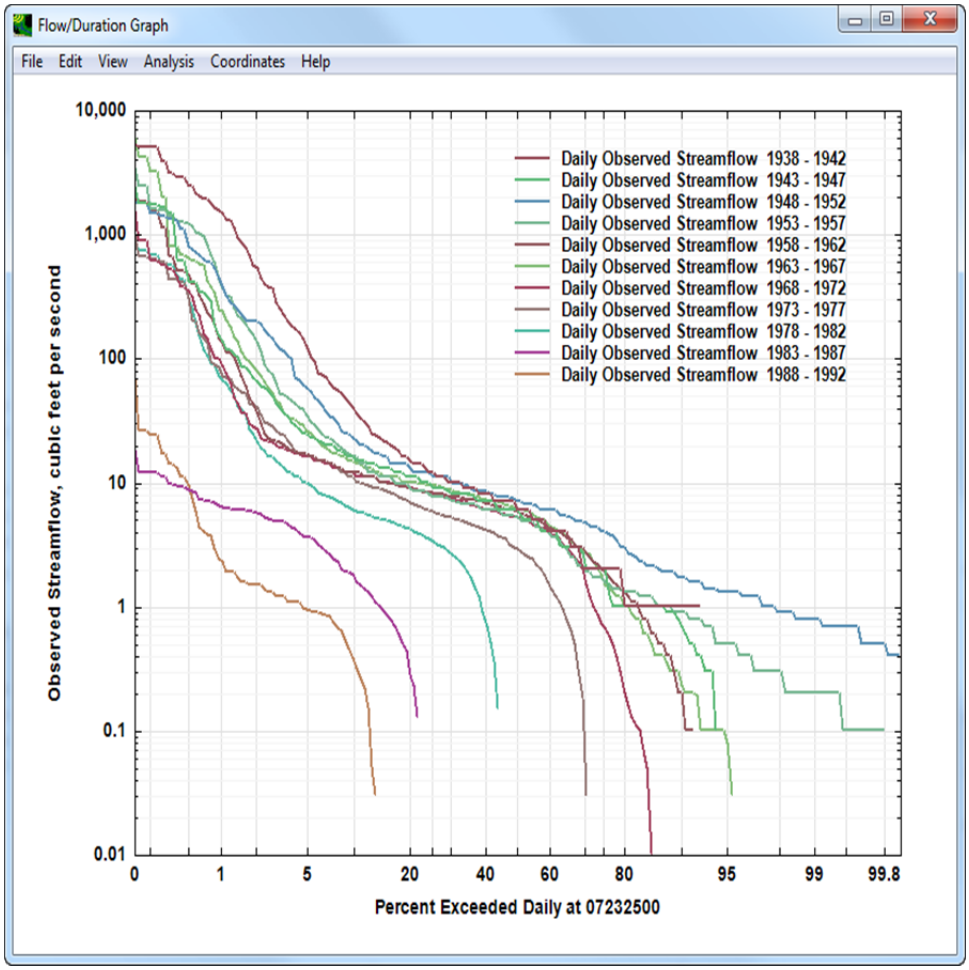


For this analysis, the user checks the 'Split Into Seasons' button, selects 'Calendar Year' under 'Type of seasons to split into:', highlights the years of interest in blue (which in this case have been pre-loaded for 1938-1992), checks the 'Separate time series for each group of __ seasons' button,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



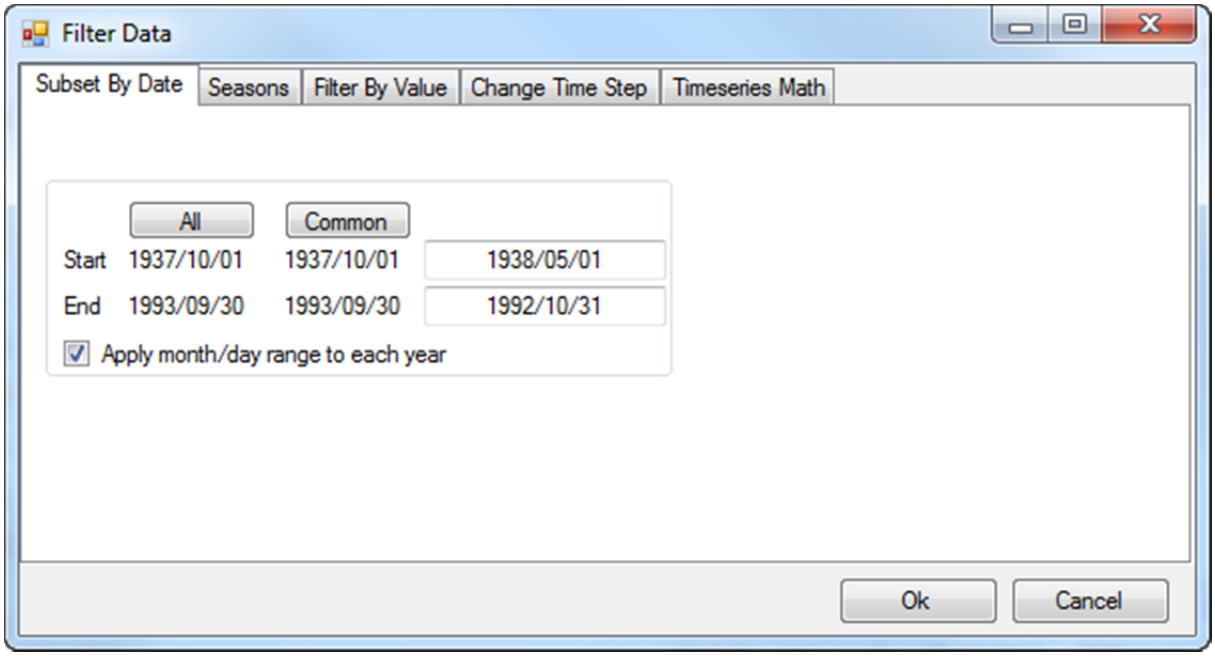
The resulting 'Time Series' and 'Flow/Duration' graphs for these selection criteria are:



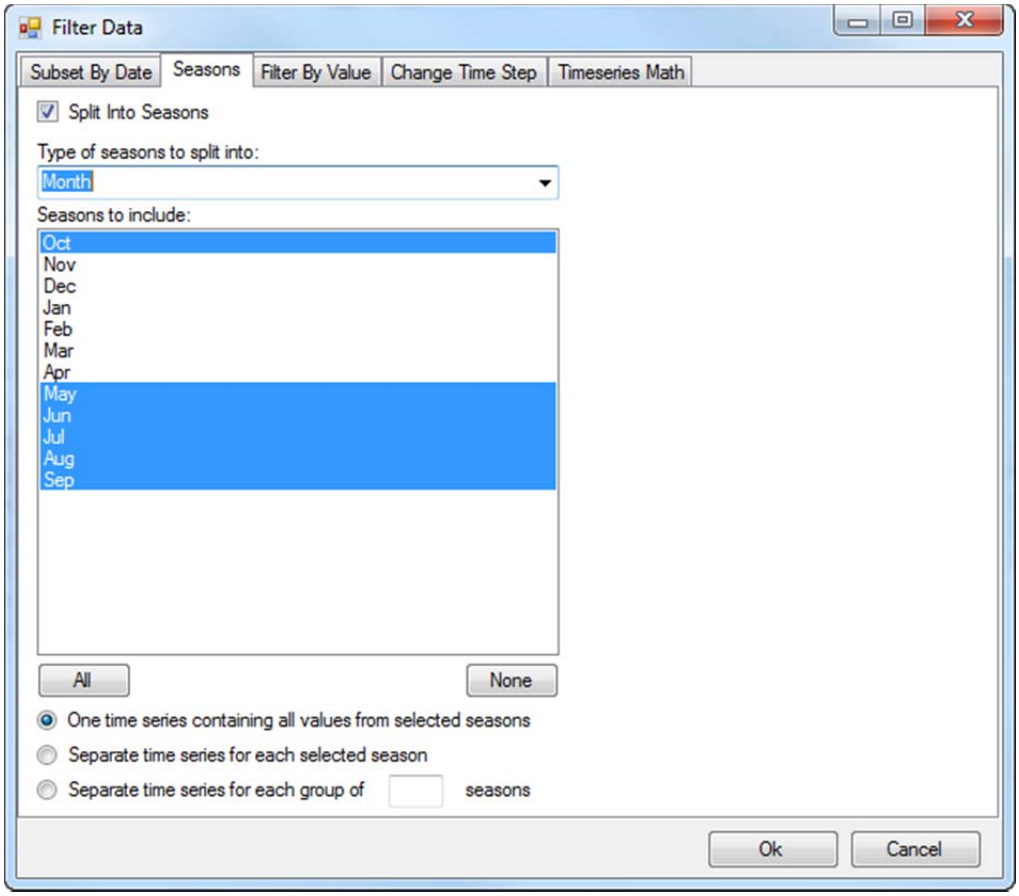


The flow-duration curves for the 5-year intervals clearly demonstrate a decline in streamflow over the 55-year period, with those for the earliest time periods showing streamflows greater than 0.1 cubic feet per second more than approximately 95-percent of the time and those for the last two time periods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

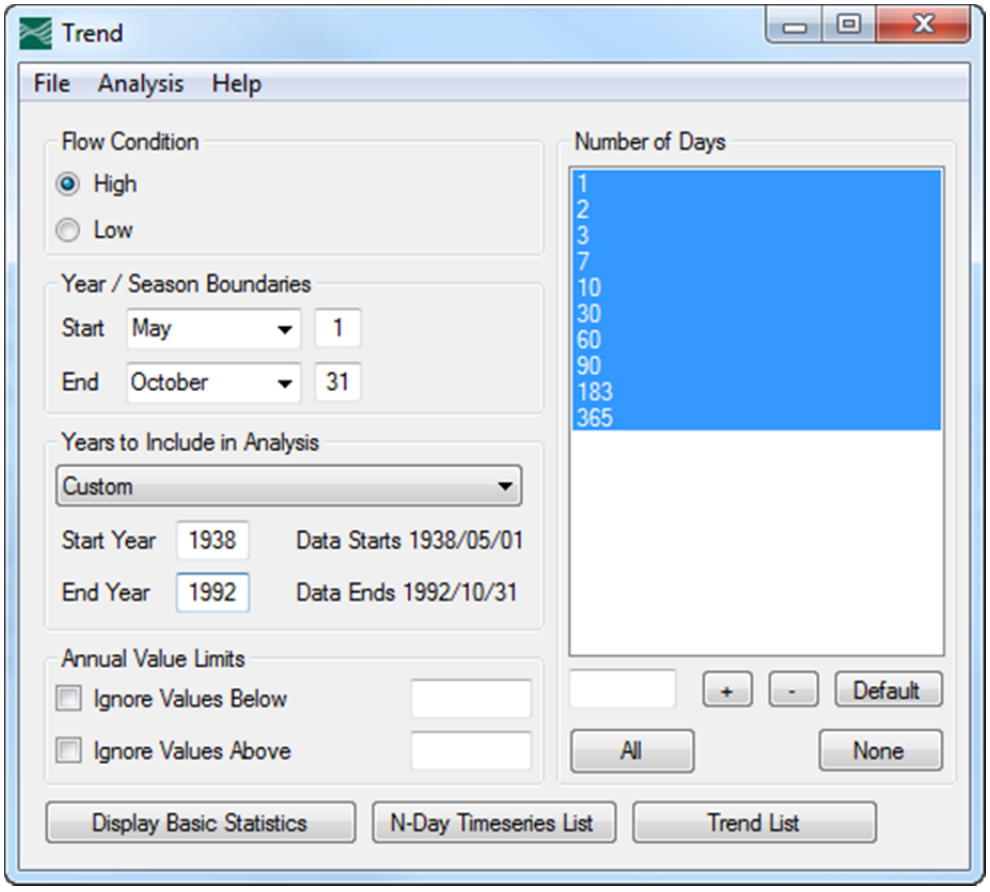
A third example illustrates a trend analysis of the base-flow data calculated by the BFI Standard method for the 6-month period May-October each year (a typical irrigation season in parts of the United States, such as the Central Valley of California), for the period 1938-1992. After selecting the "**Trend**" functionality ("**Analysis>USGS Surface Water Statistics (SWSTAT)>Trend**"), the 6-month period and date range are specified in the "Subset by Date" tab:



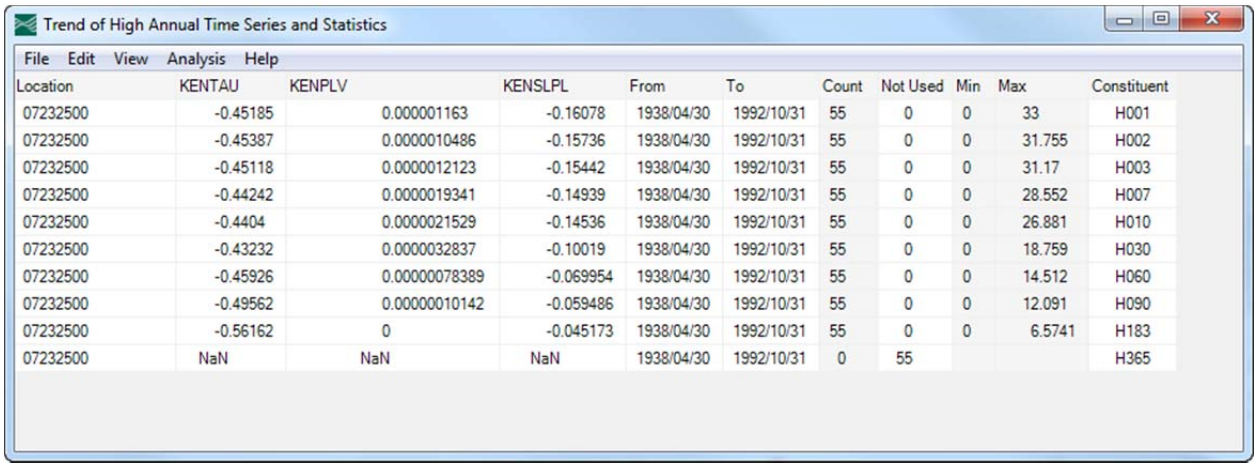
Additional information is then specified in the “Seasons” tab:



After hitting “Ok,” the user is directed to the “Trend” dialog box. The May 1 through October 31 season boundaries have been pre-loaded, but the user needs to specify a “Custom” “Start Year” of 1938 and “End Year” of 1992.



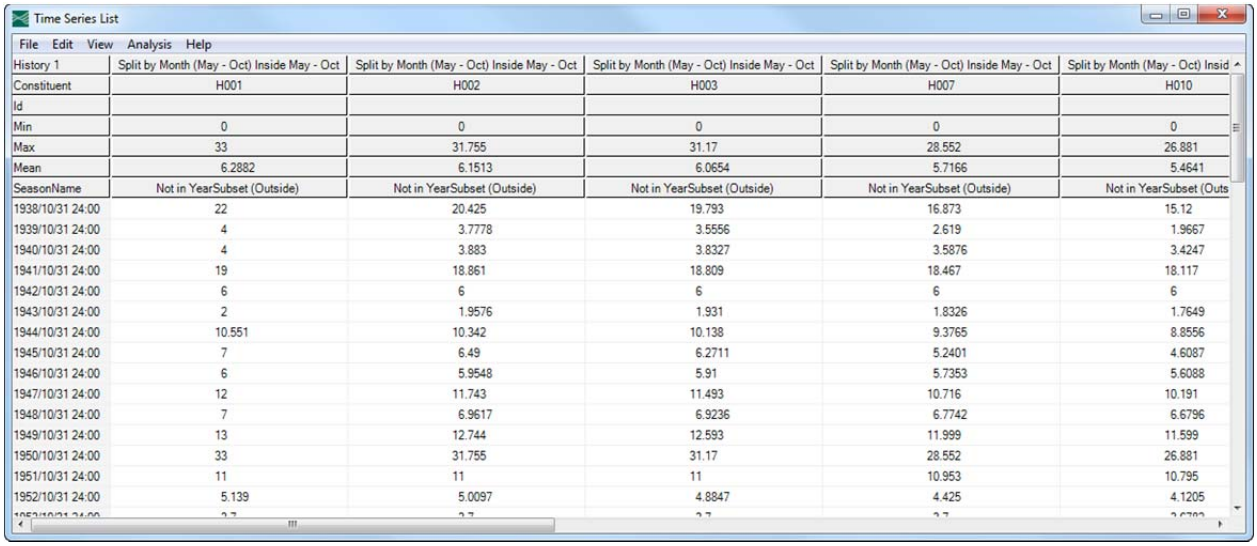
Hitting “Trend List” results in the following high-flow trends analyses:



Location	KENTAU	KENPLV	KENSLPL	From	To	Count	Not Used	Min	Max	Constituent
07232500	-0.45185	0.000001163	-0.16078	1938/04/30	1992/10/31	55	0	0	33	H001
07232500	-0.45387	0.0000010486	-0.15736	1938/04/30	1992/10/31	55	0	0	31.755	H002
07232500	-0.45118	0.0000012123	-0.15442	1938/04/30	1992/10/31	55	0	0	31.17	H003
07232500	-0.44242	0.0000019341	-0.14939	1938/04/30	1992/10/31	55	0	0	28.552	H007
07232500	-0.4404	0.0000021529	-0.14536	1938/04/30	1992/10/31	55	0	0	26.881	H010
07232500	-0.43232	0.0000032837	-0.10019	1938/04/30	1992/10/31	55	0	0	18.759	H030
07232500	-0.45926	0.00000078389	-0.069954	1938/04/30	1992/10/31	55	0	0	14.512	H060
07232500	-0.49562	0.00000010142	-0.059486	1938/04/30	1992/10/31	55	0	0	12.091	H090
07232500	-0.56162	0	-0.045173	1938/04/30	1992/10/31	55	0	0	6.5741	H183
07232500	NaN	NaN	NaN	1938/04/30	1992/10/31	0	55			H365

As with the previous analyses, there are statistically significant declines in base flow during the 6-month season May-October during the period 1938-1992.

Additional details for the analysis can be shown by selecting "**List**" within the "**Analysis**" menu option of the trends dialog box:



History 1	Split by Month (May - Oct) Inside May - Oct	Split by Month (May - Oct) Inside May - Oct	Split by Month (May - Oct) Inside May - Oct	Split by Month (May - Oct) Inside May - Oct	Split by Month (May - Oct) Insid
Constituent	H001	H002	H003	H007	H010
Id					
Min	0	0	0	0	0
Max	33	31.755	31.17	28.552	26.881
Mean	6.2882	6.1513	6.0654	5.7166	5.4641
SeasonName	Not in YearSubset (Outside)	Not in YearSubset (Outside)	Not in YearSubset (Outside)	Not in YearSubset (Outside)	Not in YearSubset (Outs
1938/10/31 24:00	22	20.425	19.793	16.873	15.12
1939/10/31 24:00	4	3.7778	3.5556	2.619	1.9667
1940/10/31 24:00	4	3.883	3.8327	3.5876	3.4247
1941/10/31 24:00	19	18.861	18.809	18.467	18.117
1942/10/31 24:00	6	6	6	6	6
1943/10/31 24:00	2	1.9576	1.931	1.8326	1.7649
1944/10/31 24:00	10.551	10.342	10.138	9.3765	8.8556
1945/10/31 24:00	7	6.49	6.2711	5.2401	4.6087
1946/10/31 24:00	6	5.9548	5.91	5.7353	5.6088
1947/10/31 24:00	12	11.743	11.493	10.716	10.191
1948/10/31 24:00	7	6.9617	6.9236	6.7742	6.6796
1949/10/31 24:00	13	12.744	12.593	11.999	11.599
1950/10/31 24:00	33	31.755	31.17	28.552	26.881
1951/10/31 24:00	11	11	11	10.953	10.795
1952/10/31 24:00	5.139	5.0097	4.8847	4.425	4.1205