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U.S. Geological Survey Hydrologic Toolbox—A Graphical and Mapping Interface for Analysis of Hydrologic Data

Chapter 3 of
Section D, Interrelated Phases of the Hydrologic Cycle
Book 4, Hydrologic Analysis and Interpretation

Techniques and Methods 4–D3

U.S. Department of the Interior
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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
foot (ft)	0.3048	meter (m)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Abbreviations

1B3	1-day average flow that occurs on average no more than once every 3 years
7Q10	7-day minimum flow that occurs on average only once every 10 years
BASINS	Better Assessment Science Integrating Point and Nonpoint Sources software
BFI	Base-Flow Index method
CU	Cataloging Units
EPA	U.S. Environmental Protection Agency
GIS	geographic information system
GW	groundwater
GWToolbox	Groundwater Toolbox computer program
HUC	hydrologic unit code
NWIS	National Water Information System database
RDB	relational database
SW	surface water
SWSTAT	Surface-Water Statistics program
SWToolbox	Surface-Water Toolbox computer program
USGS	U.S. Geological Survey
VB.NET	Visual Basic .NET programming language

U.S. Geological Survey Hydrologic Toolbox—A Graphical and Mapping Interface for Analysis of Hydrologic Data

By Paul M. Barlow,[1] Amy R. McHugh,[1] Julie E. Kiang,[1] Tong Zhai,[2] Paul Hummel,[2] Paul Duda,[2] and Scott Hinz[3]

Abstract

The Hydrologic Toolbox is a Windows-based desktop software program that provides a graphical and mapping interface for analysis of hydrologic time-series data with a set of widely used and standardized computational methods. The software combines the analytical and statistical functionality provided in the U.S. Geological Survey Groundwater and Surface-Water Toolboxes and provides several enhancements to these programs. The main analytical methods are the computation of hydrologic-frequency statistics such as the 7-day minimum flow that occurs on average only once every 10 years (7Q10); the computation of design flows, including biologically based flows; the computation of flow-duration curves and duration hydrographs; eight computer-programming methods for hydrograph separation of a streamflow time series, including the Base-Flow Index (BFI), HYSEP, PART, and SWAT Bflow methods and Eckhardt's two-parameter digital-filtering method; and the RORA recession-curve displacement method and associated RECESS program to estimate groundwater-recharge values from streamflow data. Several of the statistical methods provided in the Hydrologic Toolbox are used primarily for computation of critical low-flow statistics. The Hydrologic Toolbox also facilitates retrieval of streamflow and groundwater-level time-series data from the U.S. Geological Survey National Water Information System and outputs text reports that describe their analyses.

The Hydrologic Toolbox was developed by use of the DotSpatial geographic information system (GIS) programming library, which is part of the MapWindow project. DotSpatial is a nonproprietary, open-source program written for the .NET framework that includes a spatial data viewer and GIS capabilities. Advantages of the DotSpatial system include its pure .NET implementation for both the user interface and the GIS mapping engine, and thus the DotSpatial system simplifies software deployment and installation. In addition to combining the functionality of the separate Groundwater and Surface-Water Toolboxes, the Hydrologic Toolbox also organizes the functionality by theme (Groundwater Tools, Surface-Water Tools, and general Time-Series Tools).

This report provides a description of how to build a Hydrologic Toolbox project and to download and manage hydrologic time-series data. It includes an overview of the analytical and statistical capabilities of the Hydrologic Toolbox and highlights the primary differences between the Hydrologic Toolbox and the Groundwater and Surface-Water Toolboxes. The report supplements information available in an extensive online Help manual and is intended to provide a set of instructions that will allow users to quickly develop skills to use the mapping, data-retrieval, and computational tools of the program.

Introduction

The Hydrologic Toolbox is a Windows-based desktop-software program that provides a graphical and mapping interface for the analysis of hydrologic time-series data with a set of widely used and standardized computational methods. The program combines the analytical and statistical functionalities provided in the U.S. Geological Survey (USGS) Groundwater (GW) and Surface-Water (SW) Toolboxes (Barlow and others, 2015; Kiang and others, 2018) in a single Hydrologic Toolbox and provides several enhancements to these programs. The software also facilitates the downloading and plotting of streamflow and groundwater-level time-series data from the USGS National Water Information System (NWIS) database (U.S. Geological Survey, 2020a). A set of procedures is provided to

- separate the hydrograph of a streamflow time series into daily, monthly, and annual base-flow and runoff components of streamflow;
- analyze a graph showing a streamflow-hydrograph recession to determine the base-flow recession constants and the monthly and annual groundwater-recharge rates;

[1]U.S. Geological Survey.

[2]RESPEC.

[3]LimnoTech.

- compute *n*-day frequency statistics such as the 7Q10—the 7-day minimum flow that occurs on average only once every 10 years;
- analyze the frequency of any annual time series by using the log-Pearson type III distribution;
- compute biologically based design flows, flow-duration statistics, and a variety of monthly, seasonal, and annual statistics;
- test for a monotonic trend in annual time series; and
- graph time-series data, flow-duration curves, and flow-frequency curves.

The GW and SW Toolboxes were built by using the U.S. Environmental Protection Agency's (EPA's) BASINS platform (U.S. Environmental Protection Agency, 2020), which is a customized interface developed with the MapWindow software (MapWindow, 2021). The Hydrologic Toolbox was developed with the DotSpatial geographic-information system (GIS) programming library, which is part of the MapWindow project (MapWindow, 2021) and an advancement over the GIS environment of the GW and SW Toolboxes. DotSpatial is a nonproprietary, open-source program written for the .NET Framework that provides a spatial data viewer and GIS capabilities. Both MapWindow software and the DotSpatial system mostly use the same set of open-source GIS libraries and support custom applications written in Visual Basic .NET (VB.NET) programming language, such as those developed for the GW and SW Toolboxes. Advantages of the DotSpatial system include its pure .NET implementation for both the user interface and the GIS mapping engine, which together simplify software deployment. Users of the GW and SW Toolboxes will find the procedures for building a Hydrologic Toolbox project and downloading and analyzing time-series data to be similar to the procedures for the use of the GW and SW Toolboxes themselves. The Hydrologic Toolbox replaces the GW and SW Toolboxes and the USGS Surface-Water Statistics (SWSTAT) program (U.S. Geological Survey, 2020b).

This report (1) provides a description of how to build a Hydrologic Toolbox project and download and manage hydrologic time-series data, (2) includes an overview of the analytical and statistical capabilities of the Hydrologic Toolbox, and (3) highlights the primary differences between the Hydrologic Toolbox and each of the GW and SW Toolboxes. Detailed information on the analytical and statistical methods and their use in the Hydrologic Toolbox are given in Barlow and others (2015) and Kiang and others (2018). The report supplements information available in an extensive Help manual ("Hydrologic Toolbox Documentation") that is part of the computer program itself and is intended to provide a set of instructions that will allow users to quickly develop the basic skills required for the use of the mapping, data-retrieval, and computational tools of the program.

The Hydrologic Toolbox program is publicly available for downloading (see Barlow and others, 2022). Installation instructions are available with the download package. The R statistical program also must be installed to utilize the R screening tests (see section on "Surface-Water [SW] Tools"). All other aspects of the Hydrologic Toolbox will function properly without R.

A few text-formatting conventions are used throughout the report. Components of the Hydrologic Toolbox interface, such as dialog boxes, panels, or buttons, are named with initial capital letters and are in double quotation marks, such as the panel name "Select Data." Specific menu options and tools are in boldface text, such as the "**Open**" option in the "**File**" menu, which is available on the main toolbar. Unless otherwise stated, the Hydrologic Toolbox is referred to simply as "the Toolbox" in the rest of the report.

Building, Saving, and Reopening a Hydrologic Toolbox Project

A Hydrologic Toolbox project is a collection of spatial and time-series data and analysis results for a specific geographic area. The project area can consist of a State, County, or one or more hydrologic unit code (HUC) hydrologic cataloging units. A cataloging unit is one of the divisions of the hydrologic unit code classification system of river basins in the United States developed by the USGS (Seaber and others, 1987). Each cataloging unit is given an 8-digit HUC—for example, the Pawcatuck-Wood Basin in Rhode Island has a HUC–8 code of 01090005.

Opening the Hydrologic Toolbox for the first time results in the two dialog boxes shown on figure 1. A new project can be created by selecting the "Build New Project" option, which produces a map that shows the States and cataloging-unit boundaries (fig. 2) of the conterminous United States. The user can then zoom into an area of interest with the "Pan" and "Zoom" tools. Adding cataloging-unit identifiers to the map aids in the selection of a basin of interest. This is done by right-clicking on the Cataloging Units (CU) layer, which results in a list of several menu options; the user selects "Labeling" and then "Label Setup" from the next list of options. The result of these selections is the "Feature Labeler" dialog box shown on figure 3. The user can then scroll down to the "CU" option in the "Field Names" list. Double-clicking on the "CU" field and then clicking "OK" adds the labels to the map (fig. 4*A*).

The "Select" tool can then be used to select the cataloging unit of interest (01090005, fig. 4*B*). The user selects the "Build" check box from the "Build New USGS Hydrologic Toolbox (1.0.0) Project" dialog box (fig. 2). At this point, the Toolbox will prompt the user with a "Save new project as…" dialog box to select a directory in which to save the project. Project information is stored in a DotSpatial system project file (ending in .dspx) in the chosen project directory.

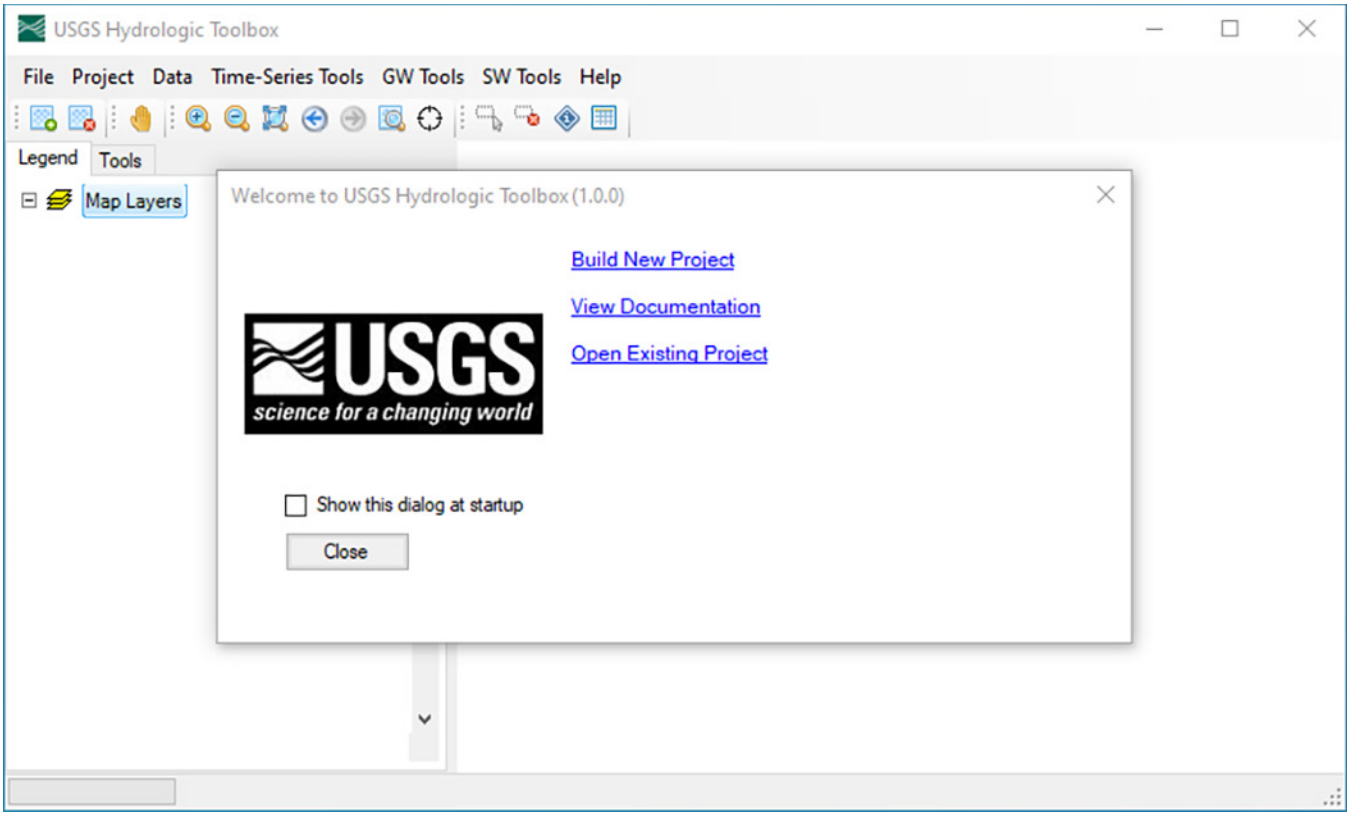


Figure 1. Screen capture of the "Welcome to the USGS Hydrologic Toolbox (1.0.0)" and "USGS Hydrologic Toolbox" dialog boxes that appear during the first use of the U.S. Geological Survey Hydrologic Toolbox.

If multiple projects have been created for the same HUC–8 area, a sequence number will be appended by a hyphen to the subdirectory and project names (for example, 01090005-2). A "Projection Properties" dialog box will appear, and the user can select the desired map projection for the GIS data layers in the project: the default "Albers Equal-Area (Conterminous U.S.)" option was selected for this example. The project then will be populated with a set of standard data layers, including the locations of NWIS streamgages and monitoring wells with daily data (fig. 4*C*). (Symbols for each data layer can be shown on the map by toggling the "+/-" options for each map layer in the "Legend.") The project can now be saved by using the "Save" or "Save as…" options under the "File" menu. To close the project, use the "Close" option under the "Project" menu. Note that opening a new project with the "New" option under the "File" menu will close an opened project.

There are additional approaches for building a new project while working in the Toolbox. First, the user can access the "Welcome to USGS Hydrologic Toolbox (1.0.0)" dialog box by using the "Welcome Screen" option from the "Help" menu. Alternatively, the user can access the "New HUC8 project…" option from the "Project" menu. In both cases, the "Pan," "Zoom Out," and "Zoom In" tools can be used to navigate to the basin(s) of interest within the map that is shown in the dialog box.

An existing project can be reopened from the "Welcome to USGS Hydrologic Toolbox (1.0.0)" dialog box or with the "Open…" option from the "File" menu. MapWindow projects created with either the GW or SW Toolbox also can be opened and modified with the Hydrologic Toolbox, but must then be saved as a DotSpatial system project.

Data layers for the Hydrologic Toolbox are stored on a web server maintained by the EPA. If that server is temporarily unavailable, a dialog box will be shown indicating that "One (or more) of the core data sets is temporarily unavailable for download."

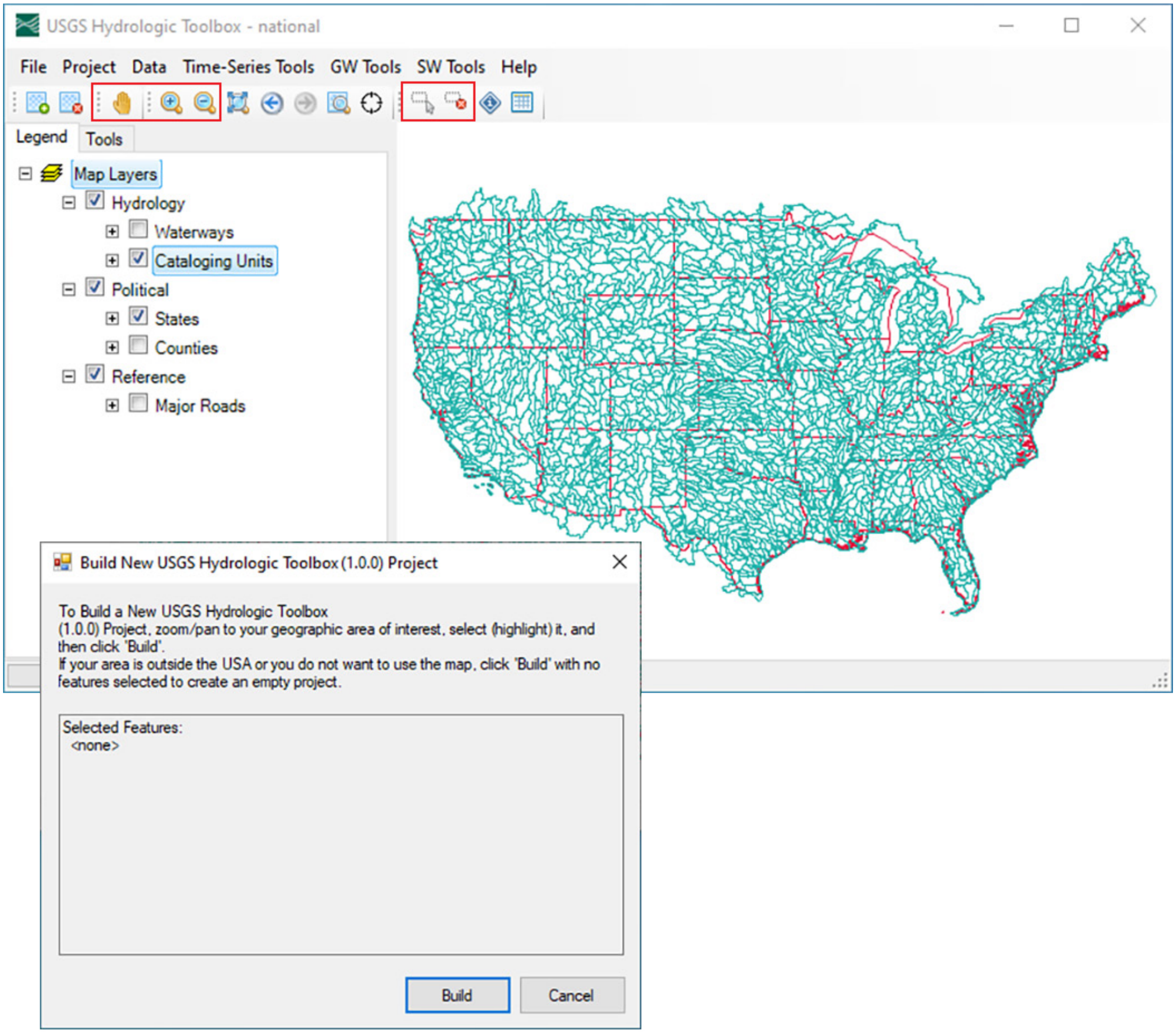


Figure 2. Screen capture from the U.S. Geological Survey Hydrologic Toolbox of the initial map with active State and hydrologic unit code and eight-digit (HUC–8) hydrologic cataloging-unit data layers. From left to right, the "**Pan**," "**Zoom In**," "**Zoom Out**," "**Select**," and "**Deselect**" icons within the red boxes are identified.

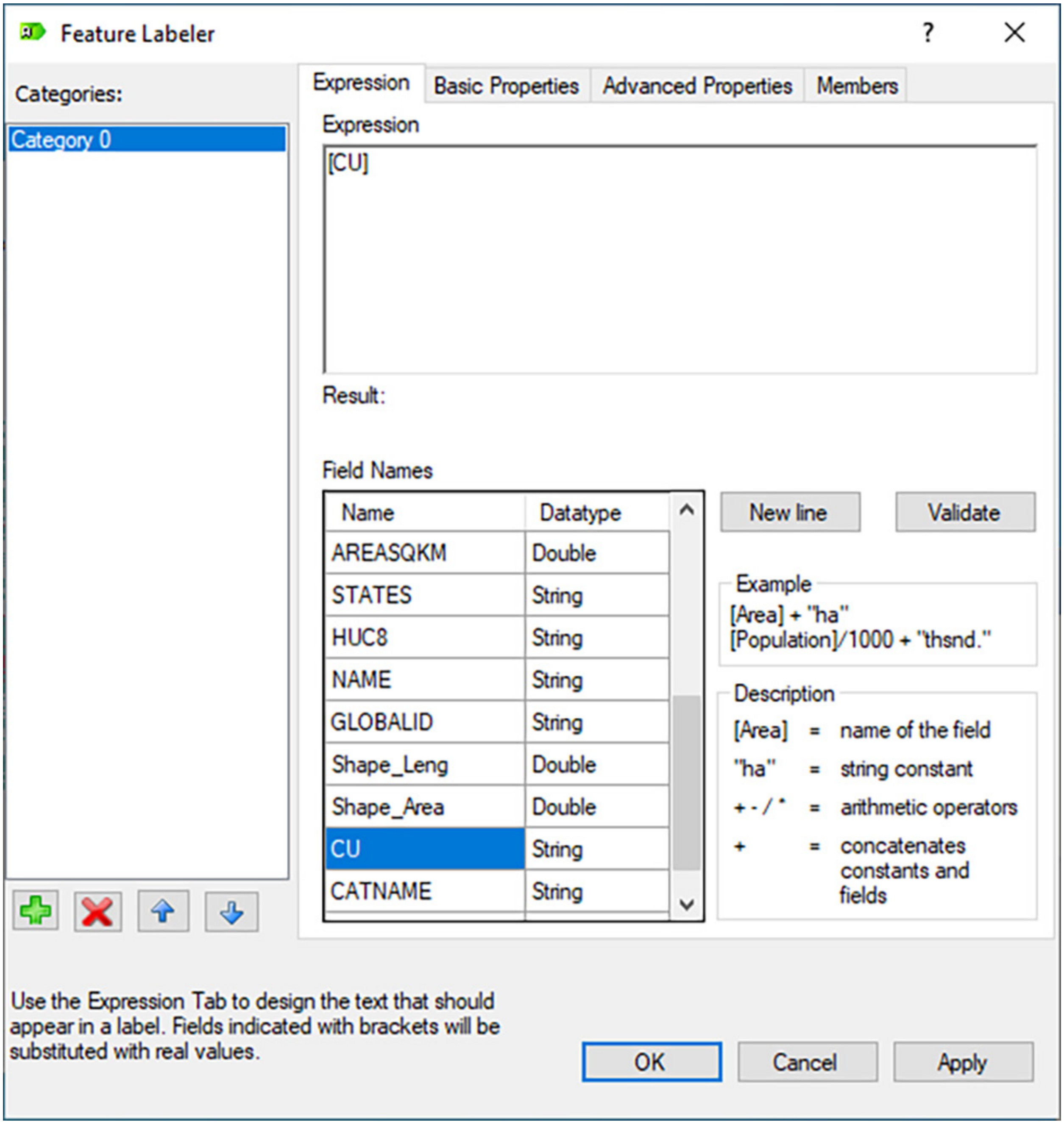


Figure 3. Screen capture from the U.S. Geological Survey Hydrologic Toolbox of the “Feature Labeler” dialog box used to add labels to a map layer.

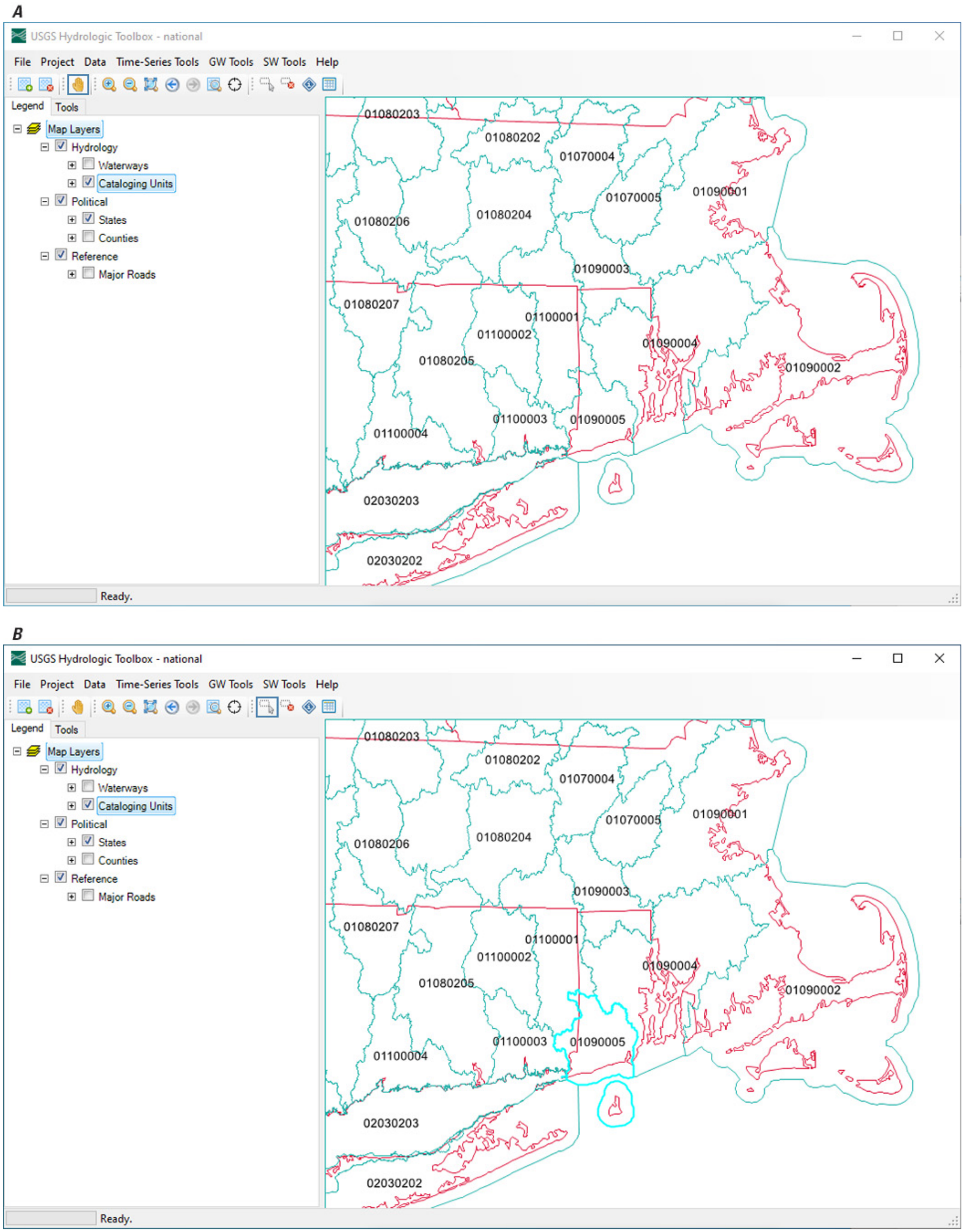


Figure 4. Screen captures from the U.S. Geological Survey Hydrologic Toolbox showing steps selected to build a Hydrologic Toolbox project. *A*, Cataloging-unit numbers are added to identify hydrologic unit code and eight-digit (HUC–8) basins in the area of interest. *B*, The basin of interest is selected (Pawcatuck-Wood, 01090005). *C*, The resulting map includes locations of measured daily streamflow (discharge) and groundwater levels near and within the basin.

C

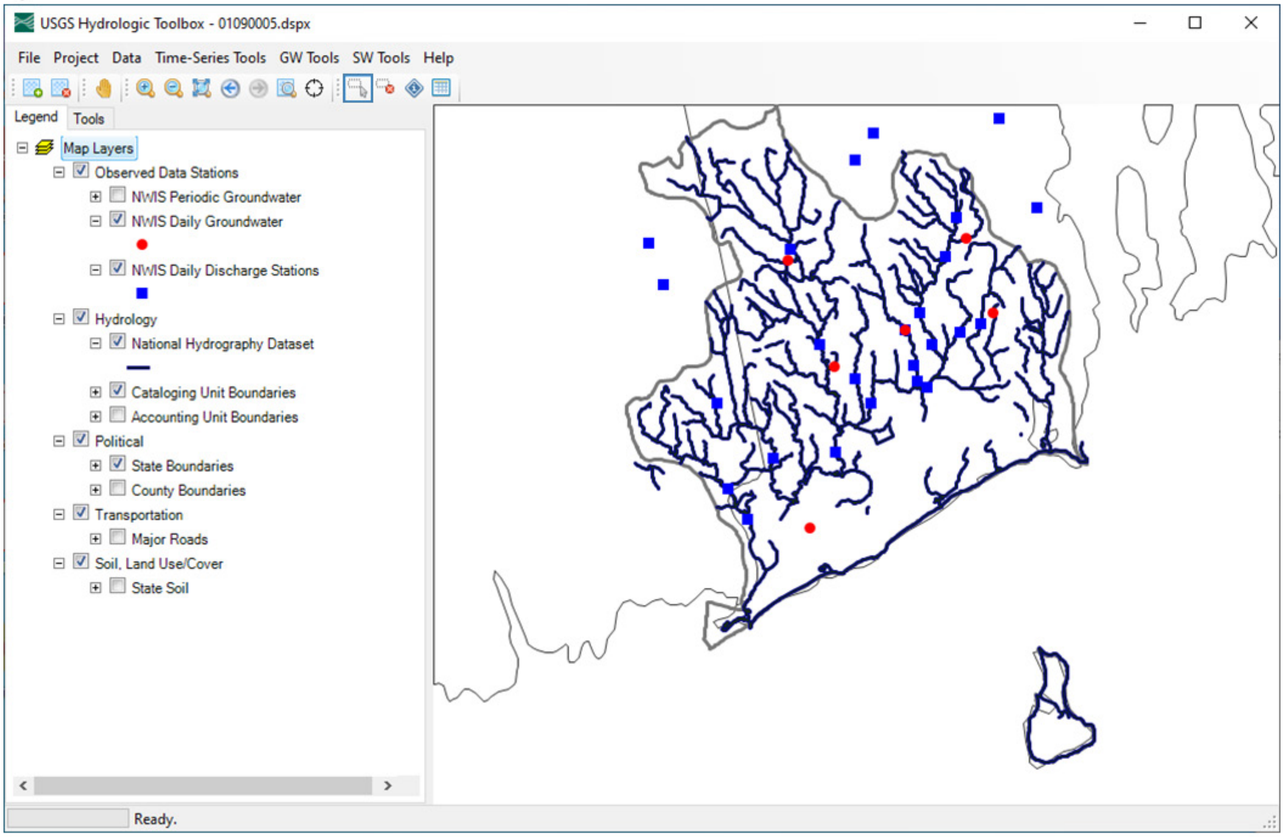


Figure 4.—Continued

Downloading, Opening, and Managing Data

The Hydrologic Toolbox provides several options for downloading, opening, and managing data. When a Hydrologic Toolbox project is created, a large cache of map layers is downloaded and stored in the project directory. A subset of these layers, which is shown in the "Legend" panel (fig. 4*C*), is made available as part of the initial build of the project. Collection sites for several types of monitored data are shown by default on the project map. These are sites for which a minimum of 10 data values of daily streamflow (discharge), daily groundwater levels, and periodic groundwater levels are available through the NWIS database. The sites at which periodic groundwater-level data have been collected are not displayed on the map by default because they tend to be numerous. Their locations can be seen by toggling the check box next to the layer identifier to the "on" (checkmarked) position.

The first step in data retrieval is to select specific data sites on the project map for which data will be downloaded from NWIS. For this example, streamflow-discharge data will be retrieved for all streamgage locations shown on the project map. This is done by clicking on the "NWIS Daily Discharge Stations" data layer (fig. 5, step 1), selecting the "Select" tool (step 2), and then drawing a box that encloses all of the discharge stations on the map (the box is not shown on the figure). The selected streamgages will show a light-blue circle in the middle of the dark-blue square symbol. Data for a single station can be retrieved by using steps 1 and 2 and then selecting individual stations on the map. (To select multiple stations, hold down the "shift" key while selecting the stations.) Stations can be deselected with the "Deselect" tool (located to the right of the "Select" tool) or by clicking any empty area of the map.

After one or more sites are selected, the "Download…" option from the "Data" menu is used to retrieve data from NWIS. Selecting this option results in the "Download Data" dialog box shown in figure 6*A*. As shown on the figure, several types of data can be downloaded; each data type is explained in the online "Hydrologic Toolbox documentation." For this example, the "Daily Discharge" button already has been selected because of the steps described in the previous paragraph. Daily-discharge data are reported in units of cubic feet per second (USGS NWIS parameter code 00060). The user simply clicks the "Download" button to download the data; the status of the download's progress is displayed as the data

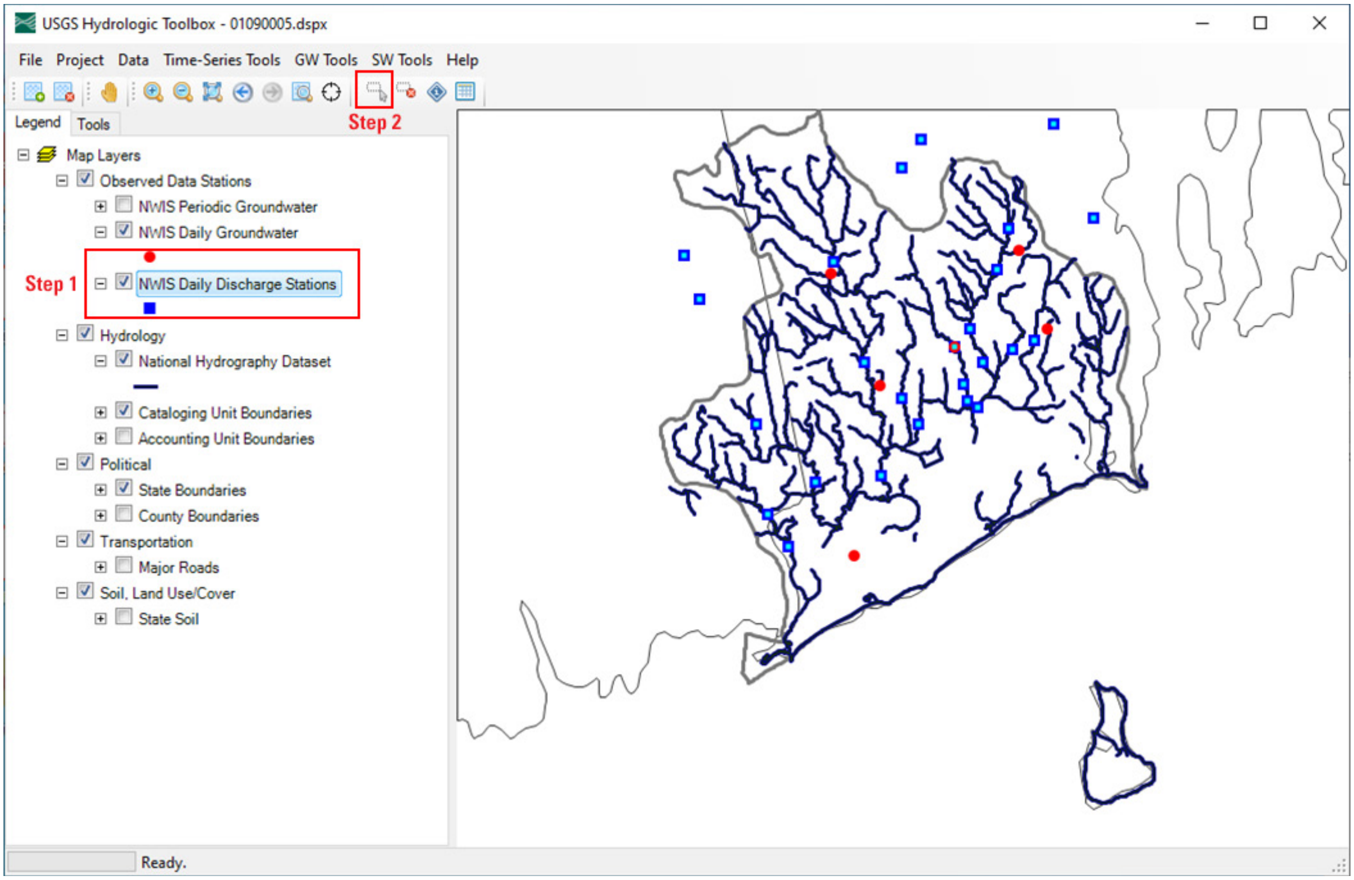


Figure 5. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing steps used to select sites for which data will be retrieved from the U.S. Geological Survey National Water Information System. Steps are described in the text.

are retrieved. A message will appear if the download has been successful (fig. 6*B*). After clicking "OK," a list of the data files that have been created and automatically saved in the project directory will be shown (fig. 6*C*). These data are saved in the USGS NWIS RDB's (relational database) time-series format. The user can close the "Data Sources" dialog box by clicking on the "X" in the upper-right corner of the dialog box. The data are now part of the project and available for use in the Toolbox.

Similar steps can be taken to retrieve daily groundwater-level data from NWIS. These data are stored in NWIS in several formats: two examples are the depth to water level in feet below land surface (parameter code 72019) and the elevation of the water level in feet above the National Geodetic Vertical Datum of 1929 (parameter code 72020). The Hydrologic Toolbox converts all data formats to depth to water level in feet below land surface.

The user can adjust the minimum number of measurement values required at an observation site for the site to be shown on the project map by changing the value specified in "Min Count" on the "Download Data" dialog box. The default value for "Min Count" is 10 measurement values, but this value can be modified. After the value of "Min Count" has been adjusted for a selected data type, the user clicks on the "Download" button, which causes the map to be updated with sites that meet the minimum specified count.

When an existing project is reopened, the Toolbox will read time-series data that have been previously saved in the project directory. These saved datasets might not include the most recent data values from NWIS that were added to the site(s) after the previous project was saved. The user can redownload to get the latest data from the online data sources by checking the "Get Newest" checkbox in the "Download Data" dialog box (fig. 6*A*). Note that each time the user downloads data, a copy of the data will be placed under the "cache" subdirectory in the "Hydrologic Toolbox" directory. By default, the download process will look for available data files in the cached folder first to save processing time. Understandably, these cached data can become outdated as new data are added to NWIS. Hence, when the user needs to download the latest data from online sources, the "Get Newest" checkbox should be checked before starting the data-download process. The Toolbox will then disregard cached data files and download the latest full period of record for the sites selected. After the data are downloaded, the new data will be saved in the project and "cache" directories.

A

B

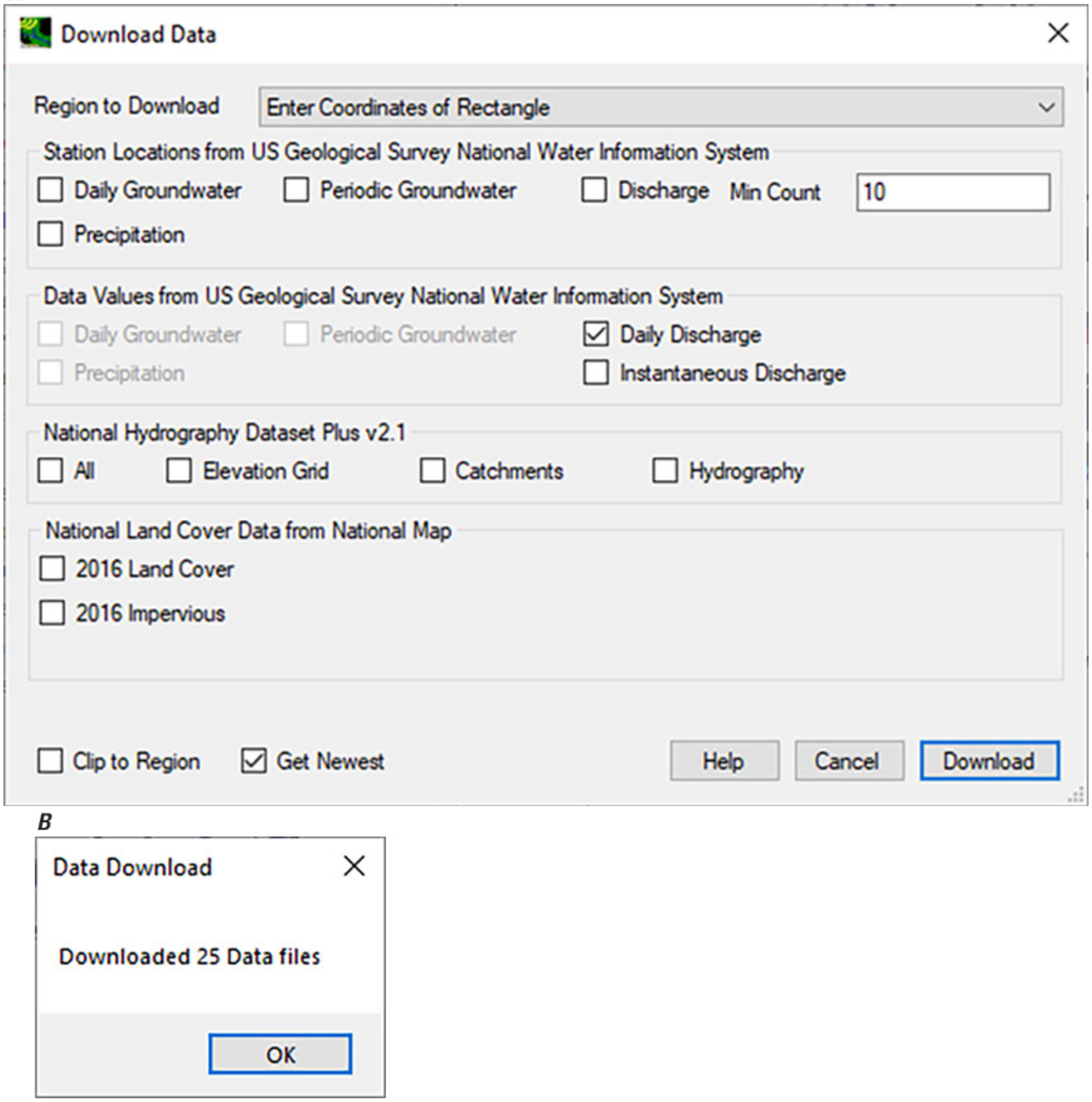


Figure 6. Screen captures from the U.S. Geological Survey Hydrologic Toolbox showing dialog boxes related to downloading data for the Hydrologic Toolbox. *A*, Dialog box used to select data type. In this example, daily-discharge (streamflow) data will be downloaded from the U.S. Geological Survey National Water Information System. *B*, Dialog box generated by the successful download of discharge data from 25 streamgaging sites. *C*, List of data files that have been saved in the project directory. RDB, relational database.

C

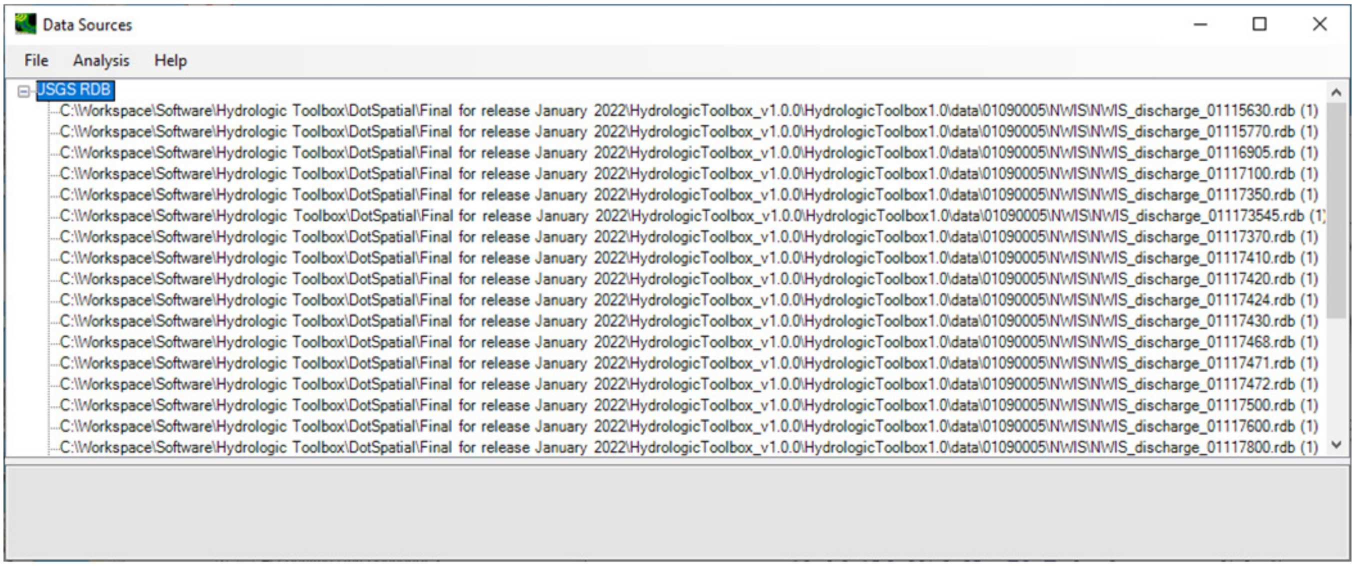


Figure 6.—Continued

Data can also be added to a project by reading them directly from a USGS RDB file or by using the scripting capabilities available with the Toolbox (such as reading data stored in an Excel file). These options are available by selecting the "Open…" item from the "Data" menu. Specific steps for using these two options are described in the "RDB File Structure" and "Scripting to Import Excel Data" tutorials provided with the Toolbox download package.

The "Manage…" option under the "Data" menu provides several processes with which to manage the data files that are part of the project. These processes are accessed by selecting one or more of the RDB files listed on the "Data Sources" dialog box and then selecting one of the options under the "File" or "Analysis" menus. For example, a data file can be removed from the project by selecting "Close selected" under the "File" menu.

Time-Series Tools

The Hydrologic Toolbox provides several generic utilities through the "Time-Series Tools" menu option for the analysis of project time-series data (fig. 7). Each utility is described in detail in the online documentation and is briefly summarized here.

Attributes—Computes a variety of annual, seasonal, and monthly statistics, such as the mean, minimum, and maximum values, for a selected time series (fig. 8*A*).

Data Tree—Provides a list of many of the attributes and computed statistics for a selected time series (fig. 8*B*).

Events—Provides a synoptic analysis of an observed event during the selected time series (fig. 8*C*).

Graph—Graphs of time-series data, flow-duration curves, flow frequencies, running sums, as well as residuals, cumulative differences, scatter plots of one or more time-series record, double-mass curve, and box whisker (fig. 8*D*).

List—Generates a list of dates and associated values for a selected time series (fig. 8*E*).

Subset and Filter Time Series—Allows the user to transform the selected data into a variety of formats such as creating a subset dataset by date or season or filtering the dataset by specific ranges of values (fig. 8*F*).

Trend—Computes an *n*-day high or low annual time series and uses the Mann-Kendall test to identify monotonic trends in the annual time series aggregated from a daily time series (fig. 8*G*).

Generate Time Series—Allows the user to generate new time series from one or more of the project time series by using a variety of mathematical functions and subsetting options.

Selection of any of the "**Time-Series Tools**" brings up the "Select Data" form, which allows the selection of one or more time-series datasets available for the project. For example, if the "**Graph**" tool has been selected, the "Select Data to Graph" form is opened (fig. 9). The top panel of the "Select Data to Graph" form is titled "Select Attribute Values to Filter Available Data" and contains dropdown lists with time-series attributes. The number and content of these lists can be managed through the "**Attributes**" menu. The default

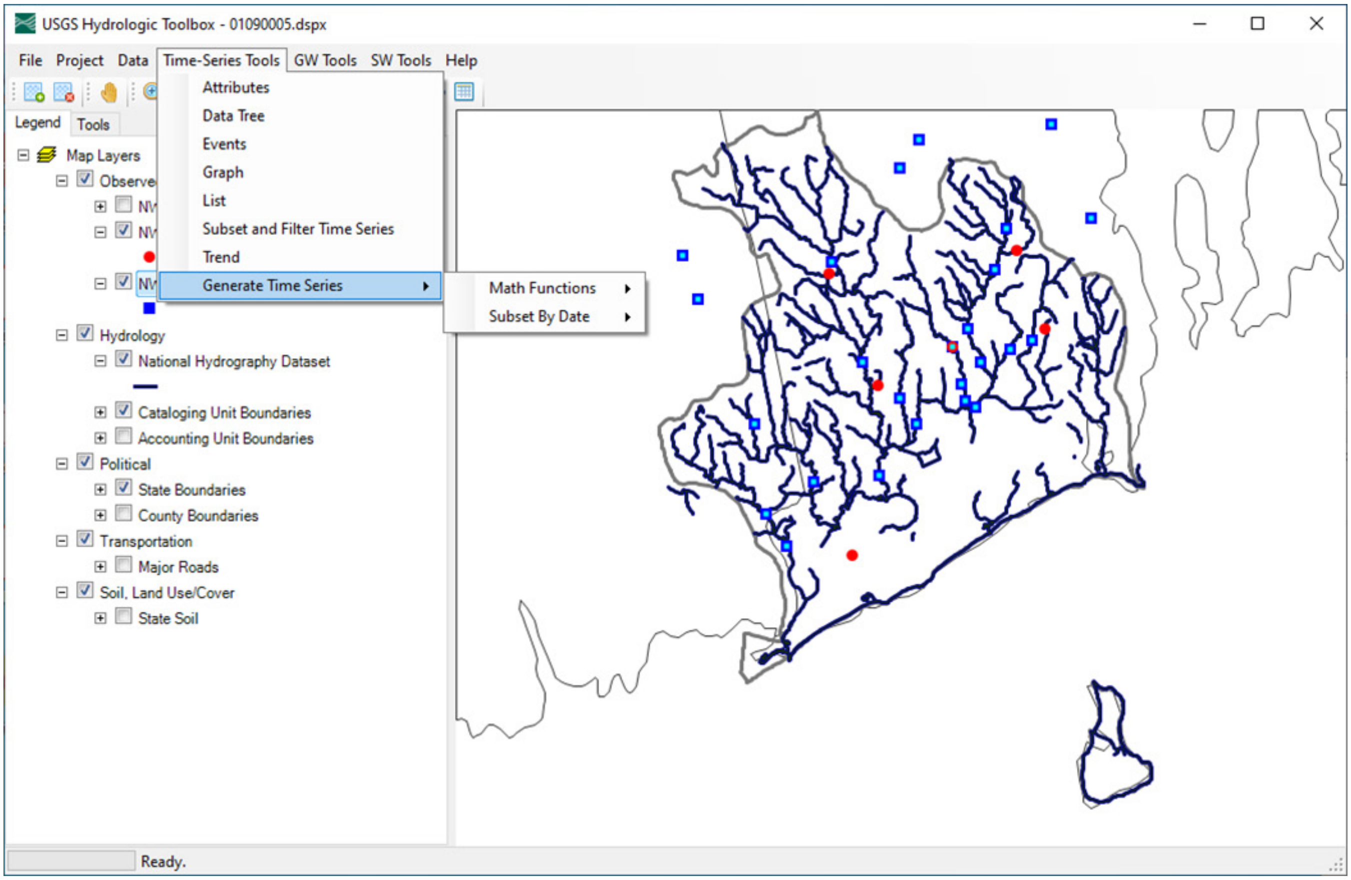
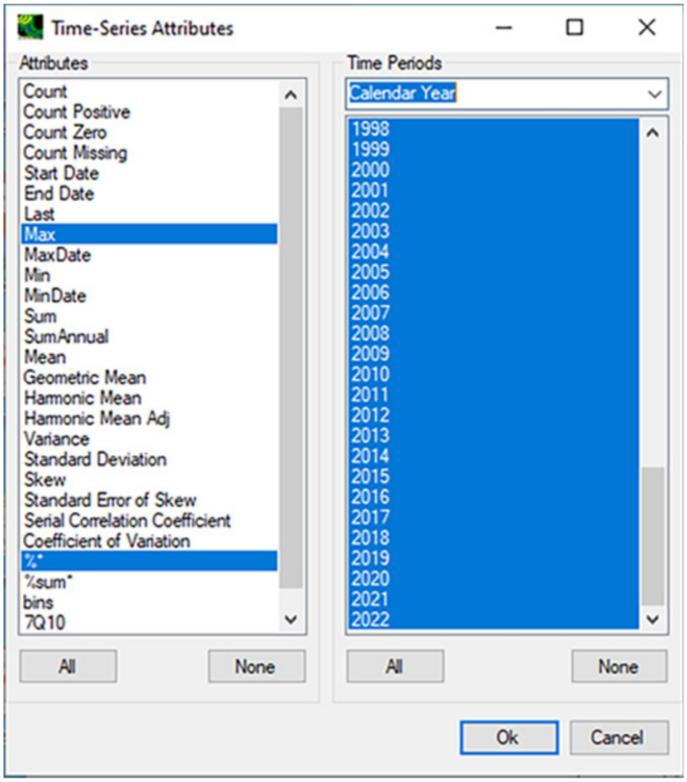


Figure 7. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing the list of "**Time-Series Tools**" available with the Hydrologic Toolbox.

attributes shown with the Hydrologic Toolbox are "Scenario," "Location," and "Constituent," but these can be changed by the user. When the user selects an attribute from any of the lists, the "Matching Data" panel is populated with the datasets having the attribute(s) selected. In the example above, all 25 of the streamflow records ("Constituent" equal to "Streamflow") were selected by default from the "Location" attribute list. The user then selects datasets from the "Matching Data" panel to populate the "Selected Data" panel of the form. The user can now click "Ok" to graph the selected datasets. The section of the form entitled "Date Range of Selected Data" lists both the full date range of all the datasets selected as well as the common date range for the datasets.

Two optional check boxes are available in the lower right corner of the "Select Data" dialog box. The first check box allows the user to include provisional data in the selected time series. By default, provisional data are not included in the Hydrologic Toolbox analyses. Selection of the "Subset and Filter Time Series" check box will allow the user to subset and filter the time series before operation of the specific utility that has been selected.

A



B

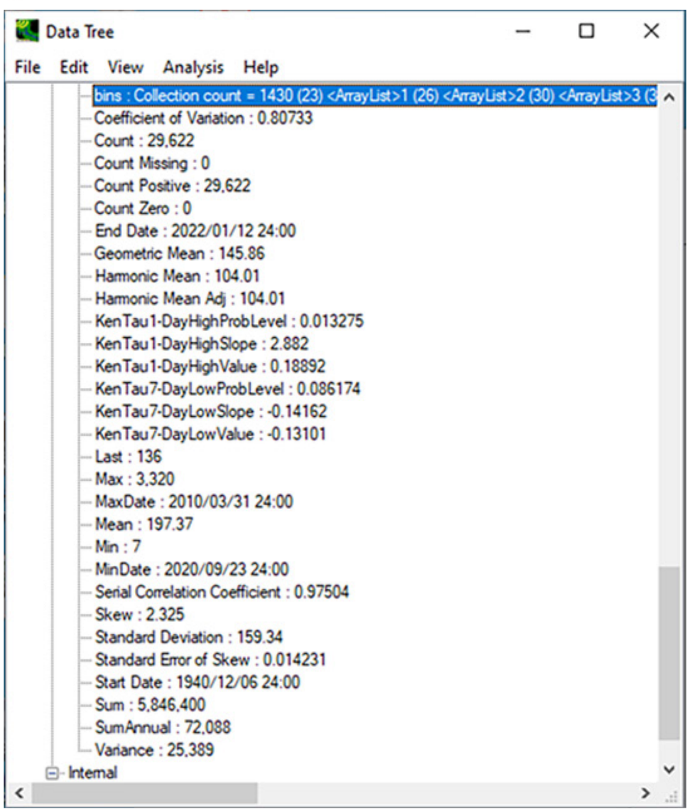
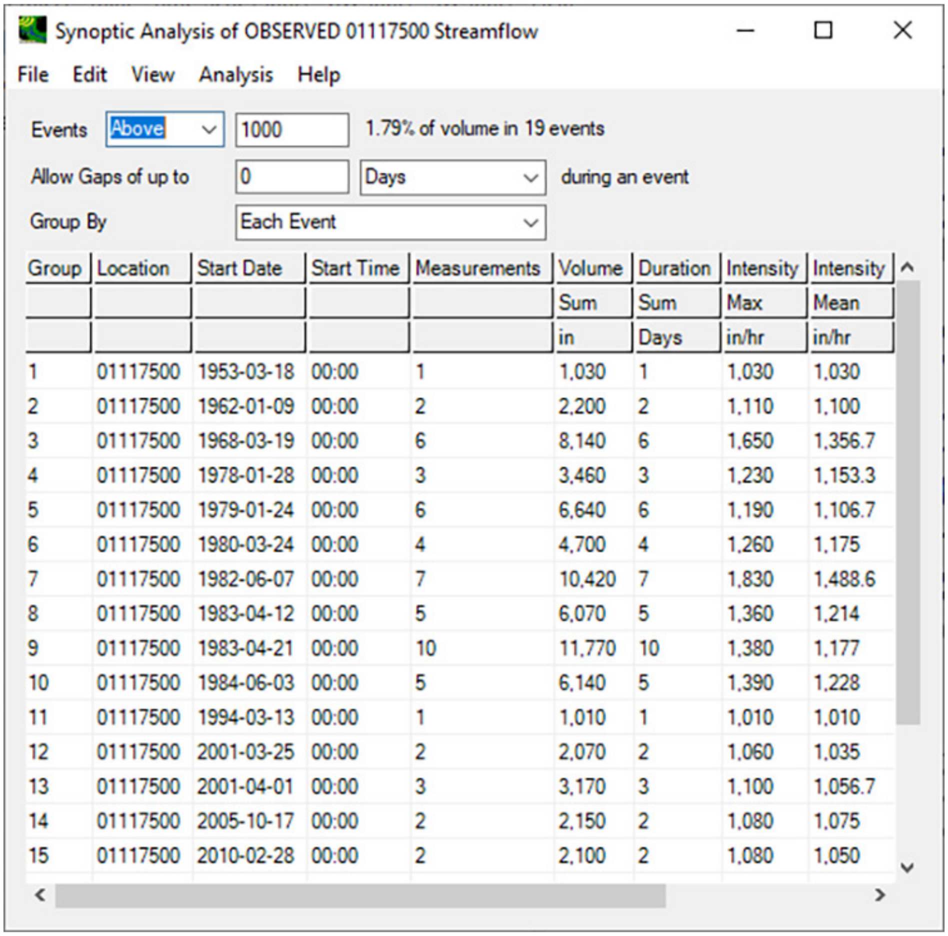


Figure 8. Screen captures from the U.S. Geological Survey Hydrologic Toolbox showing dialog boxes for several of the "**Time-Series Tools**": *A*, "**Attributes**"; *B*, "**Data Tree**"; *C*, "**Events**"; *D*, "**Graph**"; *E*, "**List**"; *F*, "**Subset and Filter Time Series**"; *G*, "**Trend**."

C



Group	Location	Start Date	Start Time	Measurements	Volume	Duration	Intensity	Intensity
					Sum	Sum	Max	Mean
					in	Days	in/hr	in/hr
1	01117500	1953-03-18	00:00	1	1,030	1	1,030	1,030
2	01117500	1962-01-09	00:00	2	2,200	2	1,110	1,100
3	01117500	1968-03-19	00:00	6	8,140	6	1,650	1,356.7
4	01117500	1978-01-28	00:00	3	3,460	3	1,230	1,153.3
5	01117500	1979-01-24	00:00	6	6,640	6	1,190	1,106.7
6	01117500	1980-03-24	00:00	4	4,700	4	1,260	1,175
7	01117500	1982-06-07	00:00	7	10,420	7	1,830	1,488.6
8	01117500	1983-04-12	00:00	5	6,070	5	1,360	1,214
9	01117500	1983-04-21	00:00	10	11,770	10	1,380	1,177
10	01117500	1984-06-03	00:00	5	6,140	5	1,390	1,228
11	01117500	1994-03-13	00:00	1	1,010	1	1,010	1,010
12	01117500	2001-03-25	00:00	2	2,070	2	1,060	1,035
13	01117500	2001-04-01	00:00	3	3,170	3	1,100	1,056.7
14	01117500	2005-10-17	00:00	2	2,150	2	1,080	1,075
15	01117500	2010-02-28	00:00	2	2,100	2	1,080	1,050

D

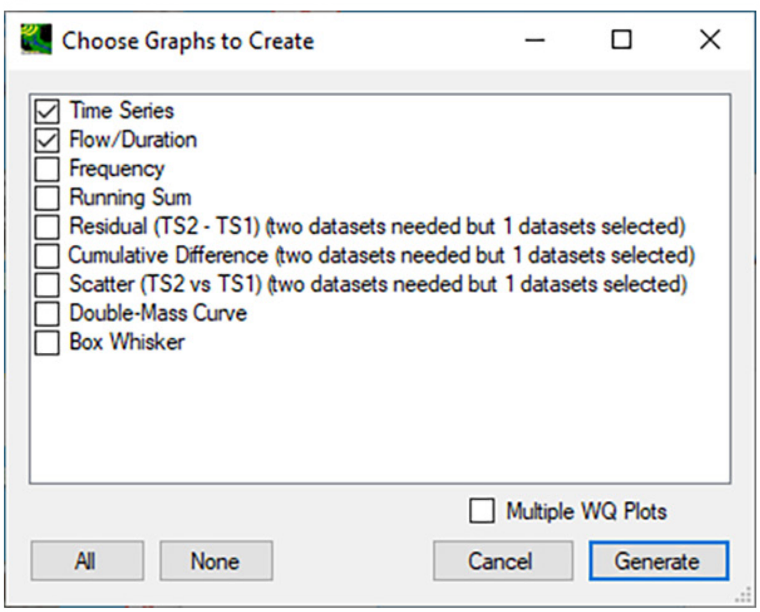


Figure 8.—Continued

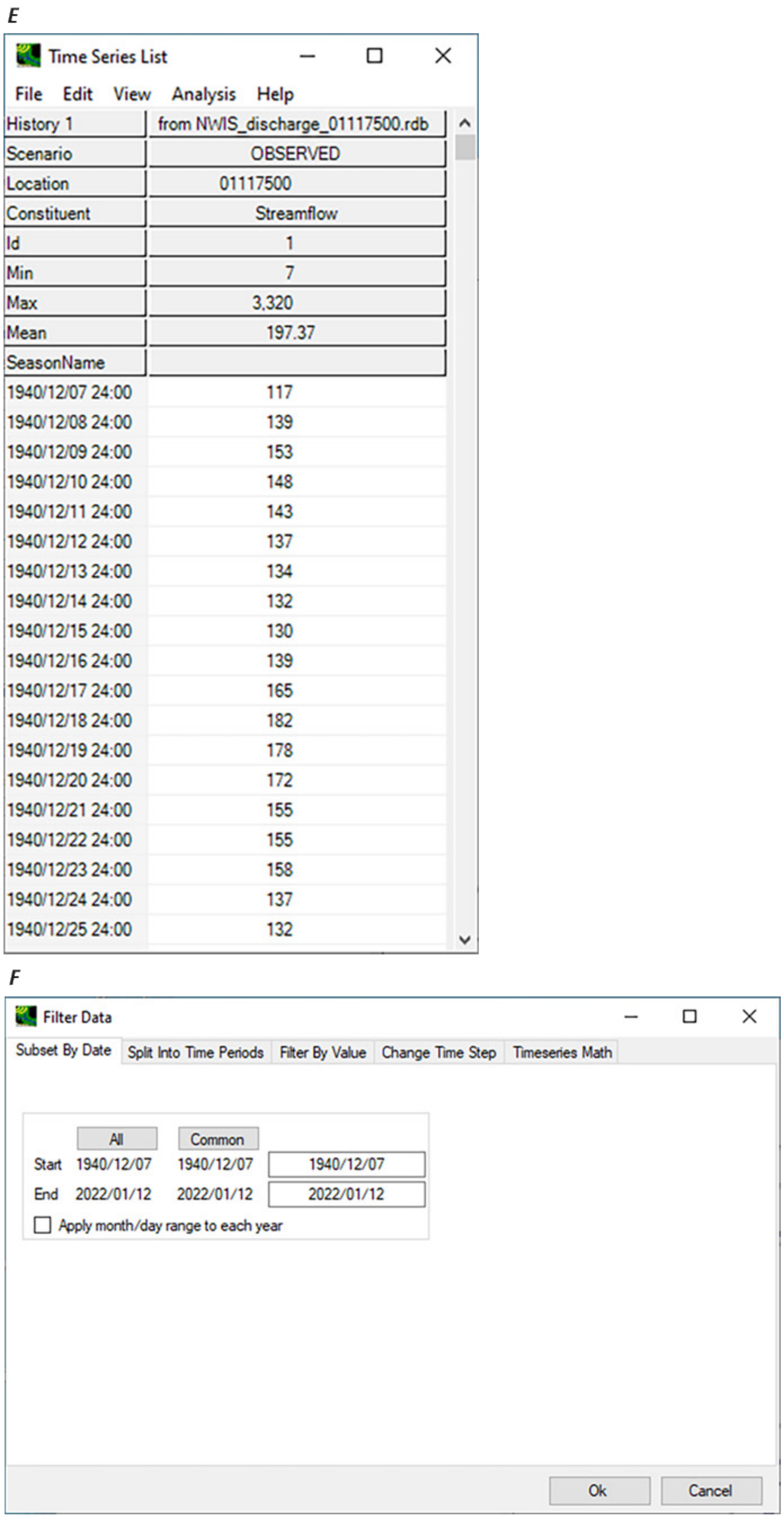


Figure 8.—Continued

G

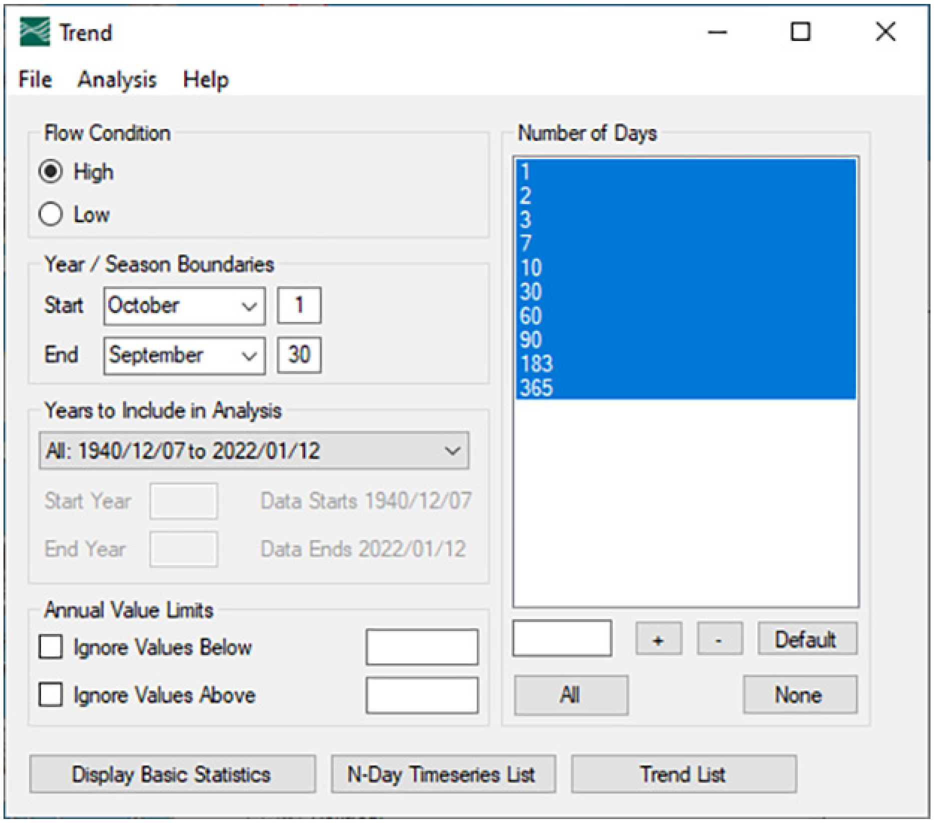


Figure 8.—Continued

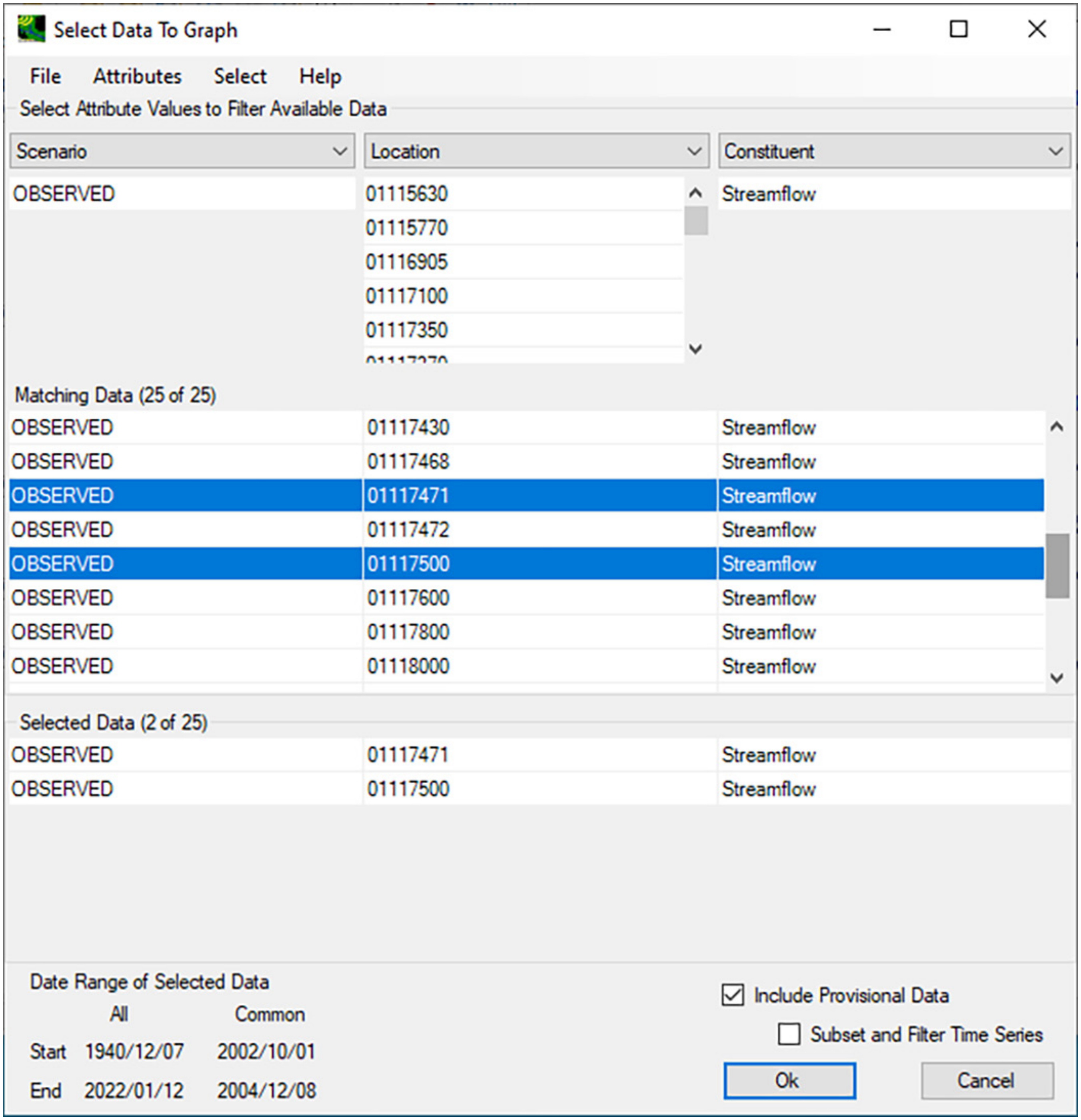


Figure 9. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing "**Select Data to Graph**" dialog box.

Groundwater (GW) Tools

The Hydrologic Toolbox provides the following three options for analysis of groundwater systems that use time-series streamflow records: (1) a hydrograph (or base-flow) separation to compute the base-flow and runoff components of streamflow, (2) a recession-curve displacement method by RORA to estimate groundwater recharge, and (3) a hydrograph-recession analysis to determine base-flow-recession constants and master (that is, universal) recession curves. These methods are identified under the "GW Tools" menu as the "Base-Flow Separation," "Recharge Estimation with RORA," and "Estimate Hydrograph Parameters" options (fig. 10). The methods "Base-Flow Separation" and "Estimate Hydrograph Parameters" are briefly described here. No modifications were made to the RORA (Rutledge, 1998) program in the Hydrologic Toolbox; its use is described in the original

Groundwater Toolbox (GWToolbox) documentation (Barlow and others, 2015) and in the Help manual that is part of the program.

Base-Flow Separation

Eight hydrograph-separation methods are provided in version 1.0.0 of the Hydrologic Toolbox. Each of the computer programs in which the methods were originally implemented was reprogrammed from its original Fortran language into the VB.NET language. As named in the Toolbox, the methods are the following:

HYSEP—The HYSEP Fixed Interval, Local Minimum, and Sliding Interval methods originally developed by Pettyjohn and Henning (1979) and implemented in the HYSEP software by Sloto and Crouse (1996).

PART—The PART method developed and implemented in a computer program by Rutledge (1998).

BFI—The Base-Flow Index (BFI) method Standard and Modified methods originally developed by the Institute of Hydrology (1980a, b) and implemented in a computer program by Wahl and Wahl (1995).

DF-One Param—The single-parameter digital filter originally described by Nathan and McMahon (1990) and implemented in the SWAT Bflow computer program by Arnold and others (1995) and Arnold and Allen (1999).

DF-Two Param—The two-parameter digital filter developed by Eckhardt (2005) and later implemented in a computer program described by Eckhardt (2008).

Each method is described in detail in the specific references cited above. Additional information about the HYSEP, PART, and BFI methods is given in Barlow and others (2015) and about the digital-filter methods in the “Digital Filters” tutorial available with the software download package. Barlow and others (2015) also summarize the simplifying assumptions of the hydrograph-separation methods and provide guidance for the appropriate use of these methods.

The Toolbox provides three modes of analysis for hydrograph separation: Interactive, Batch Map, and Batch File:

Interactive—To analyze a single continuous or intermittent streamflow record.

Batch Map—To analyze multiple continuous or intermittent streamflow records simultaneously and to create a batch-run configuration file.

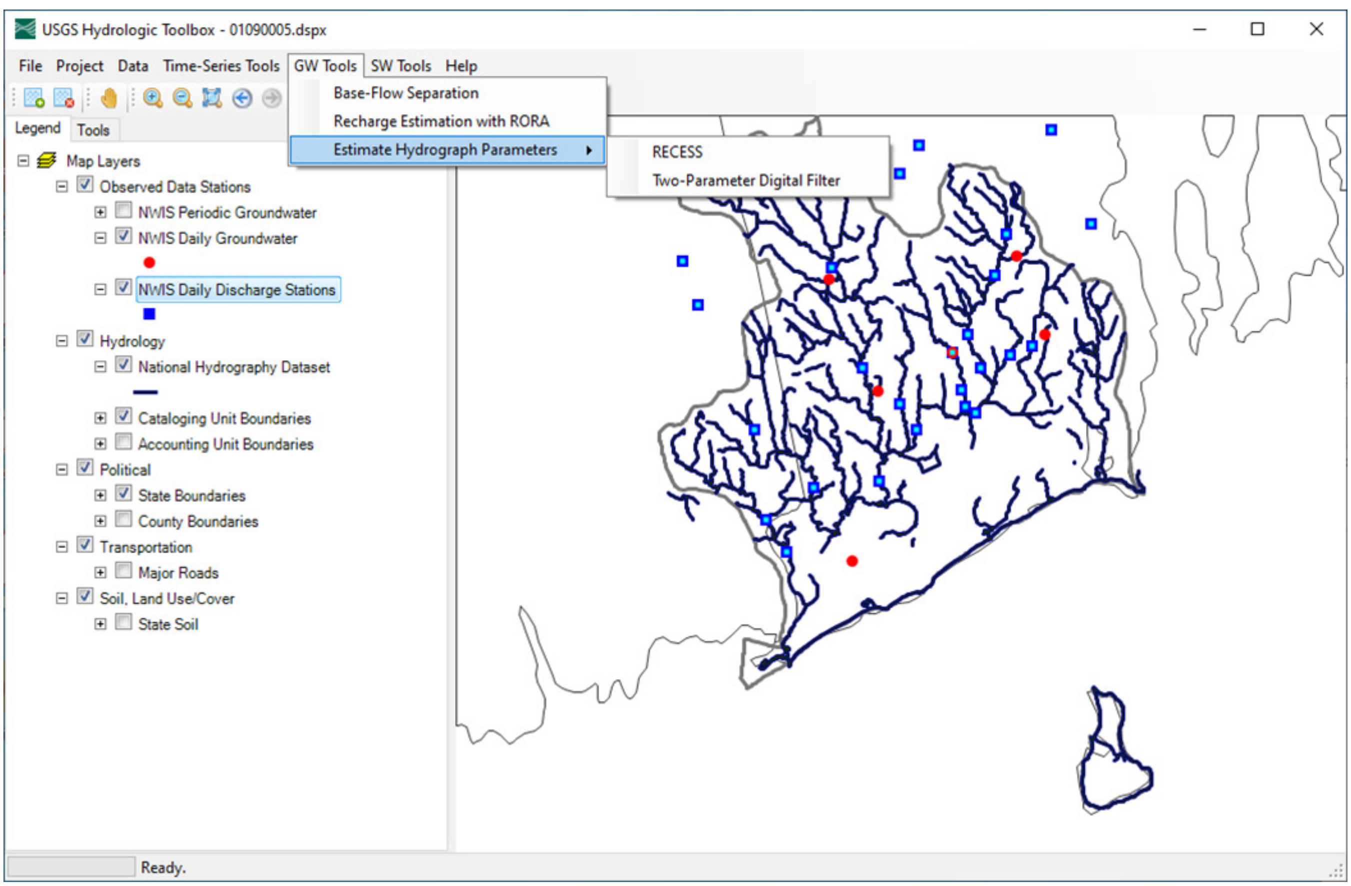


Figure 10. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing the list of the “**GW Tools**” available in the Hydrologic Toolbox.

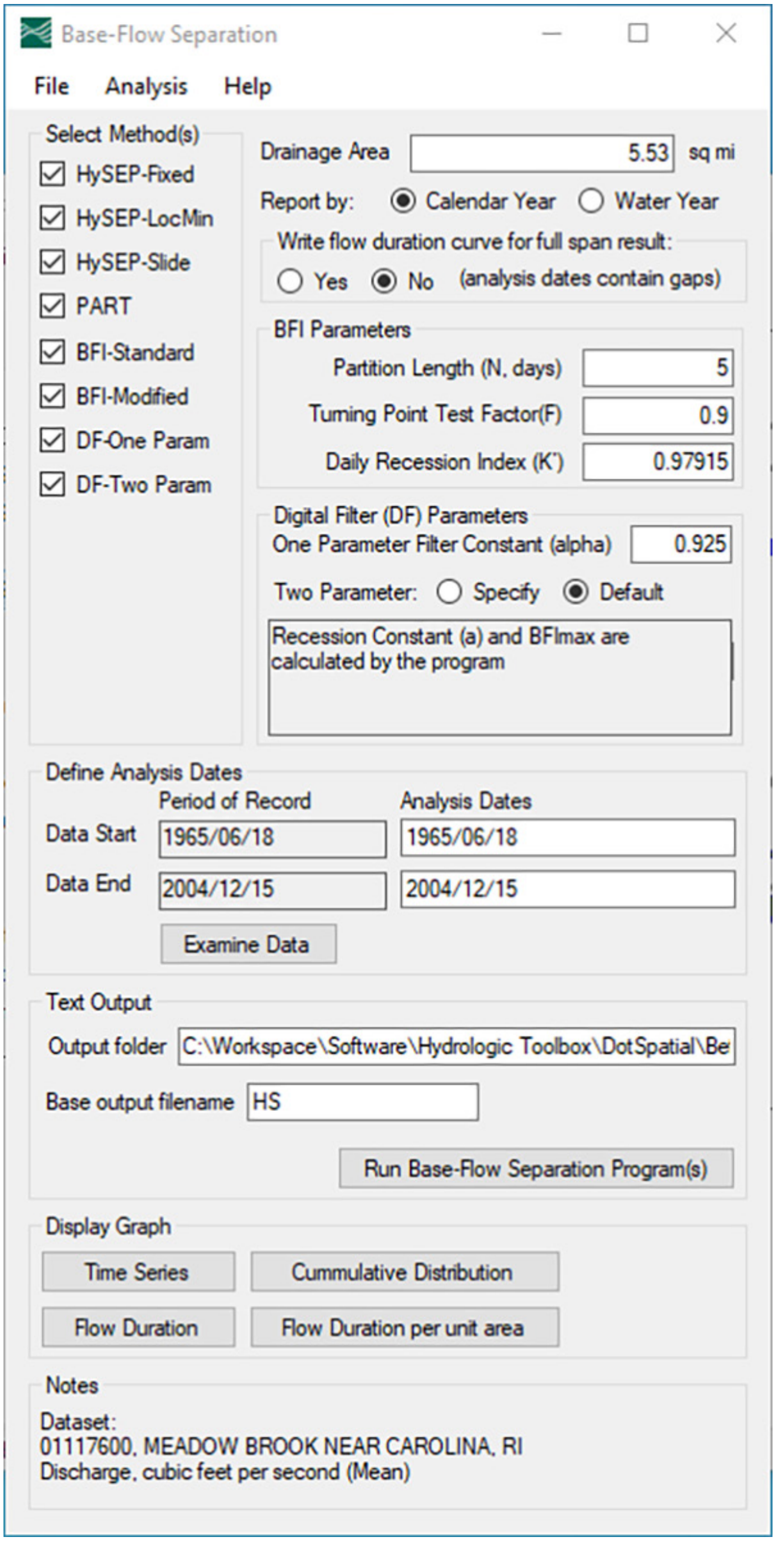


Figure 11. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing dialog box in the interactive mode of the "**Base-Flow Separation**" program for analysis of the streamflow record for Meadow Brook near Carolina, Rhode Island.

Batch File—To automatically run an existing batch-run configuration file.

Figure 11 shows the “Base-Flow Separation” dialog box used for an interactive analysis of a single streamflow record. The “Display Graph” options can be used to generate time-series graphs and flow-duration curves of the calculated base-flow and runoff time series. Two tutorials are provided with the Toolbox download package to assist the user: (1) the “Hydrograph Separation” tutorial provides a detailed guide for use of the three analysis modes, and (2) the “Analysis of Base Flow” tutorial provides examples of trend and subset analyses for a base-flow time series computed by the Hydrologic Toolbox.

Estimate Hydrograph Parameters

The Hydrologic Toolbox provides two methods to estimate base-flow recession constants—the RECESS method developed by Rutledge (1998) and a correlation method initially described by Langbein (1938) and implemented for use with the two-parameter digital filter by Eckhardt (2005, 2008). The RECESS method, which also can be used to compute a master base-flow recession curve from a streamflow time-series record, was included with the initial release of the GWToolbox and subsequently updated for version 1.3 of that program. The tutorial named “RECESS” describes how this method is updated in the Hydrologic Toolbox.

For the two-parameter digital filter, a recession constant and a maximum calculable long-term ratio of base flow to total streamflow (BFI_{max}; Eckhardt, 2005) must be specified. The “Two-Parameter Digital Filter” function provides procedures to estimate these two parameters. The correlation method is used to compute the recession constant, and the backwards-filtering approach developed by Collischonn and Fan (2013) is used to compute BFI_{max}. The function of the two digital filters is described in the “Digital Filters” tutorial and in the Help manual provided with the program.

Surface-Water (SW) Tools

The Hydrologic Toolbox functions in the same way as the original Surface-Water Toolbox (SWToolbox) for computing duration and frequency analyses of streamflow time series (Kiang and others, 2018). The duration analyses include the computation of flow durations at a single site, a statistical comparison of duration values for two time series, and the creation of hydrographs of daily-mean flow durations. The integrated frequency analyses include the calculations of both biologically and hydrologically based design flows, such as the 1B3 and the 7Q10. To support interpretation of the frequency analyses, the Toolbox also provides tests to determine statistical trends, outliers, and the fit of the data distribution. Methods used in the calculations of the surface-water statistics are described in the original SWToolbox documentation (Kiang and others, 2018). Instructions to perform the analyses are available in the documentation manual and tutorials found within the Hydrologic Toolbox “Help” menu.

The EPA legacy program DFLOW 4.0 (U.S. Environmental Protection Agency, 2020), which was included in SWToolbox, is not included in the new Toolbox. The legacy DFLOW program within SWToolbox was intended to allow comparisons between the deprecated EPA program and the newly implemented “Design Flow” functionality of SWToolbox; however, this comparison is no longer needed for the statistical analyses provided in the Hydrologic Toolbox. The menu configuration remains largely the same, but there are a few noteworthy enhancements and corrections to surface-water analyses included in the new Hydrologic Toolbox software.

Menu Configuration

The duration and flow-frequency analyses are now consolidated under the “SW Tools” menu within the Hydrologic Toolbox, as shown on fig. 12, providing ease of access. Flow-duration analyses are in the same “Duration/Compare” and “Duration Hydrograph” menu options. Frequency analyses are still provided under the “USGS Integrated Design Flow (IDF)” menu. Options to create and run batch-frequency analyses are also still accessed under the “Create SWSTAT Batch,” “Create DFLOW Batch,” and “Run Existing Batch” menu options.

By selecting the “Interactive” submenu of the “USGS Integrated Design Flow (IDF)” menu, the user is presented with the same collection of tabs for the “Select Dates”; “N-day, Trend, Frequency”; “Design Flow”; and “Group Outlier Test” functions as shown on figure 13. Each of the tabbed dialog boxes has the same configurations as in the previous program. As was the case for the SWToolbox, the R statistical program (R) must be installed to activate the “Group Outlier Test” tab and the “Screening Tests (R)” function, both of which are available in the “N-day, Trend, Frequency” tab.

Enhancements and Code Corrections

Output from the frequency analysis from the SWSTAT batch has been enhanced since the initial release of the SWToolbox. Previously, the descriptive statistics and variables associated with the *n*-day frequency analysis, such as the K-value, standard deviation, and the beginning and ending dates, were available in the interactive mode only by exporting the “Frequency Grid” results or written within the text output of the “Frequency Report.” This information is useful in assessing the results of the analyses and also in developing regional regression equations of the computed frequency statistics. The information associated with the analysis is now appended in tab-delimited format at the bottom of the “Frequency Grid” output file that is generated during the

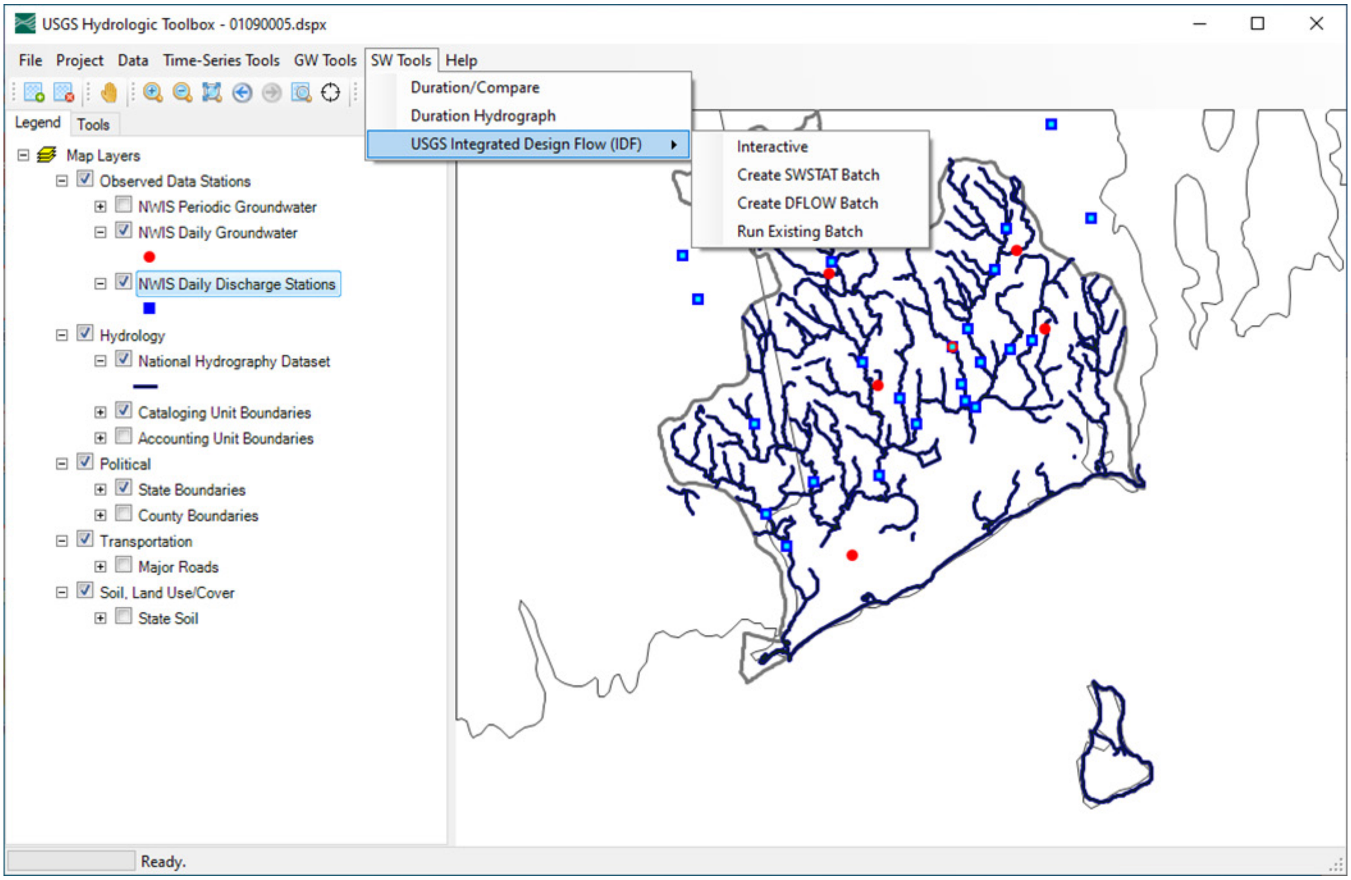


Figure 12. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing the "**SW Tools**" available within the Hydrologic Toolbox.

SWSTAT batch run (fig. 14) within the Hydrologic Toolbox. This enhancement was first made available in SWToolbox version 1.0.5 (Kiang and others, 2021).

The outputs of two scenarios from the initial SWToolbox were found to be inconsistent and were updated in the Hydrologic Toolbox. First, during low-flow frequency analyses, the application of the conditional-probability adjustment (CPA) for records with zero-flow values was found to have been applied only to the "Frequency Report" output. Also, the option for choosing "Custom" years on the "Select Dates" tab was also being applied only to the "Frequency Report" output. Within the Hydrologic Toolbox, the CPA for zero flows and the "Custom" years are now applied for all output types in both the "N-day, Trend, Frequency" and "Design Flow" frequency analyses. These corrections were first made in SWToolbox version 1.0.5 (Kiang and others, 2021).

An adjustment is also applied to the calculation of the harmonic mean when zeroes are present in the flow record. The calculation of the harmonic mean is part of the "Design Flow" analyses. In the initial version of SWToolbox, the program was treating gaps in the record as zeroes and thereby incorrectly overadjusting the harmonic mean for zeroes that were not actually present in the record. The gaps are now excluded, and the adjusted harmonic mean is computed correctly within the Hydrologic Toolbox.

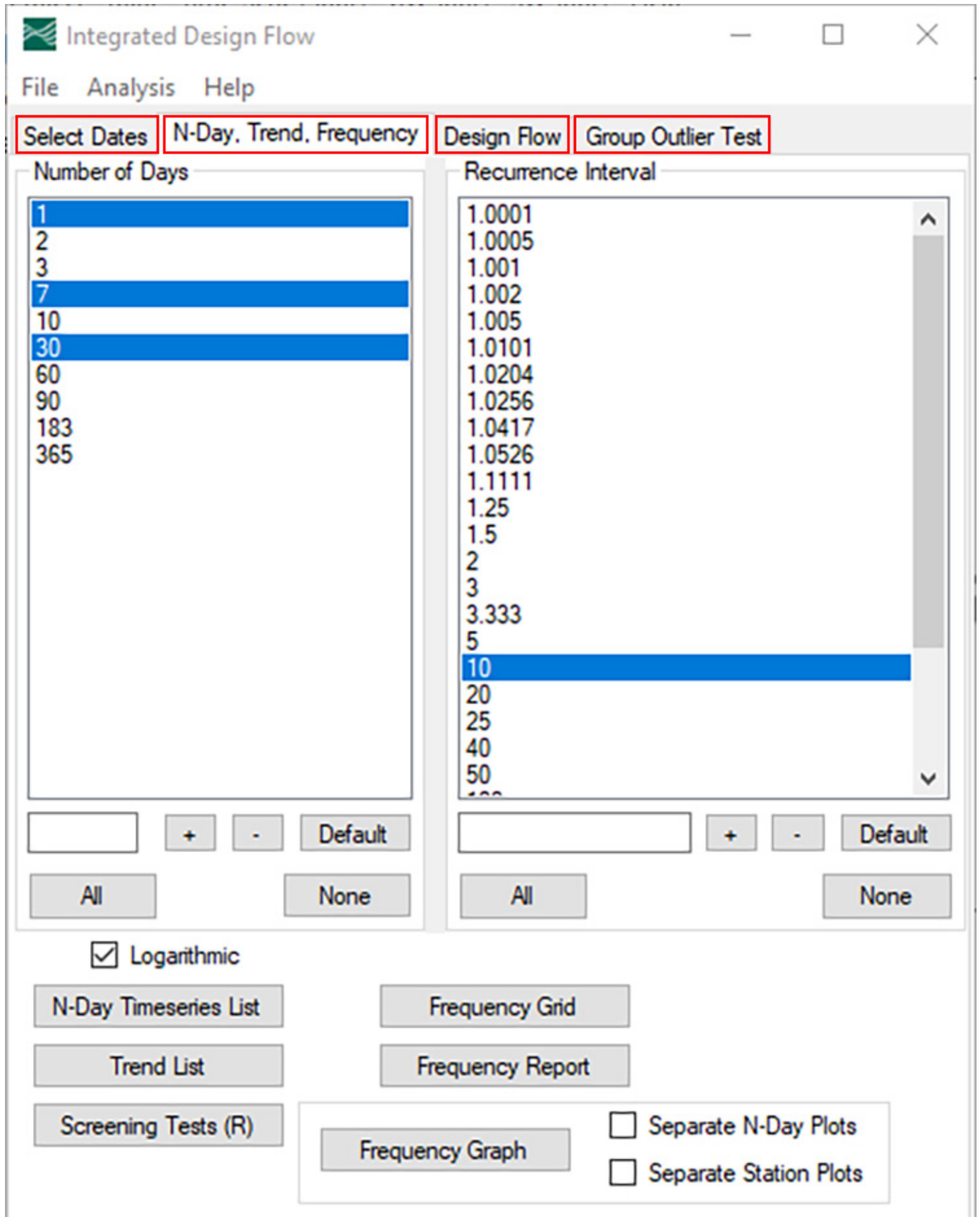
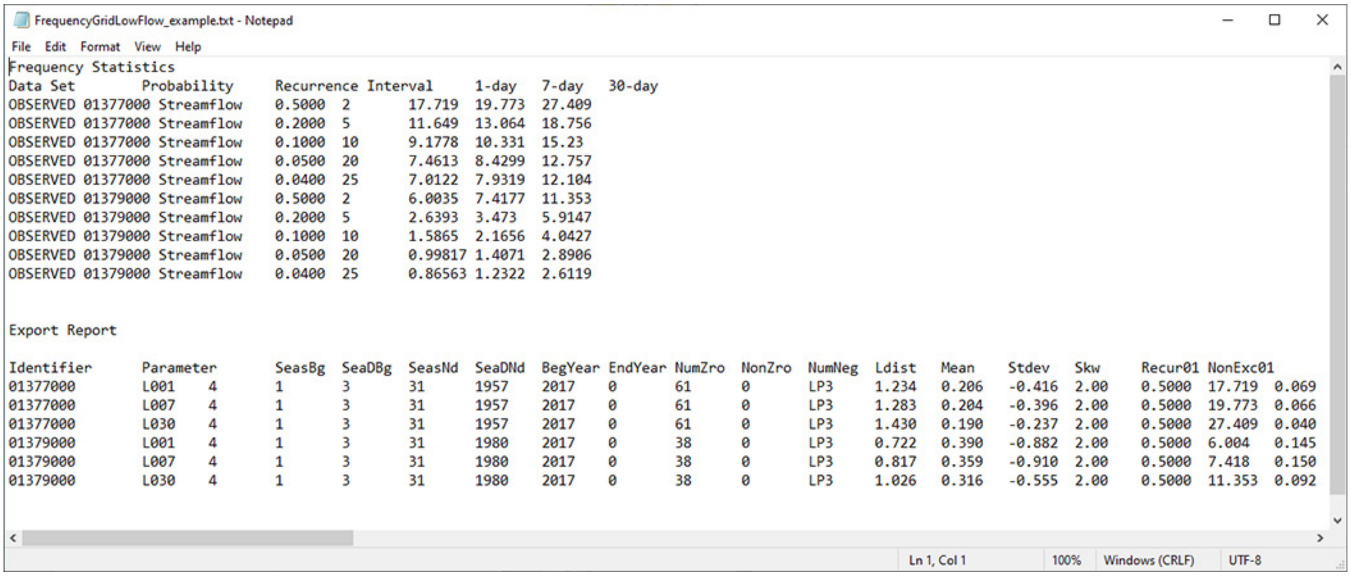


Figure 13. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing the "**Integrated Design Flow**" dialog box and tabs. The four items enclosed in red rectangles are discussed in the text.



FrequencyGridLowFlow_example.txt - Notepad

File Edit Format View Help

```
Frequency Statistics
Data Set           Probability     Recurrence Interval     1-day   7-day   30-day
OBSERVED 01377000 Streamflow    0.5000  2        17.719  19.773  27.409
OBSERVED 01377000 Streamflow    0.2000  5        11.649  13.064  18.756
OBSERVED 01377000 Streamflow    0.1000  10       9.1778  10.331  15.23
OBSERVED 01377000 Streamflow    0.0500  20       7.4613  8.4299  12.757
OBSERVED 01377000 Streamflow    0.0400  25       7.0122  7.9319  12.104
OBSERVED 01379000 Streamflow    0.5000  2        6.0035  7.4177  11.353
OBSERVED 01379000 Streamflow    0.2000  5        2.6393  3.473   5.9147
OBSERVED 01379000 Streamflow    0.1000  10       1.5865  2.1656  4.0427
OBSERVED 01379000 Streamflow    0.0500  20       0.99817 1.4071  2.8906
OBSERVED 01379000 Streamflow    0.0400  25       0.86563 1.2322  2.6119


Export Report

Identifier      Parameter       SeasBg  SeaDBg  SeasNd  SeaDNd  BegYear EndYear NumZro  NonZro  NumNeg  Ldist   Mean    Stdev   Skw     Recur01 NonExc01
01377000        L001    4       1       3       31      1957    2017    0       61      0       LP3     1.234   0.206   -0.416  2.00    0.5000  17.719  0.069
01377000        L007    4       1       3       31      1957    2017    0       61      0       LP3     1.283   0.204   -0.396  2.00    0.5000  19.773  0.066
01377000        L030    4       1       3       31      1957    2017    0       61      0       LP3     1.430   0.190   -0.237  2.00    0.5000  27.409  0.040
01379000        L001    4       1       3       31      1980    2017    0       38      0       LP3     0.722   0.390   -0.882  2.00    0.5000  6.004   0.145
01379000        L007    4       1       3       31      1980    2017    0       38      0       LP3     0.817   0.359   -0.910  2.00    0.5000  7.418   0.150
01379000        L030    4       1       3       31      1980    2017    0       38      0       LP3     1.026   0.316   -0.555  2.00    0.5000  11.353  0.092
```

Ln 1, Col 1 100% Windows (CRLF) UTF-8

Figure 14. Screen capture from the U.S. Geological Survey Hydrologic Toolbox showing SWSTAT batch-output file with descriptive statistics and variables appended to the file.

Summary

The Hydrologic Toolbox is a Windows-based desktop software program that provides a graphical and mapping interface for the analysis of hydrologic time-series data with a set of widely used and standardized computational methods. The software is the most comprehensive and up-to-date in a series of programs for the computation of low-flow statistics, hydrograph separation, and recession analyses. It combines the analytical and statistical functions provided in the U.S. Geological Survey Groundwater and Surface-Water Toolboxes into a single computing environment, provides several enhancements to the original toolboxes, and supersedes these two programs and several additional legacy programs that have a more limited functionality. The Hydrologic Toolbox also facilitates retrieval of streamflow and groundwater-level time-series data from the U.S. Geological Survey National Water Information System and outputs text reports for a record of the analysis.

This report describes how to build a project in the Hydrologic Toolbox and to download and manage hydrologic time-series data, includes an overview of the analysis and statistical capabilities of the Hydrologic Toolbox, and highlights the primary differences between the Hydrologic Toolbox and the Groundwater and Surface-Water Toolboxes. The report is intended to be used in conjunction with an online user manual for the software and previously published technical reports that document the analytical methods.

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For more information about this report, contact:
Director, New England Water Science Center
U.S. Geological Survey
10 Bearfoot Road
Northborough, MA 01532
dc_nweng@usgs.gov
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