Groundwater Toolbox Tutorial

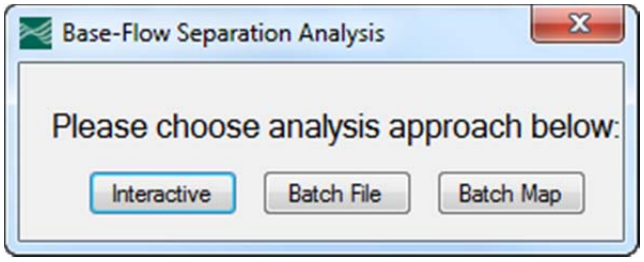
New and Updated Functionality for Hydrograph Separation with the Groundwater Toolbox

October 1, 2016 (Version 1.2 release)

This document describes new and updated functionality developed for hydrograph separation by use of the Groundwater (GW) Toolbox. The updates allow users to evaluate (1) multiple streamflow records simultaneously, (2) streamflow records with intermittent (noncontinuous) periods of record, and (3) streamflow records that are less than a full calendar year in length or that extend over periods that are not full calendar years. Each of these new capabilities is described below. Readers of this document should be familiar with the basic hydrograph-separation capabilities of the GW Toolbox described in USGS Techniques and Methods 3-B10, which is distributed with the software.

Modes of Hydrograph Separation

The base-flow and runoff components of streamflow are determined from a streamflow record by use of the "**USGS Base-Flow Separation**" option in the "**Analysis**" menu. Selecting this option will result in the following dialog box



The three options provide three modes of analysis:

"Interactive" is used to analyze a single streamflow record, including those with intermittent record.

"Batch File" opens an existing batch-run configuration file to run the hydrograph-separation methods on one or more streamflow records with pre-defined user options.

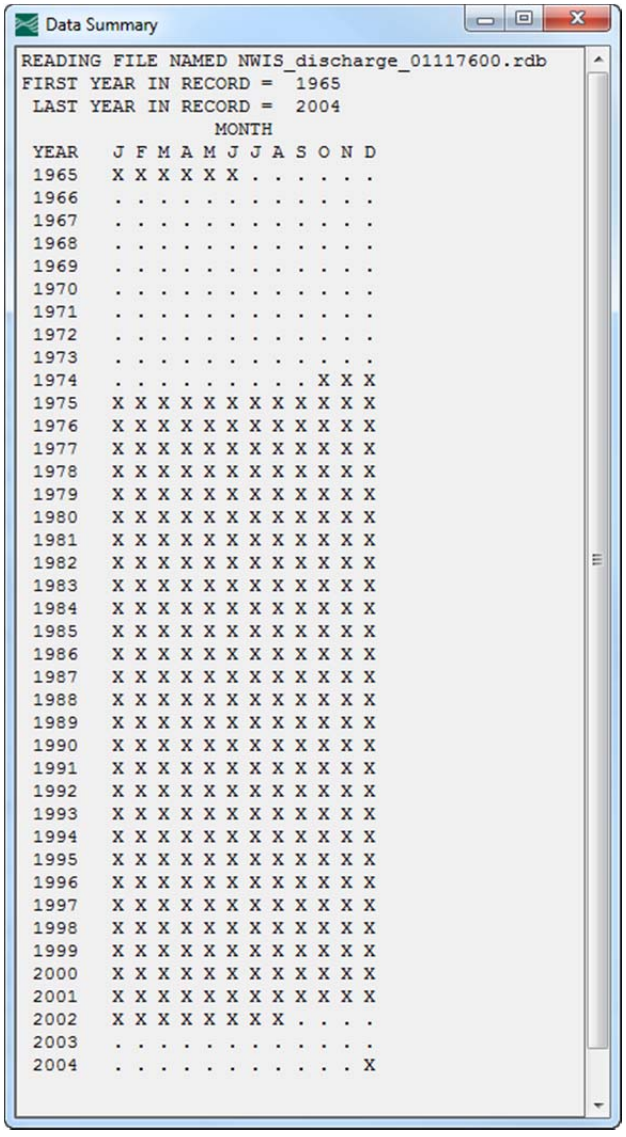
"Batch Map" is used to create a configuration file and, optionally, to run the hydrograph-separation methods on one or more streamflow records.

Each mode is described below, in order of "Interactive" (page 2), "Batch Map" (page 6), and "Batch File" (page 22).

“Interactive” Mode: Example Analysis of a Record with Intermittent Data

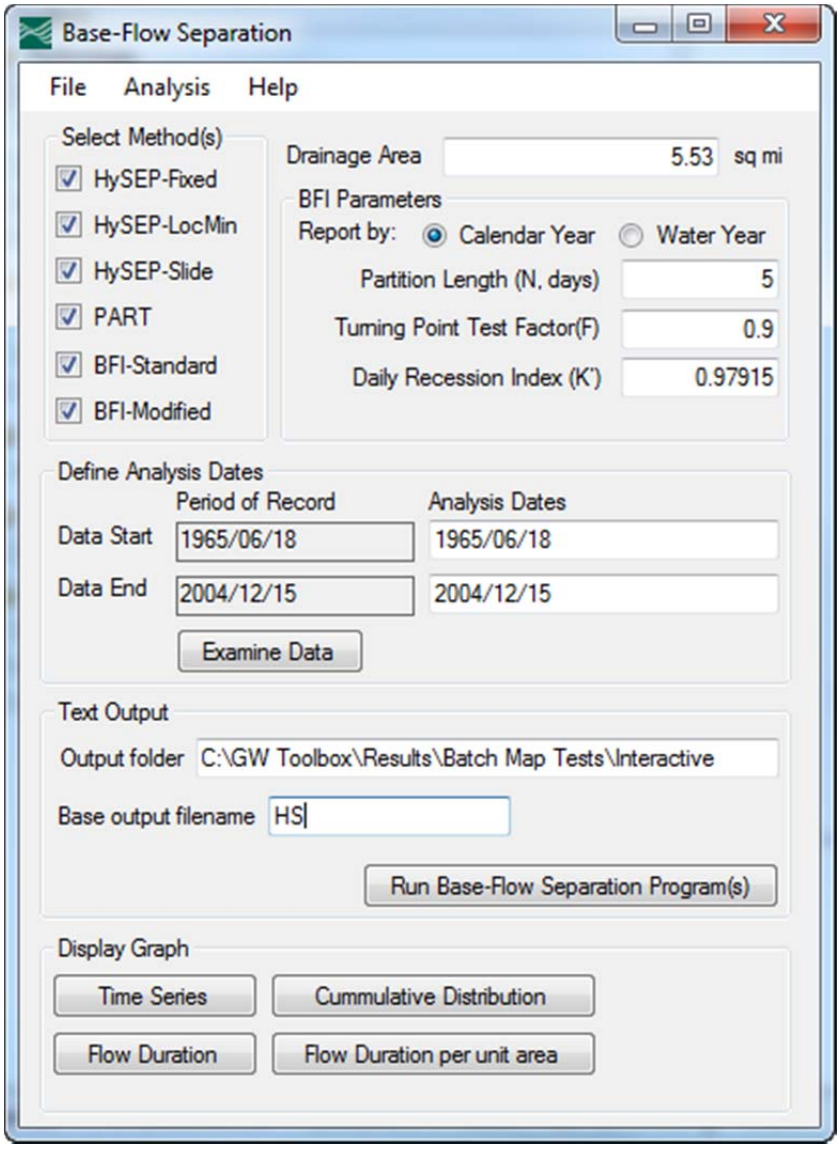
Selecting “Interactive” mode brings up the dialog box “Select Daily Streamflow for Analysis,” which is used to select a streamflow record for analysis (see USGS TM 3-B10 for details). In this example, streamflow data for USGS gaging station Meadow Brook near Carolina, Rhode Island (station 01117600) will be analyzed. The gaging station was operated intermittently between June 18, 1965, and December 15, 2004.

The user can view the months of complete and incomplete record with the “Examine Data” option in the “Base-Flow Separation” dialog box:

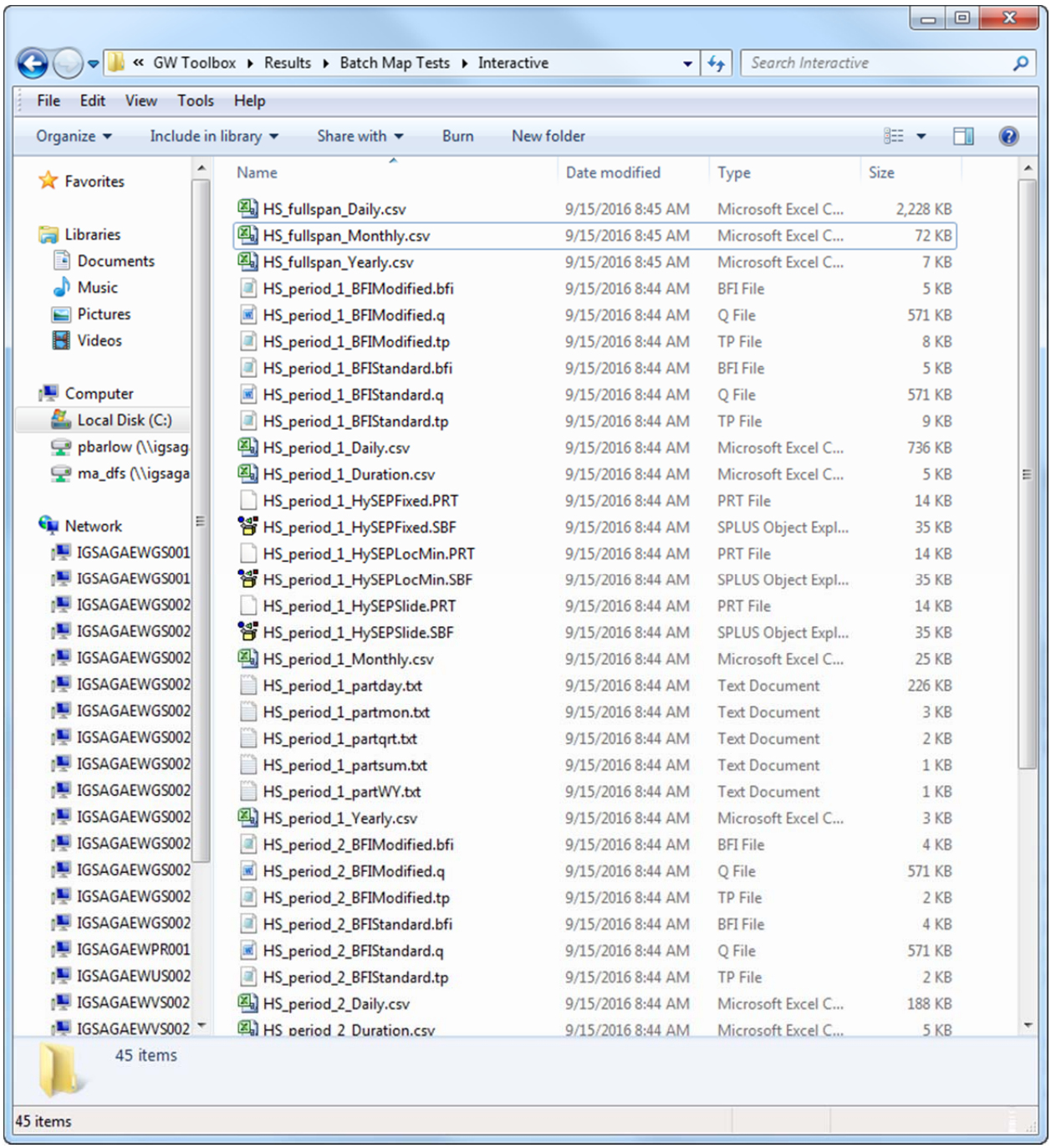


Two periods of record are identified: the first within 1965-1974 and the second within 2002-2004.

The user does not need to do anything differently on the “Base-Flow Separation” dialog box from previous releases of the GW Toolbox. For this example, the following options were specified on the dialog box:



After running the six hydrograph-separation methods, several new output files are written to the “Output folder” specified above, most of which are shown in this screen capture:



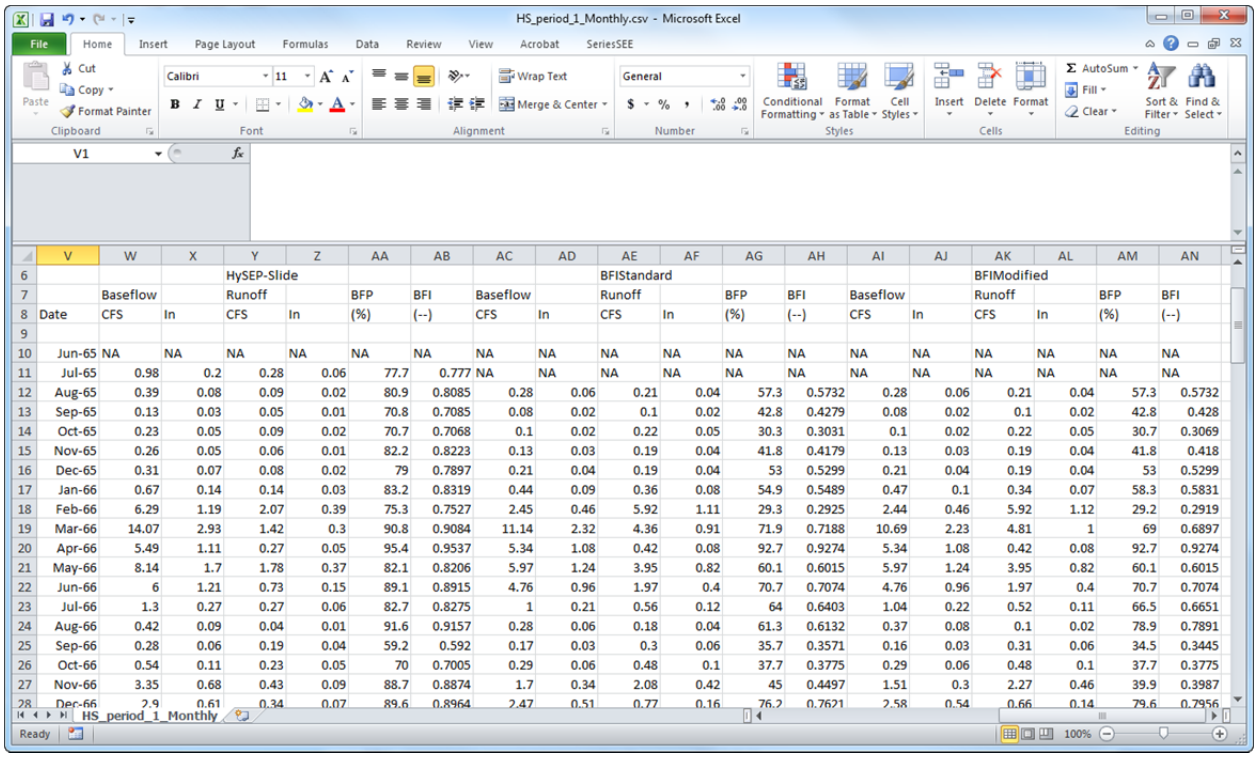
There are three sets of output files: the first set (identified with the text 'period_1' in the file name) is for the first period of record (June 18, 1965, through September 30, 1974), the second set ('period_2)' is for the second period of record (August 2, 2002, through December 15, 2004), and the third set ('fullspan') for the full span of record (June 18, 1965, through December 15, 2004). Output files for the first and second periods of record include the original output files generated by each of the individual hydrograph-separation programs (PART, HYSEP, and BFI) as well as comma-delimited (.csv) output files for daily, monthly, and yearly time periods and for flow-duration analyses. Output files for the full period only include .csv files for

the daily, monthly, and yearly results, and are generated so that the user can easily merge output from different stations.

There are two points to note about the output files:

1. the 'Duration.csv' files include information on the 'Period of analysis' used to calculate the duration statistics (that is, the date range for each individual period of record). These files are only created for the individual periods of record, and not for the full time span of record, which might include intermittent periods of record.

2. Output is only written to the 'Monthly.csv' and 'Yearly.csv' files for months and calendar years having complete record. So, for example, the 'period_1' output file for the station analyzed here has values of 'NA' (not applicable) for June 1965 in the 'period_1_Monthly.csv' file and no values shown for 1965 or 1974 for the 'period_1_Yearly.csv' file. Also note that in some cases the BFI methods will not find an initial turning point in the streamflow record for several days or weeks; in these cases, there will be base-flow and runoff calculations provided by the PART and HYSEP methods, but not for the BFI methods. This is demonstrated for the station analyzed here for the HYSEP sliding method and BFI methods for June and July 1965 in the following screen capture of part of the 'period_1_Monthly.csv' file:



	V	W	X	Y	Z	AA	AB	AC	AD	AE	AF	AG	AH	AI	AJ	AK	AL	AM	AN
6				HySEP-Slide						BFIStandard						BFIModified			
7		Baseflow		Runoff		BFP	BFI	Baseflow		Runoff		BFP	BFI	Baseflow		Runoff		BFP	BFI
8	Date	CFS	In	CFS	In	(%)	(--)	CFS	In	CFS	In	(%)	(--)	CFS	In	CFS	In	(%)	(--)
9																			
10	Jun-65	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
11	Jul-65	0.98	0.2	0.28	0.06	77.7	0.777	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
12	Aug-65	0.39	0.08	0.09	0.02	80.9	0.8085	0.28	0.06	0.21	0.04	57.3	0.5732	0.28	0.06	0.21	0.04	57.3	0.5732
13	Sep-65	0.13	0.03	0.05	0.01	70.8	0.7085	0.08	0.02	0.1	0.02	42.8	0.4279	0.08	0.02	0.1	0.02	42.8	0.428
14	Oct-65	0.23	0.05	0.09	0.02	70.7	0.7068	0.1	0.02	0.22	0.05	30.3	0.3031	0.1	0.02	0.22	0.05	30.7	0.3069
15	Nov-65	0.26	0.05	0.06	0.01	82.2	0.8223	0.13	0.03	0.19	0.04	41.8	0.4179	0.13	0.03	0.19	0.04	41.8	0.418
16	Dec-65	0.31	0.07	0.08	0.02	79	0.7897	0.21	0.04	0.19	0.04	53	0.5299	0.21	0.04	0.19	0.04	53	0.5299
17	Jan-66	0.67	0.14	0.14	0.03	83.2	0.8319	0.44	0.09	0.36	0.08	54.9	0.5489	0.47	0.1	0.34	0.07	58.3	0.5831
18	Feb-66	6.29	1.19	2.07	0.39	75.3	0.7527	2.45	0.46	5.92	1.11	29.3	0.2925	2.44	0.46	5.92	1.12	29.2	0.2919
19	Mar-66	14.07	2.93	1.42	0.3	90.8	0.9084	11.14	2.32	4.36	0.91	71.9	0.7188	10.69	2.23	4.81	1	69	0.6897
20	Apr-66	5.49	1.11	0.27	0.05	95.4	0.9537	5.34	1.08	0.42	0.08	92.7	0.9274	5.34	1.08	0.42	0.08	92.7	0.9274
21	May-66	8.14	1.7	1.78	0.37	82.1	0.8206	5.97	1.24	3.95	0.82	60.1	0.6015	5.97	1.24	3.95	0.82	60.1	0.6015
22	Jun-66	6	1.21	0.73	0.15	89.1	0.8915	4.76	0.96	1.97	0.4	70.7	0.7074	4.76	0.96	1.97	0.4	70.7	0.7074
23	Jul-66	1.3	0.27	0.27	0.06	82.7	0.8275	1	0.21	0.56	0.12	64	0.6403	1.04	0.22	0.52	0.11	66.5	0.6651
24	Aug-66	0.42	0.09	0.04	0.01	91.6	0.9157	0.28	0.06	0.18	0.04	61.3	0.6132	0.37	0.08	0.1	0.02	78.9	0.7891
25	Sep-66	0.28	0.06	0.19	0.04	59.2	0.592	0.17	0.03	0.3	0.06	35.7	0.3571	0.16	0.03	0.31	0.06	34.5	0.3445
26	Oct-66	0.54	0.11	0.23	0.05	70	0.7005	0.29	0.06	0.48	0.1	37.7	0.3775	0.29	0.06	0.48	0.1	37.7	0.3775
27	Nov-66	3.35	0.68	0.43	0.09	88.7	0.8874	1.7	0.34	2.08	0.42	45	0.4497	1.51	0.3	2.27	0.46	39.9	0.3987
28	Dec-66	2.9	0.61	0.34	0.07	89.6	0.8964	2.47	0.51	0.77	0.16	76.2	0.7621	2.58	0.54	0.66	0.14	79.6	0.7956

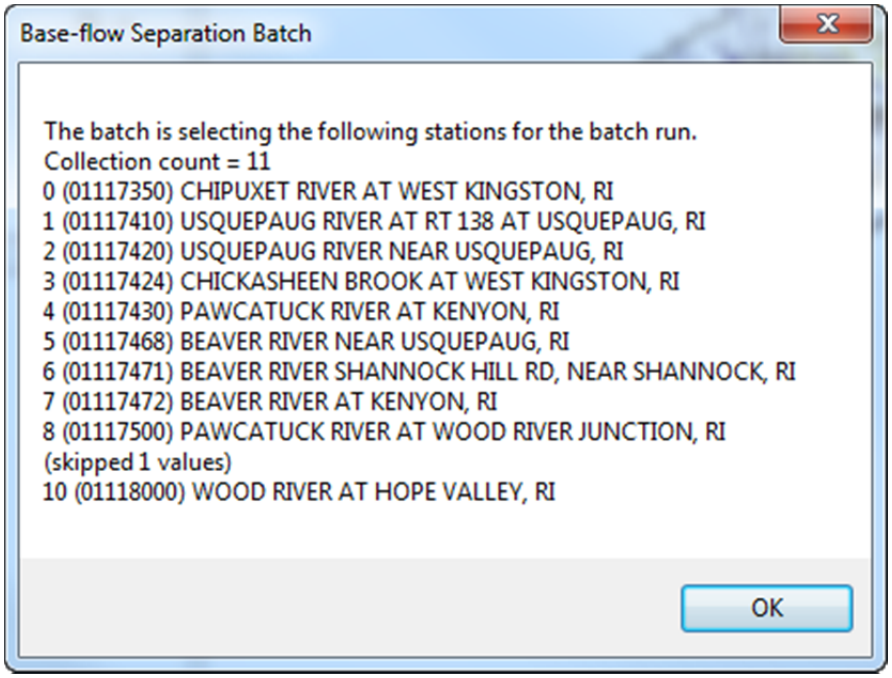
Finally, unlike previous versions of the GW Toolbox, the base-flow and runoff time series calculated by the hydrograph-separation methods are now directly available for analysis with other Toolbox functionalities, such as graphing, statistics, and trends analysis. Further discussion of this topic is provided in the tutorial titled "Updated Functionality for Analysis of Time-Series Data."

“Batch Map” Mode: To generate and execute a batch-run configuration file

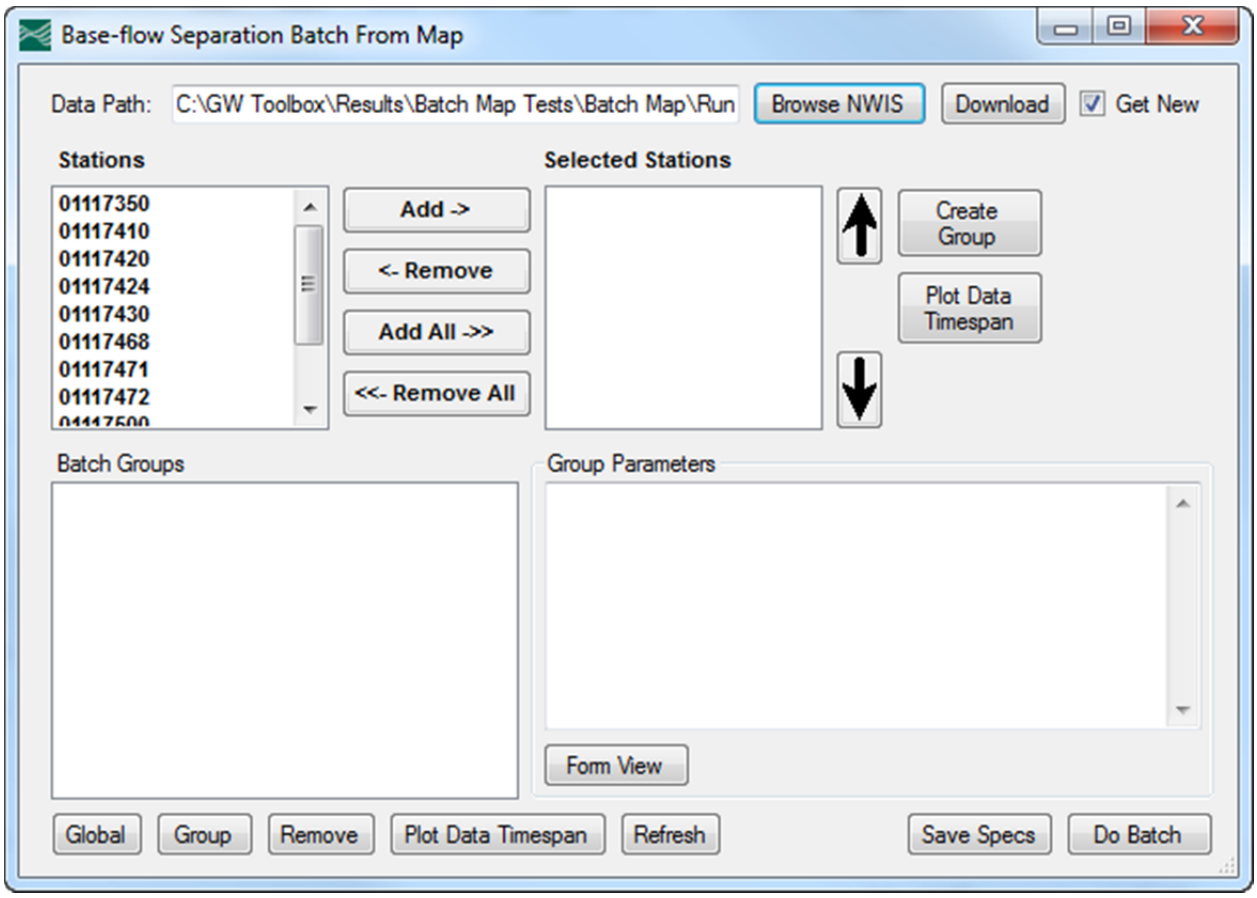
Two examples are provided to describe the process for generating a batch-run configuration file and, optionally, running the file within the “Batch Map” option. The first example assumes that the user has downloaded streamflow records for one or more stations in the working GW Toolbox project. The second example assumes that no data have been downloaded in the working project, but are either available on the user’s computer or will be downloaded on the basis of a list of station identifiers provided in an existing text file.

a. Streamflow records have been downloaded in the working project

In this example, data have been downloaded for eleven streamgaging stations within a GW Toolbox project and are available for analysis. Selecting “Batch Map” from the “**Base-Flow Separation Analysis**” dialog box brings up the following screen:

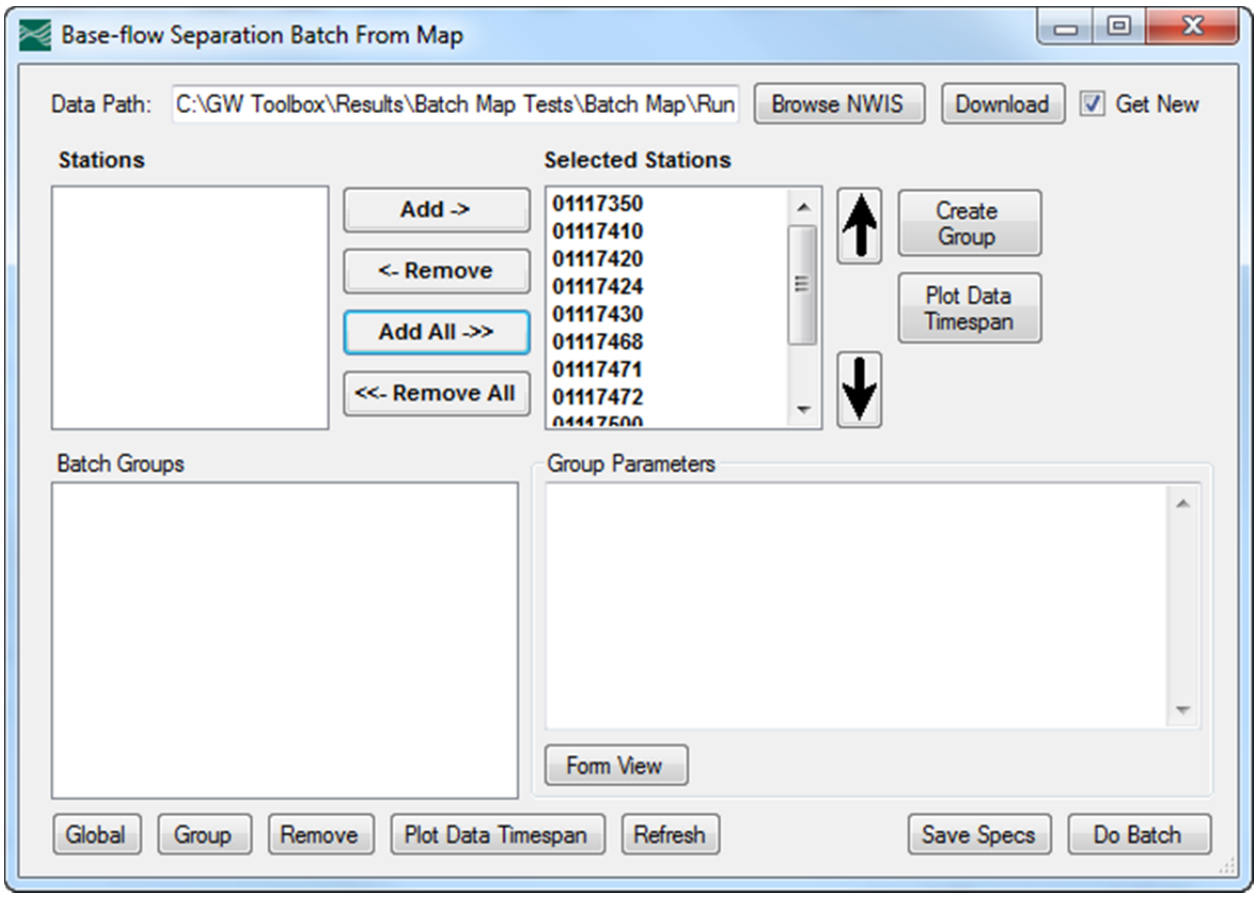


Click on “OK,” which bring up the “Batch Map” dialog box:

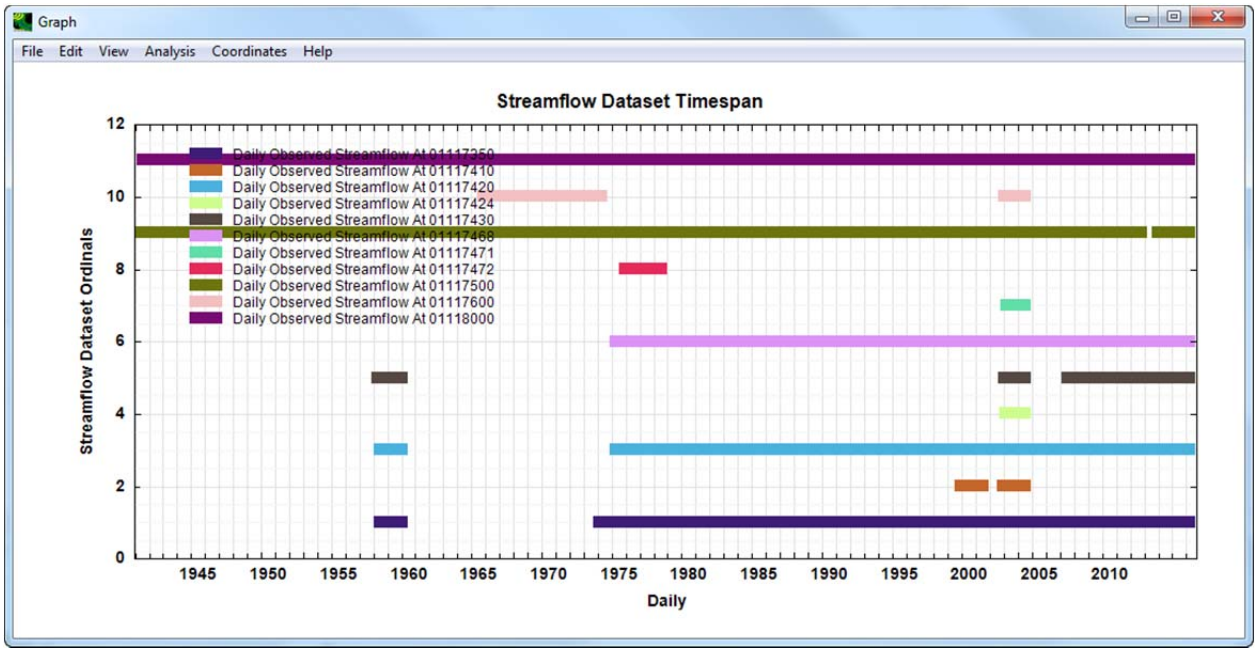


The user must first specify a “Data Path” into which the output files will be placed. The GW Toolbox will search your computer for existing, cached NWIS streamflow data, so it may be useful to check the ‘Get New’ button to ensure that the most up-to-date data will be downloaded for the analysis. Also, in this example an empty folder was created outside of the GW Toolbox with the name ‘Run 1’ under the path partially shown above. The user can now “Download” data for the eleven stations into a subdirectory named ‘NWIS’ in the Run 1 folder.

A useful first step for the analysis is to plot a graph of the timespans of the eleven records. This is done by adding all of the stations to the “Selected Stations” box using the “Add All->>” button, which gives:



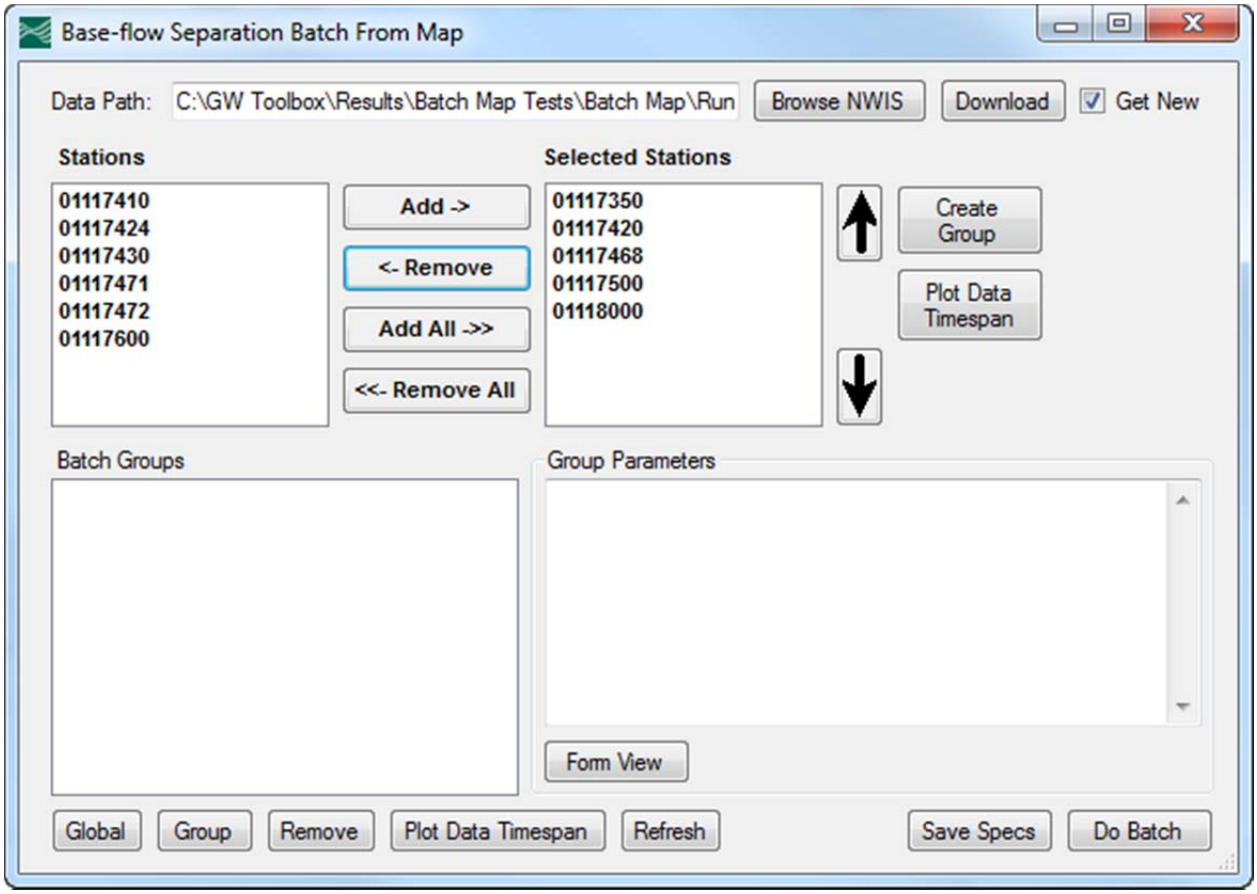
The user now clicks on "Plot Data Timespan," which gives the following graph:



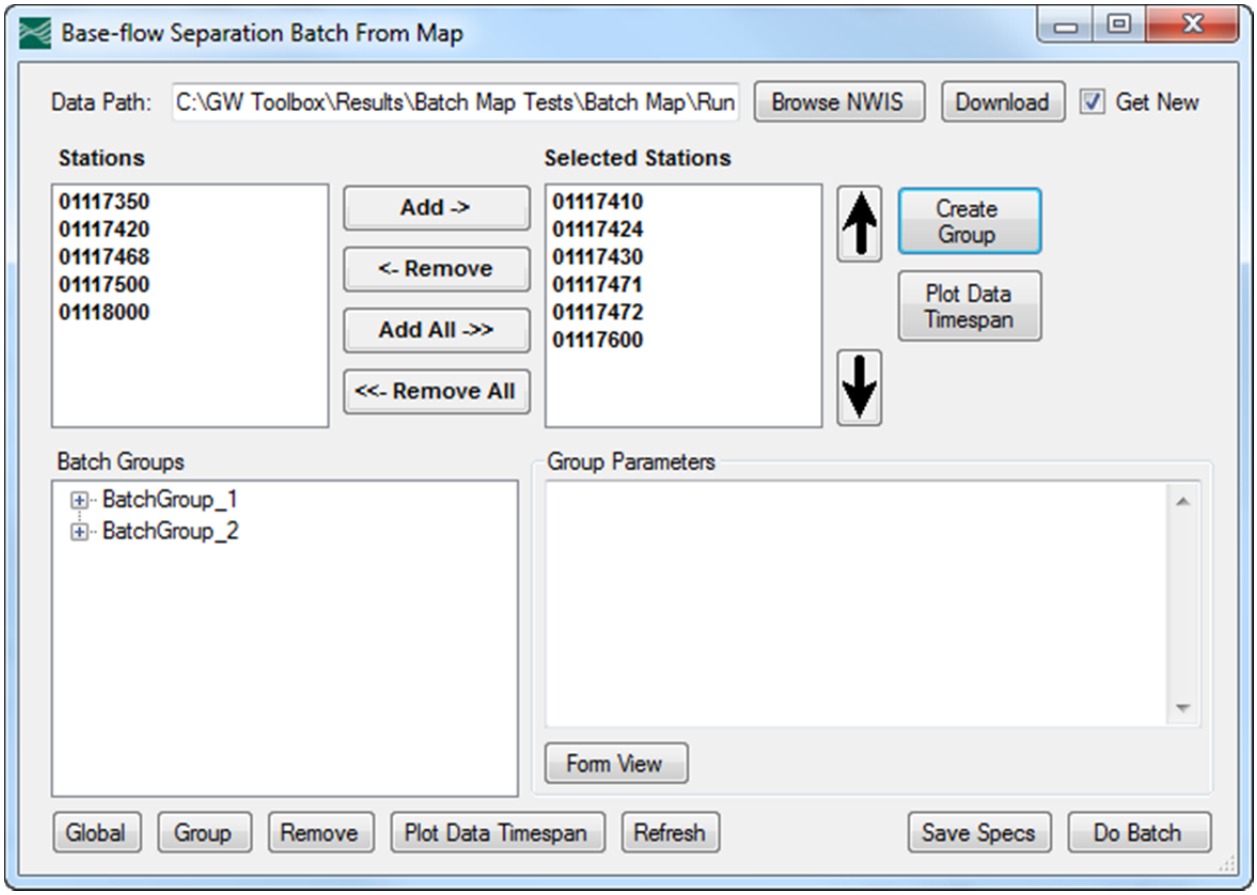
The graph provides a simple way to visualize the periods of record for the several gages within the study area; the user may want to organize different groups of stations on the basis of their record length.

For this example, the dataset of eleven records will be divided into two groups, the first with the five longest periods of record and the second with the remaining records.

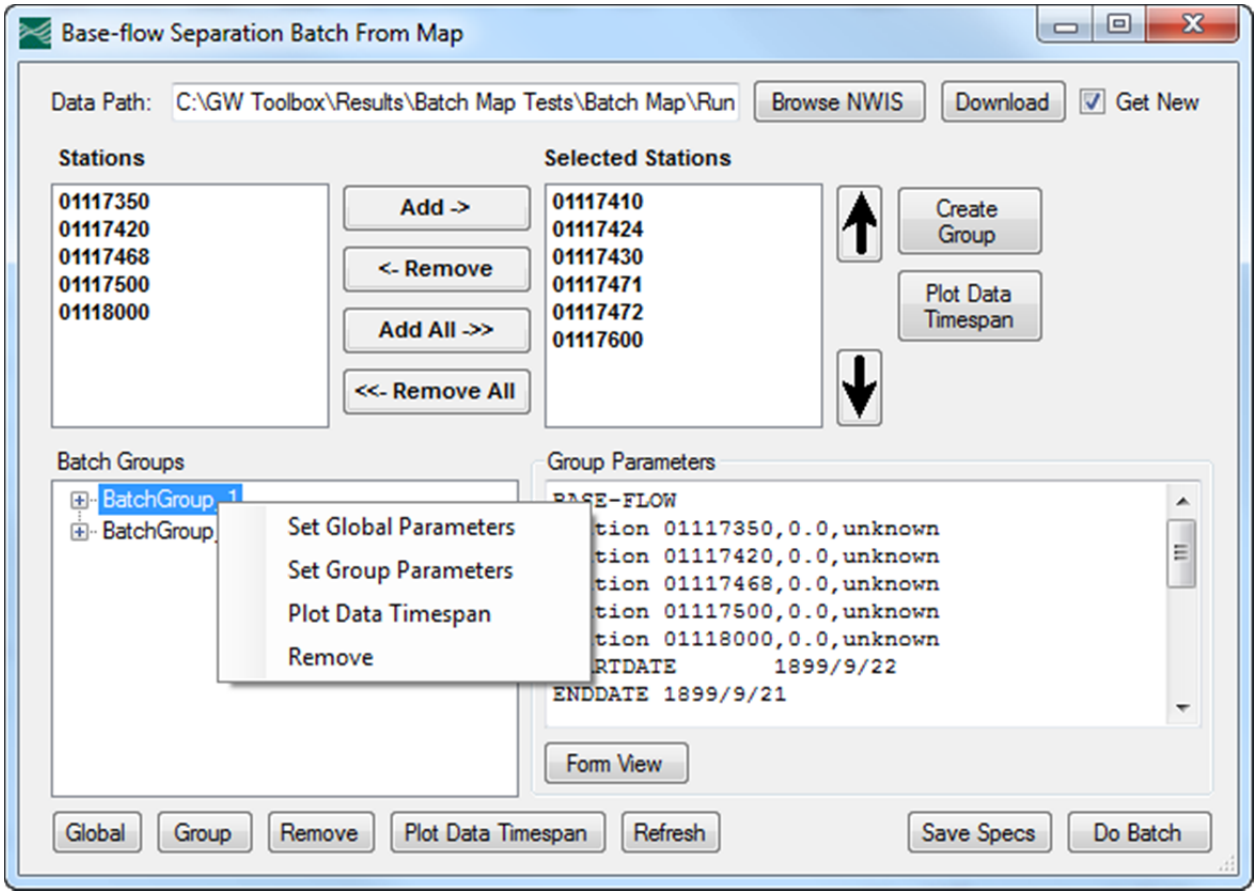
The first group is created by removing six records from the “Selected Stations” window, leaving the following:



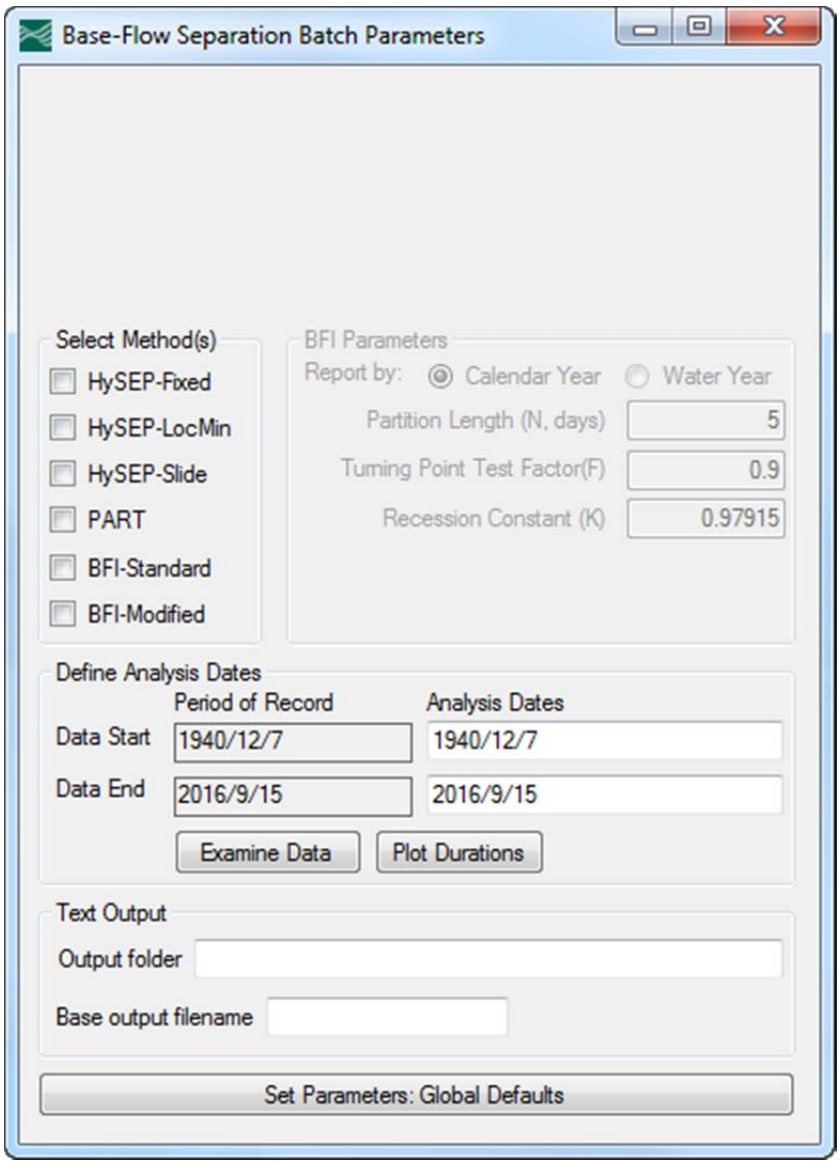
The user now selects the “Create Group” button, which creates a first Batch Group under the “Batch Groups” window. A second group is then created by removing the first five stations from the “Selected Stations” window and adding the remaining six stations. After creating the second group, the following dialog box results:



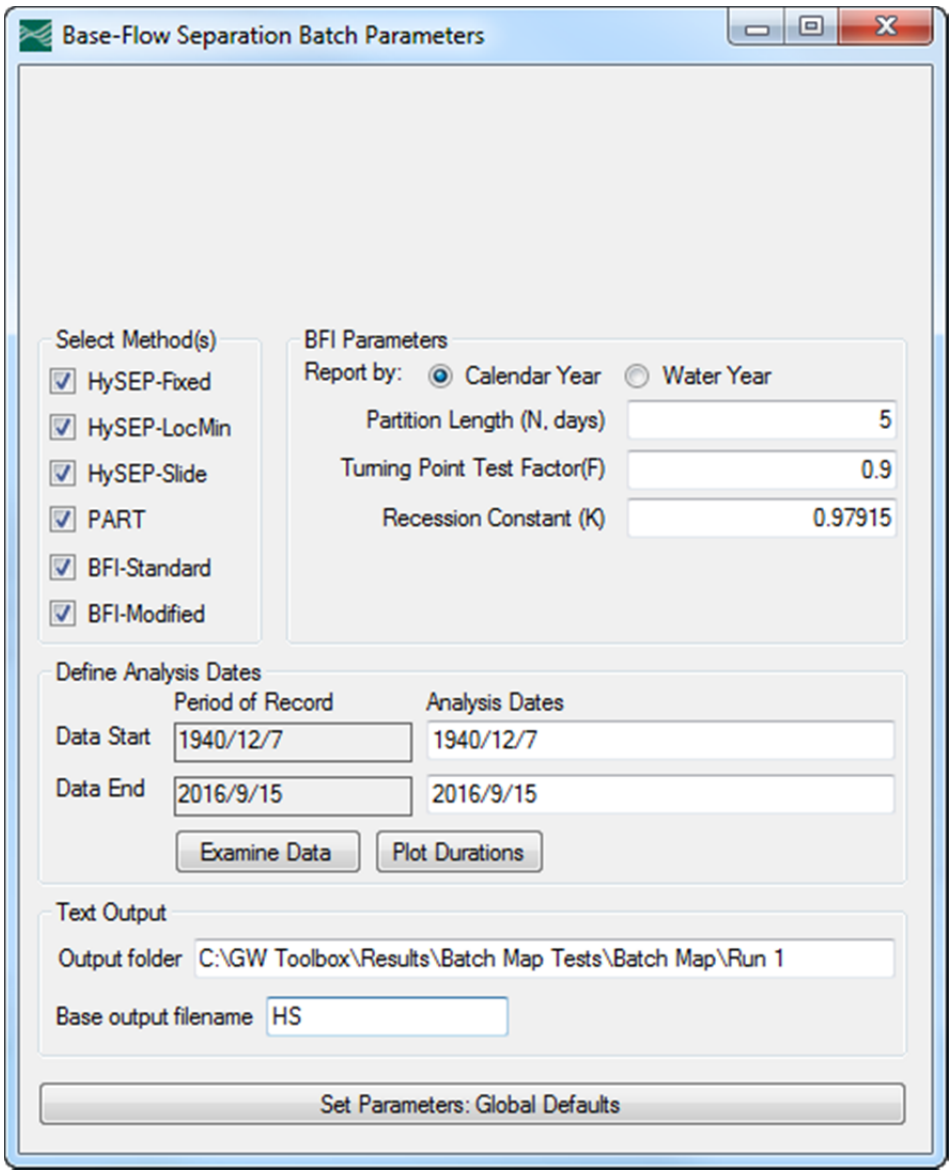
The user now needs to create a configuration file to run the batch process. There are two steps for creating this file: setting global parameters that apply to all stations that are analyzed and then setting group parameters for each group of stations. These steps are shown by right-clicking on either of the two Batch Groups:



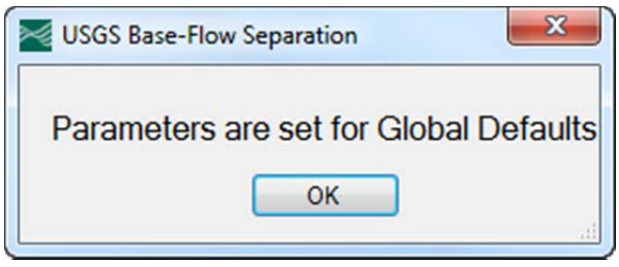
The first step is to select the 'Set Global Parameters' option, which results in the following screen:



Note that the GW Toolbox has identified the full time span of record for the eleven stations, November 27, 1940 through September 15, 2016. For this example, all hydrograph-separation methods will be selected, and the output folder identified:



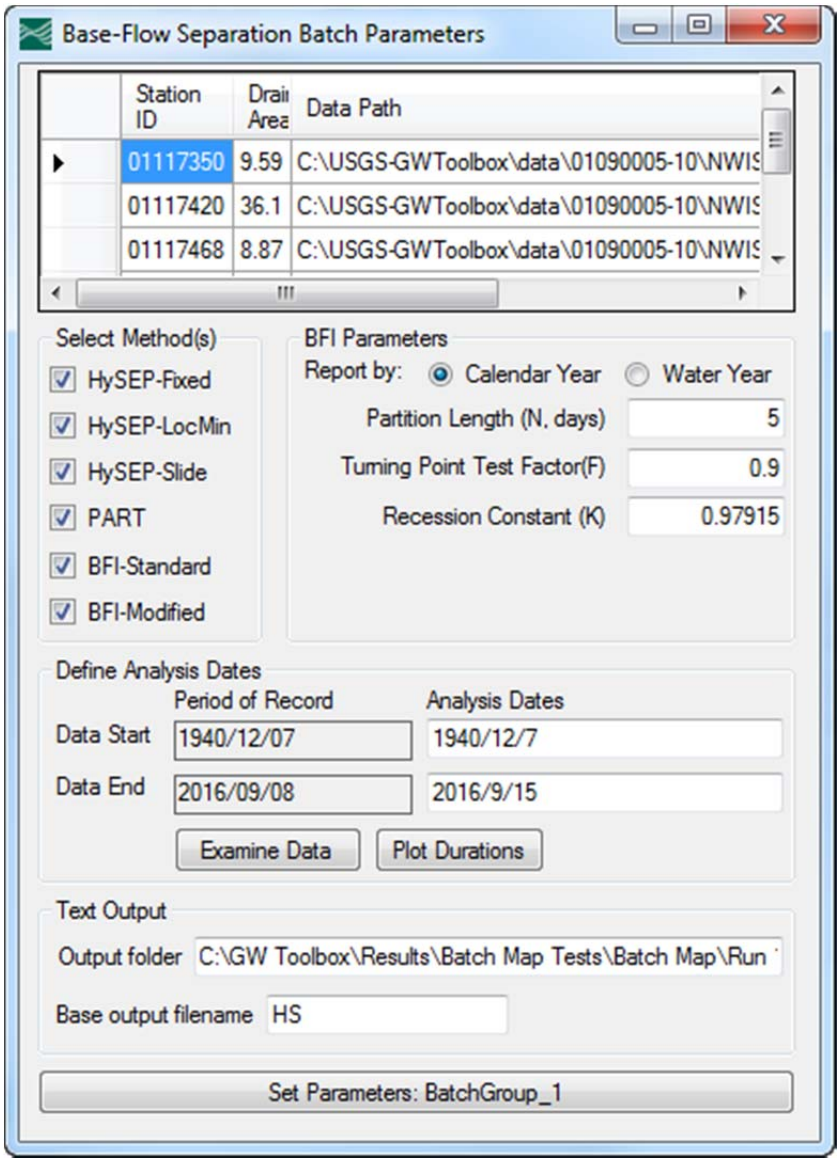
The user now clicks on 'Set Parameters: Global Defaults,' which results in



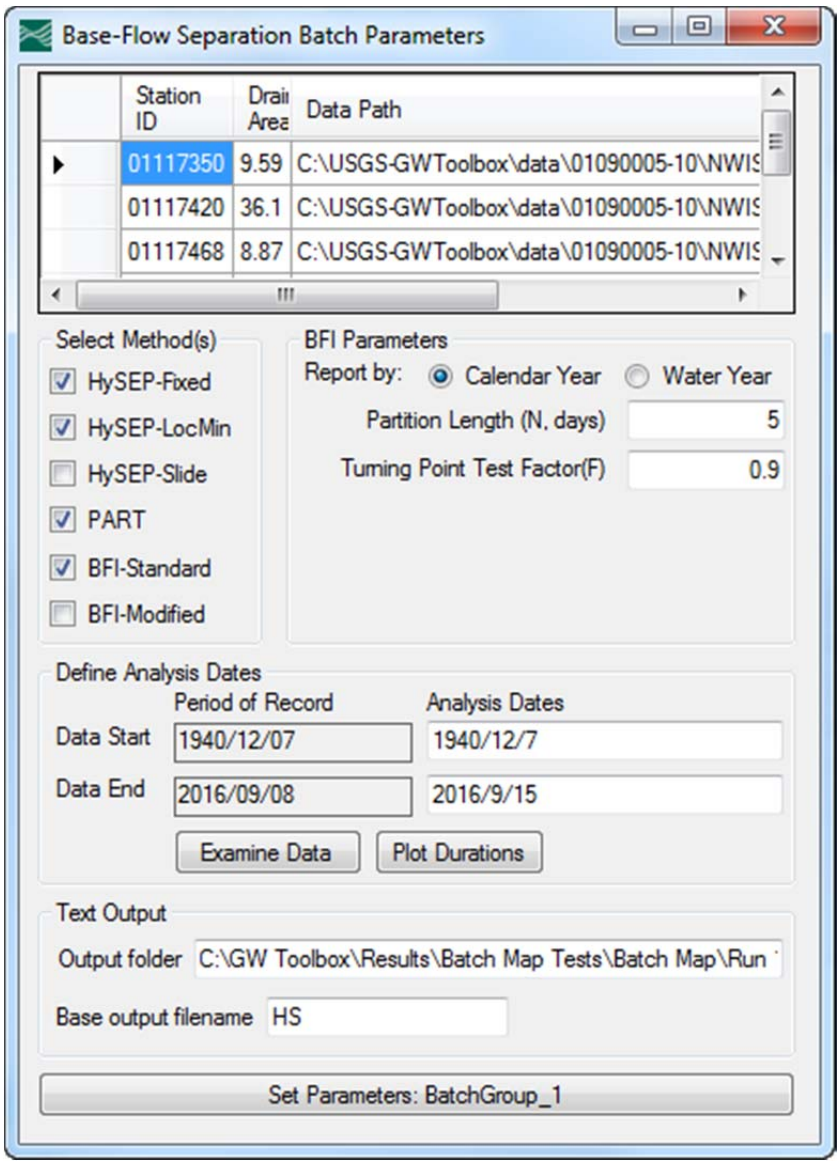
By hitting 'OK,' the user is returned to the main Batch-Map dialog box. If the user now selects 'Save Specs,' a configuration file is saved in the specified folder. In this example, the name of the file is 'BatchConfigBase-flowSep_9_15_2016 9_32_30 AM.txt.' At this point, default Group

Parameters have been defined for each of the two groups that are equivalent to those specified for the Global Parameters, and the user could procede to the “Do Batch” analysis.

However, for this example, the Group Parameters will be updated for each of the two groups. The Group Parameters screen is:



For this example, we will eliminate the HySEP-Slide and BFI-Modified options for each group (only the change to the first group is shown here):

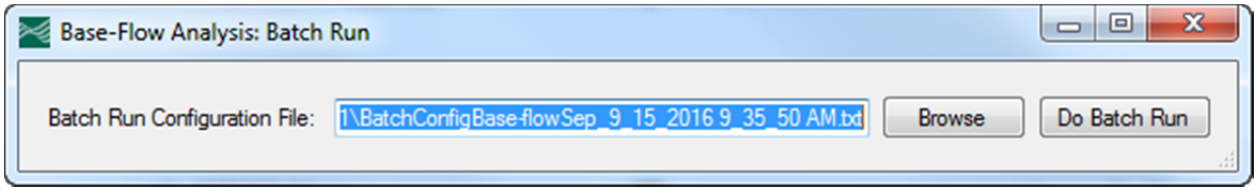


Now select 'Set Parameters: BatchGroup_1' and then 'OK' in the resulting screen, which returns the user to the main Batch-Map dialog box. After saving the specifications for each group modification, the resulting configuration file (now named 'BatchConfigBase-flowSep_9_15_2016 9_35_50 AM.txt') is as follows:

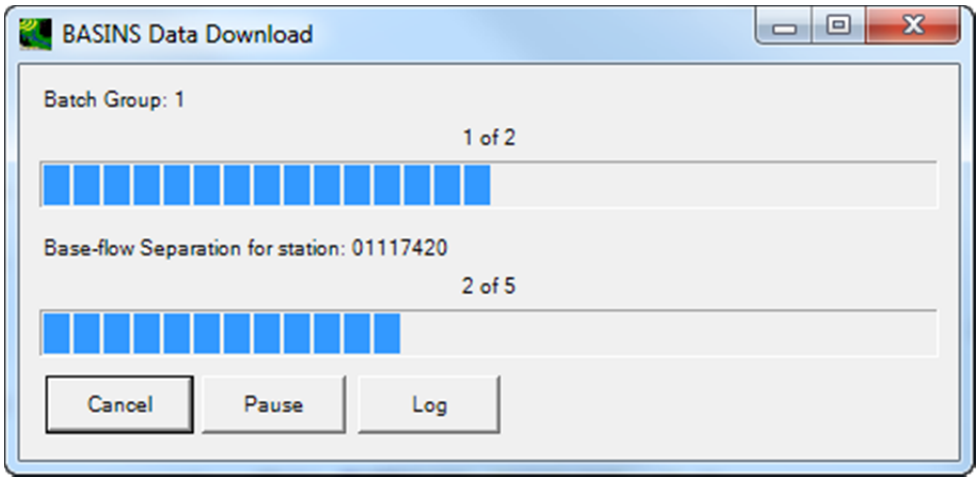
```
GLOBAL
STARTDATE       1940/12/7
ENDDATE         2016/9/15
BFMethod        PART
BFMethod        HYFX
BFMethod        HYLM
BFMethod        HYSL
BFMethod        BFIS
BFMethod        BFIM
BFI_TurnPtFrac  0.9
BFI_NDayScreen  5
```

```
BFI_RecessConst 0.97915
BFI_Reportby CY
DataDir C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 1
OUTPUTDIR C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 1
OUTPUTPrefix HS
END GLOBAL

BASE-FLOW
Station 01117350,9.59,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117350.rdb
Station 01117420,36.1,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117420.rdb
Station 01117468,8.87,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117468.rdb
Station 01117500,100,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117500.rdb
Station 01118000,72.4,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01118000.rdb
STARTDATE 1940/12/7
ENDDATE 2016/9/15
BFMethod PART
BFMethod HYFX
BFMethod HYLM
BFMethod BFIS
BFI_TurnPtFrac 0.9
BFI_NDayScreen 5
BFI_RecessConst 0.97915
BFI_Reportby CY
OUTPUTDIR C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 1
OUTPUTPrefix HS
END BASE-FLOW

BASE-FLOW
Station 01117410,32.75,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117410.rdb
Station 01117424,4.82,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117424.rdb
Station 01117430,72.7,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117430.rdb
Station 01117471,11.20,C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run
1\NWIS\NWIS_discharge_01117471.rdb
Station 01117472,11.70,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117472.rdb
Station 01117600,5.53,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117600.rdb
STARTDATE 1940/12/7
ENDDATE 2016/9/15
BFMethod PART
BFMethod HYFX
BFMethod HYLM
BFMethod BFIS
BFI_TurnPtFrac 0.9
BFI_NDayScreen 5
BFI_RecessConst 0.97915
BFI_Reportby CY
OUTPUTDIR C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 1
OUTPUTPrefix HS
END BASE-FLOW
```

The user now selects ‘Do Batch,’ which brings up the following ‘Batch Run’ dialog box:

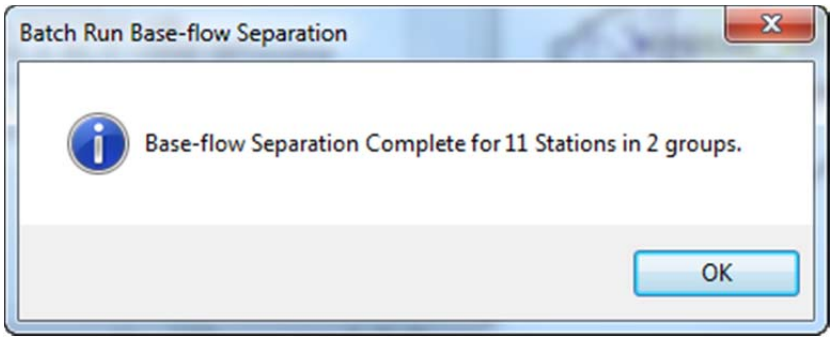


Notice that the most recent configuration file is listed in the file path. Alternatively, the user can search for another file to process. In this example, we’ll use the file that was just created, by selecting ‘Do Batch Run.’ The GW Toolbox will then complete the hydrograph-separation analyses, which might take a few minutes depending on the number of stations to process. As the analyses are being made, progress will be shown by a dialog box, such as the following:



Also, many output files will be written to the specified directory as the analyses are being done.

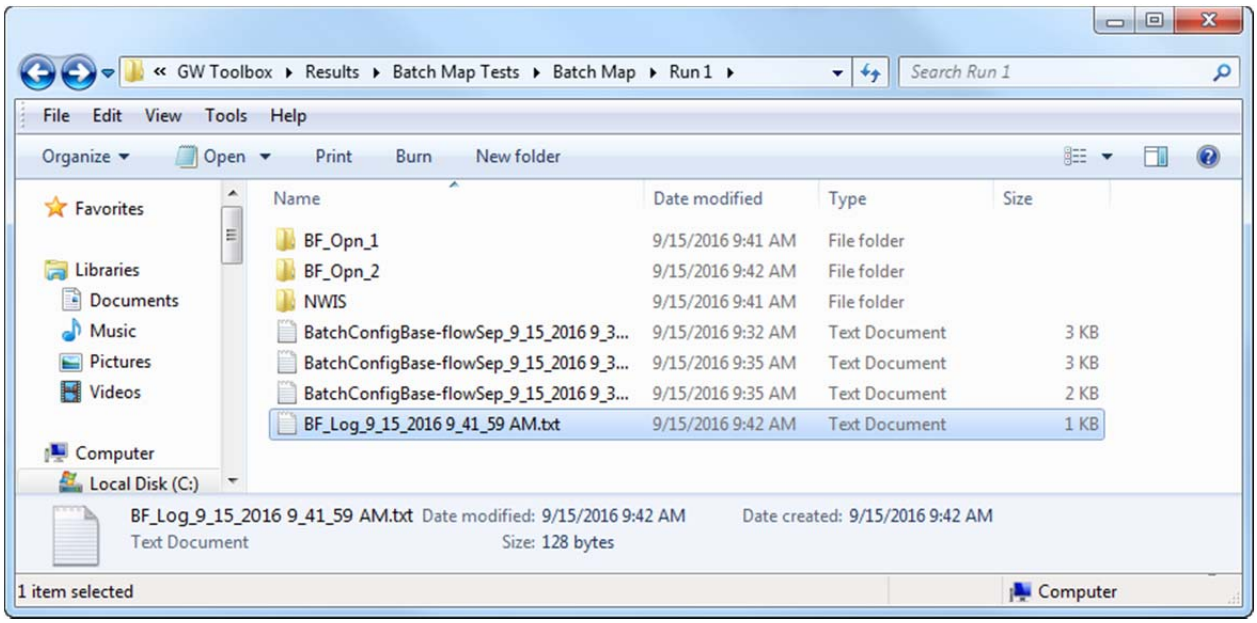
At completion, the following dialog box will be shown:



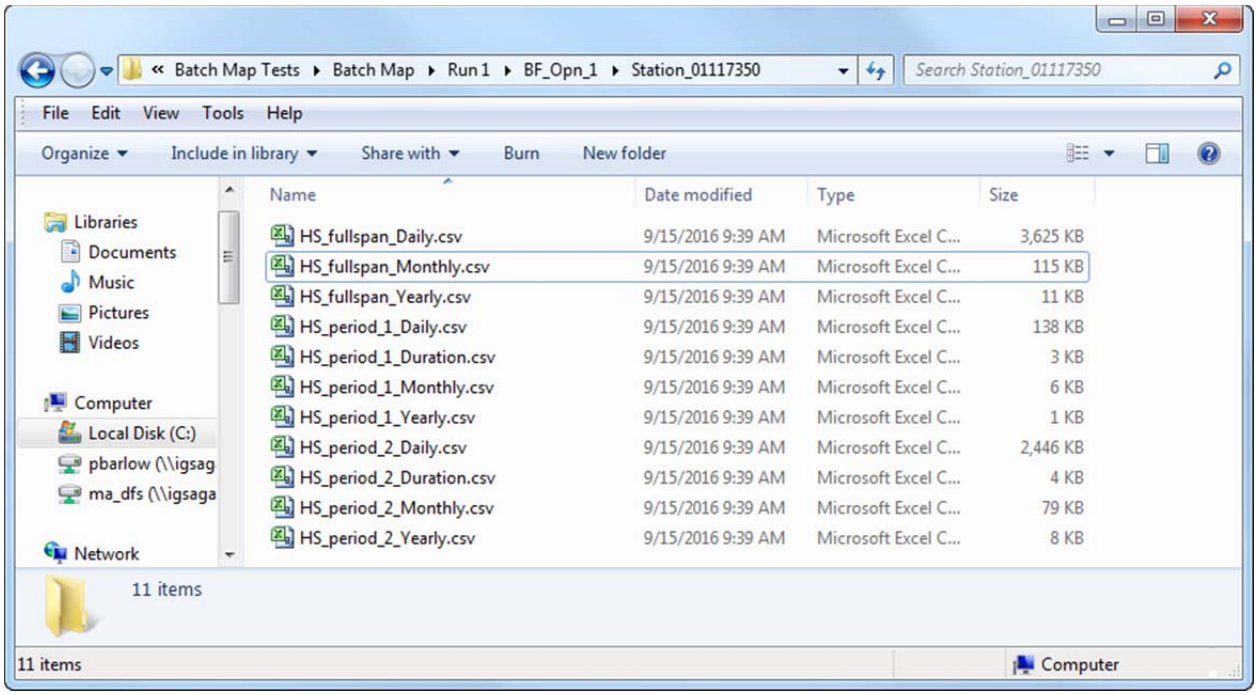
A log file also will be created in the output directory. The contents of the log file for this example run (‘BF_Log_9_15_2016 9_41_59 AM.txt’) indicates that both groups ran successfully:

Batch Run Group *** 1 ***
End Batch Run Group 1, Successful
Batch Run Group *** 2 ***
End Batch Run Group 2, Successful

The output for each station is arranged by group, as shown by the directory structure for this example:



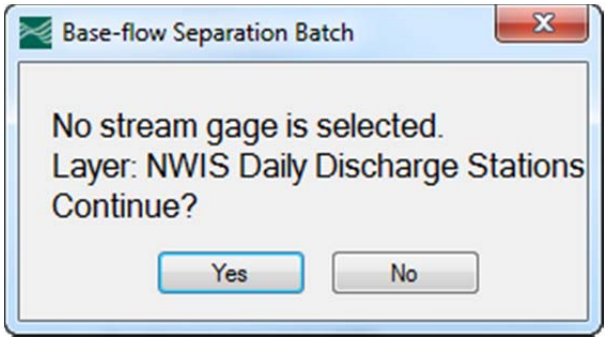
When running in 'Batch Mode,' the GW Toolbox only creates .csv files; the original files created by each of the hydrograph-separation methods are not written. This is shown for one of the stations analyzed for this example, which consists of two intermittent periods:



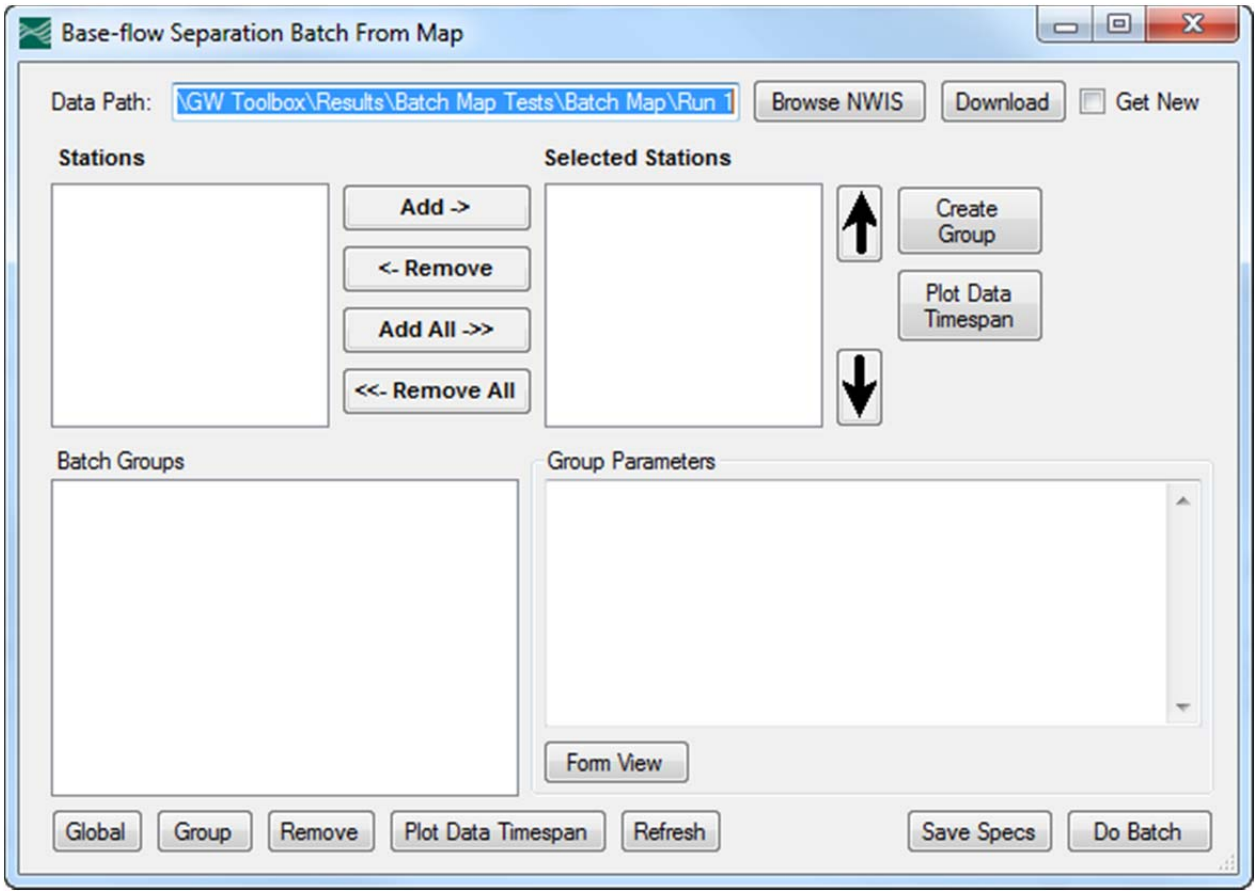
The 'fullspan' output files can be used to copy-and-paste columns for consistent time periods (that is, the full span of record for all stations analyzed) from multiple stations into one or more files.

b. Streamflow records are available on the user's computer or will be downloaded based on a "Stations.txt" file

In this example, a project has been created but no streamflow data have been downloaded into the project. Selecting "Batch Map" from the "**Base-Flow Separation Analysis**" dialog box brings up the following screen:

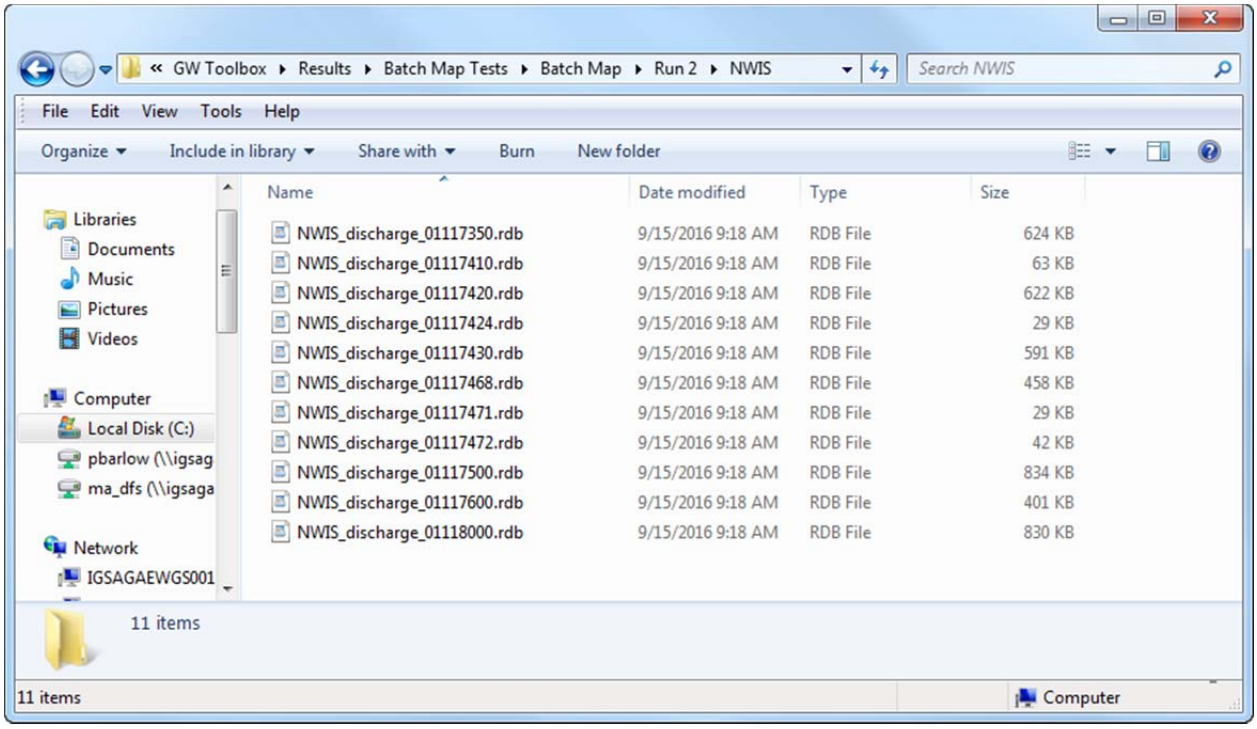


By selecting "Yes," the user will be directed to the "Batch Map" dialog box:

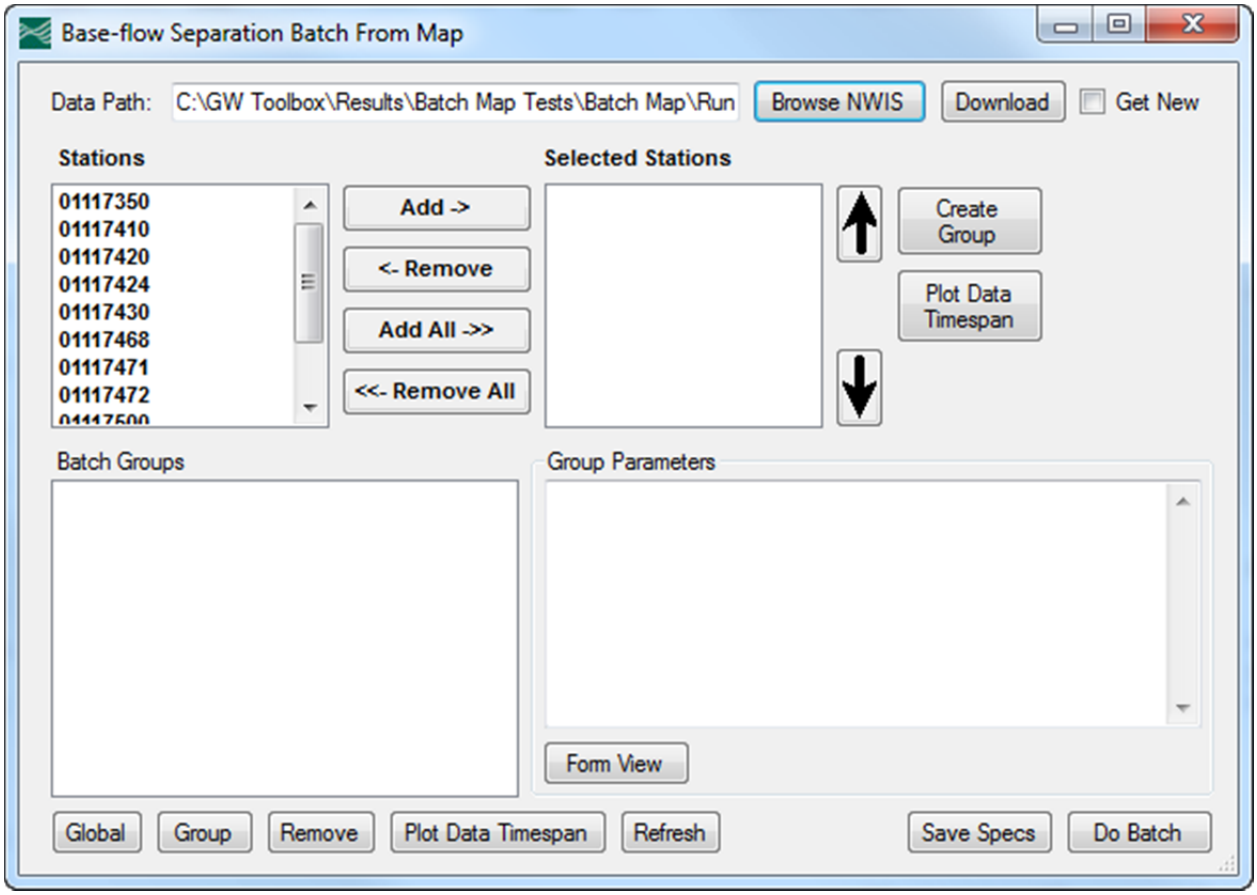


At this point, the user has two options:

Option 1: if the user selects “Browse NWIS,” they can navigate to a folder on their computer in which there is an existing “NWIS” subdirectory in which there are text relational database files (‘.rdb’) files of streamflow data. The program will then look at the file names in the folder and extract the 8-digit station identifiers for the stations found in the folder. For example, the user browses to subdirectory Run 2, and the program has searched the following “NWIS” subdirectory:



and found the eleven station identifiers that are now shown in the “Batch Map” dialog box:

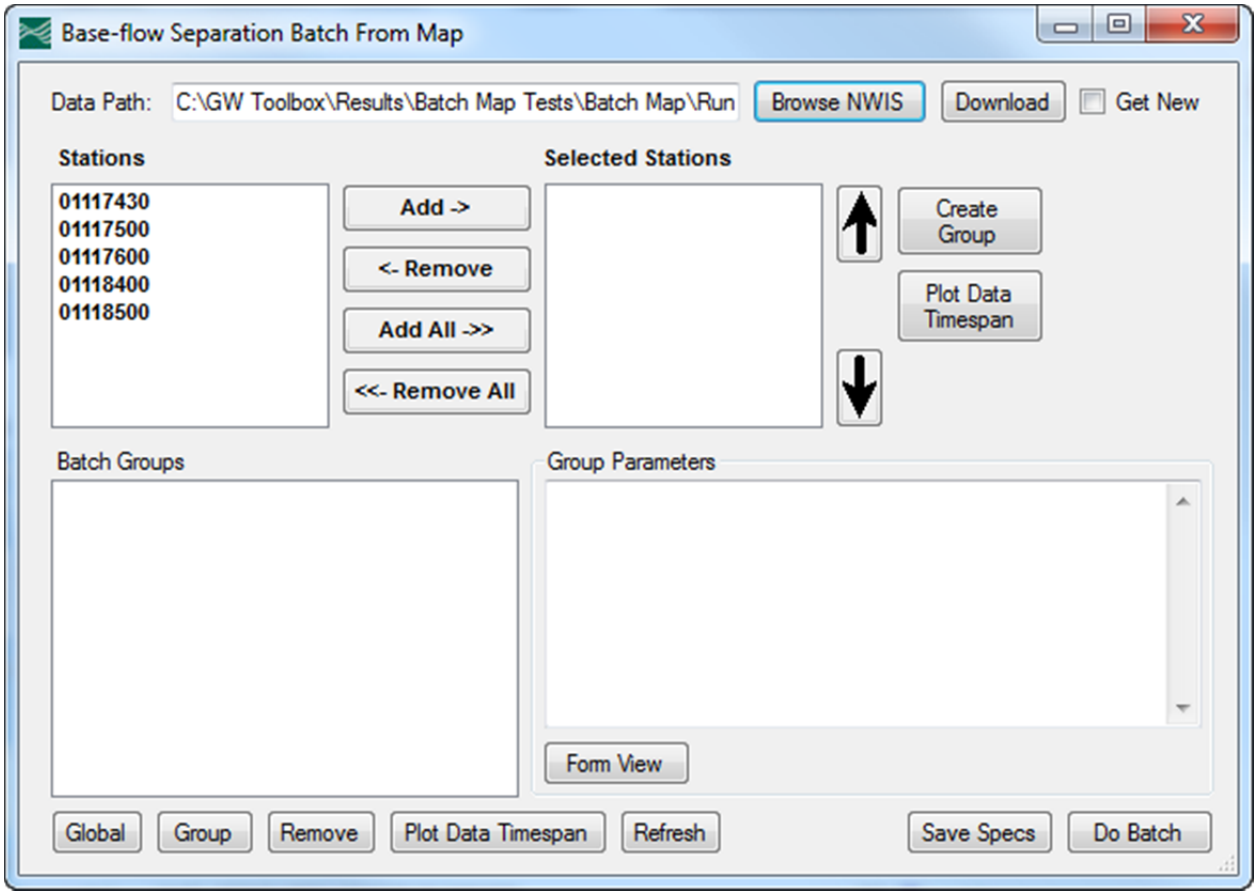


The data are now available for analysis (see subsection 'a.' beginning in the middle of page 7 of this tutorial).

Option 2: in the second approach, the user can create a list of USGS streamflow-gaging station identifiers in file 'Stations.txt,' which the program will use to download data. Each station identifier consists of numbers (typically, an 8-digit number), and only one station identifier can be listed per line. In this example, the text file 'Stations.txt' has been created in folder 'Run 3,' and includes 8-digit identifiers for the following five stations:

01117430
01117500
01117600
01118400
01118500

Now, by selecting "Browse NWIS," the user can direct the program to the 'Run 3' folder and the program will open and read the station identifiers into the 'Stations from map' window:



The user now checks the "Get New" option and then "Download" option to download new streamflow data for the gages of interest; these data will be stored in the 'NWIS' directory under the 'Run 3' folder.

The data are now available for analysis (see subsection 'a.' beginning in the middle of page 7 of this tutorial).

"Batch File" Mode: Running an existing configuration file

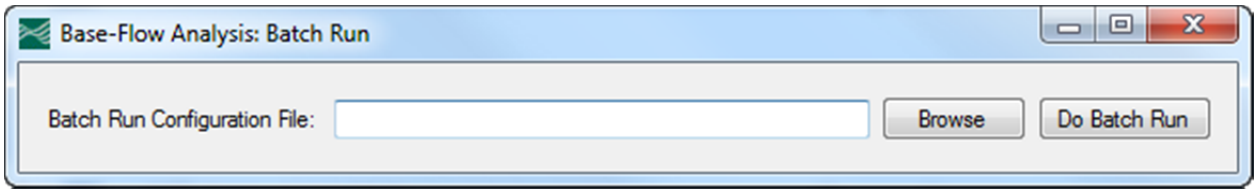
Once a user has created configuration files, they can be modified using a text editor and then rerun within the GW Toolbox.

For example, we may want to adjust the start and end dates of analysis for the stations analyzed in the previous section of this document to include only 1971-2000, and then save the output to a different directory ('Run 4'). This can be done by modifying the existing configuration file ('BatchConfigBase-flowSep_9_15_2016 9_35_50 AM.txt'). (Note: the file must be saved as a plain-text document, such as in WordPad). A portion of the revised configuration file is:

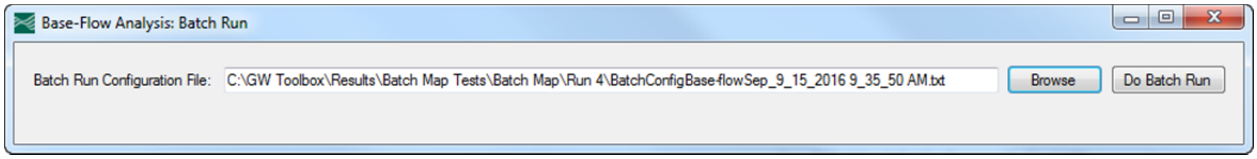
```
GLOBAL
STARTDATE       1940/12/7
ENDDATE         2016/9/15
BFMethod        PART
```

```
BFMethod        HYFX
BFMethod        HYLM
BFMethod        HYSL
BFMethod        BFIS
BFMethod        BFIM
BFI_TurnPtFrac  0.9
BFI_NDayScreen  5
BFI_RecessConst 0.97915
BFI_Reportby    CY
DataDir  C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 4
OUTPUTDIR       C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 4
OUTPUTPrefix    HS
END GLOBAL

BASE-FLOW
Station  01117350,9.59,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117350.rdb
Station  01117420,36.1,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117420.rdb
Station  01117468,8.87,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117468.rdb
Station  01117500,100,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01117500.rdb
Station  01118000,72.4,C:\USGS-GWToolbox\data\01090005-10\NWIS\NWIS_discharge_01118000.rdb
STARTDATE       1971/01/01
ENDDATE         2000/12/31
BFMethod        PART
BFMethod        HYFX
BFMethod        HYLM
BFMethod        BFIS
BFI_TurnPtFrac  0.9
BFI_NDayScreen  5
BFI_RecessConst 0.97915
BFI_Reportby    CY
OUTPUTDIR       C:\GW Toolbox\Results\Batch Map Tests\Batch Map\Run 4
OUTPUTPrefix    HS
END BASE-FLOW
```

Now, within the GW Toolbox, select the 'Batch File' option from the 'Base-Flow Separation Analysis' dialog box, which results in the following dialog box:



The user can now browse to the existing configuration file:



and then select 'Do Batch Run.' Output files for the time span (1971-2000) are then written to the 'Run 4' folder specified in the configuration file. Note that three of the stations analyzed here did not have any data within the 1971-2000 time period, which is noted in the log file:

```
Batch Run Group ***  1  ***
End Batch Run Group 1, Successful
Batch Run Group ***  2  ***
---- Station: 01117424----
No flow data within the analysis duration (1971/01/01-2000/12/31), hence no fullspan outputs.
-------------------------------------------
---- Station: 01117430----
No flow data within the analysis duration (1971/01/01-2000/12/31), hence no fullspan outputs.
-------------------------------------------
---- Station: 01117471----
No flow data within the analysis duration (1971/01/01-2000/12/31), hence no fullspan outputs.
-------------------------------------------
End Batch Run Group 2, Successful
```

otherwise, the batch-file run is successful.

In some cases the drainage area of a streamgage site that is reported on the USGS NWISWeb is inconsistent with other information that is available for the site, or two drainage areas are listed that reflect the contributing drainage area to the gage for different hydrologic conditions. In such cases, the user may want to modify the drainage area to the gage that is read from NWISWeb and stored in the RDB (relational data base) for the gage. This is done by modifying the configuration file. In a batch-file run, the GW Toolbox will use the drainage area specified in the configuration file by default. For example, in the configuration file shown above, the drainage area for station 01117500 is shown as 100 square miles, which is the value stored in NWISWeb. The user can change that value if needed and rerun the configuration file with the new specified value. The value specified for the drainage area will have two effects on the calculations: the duration of surface runoff (see equation 1 in TM 3-B10) and the flow rates over the drainage area. Of these two, the effects on the duration of surface runoff may be relatively small, depending on the differences between the value of drainage area for the basin stored in NWISWeb and that specified by the user in the configuration file.