LOW FLOW STATISTICS TOOLS

A How-To-Handbook for NPDES Permit Writers

Second Edition

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1 An Introduction to Low Flow Statistics and This Handbook

1.1 Who Is the Intended Audience for This Handbook?

National Pollutant Discharge Elimination System (NPDES) permit writers often need to calculate low flow statistics for reasonable potential analyses and water quality-based effluent limitation (WQBEL) calculations or to confirm estimates provided by the permittee during the NPDES permit development process. The typical calculation procedures for low flow statistics are complex and cumbersome to execute by hand or with spreadsheet-based tools. However, several software applications that greatly simplify this process are available to permit writers. The purpose of this handbook is to help permit writers estimate low flow statistic values in a variety of situations using these free, publicly available tools.

1.2 What Is a Low Flow Statistic?

Low flow statistics are estimates of the lowest flow event in a stream or river that would be expected to occur over some period of record. NPDES permit writers typically use these estimates when authorizing a regulatory mixing zone and associated dilution credits or dilution factors for use in reasonable potential analyses and/or WQBEL calculations. As described in Section 3.2 of EPA's *Technical Support Document for Water Quality-based Toxics Control* (hereafter, the Technical Support Document), EPA recommends that authorized dilution credits reflect the behavior of a permitted discharge as it mixes with the receiving water. In flowing rivers and streams, dilution credits are based on the critical conditions of the receiving water, which are typically defined in the applicable water quality standards (e.g., 7Q10 receiving water flow). Critical conditions are conservatively based on receiving water low flow estimates to ensure the discharge does not cause or contribute to an excursion above water quality standards.

Most permitting authorities use either the term "credit" or "factor" to refer to the level of dilution authorized in a permit. For convenience, this document primarily uses the term "dilution credit," but both are equally valid terms.

Low flow values are defined on a hydrologic design or biological design basis. Both are equally acceptable for use in NPDES permitting. Low flow values are expressed in terms of their averaging period (for example, a 4-day average flow or a 7-day average flow) and their recurrence frequency (generally once in 10 years for hydrologically based flows and once in 3 years for biologically based flows).

A hydrologically based low flow is computed using the single lowest flow event from each year of record, followed by application of distributional models (typically the Log Pearson Type III distribution is assumed) to infer the low flow value. The 1Q10 is the lowest one-day average flow that occurs (on average) once every 10 years. The 7Q10 is the lowest 7-day average flow that occurs (on average) once every 10 years.

A biologically based low flow is computed based on all low flow events within a period of record, even if several occur in one year, and reflects the empirically observed frequency of biological exposure during a period of record. The 4B3 is the lowest four-day average flow that occurs once every three years. The 1B3 is the lowest one-day average flow that occurs once every three years.

1.3 What Topics Does This Handbook Cover?

Section 2: Investigate the Watershed—Are there stream gages in the watershed of interest? Where are they and are they useful to the permit writer? This section will provide the permit writer with strategies for finding and evaluating appropriate streamflow data sources using the StreamStats web application.

Section 3: Estimating Low Flow Statistics with Hydrologic Toolbox and WREG—After exploring the watershed and identifying the available data sources, this section will guide permit writers with tips for loading data and managing settings to obtain the low flow estimates needed for NPDES permit development.

Section 4: Frequently Asked Questions—This section will answer some questions that arise frequently when permit writers estimate low flow statistics.

1.4 What Software Tools Are Discussed in This Handbook?

This handbook will discuss three pieces of software: StreamStats, Hydrologic Toolbox, and WREG. The U.S. Geological Survey (USGS) distributes all three of these publicly available tools on the web.

StreamStats

StreamStats (version 4) is a web application that provides access to an assortment of geographic information system (GIS) analytical tools that are useful for water resources planning and management, as well as engineering and design purposes. StreamStats is an excellent tool for mapping and exploring the drainage area and stream gages near a discharge location of interest. The StreamStats web application can be accessed at: https://water.usgs.gov/osw/streamstats/

Hydrologic Toolbox

Hydrologic Toolbox is a desktop application that builds upon past tools, such as SWSTAT, DFLOW, and SWToolbox, which permit writers have historically used to estimate low flow statistics from stream gage data. Hydrologic Toolbox allows users to compute n-day frequency analyses (i.e., 1Q10 or 7Q10) and biologically based flows. It also facilitates the use of USGS National Water Information System (NWIS) streamflow data, as well as user-provided data files. The Hydrologic Toolbox desktop application can be downloaded at:
https://www.sciencebase.gov/catalog/item/6197980bd34eb622f692b481

WREG

WREG is a desktop application that is used to develop a regional estimation equation for streamflow characteristics (e.g., low flow values). Users can apply these estimates at ungaged basins, or use them to improve the corresponding estimate at continuous-record streamflow gages with short records. The regional estimation equation results from a multiple-linear regression that relates observable basin characteristics, such as drainage area, to streamflow characteristics. The desktop application and additional supporting documentation for WREG can be downloaded at:
https://water.usgs.gov/software/WREG/

1.5 When Should I Use Each of These Tools?

When deciding which of these tools to use and when to use them, you should consider:

- The specific need you are attempting to address.

- The data and information available to you.
- The uses of the tools at your disposal.

Figure 1 displays a decision tree flowchart to help you evaluate these questions and pick the right tool for the job.

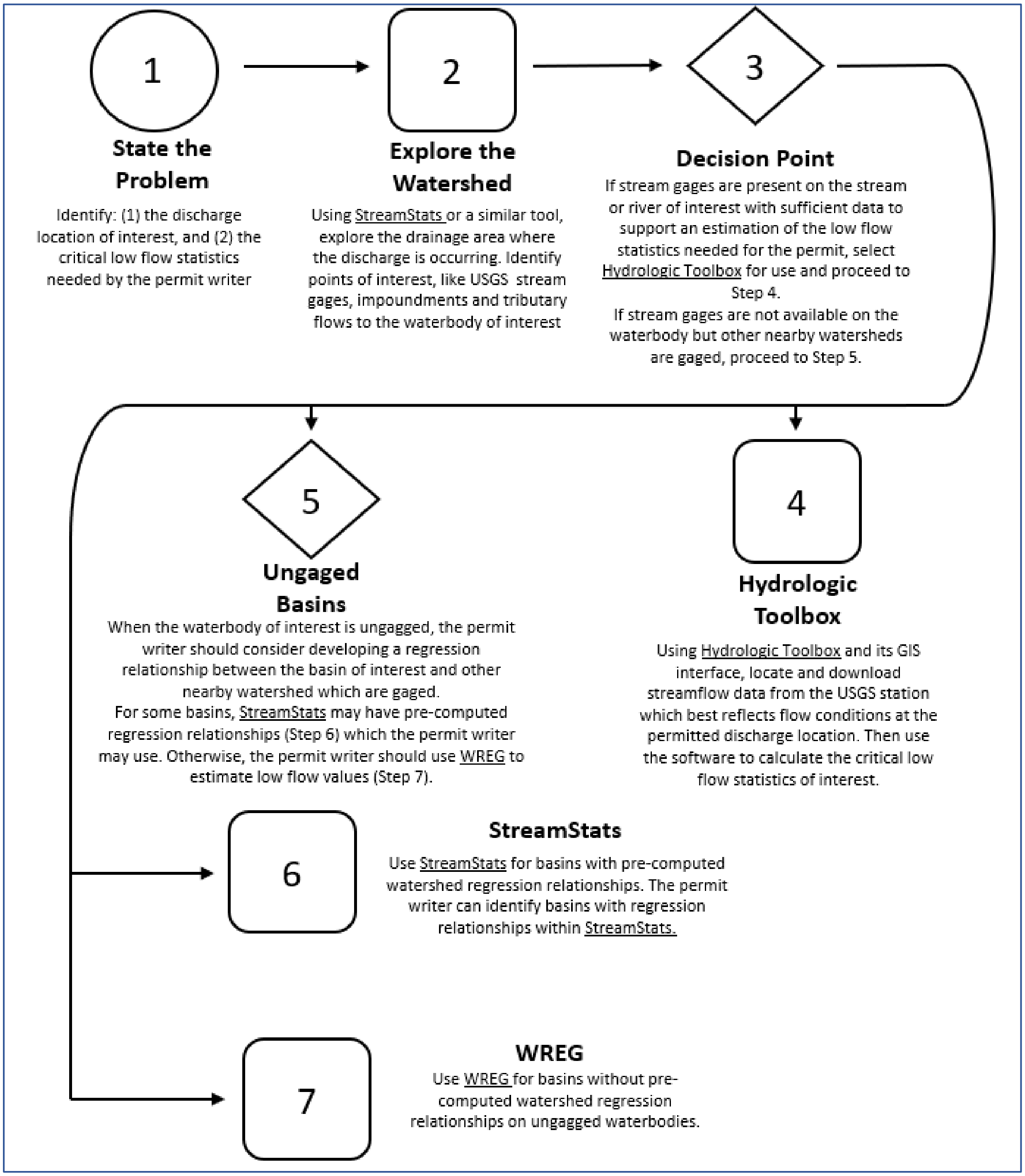


Figure 1. A decision tree for evaluating which tool to use when calculating low flow statistics.

2 Investigating the Watershed

2.1 Introduction

Your first step when estimating low flow statistics during the permit writing process is to take stock of the character and quantity of information available to you. You should identify the following pieces of information:

- The location of the permitted discharge for which you are seeking a dilution credit authorization.
- The availability, location, and proximity of any flow gages upstream or downstream of the discharge location.
- The presence and location of any impoundments, tributaries, water withdrawals, other discharges, or other factors that might influence the quantity of flow occurring at the discharge location.
- The availability of flow gages within nearby drainage basins if the stream segment where the discharge is occurring is ungaged.

In addition, once you identify stream gages, you should evaluate the quality and quantity of historical flow data available for estimating low flow values.

Several tools are available to help locate USGS flow gages and explore the watershed. The principal tool discussed in this section is USGS's StreamStats web application. However, you may also find the following alternative resources useful:

- USGS's NWIS website provides direct links to a variety of USGS monitoring sites—including streamflow gages—through a searchable map interface at: https://nwis.waterdata.usgs.gov/nwis
- Hydrologic Toolbox also includes a GIS interface allowing users to visually explore a watershed and identify potentially useful stream gage locations.
- Commercial satellite imagery and mapping software (e.g., Google Earth or similar) may be useful for locating the permitted discharge outfall on the waterbody of interest and for identifying other points of interest.

StreamStats provides a GIS interface like that of the NWIS website, but also provides additional mapping and drainage area delineation tools that may be useful. You can access StreamStats online at https://water.usgs.gov/osw/streamstats/ by selecting the "StreamStats Application" button on the navigation bar.

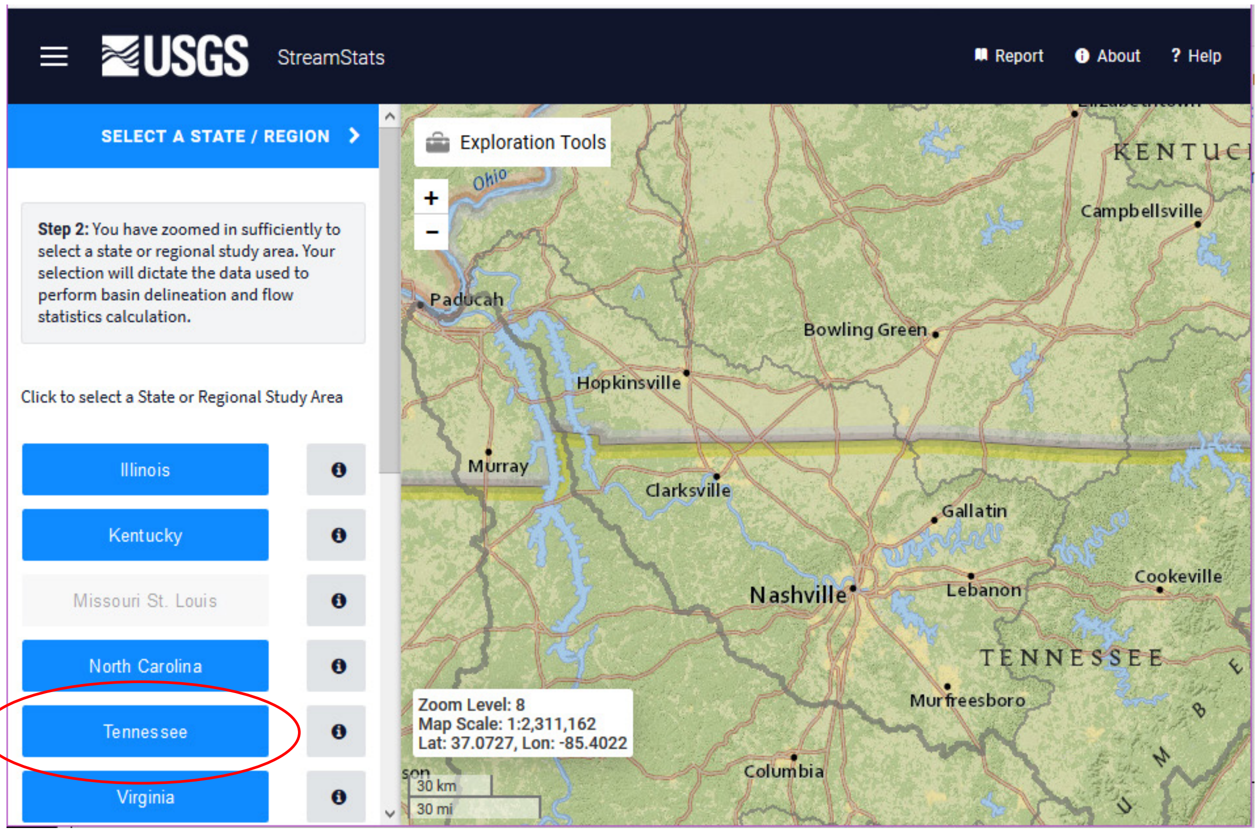
2.2 Step-by-Step Instructions for Exploring with StreamStats

Next, let's discuss some step-by-step instructions a permit writer can use when investigating the watershed with StreamStats. Illustrations accompany the instructions, which you can use to follow along on your own computer. The illustrations depict the process of locating potential stream gages for the

Cookeville Wastewater Treatment Plant located at 1870 South Jefferson Ave., Cookeville, Tennessee. The plant discharges to Pigeon Roost Creek, which is a tributary to the Falling Water River.

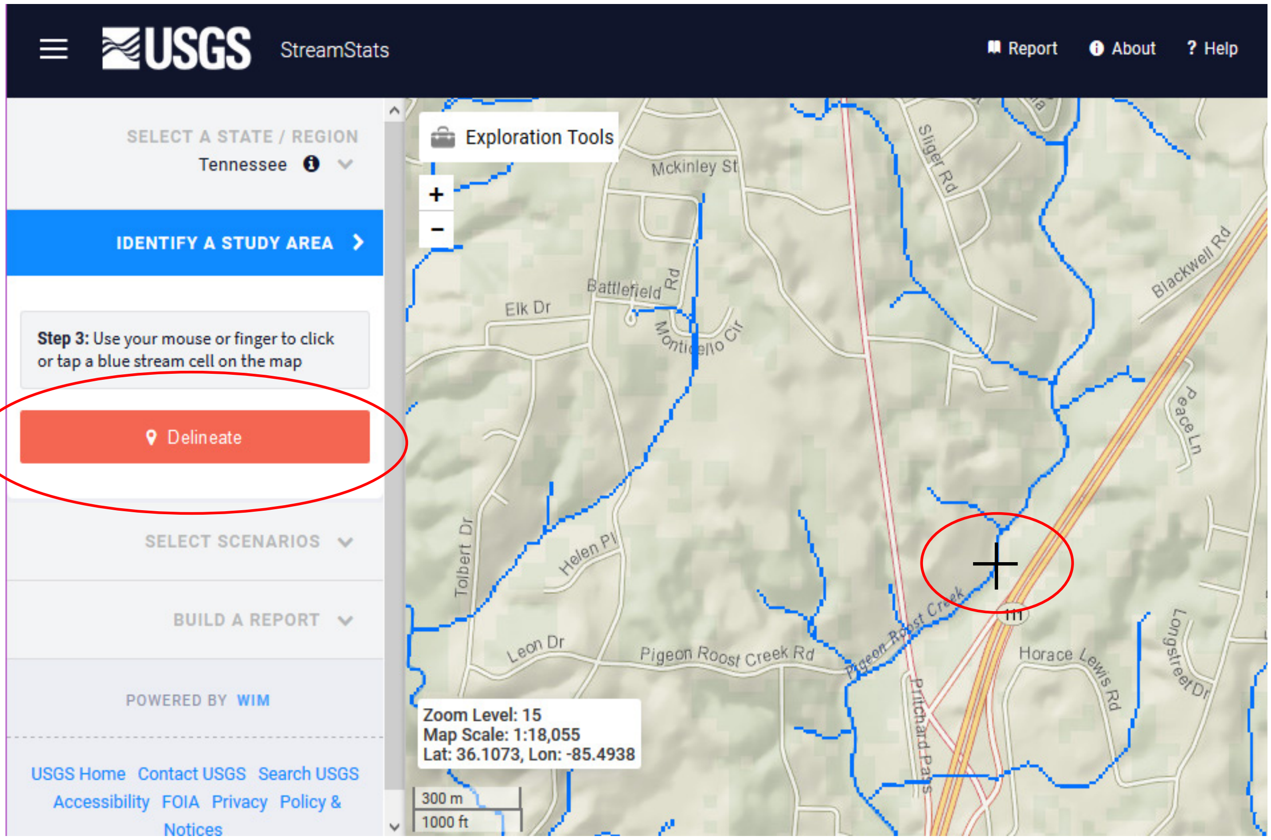
Step 1 After opening the web application, search for a location of interest in the search bar. You can search using a street address or latitude and longitude coordinates for the facility.

Step 2 Select the appropriate "State or Regional Study Area" that is presented in the search window. If an appropriate option does not appear, you should revisit the location information used in the search and verify its accuracy, or try using different search information.



Step 3 Navigate to the discharge location of interest and zoom in until the stream network data layer (i.e., a pixelated, blue tracing of the local stream) appears.

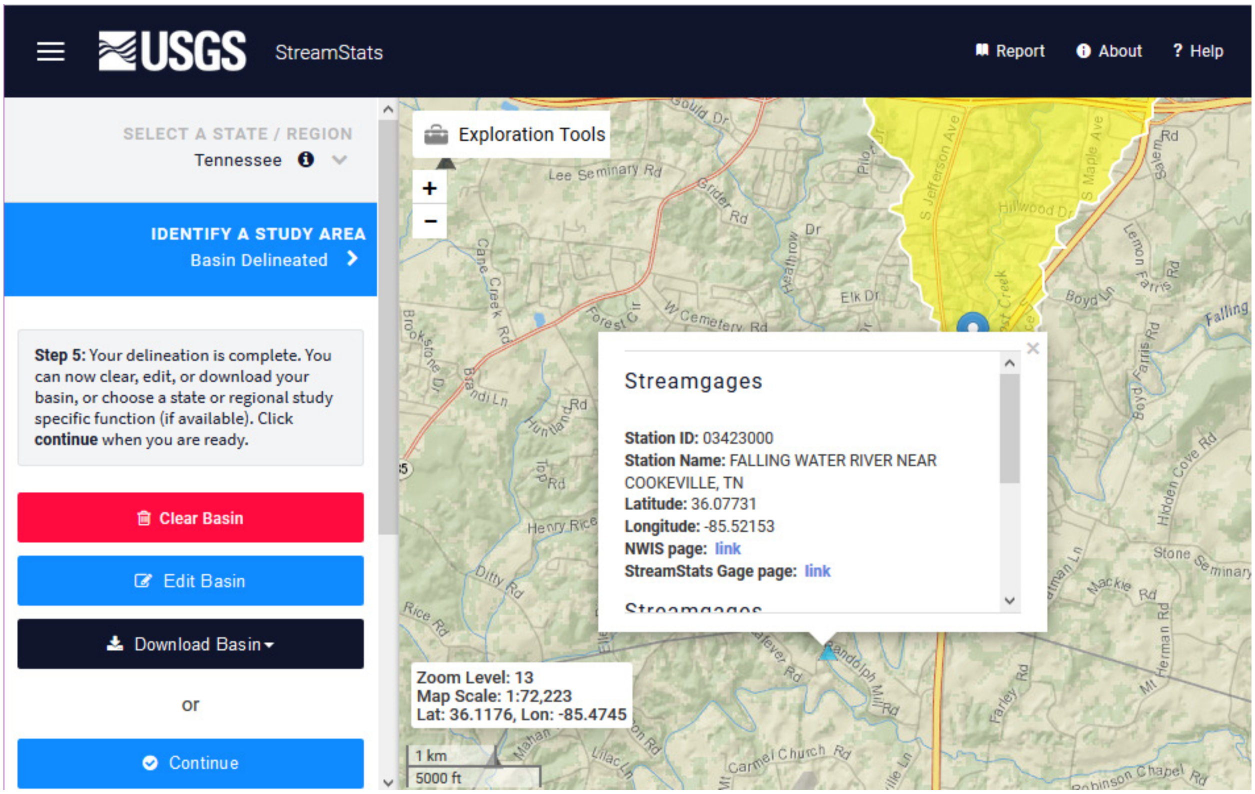
Step 4 Click the “Delineate” button on the left-hand toolbar, then click on the discharge location within the waterbody. After processing for several moments, StreamStats will display the upstream portion of the basin network that drains to the discharge location.



Step 5 Using the map interface, explore nearby locations upstream and downstream of the discharge for streamflow gages. If gages are unavailable, examine nearby watersheds that are similar to the drainage area into which the permitted outfall discharges.

StreamStats will present different sites using various colors to denote useful information for each gage station. Expand the “National Layers” button in the legend to show an expanded legend explaining each symbol used in the map.

After identifying relevant stations, click on their icons to find links to their NWIS and StreamStats pages.



The NWIS page provides facts about the area that drains to the station (e.g., total drainage area and contributing drainage area), as well as the monitoring beginning date, monitoring ending date, and number of records available for the site.

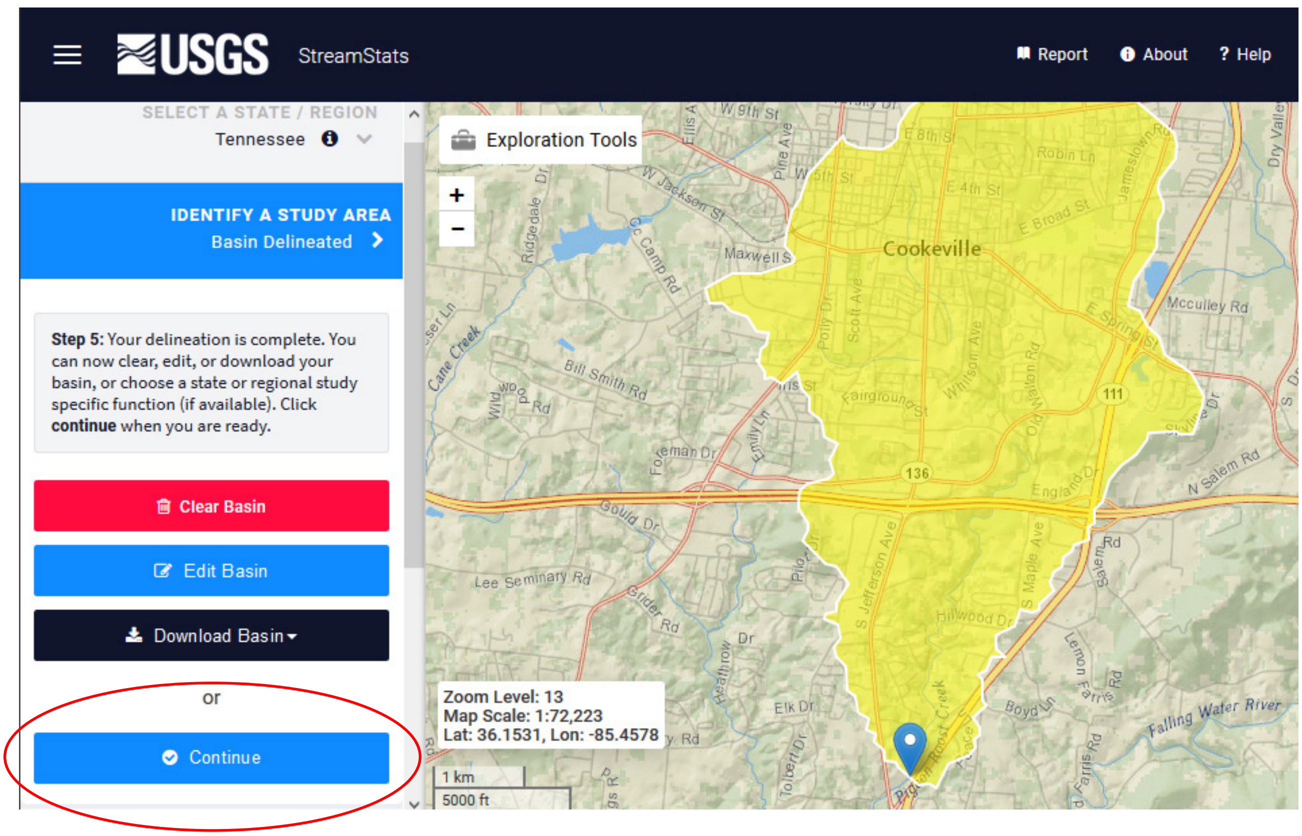
On the StreamStats page, you can find additional USGS information for the site, which may include pre-calculated low flow statistics. If the appropriate low flow statistic you are seeking is listed on the page, you should obtain the original research report that documents the estimate. When reviewing the original research report, you should look for the following information within the report:

- When was the underlying data used in the analysis collected, and is that date range sufficiently representative of current climate conditions and other conditions that contribute to in-stream flow (e.g., land use pattern)?
- What is the geographic region or area of applicability for the estimate? Does the waterbody of interest and the discharge location fall within that area or region? If not, the estimate will not be applicable to the discharge location.
- Is the estimate derived from a reputable source that utilizes peer review or other suitable quality control procedures? Typically, estimates produced by USGS will be developed using suitable quality control procedures.

Most direct estimates reported on the StreamStats gage webpage will be based on streamflow measurements that are less recent than those available to the permit writer. For more information on identifying the underlying references these estimates are based upon, please refer to Section 4, “Frequently Asked Questions.”

Step 6 Based on the available information, you should decide whether sufficient data exist on the stream segment of interest to directly calculate low flow statistics using Hydrologic Toolbox, or if you should base your estimate on a regression of nearby watershed gages using WREG. Refer to Section 1.5 of this handbook for additional discussion on making this determination. Section 3 further describes the use of Hydrologic Toolbox and WREG. Refer to Section 4 for more discussion on determining whether data are sufficient for use in your NPDES permit.

Step 7 Before leaving StreamStats, you should return to the discharge location’s delineation and collect information on its size. You can do this by clicking on “Continue” and collecting the basin characteristics, as these are likely to be useful later.



StreamStats will export a “Basin Characteristics Report” as a comma separated values (.csv) file, which can be saved and viewed later using a spreadsheet application. In addition, the delineation for the basin can be downloaded as a shapefile (or in other formats) for use in other GIS applications.

In the case of the Cookeville Wastewater Treatment Plant, there are no gages upstream of the permitted outfall, but there are two downstream gages. The first is approximately 1.8

miles downstream (Station ID No. 03422900) but does not have data available for download or information on any data associated with the station. The second is 4 miles downstream on the Falling Water River (Station ID No. 03423000) and has data available for download dating from 1932 to 2018.

In general, the first station is preferable in terms of its location (i.e., nearby and on the same stream segment); however, the flow data are not available for review. The second station, while farther downstream, is likely to be representative and has a substantial amount of data available for use.

3 Estimating Low Flow Statistics with Hydrologic Toolbox and WREG

3.1 Introduction

In this section, we will discuss how to use Hydrologic Toolbox and WREG to estimate low flow statistics. As discussed in Sections 1 and 2, you would use Hydrologic Toolbox for situations where the permittee's outfall location and a stream gage are on the same stretch of a stream or river. WREG is typically used when it is not possible to directly measure the waterbody's low flow statistics. Instead, low flow statistics are calculated for nearby, gaged basins (e.g., using Hydrologic Toolbox) and related to the discharge location of interest via regression equations.

Some experienced readers will have used other tools, such as DFLOW, Basins, and SWSTAT, to estimate low flow statistics on a gaged stream in the past. EPA and USGS developed Hydrologic Toolbox to replace these applications. Hydrologic Toolbox incorporates the functionality and computational methods used in all three legacy applications.

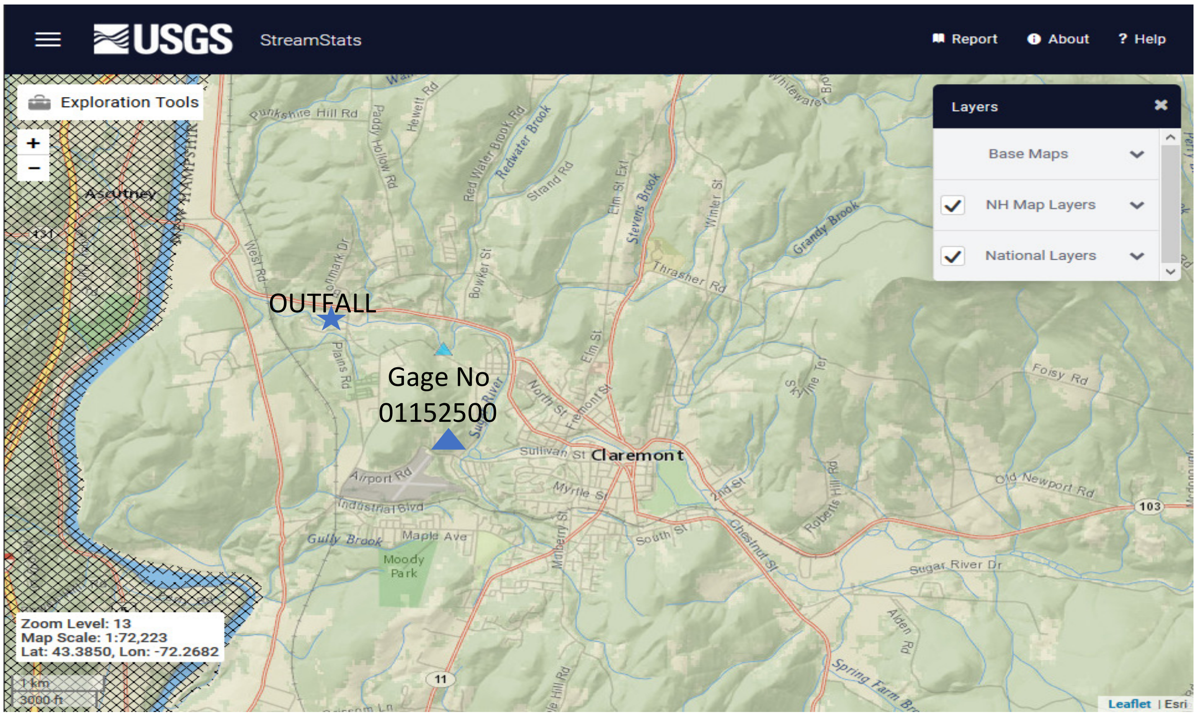
This section provides step-by-step instructions for using these applications while writing permits. This handbook assumes that you will use Hydrologic Toolbox to access and download daily flow measurements for USGS gage stations. However, please note that this information may also be obtained manually from the NWIS website. For more information on manually loading data sets into Hydrologic Toolbox and WREG, or to learn about uses of the software beyond calculating low flow statistics, please refer to the applications' user manuals.

3.2 Using Hydrologic Toolbox to Estimate Low Flow Statistics on a Gaged Waterbody

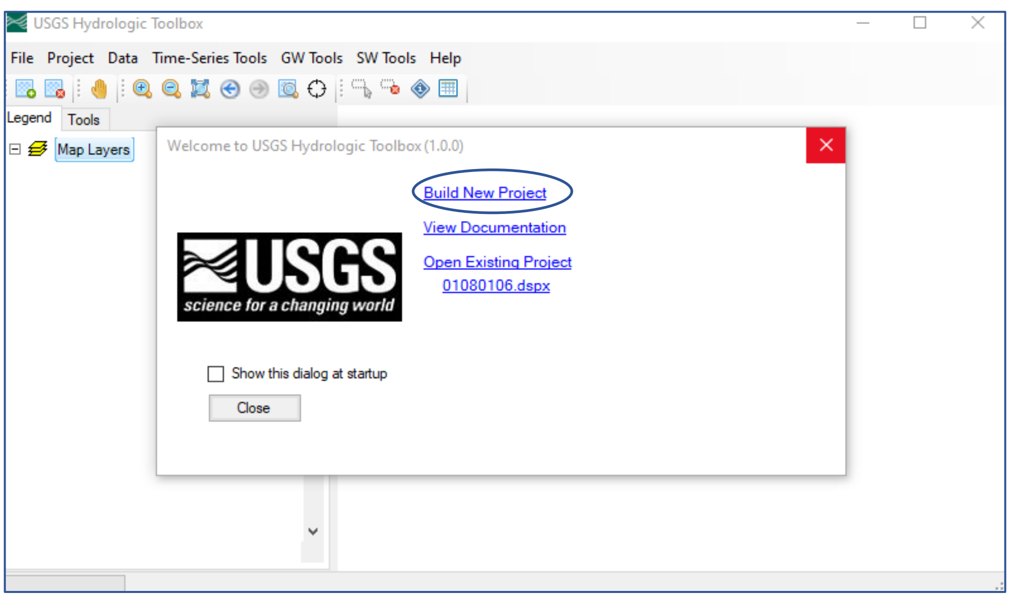
Next, let's walk through step-by-step instructions using Hydrologic Toolbox to calculate low flow values. The general workflow when using Hydrologic Toolbox is as follows:

1. In Hydrologic Toolbox, locate the flow monitoring stations identified while investigating the watershed.
2. Import the flow station data into Hydrologic Toolbox.
3. Define the calculations you wish to run.
4. Run the analysis.

Illustrations accompany the instructions, which you can use to follow along on your own computer. The illustrations depict the process for calculating a 7Q10 value for the City of Claremont Wastewater Treatment Plant (located at 338 Plains Road, Claremont, New Hampshire, 03743) using USGS's nearby Station ID No. 01152500. Both the permitted outfall and the gage are located on the Sugar River in New Hampshire, as illustrated on the StreamStats screenshot below.

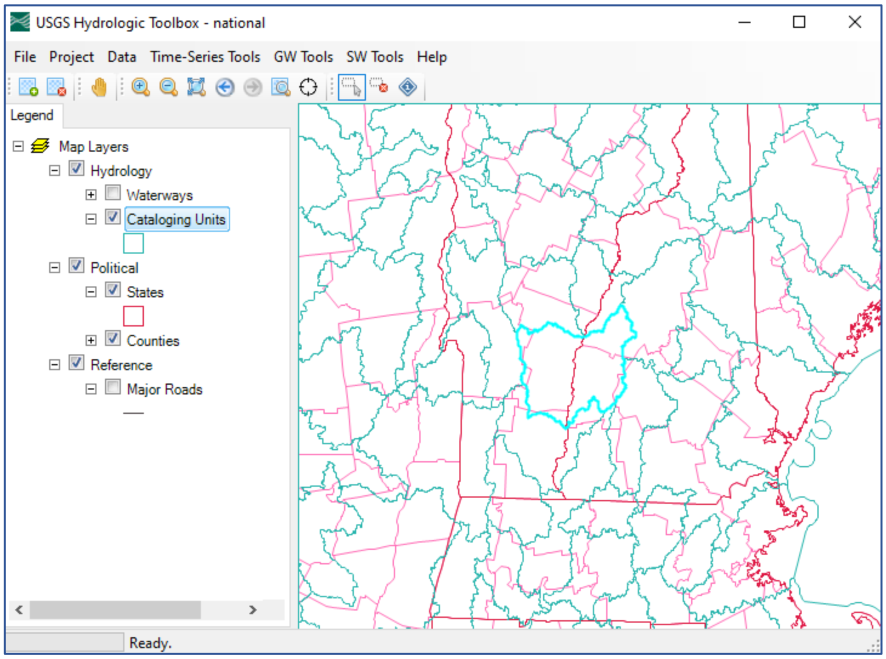


Step 1 Open Hydrologic Toolbox and select "Build New Project."

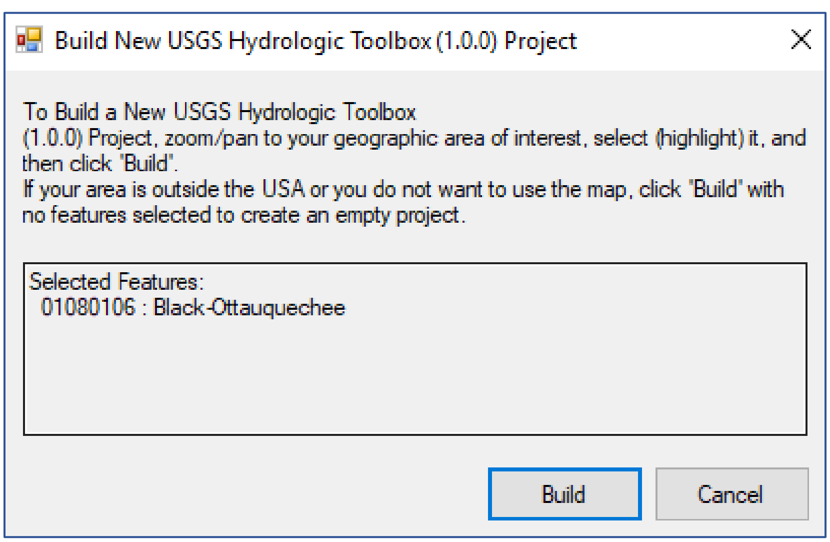


Step 2 A map of the United States will appear. Zoom and pan to the location of the stream gage to be used (Station ID No. 01152500 in our example) to estimate flow statistics. (Hint: Add state, county, and major roads to the map in the left-hand "Legend" menu to help navigate to the location of interest.)

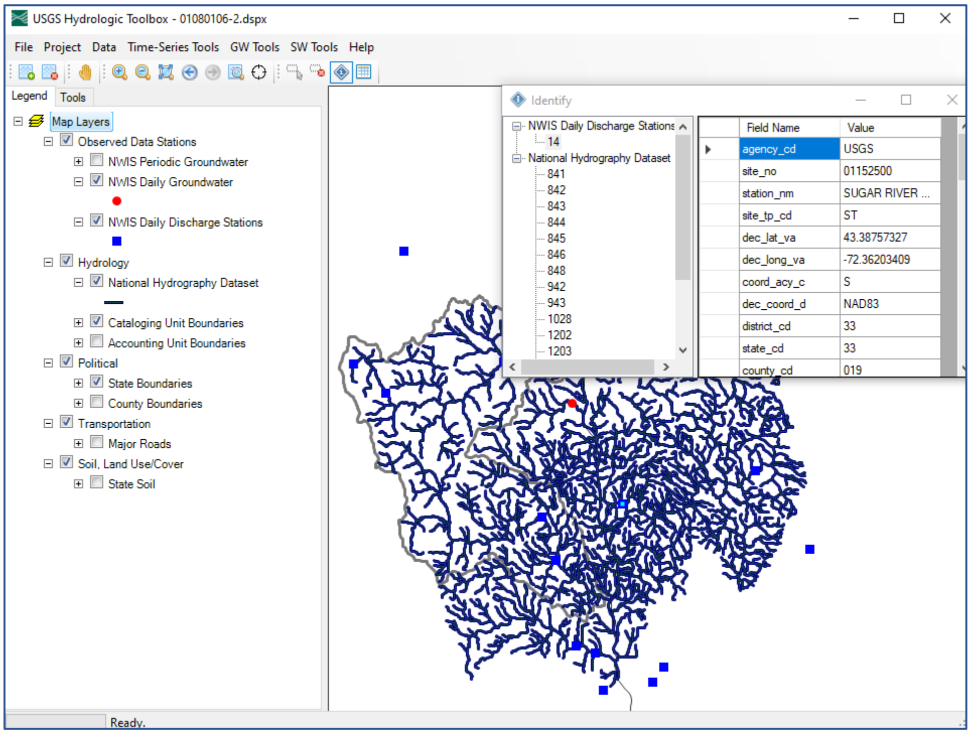
Step 3 Click "Select" in the toolbar and click on the drainage basin that includes the stream gage of interest. The selected basin's outline will be highlighted cyan.



Step 4 Click "Build" in the "Build New USGS Hydrologic Toolbox (1.0.0) Project" dialog window. Save the map projection to the default location. The software will download and then display data layers associated with the selected basin.



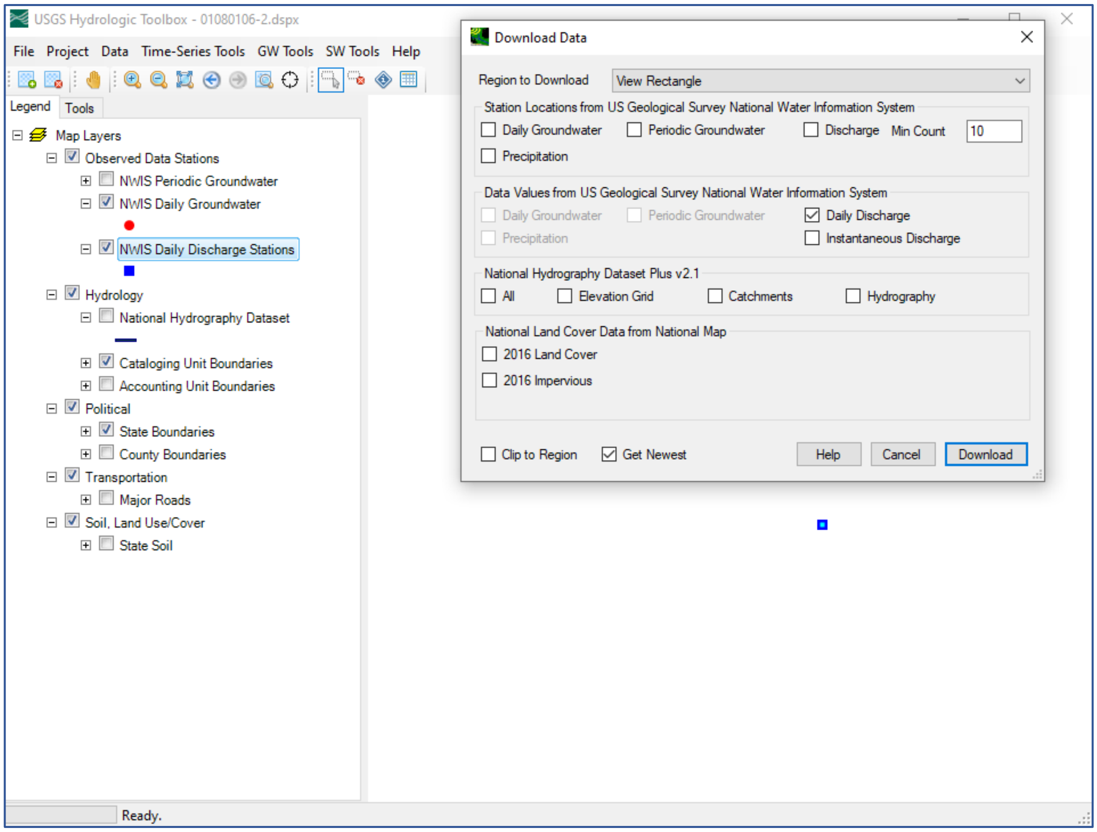
Step 5 Using zoom and pan, navigate to the stream gage previously identified in StreamStats. Click on the "Identify" button in the toolbar and click on the stream gage to display identifying information. The selected object will be highlighted cyan. Zoom so only the station of interest is visible.



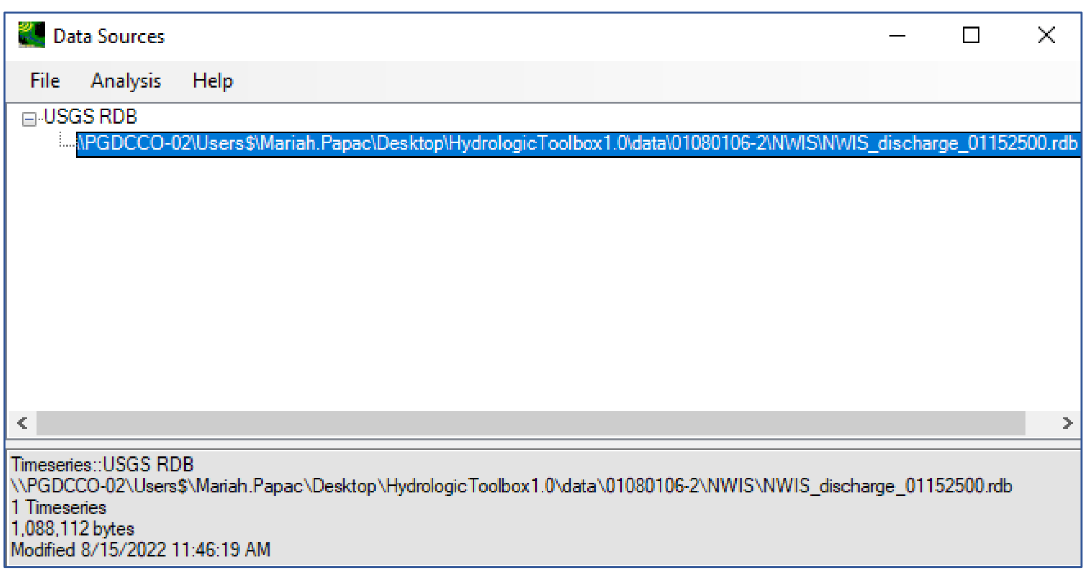
Step 6 Under the File menu, click "Download Data." A dialog box will appear to select the data to download. In the "Regions to Download" dropdown menu, select "View Rectangle."

Alternatively, permit writers can directly specify the gage station if they already know its ID number from StreamStats, and they can download its data by selecting the "Station IDs" option in the "Region to Download" dropdown menu.

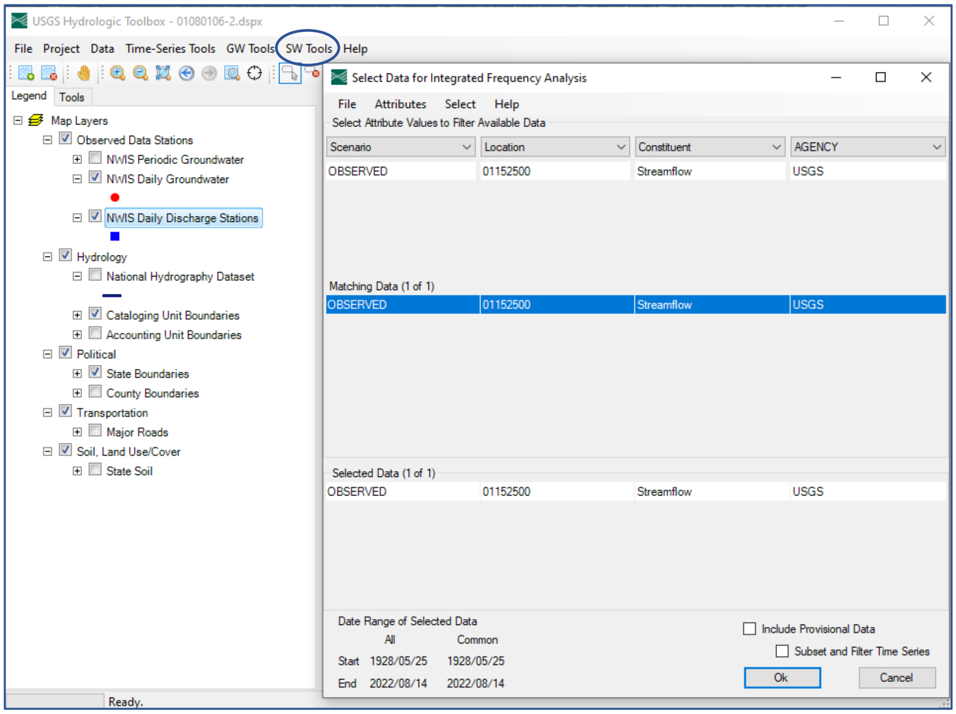
Under “Data Values from US Geographical Survey National Water Information System,” select “Daily Discharge.” Click “Download” at the bottom.



Step 7 A new dialog window, “Data Sources,” will appear. In the window, select the station of interest. (Hint: This dialog box will label stations according to their station number.) Next exit out of this window.

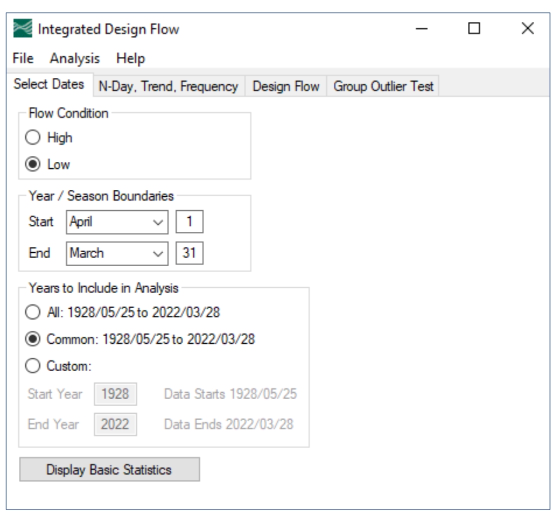


Step 8	Then select "USGS Integrated Design Flow (IDF)" under the SW Tools dropdown. Next, select the station of interest and click "OK."



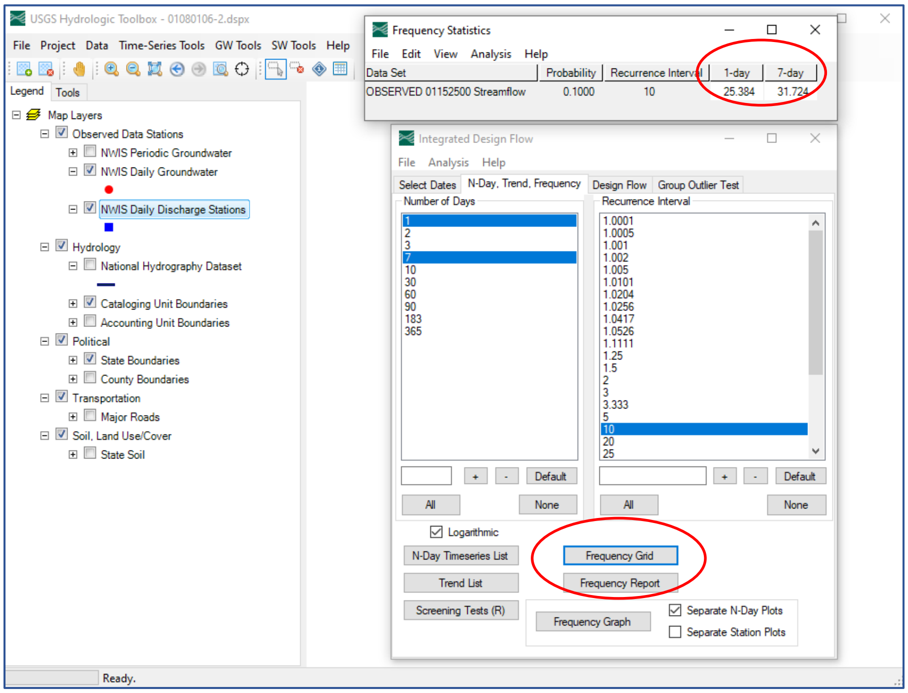
Step 9	The "Integrated Design Flow" window will appear. Under the "Select Dates" tab, specify "Low" in the "Flow Condition" window, the water year/season boundaries that will be used in the calculation, and the timespan of data to include in the analysis. For more discussion on what a "water year" is and how it fits into these calculations, please refer to Section 4, "Frequently Asked Questions."

For our example, we will specify an April 1–March 31 water year and use all data available from this station (i.e., Station ID No. 01152500).



Step 10 Next, click on the “N-Day, Trend, Frequency” tab. Specify the averaging period of the low flow statistics of interest (e.g., 1 for 1Q10, 7 for 7Q10) under “Number of Days,” as well as the recurrence interval (typically 10 for hydrologically based estimates). Make sure to leave the “Logarithmic” toggle selected.

Click on the “Frequency Grid” or “Frequency Report” buttons to calculate the values of the selected flow statistics.



For this gage location, the 7Q10 flow was estimated at 31.7 cubic feet per second (20.5 million gallons per day [MGD]). You can copy the data report to the clipboard and save it in the project file for future reference on this or subsequent permit reissuances.

Step 11 Finally, make any adjustments necessary to account for differences in the locations of the permitted outfall and stream gage. For example, if the outfall is located some distance downstream of the gage (as is the case with the Claremont Wastewater Treatment Plant), the low flow statistic would likely be slightly greater in magnitude at the outfall location than at the gage location. This is due to the larger area that is contributing flow to the outfall location. Conversely, an outfall located upstream of the gage location would have a smaller low flow statistic.

If there are no other contributors of flow between the outfall and gage location (e.g., other permitted discharges), and if no man-made impoundments or water withdrawal systems are intervening, you can make the adjustment using the rule of proportions (i.e., by multiplying gage low flow value by a ratio of the outfall drainage area and the gage drainage area). The following equation demonstrates this procedure:

$$Q_{outfall} = Q_{gage} \times \frac{A_{outfall}}{A_{gage}}$$

Where:

$Q_{outfall}$ = Low flow statistic at outfall location
Q_{gage} = Low flow statistic at gage location
$A_{outfall}$ = Area draining to outfall
A_{gage} = Area draining to gage

In general, the rule of proportions method for adjusting low flow values will provide more accurate results when the two drainage areas are roughly the same size. According to Hortness (2006), a good rule of thumb is to apply this method when the ratio between the $A_{outfall}/A_{gage}$ is around 0.5 to 1.5.

In the Claremont Wastewater Treatment Plant example, we will use the delineation tool in StreamStats (refer to Section 2, Step 7) to estimate the area of the watershed draining to the outfall (269 square miles) and the NWIS page for Station ID No. 01152500 (270 square miles). Therefore, the 7Q10 estimate for the outfall is given by:

$$Q_{outfall} = 20.5\ MGD \times \frac{269\ square\ miles}{270\ square\ miles} = 20.4\ MGD$$

If intervening flow sources, impoundments, or withdrawal systems exist, you may need to obtain supplementary data regarding these sources to better understand how they are likely to influence low flows within the waterbody near the discharge.

3.3 Using WREG to Estimate Low Flow Statistics on an Ungaged Waterbody

Next, let's walk through step-by-step instructions for using WREG to calculate low flow values on ungaged waterbodies. The general workflow when using WREG is as follows:

1. Create input files for use in WREG.
2. Create a WREG project directory with all input files and the WREG executable file.
3. Run WREG and define the variables for the regression analysis.
4. Create regression equations in WREG.
5. Estimate dependent variables for the ungaged basin and enter them into the regression equation to estimate ungaged basin low flow statistics.

Regression relationships between basin characteristics and low flow statistics are not plug-and-play tools—once developed, the user should perform diagnostic and quality control evaluations to determine the accuracy and reliability of the derived models. This handbook section focuses on the use of the WREG software package. More in-depth discussion of quality control evaluation diagnostics of regression relationships is beyond its scope, but you may find the following additional resources useful when designing regression models:

- Helsel, D.R., and R. M. Hirsch. 2002. *Statistical Methods in Water Resources Techniques of Water Resources Investigations* (Chapters 9–11). U.S. Geological Survey. https://pubs.usgs.gov/twri/twri4a3/.

- Ries, K.G., J.B. Atkins, P.R. Hummel, M. Gray, R. Dusenbury, M.E. Jennings, W.H. Kirby, H.C. Riggs, V.B. Sauer, and W.O. Thomas, Jr. 2007. *The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites*. U.S. Geological Survey. https://md.water.usgs.gov/publications/tm-4-a6/.
- Stedinger, J., and G.D. Tasker. 1985. “Regional Hydrologic Analysis: 1. Ordinary, Weighted, and Generalized Least Squares Compared.” *Water Resources Research* 21: 1421–1432. https://doi.org/10.1029/WR021i009p01421.

WREG requires the manual creation of a variety of input files. The WREG user’s manual (Eng et al., 2009) includes detailed instructions for creating these files using Microsoft Excel or text editors, and you should refer to this resource for the mechanics of creating the text input files. This handbook will walk you through calculating the distributional shape parameters and basin characteristics for use in the input files.

Illustrations accompany the instructions, which you can use to follow along on your own computer. The illustrations depict the process of calculating a 7Q10 value for the City of West Liberty Sewage Treatment Plant (located at 615 East A St., West Liberty, Iowa, 52776), which discharges to Wapsinonoc Creek. The creek is ungaged near the discharge.

Step 1 Using the gages selected, download the station timeseries data from the relevant NWIS websites (which can be accessed through StreamStats) or following the data download procedures for Hydrologic Toolbox (Section 3.2, Steps 1–6).

For West Liberty’s plant, we will use five gage stations located in nearby drainage areas (Station ID Nos. 05454090, 05454300, 05454500, 05455700, and 05465000).

Step 2 WREG requires input files that describe site, basin, and flow characteristics for the gage locations of interest, as well as shape parameters for the Log-Pearson Type III distributions that fit to the flow data for those locations. In addition, you may also include two additional files when using a weighted least squares or generalized least squares regression method—when using ordinary least squares regression, these optional files are not required. This handbook will assume the use of a weighted least squares regression. For more information on other regression techniques, refer to the WREG user’s manual (Eng et al., 2009) or to the supplementary resources listed both above and in Section 4.

Table 3-1 (reproduced from the WREG user’s manual) describes the input files needed.

Table 3-1. WREG Input Files

File Name	Description	WREG Requirements
SiteInfo.txt	Site information and basin characteristics to be used in the regression (the independent variables)	Always required
FlowChar.txt	Flow characteristics to be used in the regression (the dependent variables)	Always required
LP3G.txt	Skew for Log-Pearson Type III distribution	Always required
LP3K.txt	K for Log-Pearson Type III distribution	Always required

File Name	Description	WREG Requirements
LP3s.txt	Standard deviation for Log-Pearson Type III distribution	Always required
UserWLS.txt	User-specified weighting matrix	Required only if the user-defined WLS option is selected
USGS########.txt	Annual timeseries of flow at streamflow-gaging stations	Required only when using the GLS option. When needed, one file is required for each streamflow-gaging station listed in SiteInfo.txt.

Tips for Creating Input Files:

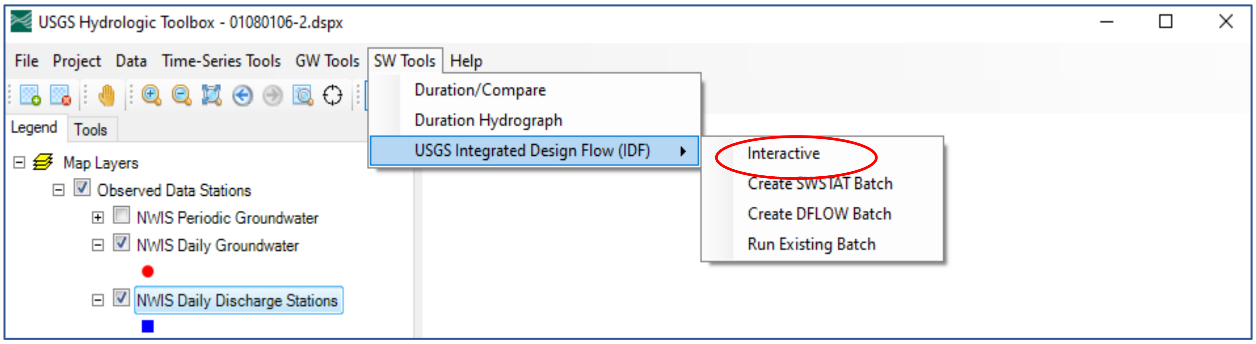
- The WREG distribution package comes with example input files—try copying these example input files into the project directory and editing them using Microsoft Excel or another spreadsheet application. This is often easier than creating them from scratch.
- Note that the same gage stations must appear in all input files. In addition, WREG expects the stations to be presented in the same order in each input file. You may find it helpful to use your spreadsheet application's "Sort" function to put the stations in numeric/alphabetical order in each of the input sheets to ensure consistency.

SiteInfo.txt & FlowChar.txt: Consistent with the instructions in the WREG manual, enter the basin information and flow values that you wish to use in the regression analysis. Note that StreamStats is a good resource for information on basin characteristics. For the flow characteristics, make sure to enter the flow statistics that are needed for the ungaged basin (e.g., 7Q10, 1Q10).

In the example for the West Liberty Sewage Treatment Plant, information on the basin drainage area, basin length, and mean annual precipitation for each of the gages and for the permitted outfall location are available and were collected from StreamStats.

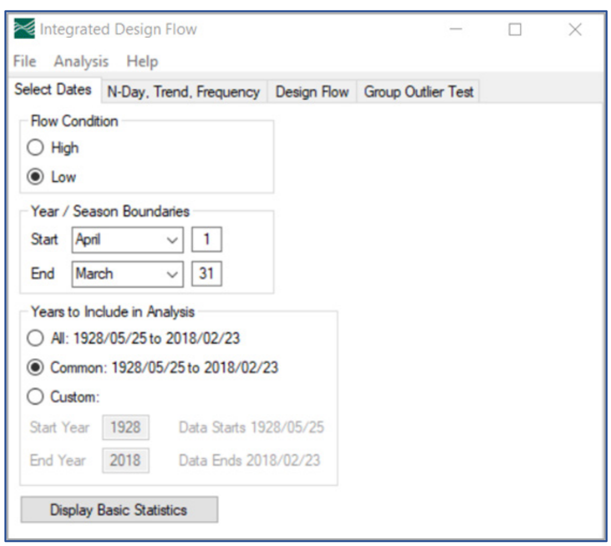
LP3G.txt, LP3K.txt, and LP3s.txt: These files contain parameters that define the Log-Pearson Type III distribution, which was fitted to each gage station's flow data when estimating their respective low flow statistics. These parameters are the skew coefficient (entered into LP3G.txt), K values for the distribution (entered into LP3GK.txt), and the standard deviation of the annual timeseries of low flow values (entered into LP3s.txt).

Step 3 To estimate the abovementioned shape parameters needed for WREG input files, follow Steps 1–6 of Section 3.2 to collect and download flow data for each gage station of interest. When presented with the "Data Sources" window exit out and return to the main Hydrologic Toolbox interface. From the SW Tools drop down menu hover over "USGS Integrated Design Flow (IDF)" and select "Interactive". Next, select one of the stations of interest and click "OK."



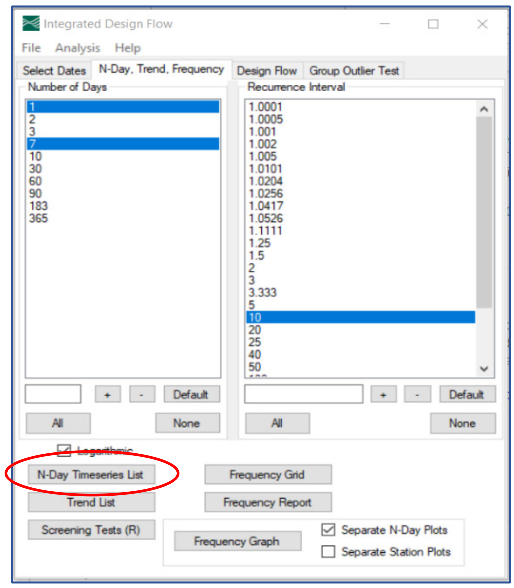
Step 4 The "Integrated Design Flow" window will appear. Under the "Select Dates" tab, specify "Low" in the "Flow Condition" window, the water year/season boundaries that will be used in the calculation, and the timespan of data to include in the analysis.

For our West Liberty plant example, we will specify an April 1–March 31 water year and use all data available from this station (i.e., Station ID No. 0545570).

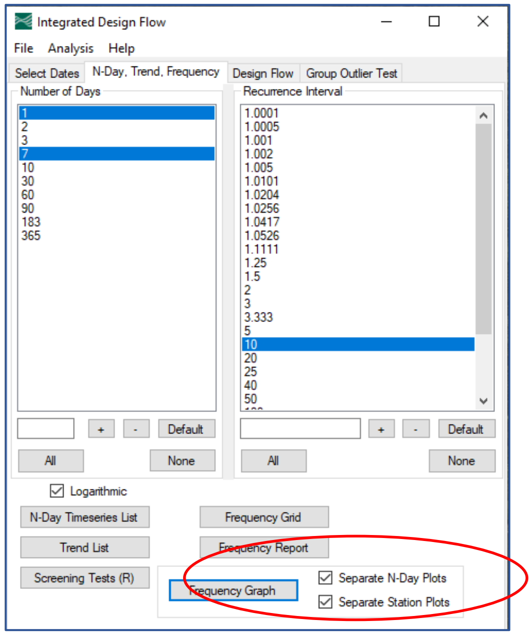


Step 5 Next, click on the "N-Day, Trend, Frequency" tab. Specify the averaging period of the low flow statistics of interest (e.g., 1 for 1Q10, 7 for 7Q10) under "Number of Days," as well as the recurrence interval (typically 10 for hydrologically based estimates). Make sure to leave the "Logarithmic" toggle selected.

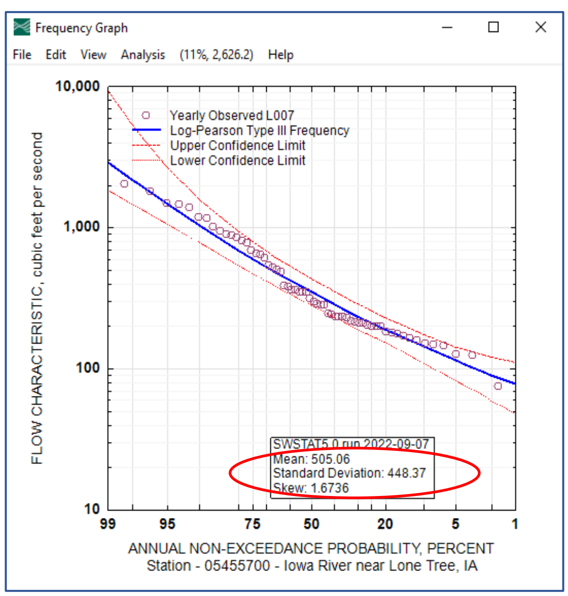
Click the "N-Day Timeseries List" to generate an annual timeseries of the estimate of interest (e.g., the lowest seven-day average observed each water year) for export and separate analysis. This allows you to perform your own calculations of distributional shape parameters if you would like. (Note that this is also how you could generate the annual low flow time series files for use in the generalized least squares technique.)



By selecting the “Separate N-Day Plots” and “Separate Station Plots” toggle and clicking the “Frequency Graph” button, you can generate plots with the Log-Pearson Type III curve-fitted to the timeseries data for each station selected. The associated skew and standard deviation estimates used in WREG will also appear on the plots.



The skew values and standard deviation from the plots may be entered into the input files. To compute the K value, use the statistic’s skew value and exceedance probability with the K-alue tables found in Appendix A. These tables are reproduced from USGS’s Bulletin 17B: *Guidelines for Determining Flood Flow Frequency* (Interagency Advisory Committee on Water Data, 1982).



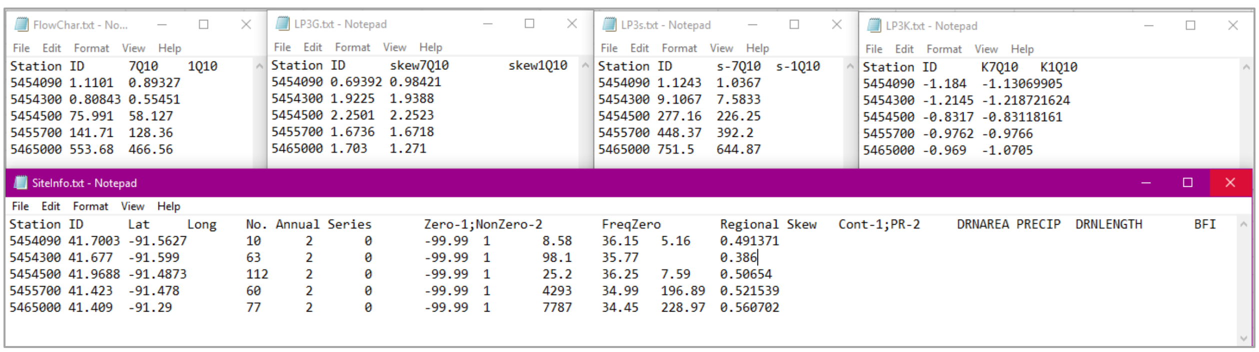
The exceedance probability can be calculated using the low flow statistics recurrence interval (T) as follows:

$$Exceedance\ Probability = 1 - \frac{1}{T}$$

So, for a 7Q10 statistic that has a recurrence interval of 10, the exceedance probability would be 0.9. For a biologically based statistic (e.g., 4B3) that has a recurrence interval of 3, the exceedance probability would be 0.67.

For Station ID No. 05455700, the skew is 1.6736, and the exceedance probability for the 7Q10 low flow is 0.9. Using Table A-1 (Appendix A), you would interpolate to estimate a K value of approximately -0.976.

You should tabulate each of the statistical parameters for each station of interest and enter them into the appropriate input file. The screenshot below reproduces the input files for the West Liberty Sewage Treatment Plant.



FlowChar.txt - Notepad

```
Station ID      7Q10    1Q10
5454090 1.1101  0.89327
5454300 0.80843 0.55451
5454500 75.991  58.127
5455700 141.71  128.36
5465000 553.68  466.56
```

LP3G.txt - Notepad

```
Station ID      skew7Q10        skew1Q10
5454090 0.69392 0.98421
5454300 1.9225  1.9388
5454500 2.2501  2.2523
5455700 1.6736  1.6718
5465000 1.703   1.271
```

LP3s.txt - Notepad

```
Station ID      s-7Q10  s-1Q10
5454090 1.1243  1.0367
5454300 9.1067  7.5833
5454500 277.16  226.25
5455700 448.37  392.2
5465000 751.5   644.87
```

LP3K.txt - Notepad

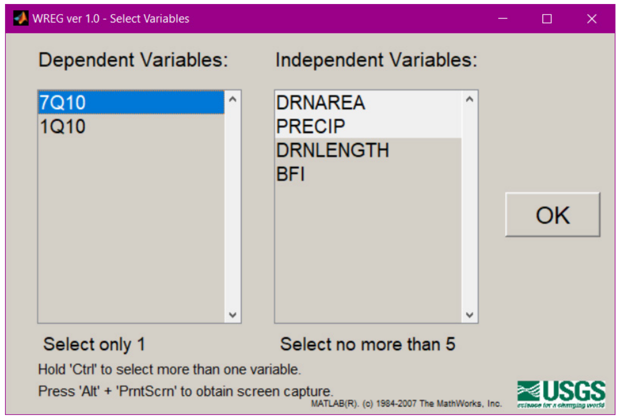
```
Station ID      K7Q10   K1Q10
5454090 -1.184  -1.13069905
5454300 -1.2145 -1.218721624
5454500 -0.8317 -0.83118161
5455700 -0.9762 -0.9766
5465000 -0.969  -1.0705
```

SiteInfo.txt - Notepad

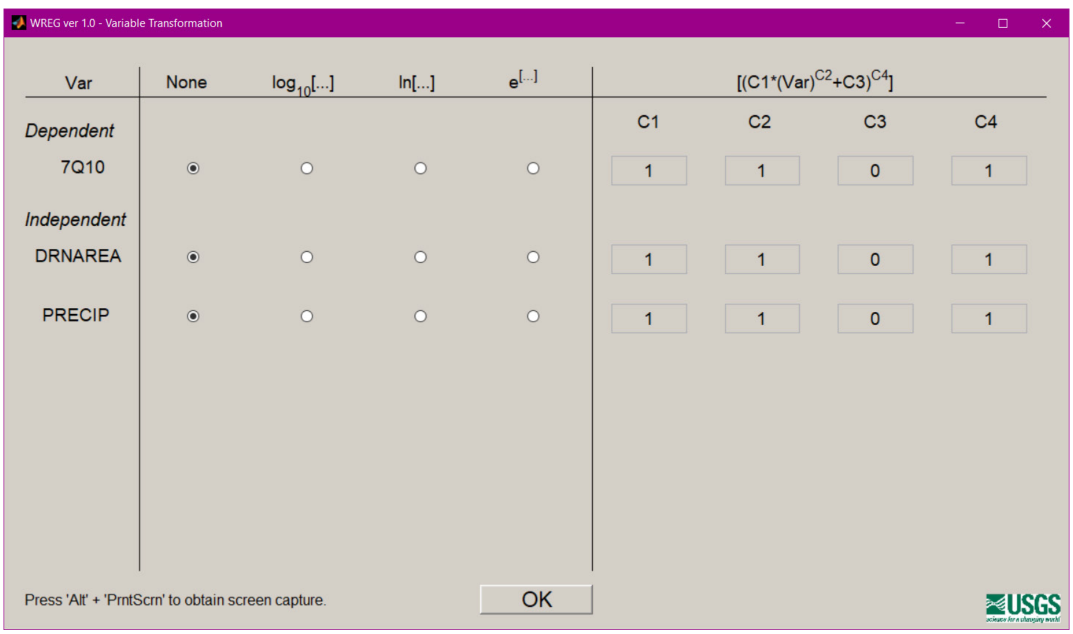
```
Station ID      Lat     Long    No. Annual Series       Zero-1;NonZero-2        FreqZero        Regional Skew   Cont-1;PR-2     DRNAREA PRECIP  DRNLENGTH       BFI
5454090 41.7003 -91.5627        10      2       0       -99.99  1       8.58    36.15   5.16    0.491371
5454300 41.677  -91.599         63      2       0       -99.99  1       98.1    35.77           0.386
5454500 41.9688 -91.4873        112     2       0       -99.99  1       25.2    36.25   7.59    0.50654
5455700 41.423  -91.478         60      2       0       -99.99  1       4293    34.99   196.89  0.521539
5465000 41.409  -91.29          77      2       0       -99.99  1       7787    34.45   228.97  0.560702
```

Step 6 Next, create a project folder on the computer's hard drive, and copy and paste the WREG executable file (WREGv1_05.exe) and input files into the folder. Open the WREGv1_05.exe file to start WREG. On the first screen that appears, select the dependent variable of interest (e.g., 7Q10) and the independent variables to be used (press the "Ctrl" key on the keyboard when clicking to select multiple independent variables). Click "OK."

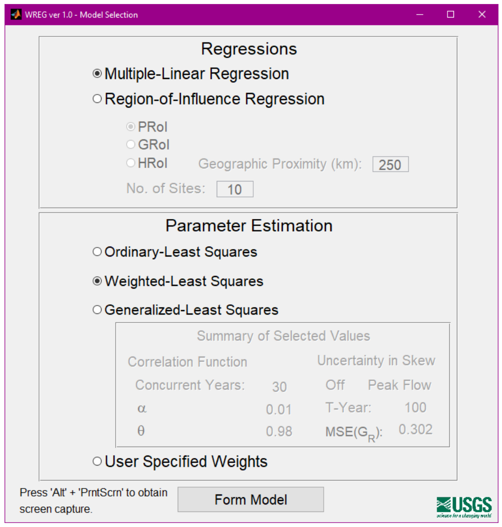
In this example, the regression relationship will use the basin drainage areas and mean annual precipitation values as the dependent variables.



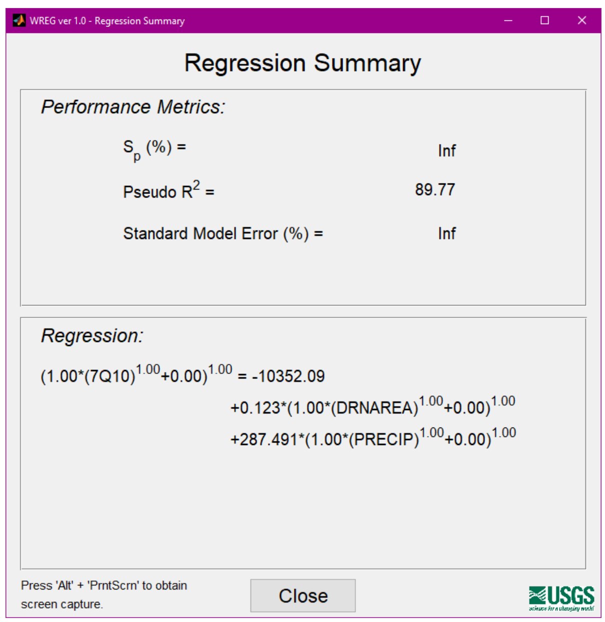
Step 7 On the next screen, select any variable transformations that may be appropriate. Transformations can help linearize the regression relationship. Determining which transformations work best may require you to run several iterations of the model to find the most reasonable model fit. In this example, the best model fit occurs without the use of transformations (i.e., option "None").



Step 8 Next, specify the type of regression model to be used. This example will use weighted least squares multiple linear regression. A discussion of the uses of region-of-influence regression and generalized least squares parameter estimation techniques are beyond the scope of this handbook; however, you are encouraged to review the WREG user's manual (Eng et al., 2009) to learn more about these techniques. Once the desired options have been selected, press "Form Model."



Step 9 The final screen, "Regression Summary," provides information on the regression model produced. If the model fit (e.g., as reflected by the R^2 value or other statistical and visual diagnostic tests) is poor, consider revising the model (i.e., applying variable transformations as described in Step 7).



Step 10 The equation in the "Regression" window is the regression model you should apply to the ungaged basin. Using this equation, enter the ungaged basin's independent variables.

For the West Liberty plant, we collected the basin drainage area (DRNAREA; 46.6 square miles) and the mean annual precipitation (PRECIP; 36.11 inches) from StreamStats using the basin delineation tool (see Section 2.2, Step 7). Using these values, we would predict a 7Q10 value of 34.9 cubic feet per second (22.6 MGD).

4 Frequently Asked Questions

4.1 General Questions

My gage is far removed from the discharge location but on the same stream or river. What should I do?

Use the rule of proportions, the drainage area of the stream gage, and the drainage area of the discharge location to estimate a flow multiplier to apply to the stream gage flow. Refer to Section 3.2, Step 11, for an illustrated example of the use of this technique. Note that you must separately factor intervening elements between the gage station and the discharge location (e.g., tributaries, impoundments, or other permitted facilities); the rule of proportions' transformation of the gage data will not adequately represent these elements.

How many data are "sufficient" for computing a low flow statistic?

As with any statistical analysis, you should consider the *representativeness* of the data and the *quantity* of the available data.

Representativeness: Does the gage location adequately represent conditions at the discharge location? Generally speaking, the level of proximity indicates greater representativeness. In addition, pay attention to land use patterns—a highly urbanized basin will have different low flow behavior than a rural or forested basin.

Quantity: Do the range of years of data available adequately capture variations in climate over time? Capturing at least 15 to 20 years of data is a good idea. For example, EPA Region 1 permit writers prefer using a 30-year data window to adequately capture variations in climate. However, if notable directional changes in precipitation patterns, water withdrawals or impervious surfaces have occurred during that time period, a more recent subset of available data may be more *representative*.

Which data should I exclude?

When computing low flow statistics, you should exclude data that have known quality issues (e.g., gage data that USGS has indicated is unreliable) or that is not deemed representative of the conditions you are attempting to model.

Should I be worried about outliers in the stream gage data?

Outliers, or observations that appear unusually large or small within the context of the broader data set, can occur for several reasons: 1) a measurement or recording error, 2) an atypical external event (e.g., a dam break or failure), or 3) a rare event from a single population that is quite skewed. Many readers will be tempted to consider all outliers "bad" data which should be removed from the analysis. However, not all outliers are "bad"—many are observations that document rare, but real conditions in the waterbody and should not be removed from the analysis.

Outliers of the first type (i.e., measurement or recording errors) are an example of non-representative data and should not be included in the analysis. These values should be removed from the analysis because they represent true errors and do not represent or reflect true conditions within the waterbody.

Outliers of the second and third types should be included in the analysis unless the permit writer can identify and articulate a strong rationale for their removal. These values should be evaluated on a case-by-case basis to determine if they are representative of the system's "normal" operations, even if they are rare. An atypical, but recurring low flow event—say, due to upstream water withdrawals during a drought—might be included, whereas a flood caused by the catastrophic failure of an impoundment structure might be removed from the data set as an unrepresentative event highly unlikely to ever recur.

As a rule-of-thumb, values should only be eliminated from the analysis if they represent errors or are due to events that are not expected to reoccur (and thus are not representative data). All other data should be included in the analysis.

Hydrologic Toolbox includes a module for performing statistical analyses to identify unusual values in flow data sets, which may be outliers. For more information on using this module data, refer to the "Surface-Water (SW) Tools" section of the Hydrologic Toolbox user's manual (Barlow, *et al*., 2022). For more discussion on the analysis of outliers in surface water data, refer to the textbook *Statistical Methods in Water Resources* (Helsel, et al., 2022).

What should I do if my watershed has man-made modifications (e.g., impoundments or irrigation channels) that will affect low flow values?

Man-made modifications often result in the active management of flow regimes that no longer reflect weather-event-driven flow patterns (e.g., some impoundments are operated on a controlled release pattern). You may need to solicit supplementary data from agencies or individuals that manage the impoundments or diversion programs. Using these supplementary data, you can pre-process the stream gage data to produce flow values that are representative of appropriate low flow conditions at the discharge location.

How often should permit writers and/or permittees be updating the low flow values used in permits?

In general, the low flow values should be reasonably representative of current climatic conditions. Climate alterations and patterns often operate on decadal scales, so a value that is only 5 years old may be reasonably representative while a value that is 25 years old may require revisiting.

When determining whether an update is warranted, you must use your own judgement in evaluating the age and relevance of the underlying data that were used to originally develop the low value.

When deciding, use StreamStats to examine if any new gages have been added to the basin or any old gages taken offline. For example, you may elect to replace an older low flow value that was developed using regression approaches (e.g., like those in WREG) if direct measurements of sufficient quality and quantity have become available on the stream segment of interest.

When calculating low flow values in Hydrologic Toolbox, what is the difference between specifying my water year boundaries based on a calendar year, a seasonal boundary, or a portion of a year?

Typically, it is a good idea to specify boundaries such that all dry season days fall in the same water year to avoid biasing estimated statistics. Hydrologic Toolbox defaults to an April 1–March 31 water year, but conditions at the permitted outfall of interest may differ from this.

In addition, you may be interested in calculating a low flow statistic for a dilution credit that is only applicable for a portion of the year. For example, a surface water discharge may only be permitted May–October in a particular waterbody. In this case, you may want to calculate the low flow statistic that pertains during the seasonal discharge window and would only use data from May to October for the historical record.

I developed a Basins Characteristics Report using StreamStats to get low flow estimates for a location on an ungaged stream. However, the application produced a report that did not include any estimates.

Not all watersheds and regions within the United States currently have low flow regression analyses computed. Low flow regression relationships presented in StreamStats come from original research and analysis developed and reported by USGS. If USGS has produced an equation for your ungaged basin, then you will have the option to include low flow statistic estimates in your Basin Characteristics Report with a citation linking to the original report that published the regression equation. If USGS has not previously developed and reported an equation applicable to the basin, you will not have the option to include a low flow estimate.

For a list of all states with pre-computed USGS flow statistic regression equations and their corresponding publications, please refer to USGS's Regional Regression Equation Publications by State website at: https://water.usgs.gov/osw/programs/nss/NSSpubs_Rural.html

When using the pre-calculated watershed regression relationships and low flow statistic estimates presented in StreamStats, where can I find supporting information on the data and methods used in the calculations? How can I determine if it is appropriate to use the regression relationship or low flow statistic in my permit?

All values presented on the StreamStats gage pages (i.e., the pages—along with the NWIS gage page—that can be found by clicking on the gage) will generally have a source or citation accompanying them.

The citation for a given value will be found in the "Citation Number" column of any given table, and the table of citations (pictured below) provides links to all cited reports at the bottom of all StreamStats gage webpages.

Citations

Citation Number	*Citation Name and URL*
30	Imported from NWIS file
41	Wolock, D.M., 2003, Flow characteristics at U.S. Geological Survey streamgages in the conterminous United States: U.S. Geological Survey Open-File Report 03-146, digital data set
42	Wolock, D.M., 2003, Base-flow index grid for the conterminous United States: U.S. Geological Survey Open-File Report 03-263, digital data set
325	Granato G.E., Ries, K.G., III, and Steeves, P.A., 2017, Compilation of streamflow statistics calculated from daily mean streamflow data collected during water years 1901�2015 for selected U.S. Geological Survey streamgages: U.S. Geological Survey Open-File Report 2017�1108, 17 p.

When developing Basin Characteristics Reports (as described in Section 2.2, Step 7), StreamStats will append a table of citations (pictured below) referring the user to the original reports containing the statistics or watershed regression relationships.

Low-Flow Statistics Parameters [Low Flow Central and East Regions 2009 5159]

Parameter Code	Parameter Name	Value	Units	Min Limit	Max Limit
DRNAREA	Drainage Area	2.02	square miles	1.3	14441
RECESS	Recession Index	50	days per log cycle	32	175
CLIMFAC2YR	Tennessee Climate Factor 2 Year	2.332	dimensionless	2.056	2.46
SOILPERM	Average Soil Permeability	1.214	inches per hour	0.45	9.72
PERMGTE2IN	Percent permeability gte 2 in per hr	71.075	percent	2	100

Low-Flow Statistics Flow Report [Low Flow Central and East Regions 2009 5159]

PII: Prediction Interval-Lower, Plu: Prediction Interval-Upper, SEp: Standard Error of Prediction, SE: Standard Error (other -- see report)

Statistic	Value	Unit	SEp
7 Day 10 Year Low Flow	0.0567	ft^3/s	89
30 Day 5 Year Low Flow	0.101	ft^3/s	70.2

Low-Flow Statistics Citations

Law, G.S., Tasker, G.D., and Ladd, D.E.,2009, Streamflow-characteristic estimation methods for unregulated streams of Tennessee: U.S. Geological Survey Scientific Investigations Report 2009–5159, 212 p., 1 pl.

When using statistical values and basin regression relationships in StreamStats, you should take care to evaluate the representativeness of the underlying data used to generate the statistic or regression equation—just as you would with your own estimates. In some cases, the underlying data (which will be described in the report cited by StreamStats) will not be sufficiently representative of the conditions relevant to the NPDES permit. The most common reason you may reject using StreamStats pre-computed estimates is that they are based on underlying data that are too outdated to represent current climatic conditions.

To evaluate the potential usefulness of the pre-calculated information, download the cited report referenced in StreamStats. Review the report while paying particular attention to the data used to develop the estimates. You should consider the following:

- Where are the report's stream gages located?
- How many data were used in the calculation and from what time period do the data originate?
- If there are seasonal considerations relevant to the permit, are those appropriately accounted for in the report?
- Are sources of uncertainty or data gaps accounted for in the analysis?
- Is the resulting estimate sufficiently accurate and representative to demonstrate its use will be protective of water quality?

If the answers to any of these questions indicate that the estimate is not sufficiently representative or protective of water quality, then you should not use the StreamStats estimate for NPDES permit development.

This report discusses several different ways of obtaining low flow statistic values for a discharge point. How should I think about the relative accuracy of these different approaches? When multiple low flow statistic estimates are available for a discharge point, which should I use for my NPDES permit?

All else being equal, a low flow statistic that is based on information that is more closely related to the discharge point in time and space will more accurately reflect the flow characteristics of the receiving water. For example, a low flow statistic computed from recent data collected near the discharge location will be more accurate than an estimate computed from a state- or regional-regression model developed a decade ago.

When multiple potential low flow statistic estimates are available for a particular discharge point, values based on direct measurements of the waterbody of interest are preferable to values based on geographically broad based statistical models (e.g., the estimates available in StreamStats or developed using WREG). In addition, you should typically prefer an estimate based on more recent and more complete streamflow and watershed data, to those based on older and less complete datasets.

Where can I find more information on low flow statistics and on implementing dilution credits in NPDES permits?

For more information on evaluating mixing zones and low flow conditions, please refer to EPA's *NPDES Permit Writer's Manual* and the Technical Support Document:

- *NPDES Permit Writer's Manual*: https://www.epa.gov/npdes/npdes-permit-writers-manual
- Technical Support Document: https://www3.epa.gov/npdes/pubs/owm0264.pdf

For more information on the statistical underpinnings of low flow frequency analysis, please refer to USGS's Bulletin 17B: https://www.fema.gov/media-library/assets/documents/8403

For more information on how to develop and evaluate watershed regression analyses used in WREG and on hydrologic regression analyses more generally, please refer to the following sources:

- Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A., and Gilroy, E.J.. 2022. *Statistical methods in water resources: U.S. Geological Survey Techniques and Methods, book 4, chap. A3.* https://doi.org/10.3133/tm4a3
- Ries, K.G., J.B. Atkins, P.R. Hummel, M. Gray, R. Dusenbury, M.E. Jennings, W.H. Kirby, H.C. Riggs, V.B. Sauer, and W.O. Thomas, Jr. 2007. *The National Streamflow Statistics Program: A Computer Program for Estimating Streamflow Statistics for Ungaged Sites*. U.S. Geological Survey. https://md.water.usgs.gov/publications/tm-4-a6/.
- Stedinger, J., and G.D. Tasker. 1985. "Regional Hydrologic Analysis: 1. Ordinary, Weighted, and Generalized Least Squares Compared." *Water Resources Research* 21: 1421–1432. https://doi.org/10.1029/WR021i009p01421.

For a list of all states with pre-computed USGS flow statistic regression equations and their corresponding publications, please refer to USGS's Regional Regression Equation Publications by State website: https://water.usgs.gov/osw/programs/nss/NSSpubs_Rural.html

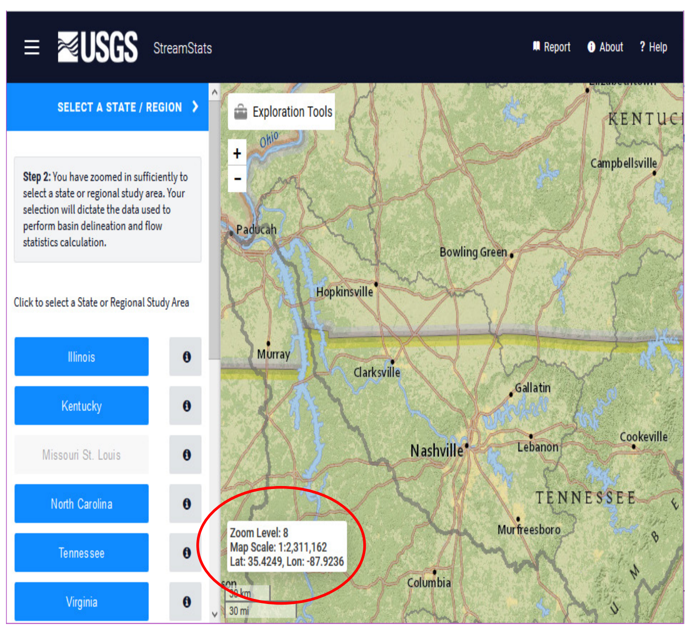
For the StreamStats, Hydrologic Toolbox, and WREG user manuals, please refer to the following webpages:

- StreamStats User Manual: https://www.usgs.gov/media/files/streamstats-version-4-user-instructions
- Hydrologic Toolbox User Manual: https://doi.org/10.3133/tm4D3
- WREG User Manual: https://pubs.usgs.gov/tm/tm4a8/

4.2 Troubleshooting Tips

I entered a location into the search bar in StreamStats but nothing happens.

You may need to zoom into the map near your location before the search will execute and prompt you to select a state or regional study area. Try to reach zoom magnification level 8 at a minimum. Your zoom level is shown in the lower left-hand portion of the screen.



I'm trying to install or run Hydrologic Toolbox and WREG, but I keep getting errors about "read access" and/or file permissions.

You may need administrative access to install these applications on your computer. Try installing them using an account with administrative permissions or contacting your organization's IT department for assistance.

5 References

Eng, K., Y-Y. Chen, and J. Kiang. 2009. *User's Guide to the Weighted-Multiple-Linear-Regression Program (WREG version 1.0): Techniques and Methods 4–A8*. U.S. Geological Survey, 21 pp. http://pubs.usgs.gov/tm/tm4a8.

Interagency Advisory Committee on Water Data. 1982. *Guidelines for Determining Flood Flow Frequency: Bulletin #17B of the Hydrology Subcommittee*. Office of Water Data Coordination, U.S. Geological Survey, Reston, VA, 183 pp.

Hortness, J.E. 2006. *Estimating Low-Flow Frequency Statistics for Unregulated Streams in Idaho: Scientific Investigations Report 2006–5035*. U.S. Geological Survey, 31 pp. https://pubs.usgs.gov/sir/2006/5035/pdf/sir20065035.pdf.

Barlow, P.M., McHugh, A.R., Kiang, J.E., Zhai, T., Hummel, P., Duda, P., and Hinz, S., 2022, U.S. Geological Survey Hydrologic Toolbox—A graphical and mapping interface for analysis of hydrologic data: U.S. Geological Survey Techniques and Methods, book 4, chap. D3, 23 p., https://doi.org/10.3133/tm4D3.

Ries, K.G., III, J.K. Newson, M.J. Smith, J.D. Guthrie, P.A. Steeves, T.L. Haluska, K.R. Kolb, R.F. Thompson, R.D. Santoro, and H.W. Vraga. 2017. *StreamStats, Version 4*. U.S. Geological Survey, Fact Sheet 2017–3046, 4 pp. https://doi.org/10.3133/fs20173046.

Appendix A: K Values Tables

Tables A-1 and A-2 partially reproduce “Appendix 3: Tables of K Values” from Bulletin 17B.

Table A-1: K Values for Positive Skew Estimates

Exceedance Probability	Skew Estimate									
	9	8	7	6	5	4	3	2	1	0
0.999	-0.22222	-0.25	-0.28571	-0.33333	-0.4	-0.5	-0.66667	-0.999	-1.78572	-3.09023
0.99	-0.22222	-0.25	-0.28571	-0.33333	-0.4	-0.5	-0.66663	-0.98995	-1.58838	-2.32635
0.90	-0.22222	-0.25	-0.28571	-0.33333	-0.4	-0.49986	-0.66023	-0.89464	-1.12762	-1.28155
0.80	-0.22222	-0.25	-0.28571	-0.33333	-0.39993	-0.49784	-0.63569	-0.77686	-0.85161	-0.84162
0.70	-0.22222	-0.25	-0.28571	-0.3333	-0.39914	-0.48902	-0.58783	-0.64333	-0.61815	-0.5244
0.60	-0.22222	-0.25	-0.28569	-0.33285	-0.39482	-0.46496	-0.51073	-0.48917	-0.39434	-0.25335
0.50	-0.22222	-0.24996	-0.28528	-0.32974	-0.37901	-0.41265	-0.39554	-0.30685	-0.16397	0
0.40	-0.22214	-0.24933	-0.28169	-0.31472	-0.33336	-0.31159	-0.22726	-0.08371	0.08763	0.25335
0.30	-0.2203	-0.24214	-0.25899	-0.2575	-0.21843	-0.1253	0.02279	0.20397	0.38111	0.5244
0.20	-0.19338	-0.18249	-0.14434	-0.06662	0.05798	0.22617	0.4204	0.60944	0.75752	0.84162
0.10	0.11146	0.23929	0.40026	0.58933	0.79548	1.00079	1.18006	1.30259	1.34039	1.28155
0.001	12.04437	11.46855	10.81343	10.06812	9.21961	8.25289	7.15235	5.90776	4.53112	3.09023

Table A-2: K Values for Negative Skew Estimates

Exceedance Probability	Skew Estimates									
	0	-1	-2	-3	-4	-5	-6	-7	-8	-9
0.999	-3.09023	-4.53112	-5.90776	-7.15235	-8.25289	-9.21961	-10.06812	-10.81343	-11.46855	-12.04437
0.99	-2.32635	-3.02256	-3.60517	-4.05138	-4.36777	-4.57304	-4.6868	-4.72613	-4.70514	-4.63541
0.90	-1.28155	-1.34039	-1.30259	-1.18006	-1.00079	-0.79548	-0.58933	-0.40026	-0.23929	-0.11146
0.80	-0.84162	-0.75752	-0.60944	-0.4204	-0.22617	-0.05798	0.06662	0.14434	0.18249	0.19338
0.70	-0.5244	-0.38111	-0.20397	-0.02279	0.1253	0.21843	0.2575	0.25899	0.24214	0.2203
0.60	-0.25335	-0.08763	0.08371	0.22726	0.31159	0.33336	0.31472	0.28169	0.24933	0.22214
0.50	0	0.16397	0.30685	0.39554	0.41265	0.37901	0.32974	0.28528	0.24996	0.22222
0.40	0.25335	0.39434	0.48917	0.51073	0.46496	0.39482	0.33285	0.28569	0.25	0.22222
0.30	0.5244	0.61815	0.64333	0.58783	0.48902	0.39914	0.3333	0.28571	0.25	0.22222
0.20	0.84162	0.85161	0.77686	0.63569	0.49784	0.39993	0.33333	0.28571	0.25	0.22222
0.10	1.28155	1.12762	0.89464	0.66023	0.49986	0.4	0.33333	0.28571	0.25	0.22222
0.001	3.09023	1.78572	0.999	0.66667	0.5	0.4	0.33333	0.28571	0.25	0.22222