

Stream-Network Navigation in the U.S. Geological Survey StreamStats Web Application

Kernell G. Ries III, Peter A. Steeves, John D. Guthrie, Alan H. Rea, and David W. Stewart

U.S. Geological Survey

kries@usgs.gov, psteeves@usgs.gov, jdguthrie@usgs.gov, ahrea@usgs.gov, dwestewar@usgs.gov, respectively

Abstract—StreamStats is a U.S. Geological Survey Web-based geographic information systems application developed as a tool for water-resources planning and management, engineering design, and other applications. The primary functionality of StreamStats allows users to obtain drainage-basin boundaries, basin characteristics, and streamflow statistics for gaged and ungaged sites. Recently, tools that allow stream-network navigation were added to StreamStats. These tools allow users to select any point along a stream and locate activities upstream and downstream from the selected point, such as streamgaging stations, dams, and point-source discharges, and obtain information about such activities. Users also can obtain stream-reach addresses and estimates of streamflow statistics for the selected points.

Keywords- GIS, statistical analysis, streamflow, web application, decision-support system, watershed characteristics, stream network

I. INTRODUCTION

StreamStats is a Web-based geographic information system (GIS) application (fig. 1) that provides users with access to an assortment of analytical tools that are useful for water-resources planning and management, engineering design, and other applications. StreamStats was developed by the U.S. Geological Survey (USGS), in cooperation with Environmental Systems Research Institute, Inc. (ESRI)¹, and is built on ESRI's ArcHydro Data Model and Tools [1]. StreamStats functionality can be accessed through a map-based user interface that appears in the user's Web browser (fig. 1), or individual functions can be requested remotely as Web services by other Web or desktop computer applications.

¹The use of trade, product, or firm names in this report is for descriptive purposes only and does not imply endorsement by the U.S. Government.

StreamStats was developed to allow users to easily obtain streamflow statistics, basin characteristics, and descriptive information for USGS data-collection stations and user-selected ungaged sites. The streamflow statistics that StreamStats provides, such as estimates of the 1-percent-probability flood, the mean flow, and the 7-day 10-year low flow, are used by engineers, land managers, biologists, and many others to help guide decisions in their everyday work. For example, estimates of the 1-percent-probability flood (a flood that is exceeded, on average, once in 100 years and has a 1-percent chance of being exceeded in any year, and which also is referred to as the 100-year flood) are used to create flood-plain maps that form the basis for setting insurance rates and land-use zoning in the United States. This and other streamflow statistics also are used for dam, bridge, and culvert design; water-supply planning and management; water-use appropriations and permitting; wastewater- and industrial-discharge permitting; hydropower-facility design and regulation; and establishing minimum streamflow requirements needed to protect freshwater ecosystems. The physical and climatic characteristics of drainage basins (basin characteristics) that StreamStats provides allows users to better understand the mechanisms that control water availability and quality at user-selected locations, and are useful for numerous planning and modeling purposes. In addition, basin characteristics are used as independent variables in regression analyses to develop equations that can be used to estimate streamflow statistics for ungaged sites.

Streamflow statistics can be computed from available data at USGS streamflow data-collection stations, which include streamgaging stations, partial-record stations, and miscellaneous-measurement stations. Streamflow data are collected continuously at streamgaging stations. Streamflow measurements are collected systematically over a period of years at partial-record stations to estimate peak-flow or low-flow statistics. Streamflow measurements usually are

collected at miscellaneous-measurement stations for specific hydrologic studies with various objectives. Most often, however, streamflow statistics are needed at locations where no streamflow data are available to compute the statistics, and alternate methods are needed to estimate streamflow statistics for these ungaged sites. StreamStats can provide estimates for ungaged sites much faster than historically used manual techniques.

Stream-network navigation tools recently were added to StreamStats. These tools allow users to identify stream reaches that are upstream or downstream from user-selected sites and obtain information for locations along the streams where activities occur that may affect streamflow conditions. This functionality allows researchers, planners, regulators, and others to better understand the effects of human activities, such as dams and water withdrawals, on streamflow upstream from locations of interest. Knowledge of the streamflow network and downstream human activities also is necessary to adequately determine whether a proposed upstream activity, such as a water withdrawal, can be allowed without adversely affecting downstream activities. Stream-network navigation and its uses are further described later in this paper.

II. STREAMSTATS WEB SITE AND FUNCTIONALITY

The StreamStats home page, at <http://streamstats.usgs.gov>, contains numerous links to other StreamStats pages that provide a description of the application, instructions for its use, news items, definitions of streamflow statistics and basin **characteristics, answers to frequently asked questions** (FAQs), and other related information. A link also provides access to a USGS Fact Sheet [2] that describes the development, functionality, and limitations of StreamStats. A gray box that contains a menu of links appears on the left side of the main StreamStats Web page. This box is duplicated on all other StreamStats Web pages to allow easy navigation between pages.

StreamStats was designed such that each state would be implemented as a separate application, with funding support from local partners, and an ultimate goal of full national implementation. Idaho became the first state to implement the national version of StreamStats in 2003, although a locally developed version was available for Massachusetts in 1999. By mid-2008, 14 states had applications available to the public, and 18 other states were in various stages of implementation.

Each state that has been implemented in StreamStats has an introductory Web page that (1)

identifies the area in which StreamStats is implemented if the entire state is not available, (2) identifies the streamflow statistics that can be estimated for ungaged sites by use of regression equations, (3) identifies and provides links to the reports that describe the development of the equations, (4) provides a link to the state application, and (5) identifies the other agencies that cooperated with the USGS in implementing the application. The current (2008) functionality in all StreamStats applications includes the abilities to:

- View a range of base-map features, such as roads, streams, political boundaries, and USGS topographic maps in the user interface map frame to facilitate finding locations of interest;
- Re-center the map on a user-specified point;
- Zoom in or out to a different map scale based on input of (1) a user-drawn rectangle, (2) a place name, (3) coordinates of longitude and latitude, (4) a specified scale, (5) a National Hydrography Dataset (NHD) reach address, or (6) the full extent of the state;
- Obtain information on the various map layers shown in the interface;
- Access previously published streamflow statistics, basin characteristics, and descriptive information for USGS data-collection stations, and link to the USGS National Water Information System (NWIS) Web site that provides access to data collected at the selected stations;
- Delineate the drainage-basin boundary for a user-selected site;
- Edit the basin boundary if the automated boundary is inaccurate or if scenarios involving a change in the basin boundaries are of interest;
- Measure basin characteristics, such as drainage area and stream slope, and determine the NHD reach address for the selected site;
- Estimate streamflow statistics and provide indicators of the accuracy of the estimates for the site;
- Edit the basin characteristics determined by StreamStats and recompute the flow statistics;
- Search upstream or downstream from a selected site to identify connected stream reaches and to locate and provide information on natural or man-made features, such as dams and wastewater discharges, that may affect the quantity or quality of the streamflow;
- Download the basin boundary for use in other applications, along with any basin

characteristics and streamflow statistics that have been computed for a selected site; and

- Print the map displayed in the user interface.

In addition to the standard functionalities listed above, some state applications also have custom functionalities. In these cases, the state introductory Web page will describe the use and limitations of the special functionality. A full explanation of the development, use, and limitations of StreamStats is not provided here. Readers are referred to the StreamStats Fact Sheet [2] and Web pages for additional explanation. Substantial parts of this paper are derived from the Fact Sheet, including subsequent explanations of stream networks and stream-network navigation in StreamStats.

III. STREAM NETWORKS

A digital stream network is a representation of streams, water bodies, and constructed channels for a given area as would be seen in an aerial photograph or on a topographic map. As with photographs and maps, stream networks can be shown at various scales, with less detail shown at smaller scales than at larger scales. In a digital stream network, connecting lines are drawn through lakes, wetlands, bridges, culverts, and any other features where the stream channel is not visible from maps or photographs, thus eliminating any breaks in the network. The stream network is divided into segments and the direction of flow is assigned as an attribute of each segment. Further discussion of digital stream networks focuses on the NHD [3], which was developed jointly by the USGS and the U.S. Environmental Protection Agency (USEPA); but more than one stream network often will be available for navigation in StreamStats.

In the NHD, the stream network is represented as a vector line-feature class layer, in which each line segment is digitized so that its geometric topology is oriented in the downstream direction. Surface-water bodies are represented as vector polygons. The stream network is segmented between confluences or at locations where the feature type changes. The stream segments are called flowlines. Each flowline has a unique identifier (ComID) and a set of descriptive attributes, some of which are stream name, length, flow direction, and feature type, such as intermittent, perennial, lake, or wetland.

Up to three versions of the NHD may be available for any given area. A medium-resolution version of the NHD is available nationally at a scale of 1:100,000. A high-resolution version of the NHD also is available for nearly the entire Nation at a scale of 1:24,000. In addition, some state and local agencies have created local-resolution versions of the NHD at

various scales with finer resolutions than can be obtained in the high-resolution NHD.

NHD reaches are composed of one or more flowlines. Each reach is identified by a unique reach code, which is shared across multiple scales of NHD. Points of interest along NHD stream reaches, such as the locations of dams, streamgaging stations, and effluent discharges, can be assigned a reach address, which consists of the reach code and measure. The measure is the percentage of distance along the reach from the downstream end. The points of interest are called point events.

The stream-network data structure establishes flow direction between flowlines and allows users to navigate upstream or downstream from a user-selected point on a stream to locate and obtain information for the associated reaches and point events. StreamStats uses the geometry of the flowlines to navigate the network and provide fast network trace results.

Another digital stream-network dataset, named NHDPlus [4], was developed by combining the medium-resolution NHD with digital elevation, land classification, and watershed boundary datasets to obtain a geospatially consistent dataset that is useful for detailed hydrologic analysis. The stream network that is available in the NHDPlus dataset, though derived from the medium resolution NHD, has been somewhat modified and has numerous attributes associated with it that are not available from the standard NHD. The NHDPlus dataset has been used to provide drainage-basin delineation capabilities in some StreamStats state applications, and it also can be used for network navigation.

IV. NETWORK NAVIGATION IN STREAMSTATS

The stream networks that are available for navigation in StreamStats vary among the applications for each state. The networks are selected based on availability, the information linked as point events, and the interest of the cooperators that fund the development of the individual applications.

StreamStats has three tools for network navigation – **Config**, **Trace from Outlet**, and **Perform an Ad Hoc Trace** - and a tool for estimating streamflow statistics at ungaged sites that relies on network navigation (described below). The **Config** tool is used to specify the network upon which tracing (navigating upstream or downstream) will be done, the direction of the trace, and the map layers of point events that will be included in the trace. The dialog window that opens when the **Config** tool button is selected is shown in figure 2. Tracing can be done either by first delineating a drainage basin for a selected site and then using the **Config** tool and the **Trace from Outlet** tool in sequence, or by first using the **Config** tool and then

the **Perform an Ad Hoc Trace** tool and selecting any point on a stream to begin the trace. The **Point Delineation** tool is used to delineate basin boundaries before the **Trace from Outlet** tool can be used. The map scale must be at least 1:24,000 before the **Point Delineation** tool can be used.

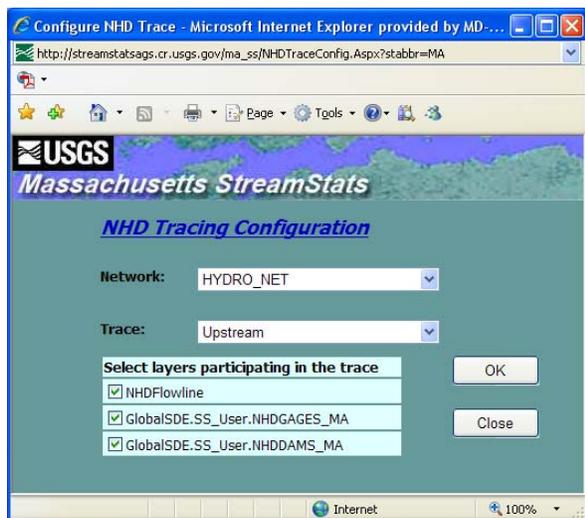


Figure 2. View of the Configure NHD Trace window, which allows user selection of the stream network on which the trace will be done, the direction of the trace, and map layers included in the trace.

A view of the StreamStats map frame that illustrates the results of an upstream trace for a user-selected point on a stream in Massachusetts is shown in figure 3. In this example, a user has selected a point and used the **Point Delineation** tool to delineate the drainage basin (shaded magenta area) for the point. The **Config** button then was used to select the NHD Flowline data layer and the upstream direction for tracing. The reaches found in the trace are highlighted in light blue. These reaches include the reach on which the selected point is located and all upstream reaches. A streamgaging station, represented as a red diamond, and three dams, represented as dark blue pentagons, also were found in the trace.

StreamStats trace reports provide the date and time that the trace was performed, the names of the network and linear reference layer on which the trace was performed, the direction of the trace, the NHD reach code and measure for the selected site, a table that lists all of the flowlines found in the trace, and a table of information for each of the layers of point events that were selected for inclusion in the trace. Hyperlinks connect the rows of each reach and point event information in each table to additional information. The report for the trace shown in figure 3 is shown below in figure 4. The flowlines found in the trace are not shown, as the listing would be too large. Only the

tables for the dams (3) and streamgaging stations (1) found in the trace are shown. In the tables, the RID is the NHD reach code and MEAS is the measure.

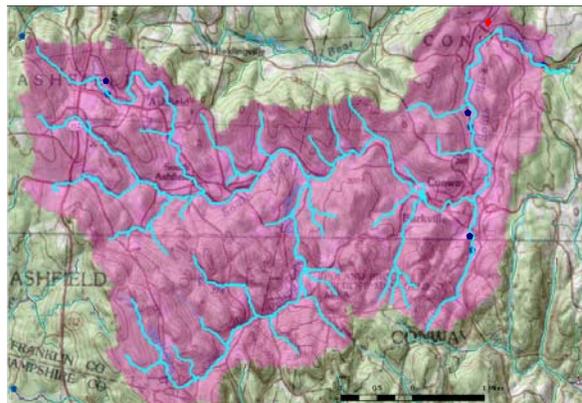


Figure 3. View of the StreamStats map frame showing an upstream network trace for a user-selected point on a stream in Massachusetts.

The primary benefit of the trace functionality is to understand how the flow at a particular site on a stream may be affected by upstream activities or how downstream flow may be affected by current or proposed activities at the selected site. The USEPA and many state and local agencies have worked to associate their water-related data to the NHD, and many similar efforts are underway. Dams from the U.S. National Inventory of Dams dataset [5] and USGS streamgaging stations also have been associated to the NHD nationally. The layers that are associated to stream networks in StreamStats vary by state and with time.

V. ESTIMATING STREAMFLOW STATISTICS FOR UNGAGED SITES

Development of the stream-network navigation tool also has led to the ability for StreamStats to estimate streamflow statistics for user-selected un-gaged sites on the basis of known flows for nearby upstream or downstream streamgaging stations. The **Point Delineation** and **Estimate Flows Based on Similar Streamgaging Stations** tools are used in sequence to obtain the estimates. The process uses network navigation to identify streamgaging stations that are upstream and downstream from an un-gaged site. The drainage area for each identified streamgaging station is retrieved from a database, and the drainage area for the streamgaging station is divided by the drainage area for the un-gaged site to obtain the drainage-area ratio. If the process identifies a streamgaging station with a drainage-area ratio between 0.5 and 1.5, then all streamflow statistics that are available for the station will be extracted from the database and multiplied by

the reciprocal of the drainage-area ratio to obtain estimates of the statistics for the ungaged site.

If the process identifies upstream and downstream stations with drainage-area ratios between 0.5 and 1.5, the closest upstream and downstream stations will be used to estimate the streamflow statistics for the ungaged site and both sets of estimates will be provided in the StreamStats output. In addition, the two sets of estimates will be weighted using equation 24 from Ries and Dillow [6], which gives more weight to the estimates for the station that is closest in drainage area to the ungaged site. These weighted estimates also are presented in the StreamStats output.



Figure 4. Results for an upstream trace from the selected basin outlet shown in figure 3.

When the **Generate Flows Based on Similar Gages** tool is used to obtain estimates for ungaged sites, StreamStats users can specify whether to include only stations with natural flow conditions in the analysis or to also include stations that are affected by flow regulations. This decision must be made carefully. If users choose to include regulated stations, they must consider how the effects of regulation could change

between the streamgaging station and the ungaged site. For example, if a regulated station is downstream from the ungaged site, it is possible that the stream is not affected by regulation at the ungaged site; therefore, the streamflow statistics estimated on the basis of the flow per unit area at the station will not be representative of the flow conditions at the ungaged site. Conversely, if the regulated station is upstream from the ungaged site, streamflow from tributaries entering between the station and the ungaged site may dampen the effects of the regulation at the station and cause the estimated streamflow statistics to be unrepresentative of conditions at the ungaged site.

StreamStats also can provide estimates for ungaged sites based on USGS-developed regression equations, but the process does not rely on network navigation. More information on this process and other StreamStats functionalities is available in Ries and others [2] and on the StreamStats Web pages at <http://streamstats.usgs.gov>. When estimates of flow statistics are available based on the drainage-area ratio method and on regression equations, StreamStats will determine final estimates by weighting the drainage-area ratio estimates with the regression-equation estimates using equation 24 from Ries and Dillow [6].

VI. REFERENCES

- [1] Environmental Systems Research Institute, Inc., Hydro Data Model, 2008, available online at <http://support.esri.com/index.cfm?fa=downloads.dataModels.filteredGateway&dmid=15>.
- [2] Ries III, K.G., Guthrie, J.D., Rea, A.H., Steeves, P.A., and Stewart, D.W., StreamStats: A water resources Web application, U.S. Geological Survey Fact Sheet 2008-3067, 6 p., 2008, (Also available online at <http://pubs.er.usgs.gov/usgspubs/fs/fs20083067>).
- [3] U.S. Geological Survey, National Hydrography Dataset, 2008, available online only at <http://nhd.usgs.gov>.
- [4] Horizon Systems Corporation, National Hydrography Dataset Plus, 2008, available online only at <http://www.horizon-systems.com/nhdplus/index.php>.
- [5] U.S. Army Corps of Engineers, National Inventory of Dams, 2008, available online only at <http://crunch.tec.army.mil/nidpublic/webpages/nid.cfm>.
- [6] Ries III, K.G., and Dillow, J.J.A., Magnitude and frequency of floods on nontidal streams in Delaware, U.S. Geological Survey Scientific Investigations Report 2006-5146, 2006, p. 31. (Also available online at <http://pubs.er.usgs.gov/usgspubs/sir/sir20065146>).