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The New Hampshire Watershed Tool: A Geographic Information System Tool to Estimate Streamflow Statistics and Ground-Water-Recharge Rates

Open-File Report 2005-1172

U.S. Department of the Interior
U.S. Geological Survey

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Conversion Factors

Multiply	By	To obtain
	Length	
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
	Area	
square mile (mi^2)	2.590	square kilometer (km^2)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

Pertinent Web Sites

Web Site	Owner	Source of	Access date
http://www.cits.rncan.gc.ca	Natural Resources Canada	Canadian elevation datasets	May 4, 2005
http://www.granit.sr.unh.edu	Complex Systems Research Center	Topographic images of New Hampshire	May 4, 2005
http://nhd.usgs.gov	U.S. Geological Survey	National Hydrography Dataset	May 4, 2005
http://ned.usgs.gov	U.S. Geological Survey	National Elevation Dataset	May 5, 2005
http://nh.water.usgs.gov	U.S. Geological Survey New Hampshire-Vermont Water Science Center	New Hampshire Watershed Tool Report	June 6, 2005
http://www.climatesource.com	Climate Source	PRISM Precipitation Datasets	May 4, 2005

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Abstract

Estimates of low-flow statistics, flow durations, and ground-water-recharge rates are needed to assist water-resource managers in assessing surface-water resources and ground-water availability. Often these estimates are required at ungaged sites where no observed streamflow data are available for analysis. Regression equations for estimating low-flow statistics and flow durations, and for estimating ground-water-recharge rates at ungaged sites have been developed for New Hampshire. However, use of these equations requires numerous input parameters, such as basin and climatic characteristics. This report describes a customized geographic information system (GIS) application, the New Hampshire Watershed Tool, that automates the measurement of the characteristics used for input to the regression equations and calculates the corresponding flow statistics and ground-water-recharge rates.

Introduction

The population of New Hampshire grew by 11.4 percent—approximately 141,000 people—from 1990 to 2000 and another 215,000 people are expected to live in the state by the year 2025 (New Hampshire State Data Center, 2001). Because this population growth has caused increased demands on water resources, improved tools are needed by water-resources managers to characterize water availability and ensure sufficient supply for all users—domestic, commercial, and agricultural—while maintaining aquatic habitat.

The U.S. Geological Survey (USGS), in cooperation with the New Hampshire Department of Environmental Services (NHDES), has developed regression equations for estimating low-flow statistics, flow durations, and ground-water recharge rates (Flynn, 2003; Flynn and Tasker, 2004). Equations for low-flow statistics include spring, summer, fall, winter, and annual 7-day 2-year and 7-day 10-year low flows. Equations for flow-duration statistics include spring, summer, fall, winter, and annual 60-, 70-, 80-, 90-, 95-, and 98-percent flow durations.

To solve the equations accurately, consistently, and quickly, a computer application, the New Hampshire Watershed Tool (referred to herein as the "Tool"), was developed. This geographic information system (GIS) application is based on the National Hydrography Dataset (NHD) tools (U.S. Geological Survey and U.S. Environmental Protection Agency, 2004) and automates the delineation of drainage-basin boundaries and the calculation of basin characteristics required by the equations. The Tool includes software that was written in the computer language FORTRAN to solve the regression equations and compute the accuracy of the results.

Purpose and Scope

The purpose of this report is to describe development and use of (1) regression equations for estimating low-flow-frequency characteristics of ungaged, unregulated, rural New Hampshire streams; (2) regression equations for estimating ground-water-recharge rates of drainage basins in New Hampshire; and (3) the New Hampshire Watershed Tool.

Estimating Flow-Frequency Characteristics of Ungaged, Unregulated, Rural New Hampshire Streams

The most reliable estimates of flow-frequency characteristics are generally obtained by frequency analysis of flow data from gaged streams. Estimates, however, often are required at stream locations where no data are available. To solve this problem, regression equations were developed for estimating low-flow statistics and flow durations at ungaged, unregulated streams in rural drainage basins in New Hampshire by relating flow-frequency characteristics to basin and climatic characteristics at gaged locations. Details of the development of the equations are discussed in Flynn (2003).

Regression Equations

The equations for estimating the flow-frequency characteristics were developed using generalized least squares (GLS) regression methods (Tasker, 1987) and the GLSNET software (G.D. Tasker, K.M. Flynn, A.M. Lumb, W.O. Thomas, Jr., U.S. Geological Survey, written commun., 1995). Tasker and Stedinger (1989) demonstrated that GLS regression provides the most appropriate results for hydrologic purposes because the principles of GLS allow weight to be given to each station in the analysis to compensate for differences in length of record and for streamflow data that are correlated spatially and temporally. The equations for estimating flow duration (daily-mean discharges exceeded a given percentage of time) were developed using ordinary least squares (OLS) regression procedures (SAS Institute Inc., 1990) because period-of-record flow-duration statistics lack the annual time series required by GLSNET software. A summary of the equations is included in table 1.

The average basin slope (BS) and maximum basin elevation (MxBE) were derived from the National Elevation Dataset (U.S. Geological Survey, 2001). The average basin slope was determined using the ARC/INFO SLOPE command (Environmental Systems Research Institute, Inc., 1994).

The basin characteristics that are climatic in nature, such as precipitation, temperature, and snow cover, were derived from 2-kilometer grid Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly, 2000) data. These grids were resampled with bilinear interpolation to a 30-meter-cell resolution with the ARC/INFO RESAMPLE command (Environmental Systems Research Institute, Inc., 1994). The grids representing the average winter precipitation, the mean annual temperature, and the summer temperature were manually extrapolated into Canada to cover portions of drainage basins for New Hampshire streams extending into Canada.

The coniferous and mixed coniferous-deciduous forest data were derived from the 1992 National Land Cover Dataset (NLCD) (U.S. Geological Survey, 2000). The grids were extended into Canada using a similar land-cover dataset available for Canada at a 25-meter resolution (Brenna Beaulieu, Quebec Ministry of the Environment, written commun., 2001).

Using the Flow-Frequency Regression Equations

Application of the regression equations developed to estimate flow-frequency characteristics is limited to sites on ungaged, unregulated streams in rural New Hampshire drainage basins and to sites with basin characteristics that are within the range used in the development of the equations. The ranges of basin characteristics used in the regression analysis are shown in table 2. If basin characteristics from an ungaged site are outside of these ranges, the accuracies of the predictions are unknown. The Tool alerts the user if basin characteristics are outside the allowable ranges. It also identifies the presence of dams, based on a dataset available from the U.S. Environmental Protection Agency (1998). Because dams may indicate flow regulation within the delineated drainage basin, users of the Tool need to assess the degree of flow regulation and its effect on the accuracy of estimated flows.

Basin characteristics used for developing the regression equations were determined with a GIS using datasets and methods explained in Flynn (2003). Application of the equations using basin characteristics derived by other means, or using data sources or methods that deviate from those described in this report, may introduce bias and produce streamflow statistics with unknown error.

The standard error of prediction and prediction intervals are measures of the accuracy of results obtained from the regression equations. These statistics are computed and output by the New Hampshire Watershed Tool. Users of the Tool can refer to the report by Flynn (2003) for a detailed explanation of the measures and how they are computed.

Estimating Ground-Water-Recharge Rates of Drainage Basins in New Hampshire

Regression equations were developed for estimating ground-water-recharge rates of rural drainage basins in New Hampshire by relating estimates of ground-water-recharge rates to basin and climatic characteristics of gaged basins. Details of the development of the equations are described in Flynn and Tasker (2004).

Regression Equations

The equations for estimating the ground-water-recharge rates were developed using generalized least squares (GLS) regression methods (Tasker, 1987). Ten basin characteristics having the most predictive power were selected as independent variables in the annual and seasonal equations. The equations are shown in table 3.

The climatic characteristics of the basin, such as precipitation, temperature, and snowcover, were derived from 2-kilometer grid Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly, 2000) data. These grids were resampled with bilinear interpolation to a 30-meter-cell resolution with the ARC/INFO RESAMPLE command (Environmental Systems Research Institute, Inc., 1994). The grids representing the average monthly mean winter temperature and the mean annual snowfall were manually extrapolated into Canada, as necessary. The mean annual precipitation grid was extended into Canada, as necessary, by using annual precipitation data from Canada (Ghislain Jacques, Environment Quebec, written commun., January 17, 2002).

The coniferous and mixed coniferous-deciduous forest grids were derived from the 1992 National Land Cover Dataset (NLCD) (U.S. Geological Survey, 2000). The grids were

Table 1. Regression equations for estimating flow duration and low-flow statistics for unregulated, ungaged, rural New Hampshire streams.

[**Statistic**, Pwinxx, Psprxx, Psumxx, Pfallxx are the xx-percent duration flows for winter (win), spring (spr), summer (sum), and fall (fall), respectively; Pporxx is the xx-percent duration flow for the period-of-record (por); **7Qt**, 7-day, t-year or season low flow. All flows are in cubic feet per second (ft^3/s); *, multiply by; **BCF**, Bias correction factor; **DA**, drainage area, in square miles; **BS**, average basin slope, in percent; **MxBE**, maximum basin elevation, in feet; The following basin characteristics were derived from 2-kilometer grid Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly, 2000) data from 1961 to 1990 resampled with bilinear interpolation to a 30-meter-cell resolution: **ABT**, basinwide mean of the average mean annual temperature, in degrees Fahrenheit; **SBT**, basinwide mean of the average monthly mean temperature during the summer (June 1 to October 31), in degrees Fahrenheit; **SGP**, average total summer precipitation (June 1 to October 31) at basin-outlet point, in inches; **WCP**, average total winter precipitation (January 1 to March 15) at the basin centroid, in inches; **SpGP**, average total spring precipitation (March 16 to May 31) at basin-outlet point, in inches. The following basin characteristics were derived from the 1992 National Land Cover Data Set (NLCD) (U.S. Geological Survey, 2000): **C**, percent of basin covered by coniferous forest, in percent; **CD**, percent of basin covered by mixed coniferous and deciduous forest, in percent]

Statistic	BCF	Regression equation
		Flow duration
Pwin60 =	1.01935	$* 10^{-0.74691} * (DA)^{1.05501} * (C)^{-0.31447} * (WCP)^{1.04311}$
Pwin70 =	1.01824	$* 10^{-0.85475} * (DA)^{1.06248} * (C)^{-0.32065} * (WCP)^{1.085}$
Pwin80 =	1.01431	$* 10^{-0.88606} * (DA)^{1.0528} * (C)^{-0.28824} * (WCP)^{1.00598}$
Pwin90 =	1.01631	$* 10^{-1.04824} * (DA)^{1.06566} * (C)^{-0.23842} * (WCP)^{0.9677}$
Pwin95 =	1.01942	$* 10^{-1.17324} * (DA)^{1.06732} * (C)^{-0.21459} * (WCP)^{0.95736}$
Pwin98 =	1.03264	$* 10^{-1.22564} * (DA)^{1.05571} * (C)^{-0.15768} * (WCP)^{0.83447}$
Pspr60 =	1.00679	$* 10^{0.000678} * (DA)^{1.01298} * (BS)^{0.31101}$
Pspr70 =	1.00596	$* 10^{-0.0748} * (DA)^{1.01608} * (BS)^{0.28206}$
Pspr80 =	1.00668	$* 10^{-0.0203} * (DA)^{1.01729} * (BS)^{0.23293} * (CD)^{-0.08555}$
Pspr90 =	1.00811	$* 10^{-0.04102} * (DA)^{1.01595} * (BS)^{0.15284} * (CD)^{-0.11743}$
Pspr95 =	1.00936	$* 10^{-0.0632} * (DA)^{1.01597} * (BS)^{0.099718} * (CD)^{-0.15498}$
Pspr98 =	1.01373	$* 10^{-0.10609} * (DA)^{1.02007} * (BS)^{0.11425} * (CD)^{-0.24025}$
Psum60 =	1.05101	$* 10^{11.8078} * (DA)^{1.18298} * (SBT)^{-9.04402} * (C)^{-0.1922} * (SGP)^{2.86063}$
Psum70 =	1.06039	$* 10^{14.0257} * (DA)^{1.19901} * (SBT)^{-10.3043} * (C)^{-0.20291} * (SGP)^{2.77037}$
Psum80 =	1.07543	$* 10^{14.0788} * (DA)^{1.2123} * (SBT)^{-10.5568} * (SGP)^{2.76521}$
Psum90 =	1.09816	$* 10^{17.8757} * (DA)^{1.2409} * (SBT)^{-12.691} * (SGP)^{2.58347}$
Psum95 =	1.12433	$* 10^{19.5562} * (DA)^{1.28282} * (SBT)^{-13.8734} * (SGP)^{2.7607}$
Psum98 =	1.13959	$* 10^{24.8367} * (DA)^{1.25479} * (SBT)^{-16.1965} * (SGP)^{1.78959}$
Pfall60 =	1.02332	$* 10^{-0.70158} * (DA)^{0.94819} * (MxBE)^{0.24926} * (C)^{-0.08028}$
Pfall70 =	1.02860	$* 10^{-1.02695} * (DA)^{0.95106} * (MxBE)^{0.32968} * (C)^{-0.12032}$
Pfall80 =	1.03285	$* 10^{-1.43202} * (DA)^{0.94519} * (MxBE)^{0.4377} * (C)^{-0.16618}$
Pfall90 =	1.04291	$* 10^{-1.90346} * (DA)^{0.95483} * (MxBE)^{0.54551} * (C)^{-0.21994}$
Pfall95 =	1.06287	$* 10^{-2.34912} * (DA)^{0.98509} * (MxBE)^{0.63994} * (C)^{-0.26681}$
Pfall98 =	1.10999	$* 10^{-2.93315} * (DA)^{1.02072} * (MxBE)^{0.76078} * (C)^{-0.29871}$
Ppor60 =	1.01422	$* 10^{-3.53416} * (DA)^{1.08542} * (SGP)^{2.54435}$
Ppor70 =	1.01800	$* 10^{-1.65947} * (DA)^{1.09815} * (ABT)^{-1.29046} * (SGP)^{2.59298}$
Ppor80 =	1.03216	$* 10^{0.14014} * (DA)^{1.14248} * (ABT)^{-2.7358} * (SGP)^{2.83256}$
Ppor90 =	1.05674	$* 10^{2.94244} * (DA)^{1.19434} * (ABT)^{-4.72162} * (SGP)^{2.92621}$
Ppor95 =	1.07750	$* 10^{5.05371} * (DA)^{1.23203} * (ABT)^{-6.13047} * (SGP)^{2.89144}$
Ppor98 =	1.11561	$* 10^{6.24458} * (DA)^{1.28081} * (ABT)^{-7.19399} * (SGP)^{3.13133}$
		Low-Flow Frequency
7Q2 win =	1.01469	$* 10^{-0.86255} * (DA)^{1.05538} * (C)^{-0.22494} * (WCP)^{0.88402}$
7Q10 win =	1.02279	$* 10^{-1.24495} * (DA)^{1.08506} * (C)^{-0.20848} * (WCP)^{0.9756}$
7Q2 spr =	1.01039	$* 10^{-0.93746} * (DA)^{1.04219} * (SpGP)^{0.93329} * (C)^{-0.12319}$
7Q10 spr =	1.01307	$* 10^{-1.35488} * (DA)^{1.06065} * (SpGP)^{1.08213} * (C)^{-0.12298}$
7Q2 sum =	1.14416	$* 10^{14.00639} * (DA)^{1.22668} * (SBT)^{-10.70843} * (SGP)^{2.88837}$
7Q10 sum =	1.27148	$* 10^{18.56974} * (DA)^{1.36816} * (SBT)^{-14.06792} * (SGP)^{3.55322}$
7Q2 fal =	1.02686	$* 10^{-1.3758} * (DA)^{0.96049} * (MxBE)^{0.39654} * (C)^{-0.12046}$
7Q10 fal =	1.06484	$* 10^{-2.55435} * (DA)^{0.97395} * (MxBE)^{0.68011} * (C)^{-0.22167}$
7Q2 yr =	1.14477	$* 10^{3.77893} * (DA)^{1.24597} * (ABT)^{-5.77815} * (SGP)^{3.39819}$
7Q10 yr =	1.27688	$* 10^{5.33462} * (DA)^{1.39481} * (ABT)^{-7.67405} * (SGP)^{4.16826}$

Table 2. Ranges of basin characteristics used in development of the regression equations for estimating flow duration and low-flow statistics of ungaged, unregulated streams in New Hampshire.

Basin characteristic	Abbreviation	Minimum	Mean	Maximum
Drainage area (square miles)	DA	3.26	97.2	689
Average basin slope (percent)	BS	3.19	16.5	38.1
Maximum basin elevation (feet)	MxBE	260	3,120	6,290
Average summer gage precipitation (inches)	SGP	16.5	18.7	23.1
Average spring gage precipitation (inches)	SpGP	6.83	8.85	11.5
Average winter basin centroid precipitation (inches)	WCP	5.79	7.96	15.1
Average mean annual basin temperature (degrees Fahrenheit)	ABT	36.0	42.3	48.7
Average mean summer basin temperature (degrees Fahrenheit)	SBT	52.9	58.7	64.4
Percent coniferous forest (percent)	C	3.07	20.9	56.2
Percent mixed coniferous-deciduous forest (percent)	CD	6.21	26.6	46.1

extended into Canada using a similar land-cover dataset available for Canada at a 25-meter resolution (Brenna Beaulieu, Quebec Ministry of the Environment, written commun., 2001).

Using the Ground-Water-Recharge Rate Regression Equations

Application of the regression equations is limited to rural New Hampshire drainage basins with basin characteristics that are within the range of those used in the development of the equations. The ranges of basin characteristics used in the regression analysis are shown in table 4. If the equations are applied to basins with characteristics outside of these ranges, the accuracies of the predictions are unknown. The New Hampshire Watershed Tool alerts the user if basin characteristics are outside the allowable ranges.

Basin characteristics used for developing the regression equations were determined with a GIS using datasets and methods explained in Flynn and Tasker (2004). Application of the equations using basin characteristics derived by other means, or using data sources or methods that deviate from those described in this report, may introduce bias and produce ground-water-recharge-rate estimates with unknown error.

The standard error of prediction and prediction intervals are measures of the accuracy of results obtained from the regression equations. These statistics are computed and output by the New Hampshire Watershed Tool. Users of the Tool can refer to the report by Flynn and Tasker (2004) for a detailed explanation of the measures and how they are computed.

Table 3. Regression equations for estimating ground-water-recharge rates of rural New Hampshire drainage basins.

[All recharge results are in inches per season or year. The following basin characteristics were derived from 2-kilometer grid Parameter-elevation Regressions on Independent Slopes Model (PRISM) (Daly, 2000) data from 1961 to 1990 resampled with bilinear interpolation to a 30-meter-cell resolution: **AGP**, average annual precipitation at basin-outlet point of basin, in inches; **WBT**, basinwide mean of the minimum monthly mean temperature during the winter (January 1 to March 31), in degrees Fahrenheit; **SpGP**, average total spring precipitation (March 16 to May 31) at basin-outlet point, in inches; **ASC**, basinwide average of the mean annual snowfall, in inches; **SPG**, average total summer precipitation (June 1 to October 31) at basin-outlet point, in inches; **ABT**, basinwide mean of the average mean annual temperature, in degrees Fahrenheit; **FCP**, average total fall precipitation (November 1 to December 31) at basin centroid, in inches; **ACP**, average annual precipitation at the basin centroid, in inches. The following basin characteristics were derived from the 1992 National Land Cover Data Set (NLCD) (U.S. Geological Survey, 2000): **C**, percent of basin containing coniferous forest, in percent; and **CD**, percent of drainage basin containing mixed coniferous and deciduous forest, in percent]

Ground-water-recharge-rate period	Regression equation
Winter	-3.485 + 0.160(AGP) + 0.168(WBT) - 0.041(C)
Spring	-1.544 + 0.721(SpGP) + 0.045(ASC) - 0.032(C)
Summer	3.725 + 0.573(SGP) - 0.223(ABT) - 0.039(CD)
Fall	0.389 + 0.499(FCP) - 0.049(C)
Annual	-1.932 + 0.589(ACP) - 0.176(C)

Table 4. Ranges of basin characteristics used in development of the regression equations for estimating ground-water-recharge rates of rural drainage basins in New Hampshire.

Basin characteristic	Abbreviation	Minimum	Mean	Maximum
Average annual gage precipitation (inches)	AGP	35.83	42.93	53.11
Average summer gage precipitation (inches)	SGP	16.46	18.60	23.11
Average spring gage precipitation (inches)	SpGP	6.83	8.85	11.54
Average annual basin-centroid precipitation (inches)	ACP	37.44	45.32	75.91
Average mean annual basin temperature (degrees Fahrenheit)	ABT	36.05	42.35	48.69
Average minimum winter basin temperature (degrees Fahrenheit)	WBT	0.8	10.61	19.88
Percent coniferous forest (percent)	C	3.07	20.65	56.18
Percent mixed coniferous-deciduous forest (percent)	CD	6.21	26.05	46.13
Average fall basin-centroid precipitation (inches)	FCP	6.57	8.38	15.20
Average annual snowcover (inches)	ASC	54.46	102.41	219.07

New Hampshire Watershed Tool

A GIS application, the New Hampshire Watershed Tool, was developed to determine the basin characteristics required by the equations for estimating low-flow frequencies, flow durations, and ground-water-recharge rates for basins in New Hampshire. This application allows the user to interactively select a point on a stream of interest. The Tool automatically delineates the upstream drainage area, quantifies the required basin characteristics, solves the regression equations, and calculates the standard error of prediction and prediction intervals.

The Tool was developed in the Environmental Systems Research Institute, Inc. (ESRI) ArcView version 3.2 software (1996a) using ESRI Avenue programming language (Environmental Systems Research Institute, Inc., 1996b) and was converted to an ESRI ArcView extension. Extensions are plug-in programs that can be easily loaded into ArcView or unloaded as needed. The drainage-basin delineation is based on the NHD and the NHD Toolkit (U.S. Geological Survey and U.S. Environmental Protection Agency, 2004) and uses drainage-boundary delineation concepts from the NHD Watershed extension (J.R. Hill, Horizon Systems Corporation, and P.A. Steeves, U.S. Geological Survey, written commun., 2001).

System Requirements

The New Hampshire Watershed Tool requires the following software and toolkits:

1. ESRI ArcView version 3.2 or 3.3;
2. The ESRI ArcView 3.x Spatial Analyst (version 2) extension; and
3. The NHD Toolkit, version 7.0.0 (U.S. Geological Survey and U.S. Environmental Protection Agency, 2004).

The NHD Toolkit is available for download from the NHD website, http://nhd.usgs.gov/. The NHD Toolkit contains a suite of extensions, some of which are used to process NHD data and others that are required for execution of the New Hampshire Watershed Tool.

The computer and operating system requirements for the Tool are defined by the ESRI ArcView software. The Tool successfully runs in Microsoft Windows98, NT, 2000, and XP. Other operating systems have not been tested. Notepad, a program for viewing text files commonly packaged with the Microsoft Windows operating system, is required. Required disk space for the entire suite of topographic map images, NHD data, and other supporting datasets for computing basin characteristics for the entire State of New Hampshire is estimated to be 5 to 6 gigabytes. Data such as the NHD and the topographic map images, however, can be installed in different locations on a local network. One gigabyte of virtual memory is required for delineating the full range of drainage-basin sizes in New Hampshire.

Data Requirements

The New Hampshire Watershed Tool requires 5 to 6 gigabytes of data to work statewide. Furthermore, for the Tool to function properly, the data directory must be structured and use the naming convention shown in figure 1. For each hydrologic unit, there are two directories whose names begin with the hydrologic unit code and end in either "_24shp" or "_ws." The folder with the "_24shp" suffix contains the 1:24,000-scale NHD for New Hampshire projected into the New Hampshire State Plane coordinate system and converted to the ESRI ArcView shapefile format using the NHD Arc2shape extension. The naming conventions of the subdirectories in the "_24shp" directory are generic to the NHD and are explained in the help files of NHD extensions. The NHD for New Hampshire, and the processing instructions,

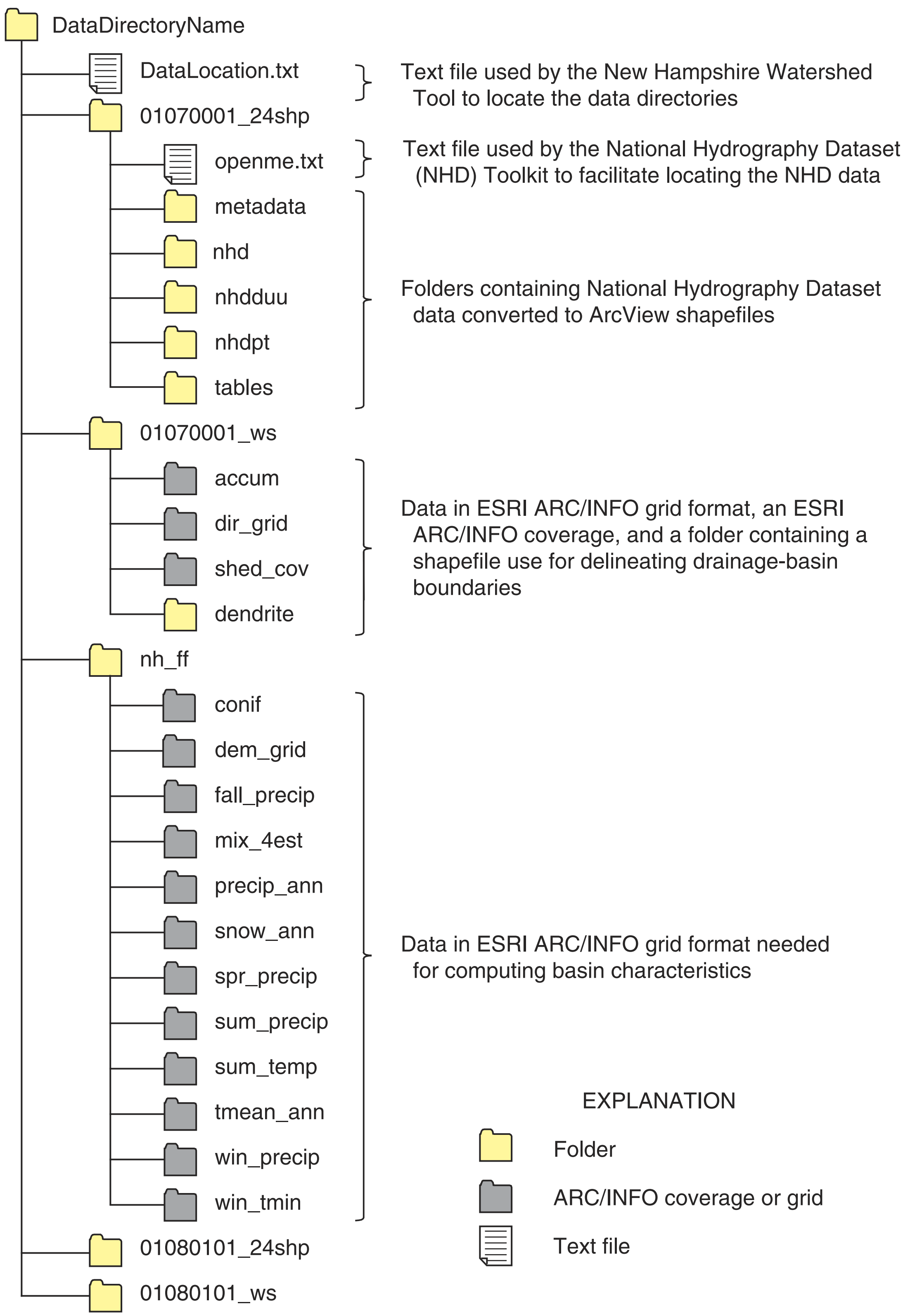


Figure 1. Directory structure and naming convention of the data files required by the New Hampshire Watershed Tool. Hydrologic unit codes 01070001 and 01080101 are shown as examples.

can be downloaded from the NHD Web site, http://nhd.usgs.gov/. In 2005, the NHD, in the format required by the NHD Toolkit version 7.0.0, was available in 5 of the 16 hydrologic units in New Hampshire (fig. 2). Automatic delineation of drainage boundaries by the New Hampshire Watershed Tool is not possible outside of the regions with NHD coverage. A function allowing the user to enter a predetermined basin boundary in any part of the state is discussed later in this report, and can be used to apply the Tool in regions where NHD coverage is unavailable.

The folders with the "_ws" suffix (fig. 1) contain the NHD WATershed SUPport (WATSUP) datasets required for delineating a drainage basin for any selected point along a NHD reach. Detailed instructions for processing the data in the "_ws" folders to prepare them for use with the New Hampshire Watershed Tool can be obtained from the Applications section of the NHD Web site, http://nhd.usgs.gov/watershed/watershed_tool_inst_TOC.html (Steeves, 2002).

The WATSUP datasets in the "_ws" folder include the flow accumulation grid, "accum"; the flow direction grid, "dir_grd"; and a polygon coverage of drainage-basin catchments for each stream reach in the NHD, "shed_cov." These WATSUP datasets are derived from the National Elevation Dataset (NED) (U.S. Geological Survey, 2001) or higher resolution U.S. Geological Survey 10-meter Digital Elevation Models (DEMs) (U.S. Geological Survey, 2004), where available.

The first step in developing the WATSUP datasets involves adjusting the elevation datasets for the hydrologic conditions observed in the NHD (Saunders, 2000). The ARC/INFO command TOPOGRID (Environmental Systems Research Institute, Inc., 1994) and the ARC/INFO script, "agree.aml," (Hellweger and Maidment, 1997) are applied to the elevation datasets to produce an elevation grid with a 10-meter cell size that is hydrologically correct and horizontally matches the NHD network. Next, basin boundaries taken from the Natural Resources Conservation Service (NRCS) 12-digit Watershed Boundary Dataset (WBD) (Natural Resources Conservation Service, 2004) are utilized to enforce agreement of the elevation grid with these boundaries.

The modified DEM, which now has horizontal agreement with the NHD and the WBD, undergoes one last hydrologic conditioning process using the ARC/INFO GRID command FILL. FILL identifies and removes isolated elevation sinks and insures proper surface drainage for all elevation cells. The ARC/INFO GRID commands FLOWDIRECTION and FLOWACCUMULATION are then used to create the flow-direction and flow-accumulation grids, "dir_grd" and "accum," respectively, using the hydrologically conditioned DEM as input.

A watershed catchment coverage is then created using the ARC/INFO GRID command WATERSHED with the flow-direction grid and a rasterized representation of the stream network as input. The ARC/INFO GRID command GRIDPOLY is used to convert the output grid from the WATERSHED command to the polygon coverage "shed_cov." Each polygon is then attributed with a code corresponding to the reach code of the NHD reach that intersects the polygon.

The final dataset in the "_ws" folder is a copy of the NHD-reach route system in ESRI shapefile format that is put into a folder named "dendrite." The shapefile is named "dendrite" also. It can be edited and reaches can be removed from the dendrite shapefile for purposes of preventing a user from selecting a reach where the regression equations are not applicable. Artificial channels and diversions are examples of channels that could be removed from the dendrite shapefile. The creation of the dendrite dataset is further explained in the instructions for processing the WATSUP dataset, http://nhd.usgs.gov/watershed/watershed_tool_inst_TOC.html.

The "nh_ff" folder (fig. 1) contains the data for computing basin and climatic characteristics. There are 12 grid datasets projected into New Hampshire State Plane coordinates in the folder. A brief description and the source for each of these grids is listed in table 5.

The "Utilities" folder contains some of the basic geographic features, such as roads and basin, town, and county boundaries, which are displayed by the New Hampshire Watershed Tool to assist the user in locating stream reaches of interest. This folder also stores the point coverage "nhdams" and the shapefile, "huc8.shp," which are used by the Tool to check for potential upstream flow regulation and to load hydrologic unit data, respectively. The programs "pdur.exe" and "recharge.exe" and datasets for solving the regression equations and analyzing the prediction intervals also are located in this directory. Each user of the Tool must have a copy of the utilities directory on their own workstation because this directory is used as a temporary workspace for saving files created during intermediate computation steps..

The final dataset used by the Tool is the USGS topographic map images in electronic format at 1:24,000 scale. These maps are known also as Digital Raster Graphics (DRG). The images simplify the process of accurately locating streams. The DRGs can be obtained from the New Hampshire Geographically Referenced Analysis and Information Transfer System (NH GRANIT) at http://www.granit.sr.unh.edu/.

Installation of the New Hampshire Watershed Tool

Once the required ESRI software and NHD toolkit have been installed, the datasets and utilities have been loaded in the appropriate directory structure, and the New Hampshire Watershed Tool extension has been copied to the ESRI ArcView extensions directory, the Tool is ready for use. To load the Tool extension into ArcView, select the "File" menu in the ArcView window and select "Extensions." A window of available extensions will open. Load the extension by clicking the box to the left of "NH Watershed Tool."

After the New Hampshire Watershed Tool extension is loaded, a menu named "NHSETUP" will appear in the ArcView application window when the project window is

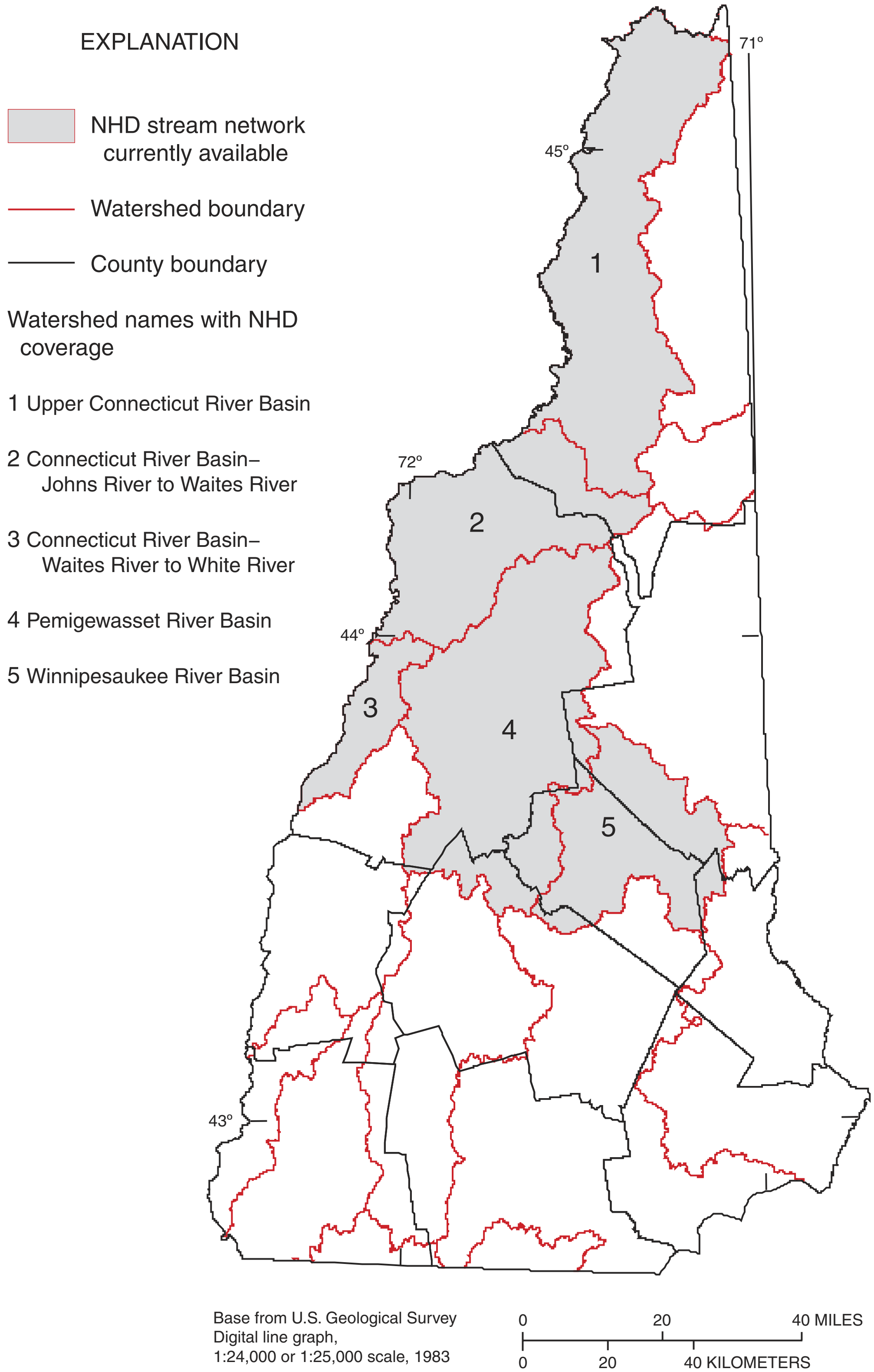


Figure 2. Available coverage in New Hampshire of National Hydrography Datasets (NHD) compatible with the NHD Toolkit version 7.0.0 and the New Hampshire Watershed Tool.

Table 5. Data layers the New Hampshire Watershed Tool used to compute basin characteristics.

[NED, National Elevaiton Dataset (U.S. Geological Survey, 2001); NLCD, National Land Cover Dataset of 1992 (U.S. Geological Survey, 2000); PRISM, Parameter-elevation Regressions on Independent Slopes Model data from 1961 to 1990 (Daly, 2000)]

Name of data layer	Description	Source
Dem_grid	Digital Elevation Model	NED
Fall_precip	Average total fall precipitation (November 1 to December 31)	PRISM
Precip_ann	Mean annual precipitation	PRISM
Snow_ann	Mean annual snowfall	PRISM
Spr_precip	Average total spring precipitation (March 16 to May 31)	PRISM
Sum_precip	Average total summer precipitation (June 1 to October 31)	PRISM
Sum_temp	Average monthly mean temperature in summer (June 1 to October 31)	PRISM
Tmean_ann	Average annual mean temperature	PRISM
Win_precip	Average total winter precipitation (January 1 to March 15)	PRISM
Win_tmin	Average monthly minimum temperature in winter (January 1 to March 31)	PRISM
Conif	Coniferous forest	NLCD
Mix_4est	Mixed coniferous and deciduous forest	NLCD

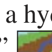
active. This setup routine should be executed when the extension is first loaded into each new ESRI ArcView project file to identify the locations of required data and the utilities folder and to create the map of New Hampshire in the view window. Once the setup routine is run, it will not be needed again in the ESRI ArcView project file and the "NHSETUP" menu will disappear. Saving and using only this project file will eliminate the need to run the setup routine again.

The setup routine first prompts the user for the location of the utilities folder. The user must browse for the "utilities-location.txt" file located in the user's utilities directory. The location of the data folders is requested in a similar manner, and the user must browse for the "datalocation.txt" file (fig. 1) located in the directory that contains the data folders. The location of the topographic map database file (topo.dbf) also is requested; however, these data are not required and the search for this file can be canceled. When the setup for the New Hampshire Watershed Tool is complete, the routine then opens a window displaying a map of New Hampshire. The Tool menu ("NHWT_Options") and buttons are now displayed in the ESRI ArcView menubar and toolbar, respectively. The ESRI ArcView window may need to be enlarged to display the entire menubar and toolbar. An example of an ESRI ArcView project window with the Tool loaded and installed is shown in figure 3.

Using the New Hampshire Watershed Tool

This section of the report includes instructions for using the New Hampshire Watershed Tool. To be successful, the user must be familiar with the basic functions of ESRI ArcView, such as panning and zooming, making themes active, interactively identifying features, and turning the display themes on and off.

With the setup complete, the Tool is ready for use. There are four buttons on the toolbar that run the major functions of the Tool. These buttons are displayed in table 6. The first button, the "Load Hydrologic Unit" button , is used to load the appropriate hydrography data and link to the appropriate support files for computing basin characteristics before a basin can be delineated. With the "Load Hydrologic Unit" button  depressed, the cursor is used to select the hydrologic unit where the stream of interest is located. The hydrologic unit boundaries are outlined in gray by default (fig. 3). Automatic delineation of drainage boundaries by the Tool is not possible outside the regions with NHD coverage. A function allowing the user to enter a predetermined basin boundary in any part of the state and obtain low-flow-frequency or ground-water-recharge-rate results is discussed later in this report.

With a hydrologic unit selected, the "Low-Flow Estimator"  or "Ground-Water-Recharge-Rate Estimator" button  can be depressed and a point on a stream selected. For a point to be selected on a stream, the "HUC_24shp – Reach" theme, where HUC is the hydrologic unit code,

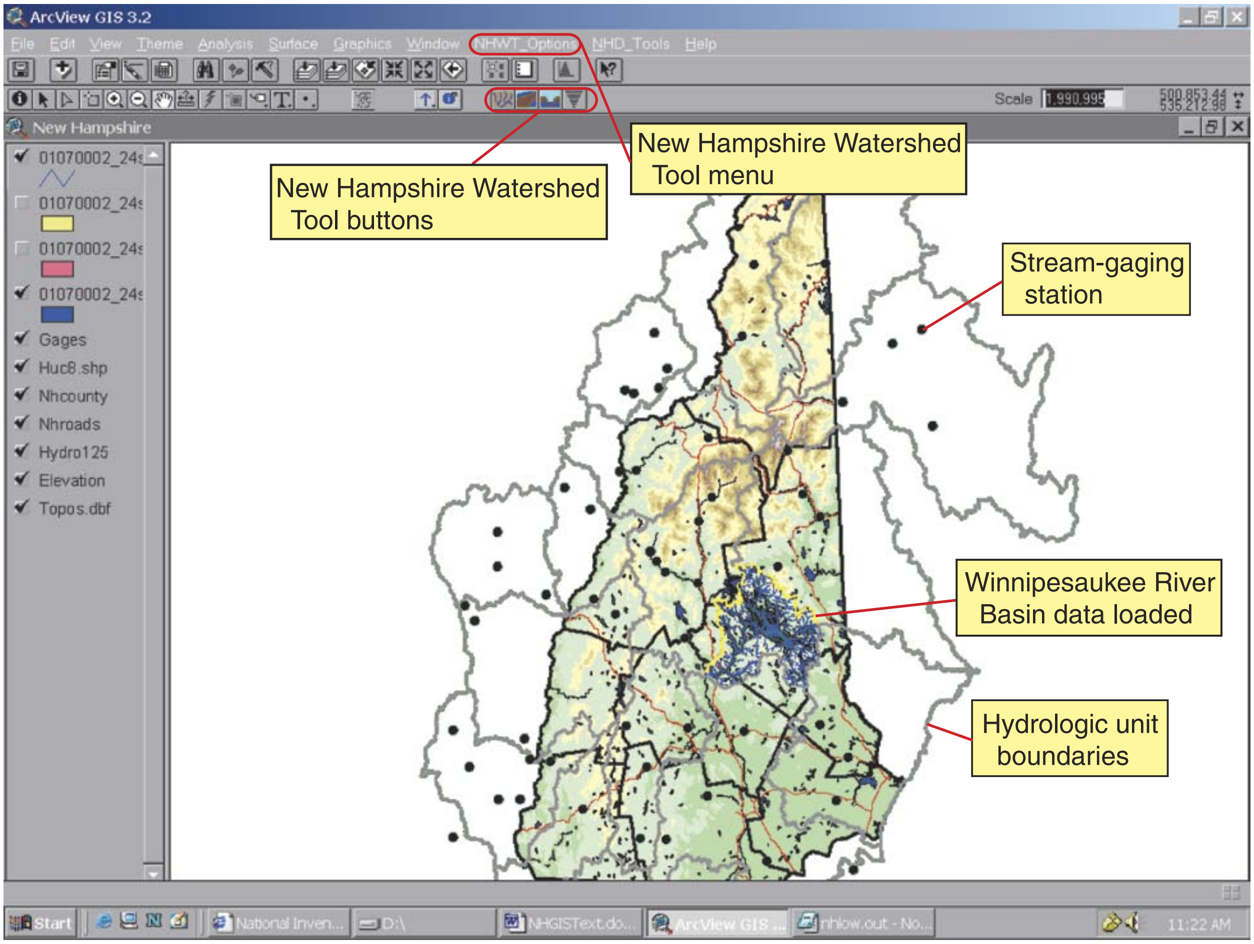


Figure 3. Screenshot of an ArcView window with the New Hampshire Watershed Tool installed.

Table 6. Buttons that run the functions of the New Hampshire Watershed Tool.

[Buttons are shown in figures 3 and 4; NHD, National Hydrography Dataset]

Button	Name	Function
	Load Hydrologic Unit	Loads NHD data and locates support data sets for the hydrologic unit interactively selected.
	Low-Flow Estimator	Delineates a drainage basin by use of NHD for a selected point on a stream, computes the basin characteristics, and solves the flow duration and low-flow frequency regression equations.
	Ground-Water-Recharge-Rate Estimator	Delineates a drainage basin by use of NHD for a selected point on a stream, computes the basin characteristics, and solves the ground-water-recharge-rate regression equations.
	Delineate with Flow-Direction Grid	Delineates a drainage basin by use of the flow direction and accumulation grids for a point interactively selected, computes the basin characteristics, and solves the selected regression equations.

must be active. The basin above this point is automatically delineated implementing the functionality of the NHD. The basin characteristics upstream of this point and the estimated flow-frequency or ground-water-recharge-rate data are then automatically computed and displayed as shown in the example in figure 4. The tabular results are displayed and can be saved to disk using Notepad. Before displaying low-flow-frequency results, the Tool identifies the presence of dams within the delineated drainage basin based on a dataset available from the U.S. Environmental Protection Agency (1998). It is the responsibility of the user to assess the degree of flow regulation that may exist as a result of any dam, including dams that may not be identified in the dam dataset, and to evaluate whether flows are sufficiently unregulated to ensure results from the Tool are valid.

The “Delineate with Flow Direction Grid” tool functions similarly to the “Low-Flow Estimator” and “Ground-Water Recharge-Rate Estimator” tool, but with several important differences. First, the basin delineation is done with flow-direction and flow-accumulation grids. A flow-direction grid is a grid in which each cell contains information on the direction of flow at that cell. This directional information can be used to compute a flow-accumulation grid—a grid in which each cell is assigned a value equal to the number of cells that flow into it. Basin delineation with these grids takes more time and computer resources than basin delineation using the NHD approach. Attempting to delineate large basins, such as those greater than a few hundred square miles, with the “Delineate with Flow Direction Grid” tool may exceed the capabilities of a personal computer. A second difference is that the user is prompted to select between estimates for flow-frequency or ground-water-recharge rates when the “Delineate with Flow Direction Grid” tool button is pressed. The user’s selection remains in effect until the “Delineate with Flow Direction Grid” tool button is pressed again. Selecting the hydrologic unit previous to the delineation is not required.

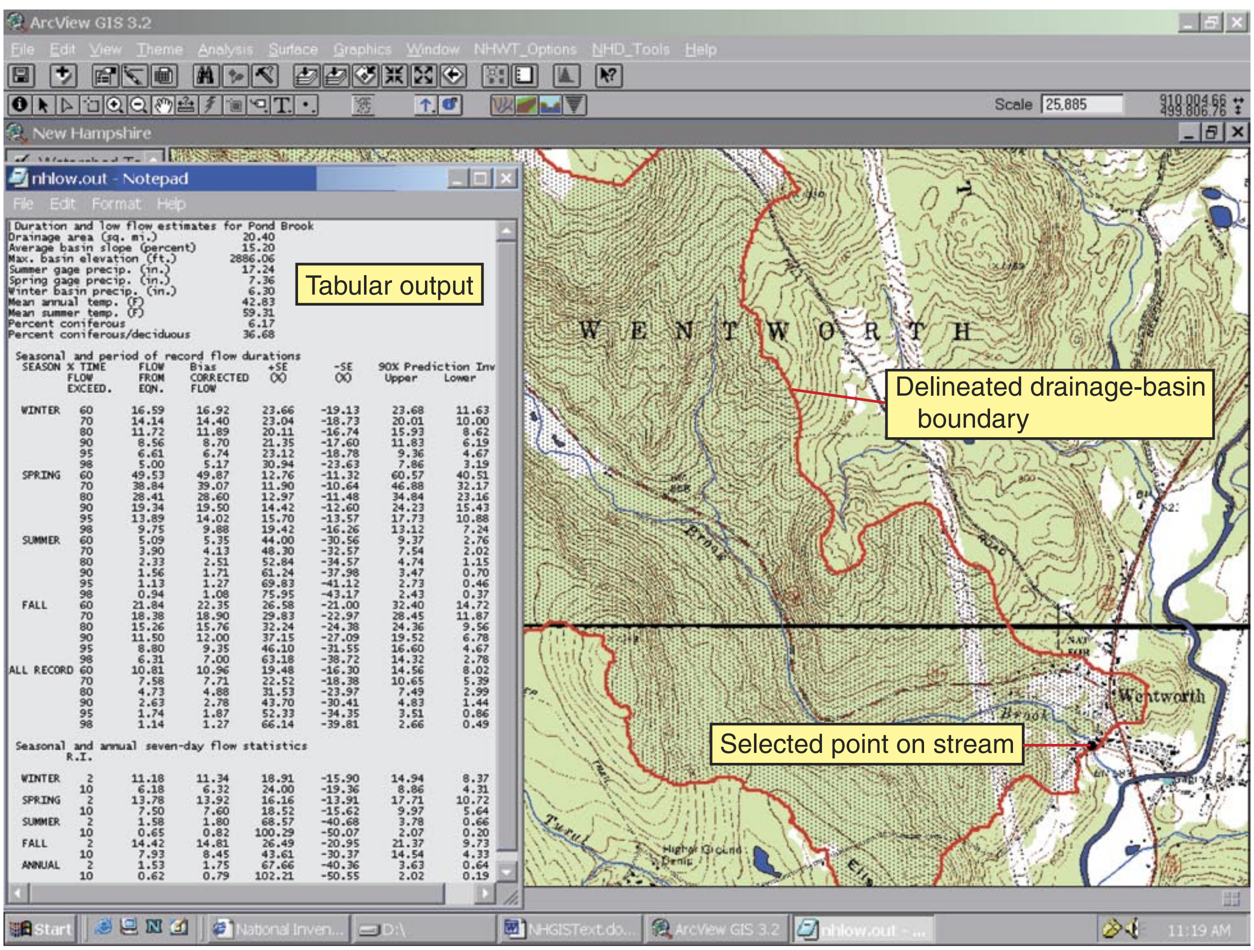


Figure 4. ArcView window displayed when a point on a stream is selected.

Two technical difficulties have been identified in the Tool. The first is related to braided streams. Users should review the boundary where it crosses the braided reach and confirm that the Tool delineated this part of the boundary correctly. It is best to avoid a braided reach by selecting a point of interest either upstream or downstream of the braid. The second problem can occur if the point chosen for delineation is at a confluence. For example, if a drainage basin above a confluence is of interest and the point selected is too close to the confluence, both catchments related to the reaches entering the confluence may be delineated; however, only the headwater catchments above the reach that the selected point is on will be included in the total drainage area. To avoid the problem, the Tool requires selected points to be farther than 100 feet (in the display's scale) upstream or downstream from the confluence.

Additional Utilities of New Hampshire Watershed Tool

Additional utilities are provided in the New Hampshire Watershed Tool. These include features such as computing flow-frequency or ground-water-recharge-rate estimates for a user-provided polygon that defines a drainage area of interest, locating streams by name, and displaying flow-frequency statistics at USGS stream-gaging stations.

A menu on the ESRI ArcView menubar titled "NHWT_Options" is visible when the Tool extension is loaded. This menu has nine selections. The first two are the "Select Utilities Location" and "Select Data Location" menu options. These can be used if datasets or the utilities folder are moved and the user does not want to run the setup routines again. When one of these options is selected, the user must browse for the respective "utilitieslocation.txt" or "datalocation.txt file," as described in the previous section "Installation of the New Hampshire Watershed Tool."

Two other options under the "NHWT_Options" menu are used to locate features and move around on the displayed map of New Hampshire. The "Zoom to New Hampshire Map" option zooms in or out so that the window displays the entire State of New Hampshire. The "Locate Stream by Name" option opens a window listing all the names of the streams in the currently loaded hydrologic unit. Once the user selects a stream, the map display zooms to that stream. Another option, "Watershed display properties," allows the user to toggle the display of the watershed polygon from shaded to unshaded for subsequent drainage-basin delineations. The option "Display Gage Information" provides streamflow statistics for selected stream-gaging stations that were originally used to develop the flow-estimating equations. The station must first be selected with the ESRI ArcView Selection tool.

The option "Compute with User Polygon" computes the basin characteristics and estimated flow-frequency characteristics of a basin polygon that is provided by the user. To use this option, the user must first load a polygon into the view window. After selecting the "Compute with User Polygon" option, the user will be prompted for the name of the polygon representing the basin of interest and for the pour point or outlet of the basin polygon. If the user does not enter a pour point coverage or shapefile, the Tool will estimate a pour point if the NHD at the pour point location has been loaded into the view window using the "Load Hydrologic Unit" button  . The "Compute with User Polygon" option is useful if the basin boundary delineated by the Tool requires manual editing, or is in hydrologic units where the NHD does not exist to support automated basin boundary delineation.

A menu item called "Clean Workspace" deletes many of the temporary work files that are left in the utilities directory. This option, however, does not delete files from the default ArcView Temp directory. A menu item called "About" provides a short explanation of the New Hampshire Watershed Tool.

Summary

This report describes a tool that has been developed by the U.S. Geological Survey, in cooperation with the New Hampshire Department of Environmental Services, for applying regression equations that estimate (1) seasonal and annual 7-day low-flow frequency for recurrence intervals of 2 and 10 years; (2) seasonal and annual flow duration for daily discharges exceeded 60, 70, 80, 90, 95, and 98 percent of the time; and (3) seasonal and annual ground-water-recharge rates. The customized geographic information system (GIS) application, the New Hampshire Watershed Tool, is based on the National Hydrography Dataset toolkit. The Tool automates the delineation of basin boundaries, derives values of basin characteristics included as independent variables in a series of regression equations, and solves the regression equations, significantly reducing the manual processing time normally required.

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