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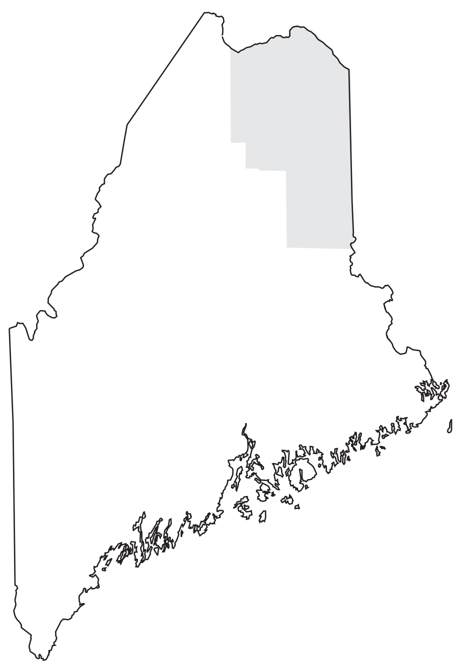
August Median Streamflow on Ungaged Streams in Eastern Aroostook County, Maine

U.S. DEPARTMENT OF THE INTERIOR
U.S. GEOLOGICAL SURVEY

Water Resources Investigations Report 03-4225



In cooperation with the

AROOSTOOK WATER AND SOIL MANAGEMENT BOARD

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By Pamela J. Lombard, Gary D. Tasker, and Martha G. Nielsen

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Augusta, Maine
2003

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CONVERSION FACTORS, VERTICAL DATUM, AND COORDINATE SYSTEM

Multiply	By	To obtain
inch (in.)	25.4	millimeter
foot (ft)	0.3048	meter
cubic foot per second (ft^3/s)	0.02832	cubic meter per second
cubic foot per second per square mile ($(ft^3/s)/mi^2$)	0.01094	cubic meter per second per square kilometer

To convert temperature in degrees Fahrenheit (°F) to degrees Celsius (°C) use the following equation:

$$°C = 5/9 * (°F - 32)$$

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83), in degrees, minutes and seconds.

Vertical coordinate information is referenced to the North American Vertical Datum of 1929 (NGVD 29).

August Median Streamflow on Ungaged Streams in Eastern Aroostook County, Maine

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ABSTRACT

Methods for estimating August median streamflow were developed for ungaged, unregulated streams in the eastern part of Aroostook County, Maine, with drainage areas from 0.38 to 43 square miles and mean basin elevations from 437 to 1,024 feet. Few long-term, continuous-record streamflow-gaging stations with small drainage areas were available from which to develop the equations; therefore, 24 partial-record gaging stations were established in this investigation. A mathematical technique for estimating a standard low-flow statistic, August median streamflow, at partial-record stations was applied by relating base-flow measurements at these stations to concurrent daily flows at nearby long-term, continuous-record streamflow-gaging stations (index stations). Generalized least-squares regression analysis (GLS) was used to relate estimates of August median streamflow at gaging stations to basin characteristics at these same stations to develop equations that can be applied to estimate August median streamflow on ungaged streams. GLS accounts for varying periods of record at the gaging stations and the cross correlation of concurrent streamflows among gaging stations. Twenty-three partial-record stations and one continuous-record station were used for the final regression equations.

The basin characteristics of drainage area and mean basin elevation are used in the calculated regression equation for ungaged streams to estimate August median flow. The equation has an average standard error of prediction from -38 to 62 percent. A one-variable equation uses only drainage area to estimate August median streamflow when less accuracy is acceptable. This equation has an average standard error of prediction from -40 to 67 percent. Model error is larger than sampling error for both equations, indicating that additional basin characteristics could be important to improved estimates of low-flow statistics.

Weighted estimates of August median streamflow, which can be used when making estimates at partial-record or continuous-record gaging stations, range from 0.03 to 11.7 cubic feet per second or from 0.1 to 0.4 cubic feet per second per square mile. Estimates of August median streamflow on ungaged streams in the eastern part of Aroostook County, within the range of acceptable explanatory variables, range from 0.03 to 30 cubic feet per second or 0.1 to 0.7 cubic feet per second per square mile. Estimates of August median streamflow per square mile of drainage area generally increase as mean elevation and drainage area increase.

INTRODUCTION

The need for information describing low-flow characteristics of streams in Maine by Federal, State, and local agencies, consulting engineers, commercial enterprises, and natural resource conservation groups is increasing. Low-flow characteristics are used to determine the adequacy of streamflow for development of water supplies, disposal of wastes, generation of electricity, agricultural irrigation, maintenance and restoration of aquatic habitat, and watershed conservation. Currently (2003), few streamflow-gaging stations are present on small streams in Aroostook County, Maine that could be used to estimate low-flow statistics in the county. New England-wide equations used to estimate August median streamflows on ungaged streams with large drainage areas may not apply to small streams in the county. Management and effective utilization of water resources could improve with low-flow estimation techniques developed specifically for small streams in Aroostook County.

The New England Aquatic Base-Flow (ABF) policy was developed by the U.S. Fish and Wildlife Service (USFWS) (1981) to better manage low streamflows for aquatic organisms while still allowing for water withdrawals for human consumption. The ABF

Policy recommends that water not be withdrawn from streams when streamflow is below the August median streamflow. The USFWS estimated the August median streamflow per square mile of drainage area by using the median of the annual series of August monthly mean streamflows on 48 streamflow-gaging stations in New England (US Fish and Wildlife Service, 1981). In the absence of adequate streamflow data from unregulated streams necessary to develop the August median statistic, the policy recommends that an ABF of 0.5 $(ft^3/s)/mi^2$ of drainage area can be used to approximate August median flow.

The definition of August median streamflow has varied in previous investigations, and thus, the resulting values of August median streamflow per square mile of drainage area also have varied. In cases where a central value of a distribution is preferable to one that may be skewed by a few extreme observations, the median of the monthly medians or the median of the daily flows is preferable to a central measure such as the mean or the median of the mean monthly streamflows (Helsel and Hirsch, 1992). Charles Ritzi and Associates (1987) and Kulik (1990) calculated the August median streamflow at streamflow-gaging stations in New England as the median of all of the daily mean streamflows measured in August during the period of record. Charles Ritzi and Associates estimated the August median from 0.33 to 0.38 $(ft^3/s)/mi^2$. Kulik (1990) determined that the August median varied by region and estimated it as 0.6 $(ft^3/s)/mi^2$ for mountain windward regions and 0.3 $(ft^3/s)/mi^2$ for non-mountain windward regions.

County and statewide policies and regulations are being developed with limited information on streams in Maine. The Aroostook Water and Soil Management Board developed a policy in 1996 for water use during low-flow periods in Aroostook County to ensure that farmers had adequate resources to maintain yields and quality of agricultural crops while protecting the environment from excessive drawdown of lakes, rivers and streams. This policy, *How to Deal with Low-flow periods and Irrigating Farmer's and Environmental Concerns in Aroostook County* [sic] (Aroostook Water and Soil Management Board, 1996), states that site-specific ABF withdrawal limits will be implemented where drawdown is creating damage to fish and wildlife. It also states that State and Federal agencies will help to establish these low-flow withdrawal limits. Additionally, the State of Maine recently adopted legislation to ensure water withdrawal reporting (Maine State Legislature, 2002). This legislation directs the Board of Environmental Protection to establish water-use standards for maintaining instream flows by 2005. Standards will be based on the natural variation of flows and water levels. Better equations to estimate low-flow statistics, including August median streamflows, are a critical first step in establishing these standards. To develop regression equations that could be used to better estimate the August median streamflow on ungaged, unregulated streams in Aroostook County, Maine, the U.S. Geological Survey (USGS) began a cooperative study with the Aroostook County Water and Soil Management Board in 1998.

Purpose and Scope

This report presents equations to estimate August median streamflow in streams in the populated, eastern part of Aroostook County, as well as an estimate of the accuracy of these equations. The report describes (1) how instantaneous streamflow measurements at partial-record gaging stations were correlated to daily mean streamflows at continuous-record index stations to estimate August median streamflows at the partial-record stations (2) how regression equations to predict August median streamflow on small, ungaged streams were developed, and (3) how weighted estimates of August median streamflow at partial-record stations were calculated in the study area.

Previous Studies

Methods for estimating low-flow statistics at partial-record stations on the basis of correlations between daily mean discharges at the partial-record stations and concurrent daily mean discharges at nearby continuous-record index stations are presented by Riggs (1972). Riggs also outlines a technique of regionalizing low-flow characteristics of rivers by multiple regression on basin characteristics, such as drainage area and surficial geology. Numerous investigators in New England have applied this technique of regionalization to develop low-flow regression models, using basin characteristics as independent variables to predict low-flow statistics on ungaged streams (Johnson, 1970; Parker, 1977; Cervionne and others, 1993; Risley, 1994; Wandle and Randall, 1994; Ries, 1994a, 1994b, 1997). Ries (1997) developed equations specifically for estimating August median streamflow in Massachusetts. These investigators all found low-flow statistics to be highly correlated to drainage area, and in most cases, the relation was specific to a geographic region of the State. Other variables that commonly were correlated with low-flow statistics were a measure of the basin relief or slope (Risley, 1994; Ries, 1994a, 1994b, 1997) and a measure of the surficial geology (Cervione and others, 1993; Wandle and Randall, 1994; Ries, 1994a, 1994b, 1997).

Location of Study Area

The majority of the streamflow-gaging stations used in this study are in the eastern part of Aroostook County, Maine (fig. 1). Aroostook County encompasses 6,453 mi^2 in northern Maine and borders Canada on its western, northern and eastern borders. Aroostook County had a population of 73,938 in 2000 (Maine Register, 2000). Nearly all the population lives in the eastern part of the county. The northwestern part of the county largely is unpopulated, forested, and consists predominantly of private land managed for forest products.

Cold winters and cool summers typify the climate of northern Maine. The average annual temperature is 36 ^{o} F with the mean monthly temperatures ranging from 19^{o}F in January to 62^{o} F in July. The mean annual precipitation is 35 in. (U.S. Department of Commerce, 1997). Water from snowmelt can be a major source of streamflow during April and May. During the summer months, streamflow comes from ground water discharged from aquifers (base flow), and rainfall from summer storms.

A large part of the county is in the St. John River Basin, which includes the upper part of the St. John, the Allagash, the Fish, the Aroostook, and the Meduxnekeag Rivers. A small section of the southern part of the county lies in the Penobscot River Basin and drains into the Mattawamkeag River, and the St. Croix River. Currently, there are nine active surface-water gaging stations in Aroostook County, all in the St. John River Basin. One station has a drainage area less than 50 mi^2.

Seven continuous-record streamflow-gaging stations used as index stations in the study are in Aroostook and Washington Counties, Maine and New Brunswick, Canada (fig. 2). Canadian stations were chosen on the basis of their proximity to the Maine border. The partial-record stations used in the final analysis are shown on figure 3. Twenty-two stations are in Aroostook County and 1 station is just over the border of southwestern Aroostook County, in Penobscot County.

Acknowledgments

Many USGS employees provided appreciable assistance in all aspects of this project. Sarah Canon, Laura Flight, Jason Cyr, Tim Sargent, Andy Cloutier, Jim Caldwell, and Gregory Stewart collected low-flow measurements; Gloria Morrill assisted with GIS work; and Glenn Hodgkins and Joseph Nielsen provided statistical and technical guidance.

DATA COLLECTION AND ANALYSIS

Ideally, equations to estimate August median streamflow on small, ungaged streams in Aroostook County would be developed from long-term continuous-record data from small streams in this same region; however, there only is one gaging station with greater than 15 years of record on a small stream in Aroostook County and thus it was necessary to use partial-record stations to develop these equations. All partial-record stations included in these analyses had a minimum of 10 base-flow measurements. Although it is possible to extend the record of a partial-record station with less than 10 measurements graphically, it is preferable to have at least 10 measurements (Riggs, 1972). Base-flow measurements and a correlation with a gaging station with a long period of record were used to extend the record and estimate an August median flow at partial-record stations.

Station Selection and Streamflow Measurements

Twenty-four partial-record stations were established specifically for this project. Standard USGS methods as described by Rantz and others (1982) were used to make streamflow measurements at these stations, including wading current-meter measurements, portable Parshall flume measurements, and volumetric measurements. All measurements were published in the USGS series of annual water-data reports from 1994 to 2002, the most recent of which is referenced (Stewart and others, 2001). Two partial-record stations were discontinued after 2 years of data collection because more than half of the base-flow measurements at each one of these stations were zero. Streamflow at the remaining 22 partial-record stations was measured 10 to 19 times from 1994 to 2002. Two additional partial-record stations were eliminated during the analysis because measurements at these stations did not correlate well with daily flow measurements at any of the index stations.

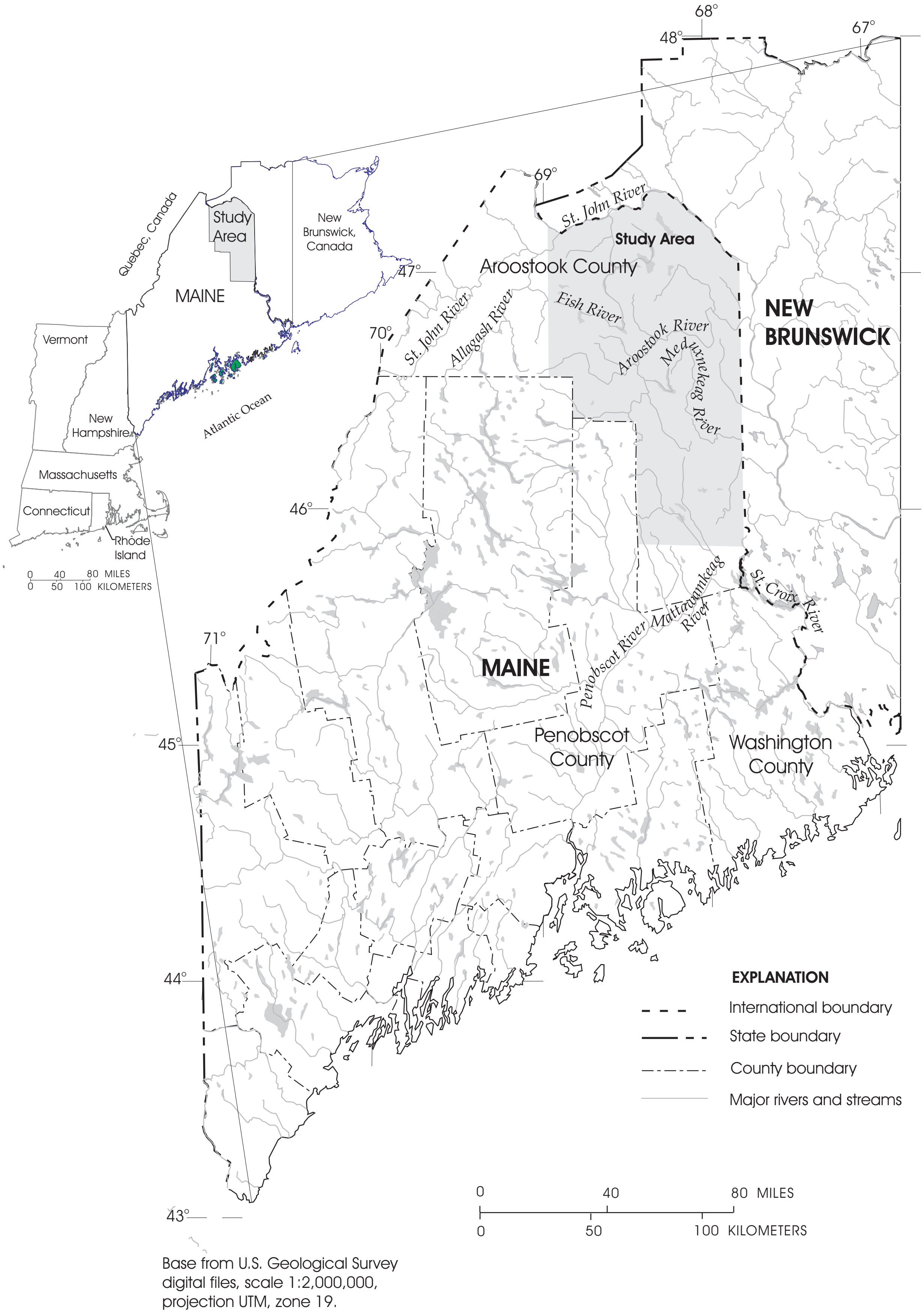

Figure 1. Location of study area, eastern Aroostook County, Maine.

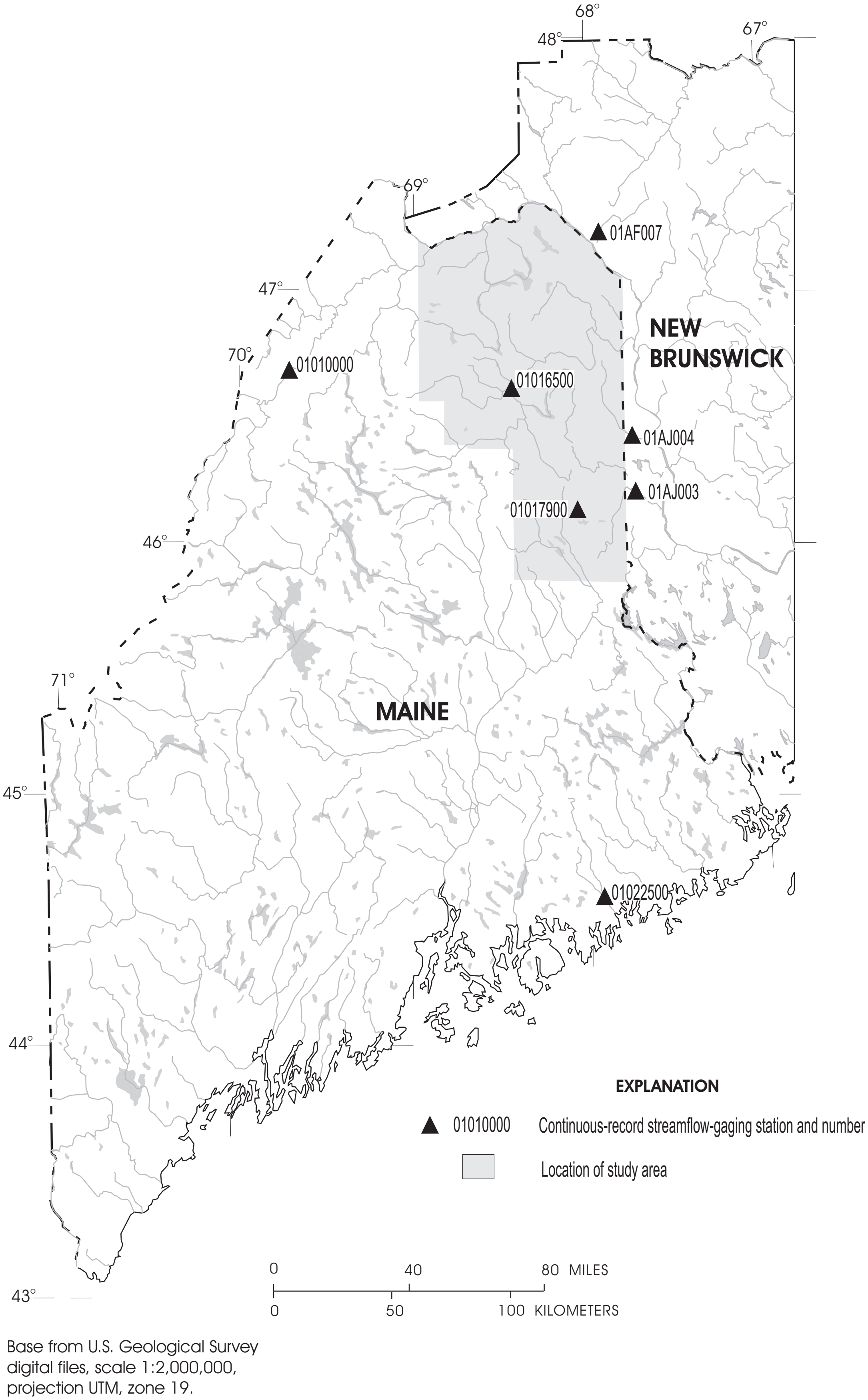

Figure 2. Location of continuous-record streamflow-gaging stations used as index stations, Maine and New Brunswick, Canada.

Streamflow data were used from three additional streamflow-gaging stations, USGS number 01012520, Bald Mountain Brook near Bald Mountain (1980-84); USGS number 01012525, Bishop Mountain Brook near Bishop Mountain (1981-84) (Fontaine, 1989); and USGS number 01017550, Williams Brook at Phair (Stewart and others, 2001). Although Bald Mountain Brook and Bishop Mountain Brook were operated as continuous-record gaging stations during the period of their operation, 3 to 4 years is not sufficient to calculate the August median streamflow, and thus, these stations were treated as partial-record stations. Williams Brook at Phair has been in operation as a continuous-record gaging station since 1999, but also does not have a sufficient period of record from which to calculate an August median streamflow. The locations of the 23 partial-record stations used in the regression analysis are shown in figure 3.

Measurements taken at the partial-record stations were correlated with daily flows at long-term gaging stations to extend the record at the partial-record stations. Partial-record stations were tested for correlation with unregulated long-term continuous-record stations in Maine and Canada. Nine continuous-record stations in northern, central, and eastern Maine, as well as seven stations in New Brunswick, Canada, were tested. Station identification numbers, station names, station locations, periods of record, and drainage areas for all stations that were tested are listed in table 1. Although three of the stations have been discontinued, these rivers have all been gaged by the USGS or the Water Survey of Canada for 18 to 50 years. The data can be found in the USGS annual water-data reports and predecessor Water-Supply Papers for the stations in Maine and the Water Survey of Canada's Surface Water Data Books for stations in New Brunswick. The most recent data reports are Stewart and others (2001) and Inland Waters Directorate (2001) for Maine and New Brunswick, respectively.

Stations with the best correlation with partial-record stations were chosen as index stations. Ideally, index stations would be close to partial-record stations geographically and have drainage areas in the same range as the drainage areas of the partial-record stations (less than 50 mi^2), but few continuous-record stations in the region meet these criteria. Three of the index stations are in Aroostook County, Maine, one is in Washington County, Maine and three are in New Brunswick, Canada. The locations of all index stations used in this study are shown in figure 2.

Station identification numbers, station names, station locations, and number of measurements for the 23 partial-record stations are listed in table 2. All stations but one are in Aroostook County, have relatively small drainage areas (from 0.38 mi^2 to 50 mi^2), are unregulated, and as a group are considered representative of the populated, eastern part of Aroostook County.

Streamflows at the partial-record stations were measured during independent base-flow events, separated by storms. A range of flows throughout the summer months was sought, and rapidly changing flows or flows that could be attributed directly to rain runoff were avoided. Measurements for a given low-flow event were made within a 30-hour period at all stations, including the two discontinued index stations (USGS streamflow-gaging station numbers 01016500 and 01017900) that were treated as partial-record stations during this period.

Basin Characteristics

Topographic, climatic, and geologic basin characteristics, which potentially could be linked to the low-flow statistic August median streamflow, were delineated and calculated using a geographic information system (GIS). Calculated basin characteristics included drainage area, average and maximum basin slope, mean elevation, elevation range, relative basin relief (median elevation minus minimum elevation), main-channel length, total stream length, main-channel slope, stream density, percent wetland and pond area, and annual and average summer precipitation and temperature at the basin centroids. The base-10 logarithmic transformation of each basin characteristic also was calculated.

Basin delineation was done by hand using contours on 1:24,000-scale USGS quadrangles. Basin characteristics including drainage area were calculated for each basin after the basin boundary was digitized using GIS. Mean and maximum basin slope, elevation range, relative basin relief, and mean elevation all were computed using a 30-meter-resolution USGS digital elevation model (DEM) obtained from the Maine Office of GIS. Slope was determined using a 9-pixel moving average of the DEM for each pixel. Mean basin slope was computed as the mean of all pixel slopes in the basin. Mean elevation was determined

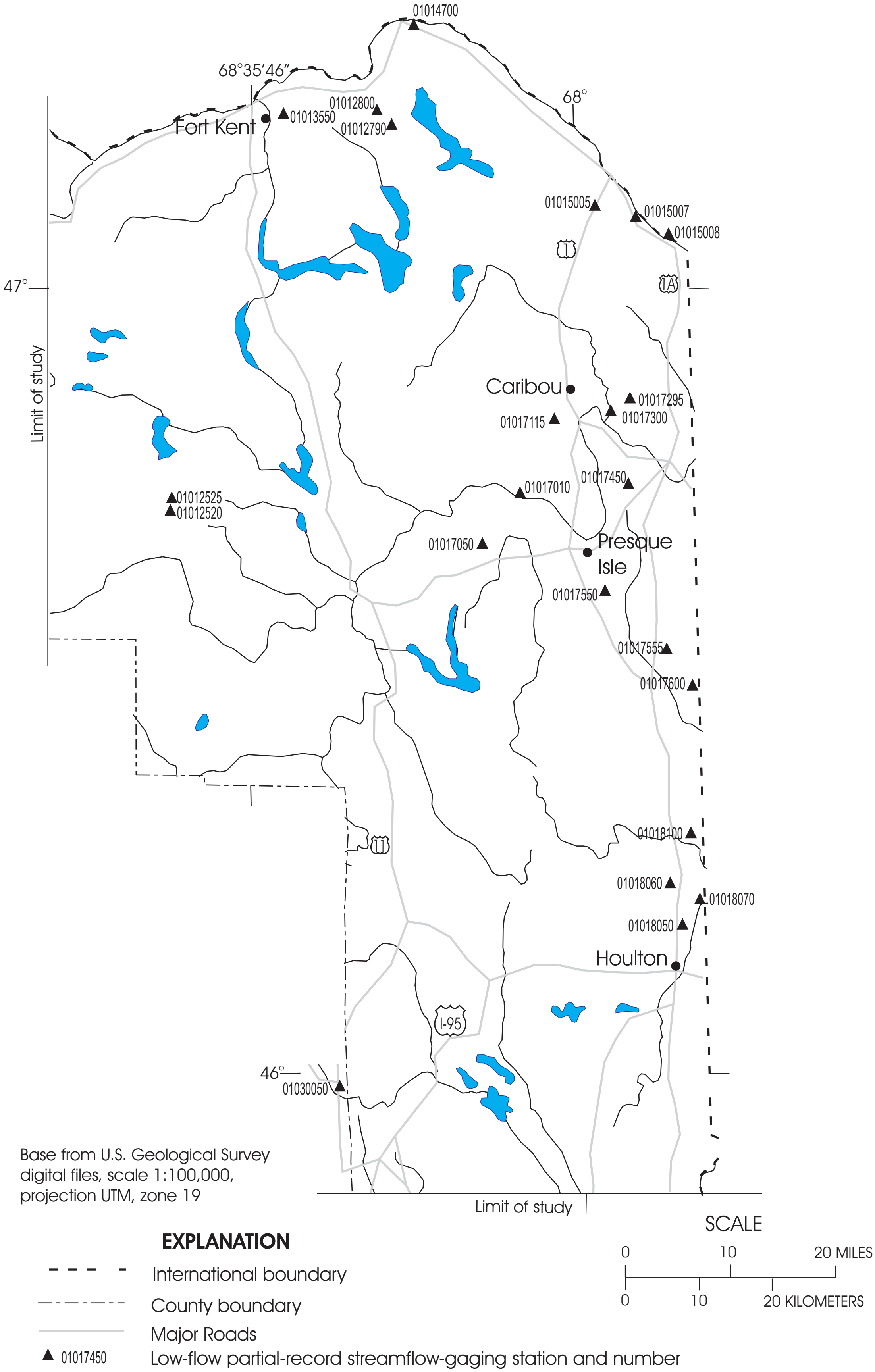

Figure 3. Location of partial-record streamflow-gaging stations in Aroostook and neighboring counties, Maine.

Table 1. Long-term continuous-record streamflow-gaging stations in Maine and New Brunswick, Canada tested for use as index stations.

[USGS, U.S. Geological Survey; Latitude and Longitude in degrees, minutes and seconds]

USGS or Canadian station number	Latitude ° ' "	Longitude ° ' "	Station name	Period of record (water years*)	Drainage area (square miles)
Continuous-record stations used as index stations (shown on fig.2)					
01010000	46 42 00	69 42 59	St. John River at Ninemile Bridge, Maine	1950-2002	1,341
01016500	46 37 42	68 26 07	Machias River near Ashland, Maine	1951-1983	329
01017900**	46 08 42	68 03 42	Marley Brook near Ludlow, Maine	1964-1982	1.47
01022500	44 36 29	67 56 10	Narraguagus River at Cherryfield, Maine	1948-2002	227
01AF007	47 14 46	67 55 16	Grande Riviere at Violette Bridge, New Brunswick	1977-2002	131
01AJ003	46 12 58	67 43 42	Meduxnekeag River near Belleville, New Brunswick	1967-2002	467
01AJ004	46 26 14	67 44 41	Big Presque Isle Stream at Tracy Mills, New Brunswick	1967-2002	187
Continuous-record stations tested, but not used					
01010070	46 53 38	69 45 08	Big Black River near Depot, Maine	1983-2002	171
01015800	46 31 21	68 22 23	Aroostook River near Masardis, Maine	1957-2002	892
01018000	46 06 17	67 52 00	Meduxnekeag River near Houlton, Maine	1941-1982	175
01031500	45 10 31	69 18 55	Piscataquis River at Dover Foxcroft, Maine	1902-2002	298
01022295	44 51 34	68 06 23	West Branch Bear Brook near Beddington, Maine	1988-2002	0.047
01AK001	45 56 42	67 19 20	Shogomoc Stream near Trans Canadian Highway, New Brunswick	1948-2002	227
01AK007	46 02 57	67 14 25	Nackawic Stream near Temperence Vale, New Brunswick	1967-2002	93
01AH002	47 10 24	67 12 36	Tobique River at Riley Brook, New Brunswick	1954-2002	861
01AJ010	46 20 27	67 27 58	Becaguimec at Coldstream, New Brunswick	1973-2002	135

*The water year is the 12-month period October 1 through September 30.

** 01017900 is the only index station that is also used in the regression equation for estimating August median flow at ungaged stations because it is the only index station with a drainage area less than 50 square miles.

Table 2. Low-flow partial-record streamflow-gaging stations in Aroostook and neighboring counties, Maine.

[USGS, U.S. Geological Survey; Latitude and Longitude in degrees, minutes and seconds]

USGS station number	Latitude ° ′ ″	Longitude ° ′ ″	Station name	Index station	Number of measurements
01012520	46 44 23	68 45 21	Bald Mountain Brook near Bald Mountain, Maine	01016500	3 yrs-summer flows*
01012525	46 44 43	68 45 11	Bishop Mountain Brook near Bishop Mountain, Maine	01016500	2 yrs-summer flows*
01012790	47 13 32	68 20 24	North Fork McLean Brook near St. Agatha, Maine	01022500	11
01012800	47 14 39	68 22 04	Unnamed tributary to East Fork Dickey Brook near St. Agatha, Maine	01AF007	11
01013550	47 14 26	68 32 32	Unnamed tributary to Pearly Brook near Michigan Settlement, Maine	01022500	11
01014700	47 21 09	68 17 50	Factory Brook near Madawaska, Maine	01AF007	17
01015005	47 07 12	67 57 46	Unnamed tributary to Hammond Brook near Cyr Plantation, Maine	01016500	13
01015007	47 06 18	67 53 12	Unnamed tributary to St. John River near Hamlin, Maine	01AF007	10
01015008	47 04 56	67 49 34	Martin Brook near Hamlin, Maine	01016500	11
01017010	46 45 19	68 06 30	Unnamed tributary to Aroostook River at Crouseville, Maine	01010000	10
01017050	46 41 29	68 10 44	Libby Brook near Mapleton, Maine	01016500	12
01017115	46 50 55	68 02 35	Caribou Stream at Caribou, Maine	01AJ003	11
01017295	46 52 25	67 54 07	Nichols Brook near Limestone, Maine	01016500	13
01017300	46 51 29	67 56 17	Nichols Brook near Caribou, Maine	01016500	13
01017450	46 45 53	67 54 26	Ginn Brook near Fort Fairfield, Maine	01AJ004	15
01017550**	46 37 37	67 57 12	Williams Brook at Phair, Maine	01AJ003	18
01017555	46 33 14	67 50 27	Hilt Brook near Mars Hill, Maine	01AJ004	10
01017600	46 30 25	67 47 39	Unnamed tributray to Young Brook near Mars Hill, Maine	01022500	10
01018050	46 12 01	67 49 08	Big Brook near Littleton, Maine	01AJ003	16
01018060	46 15 12	67 50 23	Unnamed tributary to Meduxnekeag River near Littleton Station, Maine	01AJ004	10
01018070	46 13 54	67 47 10	Unnamed tributary to meduxnekeag River near Littleton, Maine	01AF007	10
01018100	46 19 02	67 48 03	Unnamed tributary to Dead Stream near Monticello, Maine	01AJ003	10
01030050	46 00 05	68 26 58	Webb Brook near Patten, Maine	01017900	14

*Three and two years of daily summer flows from June-September were used for the correlations at 01012520 and 01012525, respectively.
** Station 01017550 has been run as a continuous-record station from 1999 to the present. It was treated as a partial-record station for this report because it does not have a sufficient period of record to calculate an August median flow.

similarly as the the mean elevation of all pixels in the basin. Main-channel length and total stream length were computed using digital line graphs of the 7.5-minute USGS quadrangles in each area. Main-channel length was the length of the main channel of each stream, projected to the basin divide. Total stream length was the summed lengths of all stream segments appearing on the 7.5-minute quadrangles. Main-channel slope was determined by intersecting the total stream length with the slope grid, buffered by 10 meters, producing a line of slope pixels. The mean of the pixels in this line was used as the mean-channel slope. Stream density was defined as the total stream length of a basin divided by its drainage area. Pond areas also were calculated using the digital line graphs of the 7.5-minute USGS topographic quadrangles, served by the Maine Office of GIS at http://apollo.ogis.state.me.us/. Wetland areas were calculated using digital National Wetland Inventory maps produced by the U.S. Fish and Wildlife Service (USFWS) at a scale of 1:24,000. Temperature and precipitation data were obtained from the Oregon State University Spatial Climate Analysis Service. These gridded datasets were produced using the Parameter-Elevation Regressions on Independent Slopes Model (PRISM) (Daly and Neilson, 1992; Daly and others, 1997). Precipitation and temperature data were determined for the centroid of each basin. Selected basin characteristics for each station that were used in the final regression equations are presented in table 3.

Table 3. Selected basin characteristics for streamflow-gaging stations used to develop regression equations

[USGS, U.S. Geological Survey]

USGS station number	Station name	Mean elevation (feet)	Drainage area (square miles)
	Partial-record stations		
01012520	Bald Mountain Brook near Bald Mountain, Maine	1,024	1.73
01012525	Bishop Mountain Brook near Bishop Mountain, Maine	978	1.04
01012790	North Fork McLean Brook near St. Agatha, Maine	796	0.56
01012800	Unnamed tributary to East Fork Dickey Brook nr St. Agatha, Maine	919	0.38
01013550	Unnamed tributary to Pearly Brook near Michigan Settlement,Maine	974	0.39
01014700	Factory Brook near Madawaska, Maine	922	5.96
01015005	Unnamed tributary to Hammond Brook near Cyr Plantation, Maine	848	0.55
01015007	Unnamed tributary to St. John River near Hamlin, Maine	639	0.66
01015008	Martin Brook near Hamlin, Maine	731	12.06
01017010	Unnamed tributary to Aroostook River at Crouseville, Maine	530	0.44
01017050	Libby Brook near Mapleton, Maine	719	2.63
01017115	Caribou Stream at Caribou, Maine	656	43.06
01017295	Nichols Brook near Limestone, Maine	627	1.69
01017300	Nichols Brook near Caribou, Maine	556	2.03
01017450	Ginn Brook near Fort Fairfield, Maine	676	6.13
01017550*	Williams Brook at Phair, Maine	654	3.82
01017555	Hilt Brook near Mars Hill, Maine	798	2.48
01017600	Unnamed tributray to Young Brook near Mars Hill, Maine	849	0.45
01018050	Big Brook near Littleton, Maine	496	14.26
01018060	Unnamed tributary to Meduxnekeag River nr Littleton Station, Maine	518	1.26
01018070	Unnamed tributary to meduxnekeag River near Littleton, Maine	437	5.07
01018100	Unnamed tributary to Dead Stream near Monticello, Maine	463	2.09
01030050	Webb Brook near Patten, Maine	736	1.04
	Continuous-record station		
01017900	Marley Brook near Ludlow, Maine	795	1.5

* Station 01017550 has been run as a continuous-record station from 1999 to the present. It was treated as a partial-record station for this report because it did not have a sufficient period of record to calculate an August median streamflow.

ESTIMATING AUGUST MEDIAN STREAMFLOW AT PARTIAL-RECORD STREAMFLOW-GAGING STATIONS

August median streamflow at partial-record gaging stations was estimated using base-flow measurements at the partial-record stations and the correlation between those base-flow measurements and concurrent mean daily streamflow values at continuous-record streamflow-gaging stations with a minimum of 15 years of record (index stations). This method is presented by Riggs (1972) and follows the USGS guidelines for regional low-flow analyses where appropriate (U.S. Geological Survey, 2003).

Computing August Median Streamflow at Index Stations

August median streamflow values at the index station and the daily mean streamflows that coincided with base-flow measurements at the partial-record stations were needed to estimate August median streamflows at the partial-record stations. Initially, annual August medians were calculated at each index station. A Mann Kendall trend test (Helsel and Hirsch, 1992) indicated that there was no trend over time in this annual series of August medians at any of the index stations. The expected August median streamflow was estimated at the index station by computing the median of the observed annual August medians. This method of computing the August median streamflow closely approximates the method of taking the August daily mean streamflow that is exceeded 50 percent of the time during the period of all August daily streamflows for the period of record, but was preferable because it allowed for the calculation of the variance around the median.

Daily mean streamflows at the continuous-record stations that corresponded to concurrent base-flow measurements at partial-record stations were used to establish a relation between the two stations. Daily mean streamflow collection was discontinued at Marley Brook near Ludlow in 1982 and the Machias River in Ashland in 1983. These stations still were used as index stations because they had sufficient periods of record to calculate August medians and were treated as partial-record stations from 1997 to 2002 to obtain daily mean streamflows that corresponded with base-flow measurements at the partial-record stations.

Estimating August Median Streamflow at Partial-Record Stations

Stedinger and Thomas (1985) developed a technique to estimate the mean and standard deviation of an annual event such as the d-day T-year low flow, which is the annual, minimum d-day consecutive low flow that will be exceeded, on average, every T years. Using this technique to calculate the *monthly median* at a partial-record station, as opposed to the d-day T-year low flow, is appropriate if the logarithms of the monthly medians at the index station are approximately normally distributed. Estimates are made on the basis of the relation between base-flow measurements at the partial-record station and concurrent daily streamflows at a continuous-record gaging station. This relation is defined using least-squares-regression analysis of the logarithms of the flows. The regression analysis and the low-flow statistic at the index station are used to estimate the desired flow characteristics at the partial-record station. The Stedinger-Thomas technique was used to calculate the August median and the variance of the August median at each partial-record station. This technique fits a least-squares regression to the data after the user determines if the base-flow measurements have an adequate linear relation with the concurrent daily streamflows at the index station.

To estimate an August median and standard deviation of the August median at the partial-record stations, the logarithm of the measured streamflows at a partial-record station has to have a linear relation with the logarithm of the concurrent daily mean streamflows at an index station. An example of the correlation between concurrent measurements at a partial-record station and an index station is shown in figure 4. All the low-flow partial-record stations used in the analysis had a correlation coefficient of greater than 0.65 with an index station. If measurements at a partial-record station correlated well with measurements from more than one index station, the index station with the higher correlation coefficient was used. If the correlation coefficient was similar for two index stations, the index station was chosen on the basis of the graphical relation between the two stations. Base-flow measurements at the partial-record station and the corresponding daily mean streamflows at an index station, total number of years of record at the index station, and the median and standard deviation of the base-10 logarithms of the August medians at the index station were used to

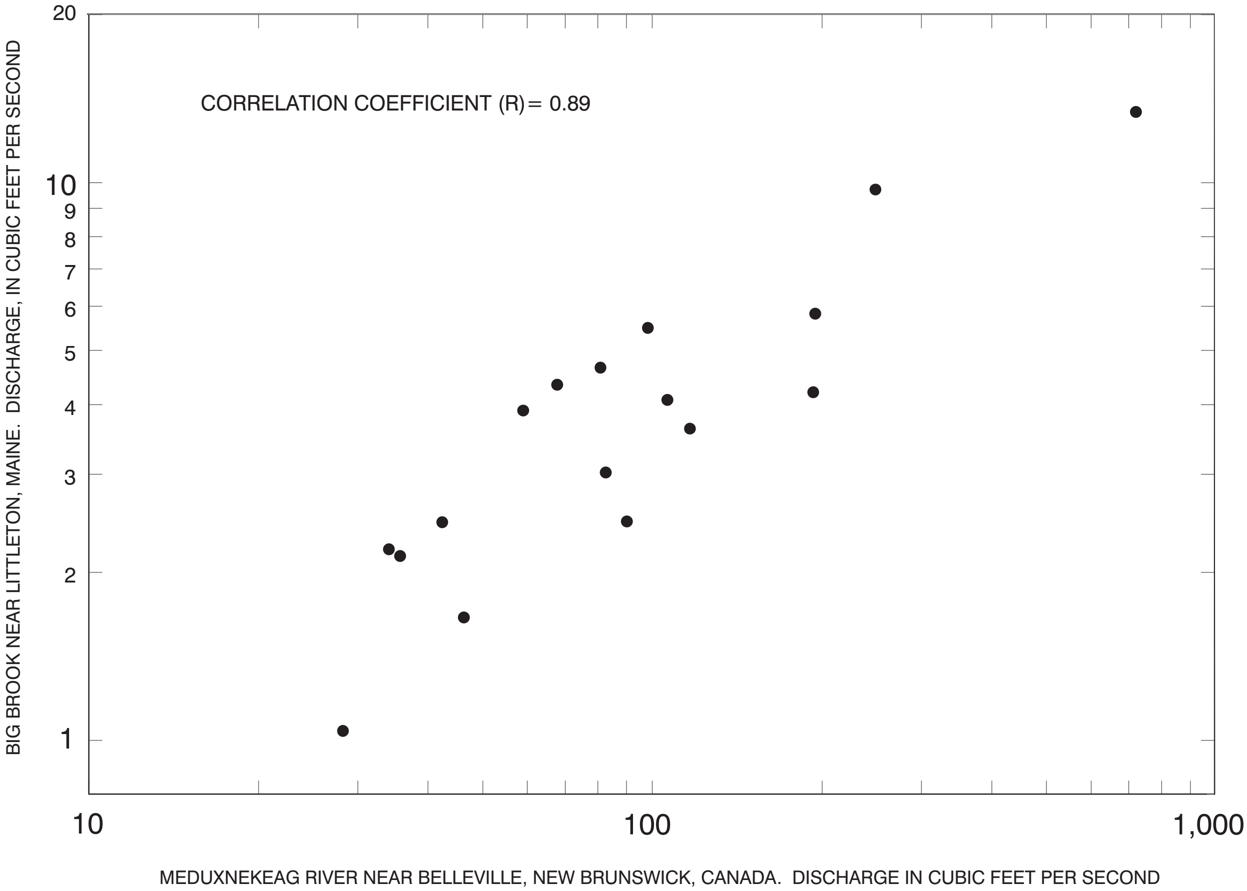

Figure 4. Example relation of base-flow measurements at partial-record station, Big Brook near Littleton, Maine, and concurrent daily mean flow measurements at index station, Meduxnekeag River near Belleville, New Brunswick, 1994-2002.

compute the base-10 logarithms of the median and its variance at the partial-record station.

All measurements at partial-record stations were included in the Stedinger-Thomas technique except in the following cases. Two partial-record stations had one streamflow measurement of zero each. The stations were used, but the zero streamflow measurements were not used because of the impossibility of taking the logarithm of zero and because the estimated August median was above the region of the graph that would have included these zero streamflow estimates. At some additional partial-record stations, measurements were taken for which no concurrent daily mean streamflow estimate was available at the most appropriate index station, number 01016500, Machias River near Ashland, Maine. This station was operated from 1951 to 1983 as a continuous-record station, resulting in 32 years from which to calculate the historic August median streamflow, and from 1997 to 2002 as a partial-record station to obtain corresponding streamflows with which to establish a correlation and extend the record of partial-record stations. Measurements from 1994 to 1996 were not available at this station; however, it still was the most appropriate index station in various cases based on measurements taken from 1997 to 2002. Estimates of the August medians at the partial-record stations are given in the section titled Weighted Estimates of August Median Streamflow at Partial-record and Continuous Record Streamflow Gaging Stations in this report.

ESTIMATING AUGUST MEDIAN STREAMFLOW ON UNGAGED STREAMS

Ordinary and general multiple-linear regression analyses were used to develop equations to estimate August median streamflow on ungaged streams. August median streamflow at 23 partial-record stations and 1 continuous-record station were related statistically to physical and climatic characteristics of the drainage basins of these stations. Station number

01017900, Marley Brook near Ludlow (Fig.2), was the only index station that also was used in the analysis to generate equations for ungaged streams because it is the only long-term continuous-record station with a drainage area less than 50 mi^2. The independent variables or basin characteristics that best explain the variability in the dependent variable, August median streamflow, were used to develop regression equations. These equations can be used to estimate August median streamflow on a river if basin characteristics can be calculated, but no streamflow data are available.

Statistical Methods

Initially, variations in the median August streamflow were related to variations in the drainage basin characteristics through ordinary least-squares regression analysis (OLS) (Helsel and Hirsch, 1992). A regression of all possible subsets in OLS was used to reduce the number of drainage basin characteristics and determine the best combination of independent variables to use in the final equation. Generalized least-squares (GLS) regression techniques were used to develop the final equations and estimates of accuracy presented in this report. Stedinger and Tasker (1985) showed that GLS regression techniques are more appropriate than OLS or weighted least-squares (WLS) for regionalizing streamflow statistics where the streamflow records at the gaged index stations are of varying lengths and concurrent streamflows at different stations are cross correlated. Although WLS can adjust for records of varying lengths, it does not adjust for the cross correlation of concurrent streamflows at sites. The cross correlation especially can be problematic when working with partial-record stations where two or more partial-record stations are extended with the same index station. Another benefit of GLS over OLS and WLS is that the prediction error of the resulting equations can be separated into model error and sampling error.

Ordinary Least-Squares Regression

Ordinary least-squares equations were developed in a regression of all possible subsets. To establish linearity, logarithmic transformations of the response variable (August median streamflow) and one of the explanatory variables (drainage area) were performed. Transformation was not necessary for the remaining explanatory variables. The equations with the strongest relations between the explanatory variables and the response variables were chosen on the basis of the p-values of the T-statistic, the adjusted R^2, and Mallow's Cp statistic. The p-values of the T-statistic indicate the significance of the individual explanatory variables. The adjusted R^2 value indicates the amount of variance in the response variable explained by the explanatory variable(s), and Mallow's Cp statistic is a compromise between maximizing the explained variance by including all relevant variables and minimizing the standard error by keeping the number of variables as small as possible (Helsel and Hirsch, 1992). Partial residual plots and residuals and predicted plots were examined. Top one- and two-variable models were tested for regression assumptions including linearity, homoscedasticity (constant variance in the response variable over the range of explanatory variables) and normality.

The three models that best satisfied the above-mentioned criteria had the following combinations of explanatory variables: (1) the logarithm of the drainage area, (2) the logarithm of the drainage area and mean elevation, and (3) the logarithm of the drainage area and average summer precipitation.

Generalized Least-Squares Regression

Final one- and two- variable models and their coefficients and estimates of error were selected with GLS. A model that estimated August median streamflow using the explanatory variables, drainage area, and mean basin elevation, minimized the standard error and maximized the explained variance. A second model only using drainage area was selected for cases where reduced accuracy was acceptable. The GLS regression adjusted for the records of varying lengths, and the cross correlation of concurrent streamflows among partial-record stations, especially those extended with the same index stations. Residuals were mapped for each partial-record station and no spatial patterns were found. A computer program was developed for performing GLS regression in situations where the majority of stations being used to develop an equation for August median streamflow are partial-record stations. A more detailed statistical analysis and rational for the use of GLS follows.

Regional Regression of Expected August Median Streamflow Using Generalized Least-Squares Regression

A regional regression model was used to estimate expected August median streamflow at a stream site based on physical, climatological, and land-use characteristics of the drainage basin. Assume a linear model is of the form

$$\psi = \boldsymbol{X}\beta + \varepsilon, \quad (1)$$

where ψ is a (N x 1) column vector of logarithms of expected August median discharge values, $\boldsymbol{X}$ is a (N x p) matrix of known basin characteristics augmented by a column of 1's, β is a (p x 1) column vector of unknown regression coefficients to be estimated, and ε is a (N x 1) column vector of errors with $E[\varepsilon]=0$ and $E[\varepsilon\varepsilon']=\boldsymbol{I}\gamma^2$. The scalar value γ^2 is called the model error variance and N is the number of gaging stations and partial-record stations in the region.

Estimating August Median Streamflow of Continuous-Record and Partial-Record Streamflow Gaging Stations

The first operational problem with the regression model in equation 1 is that the logarithm of expected August median discharge, ψ, is to be estimated from streamflow records and base-flow measurements made at partial-record stations.

At gaged, continuous-record station i with n_i years of record, the expected August median discharge, $\bar{Q}i$, is estimated by computing the median of the observed annual August medians. For the regional regression in equation 1, the dependent variable is the base-10 log of the August median. Assuming the logarithms of annual August medians approximate a normal distribution, the standard error of the log of the median of annual August medians can be estimated as

$$S_i = c[(S_x)_i / n_i^{0.5}] \text{ (Stuart and Ord, 1987)}, \quad (2)$$

where $(S_x)_i$ is the standard deviation of the logarithms of the annual August medians at station i with n_i years or record and c is a constant equal to 1.2533.

The analysis for partial-record stations is based on an assumed linear model between the logarithms of annual August medians, $y_{i,t}$, at partial-record station i in year t and the annual August medians, $x_{i,t}$, at a nearby continuous station:

$$y_{i,t} = \alpha_i + \delta_i x_{i,t} + e_{i,t}, \quad (3)$$

where $e_{i,t}$ are independent, identical normally distributed errors with mean zero and variance σ^2_e. Because no observations of August medians are available for the partial-record station, α, δ, and σ_e in equation 3 are estimated by an ordinary least-squares regression of independent base-flow measurements at the partial-record station, $\tilde{y}_i$, on concurrent daily flows, $\tilde{x}_i$, at the index station. An estimate of the expected August median at the partial-record station is obtained from

$$\log(\bar{Q}i) = a_i + b_i M_x \quad (4)$$

where a_i and b_i are estimates of α_i and δ_i from a regression of $\tilde{y}_i$ on $\tilde{x}_i$ and Mx is the sample median of annual August medians for the index station. The variance of $\log(\bar{Q}i)$ is estimated by

$$S_i^2 = Var(\log(\bar{Q}_i)) =$$

$$(s_e)_i^2\left[\frac{1}{L_i} + \frac{(M_x - m_x)^2}{s^2{}_x(L_i - 1)}\right] + \frac{b_i^2(c(S_x)_j)^2}{n_j}$$

(Stedinger and Thomas, 1985), (5)

in which L_i is the number of base-flow measurements at the partial-record station, m_x is the mean of the logarithms of the concurrent daily flows at the index station, s_x is the standard deviation of concurrent daily flows at the index station, c is a constant equal to 1.2533, and $(s_e)_i$ is the standard error of estimate of the regression of $\tilde{y}_i$ on $\tilde{x}_i$.

Estimating August Median Streamflow on Ungaged Streams

For the regional equation (1), $y_i=\log(\bar{Q}i)$ is the estimate of ψ_i at the partial-record or continuous-record stations and has a random error component such that

$$\psi_i = y_i - \eta_i, \quad (6)$$

where η_i is a random error with $E[\eta_i]=0$ and $Var[\eta_i]=S_i^2$. Substituting equation 6 into equation 1, in matrix notation, the regional regression model is

$$\boldsymbol{y} = \boldsymbol{X}\beta + \varepsilon + \eta, \quad (7)$$

with $E[\varepsilon+\eta]=\boldsymbol{0}$ and $E[(\varepsilon+\eta)(\varepsilon+\eta)']=\Lambda$. The covariance matrix of errors, Λ, is given by

$$\Lambda = \gamma^2 I + \Sigma, \quad (8)$$

where the (N x N) matrix Σ has elements of

$$\Sigma_{ij} = \begin{cases} S_i^2 & \text{for } i=j \\ \rho(y_i, y_j) C_{ij} & \text{for } i \neq j, \end{cases} \quad (9)$$

where i and j index rows and columns of the matrix, $\rho(y_i,y_j)$ is the correlation between estimates of logarithms of expected August medians at stations i and j, and C_{ij} is defined as in Tasker and Driver (1988) as

$$C_{ij} = \frac{b_i b_j (S_x)_i (S_x)_j}{\sqrt{n_i n_j}} \quad (10)$$

A regression model with this error structure was considered by Stedinger and Tasker (1985; 1986a; 1986b) to develop a generalized-least-squares (GLS) method for regional hydrologic regression. The method provides for possibly more accurate estimates of regression coefficients when compared to ordinary least-squares methods when stations have different sampling variances, an unbiased model-error estimator, and a better description of the relation between hydrologic data and information for hydrologic network analysis and design (Tasker and Stedinger, 1989; Moss and Tasker, 1991).

The GLS method for regional regression of annual recharge generally proceeds as follows. The Σ matrix is estimated by entering the S_i's from the N at-station regressions and using the relation between cross-correlation coefficients between mean annual values and annual values (Moss, 1973) as

$$\rho(y_i, y_j) = \frac{m_{ij}\rho_{ij}}{\sqrt{n_i n_j}} \quad (11)$$

where m_{ij} is the concurrent record length between index stations for partial-record stations i and j, n_i is the record length at station i, and ρ_{ij} is the correlation between concurrent annual August median values at the pair of stations. The values of ρ_{ij} used to compute $\rho(y_i,y_j)$ in equation 11 are estimated by an average value based on pairs of long-term continuous-record stations. It is necessary to use the averaged values to avoid problems with inverting the Λ matrix (Tasker and Stedinger, 1989). Once the Σ matrix is filled out from the sample data, the EGLS regression estimators of the model parameters, β, are determined by solving

$$\{\mathbf{X}'\Lambda^{-1}\mathbf{X}\}\beta = \mathbf{X}'\Lambda^{-1}\mathbf{y}, \quad (12)$$

with model-error variance γ^2 determined so that

$$(\mathbf{y}-\mathbf{X}\beta)'\Lambda^{-1}(\mathbf{y}-\mathbf{X}\beta) = N - p. \quad (13)$$

The predicted log of the August median at ungaged station k with basin characteristics

$$\mathbf{x}_k = (1, x_{k,1}, x_{k,2}, \ldots, x_{k,p}) \text{ is } \hat{y}_k = \mathbf{x}_k \mathbf{b} \quad (14)$$

The standard error of prediction is

$$S(\hat{y}_k) = \sqrt{\hat{\gamma}^2 + \mathbf{x}_k \mathbf{X}' \hat{\Lambda}^{-1} \mathbf{X}^{-1} \mathbf{x}'_k} \quad (15)$$

EQUATIONS FOR ESTIMATING AUGUST MEDIAN STREAMFLOW ON UNGAGED STREAMS

Two-Variable Model

The final equation using mean elevation (E) in feet and drainage area (A) in square miles to predict August median streamflow at ungaged stations on ungaged streams ($\overline{Q}i$) is

$$\overline{Q}i = 0.061\ (A)^{1.28}\ 10^{0.00059(E)}\ . \quad (16)$$

Drainage area and mean elevation are both significant (p-values equal to 0.0001 and 0.0489, respectively). The average standard error of prediction (ASEP) is from -38 to 62 percent. The ASEP is a measure of how well the regression equation estimates the response variable when it is applied to ungaged drainage basins that were not used to develop the equation. There is a 68-percent probability that the true value of a peak flow at a station will be within the range of the standard error of prediction.

Equation 16 is appropriate for predicting August median streamflows at unregulated drainage basins on ungaged streams in the eastern part of Aroostook County within the two-dimensional range of variables shown by the shaded area in figure 5. If the equations are used with explanatory variables outside the two-dimensional range shown in figure 5, or if the explana-

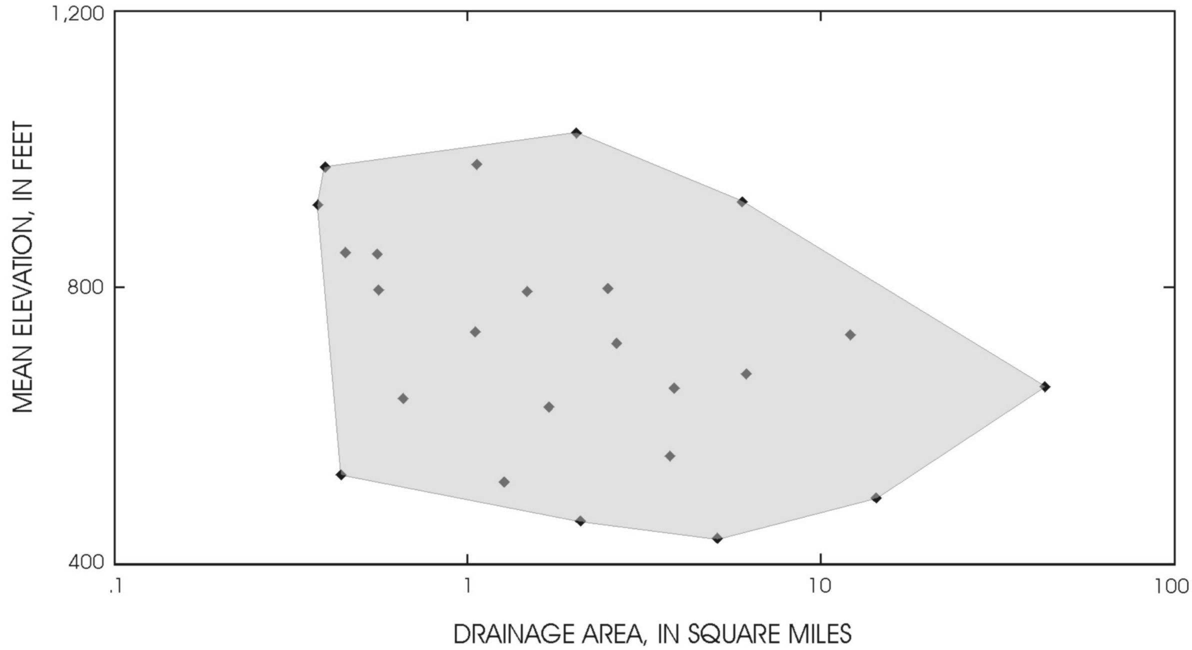

Figure 5. Two-dimensional range of explanatory variables used in regression equations for predicting August median streamflows on ungaged streams in the eastern part of Aroostook County, Maine. [Shaded area shows range.]

tory variables are calculated with methods other than those outlined above, the resulting estimates of August median streamflow will be of unknown accuracy.

Estimates of August median streamflow on ungaged streams can range from 0.03 to 30 ft^3/s within the appropriate range of explanatory variables. If estimates are divided by the drainage area, they can range from 0.1 to 0.7 $(ft^3/s)/mi^2$ and these values generally increase as mean elevation and the drainage area increase.

The generalized least-squares analysis results in an error that can be divided into sampling-error variance and model-error variance. The model-error variance is a measure of error resulting from an incomplete model, one that does include all the variables that would be necessary to completely explain the variability in the entire population of the dependent variable. Sampling-error variance is a measure of the error because of only being able to sample a subset of the complete population (both in time and in space) The average model-error variance in the above model is 0.0361 (base-10 logs) and the average sampling-error variance is 0.0074 (base-10 logs). The model error is about five times greater than the sampling error. This result indicates that future research should focus more on improving the model by developing new basin characteristics rather than on additional data collection at present partial-record stations, or creation of new partial-record stations to reduce the error in the regression equation.

Low-flow studies in other northeastern States (Cervione and others, 1993; Wandle and Randall, 1994; Ries, 1994a, 1994b, 1997) indicate that surficial geology can be important in explaining the variability of low flows. Although the sand and gravel aquifers in Maine have been mapped (Maine Geological Survey, 2003), the surficial geology in eastern Aroostook County is not particularly variable. Only one of the partial-record station drainage basins overlaps with a sand and gravel aquifer as shown by the current mapping. Either the mapping is not detailed enough to be accurate for small drainage basins or there is little variability in this eastern section of Aroostook County. Until additional, more detailed geologic mapping is available, the variability of the surficial geology cannot be accounted for. In addition, the sampling error may result from the lack of small index stations in the region of interest. Better correlations of index stations and partial-record stations could lower the sampling error.

One-Variable Model

A simplified technique using only drainage area (A) in mi^2, to estimate August median streamflow on ungaged streams ($\overline{Q}i$) is presented below. This technique is quicker and easier to apply than other techniques, but should only be used when estimates of less accuracy are acceptable.

$$\overline{Q}i = 0.17\ (A)^{1.217} \qquad (17)$$

Drainage area is highly significant (p-value < 0.0001). The average standard error of estimation is from -40 to 67 percent. This error is made up of an average model-error variance of 0.0435 (base-10 logs) and an average sampling-error variance of 0.0061 (base-10 logs). Estimates of August median streamflow range from 0.06 to 15 ft^3/s within the appropriate range of drainage areas. If these estimates are divided by the drainage area, they range from 0.1 to 0.4 $(ft^3/s)/mi^2$ and these values increase as drainage area increases.

WEIGHTED ESTIMATES OF AUGUST MEDIAN STREAMFLOW AT PARTIAL- AND CONTINUOUS-RECORD STREAMFLOW-GAGING STATIONS

It is appropriate to use weighted estimates of August median streamflow at partial-record and continuous-record streamflow-gaging stations. Weighted estimates average measurements taken at the station with an estimate for the August median at the station using the equation for ungaged stations. The weights for this average are based on the variance of the base-10 logs of the respective estimates. The variance of the regression prediction, $\hat{y}_k$ is given by

$$V_R = S^2(\hat{y}_k)\ , \qquad (18)$$

where $S(\hat{y}_k)$ is given in equation 15. The variance of the estimate based on at-station streamflow data is $V_O = S_i^2$, where S_i is given by equations 2 or 5, depending on the type of gaging station. The weighted estimate of the log of August median is

$$Y_w = w\hat{y}_k\ + (1-w)\ \log \overline{Q}i\ , \qquad (19)$$

where

$$w = V_O/(V_O+V_R). \qquad (20)$$

Assuming independence of the two estimators, the variance of Y_w would be

$$Var(Y_w) = (V_O V_R)/(V_O+V_R). \qquad (21)$$

Weighted estimates of August median streamflow at the partial-record stations used in this report are presented in table 4. The weighted estimates of August median streamflow at the partial-record stations range from 0.03 to 11.67 ft^3/s or from 0.1 to 0.4 $(ft^3/s)/mi^2$.

SUMMARY AND CONCLUSIONS

This report, prepared by the U.S. Geological Survey in cooperation with the Aroostook County Water and Soil Management Board, presents equations to estimate August median streamflow on any unregulated stream in the eastern part of Aroostook County, Maine, with a drainage area from 0.38 to 43 mi^2 and a mean basin elevation from 437 to 1024 ft. August median streamflows were estimated at 1 continuous-record station and 23 partial-record stations to develop equations for estimating August median streamflow on ungaged streams. Each estimate of August median streamflow at a partial-record station was based on the stations's relation with one of seven continuous-record stations in Maine and New Brunswick Canada.

Generalized least-squares regression analyses resulted in a two-variable regression equation to estimate August median streamflow on ungaged streams using two drainage basin characteristics, drainage area and mean basin elevation. A high standard error of prediction of from -38 to 62 percent probably can be explained by the small number of index stations with small drainage areas in the region, and by the lack of variability in the current surficial geology mapping, which often explains a great deal of variability in low-flow statistics. A one-variable regression equation using only drainage area to estimate August median streamflow on an ungaged stream also was developed along with an estimate of its accuracy. The equation only should be used when reduced accuracy is acceptable. The generalized least-squares regression accounted for records of different lengths as well as cross correlation between the stations in both the one- and two-variable models.

Weighted estimates of August median streamflow should be used at the partial-record stations and the one continous-record station, as they combine regional regression equation estimates with specific estimates based on base-flow measurements for each station. The weighted estimates of August median streamflow at the partial-record stations range from 0.03 ft^3/s to 11.67 ft^3/s. The weighted estimates of August median streamflow per square mile of drainage area at the partial-record stations range from 0.1 to 0.4 $(ft^3/s)/mi^2$. Estimates of August median streamflow on ungaged streams range from 0.03 to 30 ft^3/s or from 0.1 to 0.7 $(ft^3/s)/mi^2$ when the equation is applied within the range of acceptable explanatory variables. Estimates generally increase as mean elevation and drainage area increase.

Estimates of August median streamflow per square mile of drainage area at ungaged stations vary with drainage basin size, and for the smaller streams are lower than estimates in previous investigations. Previously, 0.5 $(ft^3/s)/mi^2$ was used on basins of all sizes to estimate August median streamflow. Differences in estimates are partially a result of the method of calculating the median streamflow. The median of the monthly median streamflow generally will be lower than the median of the mean monthly streamflow because mean streamflow data are skewed towards the higher flow events. It is also a result of the smaller drainage basins used in this analysis. Previous investigations often had few or no stations less than 10 mi^2 in drainage area. This investigation has shown that August median streamflows per square mile of drainage area increase as the basin size increases.

Table 4. Weighted August median streamflows at partial-record and continuous-record streamflow-gaging stations.
[USGS, U.S. Geological Survey].

USGS station number	Station name	Weighted August median flow (cubic feet per second)
	Partial-record stations	
01012520	Bald Mountain Brook near Bald Mountain, Maine	0.44
01012525	Bishop Mountain Brook near Bishop Mountain, Maine	.26
01012790	North Fork McLean Brook near St. Agatha, Maine	.10
01012800	Unnamed tributary to East Fork Dickey Brook near St. Agatha, Maine	.06
01013550	Unnamed tributary to Pearly Brook near Michigan Settlement,Maine	.09
01014700	Factory Brook near Madawaska, Maine	1.33
01015005	Unnamed tributary to Hammond Brook near Cyr Plantation, Maine	.15
01015007	Unnamed tributary to St. John River near Hamlin, Maine	.06
01015008	Martin Brook near Hamlin, Maine	4.77
01017010	Unnamed tributary to Aroostook River at Crouseville, Maine	.03
01017050	Libby Brook near Mapleton, Maine	.31
01017115	Caribou Stream at Caribou, Maine	11.67
01017295	Nichols Brook near Limestone, Maine	.40
01017300	Nichols Brook near Caribou, Maine	1.33
01017450	Ginn Brook near Fort Fairfield, Maine	1.65
01017550*	Williams Brook at Phair, Maine	1.06
01017555	Hilt Brook near Mars Hill, Maine	.78
01017600	Unnamed tributray to Young Brook near Mars Hill, Maine	.03
01018050	Big Brook near Littleton, Maine	5.02
01018060	Unnamed tributary to Meduxnekeag River near Littleton Station, Maine	.12
01018070	Unnamed tributary to Meduxnekeag River near Littleton, Maine	.56
01018100	Unnamed tributary to Dead Stream near Monticello, Maine	.20
01030050	Webb Brook near Patten, Maine	.21
	Continuous-record station	
01017900	Marley Brook near Ludlow, Maine	.20

* Station 01017550 has been run as a continuous-record station from 1999 to the present. It was treated as a partial-record station for this report because it did not have a sufficient period of record to calculate an August median flow.

REFERENCES CITED

Aroostook Water and Soil Management Board, 1996, How to deal with low flow periods and irrigating farmer's and environmental concerns in Aroostook County: Presque Isle, Maine, Aroostook Water and Soil Management Program 8 p.

Cervione, M.A., Richardson, A.R. and Weiss, L.A., 1993, Low-flow characteristics of selected streams in Rhode Island: U.S. Geological Survey Water-Resources Investigations Report 93-4046, 16 p.

Charles Ritzi and Associates, 1987, Computation of US Fish and Wildlife Service aquatic base flow for regulated streams: Winthrop, Maine, 15 p.

Daly, C., and Neilson, R.P., 1992, A digital topographic approach to modeling the distribution of precipitation in mountainous terrain, *in* Jones, M.E., and Laenen, A., eds., Interdisciplinary approaches in hydrology and hydrogeology: American Institute of Hydrology, p. 437-454.

Daly, C., Taylor, G.H., and Gibson, W.P., 1997, The PRISM approach to mapping precipitation and temperature: Proceedings of the 10th AMS Conference on Applied Climatology, American Meteorological Society, Reno Nevada, Oct. 20-23, 1997, p.10-12.

Fontaine, R.A, 1989, Hydrologic and meteorologic data for the Bald Mountain area Aroostook County, Maine, June 1979 through June 1984: U.S. Geological Survey Open-File Report 85-174, 166 p.

Helsel, D.R., and Hirsch, R.M., 1992, Statistical methods in water resources: New York, Elsevier, 522 p.

Inland Waters Directorate, 2001, Surface water and sediment data: Ottawa, Ontario, Water Resources Branch, Water Survey of Canada.

Johnson, C.G., 1970, A proposed streamflow data program for central New England: U.S. Geological Survey Open-File Report, 38 p.

Kulik, B.H., 1990, A method to refine the New England aquatic base-flow policy: Rivers, v.1, no. 1, p. 8-22.

Maine Geological Survey, 2003, Sand and gravel aquifer mapping, served by the Maine office of GIS: accessed September 2, 2003 at URL http://apollo.ogis.state.me.us/.

Maine Register State Yearbook and Legislative Manual, Maine Register, No. 130, Tower Publishing Company, Standish, Maine, September, 2000.

Maine State Legislature, 2002, Sec 1. 38 MRSA c.3, sub-c.I, article 4-B.

Moss, M.E., 1973, Cross correlation of the logarithms of estimates of mean streamflows: Water Resources Research, v. 9, no. 6, p. 1681-1683.

Moss, M.E., and Tasker, G.D., 1991, An intercomparison of hydrologic network-design technologies: Journal of Hydrologic Sciences, v. 6, no. 3, p. 209-221.

Parker, 1977, Methods for determining selected flow characteristics for stream in Maine: U.S. Geological Survey Open-File Report 78-871, 31 p.

Rantz, S.E. and others, 1982, measurements and compuation of streamflow volume 1, Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Ries, K.G., III, 1994a, Estimation of low-flow duration discharges in Massachusetts: U.S. Geological Survey Water Supply Paper 2418, 50 p.

_____1994b, Development and application of generalized-least-squares regression models to estimate low-flow duration discharges in Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 94-4155, 33 p.

_____1997, August median streamflows in Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 97-4190, 27 p.

Riggs, H.C., 1972, Low-flow investigations: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. B1, 18 p.

Risley, J.C., 1994, Estimating the magnitude and frequency of low flows of streams in Massachusetts: U.S. Geological Survey Water-Resources Investigations Report 94-4100, 29 p.

Stedinger, J.R., and Tasker, G.D., 1985, Regional hydrologic analysis 1. Ordinary, weighted, and generalized least-squares compared:Water Resources Research, v. 21, no. 9, p. 1421- 1432.

_____1986a, Correction to Regional hydrologic analysis 1. Ordinary, weighted, and generalized least-squares comparedí: Water Resources Research, v. 22, no. 5, p. 844.

_____1986b, Regional hydrologic analysis 2, Model error estimates, estimation of sigma, and log-Pearson Type 3 distributions: Water Resources Research, v. 22, no. 10, p. 1487-1499.

Stedinger, J.R., and Thomas, W.O., 1985, Low-flow frequency estimation using base-flow measurements: U.S. Geological Survey Open-File Report 85-95, p. 22.

Stewart, G.J., Caldwell, J.M., and Cloutier, A.R., 2001, Water resources data-Maine water year 2001: U.S. Geological Survey Water-Data Report ME-01-1, 232 p.

Stuart, A. and Ord, J.K, 1987, Kendallís Advanced Theory of Statistics, 5th ed., v. 1, Distribution Theory: Oxford University Press, 604 p.

Tasker, G.D., and Driver, N.E., 1988, Nationwide regression models for predicting urban runoff water quality at unmonitored sites: Water Resources Bulletin, v. 24, n. 5, p. 1091-1101.

Tasker G.D., and Stedinger, J.R., 1989, An operational GLS model for hydrologic regression: Journal of Hydrology, v. 111, no. 1-4, p. 361-375.

U.S. Department of Commerce, 1997, National Oceanic and Atmospheric Administration, National Environmental Satellite Data and Information Service, Climatological Data Annual Summary, New England: Vol. 109, no. 13, Asheville, North Carolina, National Climatic Data Center, 1997.

U.S. Fish and Wildlife Service, 1981, Interim regional policy for New England stream flow recommendations: Concord, N.H., U.S. Fish and Wildlife Service, Region 1.

U.S. Geological Survey, 2003,Office of Surface Water Technical Memorandum No. 89.11, July 7, 1989, accessed September 2, 2003, at URL http://water.usgs.gov/admin/memo/SW/sw89.11.html.

Wandle, S.W., Jr., and Randall, A.D., 1994, Effects of surficial geology, lakes and swamps, and annual water availability on low flows of streams in central new Engalnd and their use in low-flow estimations: U.S. Geological Survey Water-Resources Investigations Report 93-4092, 57 p.

Lombard, P.J., Tasker, G.D., and Nielsen, M.G., 2003—AUGUST MEDIAN STREAMFLOW ON UNGAGED STREAMS IN EASTERN AROOSTOOK COUNTY, MAINE — USGS WRIR 03-4225

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