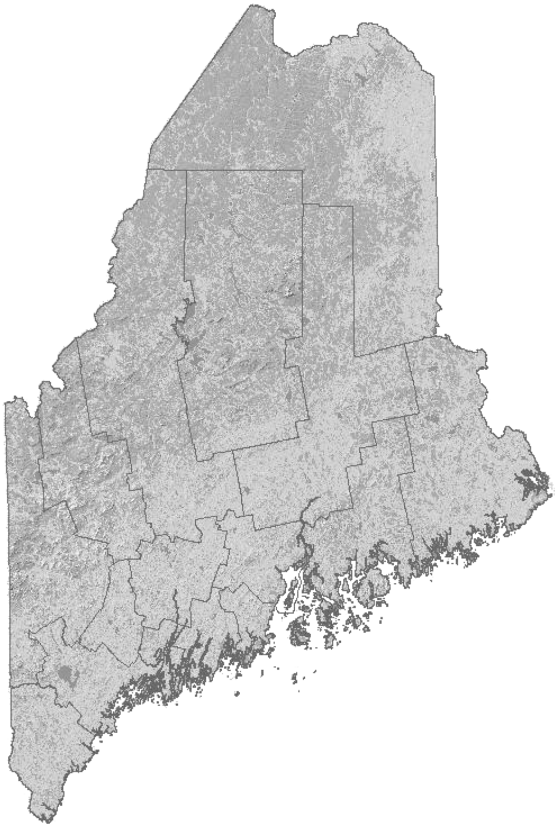
In cooperation with the
Maine Department of Transportation
Maine Department of Environmental Protection and
Maine Atlantic Salmon Commission

# Estimating Monthly, Annual, and Low 7-Day, 10-Year Streamflows for Ungaged Rivers in Maine



Scientific Investigations Report 2004-5026

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

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

**U.S. Department of the Interior**
Gale A. Norton, Secretary

**U.S. Geological Survey**
Charles G. Groat, Director

U.S. Geological Survey, Augusta, Maine: 2004

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## Conversion Factors

| Multiply | By | To obtain |
|---|---|---|
| gallon per minute (gal/min) | 3.785 | liter per minute |
| inch (in.) | 25.4 | millimeter |
| foot (ft) | 0.3048 | meter |
| mile (mi) | 1.609 | kilometer |
| square mile ($mi^2$) | 2.589 | square kilometer |
| foot per second (ft/s) | 0.3048 | meter per second |
| cubic foot per second ($ft^3/s$) | 0.02832 | cubic meter per second |

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

$$°C = 5/9 * (°F - 32)$$

# Estimating Monthly, Annual, and Low 7-Day, 10-Year Streamflows for Ungaged Rivers in Maine

*By* Robert W. Dudley

## Abstract

Regression equations to estimate monthly, annual, and low 7-day, 10-year (7Q10) streamflows were derived for rivers in Maine. The derived regression equations for estimating mean monthly, mean annual, median monthly, median annual, and low 7Q10 streamflows for ungaged rivers in Maine presented in this report supersede those derived in previous studies.

Twenty-six U.S. Geological Survey streamflow-gaging stations on unregulated, rural rivers in Maine with 10 years or more of recorded streamflow were used to develop the regression equations. Ordinary least squares (OLS) regression techniques were used to select the explanatory variables (basin and climatic characteristics) that would appear in the final regression equations. OLS regression of all possible subsets was done with 62 explanatory variables for each of 27 response variables. Five explanatory variables were chosen for the final regression equations: drainage basin area, areal fraction of the drainage basin underlain by sand and gravel aquifers, distance from the coast to the drainage basin centroid, mean drainage basin annual precipitation, and mean drainage basin winter precipitation (the sum of mean monthly precipitation for December, January, and February). Generalized least-squares regression techniques were used to derive the final coefficients and measures of uncertainty for the regression equations.

The forms of many of the derived regression equations indicate some physical, mechanistic processes. Drainage basin area is the most statistically important explanatory variable and appears in all derived regression equations. Monthly streamflows are related inversely to the distance from the coast to the drainage basin centroid during December, January, February, and March; that is, the closer a river basin is to the coast, the higher monthly streamflows are per unit drainage basin area during the winter. The relation reverses in May when higher streamflows are attributed to basins farther from the coast. These relations are consistent with colder, inland drainage basins storing more water in snowpack during the winter and releasing it in the spring. The monthly streamflows (and low 7Q10) during July, August, September, and October are related positively to areal fraction of the drainage basin underlain by sand and gravel aquifers. In general, sand and gravel aquifers underlying Maine river basins have excellent water-yielding characteristics and can provide water to streams during low-flow conditions in the summer and early fall.

## Introduction

The ability to estimate monthly, annual, and low streamflow statistics for rivers is needed by Federal, State, regional, and local water- and natural-resources professionals to effectively manage resources and plan projects. Streamflow data sufficient to estimate these statistics are available for only a small percentage of rivers in Maine. Earlier studies by Parker (1977), “Methods for Determining Selected Flow Characteristics for Streams in Maine,” and by Hayes and Morrill (1970), “A Proposed Streamflow Data Program for Maine,” presented regression equations that could be used to estimate some streamflow statistics. In 2002, the U.S. Geological Survey (USGS) began a cooperative investigation with the Maine Department of Transportation (MDOT), the Maine Department of Environmental Protection (MDEP), and the Maine Atlantic Salmon Commission (ASC) to update methods that can be used to estimate streamflow statistics for ungaged rivers in Maine.

### Purpose and Scope

This report presents updated regression equations that were derived to estimate mean monthly, mean annual, median monthly, median annual, and low 7-day, 10-year (7Q10) streamflows for unregulated, rural rivers in Maine. The regression equations were developed using streamflow data from 26 USGS streamflow-gaging stations on unregulated, rural rivers with 10 or more years of recorded streamflow; streamflow statistics for these 26 stations also are included in the report.

The regression equations can be used at sites on rivers where streamflow data are not available, assuming no diversions, regulation, or appreciable urbanization are present upstream from the site in the drainage basin. Because of improved accuracy and updated information, the regression equations presented here to estimate mean monthly, mean annual, and low 7Q10 streamflows supersede earlier equations derived by Parker (1977) and Hayes and Morrill (1970).

The updated regression equations were derived using new regression techniques that test every possible combination of explanatory variables and account for correlation of flows between sites and the relative accuracy of computed flows from different sites. The derivation of the updated regression equations made use of an additional 25 years of streamflow-gaging data for Maine and new, up-to-date information from Geographic Information System (GIS) data layers and associated spatial analysis tools describing basin and climate characteristics such as geology, land use, and precipitation.

## Description of the Study Area

The state of Maine (fig. 1) has a land area of 30,862 $mi^2$ and population of 1.27 million people in 2000 (U.S. Census Bureau, 2002). Topographic relief is predominantly moderate to low throughout the State except for high-relief areas (the Appalachian Mountains) in west-central Maine (Randall, 2001). Elevations range from 0 ft at the coast to 5,266 ft (National Geodetic Vertical Datum (NGVD) of 1929) in the Appalachian Mountains.

To derive the regression equations for estimating streamflows, 26 unregulated, rural river basins throughout Maine (fig. 1) were analyzed. Mean basin elevations for the 26 sites range from 200 ft to 1,860 ft, with a mean of 710 ft (NGVD 1929) . The East Machias River Basin, in a broad, coastal lowland region in eastern Maine, has the lowest mean elevation, and the Swift River Basin, in the high-relief parts of west-central Maine, has the highest mean elevation.

According to the National Land Cover Data (NLCD) GIS coverages (Vogelmann and others, 1998a; 1998b) for the basins used in this study, forest is the predominant land-use classification. The percentage of forested area in the 26 study basins ranges from 65 to 98 percent with a mean of 82 percent. The greatest change in land use in Maine during the 20th century has been the replacement of agriculture and pasture lands by forest. The overall forest cover in the State is estimated to have been at its lowest around 1900 at approximately 70 percent. Forest cover increased to about 90 percent by 1995 (Irland, 1998). None of the basins studied are considered urbanized nor do any of them have substantial channelization or other drainage improvements.

Maine generally has a temperate climate with mild summers and cold winters. From 1971 to 2000, the mean annual temperature for Maine was about 42 $^{o}$F, with a range from 36 $^{o}$F in Allagash in northern Maine to 47 $^{o}$F in Sanford in southern Maine. For the same time period, statewide mean monthly temperatures ranged from 15 $^{o}$F in January to 67 $^{o}$F in July (National Oceanic and Atmospheric Administration, 2002).

Precipitation in Maine is fairly evenly distributed throughout the year. The mean annual precipitation from 1971 to 2000 for Maine was 43 in., ranging from 35 in. in Presque Isle, northern Maine, to 57 in. in Acadia National Park, coastal Maine. For the same time period, statewide mean monthly precipitation was 3.6 in., with a standard deviation of 0.6 in. (National Oceanic and Atmospheric Administration, 2002).

# Data Used for this Study

## Streamflow

Streamflow data from 26 streamflow-gaging stations in Maine (fig. 1) were used to develop the regression equations for estimating monthly, annual, and low 7Q10 streamflows presented in this report. The following criteria were used to select the streamflow-gaging stations: (1) continuous streamflow records represent natural streamflow, (2) the length of streamflow record for each site is 10 years or more, and (3) the drainage basins of the stations are entirely within the State of Maine. Natural streamflow is defined as flow from a predominately rural basin unaffected by diversions and (or) regulation by dams or reservoirs.

Streamflow data were retrieved from the National Water Information System (NWIS) (U.S. Geological Survey, 1998) for all available USGS streamflow-gaging stations that met the criteria of the study. Periods of record of streamflow data for the 26 selected stations

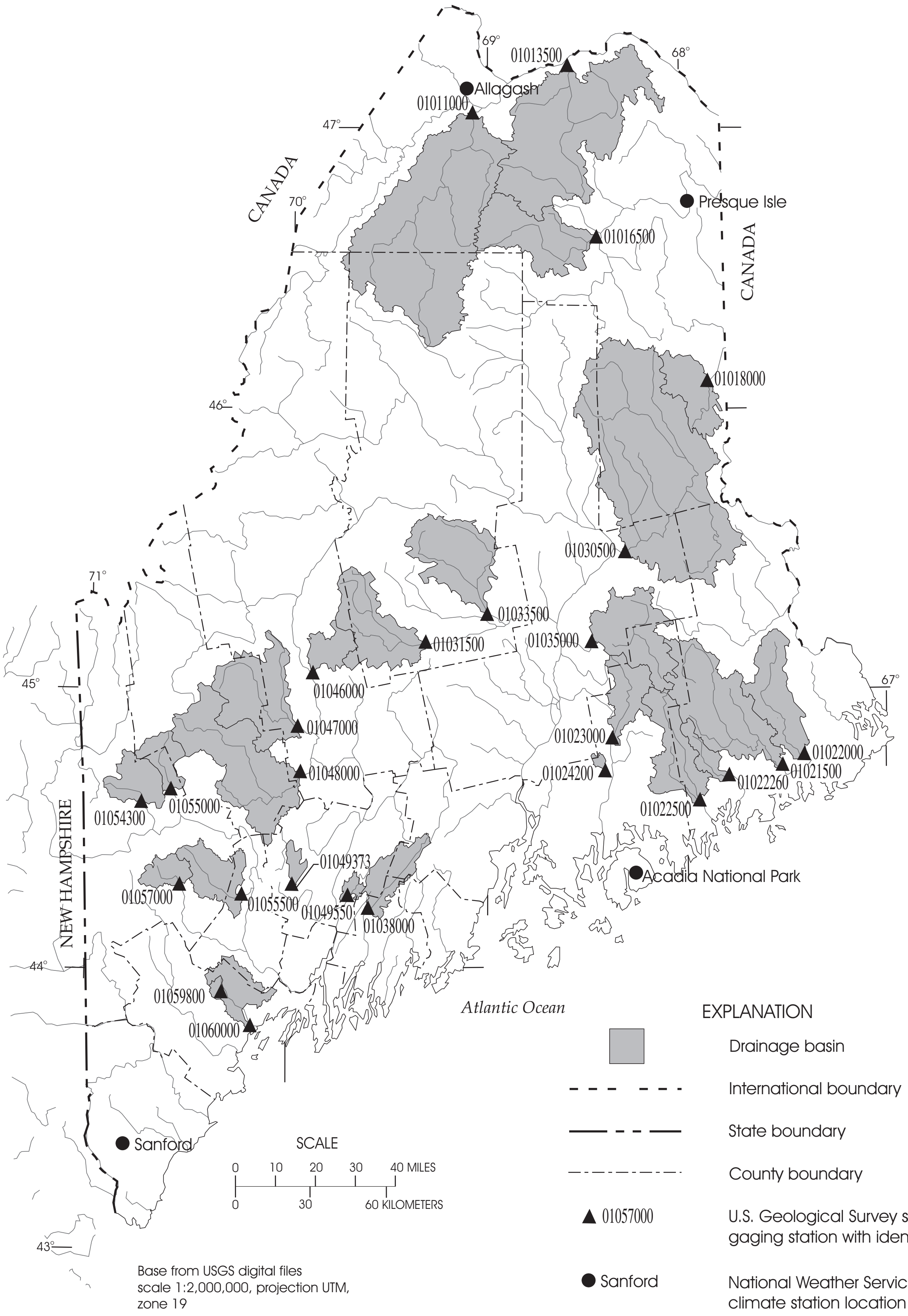


**Figure 1**. U.S. Geological Survey streamflow-gaging stations used to derive regression equations for estimating monthly, annual, and low 7-day, 10-year streamflows for ungaged rivers in Maine.

range from 14 to 99 years in length, with a mean of 52 years. The earliest and latest dates for streamflow data used in this study are October 1, 1902, and September 30, 2001, respectively.

### Monthly and Annual Streamflow

For each month, the mean monthly streamflow was computed as the mean of all monthly means over the entire period of record for each streamflow-gaging station. The mean monthly values used in the computation are updated and published annually by the USGS in the water-resources data report series and stored in NWIS. Mean monthly mean streamflows were retrieved directly from the NWIS database for this study. Mean annual streamflows were computed as the mean of all annual means (calendar year basis) over the period of record for each streamflow-gaging station as retrieved from NWIS (table 1).

The computation of median monthly streamflows was a two-step process. First, the monthly median streamflow for each month was computed on the basis of daily mean streamflow data from NWIS. Second, the median monthly streamflow was computed as the median of all monthly medians over the entire period of record for each streamflow-gaging station. Median annual streamflows were computed in a similar manner. First, the annual median streamflow for each calendar year was computed on the basis of daily mean streamflow data from NWIS. Second, the median annual streamflow was computed as the median of all annual medians over the entire period of record for each streamflow-gaging station (table 2).

### Low 7-day, 10-year Streamflow

Many regulatory agencies use the low 7Q10 streamflow statistic to regulate wastewater discharge to streams. The low 7Q10 streamflow for a stream is the lowest average streamflow for a period of 7 consecutive days that recurs, on long-term average, once every 10 years. The computation of low 7Q10 streamflows for each streamflow-gaging station was a two-step process. First, the lowest streamflow, averaged over a consecutive 7-day window, was computed for each climatic year (from April 1 to March 31) for each site. The climatic year typically is used when analyzing low streamflows in Maine because the annual low-flow period usually occurs in the summer and early fall and the highest annual streamflows usually occur in the spring. Once the yearly low 7-day streamflows were computed, a log-Pearson Type III distribution was fitted to the flows, from which the low 7-day streamflow with an annual non-exceedance probability of 0.10 (10-year recurrence interval) was determined for each streamflow-gaging station (table 3). At least 10 years of streamflow record are needed to determine the low 7Q10 streamflow statistic with reasonable confidence (Ries and Friesz, 2000).

### Basin and Climatic Characteristics

For the regression analysis in Parker (1977), nine different explanatory basin and climatic characteristics were step-wise regressed against response variables of mean monthly, mean annual, and low 7Q10 streamflows. Results from the regression analysis reduced the nine explanatory variables to three final characteristics: drainage area, mean annual precipitation, and maximum 24-hour precipitation intensity with a 2-year recurrence interval (also referred to as the 2-year, 24-hour rainfall).

For this study, 62 basin and climatic characteristics were derived and tested as potential explanatory variables in the regression analysis, with an emphasis on GIS-derived characteristics. The explanatory variables included the following characteristics and variations thereof: basin drainage area; mean monthly, seasonal, and annual precipitation; basin elevation, shape, and slope; latitude and longitude; NLCD land-cover classifications; areas of wetlands, lakes and ponds; March 1 snowpack; area of sand and gravel aquifers; and distance from the coast. Where appropriate, basinwide averages and basin centroid values were computed for each characteristic, providing two variables for a single characteristic. For example, elevation was averaged over the entire basin and derived at the basin centroid, as well.

## Regression Analyses

Regression analysis commonly is used to develop equations for estimating streamflow statistics for ungaged streams. In this analysis, a streamflow statistic of interest (the response variable) for a group of streamflow-gaging stations in a region is statistically related to the physical and (or) climatic characteristics (the explanatory variables) of the drainage basin for the streamflow-gaging stations (Ries and Friesz, 2000).

### Ordinary Least Squares Regression

Ordinary least squares (OLS) regression techniques (Helsel and Hirsch, 1992) of all possible subsets of

**Table 1**. Computed mean monthly and mean annual streamflows for selected U.S. Geological Survey streamflow-gaging stations in Maine

[ft$^3$/s, cubic feet per second; mi$^2$, square miles]

| U.S. Geological Survey streamflow-gaging stations in Maine | | Drainage area (mi$^2$) | Mean monthly streamflow (ft$^3$/s) | | | | | | | | | | | | Mean annual streamflow (ft$^3$/s) | Period of record (calendar years) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | Name | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | | |
| 01011000 | Allagash River near Allagash | 1,229 | 727 | 601 | 789 | 4,760 | 6,470 | 2,230 | 1,380 | 1,080 | 1,060 | 1,260 | 1,580 | 1,190 | 1,950 | 1910-11, 1931-2001 |
| 01013500 | Fish River near Fort Kent | 873 | 626 | 499 | 581 | 3,130 | 5,110 | 1,780 | 947 | 673 | 572 | 757 | 1,180 | 1,060 | 1,430 | 1903-08, 1911, 1929-2001 |
| 01016500 | Machias River near Ashland | 329 | 191 | 191 | 255 | 1,600 | 2,000 | 517 | 295 | 288 | 275 | 376 | 498 | 381 | 573 | 1951-83 |
| 01018000 | Meduxnekeag River near Houlton | 175 | 152 | 156 | 264 | 1,080 | 619 | 216 | 108 | 88.1 | 112 | 178 | 331 | 284 | 299 | 1940-82 |
| 01021500 | Machias River at Whitneyville | 458 | 802 | 699 | 1,190 | 2,400 | 1,720 | 859 | 463 | 310 | 340 | 541 | 913 | 1,000 | 935 | 1905-21, 1929-77, 2001 |
| 01022000 | East Machias River near East Machias | 251 | 564 | 444 | 630 | 1,270 | 859 | 423 | 220 | 137 | 141 | 253 | 506 | 660 | 500 | 1926-58 |
| 01022260 | Pleasant River near Epping | 60.6 | 101 | 153 | 190 | 307 | 184 | 115 | 66 | 63.6 | 60.5 | 82.1 | 151 | 168 | 141 | 1980-91, 2000-01 |
| 01022500 | Narraguagus River at Cherryfield | 227 | 514 | 476 | 727 | 1,200 | 673 | 338 | 191 | 130 | 163 | 265 | 572 | 640 | 495 | 1948-2001 |
| 01023000 | West Branch Union River at Amherst | 148 | 243 | 211 | 352 | 814 | 459 | 209 | 111 | 58.6 | 72.2 | 141 | 278 | 316 | 270 | 1909-19, 1929-79 |
| 01024200 | Garland Brook near Mariaville | 9.79 | 17.4 | 19.8 | 37.2 | 61.4 | 29.0 | 14.7 | 8.00 | 4.92 | 6.77 | 14.8 | 24.7 | 29.4 | 22.4 | 1964-82 |
| 01030500 | Mattawamkeag River near Mattawamkeag | 1,418 | 1,420 | 1,280 | 2,220 | 8,470 | 5,500 | 1,980 | 1,030 | 720 | 811 | 1,400 | 2,710 | 2,600 | 2,520 | 1934-2001 |
| 01031500 | Piscataquis River near Dover-Foxcroft | 298 | 312 | 276 | 612 | 2,080 | 1,260 | 472 | 242 | 170 | 185 | 394 | 679 | 546 | 605 | 1902-2001 |
| 01033500 | Pleasant River near Milo | 323 | 381 | 340 | 618 | 2,000 | 1,670 | 643 | 344 | 258 | 276 | 479 | 848 | 692 | 706 | 1920-79 |
| 01035000 | Passadumkeag River at Lowell | 297 | 357 | 333 | 469 | 1,260 | 1,070 | 606 | 344 | 208 | 211 | 278 | 454 | 488 | 503 | 1915-79 |
| 01038000 | Sheepscot River at North Whitefield | 145 | 234 | 235 | 447 | 742 | 341 | 166 | 75.2 | 47.1 | 51.5 | 87.9 | 244 | 323 | 250 | 1938-2001 |
| 01046000 | Austin Stream at Bingham | 90.0 | 79.4 | 63.8 | 139 | 578 | 435 | 127 | 69.5 | 53.1 | 62.5 | 112 | 225 | 153 | 173 | 1931-69 |
| 01047000 | Carrabassett River near North Anson | 353 | 378 | 330 | 846 | 2,340 | 1,560 | 618 | 330 | 219 | 242 | 496 | 770 | 604 | 729 | 1902-07, 1925-2001 |
| 01048000 | Sandy River near Mercer | 516 | 558 | 504 | 1,260 | 3,420 | 1,910 | 786 | 400 | 244 | 278 | 555 | 969 | 839 | 976 | 1928-79, 1987-2001 |
| 01049373 | Mill Stream at Winthrop | 32.7 | 42.7 | 44.6 | 91.4 | 168 | 97.1 | 53.6 | 22.6 | 16.7 | 11.4 | 19.3 | 34.8 | 56.5 | 54.0 | 1977-92 |
| 01049550 | Togus Stream at Togus | 23.7 | 39.2 | 34.6 | 79.4 | 120 | 50.1 | 30.1 | 8.77 | 8.43 | 7.18 | 16.2 | 44.9 | 57.4 | 41.1 | 1981-95 |
| 01054300 | Ellis River at South Andover | 130 | 133 | 151 | 243 | 759 | 565 | 201 | 114 | 75.4 | 69.4 | 159 | 246 | 234 | 248 | 1963-82, 2000-01 |
| 01055000 | Swift River near Roxbury | 96.9 | 112 | 93.8 | 205 | 623 | 487 | 177 | 86.0 | 60.0 | 73.7 | 144 | 212 | 154 | 203 | 1929-2001 |
| 01055500 | Nezinscot River at Turner Center | 169 | 218 | 227 | 490 | 969 | 447 | 223 | 119 | 81.8 | 81.6 | 165 | 311 | 298 | 301 | 1941-96, 2001 |
| 01057000 | Little Androscoggin River near South Paris | 73.5 | 89.2 | 83.4 | 210 | 465 | 214 | 110 | 51.9 | 37.3 | 41.5 | 78.0 | 138 | 128 | 138 | 1913-24, 1931-2001 |
| 01059800 | Collyer Brook near Gray | 13.8 | 22.6 | 25.5 | 44.1 | 55.3 | 31.9 | 23.6 | 18.0 | 16.0 | 17.1 | 20.9 | 25.9 | 28.4 | 27.6 | 1964-82, 1998-2000 |
| 01060000 | Royal River at Yarmouth | 141 | 230 | 237 | 556 | 746 | 318 | 185 | 92.4 | 74.9 | 86.9 | 145 | 308 | 305 | 275 | 1949-2001 |

**Table 2**. Computed median monthly and median annual streamflows for selected U.S. Geological Survey streamflow-gaging stations in Maine

[ft$^3$/s, cubic feet per second; mi$^2$, square miles]

| U.S. Geological Survey streamflow-gaging stations in Maine | | Drainage area (mi$^2$) | Median monthly streamflow (ft$^3$/s) | | | | | | | | | | | | Median annual streamflow (ft$^3$/s) | Period of record (calendar years) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Number | Name | | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | | |
| 01011000 | Allagash River near Allagash | 1,229 | 580 | 450 | 440 | 3,050 | 5,730 | 1,740 | 1,040 | 700 | 721 | 765 | 1,200 | 910 | 972 | 1910-11, 1931-2001 |
| 01013500 | Fish River near Fort Kent | 873 | 528 | 402 | 405 | 2,070 | 5,060 | 1,500 | 731 | 418 | 340 | 429 | 922 | 812 | 678 | 1903-08, 1911, 1929-2001 |
| 01016500 | Machias River near Ashland | 329 | 148 | 101 | 102 | 667 | 1,700 | 391 | 175 | 149 | 159 | 152 | 398 | 278 | 223 | 1951-83 |
| 01018000 | Meduxnekeag River near Houlton | 175 | 116 | 86.0 | 135 | 878 | 412 | 138 | 57.0 | 36.0 | 47.5 | 72.0 | 246 | 188 | 120 | 1940-82 |
| 01021500 | Machias River at Whitneyville | 458 | 508 | 498 | 765 | 2,170 | 1,700 | 606 | 327 | 235 | 224 | 305 | 634 | 677 | 540 | 1905-21, 1929-77, 2001 |
| 01022000 | East Machias River near East Machias | 251 | 545 | 345 | 540 | 1,200 | 745 | 374 | 183 | 81.5 | 83.2 | 149 | 358 | 558 | 340 | 1926-58 |
| 01022260 | Pleasant River near Epping | 60.6 | 76.0 | 108 | 138 | 296 | 138 | 78.5 | 52.0 | 44.5 | 40.0 | 66.0 | 118 | 97 | 89.0 | 1980-91, 2000-01 |
| 01022500 | Narraguagus River at Cherryfield | 227 | 328 | 324 | 461 | 974 | 480 | 243 | 132 | 84.0 | 84.5 | 174 | 395 | 405 | 277 | 1948-2001 |
| 01023000 | West Branch Union River at Amherst | 148 | 152 | 142 | 228 | 727 | 404 | 151 | 62.5 | 31.0 | 33.0 | 71.0 | 200 | 223 | 145 | 1909-19, 1929-79 |
| 01024200 | Garland Brook near Mariaville | 9.79 | 9.65 | 9.78 | 18.0 | 46.2 | 19.0 | 9.05 | 3.25 | 2.45 | 3.50 | 7.60 | 14.5 | 15.0 | 10.0 | 1964-82 |
| 01030500 | Mattawamkeag River near Mattawamkeag | 1,418 | 1,015 | 805 | 1,210 | 7,480 | 4,260 | 1,360 | 642 | 384 | 356 | 762 | 2,240 | 1,690 | 1,180 | 1934-2001 |
| 01031500 | Piscataquis River near Dover-Foxcroft | 298 | 205 | 174 | 300 | 1,790 | 938 | 288 | 126 | 86.0 | 80.0 | 168 | 413 | 328 | 244 | 1902-2001 |
| 01033500 | Pleasant River near Milo | 323 | 270 | 255 | 310 | 1,700 | 1,340 | 493 | 238 | 167 | 159 | 240 | 534 | 450 | 368 | 1920-79 |
| 01035000 | Passadumkeag River at Lowell | 297 | 305 | 269 | 313 | 1,200 | 1,000 | 528 | 290 | 168 | 140 | 192 | 344 | 354 | 348 | 1915-79 |
| 01038000 | Sheepscot River at North Whitefield | 145 | 142 | 158 | 326 | 596 | 304 | 116 | 54.5 | 30.5 | 24.8 | 35.5 | 133 | 236 | 127 | 1938-2001 |
| 01046000 | Austin Stream at Bingham | 90.0 | 52.0 | 44.2 | 62.0 | 438 | 343 | 79.5 | 37.0 | 23.5 | 22.2 | 46.0 | 131 | 90.5 | 73.0 | 1931-69 |
| 01047000 | Carrabassett River near North Anson | 353 | 235 | 214 | 362 | 1,800 | 1,140 | 388 | 193 | 122 | 116 | 220 | 446 | 336 | 311 | 1902-07, 1925-2001 |
| 01048000 | Sandy River near Mercer | 516 | 372 | 349 | 618 | 3,050 | 1,400 | 522 | 255 | 134 | 135 | 211 | 526 | 498 | 412 | 1928-79, 1987-2001 |
| 01049373 | Mill Stream at Winthrop | 32.7 | 33.0 | 39.0 | 53.0 | 144 | 91.0 | 29.5 | 21.0 | 16.0 | 10.0 | 6.20 | 9.65 | 44.0 | 27.5 | 1977-92 |
| 01049550 | Togus Stream at Togus | 23.7 | 28.5 | 27.8 | 59.5 | 90.8 | 38.5 | 15.8 | 6.45 | 5.50 | 4.65 | 4.90 | 34.5 | 47.5 | 22.0 | 1981-95 |
| 01054300 | Ellis River at South Andover | 130 | 81.0 | 82.5 | 128 | 616 | 437 | 159 | 58.5 | 38.0 | 32.8 | 82.0 | 144 | 125 | 113 | 1963-82, 2000-01 |
| 01055000 | Swift River near Roxbury | 96.9 | 58.0 | 53.0 | 81.0 | 479 | 363 | 101 | 45.0 | 26.0 | 31.0 | 57.0 | 124 | 94.0 | 81.0 | 1929-2001 |
| 01055500 | Nezinscot River at Turner Center | 169 | 124 | 134 | 280 | 784 | 343 | 151 | 70.0 | 49.0 | 38.0 | 72.5 | 201 | 188 | 143 | 1941-96, 2001 |
| 01057000 | Little Androscoggin River near South Paris | 73.5 | 54.5 | 54.5 | 104 | 382 | 152 | 61.0 | 28.0 | 15.0 | 15.0 | 34.5 | 78.8 | 76.0 | 61.0 | 1913-24, 1931-2001 |
| 01059800 | Collyer Brook near Gray | 13.8 | 17.0 | 16.8 | 22.5 | 47.5 | 28.5 | 19.5 | 16.0 | 14.0 | 13.5 | 15.0 | 20.0 | 18.5 | 19.0 | 1964-82, 1998-2000 |
| 01060000 | Royal River at Yarmouth | 141 | 115 | 134 | 331 | 494 | 213 | 106 | 63.0 | 51.0 | 44.0 | 59.0 | 154 | 180 | 123 | 1949-2001 |

**Table 3**. Computed low 7-day streamflows with 10-year recurrence interval (7Q10) for selected U.S. Geological Survey streamflow-gaging stations in Maine

[ mi$^2$, square miles; ft$^3$/s, cubic feet per second;]

| **U.S. Geological Survey streamflow-gaging stations in Maine** | | | | |
|---|---|---|---|---|
| **Number** | **Name** | **Drainage Area (mi$^2$)** | **7Q10 stream-flow (ft$^3$/s)** | **Period of record (calendar years)** |
| 01011000 | Allagash River near Allagash | 1,229 | 146 | 1910-11, 1931-2001 |
| 01013500 | Fish River near Fort Kent | 873 | 83.1 | 1903-08, 1911, 1929-2001 |
| 01016500 | Machias River near Ashland | 329 | 19.1 | 1951-83 |
| 01018000 | Meduxnekeag River near Houlton | 175 | 5.46 | 1940-82 |
| 01021500 | Machias River at Whitneyville | 458 | 60.2 | 1905-21, 1929-77, 2001 |
| 01022000 | East Machias River near East Machias | 251 | 15.0 | 1926-58 |
| 01022260 | Pleasant River near Epping | 60.6 | 22.2 | 1980-91, 2000-01 |
| 01022500 | Narraguagus River at Cherryfield | 227 | 30.3 | 1948-2001 |
| 01023000 | West Branch Union River at Amherst | 148 | 6.16 | 1909-19, 1929-79 |
| 01024200 | Garland Brook near Mariaville | 9.79 | 0.447 | 1964-82 |
| 01030500 | Mattawamkeag River near Mattawamkeag | 1,418 | 65.8 | 1934-2001 |
| 01031500 | Piscataquis River near Dover-Foxcroft | 298 | 17.7 | 1902-2001 |
| 01033500 | Pleasant River near Milo | 323 | 48.4 | 1920-79 |
| 01035000 | Passadumkeag River at Lowell | 297 | 46.6 | 1915-79 |
| 01038000 | Sheepscot River at North Whitefield | 145 | 9.01 | 1938-2001 |
| 01046000 | Austin Stream at Bingham | 90.0 | 4.35 | 1931-69 |
| 01047000 | Carrabassett River near North Anson | 353 | 46.0 | 1902-07, 1925-2001 |
| 01048000 | Sandy River near Mercer | 516 | 46.0 | 1928-79, 1987-2001 |
| 01049373 | Mill Stream at Winthrop | 32.7 | 2.23 | 1977-92 |
| 01049550 | Togus Stream at Togus | 23.7 | 1.48 | 1981-95 |
| 01054300 | Ellis River at South Andover | 130 | 14.3 | 1963-82, 2000-01 |
| 01055000 | Swift River near Roxbury | 96.9 | 6.93 | 1929-2001 |
| 01055500 | Nezinscot River at Turner Center | 169 | 13.8 | 1941-96, 2001 |
| 01057000 | Little Androscoggin River near South Paris | 73.5 | 2.48 | 1913-24, 1931-2001 |
| 01059800 | Collyer Brook near Gray | 13.8 | 7.95 | 1964-82, 1998-2000 |
| 01060000 | Royal River at Yarmouth | 141 | 24.0 | 1949-2001 |

62 explanatory variables for each of 27 response variables were used to select the explanatory variables that would appear in the final regression equations. Explanatory variables were chosen on the basis of their capacity to explain the variability in the response variable. Explanatory variables with inadequate individual statistical significance (p-values from the T-statistics of greater than 0.10) in their capacity to explain the variability in the response variable were eliminated.

In addition to statistical significance, the ease of computation of each explanatory variable was weighed against its ability to describe variability in the response variable. If a particular variable was easy to compute (such as distance from the coast), it was chosen over another variable that had slightly greater explanatory power but was more difficult to compute. Emphasis also was placed on developing a coherent set of equations. If a particular explanatory variable appeared frequently in many regression equations (especially on a seasonal basis such as fraction of the drainage basin underlain by sand and gravel aquifers, or distance from the coast), it was likely to indicate a physical process, thereby increasing confidence in the use of the variable. Such an explanatory variable was favored for use in other regression equations even if it did not introduce the maximum increase in explanatory power.

Residual plots were used to check for linearity, homoscedasicity (constant variance), normality, and the presence of outliers. Residuals were plotted against predicted values, and partial residuals were plotted. These residual plots indicated whether explanatory variables showed bias over their ranges and whether variables needed to be transformed to ensure a linear relation between explanatory and response variables—a requirement for satisfactory OLS regression. Multicollinearity among the explanatory variables was measured using the Variance Inflation Factor. No problems with multicollinearity were noted.

Influence of the individual stations on the regression equations was measured using the Cook's D statistic. The Cook's D statistic indicated that drainage basins smaller than approximately 10 $mi^2$ exerted high influence on the derivation of regression equations across almost all response variables (monthly and annual). For this reason, 4 study basins were culled from an original set of 30, reducing the final number of study basins to 26.

## Final Explanatory Variables

Using OLS regression analysis, the 62 basin and climatic characteristics were winnowed to 5 final explanatory variables: drainage area, fraction of the drainage basin underlain by sand and gravel aquifers, distance from the coast to the drainage basin centroid, mean annual precipitation, and mean winter precipitation (table 4). Detailed descriptions of the final 5 explanatory variables are provided below:

### Drainage Area

Published values for drainage areas (in square miles) for the 26 streamflow-gaging stations were retrieved from NWIS. Drainage areas used for this study were computed by measuring the planar area enclosed by the drainage-basin boundary on 1:24,000-scale USGS topographic maps using either an analog or digital planimeter. The drainage-basin boundary is defined as the topographic divide from which direct surface runoff from precipitation normally drains or falls by gravity into the body of water upstream of the point of interest (Stewart and others, 2003). References to drainage area in this report refer to contributing drainage area. Contributing drainage area is defined as the surface area of the river basin that contributes to surface-water runoff. Contributing drainage area is an important distinction to make because some drainage basins may have parts of their drainage area that do not contribute directly to surface-water runoff. The 26 drainage basins range in size from 9.79 $mi^2$ (Garland Brook, USGS streamflow-gaging station number 01024200) to 1,418 $mi^2$ (Mattawamkeag River, 01030500), with a mean of 303 $mi^2$ (table 4).

### Fraction of Drainage Basin Underlain by Sand and Gravel Aquifers

The surficial geology of Maine has been largely shaped by the last period of glaciation about 24,000 years ago through the erosion and widespread, highly variable redeposition of soil and bedrock (Randall, 2001). The redeposited soil and bedrock, called glacial drift, consist of a wide variety of materials that vary in composition depending on how they were deposited by the glaciers. Most of the State is covered by a layer of till—a nonsorted mixture of material ranging from clay to boulders—overlying bedrock (Randall, 2001). In general, till has poor water-bearing characteristics. Interspersed among the till, especially in major river valleys, are glacial stratified deposits that include gravel, sand, silt, and clay. Sand and gravel stratified-drift deposits and fractured bedrock serve as the water-bearing geologic features (aquifers) in Maine.

Since 1992, the Maine Department of Conservation, Maine Geological Survey (MGS) systematically has been delineating and digitizing at a 1:24,000 scale all sand-and-gravel glacial deposits in the State that are determined to be a "significant" aquifer (a significant aquifer is an aquifer having the potential to yield 10 gal/min or more to a properly constructed well). The aquifer boundaries are delineated on the basis of field observations of surficial materials, geophysical studies, wells, test borings, water-company exploration data, construction project information, and municipal well inventories. In some areas, a thin layer (usually less than 10 ft) of water-bearing, coarse-grained material may be readily identifiable on the surface, overlying poor water-bearing materials such as till or bedrock. In these cases, if it is determined that a well open to that surficial material could not sustain a yield of at least 10 gal/min, the area is not mapped as an aquifer. The converse may be true as well where poor water-bearing materials may overlie coarse-grained sediments causing the underlying deposit not to be recognized as a potentially significant aquifer. To determine the capacity of an aquifer to yield water, the MGS conducts geophysical studies, installs wells, and does test borings. This work provides information on the depth to water table and bedrock surface, and water yields (Marc Loiselle, Maine Geological Survey, oral commun., 2003).

**Table 4**. Basin and climatic characteristics for selected U.S. Geological Survey streamflow-gaging stations in Maine

[$\mathrm{mi}^2$, square miles; mi, miles; in., inches]

| U.S. Geological Survey streamflow-gaging stations in Maine | | Drainage area ($\mathrm{mi}^2$) | Fraction of drainage basin underlain by sand and gravel aquifers | Distance from the coast to the drainage basin centroid (mi) | Mean annual precipitation (in.) | Mean winter precipitation (in.) |
|---|---|---|---|---|---|---|
| **Number** | **Name** | | | | | |
| 01011000 | Allagash River near Allagash | 1,229 | 0.000 | 189 | 37.8 | 7.72 |
| 01013500 | Fish River near Fort Kent | 873 | 0.003 | 193 | 39.3 | 7.71 |
| 01016500 | Machias River near Ashland | 329 | 0.001 | 175 | 40.0 | 7.78 |
| 01018000 | Meduxnekeag River near Houlton | 175 | 0.030 | 121 | 39.8 | 8.59 |
| 01021500 | Machias River at Whitneyville | 458 | 0.162 | 51.4 | 46.4 | 12.0 |
| 01022000 | East Machias River near East Machias | 251 | 0.032 | 46.1 | 46.6 | 12.1 |
| 01022260 | Pleasant River near Epping | 60.6 | 0.346 | 42.7 | 47.9 | 12.6 |
| 01022500 | Narraguagus River at Cherryfield | 227 | 0.151 | 47.0 | 46.4 | 12.1 |
| 01023000 | West Branch Union River at Amherst | 148 | 0.047 | 65.4 | 43.5 | 10.6 |
| 01024200 | Garland Brook near Mariaville | 9.79 | 0.103 | 54.1 | 43.8 | 11.0 |
| 01030500 | Mattawamkeag River near Mattawamkeag | 1,418 | 0.020 | 111 | 42.2 | 9.33 |
| 01031500 | Piscataquis River near Dover-Foxcroft | 298 | 0.018 | 111 | 44.1 | 9.78 |
| 01033500 | Pleasant River near Milo | 323 | 0.052 | 116 | 46.4 | 10.4 |
| 01035000 | Passadumkeag River at Lowell | 297 | 0.030 | 76.7 | 44.0 | 10.5 |
| 01038000 | Sheepscot River at North Whitefield | 145 | 0.043 | 55.6 | 44.2 | 10.4 |
| 01046000 | Austin Stream at Bingham | 90.0 | 0.025 | 112 | 47.6 | 9.91 |
| 01047000 | Carrabassett River near North Anson | 353 | 0.089 | 111 | 46.4 | 10.1 |
| 01048000 | Sandy River near Mercer | 516 | 0.049 | 98.4 | 46.9 | 10.7 |
| 01049373 | Mill Stream at Winthrop | 32.7 | 0.005 | 70.1 | 44.0 | 10.1 |
| 01049550 | Togus Stream at Togus | 23.7 | 0.000 | 57.6 | 42.7 | 10.0 |
| 01054300 | Ellis River at South Andover | 130 | 0.057 | 107 | 44.1 | 10.1 |
| 01055000 | Swift River near Roxbury | 96.9 | 0.012 | 109 | 46.2 | 10.2 |
| 01055500 | Nezinscot River at Turner Center | 169 | 0.086 | 77.7 | 45.4 | 10.6 |
| 01057000 | Little Androscoggin River near South Paris | 73.5 | 0.029 | 84.1 | 45.1 | 10.2 |
| 01059800 | Collyer Brook near Gray | 13.8 | 0.455 | 52.7 | 46.0 | 11.5 |
| 01060000 | Royal River at Yarmouth | 141 | 0.127 | 50.7 | 46.0 | 11.5 |

The Maine office of GIS (MEGIS) maintains a digital coverage of the mapped significant sand and gravel aquifers in Maine *(http://apollo.ogis.state.me.us/)*. The coverage includes mapped aquifers for the entire State except for the sparsely populated, heavily forested, northwestern region of the State that has not yet been completed (fig. 2). The coverage includes an attribute table that stores aquifer-classification information for each polygon. The classification value is stored in the attribute label, ATYPE. A value of ATYPE = 1 denotes a high-yield aquifer with an estimated yield greater than 50 gal/min, whereas a value of ATYPE = 2 denotes an aquifer with an estimated yield of 10 to 50 gal/min.

The significant sand and gravel aquifer GIS coverage was used to derive the fraction of the drainage basin underlain by significant sand and gravel aquifers in each study basin. The fraction of drainage basin underlain by sand and gravel aquifer is computed as the sum of polygon areas of the mapped sand and gravel aquifers in the basin (coded as ATYPE=1 or 2), divided by the total basin drainage area. The explanatory power of ATYPE=1, ATYPE=2, and the combination of both types in the regression analysis was tested. Among these three variables tested, the sum of both aquifer types had the greatest explanatory power. Fractions of drainage basin underlain by sand and gravel aquifers among basins used in this study range from 0.000 (Allagash River, 01011000, and Togus Stream, 01049550) to 0.455 (Collyer Brook, 01059800), with a mean of 0.076 (table 4).

The Allagash River (01011000) drainage basin is located just outside the significant sand-and-gravel mapped region, and the Fish River (01013500) and Machias River (01016500, near Ashland) each have a small part of their drainage basins outside the mapped region (fig. 1, fig. 2). On the basis of available published and unpublished geologic and topographic information for the unmapped region, it was estimated that the Allagash River Basin has no significant sand and gravel aquifers (table 4) (Marc Loiselle, Maine Geological Survey, oral commun., 2003). Similarly, the Fish and Machias River Basins were estimated not to have any additional significant sand and gravel aquifers other than the small amounts already mapped (fig. 2, table 4) (Marc Loiselle, Maine Geological Survey, oral commun., 2003).

### Distance from the Coast to the Drainage Basin Centroid

The distance from the coast to the drainage basin centroid is derived as the shortest distance (in miles) from an arbitrary line in the Gulf of Maine (referred to as the GOM Line; fig. 3) to the basin centroid. The GOM Line approximately parallels the Maine coast (table 5, fig. 3). The shortest line of measure between a basin centroid point and the GOM Line is a perpendicular intersector of the GOM Line. For this study, all distance measurements were made in a GIS using North American Datum (horizontal) 1983, Universal Transverse Mercator Zone 19 coordinate system. Distances from the GOM Line to the centroid of river basins used in this study range from 42.7 mi (Pleasant River near Epping, 01022260) to 193 mi (Fish River, 01013500), with a mean of 91.7 mi (table 4).

### Mean Annual Precipitation

Mean annual precipitation for each drainage basin was computed using output grids from the Parameter-elevation Regressions on Independent Slopes Model (PRISM). PRISM precipitation output grids were chosen for use in this study because the PRISM products are GIS-compatible. The PRISM GIS grids provide a convenient data set for computing spatial values of precipitation such as basinwide averages.

PRISM precipitation output grids are derived using a hybrid statistical-geographic modeling approach (Daly and Neilson, 1992; Daly and others, 1994; 1997). PRISM uses observed precipitation data, a digital elevation model (DEM), and other spatial data sets specific to the region being simulated (such as snowpack) to derive spatial estimates of annual and monthly precipitation. As evidenced by Randall's (1996) map of mean annual precipitation in the northeastern United States, land-surface elevation is a dominant factor in the distribution of precipitation. For this reason, PRISM uses a general elevation regression function that serves as the main predictive equation in the precipitation model (Natural Resources Conservation Service, 1998).

The PRISM modeling effort is a part of the Spatial Climate Mapping Project managed and funded by the Natural Resources Conservation Service's (NRCS) National Water and Climate Center (NWCC) in cooperation with Oregon State University. The NRCS maintains the PRISM Internet site containing non-proprietary versions of the annual and monthly PRISM precipitation data for all 50 States in the U.S. These data can be accessed at *http://www.ftw.nrcs.usda.gov/prism/prismdata_state.html.*

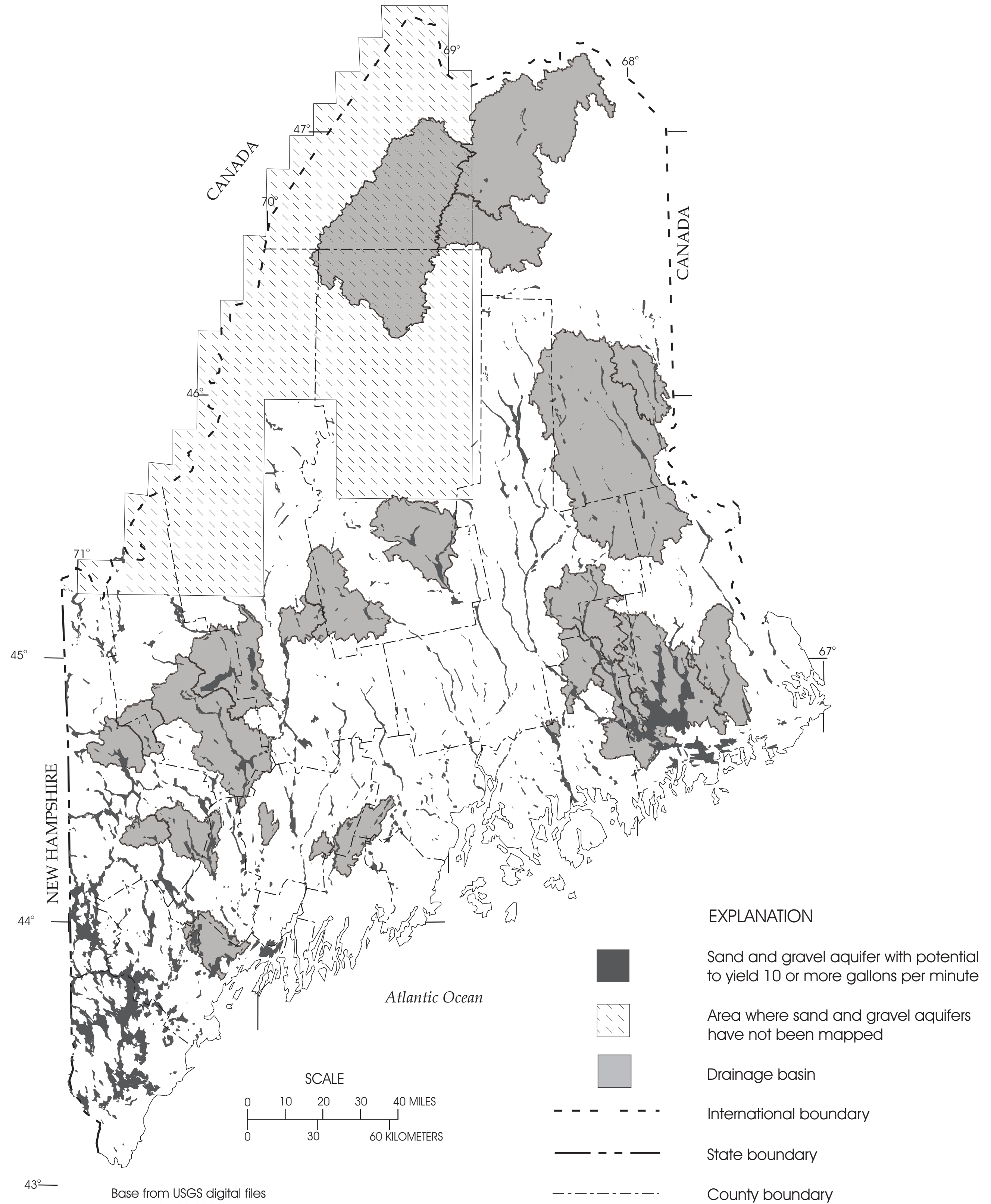
For this study, a non-proprietary PRISM GIS map of mean annual precipitation for the State of Maine (derived on the basis of precipitation data collected from 1961 to 1990) was downloaded from the NRCS PRISM Internet site. The NRCS PRISM map was loaded into a GIS application and interpolated to 1-km grids. Basin-wide averages of mean annual precipitation (in inches) were computed for each study basin by averaging the values of all 1-km grids within the bounds of the drainage basin on an area basis. Mean annual precipitation for river basins used in this study range from 37.8 in. (Allagash River, 01011000) to 47.9 in. (Pleasant River near Epping, 01022260), with a mean of 44.3 in. (table 4).

### Mean Winter Precipitation

Mean winter precipitation was computed similarly to the mean annual precipitation using non-proprietary PRISM GIS grids. The mean winter precipitation was computed for each study basin as the sum of the basin-wide averages of mean December, January, and February precipitation (in inches). The monthly PRISM grids were handled in the same way as the annual grids: downloaded from the NRCS PRISM internet site, converted to 1-km grids, and averaged on an area basis for each study basin. Mean winter precipitation for river basins used in this study range from 7.7 in. (Allagash River, 01011000 and Fish River, 01013500) to 12.6 in. (Pleasant River near Epping, 01022260), with a mean of 10.3 in. (table 4).

## Generalized Least Squares Regression

Generalized least squares (GLS) regression techniques (Stedinger and Tasker, 1985) were used to derive



Base from USGS digital files
scale 1:2,000,000, projection UTM,
zone 19. Geology from Maine
Geological Survey.

**Figure 2**. Significant sand and gravel aquifers in Maine.

the final coefficients and measures of uncertainty for the regression equations identified from the OLS analyses. Stedinger and Tasker (1985) found that GLS regression equations are more accurate and provide better estimates of uncertainty than OLS regression equations when streamflow records are of different and widely varying lengths, and when concurrent streamflow records are correlated. GLS regression techniques give less weight to stations with shorter periods of streamflow record and to stations where the streamflow record is more highly correlated with concurrent record of other stations in the analysis.

# Regression Equations for Estimating Monthly, Annual, and Low 7-Day, 10-Year Streamflows for Ungaged Rivers in Maine

The final regression equations for estimating monthly, annual, and low 7Q10 streamflows for ungaged rivers in Maine are presented in tables 6, 7, and 8. Although an explanatory variable (basin characteristic) appears in a regression equation, it does not necessarily mean that the explanatory variable directly causes the response variable to occur, just that the explanatory variable explains the variability observed in the response variable. In most of the final regression equations, the explanatory variables intuitively describe the physical processes of the natural hydrologic system.

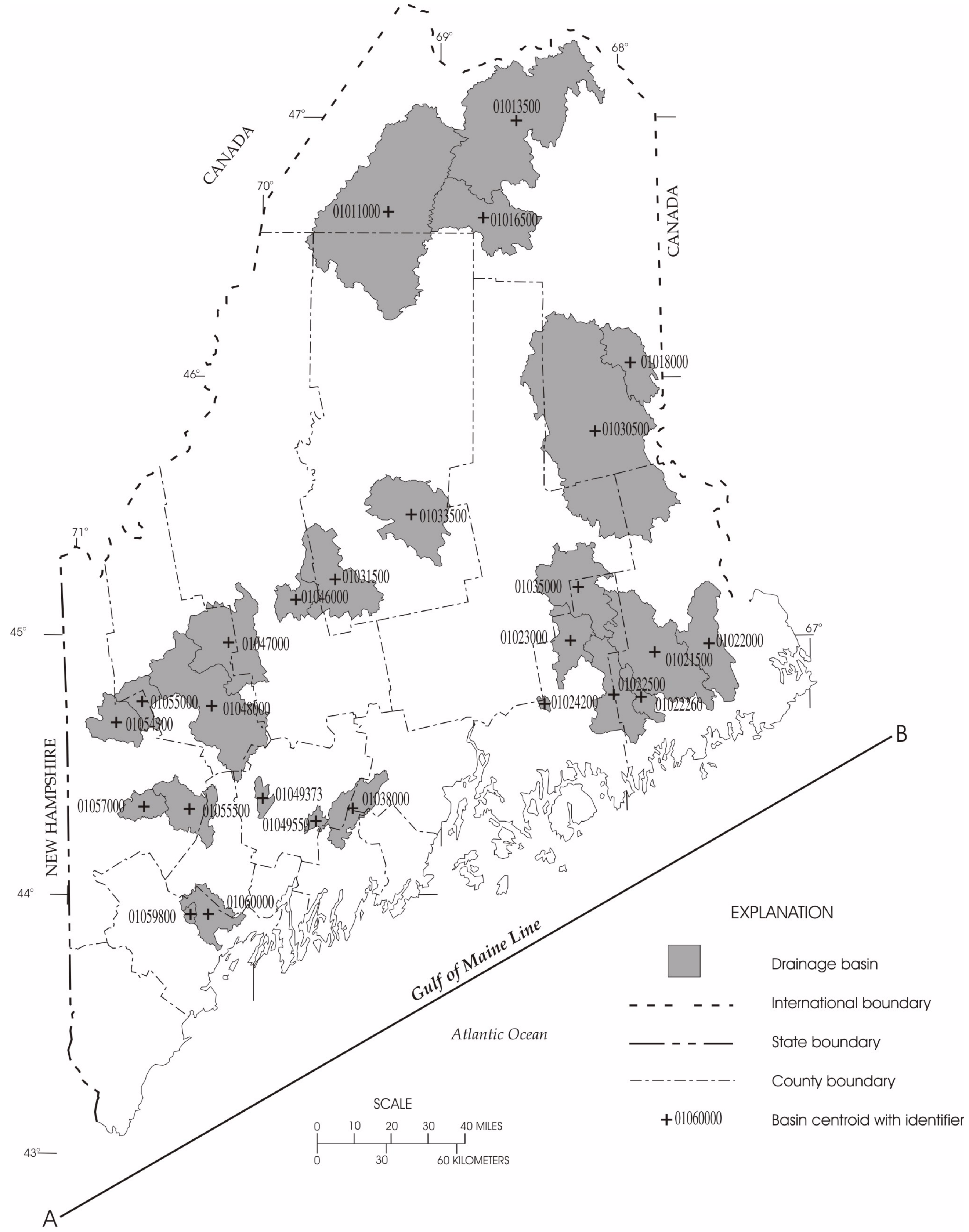
Drainage area is a highly significant explanatory variable (basin characteristic) for all equations. This is an intuitive relation—a larger drainage basin contributes to a larger streamflow. In general, the fraction of the drainage basin underlain by sand and gravel aquifers provides considerable explanation for the variability in low 7Q10 and summer-month response variables. This explanation makes sense in that sand and gravel aquifers typically are recharged during the spring and discharge ground water to streams during the summer low-flow period. The drainage basin centroid distance from the coast provides considerable explanation for the variability in flows during winter and spring months. During December, January, February, and March, mean and median streamflows are related inversely to the drainage basin distance from the coast; that is, the closer to the coast a basin is, the higher the mean monthly or median monthly streamflow. This results because heat in the Atlantic Ocean has a warming effect on winter air temperatures near the coast so that larger volumes and (or) greater rates of rain and snowmelt can take place closer to the coast during the winter. The distance-from-the-coast relation reverses in May when sites farther inland have greater contributions to surface-water runoff from snowmelt relative to sites close to the coast.

## Accuracy and Limitations of the Equations

Uncertainties for the equations are quantified by the average standard error of prediction (ASEP). ASEP is a measure of how well the regression equation will estimate the flow statistic of interest when applied to an ungaged, unregulated, rural basin in Maine. The probability that the true value of the flow statistic at a site is between the negative- and positive-percent ASEP is approximately 68 percent. For example, there is a 68-percent probability that the true low 7Q10 streamflow at a site is between –34.5 and 52.6 percent (table 6) of the

**Table 5**. Point coordinates that define the Gulf of Maine Line (GOM Line; fig.3). Latitude and longitude coordinates referenced to North America Datum of 1983, meter coordinates referenced to Universal Transverse Mercator Zone 19 datum

| | X-coordinate | Y-coordinate |
|---|---|---|
| Point A | 71.00 west longitude | 42.75 north latitude |
| | 336321.28 meters | 4734992.89 meters |
| Point B | 65.50 west longitude | 45.00 north latitude |
| | 775853.75 meters | 4988911.83 meters |



Base from USGS digital files
scale 1:2,000,000, projection UTM,
zone 19

**Figure 3**. The Gulf of Maine Line (GOM Line) and study basin centroids.

computed low 7Q10 streamflow yielded by the regression equation.

The prediction error sum of squares (PRESS) statistic is a measure of validation for the regression equations. PRESS is computed by removing the observed streamflow statistic of interest of one study basin from the set of 26 study basins used to develop the regression equation, then predicting the value of the streamflow statistic for the omitted site; the procedure is done in turn for all 26 stations. The differences between the predicted streamflow statistics and the observed streamflow statistics for each site are squared and summed yielding the PRESS statistic. PRESS/n is analogous to the average variance of prediction, and the square root of PRESS/n is analogous to the ASEP (where n is the number of data points used in regression). Values of $(\mathrm{PRESS}/n)^{1/2}$ close to the values of the ASEP provide a measure of validation of the regression equation.

The average equivalent years of record (EYR) statistic is a measure of uncertainty of the regression equations. The EYR indicates the average number of years of streamflow-gaging data required to compute the same streamflow statistic of interest with an uncertainty equal to that of the regression equation.

When applying the regression equations, it is important that the explanatory variables (basin and climatic characteristics) be derived using the same or comparable methods as those documented in this report. Basin and climatic characteristics derived using techniques different from the techniques used for this study will yield results of unknown error. Similarly, using values for any explanatory variables outside the ranges used to develop these regression equations will yield results of unknown error (figs. 4-7).

The regression equations presented in this report have been derived on the basis of streamflow data and basin and climatic characteristics of unregulated, rural drainage basins without significant drainage improvements. Applying these equations to regulated or urbanized basins or basins with appreciable drainage improvements will yield results of unknown error.

For this study, a basin was considered to be unregulated if either there was no regulation of streamflow by dams, or historical and (or) present regulation was small enough so as to have no effect on the computation of a monthly mean streamflow value computed on the basis of the daily mean streamflow data (Slack and Landwehr, 1992).

The percentages of urban area in the 26 study drainage basins, classified by NLCD as either high-intensity residential or commercial/industrial/transportation development, ranged from less than 0.01 percent (Allagash River, 01011000, in northern Maine) to 5.91 percent (Collyer Brook, 01059800, in southern Maine) with a mean of 0.472 percent. If areas classified by NLCD as low-intensity residential development were included in the analysis, percentages of developed area in the study basins would range from less than 0.01 percent (Allagash River) to 10.6 percent (Collyer Brook) with a mean of 1.03 percent.

Development in the Collyer Brook Basin has been substantial during the period from 1964 to 1999; population doubled, the number of buildings (commercial and residential) tripled, and impervious area increased 161 percent (Dudley and others, 2001). An evaluation of the effects of development on storm-runoff streamflow for Collyer Brook in 2001 by Dudley and others (2001) found no statistically detectable change in either amount or duration of runoff during the 1990's compared to streamflow runoff during the 1960's in this basin. The results suggest that the Collyer Brook Basin still may be considered a rural basin for the purposes of this investigation.

In a nationwide study of flood magnitude and frequency in urban drainage basins, Sauer and others (1983) determined that a watershed must have at least 15 percent of the drainage area covered with commercial, industrial, and (or) residential development to be considered urban; however, that was for streamflow events much larger than the streamflow events examined in this report. Results presented by Sauer and others (1983) illustrate that small, frequently occurring peak-streamflow events are more sensitive to increases in impervious area, which commonly accompany development. This result suggests that the percentage of urban area for this investigation should be lower than 15 percent. The highest amount of development (low- and high-intensity combined) observed in this investigation was 10.6 percent, of which about half was classified as either high-intensity residential or commercial/industrial/transportation development.

Drainage improvements include storm sewers, channel modifications (straightening, enlarging), impervious channel linings, and curb-and-gutter streets. Drainage improvements commonly accompany urbanization. Sauer and others (1983) provide a Basin Development Factor (BDF) scoring system to quantify the prevalence of drainage improvements in urbanized

**Table 6**. Regression equations and their accuracy for estimating mean annual, median annual, and low 7-day, 10-year (7Q10) streamflows for ungaged, unregulated streams in rural drainage basins in Maine

[ASEP, average standard error of prediction; PRESS, prediction error sum of squares; EYR, equivalent years of record; n, number of data points used in regression]

| Regression equation | ASEP (in percent) | $(PRESS/n)^{1/2}$ (in percent) | Average EYR |
|---|---|---|---|
| $Q_{7,10} = 0.023\,(A)^{1.173}10^{\,2.54(SG)}$ | -34.5 to 52.6 | -35.0 to 53.8 | 2.90 |
| $Q_{annual\ mean} = 1.151\,(A)^{0.991}10^{\,0.023(pptW)}$ | -7.35 to 7.94 | -7.97 to 8.66 | 9.87 |
| $Q_{annual\ median} = 0.239\,(A)^{1.006}10^{\,0.057(pptW)}$ | -12.6 to 14.4 | -13.2 to 15.2 | 6.92 |

where,
*Q* - streamflow statistic of interest.

*A* - contributing drainage area, in square miles.

*SG* - fraction of the drainage basin that is underlain by significant sand and gravel aquifers, on a planar area basis, expressed as a decimal. For example, if 15 percent of the drainage area of a basin has significant sand and gravel aquifers, *SG* = 0.15. Based on the significant sand and gravel aquifer maps produced by the Maine Geological Survey and maintained as GIS data sets by the Maine Office of GIS.

*pptW* - mean winter precipitation, in inches, computed as the sum of the monthly precipitation for December, January, and February spatially averaged over the contributing basin drainage area. Based on non-proprietary PRISM precipitation data spanning the 30-year period 1961-1990. Data maintained as GIS data sets by the Natural Resources Conservation Service (1998).

See the Regression Analyses section of this report for more details.

**Table 7**. Regression equations and their accuracy for estimating mean monthly streamflows for ungaged, unregulated streams in rural drainage basins in Maine

[ASEP, average standard error of prediction; PRESS, prediction error sum of squares; EYR, equivalent years of record; n, number of data points used in regression]

| Regression equation | ASEP (in percent) | $(PRESS/n)^{1/2}$ (in percent) | Average EYR |
|---|---|---|---|
| $Q_{jan\ mean} = 36.36\,(A)^{1.007}\,(DIST)^{-0.771}$ | -10.2 to 11.4 | -11.1 to 12.5 | 29.9 |
| $Q_{feb\ mean} = 46.79\,(A)^{0.991}\,(DIST)^{-0.829}$ | -9.79 to 10.8 | -12.0 to 13.7 | 41.2 |
| $Q_{mar\ mean} = 109.10\,(A)^{0.924}\,(DIST)^{-0.807}$ | -21.0 to 26.6 | -22.4 to 28.8 | 7.27 |
| $Q_{apr\ mean} = 1.362\,(A)^{1.006}10^{0.013(pptA)}$ | -15.6 to 18.4 | -16.7 to 20.0 | 4.94 |
| $Q_{may\ mean} = 0.350\,(A)^{1.035}\,(DIST)^{0.486}$ | -15.8 to 18.8 | -16.8 to 20.2 | 6.96 |
| $Q_{jun\ mean} = 1.372\,(A)^{1.030}$ | -14.6 to 17.1 | -15.2 to 17.9 | 13.1 |
| $Q_{jul\ mean} = 0.475\,(A)^{1.089}10^{0.631(SG)}$ | -19.3 to 24.0 | -21.4 to 27.2 | 8.38 |
| $Q_{aug\ mean} = 0.353\,(A)^{1.075}10^{0.822(SG)}$ | -22.0 to 28.2 | -22.9 to 29.6 | 8.60 |
| $Q_{sep\ mean} = 0.434\,(A)^{1.049}10^{0.834(SG)}$ | -19.9 to 24.9 | -23.2 to 30.2 | 13.9 |
| $Q_{oct\ mean} = 1.084\,(A)^{0.989}10^{0.399(SG)}$ | -19.3 to 24.0 | -22.5 to 29.1 | 17.0 |
| $Q_{nov\ mean} = 2.497\,(A)^{0.948}$ | -18.6 to 22.9 | -20.7 to 26.0 | 11.9 |
| $Q_{dec\ mean} = 16.92\,(A)^{0.979}\,(DIST)^{-0.476}$ | -12.4 to 14.1 | -13.6 to 15.7 | 28.9 |

where,

$Q$ — streamflow statistic of interest.

$A$ — contributing drainage area, in square miles.

$SG$ — fraction of the drainage basin that is underlain by significant sand and gravel aquifers, on a planar area basis, expressed as a decimal. For example, if 15 percent of the drainage area of a basin has significant sand and gravel aquifers, then $SG = 0.15$. Based on the significant sand and gravel aquifer maps produced by the Maine Geological Survey and maintained as GIS data sets by the Maine Office of GIS.

$pptA$ — mean annual precipitation, in inches, computed as the spatially averaged precipitation in the contributing basin drainage area. Based on non-proprietary PRISM precipitation data spanning the 30-year period 1961-1990. Data maintained as GIS data sets by the Natural Resources Conservation Service (1998).

$DIST$ —distance from the coast, in miles, measured as the shortest distance from a line in the Gulf of Maine to the contributing drainage basin centroid. The line in the Gulf of Maine is defined by end points 71.0W, 42.75N and 65.5W, 45.0N, referenced to North American Datum of 1983.

See the Regression Analyses section of this report for more details.

**Table 8**. Regression equations and their accuracy for estimating median monthly streamflows for ungaged, unregulated streams in rural drainage basins in Maine

[ASEP, average standard error of prediction; PRESS, prediction error sum of squares; EYR, equivalent years of record; n, number of data points used in regression]

| Regression equation | ASEP (in percent) | $(\text{PRESS}/n)^{1/2}$ (in percent) | Average EYR |
|---|---|---|---|
| $Q_{\text{jan median}} = 20.71\,(A)^{1.036}\,(DIST)^{-0.762}$ | -16.1 to 19.2 | -17.3 to 20.9 | 8.87 |
| $Q_{\text{feb median}} = 36.54\,(A)^{1.017}\,(DIST)^{-0.890}$ | -13.4 to 15.5 | -14.9 to 17.5 | 17.5 |
| $Q_{\text{mar median}} = 183.7\,(A)^{0.999}\,(DIST)^{-1.142}$ | -16.9 to 20.4 | -19.0 to 23.5 | 13.3 |
| $Q_{\text{apr median}} = 0.227\,(A)^{1.010}10^{0.028(pptA)}$ | -20.8 to 26.2 | -22.0 to 28.3 | 3.75 |
| $Q_{\text{may median}} = 0.262\,(A)^{1.070}\,(DIST)^{0.461}$ | -20.4 to 25.6 | -21.0 to 26.6 | 3.92 |
| $Q_{\text{jun median}} = 0.734\,(A)^{1.076}$ | -22.5 to 29.0 | -23.6 to 30.8 | 4.26 |
| $Q_{\text{jul median}} = 0.210\,(A)^{1.149}10^{1.02(SG)}$ | -26.1 to 35.4 | -27.3 to 37.5 | 3.58 |
| $Q_{\text{aug median}} = 0.152\,(A)^{1.120}10^{1.31(SG)}$ | -28.6 to 40.2 | -29.6 to 42.1 | 3.86 |
| $Q_{\text{sep median}} = 0.169\,(A)^{1.093}10^{1.25(SG)}$ | -26.8 to 36.7 | -27.8 to 38.5 | 5.37 |
| $Q_{\text{oct median}} = 0.307\,(A)^{1.074}10^{1.11(SG)}$ | -25.8 to 34.8 | -30.0 to 43.0 | 8.28 |
| $Q_{\text{nov median}} = 1.222\,(A)^{1.004}$ | -28.9 to 40.6 | -30.6 to 44.1 | 4.39 |
| $Q_{\text{dec median}} = 12.00\,(A)^{1.000}\,(DIST)^{-0.513}$ | -13.1 to 15.0 | -14.6 to 17.1 | 21.6 |

where,

$Q$ — streamflow statistic of interest.

$A$ — contributing drainage area, in square miles.

$SG$ — fraction of the drainage basin that is underlain by significant sand and gravel aquifers, on a planar area basis, expressed as a decimal. For example, if 15 percent of the drainage area of a basin has significant sand and gravel aquifers, then $SG = 0.15$. Based on the significant sand and gravel aquifer maps produced by the Maine Geological Survey and maintained as GIS data sets by the Maine Office of GIS.

$pptA$ — mean annual precipitation, in inches, computed as the spatially averaged precipitation in the contributing basin drainage area. Based on non-proprietary PRISM precipitation data spanning the 30-year period 1961-1990. Data maintained as GIS data sets by the Natural Resources Conservation Service (1998).

$DIST$—distance from the coast, in miles, measured as the shortest distance from a line in the Gulf of Maine to the contributing drainage basin centroid. The line in the Gulf of Maine is defined by end points 71.0W, 42.75N and 65.5W, 45.0N, referenced to North American Datum of 1983.

See the Regression Analyses section of this report for more details.

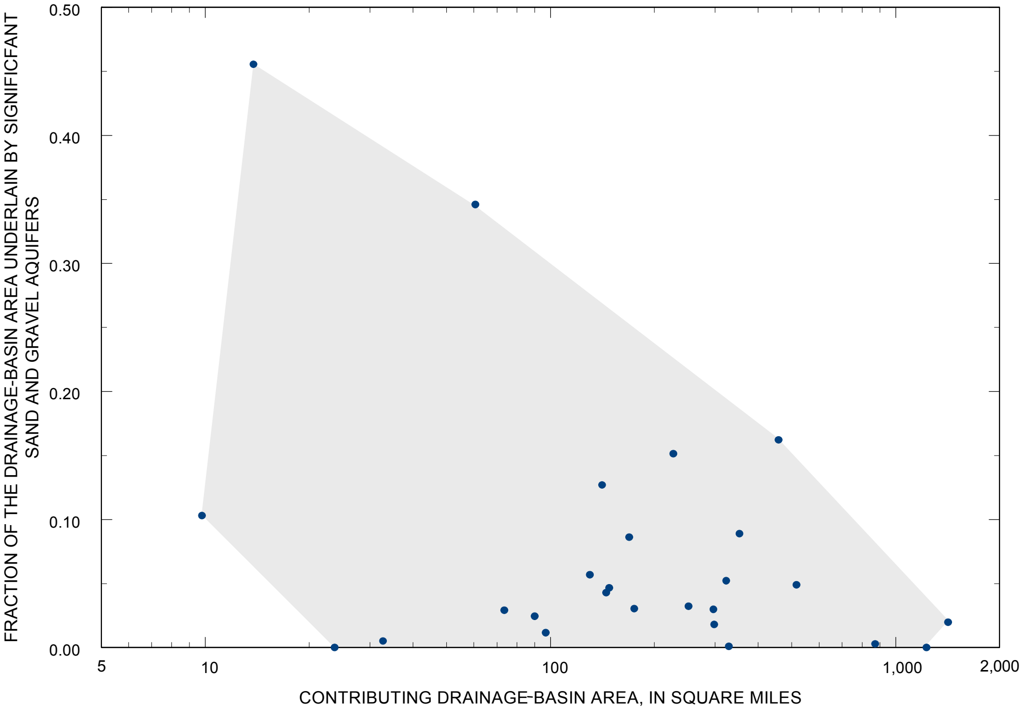


**Figure 4.** Two-dimensional range of explanatory variables for regression equations estimating mean and median July, August, September, and October streamflows, and low 7-day, 10-year streamflows for unregulated, rural rivers in Maine.

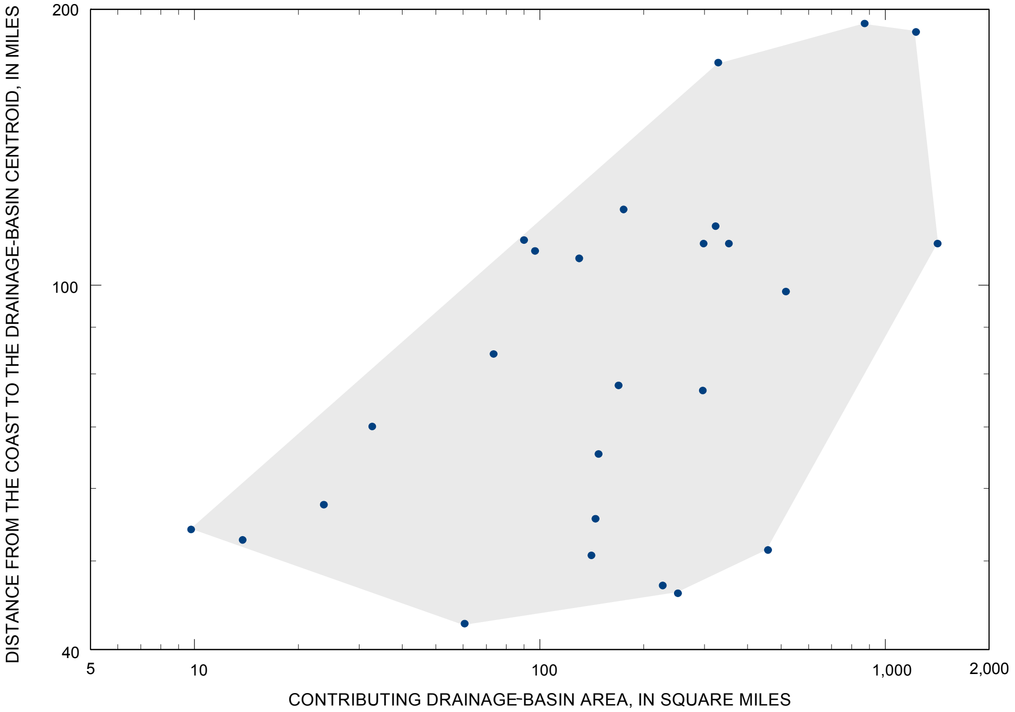


**Figure 5.** Two-dimensional range of explanatory variables for regression equations estimating mean and median December, January, February, March, and May streamflows for unregulated, rural rivers in Maine.

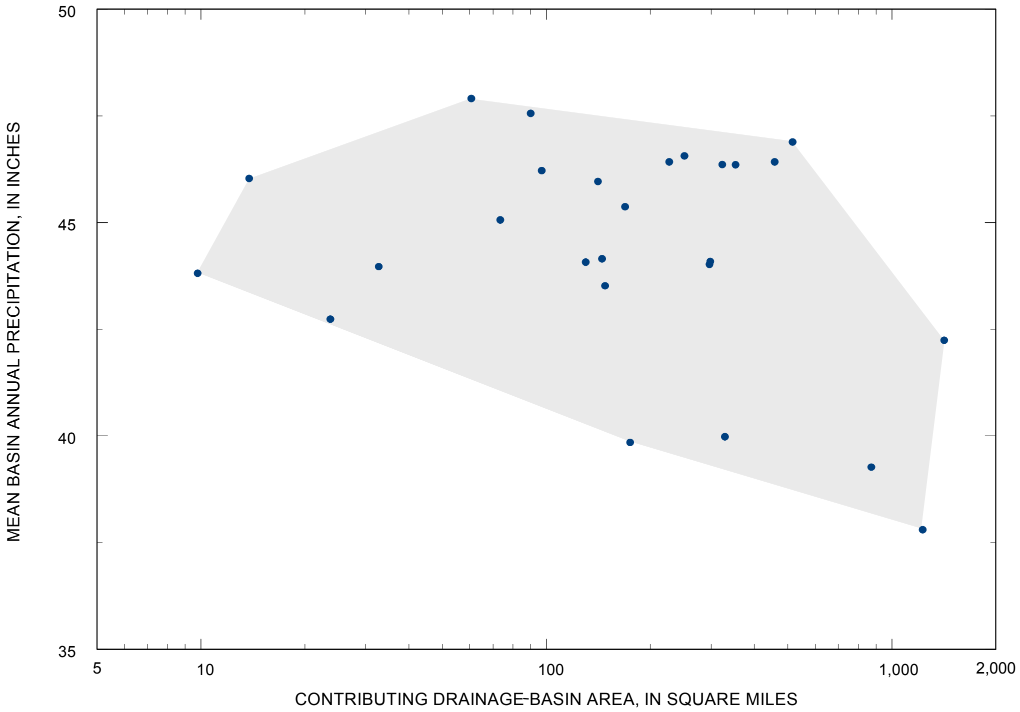


**Figure 6.** Two-dimensional range of explanatory variables for regression equations estimating mean and median April streamflows for unregulated, rural rivers in Maine.

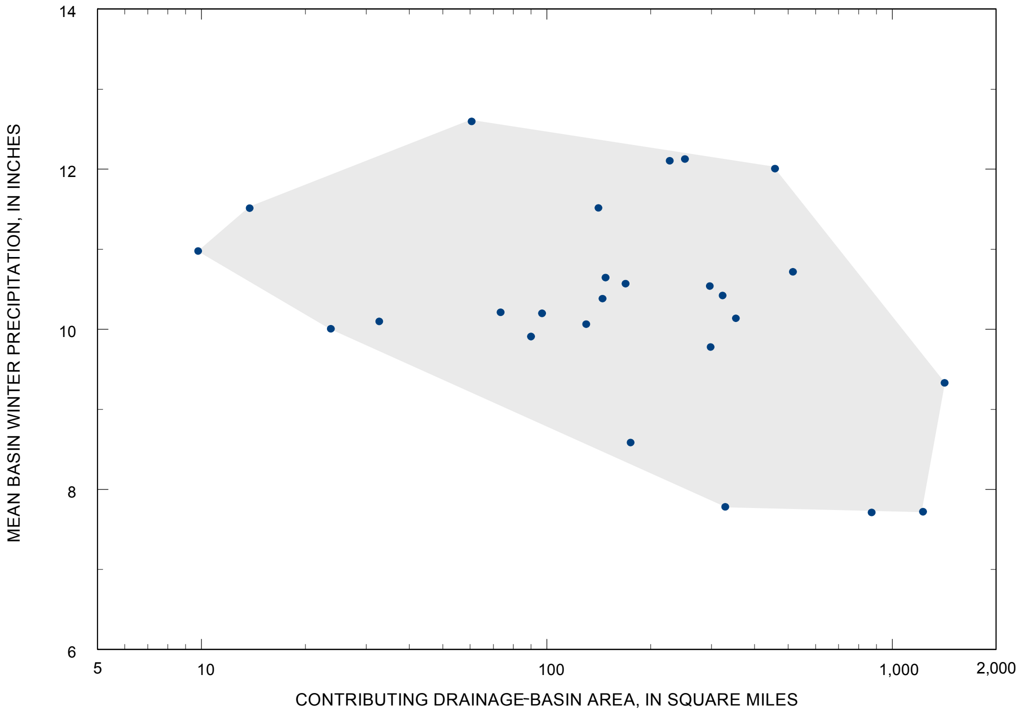


**Figure 7.** Two-dimensional range of explanatory variables for regression equations estimating mean and median annual streamflows for unregulated, rural rivers in Maine.

drainage basins. Collyer Brook is the most highly developed basin in this investigation (5.91 percent). A 2001 field reconnaissance of the Collyer Brook Basin scored the basin with a BDF value of zero (Dudley and others, 2001). Because all the drainage basins in this investigation were less developed than Collyer Brook, drainage improvements were assumed not to be prevalent in any of the study basins.

The PRISM precipitation grids used for this study were downloaded from the USDA-NRCS Internet site in 2002. The coverages are based on precipitation data spanning the 30-year period 1961-90. In the event that updated PRISM precipitation grids are created in future years, they should not be applied to these regression equations—using PRISM precipitation grids other than the ones used to develop the regression equations will yield results of unknown uncertainty. Currently (2003), the NRCS does not have any plans to prepare any new maps (Steven Nechero, National Cartography and Geospatial Center, Natural Resources Conservation Service, written commun., 2003).

The sand and gravel aquifer mapping has been completed for all but northwestern Maine. It is expected that if sand and gravel aquifers in these areas were mapped using the same or similar methods as those used to map aquifers in the rest of Maine, these equations would be applicable in those regions.

An underlying assumption in the development of these regression equations is that no systematic changes in streamflow or basin and climatic characteristics have taken place over time. Recent studies of the effects of climate variability on hydrology in Maine and New England (Dudley and Hodgkins, 2002; Hodgkins and others, 2002) show that this may not be the case. The development of the regression equations presented in this report has integrated historical streamflow and precipitation data that may be trending on a seasonal, annual, or longer basis. It also is well known that the greatest changes in land use in Maine during the 20th century were the replacement of agriculture and pasture lands by forest. In particular, a doubling in forest cover over the last century has occurred in river basins in southern counties of Maine (Irland, 1998). Quantification of the effects of climate and land-use changes on regression equations for estimating selected flow statistics was beyond the scope of this study; however, the observed trends suggest that future investigations of this kind should be done at regular intervals using a moving temporal window of contemporary data or consider methods for incorporating these large-scale hydrologic trends into the statistical models.

## Summary

In 2002 the U.S. Geological Survey (USGS) began a cooperative investigation with the Maine Department of Transportation (MDOT), the Maine Department of Environmental Protection (MDEP), and the Maine Atlantic Salmon Commission (ASC) to update methods that can be used to estimate streamflow statistics for ungaged rivers in Maine. Regression equations were derived to estimate mean monthly, mean annual, median monthly, median annual, and low 7-day, 10-year (7Q10) streamflows for unregulated, rural rivers in Maine. The regression equations are used to estimate these characteristic streamflows at a site on a stream where streamflow data are not available, provided that no diversions, regulation, or appreciable urbanization in the basin is present upstream of the site. This report also provides mean monthly, mean annual, median monthly, median annual, and low 7Q10 streamflows tabulated for 26 USGS streamflow-gaging stations in Maine on unregulated, rural rivers with 10 years or more of recorded streamflow.

Because of their improved accuracy and use of updated information, the regression equations for estimating mean monthly, mean annual, and low 7Q10 streamflows for ungaged rivers presented in this report supersede those by Parker (1977), "Methods for Determining Selected Flow Characteristics for Streams in Maine," and by Hayes and Morrill (1970), "A Proposed Streamflow Data Program for Maine." In addition to updated regression equations for estimating mean monthly, mean annual, and low 7Q10 streamflows, this report presents regression equations for estimating median monthly and median annual streamflows.

Streamflow-gaging station data were retrieved from the National Water Information System (NWIS) for all available USGS streamflow-gaging stations that met the criteria of the study. Available periods of record of streamflow data for the 26 study streamflow-gaging stations range from 14 to 99 years in length, with a mean of 52 years. The earliest and latest dates for streamflow data used in this study are October 1, 1902, and September 30, 2001, respectively.

For this study, 62 basin and climatic characteristics were derived and tested as potential explanatory variables in the regression analysis, with an emphasis on GIS-derived characteristics. The explanatory variables included the following characteristics and variations thereof: basin drainage area; mean monthly, seasonal, and annual precipitation; basin elevation, shape, and slope; latitude and longitude; National Land-Cover Data (NLCD) classifications; areas of wetlands, lakes and ponds; March 1 snowpack; area of significant sand and gravel aquifers; and distance from the coast.

OLS regression analysis winnowed the 62 basin and climatic characteristics down to 5 final explanatory variables: drainage area, fraction of the drainage basin underlain by sand and gravel aquifers, distance from the coast to the drainage basin centroid, mean annual precipitation, and mean winter precipitation. For the 26 basins studied, drainage areas range in size from 9.79 $mi^2$ to 1,418 $mi^2$, with a mean of 303 $mi^2$; fractions of the drainage basin underlain by sand and gravel aquifers range from 0.000 to 0.455, with a mean of 0.076; distances from the coast to the drainage-basin centroid range from 42.7 mi to 193 mi, with a mean of 91.7 mi; mean annual precipitation ranges from 37.8 in. to 47.9 in., with a mean of 44.3 in.; and mean winter precipitation ranges from 7.7 in. to 12.6 in., with a mean of 10.3 in. GLS regression techniques were used to derive the final coefficients and measures of uncertainty for the regression equations.

When applying the regression equations, it is important that the explanatory variables (basin and climatic characteristics) be derived using the same or comparable methods as those documented in this report. Basin and climatic characteristics derived using techniques different from those techniques used for this study will yield results of unknown error. Similarly, using values for any of the explanatory variables outside the ranges used to develop the regression equations will yield results of unknown error.

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