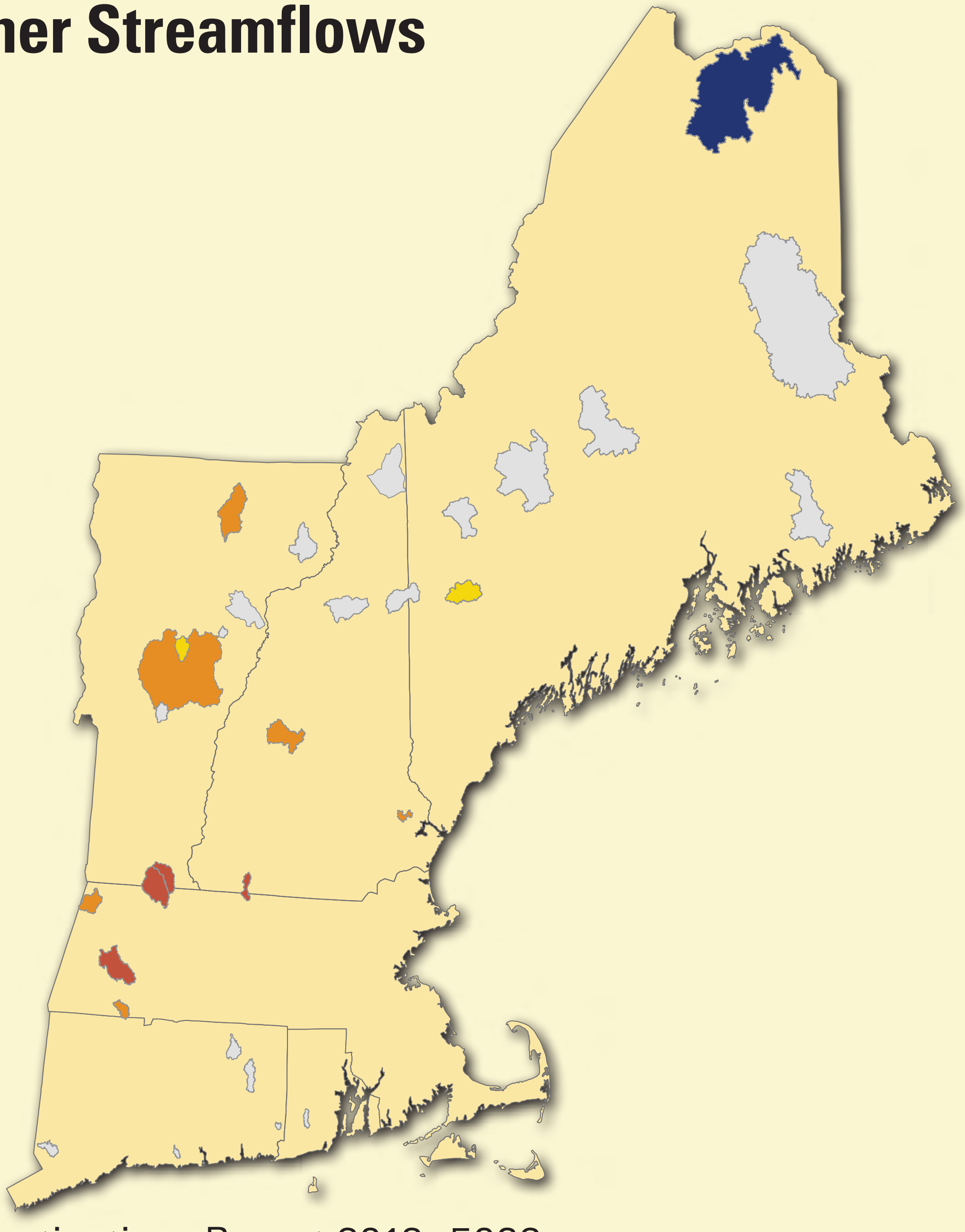
# Relations between Winter Climatic Variables and April Streamflows in New England and Implications for Summer Streamflows



Scientific Investigations Report 2012–5092

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

**Cover.** Map of New England showing drainage basins.

# Relations between Winter Climatic Variables and April Streamflows in New England and Implications for Summer Streamflows

By Glenn A. Hodgkins, Robert W. Dudley, and Luther F. Schalk

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# Contents



# Figures



# Tables

# Conversion Factors

Inch/Pound to SI

| Multiply | By | To obtain |
|---|---|---|
| | Length | |
| inch (in.) | 2.54 | centimeter (cm) |
| inch (in.) | 25.4 | millimeter (mm) |
| foot (ft) | 0.3048 | meter (m) |
| mile (mi) | 1.609 | kilometer (km) |
| | Area | |
| square mile ($mi^2$) | 259.0 | hectare (ha) |
| square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F–32)/1.8

# Relations between Winter Climatic Variables and April Streamflows in New England and Implications for Summer Streamflows

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## Abstract

A period of much below normal streamflow in southern New England during April 2012 raised concerns that a long-term period of drought could evolve through late spring and summer, leading to potential water availability issues. To understand better the relations between winter climatic variables and April streamflows, April streamflows from 31 streamflow gages in New England that drain relatively natural watersheds were tested for year-to-year correlation with winter precipitation and air temperature from nearby meteorological sites. Higher winter (December through March) precipitation is associated with higher April streamflows at many gages in northern and central New England. This implies that snowpack accumulation is an important mechanism for winter water storage and subsequently important for spring streamflows in this area. Higher March air temperatures are associated with lower April streamflows at many gages in central and southern New England, likely because the majority of snowmelt runoff occurs before April in warm years. A warm March 2012 contributed to early snowmelt runoff in New England and to much below normal April streamflows in southern New England. However, no strong relation was found between historical April streamflows and late-spring or summer streamflows in New England. The lack of a strong relation implies that summer precipitation, rather than spring conditions, controls summer streamflows.

## Introduction

Streamflow represents the integrated response of a watershed to climatic variables, particularly precipitation and air temperature. New England (a region of the United States that includes Maine, New Hampshire, Vermont, Massachusetts, Rhode Island, and Connecticut) is a good region in which to study the historical variation of streamflows and how they relate to climatic variables. With a large annual snowpack in many parts of the region and near-freezing temperatures from late fall to early spring, seasonal streamflows are potentially sensitive to changes in air temperature as well as to changes in precipitation. Also, there are many rivers with more than 50 years of U.S. Geological Survey (USGS) continuous streamflow data in New England that are not strongly influenced by direct human watershed changes. It is important to understand the sensitivity of streamflow to climatic variation because people and aquatic ecosystems are dependent upon a water supply that is adequate, particularly in summer low-flow seasons.

### Purpose and Scope

The purpose of this report is to describe a study of (1) the relative importance of winter precipitation and air temperature to April streamflows in New England and (2) the relation between April streamflows and late-spring and summer streamflows. The study uses USGS streamflow gages that are minimally impacted by direct human watershed changes in an attempt to isolate climatic signals in the streamflows. There is a large amount of year-to-year variability in New England streamflows and climate. This large variability is used to infer the relative strength of relations between April streamflows and other variables by testing for interannual correlations. The 2012 winter climatic variables and April streamflows are then put into perspective by comparing them to historical values.

### Influence of Precipitation and Air Temperature on Winter-Spring Streamflows

The relative amount of precipitation falling as rain or snow in New England directly affects the magnitude and timing of streamflow in the late fall, winter, and early spring. Median total seasonal snowfall in New England ranges from more than 100 inches (in.) to less than 40 in. (Cember and Wilks, 1993). Winter streamflows are generally low in northern and mountainous areas of New England where most winter precipitation typically falls as snow and accumulates as snowpack which melts and runs off later in the spring. Winter streamflows in southern areas are more variable than streamflows in northern areas; streamflows tend to be higher in the southern areas because of more winter rain and snowpack melt.

The largest streamflows in New England often occur in the spring when rain falls on a ripe (dense, ready to melt) snowpack or on saturated soils; snowmelt runoff can contribute a large part of the water for these winter-spring streamflows. At the Swift River in northern New England (Maine), 46 percent of the total streamflow from 1929 to 2003 was in April and May (Hodgkins and Dudley, 2005). For the Yantic River in southern New England (Connecticut), 32 percent of the streamflow from 1930 to 2003 was in March and April. The seasonal streamflow in the Yantic River corresponds with a smaller and earlier spring snowmelt runoff. Streamflows in New England recede as snowmelt ends and as evapotranspiration increases. These receding streamflows are frequently augmented by runoff from rainstorms.

In mid-April 2012, streamflows in southern New England were much below normal (in the lowest 10 percent of flows historically recorded on that day at streamflow gages) (http://waterwatch.usgs.gov/index.php?id=ww_past, accessed April 17, 2012), generating interest in the climatological factors contributing to the low-streamflow conditions. While the relative influence of precipitation and air temperature on some aspects of winter-spring hydrology in New England have been previously analyzed, no studies are known that have quantified the relative effects of winter air temperature and precipitation on the magnitude of April streamflows. Air temperature in the few months before and during snowmelt explains about half of the year-to-year variability in the timing of snowmelt-related streamflows in northern New England (Hodgkins and others, 2003); higher air temperatures were associated with earlier streamflows. All precipitation correlations were much lower than the highest temperature correlations, indicating that the timing of spring snowmelt runoff was more sensitive to changes in temperature than to changes in precipitation amount. The year-to-year ratio of snowfall to total precipitation in northern New England was found to be correlated with air temperature but not with total precipitation (Huntington and others, 2004).

## Historical Changes in Winter-Spring Hydrology

The timing of winter-spring streamflows, which is influenced by the timing of snowmelt runoff, became earlier in northern and mountainous sections of New England during the 20th century, with most of the 1- to 2-week change occurring since the early 1970s (Dudley and Hodgkins, 2002; Hodgkins and others, 2003; Hodgkins and Dudley, 2006a). Eighteen of twenty-three snow-measurement sites in and near Maine with at least 50 years of record had a significant decrease in snowpack depth or an increase in snowpack density over time for specific late-winter dates (Hodgkins and Dudley, 2006b). These changes are consistent with changes toward warmer air temperatures. Average March through April temperatures in northern New England increased by 1.3°F from 1953 to 2002 (Hodgkins and Dudley, 2006a).

## Influence of Winter-Spring Hydrology on Summer Low Streamflows

With much below normal streamflows in southern New England in mid-April 2012 (http://waterwatch.usgs.gov/index.php?id=ww_past, accessed April 17, 2012) there is concern that long-term drought levels could evolve through the late spring and summer, with potential water availability issues. The lowest streamflows of the year tend to be in late summer in New England. Hodgkins and Dudley (2011) found that the lowest summer base flows for New England streams were weakly and inconsistently related to the timing of winter-spring streamflows, but were strongly and consistently related to summer precipitation. The relation between April streamflows and late-spring and summer streamflows, however, has not been investigated.

# Data and Methods

Streamflow data in the current study are from USGS streamflow gages that have relatively natural streamflows; in other words, gages with streamflows minimally impacted by direct human watershed changes such as reservoir regulation and urbanization. The gages come from the Hydro-Climatic Data Network 2009 (HCDN-2009; Lins, 2012), a subset of the USGS Geospatial Attributes of Gages for Evaluating Streamflow, version II (GAGES II) dataset (Falcone, 2011). The HCDN-2009 designation in GAGES II indicates watersheds that represent hydrologic conditions which are least disturbed by human influences (relative to other watersheds within 12 major ecoregions in the United States) for potential study of climate-related streamflow trends. All 31 HCDN-2009 gages in New England were used for the current study (table 1). Streamflow data for these gages had an average length of record of 68 years and a minimum record of 27 years. All available data approved for publication through 2011 were used at the 31 gages. Provisional data for January through April 2012 were used for three selected gages.

Monthly precipitation and air temperature data from the U.S. Historical Climatology Network (HCN) Version 2 data set (Quinlan and others, 1987; Menne and others, 2009) were used in this study for interannual correlation testing with April streamflow magnitudes (table 2). HCN data are quality controlled and evaluated on the basis of record length and completeness. Qualifying data are subject to time-of-observation bias adjustments (Karl and others, 1986; Vose and others, 2003) and homogeneity testing and adjustment procedures to account for non-climate related changes in the record such as instrument and gage location changes (Menne and Williams, 2009). Missing data are estimated using weighted averages of highly correlated neighboring sites. Twenty-six of the thirty-one matched pairs of streamflow gages and HCN sites (table 2) were within 30 miles (mi) of each other; the farthest pair was 56 mi away from each other. The average elevation

**Table 1.** USGS streamflow gages from relatively natural watersheds in New England.

[USGS, U.S. Geological Survey; Relatively natural status based on USGS Geospatial Attributes of Gages for Evaluating Streamflow, version II (GAGES II) dataset; mi$^2$, square miles]

| Station number | Stream and state | Drainage area (mi$^2$) | Years of record |
|---|---|---|---|
| 01013500 | Fish River, Maine | 873 | 87 |
| 01022500 | Narraguagus River, Maine | 227 | 63 |
| 01030500 | Mattawamkeag River, Maine | 1,418 | 77 |
| 01031500 | Piscataquis River, Maine | 298 | 109 |
| 01047000 | Carrabassett River, Maine | 353 | 90 |
| 01052500 | Diamond River, New Hampshire | 152 | 70 |
| 01054200 | Wild River, Maine | 69.6 | 47 |
| 01055000 | Swift River, Maine | 96.9 | 82 |
| 01057000 | Little Androscoggin River, Maine | 73.5 | 90 |
| 01073000 | Oyster River, New Hampshire | 12.1 | 76 |
| 01078000 | Smith River, New Hampshire | 85.8 | 92 |
| 01117468 | Beaver River, Rhode Island | 8.87 | 34 |
| 01118300 | Pendleton Hill Brook, Connecticut | 4.02 | 51 |
| 01121000 | Mount Hope River, Connecticut | 28.6 | 69 |
| 01123000 | Little River, Connecticut | 30 | 58 |
| 01134500 | Moose River, Vermont | 75.2 | 63 |
| 01137500 | Ammonoosuc River, New Hampshire | 87.6 | 71 |
| 01139000 | Wells River, Vermont | 98.4 | 70 |
| 01139800 | East Orange Branch, Vermont | 8.95 | 52 |
| 01142500 | Ayers Brook, Vermont | 30.5 | 70 |
| 01144000 | White River, Vermont | 690 | 94 |
| 01150900 | Ottauquechee River, Vermont | 23.4 | 25 |
| 01162500 | Priest Brook, Massachusetts | 19.4 | 92 |
| 01169000 | North River, Massachusetts | 89 | 69 |
| 01170100 | Green River, Massachusetts | 41.4 | 42 |
| 01181000 | West Branch Westfield River, Massachusetts | 94 | 74 |
| 01187300 | Hubbard River, Connecticut | 19.9 | 70 |
| 01195100 | Indian River, Connecticut | 5.68 | 27 |
| 01208990 | Saugatuck River, Connecticut | 21 | 45 |
| 01333000 | Green River, Massachusetts | 42.6 | 60 |
| 04296000 | Black River, Vermont | 122 | 59 |

difference between the matched pairs was 368 feet (ft) with a maximum difference of 936 ft. All but one of the streamflow gages were higher than the HCN sites.

The strength of interannual correlations between April streamflows and other variables were measured with Pearson's correlation coefficient (r) (Helsel and Hirsch, 1992). It is the most commonly used measure of correlation and measures the linear association between two variables. The statistical significance of the correlations (whether they are statistically different than zero) also was computed.

**Table 2.** Selected HCN meteorological sites in New England.

[HCN, U.S. Historical Climatology Network]

| Station number | Station name | State | Paired streamflow gage number |
|---|---|---|---|
| 062658 | Falls Village | Connecticut | 01187300 |
| 063207 | Groton | Connecticut | 01118300 |
| 067970 | Stamford 5 N | Connecticut | 01208990 |
| 068138 | Storrs | Connecticut | 01121000, 01123000 |
| 170100 | Acadia NP | Maine | 01022500 |
| 171628 | Corinna | Maine | 01031500 |
| 172765 | Farmington | Maine | 01047000, 01055000 |
| 174566 | Lewiston | Maine | 01057000 |
| 175304 | Millinocket | Maine | 01030500 |
| 176937 | Presque Isle | Maine | 01013500 |
| 190120 | Amherst | Massachusetts | 01169000, 01170100, 01181000 |
| 270706 | Bethlehem 2 | New Hampshire | 01054200, 01137500 |
| 272174 | Durham | New Hampshire | 01073000 |
| 272999 | First Connecticut Lake | New Hampshire | 01052500 |
| 273850 | Hanover | New Hampshire | 01078000, 01144000 |
| 274399 | Keene | New Hampshire | 01162500 |
| 300889 | Bridgehampton | New York | 01195100 |
| 308600 | Troy Lock & Dam | New York | 01333000 |
| 374266 | Kingston | Rhode Island | 01117468 |
| 431243 | Cavendish | Vermont | 01150900 |
| 431360 | Chelsea | Vermont | 01139800, 01142500 |
| 437054 | Saint Johnsbury | Vermont | 01134500, 01139000, 04296000 |

# Historical Relations between April Streamflows and Winter Precipitation and Temperature

Year-to-year correlations between April streamflows and winter precipitation and air temperature at the 31 streamflow gages in this study are summarized in table 3. Nearly 68 percent of gages have correlation coefficients greater than +0.3 between April streamflows and winter (December through March) precipitation, and some gages (6.5 percent) have correlations greater than +0.5. Higher winter precipitation is associated with higher April streamflows. A correlation coefficient (r) of 0.3 corresponds to an $r^2$ of 0.09 and means that 9 percent of the year-to-year variability of April streamflows is related to winter precipitation; a correlation coefficient of 0.5 means that 25 percent of the year-to-year variability is explained.

The highest percentage of gages with correlations greater than +0.3 between April streamflows and precipitation were with February–March, January–March, and December–March precipitation, rather than with precipitation in any one month. This implies that the aggregate amount of winter precipitation is more important to the magnitude of April streamflows than is precipitation in March. The concentration of gages with correlations in northern and central New England (fig. 1) implies that snowpack accumulation is an important mechanism for winter water storage. The amount of water stored in the snowpack in late winter in northern and central New England is substantial; the average water content (the amount of water in the snowpack if it were melted) in late winter in Maine ranges from less than 4 in. near the coast to more than 9 in. in northern Maine (Loiselle and Hodgkins, 2002). Some gages in south coastal New England have correlations greater than +0.3 (fig. 1). Natural water storage in sand and gravel aquifers may be present in these watersheds.

Almost 39 percent of the streamflow gages have correlations less than -0.3 between April streamflows and March air temperatures, and almost 13 percent of the correlations are less than -0.5 (table 3); higher March air temperatures are associated with lower April streamflows. January through March and December through March temperatures had correlations at many fewer sites than did March temperatures. This implies that March air temperatures are more important to the magnitude of April streamflows than season-long winter air temperatures. Most of the correlations less than -0.3 with March temperatures are located in central and southern New England (fig. 2). In this area, higher March air temperatures may be causing the majority of snowmelt to occur before April.

In contrast, April streamflows are positively correlated with March temperatures at the Fish River in northern Maine (fig. 2, gage number 01013500). This far north, higher March temperatures may lead to higher April streamflows because the timing of snowmelt is later than in central and southern New England. A warmer March may cause higher April runoff

**Table 3.** Summary of interannual correlations between the magnitude of April streamflows and winter precipitation and temperature.

[r, correlation coefficient; p, attained significance level; <, less than; >, greater than]

| Month | Percent of 31 stations with magnitude of correlations greater than or less than defined level | | | | Percent of 31 stations with significance of correlations less than defined level | | |
|---|---|---|---|---|---|---|---|
| | r < -0.5 | r < -0.3 | r > +0.3 | r > +0.5 | p < 0.05 | p < 0.01 | p < 0.001 |
| Precipitation | | | | | | | |
| December | 0.0 | 0.0 | 0.0 | 0.0 | 12.9 | 3.2 | 0.0 |
| January | 0.0 | 0.0 | 3.2 | 0.0 | 9.7 | 3.2 | 0.0 |
| February | 0.0 | 0.0 | 29.0 | 3.2 | 35.5 | 22.6 | 19.4 |
| March | 0.0 | 0.0 | 29.0 | 9.7 | 61.3 | 29.0 | 9.7 |
| February–March | 0.0 | 0.0 | 64.5 | 9.7 | 71.0 | 54.8 | 25.8 |
| January–March | 0.0 | 0.0 | 58.1 | 9.7 | 64.5 | 45.2 | 19.4 |
| December–March | 0.0 | 0.0 | 67.7 | 6.5 | 74.2 | 58.1 | 35.5 |
| Temperature | | | | | | | |
| December | 0.0 | 0.0 | 0.0 | 0.0 | 12.9 | 0.0 | 0.0 |
| January | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| February | 0.0 | 3.2 | 3.2 | 0.0 | 19.4 | 6.5 | 0.0 |
| March | 12.9 | 38.7 | 3.2 | 3.2 | 51.6 | 41.9 | 35.5 |
| February–March | 9.7 | 35.5 | 3.2 | 3.2 | 48.4 | 38.7 | 32.3 |
| January–March | 0.0 | 22.6 | 3.2 | 0.0 | 38.7 | 25.8 | 9.7 |
| December–March | 0.0 | 12.9 | 3.2 | 0.0 | 32.3 | 16.1 | 6.5 |

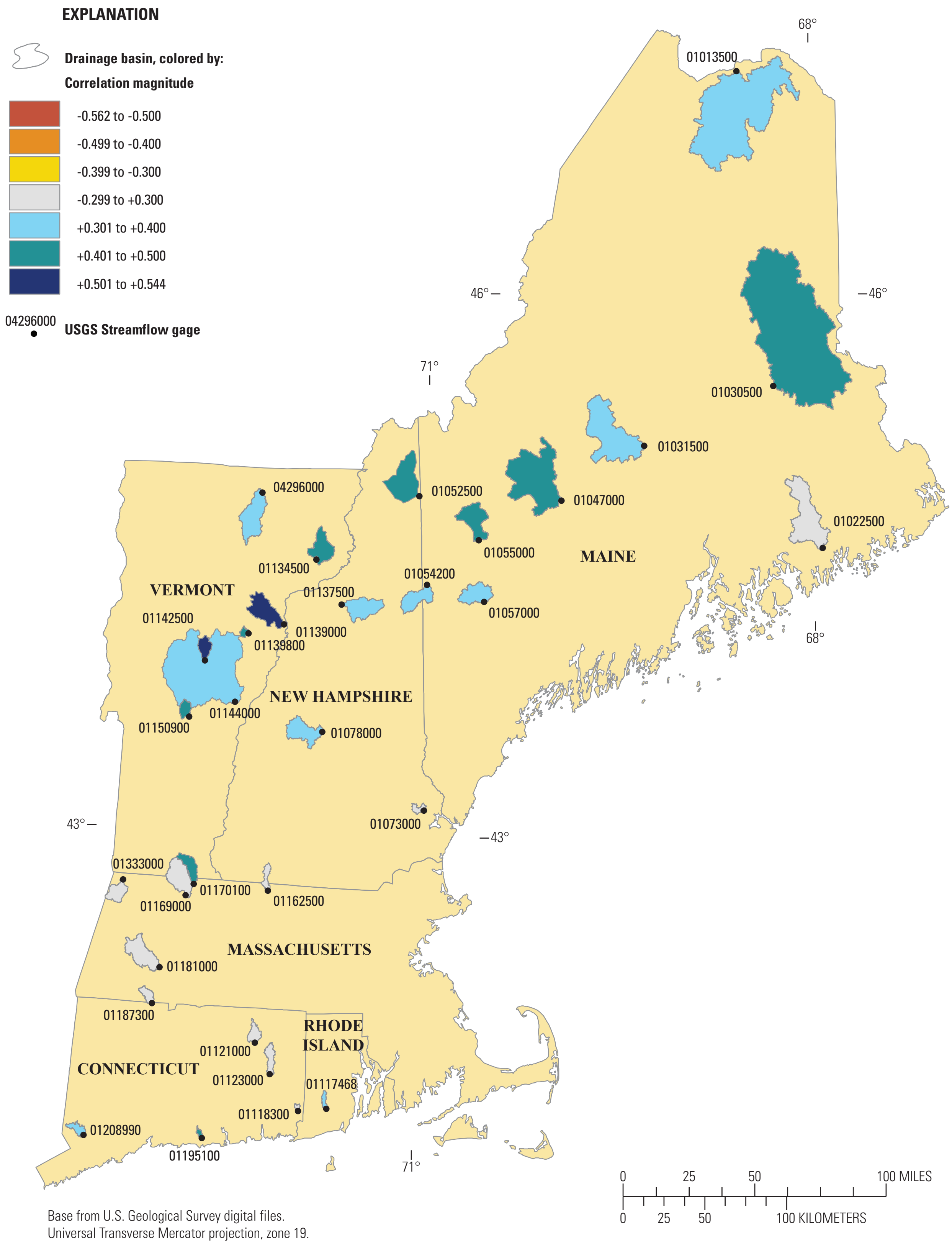


**Figure 1.** Interannual correlations between the magnitude of April streamflows and December through March precipitation.

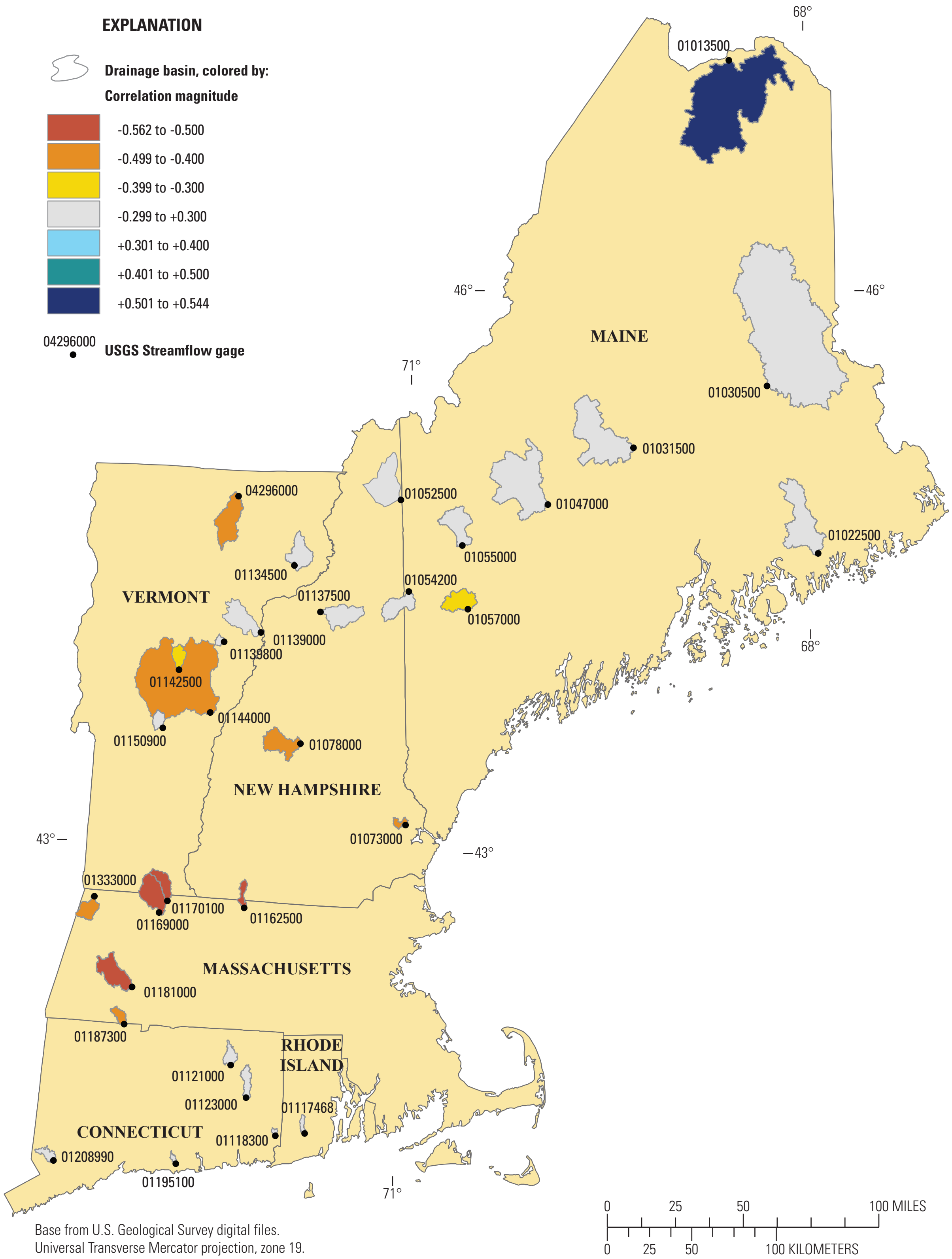


**Figure 2.** Interannual correlations between the magnitude of April streamflows and March air temperature.

by ripening the snowpack; a snowpack needs to reach a relatively high density before substantial snowmelt runoff occurs (Hodgkins and Dudley, 2006b). There may not be enough snowpack in Connecticut and Rhode Island to affect correlations between late winter air temperatures and April streamflows.

Plots of the relation between April streamflow magnitudes and winter precipitation and air temperature for three example gages (fig. 3) are consistent with the correlations discussed above. April streamflows at the Fish River in northern Maine (01013500) were correlated with both winter precipitation and March air temperatures (figs. 1 and 2). In general, the highest April streamflows are associated with above average precipitation and temperatures (large dark circles in the wet, warm quadrant of fig. 3A). April streamflows in the Carrabasset River in central Maine (01047000) were correlated with winter precipitation but did not have a measurable correlation with March air temperature (figs. 1 and 2). This can be seen in figure 3B with generally higher streamflows for above average winter precipitation but no clear signal related to temperature. In contrast, the West Branch Westfield River in western Massachusetts (01181000) shows higher April streamflows generally associated with below average March temperatures but no clear signal related to winter precipitation (fig. 3C).

## Historical Relations between April Streamflows and Summer Streamflows

Year-to-year correlations between streamflows in April and in the spring and summer months at the 31 streamflow gages in this study are summarized in table 4. There is almost no correlation at the gages between April streamflows in any given year and streamflows later in that spring or summer. The highest percentage of gages with correlation coefficients greater than 0.3 or less than -0.3 was 3.2 percent (or one of the gages). A correlation coefficient (r) of 0.3 means that 9 percent of the year-to-year variability of a late-spring or summer streamflow is related to April streamflows. These results imply that the predictive power of April streamflows is very low and that summer precipitation is much more important to summer streamflows than April streamflows. The lowest summer base flows for New England streams were found by Hodgkins and Dudley (2011) to be strongly and consistently related to summer precipitation.

## Perspective on April 2012 Streamflows

April 2012 streamflows and corresponding winter precipitation and March air temperatures for the same three example gages discussed above are plotted in figure 3. The Fish River in northern Maine had a relatively high April 2012 streamflow associated with well above average March air temperature and near average winter precipitation (fig. 3A). The January through April 2012 hydrograph for this gage shows above normal streamflow in late March and early April (fig. 4A) which was associated with early snowmelt runoff. Most snowpack in the Fish River watershed melted by April 3 (http://www.maine.gov/rfac/rfac_snow_display_wc.shtml?id=326225, accessed May 2, 2012). The increasing streamflows in late April were caused by rainfall. Note that 2012 streamflows in this report are provisional and could change when records receive their final corrections.

**Table 4.** Summary of interannual correlations between the magnitude of April streamflows and late-spring and summer streamflows.

[r, correlation coefficient; p, attained significance level; <, less than; >, greater than]

| Month | Percent of 31 stations with magnitude of correlations greater than or less than defined level | | | | Percent of 31 stations with significance of correlations less than defined level | | |
|---|---|---|---|---|---|---|---|
| | r < -0.5 | r < -0.3 | r > +0.3 | r > +0.5 | p < 0.05 | p < 0.01 | p < 0.001 |
| May | 0.0 | 3.2 | 3.2 | 3.2 | 22.6 | 9.7 | 3.2 |
| June | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 0.0 | 0.0 |
| July | 0.0 | 0.0 | 0.0 | 0.0 | 3.2 | 0.0 | 0.0 |
| August | 0.0 | 0.0 | 0.0 | 0.0 | 6.5 | 0.0 | 0.0 |
| September | 0.0 | 3.2 | 0.0 | 0.0 | 6.5 | 0.0 | 0.0 |
| May–June | 0.0 | 3.2 | 3.2 | 0.0 | 9.7 | 6.5 | 0.0 |
| August–September | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| July–September | 0.0 | 0.0 | 0.0 | 0.0 | 6.5 | 0.0 | 0.0 |

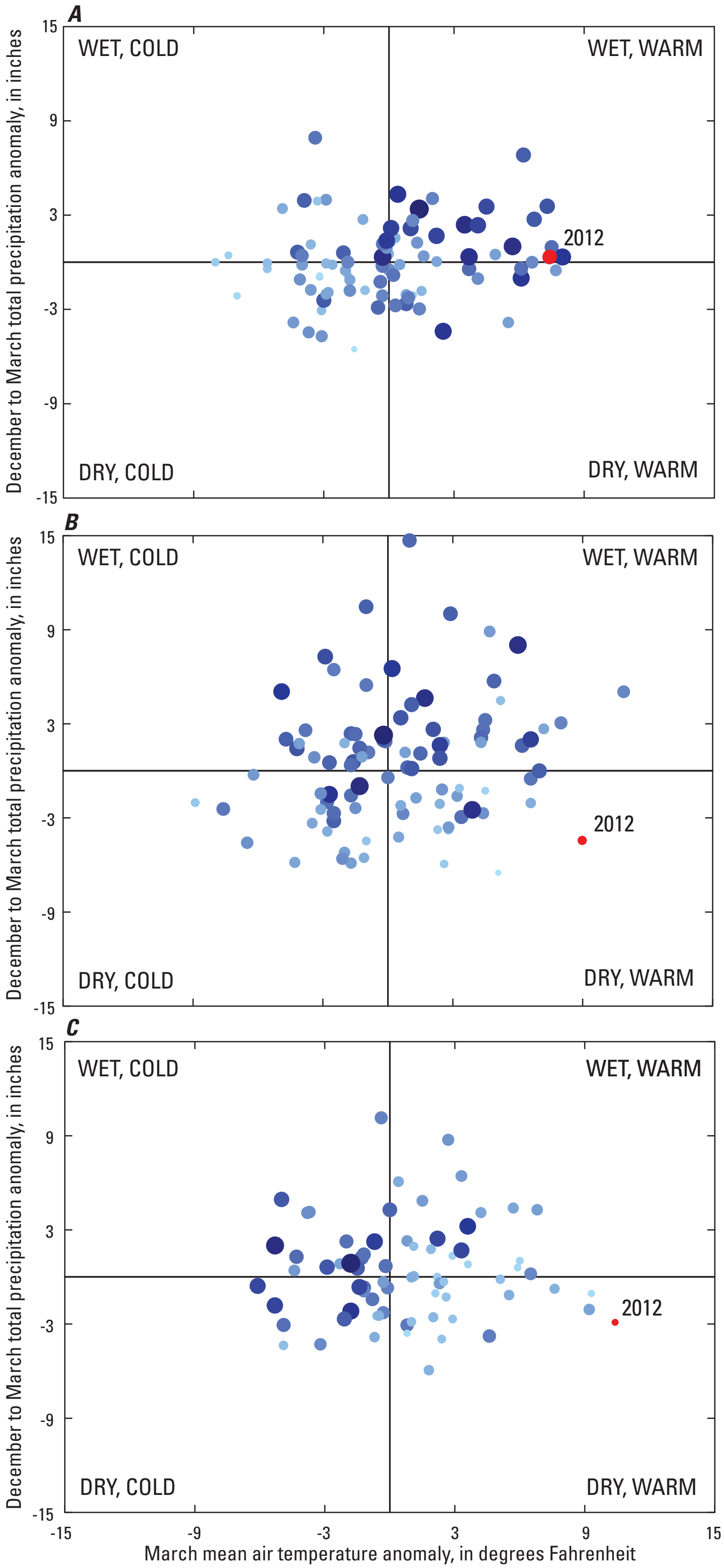


**Figure 3.** The relation between winter climatic variables and April streamflow magnitudes for *A,* Fish River in northern Maine; *B,* Carrabasset River in central Maine; and *C,* West Branch Westfield River in western Massachusetts. (Anomalies for the winter climatic variables are the difference between annual air temperature and precipitation values and their historical medians from their entire record. The circles represent the relative magnitude of April streamflows for corresponding precipitation and air temperature; larger and darker circles correspond with higher April streamflows.)

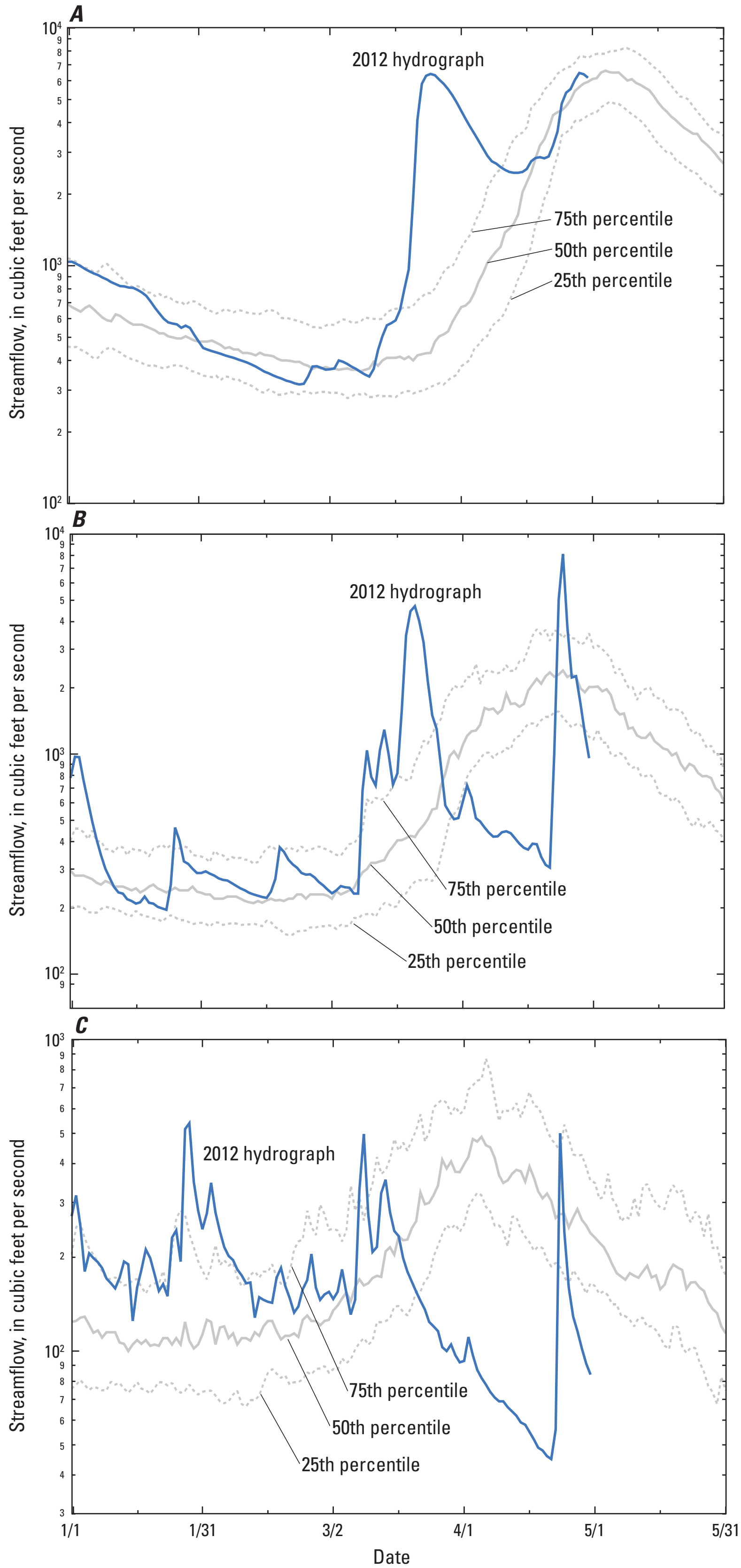


**Figure 4.** Historical January through May hydrographs and 2012 hydrograph for *A*, Fish River in northern Maine; *B*, Carrabasset River in central Maine; and *C*, West Branch Westfield River in western Massachusetts.

The Carrabassett River in central Maine had a relatively low April 2012 streamflow associated with below average winter precipitation and above average March temperatures (fig. 3B). The low April streamflow is consistent with other years at this gage that had relatively low winter precipitation. Like the Fish River in northern Maine, the 2012 hydrograph for the Carrabassett River (fig. 4B) shows above average streamflows in March associated with early snowmelt runoff. All snowpack in the Carrabassett River watershed melted by March 27 (http://www.maine.gov/rfac/rfac_snow_display_wc.shtml?id=326222, accessed May 2, 2012).

The much below normal April 2012 streamflow in the West Branch Westfield River in western Massachusetts is consistent with other years at this gage that had a warm March (fig. 3C); the 2012 March air temperature is the highest recorded in 74 years at the meteorological site closest to this site. Winter streamflows were higher than average for most of the winter (fig. 4C), possibly due to an above normal winter rain to snow ratio and early snowmelt runoff. In late March and early April, streamflows receded to much below normal and set new low daily streamflow records for about two weeks in early April. A large rainfall event in late April caused a short period of above normal streamflows before receding at the end of April and returning to below normal levels.

A warm March 2012 contributed to early snowmelt runoff in New England and to much below normal April streamflows in southern New England and above normal April streamflows in far northern New England. Climate models project warmer winter air temperatures during the next century in New England (Hayhoe and others, 2007; Christensen and others, 2007) which may lead to winter-spring streamflow changes (Markstrom and others, 2012; Dudley and others, 2012). If warm March air temperatures become more common in the future, April streamflows could change in different ways in southern and northern New England.

Water managers are concerned with the much below normal April 2012 streamflows in southern New England and whether low streamflows will continue through the summer. However, there is no strong relation between April streamflows and late-spring or summer streamflows in New England. The lack of a strong relation implies that summer precipitation rather than spring conditions will control summer streamflows.

## Acknowledgments

Thanks to USGS colleagues Laura Flight and Andrew Cloutier for providing 2012 provisional streamflows that account for river ice at two streamflow gages in Maine.

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