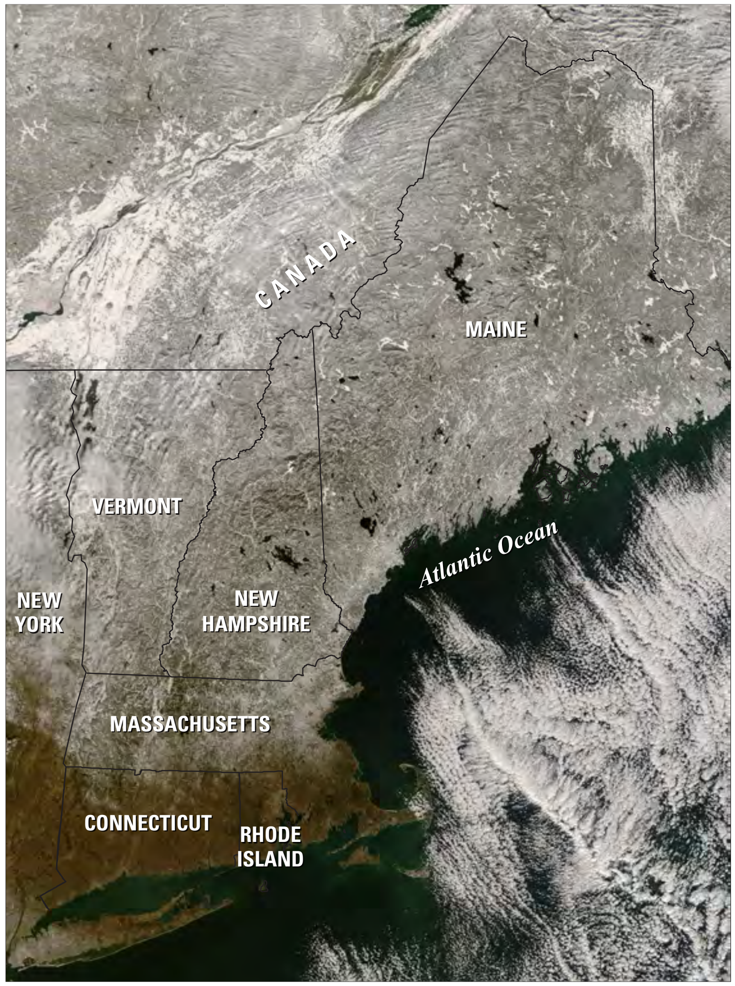
Quantifying Effects of Climate Change on the Snowmelt-Dominated Groundwater Resources of Northern New England

Recent U.S. Geological Survey (USGS) climate studies in New England have shown substantial evidence of hydrologic changes during the last 100 years, including trends toward earlier snowmelt runoff, decreasing occurrence of river ice, and decreasing winter snowpack. These studies are being expanded to include investigation of trends in groundwater levels and fluctuations. Groundwater is an important drinking-water source throughout northern New England (Maine, New Hampshire, and Vermont; fig. 1). The USGS is currently investigating whether or not groundwater recharge from snowmelt and precipitation exhibits historical trends. In addition to trend-testing, groundwater resources also will be analyzed by relating groundwater-level changes to the large year-to-year variability in weather conditions.

Introduction

The USGS has documented many seasonal climate-related changes in the northeastern United States that have occurred during the last 30 to 150 years. These changes include earlier snowmelt runoff in the late winter and early spring (fig. 2), decreasing duration of ice on rivers and lakes (fig. 3), decreasing ratio of snowfall to total precipitation, and denser and thinner late-winter snowpack. All of these changes are consistent with warming winter and spring air temperatures (Dudley and Hodgkins, 2002; Hodgkins and others, 2002; Huntington and others, 2004; Hodgkins and others, 2005; Hodgkins and Dudley, 2006a; Hodgkins and Dudley, 2006b). Climate-model projections for the Northeast indicate air-temperature warming, earlier snowmelt runoff, increases in annual evaporation, and decreased low streamflows (Hayhoe and others, 2007).

The contribution and timing of spring snowmelt to groundwater recharge is particularly important to groundwater resources in the northeastern United States where aquifers typically consist of thin sediments overlying crystalline bedrock with relatively little storage capacity (Mack, 2009). Following spring recharge, groundwater slowly flows into streams throughout the summer. This groundwater flow is a source of cool water during the summer and accounts for a large proportion of the streamflow during summer low-flow periods.



NASA image courtesy Jeff Schmaltz, MODIS Rapid Response Team at NASA GSFC

Figure 1. The snow-covered landscape of New England following snowstorms in early December 2007. Water resources in northern New England are heavily influenced by the accumulation of snowpack throughout the winter and its melt in the spring (National Aeronautics and Space Administration (NASA) image courtesy Jeff Schmaltz, Moderate Resolution Imaging Spectroradiometer Rapid Response Team at NASA Goddard Space Flight Center).

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December 2010

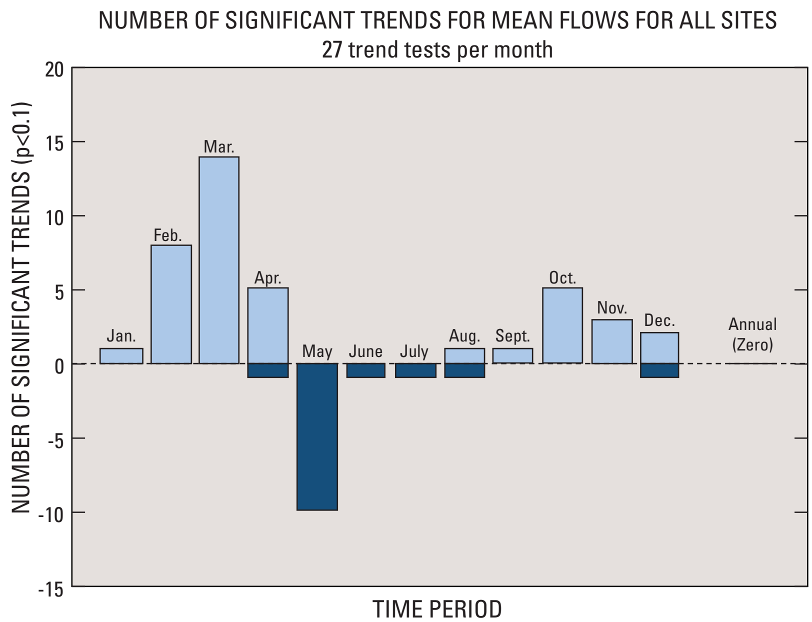

Figure 2. Number of significant changes in monthly streamflow magnitudes over time (average of 71 years through 2002) for streamgages in New England. Increasing streamflows in February, March, and April and decreasing streamflows in May are supporting evidence of a shift in timing toward earlier winter/spring runoff (Hodgkins and Dudley, 2005).

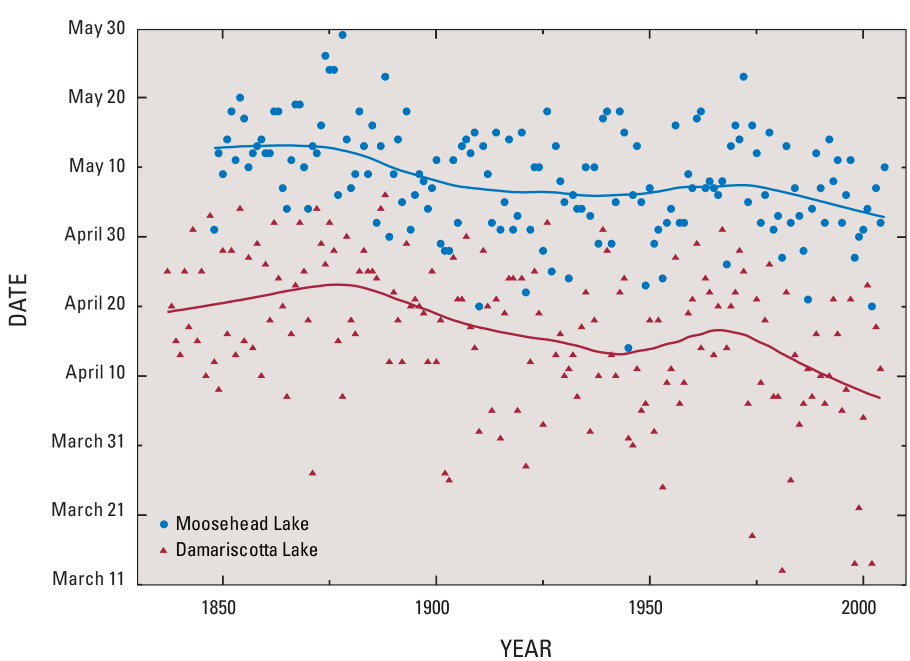

Figure 3. Lake ice-out dates for two lakes in New England with long-term data. Note the large amount of variability from year to year, the clumping of data in multiple decades, and the long-term trend toward earlier ice-out.

Groundwater is an important drinking-water source in northern New England. Approximately 32 percent of public water suppliers draw water from groundwater sources in Vermont, New Hampshire, and Maine, and approximately 40 percent of the population derives its drinking water from private wells (Kenny and others, 2009). It is vital to understand changes that may be occurring to such an important resource for planning industrial and agricultural water uses and protecting drinking water.

Study Approach

USGS scientists will analyze groundwater levels from dozens of wells throughout northern New England that have from at least 10 to more than 50 years of data. From these data, scientists will compute the timing and quantity of seasonal groundwater recharge from snowmelt and rain.

The monthly and seasonal variability in groundwater recharge and discharge will be compared to the variability of monthly and seasonal air temperatures and precipitation. This analysis will show the sensitivity of groundwater levels to changes in air temperature and precipitation. Changes in groundwater recharge and discharge also will be correlated with other hydrologic indicators such as snowpack water content and depth, timing of snowmelt runoff, and seasonal streamflows to provide context for interpreting any historical changes in groundwater resources.

USGS scientists will be assessing historical changes in groundwater recharge and discharge during the last 25 to 50 years for wells with long-term data. Trend and correlation analyses will quantify whether groundwater recharge and discharge have changed over time, how much they have changed, and what meteorological and hydrologic indicators these changes most closely correspond with. Any historical changes will be put into a longer-term perspective by comparing them to other documented long-term trends related to rivers, lakes, and snowpack during the last 50 to 150 years throughout northern New England.

Winter snowpack (top) and spring melt (bottom) on the Ducktrap River, Maine. Groundwater is recharged by melting snow in the spring. (Photographs by Josh Kempf, U.S. Geological Survey, February 25 (top) and April 3 (bottom), 2005).

Detailed groundwater and streamflow records from two experimental watersheds, Sleepers River in Vermont and Hubbard Brook in New Hampshire, will be examined to more fully understand the effects of frozen soil and snowpack depth and timing of melt on groundwater amounts and movement. The Sleepers River Research Watershed in northeastern Vermont is operated by the USGS in collaboration with other Federal agencies and universities. Hydrologic measurements in this watershed over the past 50 years have contributed to the fundamental understanding of water movement along surface and subsurface pathways from the hillslope to the stream and contributed to understanding how ecosystems may respond to climatic change (Shanley, 2000). The Hubbard Brook Experimental Forest is part of the National Science Foundation's Long Term Ecological Research Network. Scientists at Hubbard Brook have provided valuable insight to the ecology of forested watersheds and the effects of climate change and other natural and human-caused disturbances on the movement of water through this watershed (Likens and Buso, 2005; Likens, 2007; Rosenberry and others, 2007).

USGS scientists will assess the effects of the annual snowmelt process on groundwater recharge, storage, and discharge using detailed groundwater records in conjunction with streamflow data and climate data (including air and ground temperatures and frozen soil depth) at these experimental watersheds. Findings from the local-scale process investigation will aid in the interpretation of results of the regional groundwater assessment across northern New England. Knowledge of the local-scale processes of frozen soil development and retreat, snowmelt, and groundwater movement, combined with correlations of trends in groundwater levels to water and climate data provides a means to more fully understand observed short- and long-term changes in groundwater resources as a function of climate change.

USGS scientist measures groundwater levels with a steel tape to check the accuracy of an automated water-level measurement system at Mirror Lake groundwater-research site within the Hubbard Brook Experimental Forest. (Photograph by U. S. Geological Survey, http://toxics.usgs.gov/photo_gallery/gwflow.html).

Benefits

Many hydrologic changes in northern New England during the last century have been systematically documented as part of a USGS climate-response program designed to provide early warning of changes in the seasonal water cycle of Maine (Hodgkins and others, 2009). This study of groundwater resources will contribute to understanding the sensitivity of those resources to climate change in the snowmelt-dominated hydrologic system of northern New England and will provide important base-line information against which future climatic change can be measured. The study will help identify gaps in groundwater data-collection networks, thereby aiding in the design of data-collection networks for assessing the effects of climate change on groundwater resources. Results of this study and continued operation of groundwater-data collection networks will contribute to the body of science necessary for the effective management of water resources in northern New England in the face of short-term variability and long-term changes in climate.

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Prepared by the Pembroke Publishing Service Center