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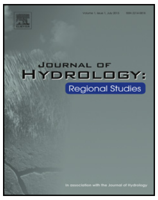

Regional climate change projections of streamflow characteristics in the Northeast and Midwest U.S.

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ABSTRACT

Study region: Northeast and Midwest, United States.
Study focus: Assessing the climate change impacts on the basin scale is important for water and natural resource managers. Here, the presence of monotonic trends and changes in climate-driven simulated 3-day peak flows, 7-day low flows, and mean base flows are evaluated in the Northeast and Midwest U.S. during the 20th and the 21st centuries using climate projections from sixteen climate models. Proven statistical methods are used to spatially and temporally disaggregate precipitation and temperature fields to a finer resolution before being used as drivers for a hydrological model.
New hydrological insights for the region: Changes in the annual cycle of precipitation are likely to occur during the 21st century as winter precipitation increases and warmer temperatures reduce snow coverage across the entire domain especially in the northern basins. Maximum precipitation intensities are projected to become more intense across the region by mid-century especially along the coast. Positive trends in 3-day peak flows are also projected in the region as a result of the more intense precipitation, whereas the magnitude of 7-day low flows and mean base flows are projected to decrease. The length of the low flows season will likely extend by mid-century despite the increased precipitation as the atmospheric demand increases.

1. Introduction

Changes in the magnitude and frequency of river flows can have significant impacts on freshwater resources for the ecosystem and human activities. Shifts in the volume and timing of streamflows can be critical to aquatic species that rely on them for important transitions in their life cycle, which can affect the existing infrastructure, and impact the water quality and the quantity for human water supply (Barnett et al., 2005; Comte et al., 2013; Hayhoe et al., 2007). The Northeast Climate Science Center (NE CSC) was established in 2012 by the Department of the Interior to address the regional challenges of climate variability and change in the Northeast and Midwest of the US. The NE CSC study area encompasses the 22 U.S.

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states east of the −98° W meridian and north of 36° N latitude. This region is inhabited by 131 million people (40% of the U.S. population), and the population is projected to increase by 20% by the year 2050 which will impose more stress on an already affected natural ecosystem and will have long-term impacts on the ecological and socioeconomic systems. This region contains several basins of economic and ecologic importance in the country, such as the Great Lakes Drainage, the Upper Mississippi river basin, the Ohio River basin, and the Connecticut River basin.

There is strong evidence that the intensity of precipitation events in the Northeast (NE) U.S. has increased in the 20th century as a result of anthropogenic effects in the hydrological cycle (Brown et al., 2010; Changnon, 2002; Douglas and Fairbank, 2011; Easterling et al., 2000; Groisman et al., 2001; Guilbert et al., 2015; Mishra and Lettenmaier, 2011). Heavy downpours, the events that are exceeded 1% of the time in any given year, have increased by 71% in the Northeast and 37% in the Midwest during the last three to five decades (Walsh et al., 2014). However, studies have found that the magnitude of annual maximum streamflows in the NE has not necessarily increased accordingly (Douglas et al., 2000; Lins and Slack, 1999, 2005; Villarini and Smith, 2010; Villarini et al., 2011). Positive trends in the number of high-frequency floods (5-year return period) have been found in most New England rivers throughout the 20th and early 21st centuries with a steep increase around 1970 (Armstrong et al., 2012). More frequent extreme streamflow events (above the 95th percentile) have been observed in the 21st century during the warm season in New England (Frei et al., 2015). In addition, earlier winter-spring flows in the range of 6–8 days has also been observed in the region and is thought to be linked to increased snow melting and rain-on-snow episodes (Hodgkins and Dudley, 2006), and this trend is likely to continue during the 21st century (Campbell et al., 2011). Increases in the magnitude and frequency of flood events have been observed in the central United States during the period of 1962–2011 (Mallakpour and Villarini, 2015).

Mean annual flows have increased in the eastern part of the United States during the last half of the 20th century (Collins, 2009; Hodgkins et al., 2005; McCabe and Wolock, 2011). Furthermore, low flows or base flows (groundwater contribution) have also shown robust upward trends (Douglas et al., 2000; Lins and Slack, 2005) that have been linked to the increasing precipitation during the summer in New England (Hodgkins et al., 2005), and during the fall in the upper Mississippi basin and upper Midwest (Small et al., 2006). From an ecosystems perspective, base flow is particularly important because it influences water temperatures in the summer and provides a minimum flow to sustain aquatic life. Climate model simulations indicate a shift toward higher winter flows and lower spring flows in New England (Campbell et al., 2011) and in the Great Lakes (Marshall and Randhir, 2008). In addition, short term soil moisture deficits, directly linked to the availability of water for agriculture and public water supplies, may also become more frequent (Hayhoe et al., 2007).

Several studies have identified the presence of changes in the mean and variance of observed streamflows in the region. McCabe and Wolock (2002) examine the maximum, mean, and minimum annual streamflows for the continental U.S. for the period of 1941–1999 and finds a step change in the mean and minimum values around 1970, suggesting that the climate system has shifted to a new regime with different statistical properties. Collins (2009) identifies a step change in the maximum annual observed flows around 1970 in 23 (out of 28) basins in New England (U.S.) and attributes those changes to the influence of the North Atlantic Oscillation's variability. The author also finds statistically significant upward trends in 40% of the basins. Conversely, changes in the mean and variance of flood peaks in 27% (40%) of the stations analyzed in the Eastern (Midwestern) U.S., have been attributed to changes in land use-land cover and might not be linked to climatic forcings (Villarini and Smith, 2010; Villarini et al., 2011).

Precipitation projections for the 21st century consistently indicate a wetter winter by the end of the century (Anderson et al., 2010; Hayhoe et al., 2007; Rawlins et al., 2012; Thibeault and Seth, 2014). For spring and fall, model projections agree on small positive changes in the Northeast U.S., which are significant over much of the region in spring and within the level of natural variability in the fall (Rawlins et al., 2012). In the Great Lakes region, winter and spring precipitation is projected to rise by as much as 20–30% before the end of the 21st century. Summer rainfall will experience no or little increase, which along with warmer temperatures, is likely to increase evapotranspiration and result in a net decrease of soil moisture storage in the region. Furthermore, declining snow pack can also reduce snowmelt recharge to groundwater reserves, which provides the water supply to sustain base flows during the summer (Hayhoe et al., 2008).

Although there have been several studies that evaluated temporal changes in streamflow properties for different sub-regions in the Northeast (NE) and Midwest (MW), to date no comprehensive region-wide analysis of the temporal trends in the future streamflow characteristics has been done. In this study, three streamflow characteristics are defined: 3-day peak flows, 7-day low flows, and mean base flows. The first two are particularly relevant to decision makers since peak flows impact the egg hatching of aquatic species while minimum flows propitiate healthy ecosystems and greatly impacts the municipal water supply during the warm summer months. The purpose of this paper is to investigate the magnitude, direction, and significance of temporal changes in streamflow characteristics in the NE–MW during the 20th and 21st centuries using climate-driven hydrologic simulations. Changes in the magnitude of the peaks and low flows will be evaluated for a 100-year return period. An additional goal is to identify the climate models that best represent the climatology of the region.

2. Data sources, models, and methods

2.1. Basin selection and observational data

The NE–MW region can be subdivided into four distinct climatic regions according to Fan et al. (2014): Region A (dry-cold), Region B (wet-cold), Region C (dry-warm), and Region D (wet-warm). Fig. 1a shows the spatial extent of each region.