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Stream flow in Minnesota: Indicator of climate change

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Summary Stream flow records (up to the year 2002) from 36 USGS gauging stations in five major river basins of Minnesota were studied. Seven annual stream flow statistics were extracted and analyzed: mean annual flow, 7-day low flow in winter, 7-day low flow in summer, peak flow due to snow melt runoff, peak flow due to rainfall as well as high and extreme flow days (number of days with flow rates greater than the mean plus one or two standard deviations, respectively). The Mann–Kendal non-parametric test was used to detect significant trends over time windows from 90 to 10 years in combination with the Trend Free Pre-Whitening (TFPW) method for correcting time series data for serial correlation. Streamflows in the state of Minnesota have varied over the period of record. Trends differed significantly from one river basin to another, and became more accentuated for shorter time windows. Periodicity was detected in the trends for the *Red River of the North*, the *Mississippi Rive*r, and the *Minnesota River* basins for six of the statistics studied. Periods were on the order of 13–15 and 25 years, and the amplitudes were particularly strong after 1980.

Peak flow due to snowmelt, typically the highest flow in each year, appears to be the only streamflow statistic that has not changed at a significant rate. Peak flows due to rainfall events in the summer are increasing, as well as the number of days with higher flows (high flow days). Increases in low flow (base flow) in summer and in winter have been significant. Wetter summers and more frequent snow melt events due to warmer winters are the likely cause.

Stream flows in Minnesota reflect observed changes in precipitation with increases in mean annual precipitation, a larger number of intense rainfall events, more days with precipitation and earlier and more frequent snowmelt events. For water resources management the results suggest that the threat of snowmelt flooding has not increased, but floods due to rainfall events are more likely. Higher summer and winter base flows may benefit water quality.

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Introduction

From the late 19th or the beginning of the 20th century, up to the year 2000 the earth surface has experienced warming of about 0.6 ± 0.2 °C (IPCC, 2001a,b). These observed increases in temperature are predicted to continue into the foreseeable future. Rising global surface temperatures are likely to cause changes in atmospheric circulation, create a more active hydrological cycle, and increase the water holding capacity throughout the atmosphere (IPCC, 2001a,b). These changes are predicted to lead to increases in precipitation and atmospheric moisture. In fact, an increase in atmospheric moisture at a rate of about 5% per decade has been seen over the United States favoring stronger rainfall or snowfall events (Trenberth, 1998). Also, from 1910 to 1996 precipitation has increased by about 10%, reflected primarily in heavy and extreme daily precipitation events (Karl and Knight, 1998). Increases in the number of days with precipitation as well as increases in intensity have been seen for all categories of precipitation amounts and are significantly contributing to the observed increases in precipitation (Karl and Knight, 1998).

Precipitation is the main cause of variability in the water balance over space and time on the earth surface, and changes in precipitation have important implications for hydrology and water resources (IPCC, 2001a,b). Streamflow has been found to be sensitive to precipitation in the Midwest of the United States, including most of Southern Minnesota (Sankarasubramanian et al., 2001). Increases in warm and cold season floods were found in the Northern Midwest along with the incidence of heavy-precipitation events. Averaged over 5-year periods, precipitation changes of 8% were directly correlated with changes in the number of floods in the same areas (Changnon and Kunkel, 1995). Multi-decadal shifts to higher annual stream flows are present in the Midwest, Southwest, and Northeastern regions of the United States, consistent with the general dominance of precipitation during that time.

Studies in the state of Minnesota display similar results. In Minnesota, rising soil temperatures have been recorded at more than 10 m depth in the ground (Baker and Baker, 2002). Data also show warmer winters, higher minimum air temperatures and increases in the number of tropical dew point temperatures in recent years (Seeley, 2003). A previous study of hydrological data from Minnesota found trends in five water resources parameters that reflect climate warming over the past 25 and 40 years (Johnson and Stefan, 2006). Ice-out dates on lakes are happening earlier in the spring, stream water temperatures were found to be rising, and ice-in dates on lakes are occurring later in the year. The study also found that the first spring runoff and the first spring peak runoff in the state of Minnesota have occurred on average 0.3 days/year earlier during the period 1964–2000. A direct correlation was found with changes in air temperature for these parameters (Johnson and Stefan, 2006).

Greater annual precipitation has also been found throughout the state of Minnesota. This increase is accompanied by more days with rain and more frequent heavy rains (Seeley, 2003). Precipitation totals of 7-day duration exceeding a 1-year recurrence interval have increased in frequency throughout the state of Minnesota from 1931 to 1996 (Kunkel et al., 1999). Many studies of streamflow trends throughout the United States have been conducted (Lins and Slack, 1999; Douglas et al., 2000; Groisman et al., 2001; McCabe and Wolock, 2002; Baker et al., 2004; Garbrecht et al., 2004; Larson and Schwein, 2004). Douglas et al. found no evidence of trends in flood flows throughout the United States, but did find upward trends in low flows in the upper Midwest regions which include Minnesota. McCabe and Wolock found a step increase in steamflows predominantly in the eastern part of the United States during the 1970s. Baker et al. also found increasing flows predominately in the eastern part of the United States. Records from gauging stations throughout the United States for selected showed increasing trends in the low flow to medium flow categories were most prevalent, while the highest flows displayed the least amount of change throughout the country (Lins and Slack, 1999). Some of these studies have included gauging stations in Minnesota, but a comprehensive basin by basin study of the state of Minnesota has not been conducted. The objective of this study is to analyze historical stream flow records from gauging stations throughout Minnesota's river basins to identify any trends and to determine any correlation with changes in climate.

Station selection and data

Gauging stations throughout the state of Minnesota were selected from the United States Geological Survey (USGS) web site. Stations were selected based on the length and continuity of their records. All records ended with the year 2002 (Table 1). First, stations were identified that had a minimum of 100 years of continuous data, then stations with 70 years and finally stations with 50 years of record. If any gaps were found in the record or if the record ended before 2002 the station was excluded from the study. Streamflows regulated heavily by man made discharge control structures were discarded as well. Overall, 36 stream gauging stations were found in the state of Minnesota meeting the selection criteria. Seven stations had records over 90 years long, 11 stations had record lengths between 70 and 90 years and 18 stations had records from 50 to 70 years long. Using these records five basins could be studied: six stations were in the *Red River of the North* basin, five stations in the *Rainy River* basin, 11 stations in the *Mississippi River* basin, 12 stations in the *Minnesota River* basin, and two stations are on *tributaries to Lake Superior*. The 36 stations used are shown in Fig. 1 and listed in Table 1 along with the period of record and the drainage area.

Precipitation data was also obtained for the nine climate divisions in the state of Minnesota and for the border states of South Dakota, North Dakota and Wisconsin. The climate divisions are assumed to have homogeneous climate characteristics over multi-county clusters. All available National Weather Service climate data within the divisions were pooled and divisional averages were created from 10 to 20 locations by the Western Regional Climate Center (WRCC). The climate divisions contributing to the drainage basin of each gauging station are listed in Table 1 and displayed in Fig. 7.