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Long-term trends in climate and hydrology in an agricultural, headwater watershed of central Pennsylvania, USA☆,☆☆

Haiming Lu[a,*], Ray B. Bryant[b], Anthony R. Buda[b], Amy S. Collick[b], Gordon J. Folmar[b], Peter J.A. Kleinman[b]

[a] Nanjing Hydraulic Research Institute, State Key Laboratory of Hydrology-Water Resources and Hydraulic Engineering, 223 Guangzhou Road, Nanjing 210029, China

[b] USDA-ARS, Pasture Systems & Watershed Management Research Unit, Building 3702, Curtin Road, University Park, PA 16802, USA

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ABSTRACT

Study region: The WE-38 Experimental Watershed, which is a small (7.3 km^2) basin in the Ridge and Valley physiographic region of east-central Pennsylvania.

Study focus: We used non-parametric Mann-Kendall tests to examine long-term (1968 to 2012) hydroclimatic (precipitation, temperature, streamflow) trends in WE-38 in the context of recent climate change across northeastern US.

New hydrological insights for the region: Annual mean temperatures in WE-38 increased 0.38 °C per decade, leading to an expansion of the growing season (+2.8 days per decade) and a contraction of frost days (-3.6 days per decade). Consistent with increased temperatures, annual actual evapotranspiration rose significantly (+37.1 mm per decade) over the study period. Precipitation also trended upward, with October experiencing the most significant increases in monthly total rainfall (+8.2 mm per decade). While augmented October precipitation led to increased October streamflow (+5.0 mm per decade), the trend in WE-38 streamflow was downward, with the most significant declines in July (-1.2 mm per decade) and February (-7.5 mm per decade). Declines in summertime streamflow also increased the duration of hydrological droughts (maximum consecutive days with streamflow < 10th percentile) by 1.9 days per decade. While our findings suggest some challenges for producers and water resource managers, most notably with increased fall rainfall and runoff, some changes such as enhanced growing seasons can be viewed positively, at least in the near term.

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* Corresponding author. Nanjing Hydraulic Research Institute, State Key Laboratory of Hydrology–Water Resources and Hydraulic Engineering, 225 Guangzhou Road, Nanjing 210029, China. Tel.:+ +86 25 85828519; fax: +86 25 85828555

E-mail address: hmlu@nhri.cn (H. Lu).

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1. Introduction

Climate change has emerged as a key issue facing agriculture and water resources in the twenty-first century (Porter et al., 2014; Jiménez Cisneros et al., 2014). According to the most recent report by the Intergovernmental Panel on Climate Change (IPCC), the mean surface temperature of the earth system (land and ocean) increased 0.85 °C from 1880 to 2012 (IPCC, 2013), leading to a worldwide prolonging of warm weather periods and a contraction of cold spells. The intimate link between surface air temperature and atmospheric water vapor has also intensified earth's hydrologic cycle (Huntington, 2009), resulting in increased precipitation amounts and intensities, particularly in the Northern Hemisphere (IPCC, 2013). Because shifts in climate are highly variable, there is widespread concern and uncertainty about the specific effects of climate and hydrologic change on agriculture and water resources, particularly at regional and local scales (Walsh et al., 2014; Hatfield et al., 2014).

In the humid northeastern USA, climate change concerns revolve around increases in annual and seasonal temperatures, changes in seasons, and greater variability in weather patterns that adversely impact agriculture. For instance, annual mean temperatures in the northeast have been increasing 0.09 °C per decade since 1900, yielding a total temperature increase of 1.11 °C (Kunkel et al., 2013). Remarkably, minimum temperatures have been warming faster than maximum temperatures, especially during the winter season (Burakowski et al., 2008; Brown et al., 2010). In response to warming temperatures, growing seasons have expanded in length across the northeast region at rates of up to 50 days per decade (Brown et al., 2010), while cold spells and frost days have largely truncated. In addition, there has been a general increasing trend in actual evapotranspiration nationally (Szilagyi et al., 2001; Walter et al., 2004), as well as across the northeast (Yang et al., 2014a).

Past climate change in the northeastern US has also altered precipitation patterns and watershed hydrology, especially with regard to extreme events (Walsh et al., 2014). On an annual basis, total precipitation has risen significantly since 1900 at rates approaching 9 mm per decade. Most notably, extreme precipitation events (defined as the heaviest 1% of all daily events) have increased faster in the northeastern US than anywhere in the nation (Groisman et al., 2013). Paradoxically, the increase in extreme rainfall has not led to a corresponding increase in the magnitude of river flooding (Hirsch and Ryberg, 2012; Peterson et al., 2013) because the majority of increased rainfall has occurred in fall when streamflows are lowest (Small et al., 2006). In general, streamflow has increased across the eastern US (Sagarika et al., 2014; Yang et al., 2014b) in response to increased precipitation totals. However, the expansion of rain-free episodes (Groisman and Knight, 2008) in recent decades has also increased the risk of low flow periods during summer and fall.

To date, much of the research on past climate change impacts on agriculture and water resources has focused on regional and national scale assessments (Horton et al., 2014; Walsh et al., 2014). While these assessments are clearly important, they tend to average the effects of changing conditions over large spatiotemporal scales and ignore specific impacts at local scales that have relevance for agricultural and water resources managers. Numerous studies of historical changes in climate and hydrology have been conducted across the northeastern USA, with particular emphases on forested regions in New England (Huntington, 2003; Hodgkins et al., 2003; Campbell et al., 2011; Hamburg et al., 2013) and in New York (Burns et al., Insaf et al., 2013; Matonse and Frie, 2013). Notably absent are studies from the central Appalachian region of Pennsylvania (Douglas et al., 2013) where agricultural production is regionally important. Characterizing the effects of recent climate warming on representative, upland agricultural watersheds in the central Appalachians is critical for improved management of local agriculture and water resources, as well as for downstream aquatic ecosystems and ultimately, the Chesapeake Bay (Najjar et al., 2010; Zhang et al., 2013).

In this paper, we present a holistic, long-term (1968 to 2012) analysis of climate and hydrologic trends (annual, seasonal, and monthly) in the WE-38 watershed, an intensively monitored upland basin in the Appalachian Mountain region of east-central Pennsylvania. The WE-38 watershed is one of 23 benchmark experimental watersheds maintained by the US Department of Agriculture's Agricultural Research Service (ARS) and is part of several major long-term research efforts, including the Conservation Effects Assessment Project (CEAP; Bryant et al., 2011) and the Long-Term Agroecosystem Research (LTAR) Network (Walbridge and Shafer, 2011; Bryant et al., 2012). Long-term records of precipitation and streamflow in WE-38 stretch back to 1968, shortly after the watershed was formally established by USDA-ARS in 1966, with detailed temperature records in the watershed extending to 1978. The length (35 to 45 years) and quality (Bryant et al., 2011) of these records make WE-38 an ideal place to evaluate long-term climatic and hydrologic trends in the context of recent changes in regional and global climate.

2. Materials and methods

2.1. Study watershed

The WE-38 watershed is a 7.3 km^2 subcatchment of Mahantango Creek (420 km^2) located in the Ridge and Valley physiographic region of east-central Pennsylvania (Fig. 1). The climate of WE-38 is temperate and humid, with a mean annual temperature of 10.1 °C, annual precipitation averaging 1080 mm, and streamflow representing about 46% of total precipitation (Bryant et al., 2011). Land use and geology in WE-38 ranges from mature forest cover on sandstone ridges (350-510 m elevation) to mixed cropland and pasture in valleys (125-300 m elevation) underlain by shale and siltstone. Uplands (ridges, hillsides) feature residual soils derived from sandstones and shales that are well-drained and possess high infiltration capacities. In contrast, soils in lower landscape positions and valley bottoms are typically derived from colluvial