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Changes in monthly baseflow across the U.S. Midwest

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Abstract

Characterizing streamflow changes in the agricultural U.S. Midwest is critical for effective planning and management of water resources throughout the region. The objective of this study is to determine if and how baseflow has responded to land alteration and climate changes across the study area during the 50-year study period by exploring hydrologic variations based on long-term stream gage data. This study evaluates monthly contributions to annual baseflow along with possible trends over the 1966–2016 period for 458 U.S. Geological Survey streamflow gages within 12 different Midwestern states. It also examines the influence of climate and land use factors on the observed baseflow trends. Monthly contribution breakdowns demonstrate how the majority of baseflow is discharged into streams during the spring months (March, April, and May) and is overall more substantial throughout the spring (especially in April) and summer (June, July, and August). Baseflow has not remained constant over the study period, and the results of the trend detection from the Mann–Kendall test reveal that baseflows have increased and are the strongest from May to September. This analysis is confirmed by quantile regression, which suggests that for most of the year, the largest changes are detected in the central part of the distribution. Although increasing baseflow trends are widespread throughout the region, decreasing trends are few and limited to Kansas and Nebraska. Further analysis reveals that baseflow changes are being driven by both climate and land use change across the region. Increasing trends in baseflow are linked to increases in precipitation throughout the year and are most prominent during May and June. Changes in agricultural intensity (in terms of harvested corn and soybean acreage) are linked to increasing trends in the central and western Midwest, whereas increasing temperatures may lead to decreasing baseflow trends in spring and summer in northern Wisconsin, Kansas, and Nebraska.

1 | INTRODUCTION

The agricultural U.S. Midwest has been productive for crop production due to adequate-to-abundant moisture and management of water resources through stream straightening, constructed drainage, and when necessary irrigation. Developing a better understanding of the changes in both surface and subsurface hydrology and of how land use and climate change are interacting to affect it is critically important for the management of agricultural production, ecosystem health, and flood prevention. Knowledge of these forcing factors is essential for making baseflow estimates and documenting changes in response, which influence water availability and pollution control (Schilling & Wolter, 2001; Singh, 1968; Wayland et al., 2003). Baseflow is the portion of streamflow that is fed to channels by groundwater. It sustains streams between precipitation events, and it can be used to estimate the magnitude of groundwater recharge (Arnold, Muttiah, Srinivasan, & Allen, 2000; Gebert, Radloff, Considine, & Kennedy, 2007).

With an increasing tendency for extreme events, including low run-off during drought, catastrophic flooding events, and a changing climate, it is becoming increasingly important to study the baseflow component of streamflow, as it is often the major contributor to streamflow during droughts (Dai, Chu, Du, Stive, & Hong, 2010; Wittenberg, 2003). Trends in annual streamflow have been well documented in previous studies across the Midwest (Chien, Yeh, & Knouft, 2013; Frans, Istanbulluoglu, Mishra, Munoz-Arriola, & Lettenmaier, 2013; Mallakpour & Villarini, 2015; Ryberg, Lin, & Vecchia, 2014; Slater & Villarini, 2016; Xu, Scanlon, Schilling, & Sun, 2013), but trends in regional monthly baseflow have yet to be examined in detail.

Land use and land cover have substantially changed Midwestern landscapes and have influenced the water balance in many different watersheds. There has been a gradual shift from forest and prairie cover to agriculture and urban landscapes over the last 150 years (Donner, 2003; Knox, 2001; Meyer, 2005; Schilling & Helmers, 2008). The Midwest has historically been driven by diversified rotation of annual and perennial crops but has changed to one dominated mainly by an annual corn and soybean cropping system (Schilling, Jha, Zhang, Gassman, & Wolter, 2008). With this transition, there has been little documentation of the construction of surface and subsurface drainage networks, which makes it difficult to distinguish between the effects due to climate change and land use change on watersheds at different spatial scales and during different times of the year (Kelly, Takbiri, Belmont, & Foufoula-Georgiou, 2016).

Responses to changes in land use may increase or decrease baseflow depending on flow pathways and management practices, and studies investigating baseflow response have reported differing results in various geographical locations. Schilling and Libra (2003) found increases in annual stream discharge in Iowa that could not be explained by precipitation increases alone and hypothesized that improved land management and conservation practices, artificial drainage, increases in row crop production, and channel incision were likely responsible for baseflow trends. Ahiablame, Sheshukov, Rahmani, and Moriasi (2017) reported how changes in the Missouri River Basin's baseflows were a result of climate (increased precipitation) and land use change (conversion to agriculture). Increases in baseflow within the Upper Mississippi River Basin have been linked to conservation tillage (Kramer, Burkart, Meek, Jaquis, & James, 1999) and less annual evapotranspiration occurring in seasonal cultivation compared with native perennial ecosystems (Xu, Scanlon, et al., 2013). Conversely, previous studies in the Midwest and Great Plains have reported decreased baseflow in Nebraska and Kansas (Brikowski, 2008; Santhi, Allen, Muttiah, Arnold, & Tuppad, 2008; Wen & Chen, 2006), which was likely due to the combination of climate change, topography, land use, and irrigation demands.

Although these studies have helped characterize regional baseflow patterns, they do not address baseflow changes over large regions of the Midwest, and we still do not fully understand the mechanisms which influence baseflows (Price, 2011). The relative contribution of human versus climate factors has been the subject of debate (Belmont, Stevens, Czuba, Kumarasamy, & Kelly, 2016; Foufoula-Georgiou et al., 2016; Gupta, Kessler, Brown, & Schuh, 2016; Gupta, Kessler, Brown, & Zvomuya, 2015; Schilling, 2016; Schottler, Ulrich, & Engstrom, 2016). Although baseflow changes in response to human activities and climate change have been documented in various regions across the United States (e.g., Bosch, Arnold, Allen, Lim, & Park, 2017; Cooper, Wilkinson, & Arnell, 1995; Dai et al., 2010; Ficklin, Robeson, & Knouft, 2016; Hubbart & Zell, 2013; Price, 2011; Schilling et al., 2008), these studies are limited in terms of the number of sites considered, the regional representativeness of their findings, and factors that may be influencing trends. For example, Xu, Scanlon, et al. (2013) evaluated 55 watersheds from Iowa to Ohio but did not include important states in the northern or western areas. Ficklin et al. (2016) only examined the impact of climate change on baseflow trends at 674 sites across the entire United States. Similar studies can be a good indicator for categorizing factors affecting baseflow changes; however, they still do not address baseflow response to forcing factors throughout the Midwest. Evaluating whether or not baseflow changes have resulted from various drivers can help inform water resources policy and management, along with issues related to water quality and quantity.

Therefore, based on the above mentioned knowledge gaps, our research seeks to address if and how baseflow has changed across the Midwest. The main goals of this study are the following:

- Detect any presence of changes in monthly baseflow across the Midwest since the mid-20th century. To accomplish this, we use a data-driven approach and focus on long-term streamflow data from 458 U.S. Geological Survey (USGS) stream gages across the region. The substantial amount of sites over the large study area leads to a detailed and spatially extensive quantification of changes in baseflow.
- We start by examining the seasonality of baseflow in terms of monthly contribution as a percentage of annual total, which will allows us to assess what the most important months are and frame the trend results accordingly.
- Use statistical analyses to determine whether or not an increasing or decreasing trend is present at each gaging site during the 1966–2016 period. We complement the results from the Mann–Kendall test with those from quantile regression (Koenker, 2005), which allow for a more complete picture of baseflow changes across the entire probability distribution.
- Correlate baseflow with precipitation, temperature, and agricultural intensity (combined corn and soy bean acreage) over the same time period to provide insight into the physical drivers behind any observed changes in baseflow.

2 | DATA AND METHODOLOGY

2.1 | Data

For the purposes of this study, we defined the Midwest to include Illinois, Indiana, Iowa, Kansas, Michigan, Minnesota, Missouri, Nebraska, North Dakota, Ohio, South Dakota, and Wisconsin (Figure 1). We selected USGS stations with 50 years of data (1966–2016), which provided valuable information regarding changes in baseflow volumes for the study area. There were 458 gages which met these requirements, with 58 in Illinois, 62 in Indiana, 53 in Iowa, 52 in Kansas, 33 in

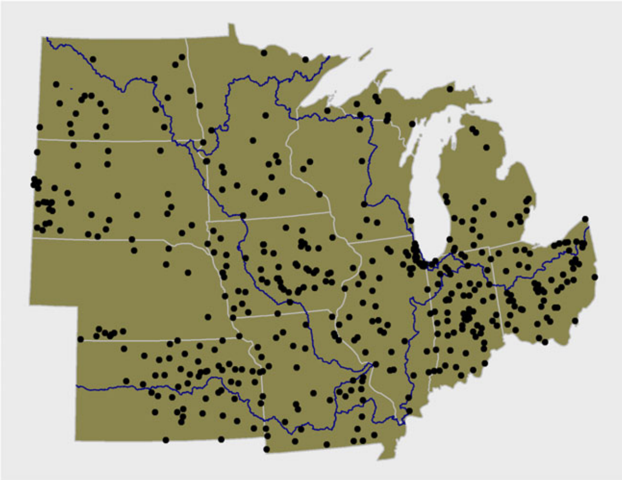

FIGURE 1 Map of the location of the 458 USGS gages used in this study with USGS Hydrologic Unit Code (HUC) 2 watershed boundaries. USGS: U.S. Geological Survey

Michigan, 22 in Minnesota, 38 in Missouri, 14 in Nebraska, 21 in North Dakota, 55 in Ohio, 40 in South Dakota, and 10 in Wisconsin. Within the defined study region, there are five different USGS Hydrologic Unit Code 2 watersheds, within a range of scales from 7.58 to 414,900 mi^2 and an average (median) catchment size of 589 mi^2.

To obtain monthly baseflow data, we used the Web-based Hydrograph Analysis Tool (Lim et al., 2005). This tool incorporates different digital filter methods for baseflow separation using the iSep system. Three separation modules, the local minimum method and two digital filter methods (one- or two-parameter digital filter), are available in the Web-based Hydrograph Analysis Tool. In our study, we selected the one parameter digital filter method, which uses a single baseflow filter parameter in the hydrograph separation method. This technique is the recommended method by Nathan and McMahon (1990) who evaluated different digital filter parameters and concluded that using a simple digital filter with a parameter of 0.925 was the fastest and most objective method for baseflow separation. To view a time series for monthly baseflow discharge at all 458 streamflow gages, please refer to Figure S1. We also reported monthly baseflow contribution as a percentage of the total annual baseflow discharged to streams for the 1966–2016 record period (Figure 2).

We obtained monthly precipitation and temperature data at approximately 4-km resolution from Oregon State University's Parameter elevation Regression on Independent Slopes Model Climate Group (Daly, Gibson, Taylor, Johnson, & Pasteris, 2002). Agricultural land use data were obtained from the U.S. Department of Agriculture's National Agricultural Statistics Service QuickStats database; here, we focused on combined corn and soybean harvested acreage. For the purposes of this study, the county-level harvested acres were used to compute a weighted average for each watershed based on the percentage of each county contained within each watershed.

2.2 | Statistical analyses

We examined the presence of temporal trends in monthly baseflow using two different approaches. We used the Mann–Kendall

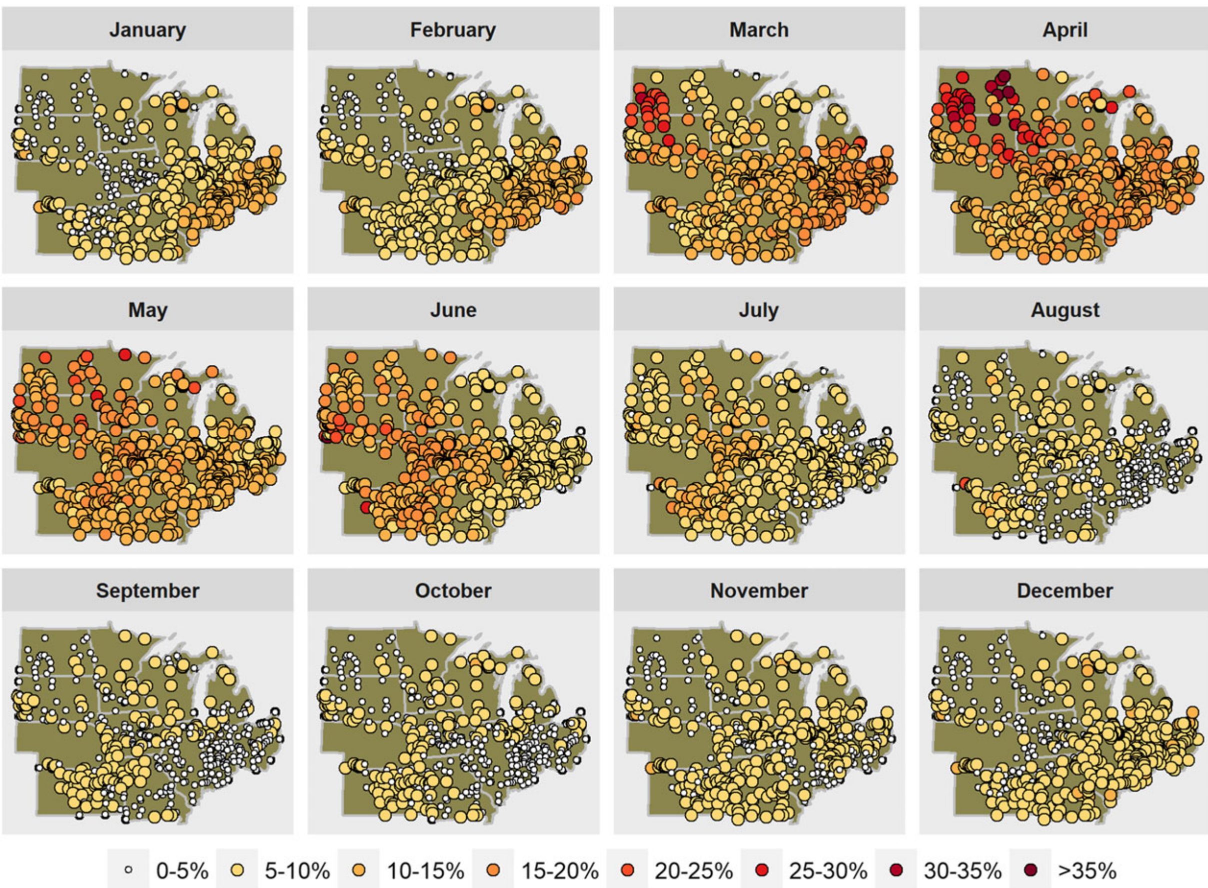

FIGURE 2 Monthly contribution as a percentage of the total annual baseflow discharge to streams

nonparametric trend test (Kendall, 1948; Mann, 1945) to determine the presence of monotonic patterns in the central part of the distribution, as this is one of the most widely used tests in studies of this kind (e.g., Dai et al., 2010; Ficklin et al., 2016; St. Jacques & Sauchyn, 2009). To account for the potential impacts of autocorrelation on the results, we use a variation of the Mann–Kendall test that allows the prewhitening of the time series based on the approach described by Yue, Pilon, Phinney, and Cavadias (2002).

While the Mann–Kendall test allows the detection of monotonic patterns in the central part of the distribution, it does not allow for an analysis of potential changes in other parts of the distribution, in particular at the extremes (Kinsvater & Fried, 2017). Therefore, we complemented the Mann–Kendall test with quantile regression, which gives the estimation of the functional relationships between variables across the probability distribution. Quantile regression models the relationship between a set of predictors (time in our case) and specific quantiles of the response variable (baseflow in our study; Koenker & Bassett, 1978). This form of regression allowed us to explore the potential effects of a factor on different quantiles of a response variable. Quantile regression framework estimates multiple rates of change from the minimum to the maximum response, providing a more comprehensive understanding of the relationship between variables that is sometimes missed by focusing only on the central tendency (Koenker, 2005). By focusing on changes in the mean, other methods may underestimate, overestimate, or fail to determine nonzero changes in the distribution; therefore, we used quantile regression as a way to further investigate the presence of statistically significant trends (Koenker, 2005). We focused on quantiles for 0.05 to 0.95 with a step of 0.05 and computed the significance of the slope with bootstrapping. For a more thorough explanation of quantile regression, see Koenker (2005).

To provide insight into the potential drives of any observed changes in baseflow, we applied the Mann–Kendall test to obtain correlation coefficients of monthly baseflow with monthly precipitation, monthly temperature, and annual combined corn and soybean acreage. All the calculations were performed in R using the Kendall (McLeod, 2011), modifiedmk (Patakamuri & O'Brien, 2018) and the quantreg (Koenker, 2017) packages. In all the analyses, we set a significance level of 5%.

3 | RESULTS

3.1 | Climatology

Baseflow discharge to streams varies during the year in response to seasonal changes in weather, climate, and land use. To describe its seasonality, we quantify historical discharge volumes for each month as a percent contribution to the total annual flow at each USGS gaging station (Figure 2).

The monthly baseflow regime in the Midwest varies with regional climate differences where spring (March–May) and summer (June–August) months experience larger relative contributions to streams. Higher baseflow volumes are observed beginning in March and continue to increase into the spring. April baseflow volumes contributed in the northwestern part of the study region (North and South Dakota, and Minnesota) are markedly high, reaching up to 46% of the annual total, whereas the rest of the Midwest experience relatively lower flows in April; however, they still represent a sizable contribution when compared with the rest of the year. Further east in the Ohio River Basin monthly contributions are 20–25% of the annual total for both March and April but are less in the central Midwest (around 15–20%), causing monthly baseflow volumes to be more evenly distributed throughout the year. Although flow volumes are higher in the spring, baseflow comprises a higher relative amount throughout the summer as compared with the fall and winter.

From August to November, baseflow discharges are generally low, with contributions to the annual total at less than 10% for each month throughout the region. Slightly higher annual contributions (5–10%) are located in the central part of the study area (Iowa, Kansas, and Missouri). During the fall, baseflow contributions are the lowest in the eastern and northwestern parts of the Midwest. Moving into winter, larger relative monthly baseflow percentages are observed in the east and southcentral regions as compared with in the west.

3.2 | Trends in baseflow

Across the U.S. Midwest, streamflow records from 458 gages were analysed to identify statistically significant baseflow trends (significant at the $\alpha \leq 0.05$ level) during 1966–2016 on a monthly time scale. The Mann–Kendall test allowed us to test for the presence of monotonic patterns in the historical baseflow observations, whereas quantile regression provided a comprehensive characterization of the changes throughout the entire baseflow distribution. The results in Figure 3 provide a summary comparison between the two approaches whereas Figure 4 illustrates the spatial variability of the changes as detected with the modified Mann–Kendall test. Consult Figure S2 for the spatial representation of the trends based on quantile regression compared with Mann–Kendall for each month and Figure S1 for the time series of baseflow at each USGS site.

Statistically significant increasing trends are more numerous than decreasing trends (Figures 3, 4), regardless of the month or methodology. We note how the Mann–Kendall test consistently detected more significant trends than quantile regression analyses even at $\tau = 0.50$. Quantile regression results indicate that for the majority of the year, the median baseflow has increased as opposed to the extremes, which is shown by the stronger detection of significant increasing trends in the central part of the distribution (Figure 3). However, there are some months where extreme quantiles are at elevated levels, for example, at $\tau = 0.95$ from February to May and also for larger quantiles in June. In addition, from August to October, lower quantiles (below $\tau = 0.50$) experience more detection of increasing trends in comparison to other months.

Figure 4 shows how the substantial differences between increasing and decreasing trends vary throughout the year and across the Midwest. Statistically significant decreasing trends occur

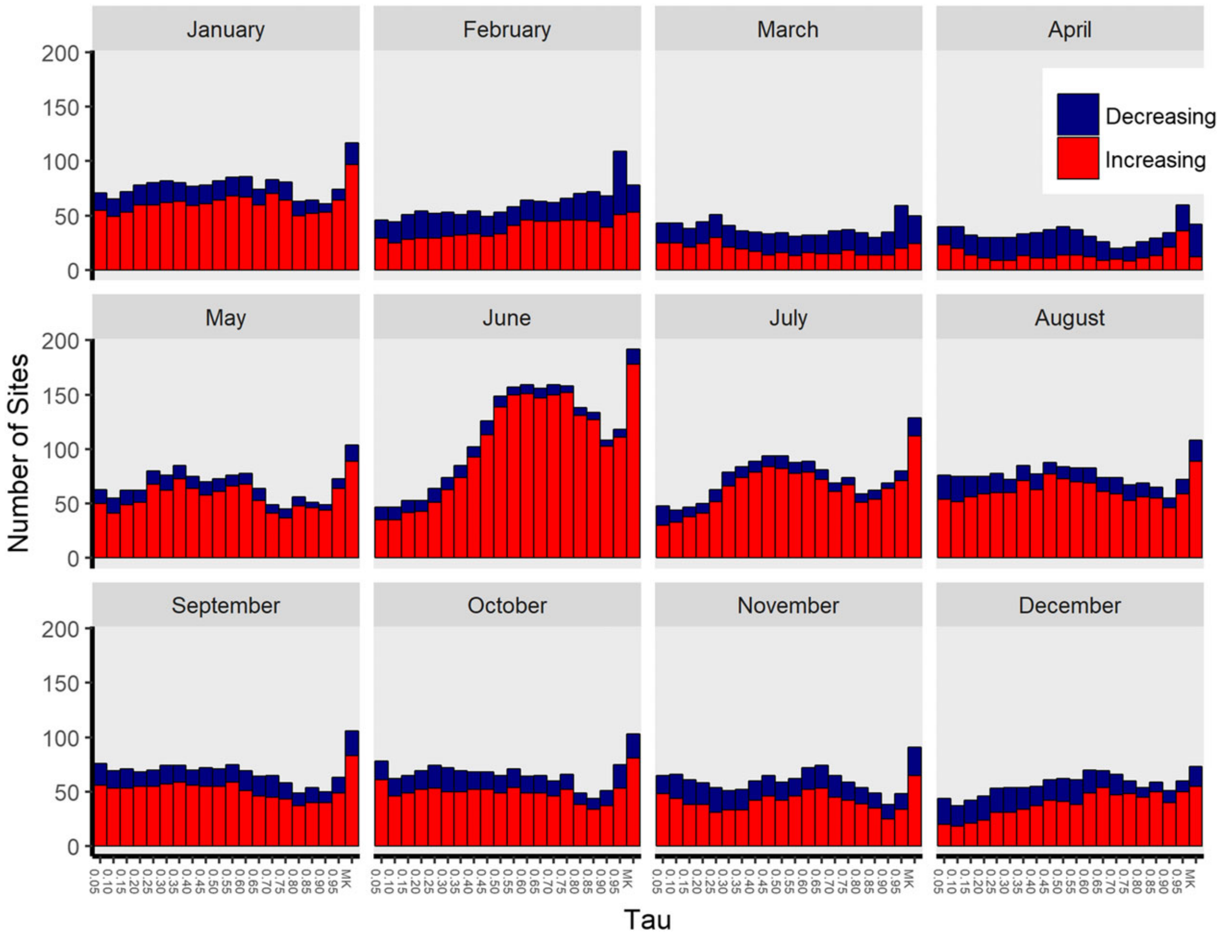

FIGURE 3 Quantile regression (for values of the tau quantiles between 0.05 and 0.95, with a step of 0.05) and Mann–Kendall frequencies for each month with a level of significance at 5%. In each panel, the Mann–Kendall results are represented by the bar to the right ("MK")

at ~3–7% of sites, without a strong dependence on the detection test. Whereas decreasing trends exhibit no seasonal dependence, increasing trends present stronger variability throughout the year. From May to August, increasing trends are more present than during any other time of the year where the Mann–Kendall test indicates that June and July show the highest percentage (39% and 24%, respectively) of sites with a detected increasing trend. Significant increasing trends are also common from September to February; on the contrary, during the spring (March and April), there are fewer detected increasing trends based on the Mann–Kendall test (5% and 3%, respectively).

Across the region, decreasing trends are limited to southern Nebraska and Kansas and in northern Wisconsin and Michigan (Figure 4). Significant increasing trends are detected in North Dakota, South Dakota, Minnesota, Iowa, central Missouri, Southern Wisconsin, Illinois, Indiana, Ohio, and southern Michigan. In the summer, increasing trends are concentrated in the central part of the study region in southern Wisconsin, Iowa, western Minnesota, eastern North, and South Dakota. During the fall and winter, increases are located throughout the Missouri River Basin and scattered throughout the Ohio River Basin, dissimilar to what is detected in the summer. In the spring (March and April), increases are scarcely found in the Dakotas and western Minnesota.

3.3 | Statistical analyses of baseflow and forcing factors

We examine the correlation between baseflow and precipitation, temperature, and combined corn and soybean acreage over the historical record (1966–2016) using the Mann–Kendall test (Figures 5–7) to provide insight on the potential drivers of observed changes in baseflow response.

Figure 5 presents the correlation coefficients of concurrent monthly baseflow and monthly precipitation based on the Mann–Kendall test. Baseflow is positively correlated to precipitation throughout the year over a large portion of the region. There is a stronger relationship between baseflow and precipitation throughout the spring (March–May) and summer (June–August) as compared with the fall (September–November) and winter (December–February), where the relationship reflects the storm track over the area (Nayak & Villarini, 2017). From April to June, sites showing a statistically significant positive correlation are present in large quantities (72–88%), with values of Kendall's tau coefficient averaging between 0.33 and 0.43. Further, the strongest correlations with baseflows are observed during May and June where tau values are 0.42–0.43. Sites with significant baseflow–precipitation correlation drop to 57% by August and remain relatively lower but is still substantial throughout the fall and winter

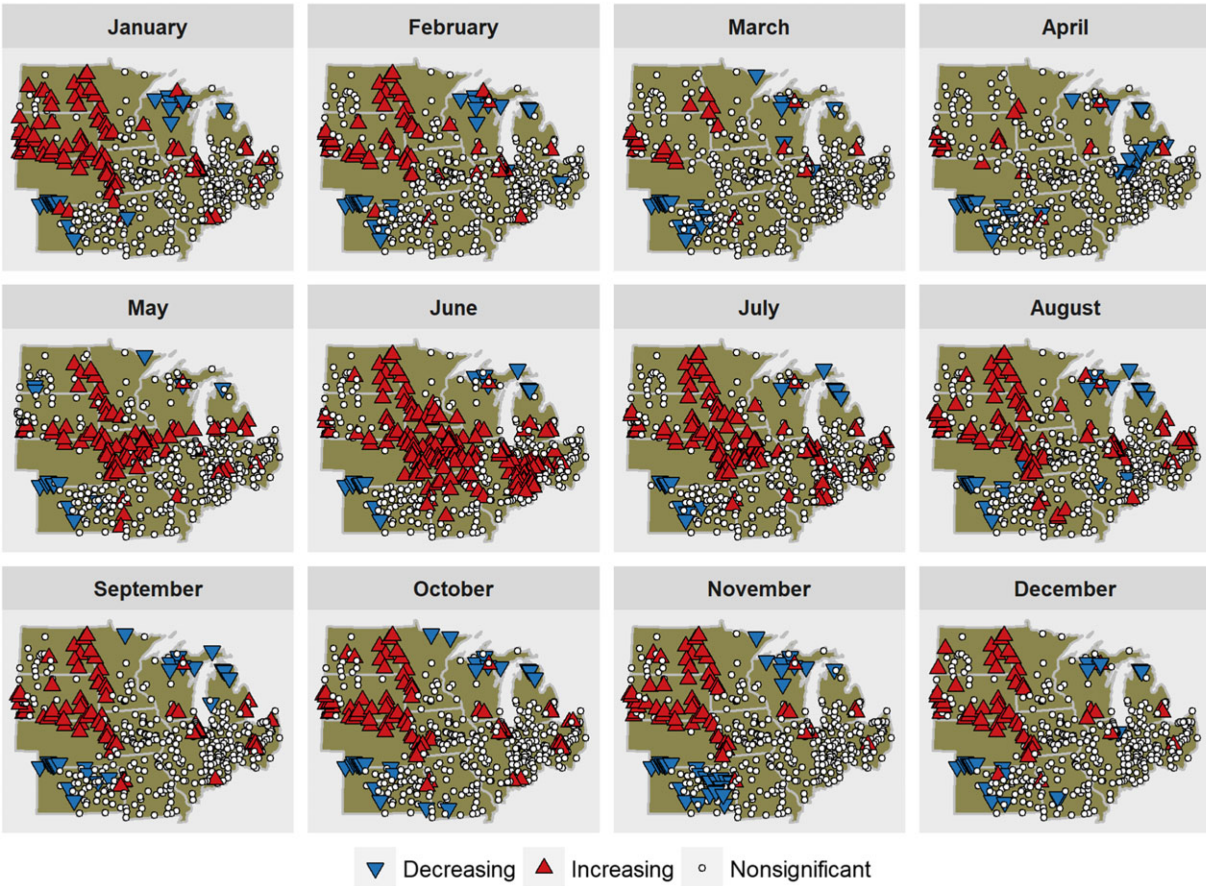

FIGURE 4 Results of the Mann–Kendall test applied to trend free prewhitened time series data in the presence of serial correlation using the approach described by Yue et al. (2002). We examine historical trends from 1966 to 2016 using stream gages throughout the Midwest with a significance level of 5%. A red upward (blue downward) arrow indicates an increasing (decreasing) trend, whereas a white circle represent a site with no statically significant trends

(46–72%). Although the percentage of sites with positive correlation are somewhat comparable, the strength of this relationship is lower in comparison to the spring and summer. Significant positive tau values for baseflow and precipitation for the fall (September–November) and winter (December–February) average at 0.25 and 0.21, respectively.

In the winter (December–February), positive correlations are concentrated in the Ohio River Basin and become more numerous during the spring when sites in Iowa, southern Minnesota, Wisconsin, and South Dakota begin to respond to precipitation. By May, significant correlation is detected across the entire study area, with a picture that does not change during June and July. From August into the fall (September and October), the correlation between baseflow and precipitation tends to decrease, consistent with the seasonality of precipitation over the U.S. Midwest. By November and into February, positive relationships remain only within the central and eastern parts of the study region.

After precipitation, we focus our attention on the relationship between baseflow and temperature (Figure 6). Statistically significant positive correlation between the two variables is detected during the winter (December–February) and further into March. The generally colder months of January and February have the most sites (33–34%) showing a positive correlation with baseflow. The values of the Kendall's tau coefficient average at 0.26 in January and 0.25 in February for all significant positive values and are concentrated within some of the coldest areas of the region, that is, Minnesota, North and South Dakota, Iowa, and northern Nebraska as well as further east in Indiana and Ohio. Correlations during March are located in the north throughout Minnesota, Wisconsin, and northern Michigan.

Negative relationships of monthly baseflow with monthly temperature are present during the spring (beginning in April) and summer. In April, significant negative correlation coefficients are observed at 31% of sites, and they are located in the south central region and scattered throughout the Dakotas. There is a shift in the areas showing significant correlation with temperature in May with focus areas located west in the Dakotas and east of the Mississippi River; however, continuing into June, negative correlations are concentrated in the south central portion of the region. Within this area, detections are present throughout the end of the summer (August). In July, sites with a negative correlation are numerous (44% of sites) with an average value of −0.26 and are located throughout the entire region. In the summer crop water use and evapotranspiration are at or near their maximum, which correlates with these observed negative correlation coefficients. By September and into November, there is hardly any detection of either significant positive or negative correlation between the two variables.

Figure 7 illustrates the relationship between monthly baseflow and combined annual harvested corn and soybean acreages for sites with significant positive and negative Kendall's tau. Throughout the

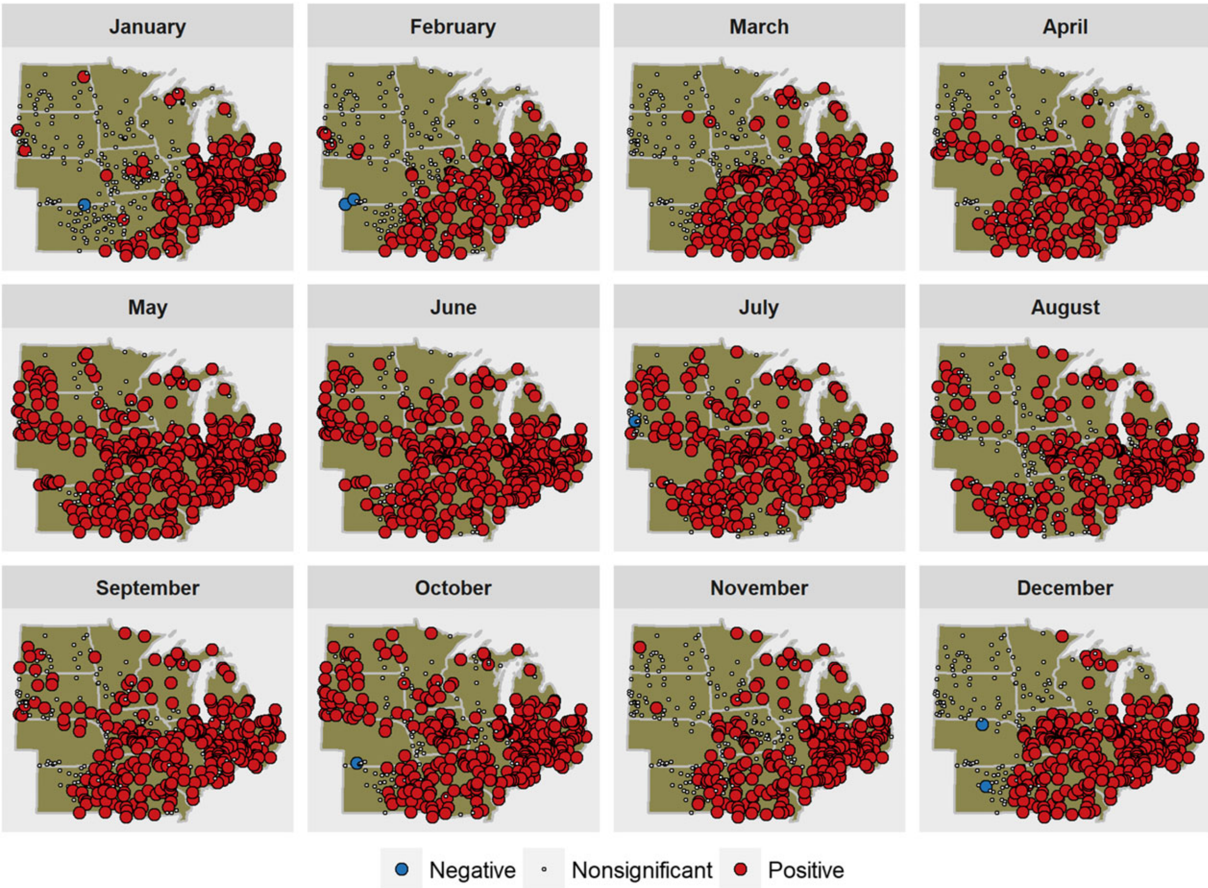

FIGURE 5 Monthly baseflow–monthly precipitation statistically significant correlation coefficients generated by Mann–Kendall's tau where a red circle indicates a positive correlation and a blue one indicates a negative correlation

year, significant positive Kendall's tau values average between 0.25 and 0.32 over all sites. Positive values are more frequently observed in the summer (June–August) during the growing season in comparison to the fall and winter. June detects the largest number of sites with significant positive correlations (23% of total sites), and they are mainly located in the corn–soybean growing area from the northeastern Dakotas across Iowa into Indiana. From September to March, however, only 10–12% of sites exhibit significant positive correlation with baseflow. During this time period, they are located in Minnesota and in the eastern Dakotas.

Significant negative correlation values between baseflow and agricultural intensity occur less frequently throughout the year when compared with positive ones. They do not vary greatly by month, and significant values only occur between 4% and 7% of sites across the entire region and year. Those that are detected are present in Nebraska, Kansas, and western North and South Dakota where irrigation of corn and soybean is common.

4 | DISCUSSION

Statistically significant increasing baseflow trends over the 1966–2016 period were widespread throughout the majority of the year. Increases were the strongest during the late spring and summer (May–August), which is important because of the large contribution baseflow makes to streams during the spring and summer. These results are consistent with other studies in the literature; for example, Ficklin et al. (2016) estimated the spatial variation in seasonal baseflow trends across the United States, identifying statistically significant increases in the central/upper Great Plains (albeit for a much more limited number of sites) for spring and summer seasons, although they found decreasing trends in the Upper Missouri River Basin where we found increasing ones. Statistically significant increasing baseflow trends found in our study were present throughout the fall and winter, which may indicate a tendency towards higher low flow volumes.

Decreasing baseflow trends were more limited in comparison to the increasing ones and were pronounced in Nebraska, Kansas, and in the northern Great Lakes Region of Wisconsin and Michigan. Our results suggest that temperature is an important predictor affecting baseflow in the upper Great Lakes region, whereas the results based on precipitation and agricultural intensity do not show a statistically significant correlation. Baseflow signals in northern Wisconsin are compared with results from Gebert et al. (2007) who found no significant trends where the primary land use was forest cover, as compared with other areas of Wisconsin where agriculture was the main driver of statistically significant trends. Decreasing trends in baseflow within Nebraska and Kansas also coincide with negative correlation in temperature during the summer, suggesting that increasing temperatures, especially through evapotranspiration, are contributing to decreased baseflows. Decreasing baseflows in the Great Plains are likely due to

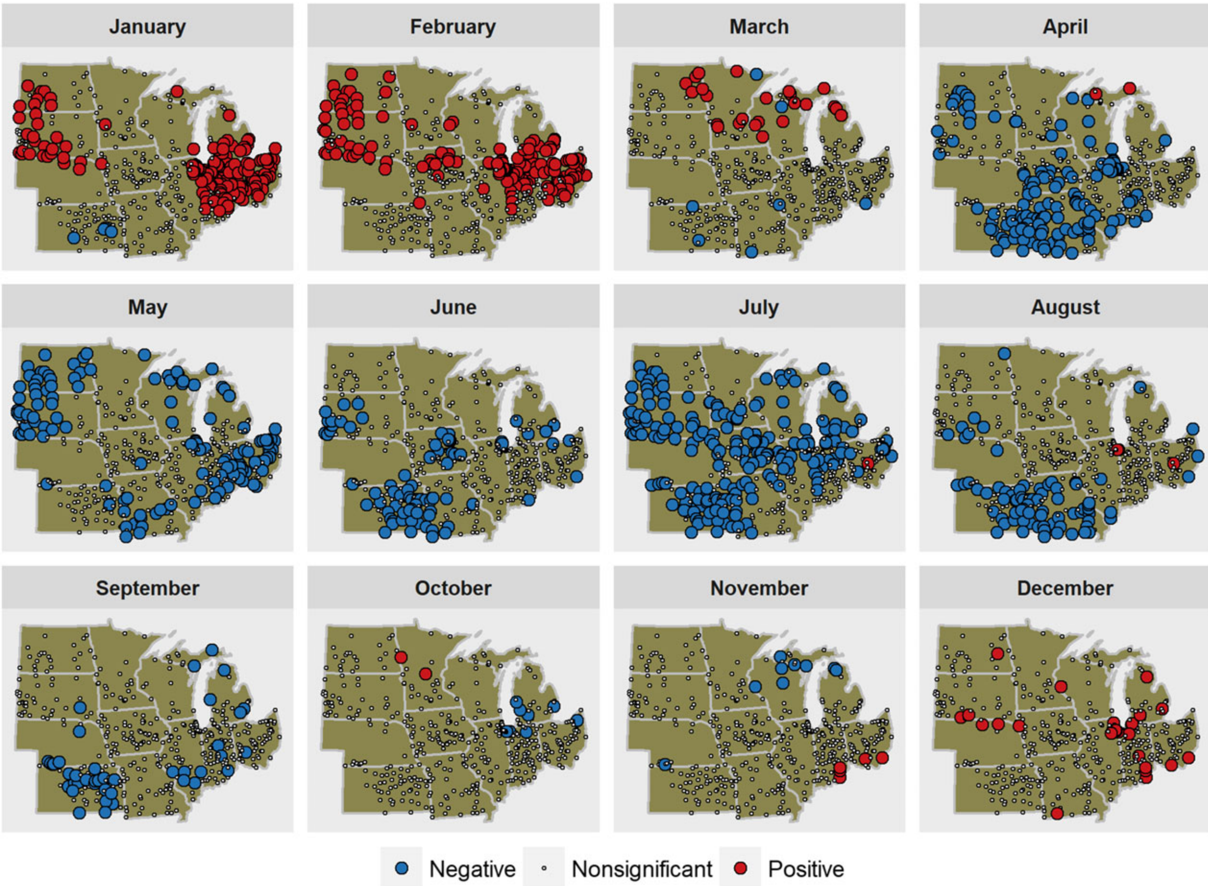

FIGURE 6 Monthly baseflow–monthly temperature statistically significant correlation coefficients generated by Mann–Kendall's tau where a red circle indicates a positive correlation and a blue one indicates a negative correlation

groundwater withdrawal, consistent with other studies (Sophocleous, 2005; Wang, Istanbulluoglu, Lenters, & Scott, 2009; Wen & Chen, 2006; Young et al., 2017). For example, in western Kansas, Brikowski (2008) showed decreases in baseflow due to changes in land use and groundwater withdrawal for irrigation.

Our findings suggest that baseflow trends may be attributed to a few different factors and are likely a result of both climate and land use. Statistical analyses show positive correlation between baseflow and precipitation over the Midwest (Figure 5). These relationships are pronounced during the spring and summer in the central and western regions in the Upper Mississippi River Basin, Missouri River Basin, and the Red River Basin. As expected, increases in precipitation inputs lead to more baseflow being routed to streams and are more pronounced in the spring when there is a larger baseflow contribution. Ahiablame et al. (2017) also found a strong link between increased baseflow and precipitation in North Dakota, South Dakota, and eastern parts of Iowa and Missouri. Changes in the climate system and anomalous weather conditions could be increasing winter precipitation and temperatures along with increased snowmelt infiltrations, which could be why we observe prominent correlation between variables in the fall and winter (St. Jacques & Sauchyn, 2009; Walvoord & Striegl, 2007; Zhang & Villarini, 2017).

Over the last half century, there has been a shift from a diversified cropping system to one dominated by corn and soybean production, along with associated drainage practices throughout the area (Donner, 2003; Kelly et al., 2016; Schilling et al., 2008). The results found in this study (Figure 7) give indication that corn and soybean production has played a major role in changing the hydrology within the Midwest. Whereas correlations between baseflow and precipitation or temperature vary from southeast to northwest and change throughout the year, correlations between baseflow and corn–soybean area are strongest where these agricultural systems have expanded over the 50-year study period. Statistical analyses showed significant baseflow increases in southern Minnesota, Iowa, northern Missouri, southern Wisconsin, Illinois, Indiana, Ohio, and southern Michigan. Results reported for corn and soybean acreage showed positive correlation in complimentary areas, demonstrating that baseflow response has likely increased as a result of land use practices. These findings are consistent with Schottler et al. (2014) who found increased Minnesota streamflows associated with a transition from small grains and sod crops to soybeans and Schilling (2005) who concluded that increasing baseflow in Iowa was significantly related to increasing row crop intensity, which has also contributed to increasing nitrate concentrations in Iowa's rivers and streams. Increases in baseflow within the Upper Mississippi River Basin have previously been linked to less annual evapotranspiration occurring in seasonal cultivation compared with native perennial ecosystems (Zhang & Schilling, 2006). Kelly et al. (2016) documented changes in streamflow across the Midwest, arguing that agricultural land use change, including wetland removal

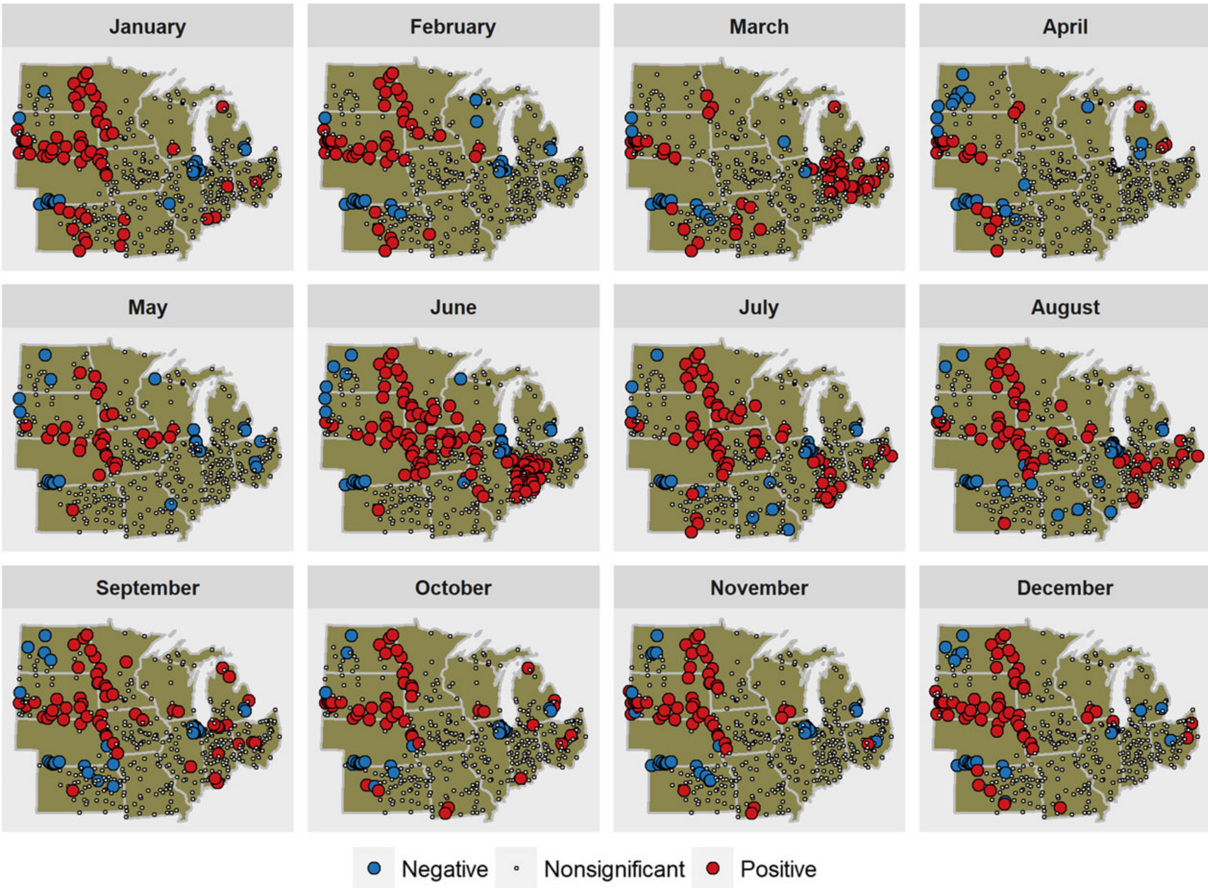

FIGURE 7 Monthly baseflow–annual combined corn/soybean statistically significant correlation coefficients generated by Mann–Kendall's tau where a red circle indicates a positive correlation and a blue one indicates a negative correlation

and artificial drainage has decreased watershed storage and increased streamflow response to climatological factors.

One element to keep in mind while interpreting the results of our correlation analyses is that we considered one potential predictor at a time, rather than performing a more extensive model selection. Although our results make physical sense overall, it is likely that there would be differences if we were trying to identify the "best" model by selecting the final set of predictors among multiple variables.

5 | CONCLUSIONS

Long-term baseflow records for 458 streamflow gages across the U.S. Midwest were analysed to detect trends over the 1966–2016 period at the monthly time scale. The main findings of this study can be summarized as follows:

- Results revealed that baseflow contributions vary throughout the year, with the largest contributions during the spring.
- Statistical analyses indicated significant baseflow increases throughout the majority of the region in southern Minnesota, Iowa, northern Missouri, southern Wisconsin, Illinois, Indiana, Ohio, and southern Michigan. These trends were present in warmer months of the year (May–August) but were also found during in the fall and winter. From September to February, increasing baseflow signals were located in the northwestern part of the study region within North and South Dakota, western Minnesota, and Iowa.
- The results of the trend analyses showed that substantial changes have occurred in the distribution of discharge, with increasing volumes of water being transported as baseflow. Quantile regression showed that these changes over time were more significant for the central part of the baseflow distribution. We also observed slightly more detection of increasing trends in the extremes for higher quantiles ($\tau = 0.95$) from February to March, and conversely in the lower quantiles during the fall.
- Decreasing trends in baseflow were few in comparison to increasing trends. They were detected in Kansas and Nebraska, where irrigation is present, and in forested areas of northern Wisconsin. These signals also coincided with negative temperature correlations, suggesting that increasing temperature, especially in the summer, may be contributing to decreased baseflows in both areas of the Midwest.
- Baseflow was positively correlated with precipitation throughout the entire year but was present in larger quantities throughout the summer (May–August) and with stronger significant correlation coefficients. Positive correlation was found throughout the entire region for the summer and fall, but only in the central and eastern parts of the study region during the winter. Temperatures may also be contributing to increasing trends in baseflow where increasing temperatures could lead to more water being routed to streams.

- Agricultural intensity displayed significant positive correlation throughout the Corn Belt region of the study area in the western Dakotas, Minnesota, Iowa, Illinois, Indiana, and Ohio. These signals were more prominent during the summer growing season.

Although these trends may suggest that both climate and land use factors are influencing baseflow response across the region, there is still more work needed to investigate the interaction of both types of factors and their influence on baseflow response. Preliminary examination of the climatology and land use that has been discussed here can shape future studies on Midwestern baseflow. A more detailed analyses beyond the scope of this study would improve our understanding of water resources and predicted consequences of future land use on baseflow. Water managers in the study region should be aware of these trends, as increases in baseflow could have negative impacts on flooding risk. Conversely, decreasing baseflows may be vital in quantifying water resources for drought conditions and water consumption, especially for Midwestern agricultural systems.

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