EPA Public Access

Author manuscript

Ecohydrology. Author manuscript; available in PMC 2019 January 01.

About author manuscripts

Submit a manuscript

Published in final edited form as:

Ecohydrology. 2018 ; 11(1): 1909–. doi:10.1002/eco.1909.

Ecohydrological Index, Native Fish, and Climate Trends and Relationships in the Kansas River Basin

Sumathy Sinnathamby^{1,2}, Kyle R. Douglas-Mankin^{1,3}, Muluken E. Muche^{1,4}, Stacy L. Hutchinson¹, and Aavudai Anandhi^{1,5}

¹Biological and Agricultural Engineering, Kansas State University, 147 Seaton Hall, Manhattan, KS-66506

²Oak Ridge Institute for Science and Education (ORISE) Postdoctoral Research Participant at U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Watershed Exposure Branch, 960 College Station Rd., Athens, GA-30605

³U.S. Geological Survey, New Mexico Water Science Center, Albuquerque, NM-87113

⁴U.S. Environmental Protection Agency, Office of Research and Development, National Exposure Research Laboratory, Watershed Exposure Branch, 960 College Station Rd., Athens, GA-30605

⁵Biological and Agricultural Systems Engineering, Florida A&M University, 1601 S Martin Luther King Jr. Blvd., Tallahassee, FL-32307

Abstract

This study quantified climatological and hydrological trends and relationships to presence and distribution of two native aquatic species in the Kansas River Basin over the past half-century. Trend analyses were applied to indicators of hydrologic alteration (IHAs) at 34 streamgages over a 50-year period (1962–2012). Results showed a significant negative trend in annual streamflow for 10 of 12 western streamgages (up to -7.65 mm/50 yr) and smaller negative trends for most other streamgages. Significant negative trends in western Basin streamflow were more widespread in summer (12 stations) than winter or spring (6 stations). The negative-trend magnitude and significance decreased from west to east for maximum-flow IHAs. Minimum-flow IHAs, however, significantly decreased at High Plains streamgages but significantly increased at Central Great Plains streamgages. Number of zero-flow days showed positive trends in the High Plains. Most streamgages showed negative trends in low- and high-flow pulse frequency and high-flow pulse duration, and positive trends in low-flow pulse duration. These results were consistent with increasing occurrence of drought. Shift in occurrence from present (1860–1950) to absent (2000–2012) was significantly related ($p < 0.10$) to negative trends of 1-day maximum flows (both species) and indices associated with reduced spawning-season flows for Plains Minnow and shifting annual-flow timing and increased flow intermittency for Common Shiner. Both species were absent for all western Basin sites and had different responses to hydrological index trends at eastern Basin sites. These results demonstrate ecohydrological index changes impact distributions of native fish and suggest target factors for assessment or restoration activities.

Keywords

Hydrologic indices; Trend analysis; Ecohydrology; Hydrologic change impacts; Plains Minnow; Common Shiner

1. Introduction

Streamflow trend analysis provides important insights and understanding of historical responses to changes in climate, land cover, and landscape management. Numerous analyses of streamflow trends have been presented at state (Aguilar, 2009; Kibria et al., 2016), regional (Stewart et al., 2005; Clow, 2010; Ryberg et al., 2015), and national (Lins and Slack, 2005; Dudley et al., 2017) scales. This study presents an extensive regional trend analysis of streamflow characteristics for the Kansas River Basin (KRB) with the purpose of providing insights and understanding to observed shifts in distribution of two native fish species.

Natural flows in streams and rivers have been impacted by both climate (Gleick and Chalecki, 1999; Groisman et al., 2001; Hodgkins et al., 2003; Hodgkins et al., 2005; Novotny and Stefan, 2007) and human activities (Poff et al., 2006; Poff and Zimmerman, 2010; Khedkar et al., 2014; Taylor et al., 2014). Climate and landscape change have led to temporal and spatial variations in hydrological regimes across North America (Poff, 2002; Bower et al., 2004; Knight et al., 2012; Lynch et al., 2016) as well as regionally, including the KRB (Brunsell et al., 2010; Lin and Brunsell, 2013).

These alterations in natural flow regimes have had a profound influence on aquatic organisms and habitat (Jowett and Duncan, 1990; Poff and Allan, 1995; Gasith and Resh, 1999; Lytle and Poff, 2004). Climate-induced hydrological changes to North American inland fish species include shifts in spatial distribution, abundance and phenology (e.g., migrations, spawning), and exhibit altered population dynamics (changes to abundance, growth, and recruitment) and genetic changes (or hybridization) (Lynch et al., 2016). Flow regulation by various forms of river impoundment has been linked to reduced abundance of fish larvae (Scheidegger and Bain, 1995), suppressed growth rates (Weisberg and Burton, 1993), altered community structure (Bain et al., 1988; Gido et al., 2013), reduced species diversity (Gehrke et al., 1995; Small et al., 2009; Alexandre et al., 2013), and introduction of invasive species (Brown and Bauer, 2009; Perkin and Bonner, 2011; Alexandre et al., 2013).

Studies of hydrological variability using hydrological indices are ubiquitous. Water resource indicators (WRIs), such as monthly, seasonal, and annual flows and center of timing of annual flows, have been used in many studies as indicators of hydrological impacts of climate change (Dibike and Coulibaly, 2005; Merritt et al., 2006; Toth et al., 2006; Shrestha et al., 2013). In addition, the indicators of hydrologic alteration (IHAs) (Richter et al., 1996; The Nature Conservancy, 2009), an expanded version of the WRIs, are considered to reflect the most influential hydrological factors in ecological studies (Risbey and Entekhabi, 1996; Poff et al., 1997; The Nature Conservancy, 2009). These indicators provide detailed representations of the hydrological regime and characterize intra-annual variability in water conditions (The Nature Conservancy, 2009).

Numerous studies globally have used IHAs to characterize the flow-related changes (pre- and post-regulation scenarios) in regulated rivers (Tharme, 2003; Shieh et al., 2007; Small et al., 2009; Wang et al., 2016). In a few cases, data were available and sufficient to relate those changes to measured responses in habitats (Rypel et al., 2009; Mortenson and Weisberg, 2010; Martinez-Capel, 2013) and aquatic species (Quinn and Kwak, 2003; Rypel et al., 2009; Perkin and Bonner, 2011; Gido et al., 2013; Alexandre et al., 2013; Arthington et al., 2014). These relationships have varied widely by region, reflecting local ecohydrological factors (Gido et al., 2013). More research is critical to quantify regional relationships between IHAs and aquatic species responses.

The objectives of this study were to quantify magnitude and significance of temporal trends in climatic and ecohydrological variables (WRIs and IHAs) using long-term climate and non-impounded watershed streamflow data in the KRB; determine the degree of spatial and temporal relationships between climatic variables, ecohydrological indicators, and ecoregional structure of the KRB; and evaluate the extent to which trends in ecohydrological indicators can differentiate between current presence or absence of native aquatic faunal species at sites where they were present historically. A central hypothesis of this study was that alterations in streamflow and associated aquatic habitat suitability have occurred historically within the KRB and can be used to explain the observed shift in presence of native aquatic fauna.

2. Methods and materials

2.1 Study area

The Kansas River Basin (KRB) is located within northern Kansas, southern Nebraska, and eastern Colorado (Figure 1). The Kansas River is vitally important to the social, economic, and ecological character of these regions. It is formed by the union of the Republican River and the Smoky Hill River, and its outflow forms a confluence with the Missouri River. The KRB covers an area of 155,000 km² (60,000 mi²) and includes some of the largest tracts of native prairie left in the United States. It spans six U.S. Environmental Protection Agency (EPA) level- III ecoregions: High Plains, Central Great Plains, Flint Hills, Western Corn Belt Plains, Central Irregular Plains, and Nebraska Sand Hills (Figure 1). These ecoregions contain productive grasslands and croplands. Flint Hills contains some of the largest native prairie left in the U.S. These conditions make the KRB an important region for agriculture and conservation.

The KRB has a prevailing east-to-west precipitation gradient and spatial variability in biophysical factors (e.g., soil quality, water availability, land use), which provides a range of conditions for hydroecological study (Sinnathamby, 2014). Agriculture and prairie are dominant land covers of the KRB. Croplands are distributed primarily in the central to west, grasslands range from tallgrass prairie in the east to shortgrass prairie in the west, and woodlands progress from hardwood forest in the east to riparian vegetation in the central KRB. Future shifts in land cover are expected with increasing biofuel demands in the Midwest Corn Belt region. KRB has an average rainfall of about 1000 mm/yr in the east and 400 mm/yr in the west (Lin and Brunzell, 2013). The basin has a wide gradient of soil permeability, with lowest levels in the eastern one- third and moderate to high levels in the

western two-thirds. The highest permeability is observed in the northwestern KRB. The flood potential is higher in areas with low soil permeability area than in areas with higher soil permeability. The higher soil permeability areas tend to allow more infiltration and lower runoff, which may allow greater baseflow contribution to the stream (Perry et al., 2004).

The High Plains Aquifer, one of the largest aquifers in the U.S., is beneath nearly half of the KRB. The groundwater condition in High Plains Aquifer is generally defined as unconfined. Its saturated thickness ranges from 15.2 m to about 350.5 m (McGuire et al., 2012). The High Plains Aquifer underlays much of the nation's primary agriculture regions. In parts of Texas, Oklahoma and southwestern Kansas, the High Plains Aquifer has declined more than 30.5 m in water level due to groundwater withdrawals for irrigation (Luckey et al., 1981; McGuire, 2001).

2.2 Dataset and site selection

A set of 34 U.S. Geological Survey streamgages (USGS, 2014) (Figure 1; Table 1) located across the KRB were used in this study. These streamgages were selected based on Brimley et al. (1999) and Harvey et al. (1999) station selection criteria: (i) sites with natural flow conditions, (ii) absence of diversions, dams, or other significant regulations, (iii) minimum 20 years of data, (iv) expected longevity of the station in the future, and (v) accurate data.

Daily mean discharge data for water years (WYs) 1962–2012 (where WY extends for 12 months ending on September 30 of the stated year) were extracted from the USGS National Streamflow Information Program (NSIP) website (<https://waterdata.usgs.gov/ks/nwis/current/?type=flow>, accessed on 4/12/2014). All streamgages have a minimum of 30 years of data with watershed size from 11.5 to 21,000 km². A large majority of streamgages (82%) had more than 50 years of data over the study period. Three streamgages (map index numbers 21, 26, and 33) had data only for WYs 1980–2012. In this study a minimum 30-year period was assumed to be adequate to ensure validity of the trend results (Kite, 1991; Kahya and Kalayci, 2004). To ensure a high level of accuracy, only the “approved for publication data” (USGS, 2014) for active hydrometric stations were used in this study. USGS quality assurance and quality control procedures for measuring stream stage and discharge can be found in Sauer and Turnipseed (2010) and Turnipseed and Sauer (2010).

The watershed draining to each USGS streamgage was assumed to represent conditions of the predominate ecoregion within the watershed boundaries. In all cases, the predominant ecoregion represented at least 50% of the watershed area (Figure 1).

2.3 Calculation of ecologically relevant hydrological variables

For the calculation of ecologically relevant hydrological variables, daily averaged discharge data (cfs) obtained from the USGS NSIP website database were converted to daily average streamflow per unit watershed area (mm/day) to standardize the effects of drainage area on streamflow generation (Monk et al., 2011), and all remaining analyses used these normalized daily streamflow depth data. Six WRIs and 33 IHAs were calculated using up to 50 WYs of data (1962–2012), which was more than the 35 years of data recommended (The Nature Conservancy, 2009).

Seasonal mean values were calculated as the mean daily streamflow depth from March through May (spring), June through August (summer), September through November (autumn), and December through February (winter). The center of timing (CT) of annual flow (day of occurrence of 50% annual flow from October 1 through September 30) was calculated from

$$CT = \sum (t_i q_i) / \sum q_i, \quad (1)$$

where t_i is time (days) from October 1 (beginning of WY) and q_i is the corresponding streamflow per unit area (mm/day) for day i . Because of the skewed nature of hydrological datasets, non-parametric statistics were used for most of the other indices. This resulted in presentation of median values for all IHA parameters, except 1-day to 90-day minimums and maximums. The 1-day to 90-day minimums and maximums were calculated from moving averages of every possible period. If multiple periods had the same value, the earliest period was reported. The 25th and 75th percentile flows were used as the thresholds for low- and high-flow pulse calculations. Flow reversals were calculated by dividing the hydrological record into 'rising' and 'falling' periods, which corresponded to periods in which daily changes (from the previous day) in flows were either positive (rising) or negative (falling). Flood and drought conditions were characterized by the magnitude and timing of events (annual maximum/minimum 1-, 3-, 7-, 30-, and 90-day mean flows) along with intra-annual and inter-annual variability in flow conditions (e.g., rise/fall rate and number of reversals in the hydrograph). Number of zero-flow days and baseflow index (7-day-minimum flow mean) indicators provided additional description of low- flow conditions. Detailed descriptions of the IHAs and their ecological significance can be found in the foundational IHA articles (Richter et al., 1996; Poff et al., 1997; The Nature Conservancy, 2009) and subsequent user studies (Monk et al., 2011; Sinnathamby, 2014).

2.4 Trend analysis techniques

Trends in IHAs and WRIs from each streamgage were evaluated using Mann-Kendall trend analysis (Mann, 1945; Kendall, 1975; Kendall and Gibbons, 1990). The Mann-Kendall test is a non-parametric correlation statistical test and is appropriate for detecting linear trends of hydrological time-series data. The Mann-Kendall test is not affected by extreme values or skewness in the data, making it effective for analyzing trends in streamflow (Rasmussen and Perry, 2001). The null hypothesis was that there was no trend in the series, and significance was tested at p values of 0.05 and 0.10 (where p is the probability of erroneously rejecting the null hypothesis, or saying there is a trend when there is not).

Sen's estimator of trend slope (Sen, 1968) was included in the analysis to estimate the true slope (change per unit time) when there was a linear trend. Sen's slope estimator has been widely used in hydro-meteorological time series (Tabari et al., 2011; Martinez et al., 2012). The MATLAB code written by Burkey (2006) was used to calculate Mann-Kendall tau and Sen's slope.

2.5 Precipitation and temperature trend analysis

The Mann–Kendall test was applied to annual average data from 16 precipitation stations and 17 temperature stations. The data were gathered from Kansas State University weather data library (<http://www.ksre.ksu.edu/wdl/>, accessed on 5/22/2014), which includes data from the National Climatic Data Center's database. All stations had 50 years of data (1962–2012 WYs) except the Beatrice temperature station in Western Corn Belt (Figure 2), which had 48 years (1962–2011 WYs). In addition, Pearson correlation coefficient (R) was used to analyze the trends between flow and climate data for eight sites with overlapping weather and streamflow data.

2.6 Ecological data and analysis

Fish occurrence data (presence/absence) at sites throughout Kansas were gathered from the Kansas Aquatic GAP Project database of the USGS National Gap Analysis Program (GAP; <http://gapanalysis.usgs.gov/>), which includes collections from the Kansas Department of Wildlife, Parks and Tourism, museum records, university research collections, and various other sources. The database includes more than 7,000 sites (collected between 1860 and 2012) represented by 133 fish species. The fish occurrence data are recommended to examine long-term functional responses of fish assemblages to hydrology rather than abundance (Mims and Olden, 2012; Gido, 2014, personal communication). For the analysis, the fish-streamgage pairs were identified in close geographic proximity by intersecting survey sites and streamgage watersheds using ArcGIS. Fish-streamgage pairs were selected such that fish survey sites were within 20 river kilometers (upstream or downstream) of the streamgage and were not separated by an impoundment (Mims and Olden, 2012). Two fish species native to Kansas and identified as threatened or in need of conservation (Distler et al., 2014) were selected for study: Plains Minnow (*Hybognathus placitus*) and Common Shiner (*Luxilus cornutus*).

The Plains Minnow occurs in shallow perennial streams with shallow, braided flow over broad beds of shifting sand. An adult Plains Minnow is about 13 cm in length. The Plains Minnow was abundant and widely distributed throughout the KRB and started to decline by 1970 (Taylor and Eberle, 2014). Changes in the streamflow volume, pattern and the fragmentation by dams were identified as major sources of decline (Gido et al., 2010; Perkin and Gido, 2011). The Plains Minnow has been listed as a threatened species in Kansas.

Common Shiner occupies streams with coarse substrates. Adults are commonly 8–13 cm in length, and total length can range up to 18 cm. The Common Shiner was extirpated from northwestern Kansas streams due to turbidity and dewatering and has been listed as a species in need of conservation in Kansas and as a threatened species in Colorado (Cathcart, 2014).

Streamflow data were not available for the entire period of fish sampling (1860–2012), but for most streamgages, data were available since 1962 and span the period of most dynamic landscape change. Most reservoirs of the KRB were constructed and irrigation agriculture was initiated at a low level during 1947 to 1962 (Gido et al., 2010). Prior to 1947, streams were presumed to be natural and unimpounded. Rapid impoundment development and

increase in irrigated land acreage (primarily in western Kansas) occurred during 1963–1977 (Cross and Moss, 1987; Eberle, 2007).

To analyze the relationship between ecohydrological variables and riverine fish species, the fish data were divided into two time periods: historical (1860–1950) and present (2000–2012). The historical period was selected prior to most impoundment and irrigation development and similar to Distler et al. (2014), and the present period was selected to correspond with a period of a comprehensive survey of many streams in Kansas and to allow sufficient lag time for effects of reservoir construction and groundwater pumping to occur (Gido et al., 2010). If a specific fish species was present for > 3 years during the historical period, its presence or absence was determined for the present period for each selected gage. In this way, two treatment groups were created: historically present + currently present (“Present”) and historically present + currently absent (“Absent”).

A two-sample t-test (assuming unequal variance) was used to test if trends in each ecohydrological index were different between the two treatment groups (Present and Absent). A significant difference in trends was used as an indication that species occurrence was sensitive to change in that ecohydrological index.

3. Results and Discussion

3.1 Climate trends

Mean annual precipitation (1962–2012) showed a positive trend at 12 of 16 stations in the KRB up to 2.70 mm/50 yr, with 4 of these trends being significant at $p < 0.05$ and 1 at $p < 0.10$ (Figures 2a, 3a, Table 2). The greatest positive trend in precipitation was observed at Beatrice station (Western Corn Belt). Similar positive trends in precipitation have been observed in other studies of Kansas climate (Hu et al., 1998; Garbrecht et al., 2004; Rahmani et al., 2014). Brunsell et al. (2010) found altered precipitation for the 21st century in Kansas, but with a slight increase in winter and decrease in summer and fall based on decadal averaged monthly outputs of 21 A1B scenario global climate models under the Special Report on Emissions Scenarios used in the Intergovernmental Panel on Climate Change (IPCC) Assessment Report 4.

Mean annual temperature showed a mix of positive trends (10 of 17 stations, 2 significant at $p < 0.05$) up to 0.02 °C/yr and negative trends (7 of 17 stations, 3 significant at $p < 0.05$ and 1 at $p < 0.10$) up to −0.02 °C/yr (Figures 2b, 3b). The greatest positive trend in temperature was observed at Wakeeney station (Central Great Plains) and greatest negative trend at Beatrice (Western Corn Belt). Brunsell et al. (2010) reported a slightly greater magnitude of warming for Kansas in the 21st century, with the largest trends of 0.04 °C/yr in summer and fall based on the mean of 21 A1B scenario monthly global climate model outputs from IPCC-4. Depending on seasonal timing, the effect of the positive precipitation trend on the local net water budget could be offset by the trend of increasing temperature due to its influence on increasing evapotranspiration. Conversely, the decreasing temperature trend could have a reinforcing effect and result in more of the precipitation being available for runoff or groundwater recharge.

3.2 Streamflow per unit area trends

The spatial distribution and significance of trends (Mann-Kendall) in annual mean streamflow per unit area for the 50-year study period are presented in Figures 4 and 5. Many more streamgages show negative Sen's trend slopes (29 of 34 stations) than positive trend slopes (5 of 34 stations) within the KRB (Figure 5). Streamflow trend magnitude, both annually and seasonally (Figure 5), tended to decrease from west to east in the KRB. Significant negative trends ($p < 0.05$) in annual streamflow were observed at 6 of 7 streamgages in the High Plains as well as 4 additional streamgages in the western Central Great Plains (Figures 4, 5). The majority of streamgages in Central Great Plains, Flint Hills, and Western Corn Belt showed non-significant negative trends.

Decreasing streamflow volume in western Kansas has been supported by previous trend studies in this study area (Jordan, 1982; Angelo, 1994; Rasmussen and Perry, 2001; Perry et al., 2004). Irrigated agriculture is considered to be a primary factor in the shift from perennial to intermittent streams in the KRB, especially western Kansas (Perry et al., 2004; Aguilar, 2009). Many streams considered as perennial streams in the 1960s were reported as intermittent streams in 1990 (Perry et al., 2004). The western KRB has streams with lower flow (per unit area) compared to the eastern KRB because of the regional gradient in precipitation and soil characteristics. The western two-thirds of the KRB typically has moderate to high permeability soils, and the eastern one-third has lower permeability soils (U.S. Department of Agriculture, 1993). The KRB has an east-to-west annual precipitation gradient with less north-to-south variation. These differences lead to lower-unit-discharge streams in the western region and higher-unit-discharge streams in the eastern region. Along with the variation in unit discharge, variation in irrigation pumping, agricultural management practices, and soil and water conservation structures may have had a greater impact on High Plains streams and contributed to their greater decreasing trends in annual flow per unit area compared to the other KRB ecoregions (Figures 4, 5).

Seasonal streamflow across the ecoregions demonstrated similar trends to annual streamflow (Figure 5). Again, the High Plains had significant negative trends at most streamgages in every season, and the Central Great Plains served as a transitional zone in which trends decreased in magnitude and became less significant from west to east. In the Central Great Plains, summer had the greatest number of streamgages (6) with significant negative trends (5 at $p < 0.05$, 1 at $p < 0.10$) compared to 4 (2 at $p < 0.05$, 2 at $p < 0.10$) in autumn, 2 ($p < 0.05$) in winter, and 1 ($p < 0.05$) in spring (Figure 5). For the eastern half of the KRB (map indices 1, 14–34), no streamgages had significant annual trends (Figure 4, $p > 0.10$) and only 4 gages had significant seasonal trends (Figure 5), although a majority of those streamgages showed small positive seasonal trends during spring and small negative seasonal trends during summer and autumn.

The annual trends in streamflow (Figures 4, 5) were not consistent with the annual trends in climatic variables (Figures 2, 3). Ten of the 12 most-westerly streamgages (map indices 2–13) had significant negative annual streamflow trends ($p < 0.05$) (Figures 4, 5). However, of the 5 most-westerly climate stations, which spanned a similar geographic area, 3 showed significant positive annual precipitation trends and 2 showed significant negative annual temperature trends, both of which would generally support increasing streamflow (Figures 2,

3). Consistent with Aguilar (2009), the streamflow trends were more pronounced in the High Plains and western Central Great Plains streams (Figure 4), where the magnitude of annual precipitation was lower. These data suggest that changes in climate (precipitation and temperature) that would have led to increasing streamflow trends were more than offset by other factors that contributed to the observed decreasing streamflow trends. Among these factors could be greater consumptive water use (evapotranspiration) and greater alluvial aquifer withdraws from increased production intensity of agricultural crops (irrigation). This is consistent with documented trends of increasing irrigated corn and soybean acreages and decreasing irrigated grain sorghum acreage from 1972 to 2011 together with a rapid increase in Kansas irrigated acreage from the 1960s to 1980s, where an overwhelming majority of irrigation is in western Kansas (Rogers et al., 2015).

3.3 Extreme streamflow conditions trends

Trends for each streamgage were fairly consistent across all levels of flow minimums or maximums, but trends varied across streamgages and ecoregions (Figure 6). The High Plains streamgages showed negative trends in minimum flows (at least 3 of 6 were significant, $p < 0.05$). A majority of the Central Great Plains streamgages showed positive trends (6 were significant, $p < 0.05$) for all duration levels of minimum flows (Figure 6).

Maximum-flow trends tended to decrease in magnitude from west to east in the watershed similar to annual and seasonal flows (Figure 5). Most streamgages in the High Plains showed significant ($p < 0.05$ or $p < 0.10$) negative trends for all levels of maximum flow, except station 4 (negative, but not significant). Trends near zero (not significant) in maximum flows were observed in the eastern half of the KRB (map indices 1, 14–34), except 3 streamgages located closer to central KRB (Figure 6). Pronounced negative trends in minimum- and maximum-flow IHAs in the High Plains and western Central Great Plains streams, which reflect the prevailing east-to-west gradient in precipitation and other biophysical factors, demonstrated a 50-year trend toward increasing drought in this region.

Five of the 12 most westerly streamgages in the KRB showed significant positive trends ($p < 0.05$) in number of zero-flow days (Figure 7). Each of these significant streamgages also showed negative (generally nonsignificant) trends in baseflow index (Figure 7). Conversely, in the Central Great Plains, 16 of 19 streamgages (4 significant, $p < 0.05$) showed positive trends in baseflow index, with 3 of 4 significant streamgages also showing significant negative trends ($p < 0.05$) in zero-flow days. This prevalence of decreasing baseflow during dry periods and increasing duration of dry periods in the High Plains and increasing baseflow with decreasing duration of dry periods in the Central Great Plains reveals a more complex interaction than can be described by climate (precipitation and temperature) alone. The Central Great Plains appears to be more consistent with the observed positive trends in precipitation in this region. Conversely, the High Plains has become droughtier despite generally increased rainfall and decreased temperature, potentially reflecting signatures of human hydrological alteration in this region, such as increasing groundwater use, decreasing groundwater level and lower recharge of the western KRB.

3.4 Streamflow timing trends

A negative trend in the center of timing of annual streamflow for a majority of streamgages (27 of 34 stations) indicates a shift in annual streamflow towards earlier in the year. Among those, 4 streamgages located in western Central Great Plains were significant at $p < 0.05$ and 4 were significant at $p < 0.10$ (Figure 7). Five (of 7) High Plains streamgages, 1 (of 3) Flint Hills streamgages, and 4 (of 5) Western Corn Belt streamgages also showed negative (nonsignificant) trends. The magnitudes of trend slope were up to -3.5 days/50 yr (Figure 7). Several studies have found shifts toward earlier center of timing for snowmelt-dominated streams in North America (Clow, 2010; Ryberg et al., 2015; Dudley et al., 2017); for example, Stewart et al. (2005) found 3-day earlier center of timing for 73% (214) of gages in western North America, with about half of these being significant shifts. But snowmelt-dominated areas tend to fall west and north of the study region. Less work has focused on non-snowmelt-dominated streams of the Midwest U.S. In the Missouri River Basin, Lins and Slack (2005) found no seasonal shifts in timing of streamflows during the 1940–1999 period but considerable interdecadal variability.

Figure 7 shows the date of annual minimum streamflow tends to be occurring later (positive trend up to 4 days/50 yr) and the date of annual maximum streamflow tends to be occurring earlier in the year (negative trend to 4 days/50 yr) for a majority of the streamgages studied. However, only 8 of these streamgages (of 34) had significant (7 at $p < 0.05$, 1 at $p < 0.10$) negative trends in date of annual maximum flow, and only 3 of these streamgages showed positive trends ($p < 0.05$) in date of annual minimum flow.

These shifts toward earlier median and maximum flows and later minimum flows may have meaningful impact on aquatic species migration, spawning, and other phenotypic behaviors.

3.5 Streamflow frequency trends

Low-flow pulse ($< 25^{\text{th}}$ percentile of daily flows) and high-flow pulse ($> 75^{\text{th}}$ percentile of daily flows) events were analyzed and displayed (Figure 8) by frequency (counts per year) and median duration (days) of high- and low-pulse events and rate and frequency of water condition changes. Some streamgages (7, 8, 13 and 21) were removed from these analyses because they had missing values and to avoid truncated pulses (The Nature Conservancy, 2009). Most streamgages in the High Plains and western Central Great Plains showed significant negative trends in the number and duration of high-flow pulses and significant positive trends in duration of low-flow pulses, but results for number of low-flow pulses were mixed for streamgages across ecoregions (Figure 8). A majority of streamgages showed negative trends in rise rates and positive trends in fall rates (Figure 8), with 7 of the 8 most westerly streamgages having significant trends ($p < 0.05$). Both trends toward decreasing rise rates and increasing fall rates indicated an increasing threat of drought incidence. Significant positive trends observed in the number of flow reversals over the study period showed greater variability across Central Great Plains, Flint Hills and Western Corn Belt ecoregions (Figure 8).

Fewer lower-duration and higher-flow pulses, greater duration of low-flow pulses, smaller rise rates and greater fall rates, and increasing flow reversals all represent important shifts to

streamflow timing and patterns that may impact critical seasonal stages in aquatic species life cycles.

3.6 Relationship of climate and streamflow

The overall observed negative trend in annual average streamflow can be caused by climatic changes in rainfall and temperature patterns. The Pearson correlation coefficient (R) results show 0.63 correlation between annual average flow trends and annual average precipitation trends and 0.41 correlation between annual average flow trends and annual average temperature trends (Table 3). However, neither of these was significant ($p>0.10$).

The absence of a significant correlation may be influenced by the relatively small sample size ($n=8$) used in this study. As discussed above, however, it may also reflect influence of other anthropogenic factors that more than offset the effects of climatic drivers. Other than precipitation and temperature, groundwater depletion, terracing (particularly in western Kansas), and changes in land use and farming practices (such as contour farming, crop rotation, pasture improvement, and conservation reserve program) also can be related to the decreasing annual trend (Rasmussen and Perry, 2001). Correlation to these other factors was not assessed in this study.

3.7 Influence of streamflow on two native fish species

The Plains Minnow was historically present (1860–1950) at 16 sites in the KRB associated with the following streamgages and ecoregions (identified by map index, Table 1): High Plains stations 2, 3, 4, 7, 10, 11; Central Great Plains stations 6, 8, 9, 13, 18; Flint Hills stations 21, 30; and Western Corn Belt stations 32, 33, 34. These 16 sites showed a westerly bias, including 11 of the 13 most-westerly streamgages (as shown on Figures 5–8) and just 5 streamgages in the eastern half of the KRB. Occurrence of the species at study sites shifted from present (1860–1950) to absent (2000–2012) at all but 2 sites (33, 34); these 2 “Present” sites were the 2 most-easterly sites in the KRB.

Common Shiner was historically present (1860–1950) at 11 sites in the KRB associated with the following streamgages and ecoregions (identified by map index, Table 1): Central Great Plains stations 9, 12, 13, 14, 16, 28; Flint Hills stations 21, 30, 31; and Western Corn Belt stations 32, 33. These 11 sites showed an easterly bias, including 6 of the 9 most-easterly streamgages (as shown on Figures 5–8) and just 5 streamgages in the western two-thirds of the KRB, with none in the High Plains ecoregion. Occurrence of the species at study sites went from present (1860–1950) to absent (2000–2012) at all but 4 sites (21, 28, 30, 32). All 4 of the “Present” sites were in the grouping of 6 easterly sites, and all 5 of the westerly locations were “Absent” sites.

Results demonstrated specific detrimental effects of flow-regime change on these two native fish species of Kansas (Table 4, Figure 9). Both species were Absent from sites with greater decreasing trends of 1-day maximum flow ($p<0.10$). Otherwise, change in species occurrence appeared to respond to different hydrological cues.

Plains Minnow occurrence generally responded negatively to greater decreasing trends (or shifts from increasing to decreasing trends) for many ecohydrological indices. Plains

Minnow Absence was significantly (or marginally significantly) related to streamflow records having greater decreasing trends of annual volume ($p=0.095$), seasonal flow in summer ($p=0.088$), monthly flow in April ($p=0.102$), July ($p=0.102$), and September ($p=0.082$), 30-day minimum flow ($p=0.105$), and 1-day ($p=0.081$), 3-day ($p=0.109$), 90-day ($p=0.034$) maximum flows, rise rate ($p=0.034$) and reversals ($p=0.006$), and greater increasing trends in fall rate ($p=0.015$) (Table 4, Figure 9). The decreasing trends indicate declining flows overall (annual volume), at critical times of the year (summer in general and spanning the months of April through September), and for critical hydrological periods (sustained minimum flow or maximum flow periods).

The correlations observed between the shifts in Plains Minnow occurrence and ecohydrological indices do not demonstrate causal relationships, but the observed correlations are generally supported by important ecological response characteristics specific to Plains Minnow. Decreasing flow trends and species disappearance can be related to unsuccessful spawning events. Spawning for Plains Minnow is known to occur in the summer period (Distler et al., 2014) with higher flows sufficient to maintain buoyancy of their nonadhesive, semi-buoyant eggs (Talyor and Eberle, 2014). Since Plains Minnow eggs are semi-buoyant, there must be sufficient flow to keep eggs from sinking to the bottom and being covered with substrate. Where there is insufficient water, eggs could be damaged and killed or dried due to extreme temperature (Taylor and Eberle, 2014). In the KRB, higher flows generally occur in the summer season, which is consistent with the observed Absent response to decreasing flows, particularly for ecohydrological indices that describe trends in summer, maximum-flow periods, and high-flow pulse frequency (Table 4). Decreasing trends in rise rates and reversals and increasing trends in fall rates (Table 4) all describe a condition having more-gradual changes in and less-frequent alternations between the rising- and falling-limbs of the streamflow hydrograph, which would also be detrimental to maintaining higher-flow conditions suitable for suspension of semi-buoyant eggs. It may also be important that the decreasing-flow trends extend from April through September, so even though Plains Minnow can have multiple spawns (Taylor and Eberle, 2014), this resilient characteristic would not be adequate to overcome a persistent decreased-flow stressor that spans the entire high-flow spawning period.

Another possible ecological response of Plains Minnow consistent with the observed decreasing ecohydrological index trends could be changes to the hyporheic zone, where shallow groundwater and surface water mix beneath and alongside a stream bed. This zone is an important region of biogeochemical cycling and biological activity. It also serves to regulate temperature, especially in small streams, and acts as a natural treatment system. The Plains Minnow is found in perennial streams with shallow, braided flow over broad beds of shifting sand, where they feed on diatoms and other algae. When there are no seasonal scouring-level discharges and diminished summer flows, those diatoms and algae may be eliminated due to insufficient water to maintain the hyporheic zone. This change has been previously linked to declines in Plains Minnow (Distler et al., 2014), and is consistent with the significant declines in 30-day minimum flow trends and consistent (but non-significant) declines in baseflow and increases in zero-flow days, low-flow pulses, and other (particularly longer-duration) minimum-flow periods (Table 4).

Similar results were reported by Gido et al. (2013), who found native fish in natural flow regimes of the southwest U.S. responded positively to higher mean spring flows and baseflow index, slightly positively to high pulse count, and negatively to summer discharge variability. In a study of subtropical rivers in Australia, Arthington et al. (2014) also found high-flow pulse count and mean daily flows and their variability were important in structuring fish assemblages; other important antecedent flow conditions were baseflow, number of zero-flow days, magnitude of the 1-year annual return interval flood, and the constancy and predictability of monthly flows. Common Shiner occurrence demonstrated a significant response to just four ecohydrologic indices.

Common Shiner Absence was significantly related to streamflow records having greater decreasing trends (i.e., toward earlier in the water year) of center of timing ($p=0.025$) and date of maximum flow ($p=0.090$), decreasing trends of 1-day maximum flow ($p=0.095$), and increasing trends in March monthly flow ($p=0.075$).

Again, although the correlations observed between the shifts in Common Shiner occurrence and ecohydrological indices do not demonstrate causal relationships, the results suggest several important ecological response characteristics specific to Common Shiner that warrant further study. Common Shiner normally spawns from late April to early July with peaks in mid-May (Cathcart, 2014). They use already-built nests by other species, or the male shiner excavates pits in shallow riffles. If there is insufficient flow to form riffles, the spawning events of Common Shiner will not be successful. This does not appear to be the case in the KRB. Sites consistently (10 of 12 months, September through June) had weakly positive or negative monthly trends (-0.065 to 0.048 mm/50 yr) for Present sites but stronger increasing trends (-0.022 to 0.115 mm/50 yr) for Absent sites, increasing by a monthly average of 0.07 mm/50 yr. Though Common Shiner reside in riffle zones, during droughts they survive in isolated pools (Cathcart, 2014). The increasing trends at Absent sites relative to Present sites may result in a decreasing intermittency of these streams that reduces the number and severity of periods when they otherwise would seek refuge in isolated pools, which may result in conditions that place Common Shiner at a competitive disadvantage. While plausible, this result is speculative and would require more-detailed study for confirmation.

Several other trend comparisons present a consistent story, though they did not attain statistical significance. Mean summer discharge trends increased and mean winter and spring discharge trends decreased for the Absent sites relative to Present sites. Response to mean spring flow trends was opposite that suggested by Gido et al. (2013) for the southwest U.S., suggesting substantial inter-species differences, even within closely proximal geographic regions. The general (nonsignificant) trends of decreasing zero-flow days and increasing low-flow pulse durations at Absent sites relative to Present sites may provide support for the decreasing intermittency suggested by the monthly flow trends. Finally, Common Shiner was Absent in streams with greater increasing mean spring discharge trends in 2000–2012. As Common Shiner is a silt-intolerant species, flow-related increasing turbidity may be a possible reason for their absence in streams with increasing trends in spring flow (Cathcart, 2014). Although these differences in trends between Absent and Present sites were “small” and not enough to show statistically significant differences (Table

4, Figure 9), even small-magnitude trends might be extremely rapid in an ecological sense to the extent that species could not develop an adequate survival response or the environmental change exceeds the phenotypic plasticity of the species. Again, this result is not directly supported by evidence from this study and would require further analysis into the species-specific ecological impacts from the observed hydrological trends.

In addition to streamflow alteration, other anthropogenic stressors, including soil erosion and fertilizer and agrochemical runoff from increasing row-crop agriculture production (beginning in 1880), habitat fragmentation caused by impoundments (beginning in the 1950s), and reduced return flow caused by groundwater withdrawal (beginning in the 1960s), could also play role in fish distribution. However, the effects of those factors were not tested in this study.

4. Conclusion

Trends of WRIs and IHAs have been observed for KRB streamgages using 50-year streamflow records. Across the entire KRB, a negative trend is evident for annual (29 of 34 stations), summer (23 of 34 stations), and autumn (31 of 34 stations) mean streamflow; 30-day (21 of 34 stations) and 90-day (24 of 34 stations) minimum streamflows; and 1-day (25 of 34 stations), 3-day (27 of 34 stations), 7-day (29 of 34 stations), 30-day (29 of 34 stations) and 90-day (29 of 34 stations) maximum streamflows. Streamflow trend magnitude, both annually and seasonally, tended to decrease from west to east in the watershed. These results show there are ongoing adverse hydrological changes in the KRB. There were regional differences in ecohydrological index trends, but these did not appear to be strongly tied to the EPA Level III ecoregions. Rather, other anthropogenic factors, likely increased irrigation withdrawals in the western KRB, reduced annual and seasonal streamflow discharges, maximum and minimum flows, and high-flow counts and hydrographic flashiness.

Mean annual precipitation showed an increasing trend (12 of 16 stations) and mean annual temperature showed a mix of increasing trends (10 of 17 stations) and decreasing trends (7 of 17 stations). The Pearson correlation coefficient (R) results showed 0.63 correlation between annual average flow trends and annual average precipitation trends and 0.41 correlation between annual average flow trends and annual average temperature trends, though neither correlation was significant, suggesting a substantial influence of non-climatic drivers on streamflow trends.

The shift in occurrence of two native fish species (Plains Minnow [*Hybognathus placitus*] and Common Shiner [*Luxilus cornutus*]) from present (1860–1950) to absent (2000–2012) was significantly related to negative trends of 1-day maximum flows (both species) and a number of ecohydrological indices that relate to reduced spawning-season flows for Plains Minnow and shifting annual flow timing and increased flow intermittency for Common Shiner. Both species were Absent for all sites in the western half of the KRB. Negative trends in minimum and maximum flows for Absent sites may suggest an additional stressor, especially in the High Plains ecoregion. In the eastern half of the KRB, sites and conditions that resulted in Absent response differed dramatically for the two species studied. In general,

but particularly for Plains Minnow, increasing trends in fall rates and low-flow pulse duration and decreasing trends in high-flow pulse count and duration for Absent sites show higher drought potential and increasingly unsuitable conditions for spawning, migration and survival for aquatic organisms in this region.

The demonstrated detrimental effect of flow-regime change on native fish species of Kansas may suggest factors that could be targeted in restoration activities. Factors that increase the number of high-flow pulse events (e.g., dam removal) or increase mean summer flows (e.g., decreased alluvial aquifer pumping) would reverse the trends of significant streamflow stressors and could improve conditions for aquatic species.

Acknowledgments

This project was supported in part by an appointment to the Internship/Research Participation Program at the Office of Research and Development, U.S. Environmental Protection Agency (EPA), administered by the Oak Ridge Institute for Science and Education through an interagency agreement between the U.S. Department of Energy and EPA. This paper has been reviewed in accordance with Agency policy and approved for publication. The views expressed in this article are those of the author(s) and do not necessarily represent the views or policies of the U.S. Environmental Protection Agency.

References

- Angelo, R. Impacts of declining streamflow on surface water quality. 11th Annual Water and the Future of Kansas Conference Proceedings; Manhattan, KS. 1994. p. 1-2.
- Aguilar, JP. PhD dissertation. Department of Biological and Agricultural Engineering, Kansas State University; Manhattan: 2009. Historic changes of ecologically relevant hydrologic indices of unregulated Kansas Streams.
- Alexandre CM, Ferreira TF, Almeida PR. Fish assemblages in non-regulated and regulated rivers from permanent and temporary Iberian systems. *River Research and Applications*. 2013; 29:1042–1058. DOI: 10.1002/rra.2591
- Arthington AH, Rolls RJ, Sternberg D, Mackay SJ, James CS. Fish assemblages in subtropical rivers: low-flow hydrology dominates hydro-ecological relationships. *Hydrological Sciences Journal*. 2014; 59:594–604. DOI: 10.1080/02626667.2013.844345
- Bain MB, Finn JT, Booke HE. Streamflow regulation and fish community structure. *Ecology*. 1988; 69:382–392. DOI: 10.2307/1940436
- Bower D, Hannah DM, McGregor GR. Techniques for assessing the climatic sensitivity of river flow regimes. *Hydrological Processes*. 2004; 18(13):2515–2543. DOI: 10.1002/hyp.1479
- Brimley B, Cantin J, Harvey D, Kowalchuk M, Marsh P, Ouarda T, Phinney B, Pilon P, Renouf M, Tassone B. Establishment of the reference hydrometric basin network (RHBN) for Canada. Environment Canada. 1999:41.
- Brown LR, Bauer ML. Effects of hydrologic infrastructure on flow regimes of California's Central Valley Rivers: implications for fish populations. *River Research and Applications*. 2009; doi: 10.1002/rra.1293
- Brunsell NA, Jones AR, Jackson TL, Feddema JJ. Seasonal trends in air temperature and precipitation in IPCC AR4 GCM output for Kansas, USA: evaluation and implications. *The International Journal of Climatology*. 2010; 30(8):1178–1193. DOI: 10.1002/joc.1958
- Burkey, J. A non-parametric monotonic trend test computing Mann-Kendall Tau, Tau-b, and Sen's Slope written in Mathworks-MATLAB implemented using matrix rotations. King County Department of Natural Resources and Parks, Science and Technical Services section; Seattle, Washington. USA: 2006. Available at: <http://www.mathworks.com/matlabcentral/fileexchange/authors/23983> [Accessed on 01/01/2014]
- Cathcart, CN. Common Shiner, *Luxilus cornutus*. *Fishes, Kansas*, editor. University Press of Kansas; Lawrence: 2014.

- Clow D. Changes in the timing of snowmelt and streamflow in Colorado: A response to recent warming. *Journal of Climate*. 2010; 23:2293–2306. DOI: 10.1175/2009JCLI2951.1
- Cross, FB., Moss, RE. Community and evolutionary ecology of North American stream fishes. University of Oklahoma; 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas.
- Dibike YD, Coulibaly P. Hydrologic impact of climate change in the Saguenay watershed: comparison of downscaling methods and hydrologic models. *Journal of Hydrology*. 2005; 307(1):145–163. DOI: 10.1016/j.jhydrol.2004.10.012
- Distler, AD., Eberle, ME., Edds, DR., Gido, KB., Haslouer, SG., Huggins, DG., Mosher, TD., Stark, WJ., Tomelleri, JR., Triplett, JR., Wiley, EO. *Kansas Fishes*. University Press of Kansas; Lawrence: 2014.
- Dudley RW, Hodgkins GA, McHale JR, Kolian MJ, Renard B. Trends in snowmelt-dominated streamflow timing in the coterminous United States. *Journal of Hydrology*. 2017; 547:208–221. doi:10.1016/j.jhydrol.2017.01.051.
- Eberle ME. Homogenization of fish faunas and concurrent anthropogenic impacts on plains streams in western Kansas: 1854–2003. *Fort Hays Studies*. 2007; 4:1–78.
- Gasith A, Resh VH. Streams in mediterranean climate regions: abiotic influences and biotic responses to predictable seasonal events. *Annual Review of Ecology and Systematics*. 1999; 30:51–81.
- Garbrecht J, Van Liew M, Brown GO. Trends in precipitation, streamflow, and evapotranspiration in the Great Plains of the United States. *Journal of Hydrologic Engineering*. 2004; 9(5):360–367. DOI: 10.1061/(ASCE)1084-0699(2004)9:5(360)
- Gehrke PC, Brown P, Schiller CB, Moffatt DB, Bruce AM. River regulation and fish communities in the Murray-Darling River system, Australia. *Regulated Rivers: Research and Management*. 1995; 11:363–375. DOI: 10.1002/rrr.3450110310
- Gido KB, Dodds WK, Eberle ME. Retrospective analysis of fish community change during a half-century of landuse and streamflow changes. *Journal of the North American Benthological Society*. 2010; 29:970–987. DOI: 10.1899/09-116.1
- Gido KB, Propst DL, Olden JD, Bestgen KR. Multidecadal responses of native and introduced fishes to natural and altered flow regimes in the American Southwest. *Canadian Journal of Fisheries and Aquatic Sciences*. 2013; 70(4):554–564. DOI: 10.1139/cjfas-2012-0441
- Gleick PG, Chalecki EL. The impacts of climatic changes for water resources of the Colorado and Sacramento-San Joaquin River basins. *Journal of the American Water Resources Association*. 1999; 35(6):1429–1441. DOI: 10.1111/j.1752-1688.1999.tb04227.x
- Groisman PY, Knight RW, Karl TR. Heavy Precipitation and High Streamflow in the Contiguous United States: Trends in the Twentieth Century. *The Bulletin of the American Meteorological Society*. 2001; 82(2):219–246. DOI: 10.1175/1520-0477(2001)082<0219:HPAHSI>2.3.CO;2
- Harvey, KD., Pilon, PJ., Yuzyk, TR. Canada's reference hydrometric basin network (RHBN): In partnerships in water resource management. CWRA 51th Annual Conference, Canadian Water Resources Association; Halifax, Nova Scotia. June; 1999.
- Hodgkins GA, Dudley RW, Huntington TG. Changes in the timing of high river flows in New England over the 20th Century. *Journal of Hydrology*. 2003; 278(1):244–252. DOI: 10.1016/S0022-1694(03)00155-0
- Hodgkins GA, Dudley RW, Huntington TG. Summer low flows in New England during the 20th century. *Journal of the American Water Resources Association*. 2005; 41(2):403–411. DOI: 10.1111/j.1752-1688.2005.tb03744.x
- Hu Q, Woodruff CM, Mudrick SE. Interdecadal variations of annual precipitation in the central United States. *The Bulletin of the American Meteorological Society*. 1998; 79(2):221–229. DOI: 10.1175/1520-0477(1998)079<0221:IVOAPI>2.0.CO;2
- Jordan, PR. Rainfall-runoff relations and expected streamflow in western Kansas. Kansas Water Office, State of Kansas; Topeka: 1982.
- Jowett IG, Duncan MJ. Flow variability in New Zealand rivers and its relationship to in-stream habitat and biota, New Zealand. *Journal of Marine and Freshwater Research*. 1990; 24(3):305–317. DOI: 10.1080/00288330.1990.9516427

- Kahya E, Kalayci S. Trend analysis of streamflow in Turkey. *Journal of Hydrology*. 2004; 289(1):128–144. DOI: 10.1016/j.jhydrol.2003.11.006
- Kendall, MG. Rank Correlation Methods. 4. Charles Griffin; London: 1975.
- Kendall, M., Gibbons, JD. Rank Correlation Methods Edward Arnold. Hodder & Stoughton; London: 1990. p. 29-50.
- Khedkar GD, Lutzky S, Rathod S, Kalyankar A, David L. A dual role of dams in fragmentation and support of fish diversity across the Godavari River basin in India. *Ecohydrology*. 2014; 7:1560–1573. DOI: 10.1002/eco.1470
- Kibria KN, Ahiablame L, Hay C, Djira G. Streamflow trends and responses to climate variability and land cover change in South Dakota. *Hydrology*. 2016; 3(2):20.doi: 10.3390/hydrology3010002
- Kite, G. Looking for evidence of climatic change in hydrometeorological time series. Western Snow Conference; April 12–15; Washington to Alaska. 1991.
- Knight RR, Gain WS, Wolfe WJ. Modelling ecological flow regime: an example from the Tennessee and Cumberland River basins. *Ecohydrology*. 2012; 5:613–627. DOI: 10.1002/eco.246
- Lin P, Brunsell N. Assessing Regional Climate and Local Landcover Impacts on Vegetation with Remote Sensing. *Remote Sensing*. 2013; 5(9):4347–4369. DOI: 10.3390/rs5094347
- Lins HF, Slack JR. Seasonal and regional characteristics of U.S. streamflow trends in the United States from 1940 to 1999. *Physical Geography*. 2005; 26(6):489–501.
- Logan KE, Brunsell NA, Jones AR, Feddema JJ. Assessing spatiotemporal variability of drought in the U.S. Central Plains. *Journal of Arid Environments*. 2010; 74:247–255. DOI: 10.1016/j.jaridenv.2009.08.008
- Luckey, RR., Gutentag, ED., Weeks, JB. Water-level and saturated-thickness changes, predevelopment to 1980, in the High Plains aquifer in parts of Colorado, Kansas, Nebraska, New Mexico, Oklahoma, South Dakota, Texas, and Wyoming: Hydrologic Investigations Atlas HA–652. US Geol. Survey; Reston, VA: 1981. Available at <http://pubs.usgs.gov/ha/652/plate-1.pdf>, <http://pubs.usgs.gov/ha/652/plate-2.pdf>
- Lynch AJ, Myers BJE, Chu C, Eby LA, Falke JA, Kovach RP, Krabbenhoft TJ, Kwak TJ, Lyons J, Paukert CP, Whitney JE. Climate Change Effects on North American Inland Fish Populations and Assemblages. *Fisheries*. 2016; 41(7):346–361. DOI: 10.1080/03632415.2016.1186016
- Lytle DA, Poff NL. Adaptation to natural flow regimes. *Trends in Ecology & Evolution*. 2004; 19(2): 94–100. DOI: 10.1016/j.tree.2003.10.002 [PubMed: 16701235]
- Mann HB. Non-parametric test against trend. *Econometrika*. 1945:13245–259.
- Martinez JC, Maleski JJ, Miller FM. Trends in precipitation and temperature in Florida, USA. *Journal of Hydrology*. 2012; 452–453:259–281. DOI: 10.1016/j.jhydrol.2012.05.066
- Martínez-Capel F, Belmar O, Bruno D, Velasco J. Effects of flow regime alteration on fluvial habitats and riparian quality in a semiarid Mediterranean basin. *Ecological Indicators*. 2013; 30:52–64. DOI: 10.1016/j.ecolind.2013.01.042
- McGuire, VL. US Geological Survey Fact Sheet 029–01. 2001. Water-level changes in the High Plains aquifer, 1980 to 1999; p. 2
- McGuire, VL., Lund, KD., Densmore, BK. [Accessed on 01/23/2014] 2012. Saturated thickness and water in storage in the High Plains aquifer, 2009, and water-level changes and changes in water in storage in the High Plains aquifer, 1980 to 1995, 1995 to 2000, 2000 to 2005, and 2005 to 2009. US Geological Survey Scientific Investigations Report 2012–5177. Available at: <http://pubs.usgs.gov/sir/2012/5177/>
- Merritt WS, Alila Y, Barton M, Taylor B, Cohen S, Neilsen D. Hydrologic response to scenarios of climate change in sub watersheds of the Okanagan basin, British Columbia. *Journal of Hydrology*. 2006; 326(1):79–108. DOI: 10.1016/j.jhydrol.2005.10.025
- Mims CM, Olden DJ. Life history theory predicts fish assemblage response to hydrologic regimes. *Ecology*. 2012; 93(1):35–45. DOI: 10.1890/11-0370.1 [PubMed: 22486085]
- Mortenson SG, Weisberg PJ. Does river regulation increase the dominance of invasive woody species in riparian landscapes? *Global Ecology and Biogeography*. 2010; 19:562–574. DOI: 10.1111/j.1466-8238.2010.00533.x

- Monk WA, Peters DL, Curry RA, Baird DJ. Quantifying trends in indicator hydroecological variables for regime-based groups of Canadian rivers. *Hydrological Processes*. 2011; 25(19):3086–3100. DOI: 10.1002/hyp.8137
- Novotny EV, Stefan HG. Stream flow in Minnesota, Indicator of climate change. *Journal of Hydrology*. 2007; 334(3):319–333. DOI: 10.1016/j.jhydrol.2006.10.011
- Perry, CA., Wolock, DM., Artman, JC. US Geol Survey Scientific Information Report 2004–5032. 2004. Estimates of median flows for streams on the 1999 Kansas Surface Water Register; p. 219
- Perkin JS, Bonner TH. Long-term changes in flow regime and fish assemblage composition in the Guadalupe and San Marcos rivers of Texas. *River Research and Applications*. 2011; 27(5):566–579. DOI: 10.1002/rra.1373
- Perkin JS, Gido KB. Stream fragmentation thresholds for a reproductive guild of Great Plains fishes. *Fisheries*. 2011; 36:371–383. <http://dx.doi.org/10.1080/03632415.2011.597666>.
- Poff NL, Allan JD. Functional organizational of stream fish assemblages in relation to hydrological variability. *Ecology*. 1995; 76(2):606–627. DOI: 10.2307/1941217
- Poff NL, Allan JD, Bain MB, Karr JR, Prestegard KL, Richter BD, Sparks RE, Stromberg JC. The natural flow regime. *Bioscience*. 1997; 47(11):769–784. DOI: 10.2307/1313099
- Poff NL. Ecological response to and management of increased flooding caused by climate change. *Philosophical Transactions of the Royal Society A: Mathematical, Physical and Engineering Sciences*. 2002; 360(1796):1497–1510. DOI: 10.1098/rsta.2002.1012
- Poff N, Bledsoe B, Cuhaciyan C. Hydrologic variation with land use across the contiguous U.S. Geomorphic and ecological consequences for stream ecosystems. *Geomorphology*. 2006; 79(3–4): 264–285. DOI: 10.1016/j.geomorph.2006.06.032
- Poff NL, Zimmerman KH. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. *Freshwater Biology*. 2010; 55:194–205. DOI: 10.1111/j.1365-2427.2009.02272.x
- Quinn JW, Kwak TJ. Fish assemblage changes in an Ozark River after impoundment: a long-term perspective. *Transactions of the American Fisheries Society*. 2003; 132:110–119. DOI: 10.1577/1548-8659(2003)132<0110:FACIAO>2.0.CO;2
- Rahmani V, Hutchinson SL, Harrington JA Jr, Hutchinson JMS, Anandhi A. Analysis of Temporal and Spatial Distribution and Change-points for Annual Precipitation in Kansas, USA. *International Journal of Climatology*. 2014; 35:3879–3887. DOI: 10.1002/joc.4252
- Rasmussen, TJ., Perry, CA. Trends in Peak Flows of Selected Streams in Kansas, US Geol Survey Water-Resources Investigations Report 01-4203. 2001. p. 62 Available at: <http://ks.water.usgs.gov/pubs/reports/wrir.01-4203.html>
- Ryberg KR, Akyuz FA, Wiche GJ, Lin W. Changes in seasonality and timing of peak streamflow in snow and semi-arid climates of the north-central United States, 1910–2012. *Hydrological Processes*. 2015; 39(8):1208–1218. DOI: 10.1002/hyp.10693
- Richter BD, Baumgartner JV, Powell J, Braun DP. A method for assessing hydrologic alteration within ecosystems. *Conservation Biology*. 1996; 10:1163–1174. DOI: 10.1046/j.1523-1739.1996.10041163.x
- Risbey JS, Entekhabi D. Observed Sacramento Basin streamflow response to precipitation and temperature changes and its relevance to climate impact studies. *Journal of Hydrology*. 1996; 184:209–223. DOI: 10.1016/0022-1694(95)02984-2
- Rogers, DH., Aguilar, J., Kisekka, I., Barnes, PL., Lamm, FR. Agricultural Crop Water Use. Proceedings of the 27th Annual Central Plains Irrigation Conference; Colby, Kansas. February 17–18, 2015; 760 N. Thompson, Colby, Kansas: CPIA; 2015.
- Rypel AL, Haag WR, Findlay RH. Pervasive hydrologic effects on freshwater mussels and riparian trees in southeastern floodplain ecosystems. *Wetlands*. 2009; 29:497–504. DOI: 10.1672/08-109.1
- Sauer, VB., Turnipseed, DP. Stage measurement at gaging stations; US Geol Survey Techniques and Methods Chap 7 of Book 3, Section A. 2010. p. 1-45. Available at: <http://pubs.usgs.gov/tm/tm3-a7/>
- Scheidegger KJ, Bain MB. Larval fish distribution and microhabitat use in free-flowing and regulated rivers. *Copeia*. 1995; 1995(1):125–135. DOI: 10.2307/1446807

- Shieh CL, Guh YR, Wang SQ. The application of range of variability approach to the assessment of a check dam on riverine habitat alteration. *Environmental Geology*. 2007; 52:427–435. DOI: 10.1007/s00254-006-0470-3
- Sen PK. Estimates of the regression coefficient based on Kendall's tau. *Journal of the American Statistical Association*. 1968; 63(324):1379–1389. DOI: 10.2307/2285891
- Shrestha RR, Peters DL, Schnorbus MA. Evaluating the ability of a hydrologic model to replicate hydro-ecologically relevant indicators. *Hydrological Processes*. 2013; 28:4294–4310. DOI: 10.1002/hyp.9997
- Sinnathamby, S. PhD dissertation. Department of Biological and Agricultural Engineering, Kansas State University; Manhattan: 2014. Modeling tools for ecohydrological characterization.
- Small MF, Bonner TH, Baccus JT. Hydrologic alteration of the Lower Rio Grande Terminus: a quantitative assessment. *River Research and Applications*. 2009; 25:241–252. DOI: 10.1002/rra.1151
- Stewart IT, Cayan DR, Dettinger MD. Changes toward earlier streamflow timing across western North America. *Journal of Climate*. 2005; 18:1136–1155. DOI: 10.1175/JCLI3321.1
- Tabari H, Somee BS, Zadeh MR. Testing for long-term trends in climatic variables in Iran. *Atmospheric Research*. 2011; 100:132–140. DOI: 10.1016/j.atmosres.2011.01.005
- Taylor, CM., Eberle, ME. Plains Minnow, *Hybognathus placitus*. *Fishes, Kansas*, editor. University Press of Kansas; Lawrence: 2014.
- Taylor JM, Seilheimer TS, Fisher WL. Downstream fish assemblage response to river impoundment varies with degree of hydrologic alteration. *Hydrobiologia*. 2014; 728:23–39. DOI: 10.1007/s10750-013-1797-x
- Tharme RE. A global perspective on environmental flow assessment: emerging trends in the development and application of environmental flow methodologies for rivers. *River Research and Applications*. 2003; 19:397–441. DOI: 10.1002/rra.736
- The Nature Conservancy. Indicators of Hydrologic Alteration Version 7.1. User's Manual. 2009. Available at: <http://www.conservationgateway.org/Files/Pages/indicators-hydrologic-10alt.aspx47.aspx>
- Toth B, Pietroniro A, Conly FM, Kouwen N. Modelling climate change impacts in the Peace and Athabasca catchment and delta: I—hydrological model application. *Hydrological Processes*. 2006; 20(19):4197–4214. DOI: 10.1002/hyp.6426
- Turnipseed DP, Sauer VB. Discharge measurements at gaging stations. *US Geological Survey Techniques and Methods*, Book 3. 2010; Ch A8:87. <http://pubs.usgs.gov/tm/tm3-a8/>.
- U.S. Department of Agriculture (USDA). Soil Conservation Service Miscellaneous Publication 1492. 1993. State soils geographic database (STATSGO) user's guide. [Accessed on 1/1/2014]
- U.S. Geological Survey (USGS). [Accessed on 1/1/2014] Water resources of the United States, historical NWIS data. US Geological Survey. 2014. Available at: <http://waterdata.usgs.gov/nwis>
- Wang Y, Rhoades BL, Wang D. Assessment of the flow regime alterations in the middle reach of the Yangtze River associated with dam construction: potential ecological implications. *Hydrological Processes*. 2016; 30:3949–3966. DOI: 10.1002/hyp.10921
- Weisberg SB, Burton WH. Enhancement of fish feeding and growth after an increase in minimum flow below the Conowingo Dam. *North American Journal of Fisheries Management*. 1993; 13:103–109.

Figure 1. Locations of USGS streamgages and their watershed boundaries, weather stations, and EPA level III ecoregions within and around the Kansas River Basin study area. Map index numbers are defined in Table 1.

Figure 2.

Trends (Mann-Kendall) in average annual (a) precipitation and (b) temperature at selected NCDC stations of Kansas River Basin (WYs 1962–2012).

Figure 3.

Trends (Sen's slope magnitude and significance) in (a) precipitation (b) temperature (WYs 1962–2012) at stations in the Kansas River Basin grouped by ecoregion: High Plains, Central Great Plains, Flint Hills (FH), Western Corn Belt (WCB), and Central Irregular Plains (CIP). Trend significance indicated by circles with dark fill ($p \leq 0.05$), light fill ($p \leq 0.10$), or no fill (n.s.). (n.d. = no data)

Figure 4.

Trends (Mann-Kendall) in average annual streamflow per unit area at streamgages in the Kansas River Basin (WYs 1962–2012). Upward and downward pointing triangles represent increasing (blue) and decreasing (red) trends, respectively. Trend significance indicated by circles with dark fill ($p=0.05$), light fill ($p=0.10$), or no fill (n.s.).

Figure 5.

Trends (Sen's slope) for annual and seasonal streamflow at streamgages (map index numbers 1–34 defined in Table 1) in the Kansas River Basin grouped by ecoregion: High Plains (HP), Central Great Plains, Flint Hills (FH), and Western Corn Belt (WCB). Trend significance indicated by circles with dark fill ($p=0.05$), light fill ($p=0.10$), or no fill (n.s.). Plains Minnow (PM) or Common Shiner (CS) Presence (P) or Absence (A) (2000–2012) after being present historically (1860–1950) indicated for each map index basin.

EPA Author Manuscript

Figure 8.

Trends (Sen's slope) in low-flow and high-flow pulse frequency (#) and duration, rise and fall rates, and reversals at streamgages (map index numbers defined in Table 1) in the Kansas River Basin grouped by ecoregion: High Plains (HP), Central Great Plains, Flint Hills (FH), and Western Corn Belt (WCB). Trend significance indicated by circles with dark fill ($p=0.05$), light fill ($p=0.10$), or no fill (n.s.). Plains Minnow (PM) or Common Shiner (CS) Presence (P) or Absence (A) (2000–2012) after being present historically (1860–1950) indicated for each map index basin.

Figure 9.

Comparison of trends (Kendall tau, 1962–2012) in significant ecohydrological indicators at 16 streamgages in the Kansas River Basin at which (a) Plains Minnow or (b) Common Shiner was either “Present” or “Absent” (2000–2012) after being present historically (1860–1950).

Table 1

USGS streamgage attributes, map index numbers (used in tables and figures), periods of record, and assigned ecoregions used in this study.

Map index	USGS Station Code	USGS Streamgage Name	Drainage area (km ²)	Period of record (yrs)	Predominant Ecoregion ^[a]	Area in selected ecoregion (%)
1	06814000	Turkey Creek near Seneca, KS	713.83	50	WCB	100%
2	06821500	Anikaree River at Haigler, NE	5622.58	50	High Plains	100%
3	06823500	Buffalo Creek near Haigler, NE	488.21	50	High Plains	100%
4	06827000	South Fork Republican River near CO-KS State Line, KS	5313.84	50	High Plains	100%
5	06828500	Republican River at Stratton, NE	21006.47	50	High Plains	99%
6	06836500	Driftwood Creek near McCook, NE	935.01	50	CGP	83%
7	06846500	Beaver Creek at Cedar Bluffs, KS	4357.76	50	High Plains	67%
8	06847500	Sappa Creek near Stamford, NE	9855.95	50	CGP	52%
9	06847900	Prairie Dog Creek above Keith Sebelius Lake, KS	1536.19	50	CGP	62%
10	06860000	Smoky Hill River at Elkader, KS	9033.35	50	High Plains	90%
11	06861000	Smoky Hill River near Arnold, KS	12897.80	50	High Plains	76%
12	06863500	Big Creek near Hays, KS	1417.27	50	CGP	85%
13	06866900	Saline River near Wakeeney, KS	1801.59	50	CGP	52%
14	06867000	Saline River near Russell, KS	3856.96	50	CGP	78%
15	06871000	North Fork Solomon River at Glade, KS	2424.41	50	CGP	82%
16	06871500	Bow Creek near Stockton, KS	903.71	50	CGP	70%
17	06872500	North Fork Solomon River at Portis, KS	6217.07	50	CGP	92%
18	06873000	South Fork Solomon River above Webster Reservoir, KS	2698.83	50	CGP	71%
19	06876700	Salt Creek near Ada, KS	1056.44	50	CGP	100%
20	06878000	Chapman Creek near Chapman, KS	776.42	50	CGP	100%
21	06879650	Kings Creek near Manhattan, KS	11.51	32	Flint Hills	100%
22	06881000	Big Blue River near Crete, NE	7024.25	50	CGP	95%
23	06882000	Big Blue River at Barneston, NE	11512.53	50	CGP	86%
24	06883000	Little Blue River near Deweese, NE	2573.64	50	CGP	100%
25	06884000	Little Blue River near Fairbury, NE	6133.18	50	CGP	100%
26	06884025	Little Blue River near at Hollenberg, KS	7171.95	32	CGP	100%
27	06884200	Mill Creek at Washington, KS	908.41	50	CGP	100%
28	06884400	Little Blue River near Barnes, KS	8655.96	50	CGP	100%

Map index	USGS Station Code	USGS Streamgauge Name	Drainage area (km ²)	Period of record (yrs)	Predominant Ecoregion ^[a]	Area in selected ecoregion (%)
29	06885500	Black Vermillion River near Frankfort, KS	1062.87	50	WCB	100%
30	06888500	Mill Creek near Paxico, KS	842.35	50	Flint Hills	100%
31	06889200	Soldier Creek near Delia, KS	385.66	50	Flint Hills	65%
32	06889500	Soldier Creek near Topeka, KS	748.58	50	WCB	52%
33	06890100	Delaware River near Muscotah, KS	1131.97	32	WCB	100%
34	06892000	Stranger Creek near Tonganoxie, KS	1092.72	50	WCB	56%

^[a]WCB = Western Corn Belt, CGP = Central Great Plains

Table 2

Kendall tau and Sen's slope for trends in precipitation and temperature (WYs 1962–2012). Trend significance indicated at $p=0.05^{**}$ and $p=0.10^{*}$. (n.d. = no data)

Station Name	COOP Station ID	Period of Record	Ecoregion	Precipitation		Temperature	
				Kendall tau	Sen's slope (mm/50 yr)	Kendall tau	Sen's slope ($^{\circ}\text{C}/50\text{ yr}$)
Tribune	148235	1962–2012	High Plains	0.19**	1.97	0.07	0.70
St. Francis	147093	1962–2012	High Plains	–0.01	–0.15	–0.21**	–2.13
Colby	141699	1962–2012	High Plains	0.21**	2.18	0.19	2.00
McCook	255310	1962–2012	Central Great Plains	0.24**	2.44	0.01	0.15
Oberlin	145906	1962–2012	Central Great Plains	0.04	0.41	–0.26**	–2.70
Wakeeney	148495	1962–2012	Central Great Plains	0.04	0.37	0.32*	3.33
Phillipsburg	146378	1962–2012	Central Great Plains	–0.01	–0.11	–0.15**	–1.56
Minden	255565	1962–2012	Central Great Plains	n.d.	n.d.	–0.04	–0.44
Hays	143527	1962–2012	Central Great Plains	0.09	0.96	0.28*	2.92
Minneapolis	145363	1962–2012	Central Great Plains	0.17*	1.75	0.06	0.58
McPherson	145152	1962–2012	Central Great Plains	0.14	1.43	–0.10	–1.04
Manhattan	144972	1962–2012	Flint Hills	0.05	0.55	0.04	0.36
Beatrice	250622	1962–2011	Western Corn Belt	0.26**	2.70	–0.34**	–3.40
Horton	143810	1962–2012	Western Corn Belt	0.05	0.49	0.01	0.11
Lawrence	144559	1962–2012	Central Irregular Plains	–0.06	–0.60	–0.06	–0.65
Ottawa	146128	1962–2012	Central Irregular Plains	0.06	0.57	0.05	0.47
Atchison	140405	1962–2012	Central Irregular Plains	–0.03	–0.31	0.08	0.81

Table 3

Trends (Sen's slope) in mean annual values for weather stations (precipitation, temperature) and corresponding USGS streamgages in the Kansas River Basin, and correlations (R) between flow and weather trends. Trend significance indicated at $p=0.05^{**}$ and $p=0.10^{*}$.

Map index	USGS Station Code	Streamflow Trend (mm/50 yr)	Weather Station	Precipitation Trend (mm/50 yr)	Temperature Trend ($^{\circ}\text{C}/50\text{ yr}$)
7	06846500	-4.71**	St. Francis	-0.15	-2.13**
13	06866900	3.09**	Colby	2.18**	2.00**
14	06867000	-1.27	Wakeeney	0.37	3.33*
15	06871000	-0.83	Oberlin	0.41	-2.70**
23	06882000	-0.34	Beatrice	2.70**	-3.40**
30	06888500	0.05	Manhattan	0.55	0.36
34	06892000	0.31	Horton	0.49	0.11
34	06892000	0.31	Atchison	-0.31	0.81
Pearson correlation coefficient (R)				0.63	0.41

Table 4

Mean trends (Kendall tau, 1962–2012) of ecohydrological indicators for streamgages in the Kansas River Basin at which Plains Minnow or Common Shiner were either “Absent” or “Present” (2000–2012) after being present historically (1860–1950). Trend significance indicated at $p = 0.05$ ** and $p = 0.10$ *.

	Plains Minnow			Common Shiner		
	Absent (tau) n=14	Present (tau) n=2	p value	Absent (tau) n=7	Present (tau) n=4	p value
Annual volume	-0.237	-0.033	0.095*	-0.044	-0.037	0.933
Center of timing of annual flow	-0.080	-0.028	0.216	-0.143	0.042	0.025**
Mean spring daily discharge	-0.125	0.052	0.308	0.092	0.005	0.333
Mean summer daily discharge	-0.190	-0.021	0.088*	-0.067	0.011	0.357
Mean autumn daily discharge	-0.189	-0.094	0.179	-0.038	-0.069	0.697
Mean winter daily discharge	-0.142	-0.014	0.150	0.091	-0.013	0.211
October	-0.117	-0.037	0.175	0.016	-0.049	0.278
November	-0.132	-0.095	0.640	0.007	-0.029	0.519
December	-0.127	-0.014	0.165	0.060	0.003	0.465
January	-0.089	-0.009	0.256	0.113	0.020	0.355
February	-0.132	-0.023	0.168	0.057	-0.053	0.185
March	-0.143	-0.004	0.234	0.061	-0.065	0.075*
April	-0.086	0.057	0.102*	0.115	0.028	0.343
May	-0.097	0.039	0.247	0.106	0.012	0.220
June	-0.137	-0.013	0.151	0.015	0.002	0.829
July	-0.113	0.020	0.012**	0.003	0.006	0.965
August	-0.064	-0.012	0.216	0.011	0.015	0.952
September	-0.137	-0.036	0.082*	-0.022	-0.042	0.781
1-day min. flow	-0.019	-0.020	0.971	0.037	0.051	0.859
3-day min. flow	-0.019	-0.003	0.721	0.052	0.057	0.954
7-day min. flow	-0.025	0.002	0.554	0.053	0.049	0.953
30-day min. flow	-0.063	0.028	0.105*	0.049	0.013	0.604
90-day min. flow	-0.114	-0.026	0.147	0.002	-0.027	0.707
1-day max. flow	-0.201	-0.036	0.081*	-0.110	0.035	0.095*

	Plains Minnow			Common Shiner		
	Absent (tau) n=14	Present (tau) n=2	p value	Absent (tau) n=7	Present (tau) n=4	p value
3-day max. flow	-0.220	-0.029	0.109	-0.104	-0.011	0.255
7-day max. flow	-0.228	-0.054	0.208	-0.103	-0.034	0.399
30-day max. flow	-0.237	-0.069	0.166	-0.094	-0.055	0.616
90-day max. flow	-0.237	-0.037	0.034**	-0.065	-0.073	0.914
Zero-flow days	0.079	0.025	0.433	-0.032	0.048	0.351
Baseflow	-0.002	-0.017	0.728	0.067	0.066	0.996
Date of min. flow	0.077	0.006	0.412	0.049	0.052	0.932
Date of max. flow	-0.085	-0.104	0.890	-0.147	-0.031	0.090*
Low-flow pulse count	0.024	0.005	0.636	-0.090	-0.087	0.953
Low-flow pulse duration	0.086	-0.035	0.330	0.098	-0.005	0.211
High-flow pulse count	-0.220	-0.029	0.109	-0.104	-0.010	0.255
High-flow pulse duration	-0.069	0.050	0.339	0.022	0.003	0.785
Rise rate	-0.171	-0.025	0.034**	-0.061	-0.034	0.732
Fall rate	0.202	0.002	0.015**	0.054	-0.034	0.270
Reversals	-0.016	0.160	0.006**	0.152	0.064	0.454