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Changes in Streamflow Statistics and Catchment Land Uses Across Select USGS Gages in Northwest and West-central Arkansas

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Abstract: Since 1901, heavy rainfall events have increased in the United States in both intensity and frequency, and human population in the United States has increased, resulting in significant land use changes. Both trends contribute to an increase in observed flood magnitude and frequency. To determine if a relationship exists between land use/land cover and changing stream flows in northwest Arkansas, this study analyzed temporal changes in various flow statistics for 14 stream gages and compared the rates of change in flow statistics from gages on streams with watersheds that have varying land uses, i.e., urban, agricultural, and undeveloped. Mann-Kendall analysis was used to determine statistically significant changes in flow statistics, which were then compared to National Land Cover Dataset (NLCD) watershed land uses from 2001 and 2019. All analyzed gages had one or more flow statistics with at least a moderately significant increase, and all analyzed flow statistics showed at least moderately significant streamflow increases at two or more gages ($P < 0.100$). There were no decreases of any significance in any flow statistic at any gage. In general, urban land development did not happen on native prairies and forests but on previously agricultural land. Significant positive relationships were found between maximum yearly flow and 2019 urban land use, urban land use change from 2001 to 2019, and 2019 Human Development Index (HDI). A similar relationship was found to exist between yearly minimum flow and 2019 HDI. These results highlight the importance of considering the cost of potential stream bank erosion and flooding in future land use planning, permitting, and zoning.

Keywords: *streamflow statistics, days exceeding floods, land use, northwest Arkansas*

Flooding often causes extensive damage, so it is one of the major weather and climate disaster types tracked by the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Information. In the United States, flooding takes 88 lives (NOAA 2021) and does $17 billion dollars of damage (FEMA 2020) annually. While deaths and cost of damage are the most common measures of flood damage, flood damage can cause utility outages, disrupt transportation and supply chains, and result in environmental problems like pollution.

Flood damage can be categorized into direct and indirect damage, then further differentiated by being tangible or intangible (Merz et al. 2010). Direct damage comes from physical contact with flood water, while indirect damage occurs outside of the flood location and/or time and is caused by direct damage. Tangible damage can be assessed in monetary value, while intangible damage cannot be assigned a value. Direct, tangible damage includes damage to buildings, property, and infrastructure. Direct, intangible damage includes loss of life and destruction of ecosystems. Indirect, tangible damage includes the disruption of transportation and other services outside of the flooded area because of direct damage to roads and infrastructure. Indirect, intangible damage includes

Research Implications

- The most prominent land use change across these watersheds appeared to be conversion of pasture to urban.
- Streamflow generally increased across all the selected United States Geological Survey (USGS) stream gages, and no statistics showed a significant decrease across the gages.
- Significant increases in streamflow were typically correlated with urban land use and or change in urban land use over time.
- The growing urban areas need to consider how increasing streamflow influence bank stability and potential flooding and frequency downstream.

psychological trauma and distrust in authorities. Often, commercial structures represent half of the monetary damages in flood prone zones (Shultz 2017). Regardless of how they are classified, the many types of flood damage have major economic, social, and environmental costs.

Flooding occurs when runoff exceeds the capacity of natural channels and manmade stormwater conveyance systems. Rainfall intensity, duration, and frequency influence runoff from the landscape, which occurs when rainfall exceeds interception, infiltration, evapotranspiration, and storage capacity. Due to climate change, temperatures are rising, and in turn, evaporation rates are also rising (Lin et al. 2017; UCAR 2021). In fact, atmospheric moisture in the United States is increasing at 5% per decade, which is expected to cause more precipitation and therefore more flooding (Trenberth 1998). The excess water vapor will likely increase precipitation outside of the subtropics (Dai et al. 2018) including temperate areas.

Although rainfall is a major factor that affects runoff rates across large spatial scales, runoff is also affected by local land use and factors such as land use change and/or development and resulting changes in vegetation cover, land slope, soil type and conditions, and impervious surfaces (USGS 2019). Removal of vegetation, compaction of soil, and increases in impervious surfaces increase runoff by lessening infiltration of rainfall into the soil. Grading a development site can either decrease runoff by decreasing land slopes, which increases time for infiltration to occur, or increase runoff by removing natural storage basins (NJDEP 2016).

Changes in land use, specifically involving urban development and conversion of forest to agricultural land, change the infiltration and storage capacity of a landscape. Urbanization increases impervious surfaces, which can cause flooding, channel degradation, and ecosystem disruption (Booth et al. 2002; Brown et al. 2005), “unless measures are taken to detain the runoff and control the rate of discharge off of newly developed sites” (City of Rogers 2018). Many states and municipalities require development sites to ensure post-developed runoff rates are less than pre-developed runoff rates for a few specific storm events (e.g., 1- and/or 2-year, 24-hour storms; USEPA 2011). In theory, this should prevent increased flooding due to land development, but runoff calculation models are not perfect, and changing precipitation patterns are not necessarily considered.

Flooding frequency has increased by 2.5 times in northern mid-latitudes since the 2000’s (Najibi and Devineni 2018), and flooding magnitude and frequency have also increased specifically in the United States (Berghuijs et al. 2017). This begs the question, which factors (precipitation or land use) that affect runoff, or both, is the major cause of the increased flooding? Since 1901, heavy rainfall events have increased in the United States in both intensity and frequency (Easterling et al. 2017), and population in the United States has increased, resulting in significant land use changes (Loveland et al. 2002). This study will evaluate discharge data from streams whose watersheds have experienced significant change in land use along with discharge data from streams whose watersheds have experienced little land use change. Specifically, changes in flow statistics were analyzed at each site in northwest Arkansas (NWA), including:

- number of days per year when mean daily flow surpassed given thresholds of moderate and severe flooding, and
- various annual flow statistics, including mean, selected percentiles, and peakflow.

This study analyzed changes in flow statistics over time for individual stream gages and compared rates of change in flow statistics for gages on streams with watersheds that have varying land uses, i.e., urban, agricultural, and undeveloped.

While this study focuses on changes in high flows, changes in low flows were also analyzed. Low flow is defined by the EPA as "flow of water in a stream during prolonged dry weather" (USEPA 2021). These low flows are not derived from direct runoff, but rather provided by groundwater discharge, subsurface return flows, surface discharge from lakes and marshes, or even melting glaciers in select regions (Smakhtin 2001). Low flows caused by groundwater recharge and subsurface return flows, which is the most prevalent low flow source in the study area, are affected by soil series distribution and infiltration, hydraulic characteristics of aquifers, evapotranspiration from the watershed, topography, and climate (Smakhtin 2001). Understanding changes in low and high flows are important for managing water supply, stormwater, waste-load allocation, reservoir storage, recreation, and wildlife conservation (Smakhtin 2001), as well as educational opportunities (Hutton and Allen 2021) and research needs (Bilotta and Peterson 2021).

Methods

Study Site Description

Data were obtained from 14 United States Geological Survey (USGS) stream gages across NWA and northeast Oklahoma using the National Water Information System (NWIS) where most of the drainage areas were in NWA (Table 1). The watersheds ranged in size from 18 km^2 (Jack Creek near Winfrey, AR USGS Site 07250974) to 1627 km^2 (Illinois River near Watts, OK USGS Site 07195500). The entirety of the period of record for each gage was used, with the longest continuous period of record being water years 1956 to 2021 (Illinois River near Watts, OK USGS Site 07195500). Some gages had gaps in their periods of record, such as Kings River near Berryville, AR (USGS Site 07050500) with a record of 1952 to 1975 and 1993 to 2021. The watersheds are primarily in Environmental Protection Agency (EPA) level 3 ecoregions Boston Mountains (38) and Ozark Highlands (39) (USEPA 2003).

Flow Statistics

Data were obtained for the 14 USGS stream gages using the NWIS (http://waterdata.usgs.gov). The average flow of each day (i.e., the mean daily discharge) from each gage was used to calculate each water year's maximum, minimum, mean, 10th percentile, 25th percentile, median, 75th percentile, and 90th percentile flow, and the number of days that had a mean flow meeting or exceeding the 1.01-year, 2-year, and 5-year flood event. These metrics will, hereafter, be referred to as the flow statistics.

The discharge for each return interval was calculated using a Log-Pearson III distribution. This distribution was chosen over a log-normal distribution because when both distribution types were plotted on log-normal and probability graph paper using the West Fork of the White River near Fayetteville data (USGS Site 07048550), the Log-Pearson III distribution fit the data better. Another reason this distribution was chosen is that it works for data with any skewness (Haan 1994). The Log-Pearson III distribution was used for each gage to maintain consistency, and the equation is:

$$\ln(X_t) = \ln(\overline{X}) * (1 + C_v K_t)$$

where X_t is the discharge of a flood with a t return period, $\overline{X}$ is the mean of the maximum yearly discharges, C_v is the coefficient of variation, and K_t is a frequency factor based on the return period, t, and coefficient of skewness, C_s.

$$C_v = \frac{\ln(\sigma)}{\ln(\overline{X})}$$

$$C_s = \frac{n\Sigma[\ln(X_i) - \ln(\overline{X})]^3}{(n - 1)(n - 2)\sigma^3}$$

where σ is the sample standard deviation of X, n is the number of water years, and X is the set of all observed maximum annual discharge. It should be noted that Log-Pearson III distribution equation used by Haan (1994) differs from USGS's Bulletin 17B Log-Pearson III distribution equation.

After the flows for each return interval were calculated, the Mann-Kendall test was used to determine if there was a trend with time in each of the flow statistics. The following steps were used to run each Mann-Kendall test:

1. List the specific flow statistics in chronological order, $x_1, x_2, \ldots, x_n$.
2. Determine if the difference $x_j - x_k$, called a pairwise comparison, is positive or negative, where j > k.

Table 1. Study site description including U.S. Geological Survey (USGS) gage name and number, latitude and longitude, watershed area, hydrologic unit code (HUC), ecoregion, and period of record used in stream flow analysis.

Gage Name	USGS Site Number	Latitude Longitude	Area (km^2)	HUC 8	Level 3 Ecoregion(s)	Period of Record
Flint Creek	07195800	36°15'22" 94°26'01"	38.5	11110103 Illinois	Ozark Highlands	1962-2021
Flint Creek	07195855	36°12'58" 94°36'19"	146.5	11110103 Illinois	Ozark Highlands	1980-2021
Frog Bayou	07250965	35°43'20" 94°06'49"	143.9	11110103 Frog-Mulberry	Boston Mountains	2001-2021
Illinois River	07194800	36°06'11" 94°20'40"	432.6	11110103 Illinois	Boston Mountains Ozark Highlands	2002-2021
Illinois River	07195500	36°07'48" 94°34'19"	1627.3	11110103 Illinois	Boston Mountains Ozark Highlands	1956-2021
Jack Creek	07250974	35°42'16" 94°05'30"	18.1	11110103 Frog-Mulberry	Boston Mountains	2002-2021
Jones Creek	07250935	35°44'09" 94°06'11"	53.1	11110103 Frog-Mulberry	Boston Mountains	2001-2021
Kings River	07050500	36°25'38" 93°37'15"	1366.2	11010001 Beaver Reservoir	Boston Mountains Ozark Highlands	1952-1975 1993-2021
Lee Creek	07249800	35°33'57" 94°31'55"	624.8	11110104 Kerr Reservoir	Boston Mountains	2000-2021
Mulberry River	07252000	35°34'37" 94°00'55"	966.0	11110201 Frog-Mulberry	Boston Mountains	1953-1995 1998-2021
Osage Creek	07195000	36°13'19" 94°17'18"	335.9	11110103 Illinois	Ozark Highlands	1953-1975 1996-2021
War Eagle Creek	07049000	36°12'00" 93°51'18"	684.1	11010001 Beaver Reservoir	Boston Mountains Ozark Highlands	1952-1970 1999-2021
West Fork	07048550	36°03'14" 94°04'59"	317.80	11010001 Beaver Reservoir	Boston Mountains Ozark Highlands	2002-2021
White River	07048600	36°04'23" 94°04'52"	1031.5	11010001 Beaver Reservoir	Boston Mountains Ozark Highlands	1963-1995 1999-2021

3. Compute S, where S equals total number of positive pairwise comparisons minus total number of negative pairwise comparisons.
4. Compute τ, where $\tau = S/[n(n-1)/2]$, n = number of data points.
5. Compute the standard deviation, σ_s, where $\sigma_s = \text{sqrt}[(n/18)(n-1)(2n+5)]$.
6. Compute the Z score, $Z\tau$, where $Z\tau = (|S|-1)/\sigma_s$.
7. Determine the corresponding p value for $Z\tau$ based on a two-tailed standard normal distribution.

These steps were followed using Microsoft Excel for one site, and then automated using the programming language "R" with the tidyverse, rkt, and ggplot2 packages loaded from the R library.

Different α values were used to suggest different levels of significance. The α values were set to 0.01 for "highly significant" trends, 0.05 for "significant" trends, and 0.10 for "moderately significant" trends (Stogner 2000). The rate of change for each flow statistic was calculated using Theil-Sen Slope, which takes the median slope of the set of slopes between every combination of data points (Helsel et al. 2020). The Theil-Sen Slope was then converted into a percent change per year by dividing the Theil-Sen Slope by the mean value of the flow statistic.

Watersheds and Land Use Percentages

To obtain land use and land cover (LULC) data on each gage's watershed, the web toolkit Wikiwatershed and Model My Watershed (Stroud Water Research Center 2021) was used. The coordinates of each gage, as published by the USGS, were entered into Model My Watershed's search function. Often, this resulted in a location that was near, but not located exactly on, a bridge crossing over the stream. In such cases, it was assumed that the gage was on the bridge.

Once the exact location of the gage was determined, Model My Watershed was used to delineate the watershed of each gage. Model My Watershed reports LULC data from the National Land Cover Dataset (NLCD) for the delineated watershed. The oldest (2001) and newest (2019) NLCD data were used to calculate the land use percentages for each watershed and the land use change from 2001 to 2019 for each watershed.

The NLCD divides LULC into sixteen classifications. Those classifications were grouped into three basic LULC types to be analyzed. Open water, perennial ice/snow, deciduous forest, evergreen forest, mixed forest, shrub/scrub, woody wetlands, and emergent herbaceous wetlands were said to be "undeveloped." Barren land (rock/sand/clay), developed open space, low intensity, medium intensity, and high intensity were said to be "urban." Finally, pasture/hay (including grassland/herbaceous) and cultivated crops were said to be "agricultural" land use. A Human Development Index (HDI) was calculated by adding urban land use and agricultural land use percentages.

The percent change per year in each flow statistic with a moderate level of significance or greater ($\alpha < 0.10$) was paired with the land use percentages and the change in percentages in land use for each watershed, and linear regression was run using the Analysis ToolPak in Microsoft Excel. As with changes in the flow statistics, different α values were used to suggest different levels of significance, as previously defined.

Results and Discussion

Land Use and Changes

Based on the 2001 NLCD, the study watersheds had urban land use percentages ranging from 1.8% (Jack Creek near Winfrey, AR USGS Site 07250974) to 28.3% (Osage Creek near Elm Springs USGS site 07195000) with an arithmetic mean (hereafter referred to as average) of 7.9%. The agricultural land use in 2001 ranged from 4.6% (Mulberry River near Mulberry USGS site 07252000) to 60.6% (Flint Creek at Springtown, AR USGS site 07195800), with an average of 30.1%. When looking at combined human development, Osage Creek near Elm Springs had the highest HDI in 2001, in addition to the highest urban land use at 85.9%, while the Mulberry River near Mulberry (USGS site 07252000) had the lowest 2001 HDI at 7.5%. The average HDI was 38.0%, showing that in 2001 there was more undeveloped area on average across these watersheds than area manipulated by humans.

For the 2019 NLCD data, urban land use percentages ranged from 1.9% (Jack Creek near Winfrey, AR USGS site 07250974) to 42.3% (Osage Creek near Elm Springs USGS site

07195000) with an average of 9.9%. Agricultural land use in 2019 ranged from 5.5% (Mulberry River near Mulberry USGS site 07252000) to 62.3% (Flint Creek at Springtown, AR USGS site 07195800) with an average of 28.9%. HDI in 2001 ranged from 8.6% (Jack Creek near Winfrey, AR USGS site 07250974) to 87.7% (Osage Creek near Elm Springs USGS site 07195000) with an average of 38.7%. In 2019, as in 2001, the average watershed had less developed land (urban plus agriculture) at 38.7% than undeveloped land. The watershed with the maximum and minimum of each of the land use categories discussed was the same in 2019 as 2001, except for the minimum HDI occurring in the Jack Creek watershed instead of the Mulberry watershed.

Urban land use increased in all study watersheds from 2001 to 2019. Seven of the watersheds showed a small increase (< 1%) in urban land use, while three watersheds showed moderate increase (1.0 - 2.3%). The remaining two watersheds showed the largest increases in urban land use at 5.1% (Illinois River near Watts, OK USGS site 07195500) and 13.9% (Osage Creek near Elm Springs USGS site 07195000).

The agricultural land use from 2001 to 2019 generally decreased, with larger losses of 12.2% and 4.3% occurring in the watershed of Osage Creek near Elm Springs (USGS site 07195000) and Illinois River near Watts, OK (USGS site 07195500), respectively. The remaining watersheds had agricultural land use changes ranging from a decrease of 0.5% to an increase of 1.7%. The two watersheds with the largest increase in urban land use also had the largest decrease in agricultural land use, with the increase in urban land being very similar in magnitude to the decrease in agricultural land. These data suggest that urban development is primarily occurring in previously agricultural lands – not previously undeveloped lands. The same conclusion is drawn when examining the change in HDI.

The maximum change in HDI from 2001 to 2019 was 3.1% (Flint Creek at Springtown, AR USGS site 07195800), while all other watersheds had a change in HDI of 1.7% or less, including four watersheds with minor decreases in HDI (≤ 0.4%). The relatively low changes in HDI (and hence relatively low changes in undeveloped land) compared to the changes in urban and agricultural land suggest that urban development is occurring in land that was previously developed by humans (agricultural land) more than in existing undeveloped lands. In fact, the average increase in urban land use per watershed of 2.0% is likely due to an average 1.2% loss of agricultural land but only 0.8% loss of undeveloped land. However, watersheds with increased urban development have been estimated to have reduced ecosystem services and value, especially if HDI increases over time (Gashaw et al. 2018).

Flow Statistics

The changes overtime of 11 flow statistics at 14 sites were analyzed, showing 65 of the 154 possible changes to be at least moderately significant. All 65 of the at least moderately significant changes in the flow statistics were increases; no decreases were observed over the study period. Every gage that was analyzed had at least one flow statistic that increased with at least moderate significance.

Three sites had only one flow statistic that increased significantly over the period analyzed. Each of the three increasing flow statistics were related to high flows or flooding frequency. The 75th percentile in flows at Jones Creek at Winfrey, AR (USGS Site 070250935) increased by 5% per year from 2001 to 2021. The maximum flow at Flint Creek at Springtown, AR (USGS site 07195800) increased 0.8% per year from 1962 to 2021. The number of days where flows met or exceeded the 1.01-year flood at Lee Creek at Short, OK (USGS Site 07249800) increased 3.9% per year from 2000 to 2021.

Only two gages showed significant changes in the occurrence of the 2-year flood and 5-year flood. This is likely because the period of record that was analyzed was not long enough to show significant changes in such rare events. Because of this, the occurrences of the 2-year flood and the 5-year flood were not included in Table 3 or analyzed against watershed land use.

Three sites had at least moderately significant increases in every flow statistic. Osage Creek near Elm Springs (USGS Site 07195000) had highly significant changes in each of the flow statistics; however, its annual percent changes were moderate, ranging from 1.2% per year (75th

Table 2. Watershed land use percentages and change for each site from 2001 to 2019 (Undev is undeveloped land use, Urban is developed land uses, Agr is agricultural land use, and HDI = sum of Urban and Agr).

	NLCD 2001				NLCD 2019				2001-2019 Change			
Name Site Number	**Undev**	**Urban**	**Agr**	**HDI**	**Undev**	**Urban**	**Agr**	**HDI**	**Undev**	**Urban**	**Agr**	**HDI**
Flint Creek 07195800	32.9%	6.5%	60.6%	67.1%	29.8%	7.9%	62.3%	70.2%	-3.1%	1.4%	1.7%	3.1%
Flint Creek 07195855	32.3%	9.7%	58.0%	67.7%	30.7%	11.6%	57.8%	69.3%	-1.7%	1.8%	-0.2%	1.7%
Frog Bayou 07250965	89.0%	2.2%	8.8%	11.0%	89.2%	2.3%	8.6%	10.8%	0.2%	0.1%	-0.3%	-0.2%
Illinois River 07194800	40.4%	8.1%	51.5%	59.6%	40.0%	10.4%	49.7%	60.0%	-0.5%	2.3%	-1.8%	0.5%
Illinois River 07195500	33.2%	15.0%	51.8%	66.8%	32.4%	20.1%	47.5%	67.6%	-0.9%	5.1%	-4.3%	0.9%
Jack Creek 07250974	91.0%	1.8%	7.2%	9.0%	91.4%	1.9%	6.8%	8.6%	0.4%	0.0%	-0.4%	-0.4%
Jones Creek 07250935	88.4%	2.7%	8.9%	11.6%	88.6%	2.9%	8.6%	11.4%	0.2%	0.2%	-0.4%	-0.2%
Kings River 07050500	67.8%	4.9%	27.4%	32.2%	67.1%	5.1%	27.8%	32.9%	-0.6%	0.2%	0.4%	0.6%
Lee Creek 07249800	86.4%	2.8%	10.8%	13.6%	86.9%	2.8%	10.3%	13.1%	0.5%	0.1%	-0.6%	-0.5%
Mulberry River 07252000	92.5%	2.9%	4.6%	7.5%	91.2%	3.3%	5.5%	8.8%	-1.3%	0.4%	0.9%	1.3%
Osage Creek 07195000	14.1%	28.3%	57.6%	85.9%	12.3%	42.3%	45.4%	87.7%	-1.7%	13.9%	-12.2%	1.7%
War Eagle Creek 07049000	60.7%	5.1%	34.2%	39.3%	59.2%	5.5%	35.3%	40.8%	-1.5%	0.4%	1.1%	1.5%
West Fork 07048550	65.3%	13.5%	21.2%	34.7%	64.8%	14.5%	20.7%	35.2%	-0.5%	1.0%	-0.5%	0.5%
White River 07048600	74.7%	7.0%	18.3%	25.3%	74.3%	7.6%	18.1%	25.7%	-0.4%	0.5%	-0.2%	0.4%

and 90th percentiles) to 1.8% (minimum yearly flow). War Eagle Creek near Hindsville (USGS Site 07049000) and the Illinois River near Watts, OK (USGS Site 07195500) also had significant increases in each flow statistic. These two sites also had moderate annual percent changes ranging from 0.6% (Illinois River yearly maximum flow) to 1.4% (War Eagle Creek yearly minimum flow). Despite each of these watersheds having statistically significant increases across their flow regimes, the magnitude of increases were less than the significant increases of Frog Bayou at Winfrey (USGS Site 07250965), Illinois River at Savoy (USGS Site 07194800), Jones Creek at Winfrey, AR (USGS Site 07250935), and the West Fork of the White River East of Fayetteville (USGS Site 07048550). These sites had percent changes per year in various flow statistics ranging from 3.0 to 5.0% per year.

Of the sites that have several, but not all, significant increases in flow statistics, most significant changes were grouped in either high flows (75th percentile, 90th percentile, occurrence of the one-year flood, and yearly maximum flow) or low flows (yearly minimum flow, 10th percentile, and 25th percentile). Frog Bayou at Winfrey (USGS Site 07250965) and the West Fork of the White River East of Fayetteville (USGS Site 07048550) had significant increases in high flows. Flint Creek near West Siloam Springs (USGS Site 07195855), Illinois River at Savoy (USGS Site 07194800), and Jack Creek near Winfrey (USGS Site 07250974) had significant increases in low flows. The cutoff between high and low flows was the median flow, and median flow was the statistic that had the least number of significant changes (3 sites out of 14).

Relationship between Flow Statistics and Land Use

Annual percent changes in the flow statistics that were at least moderately significant were compared with several land use measures in their watersheds: percent urban in 2019, change in percent urban from 2001 to 2019, and HDI in 2019. The change in HDI from 2001 to 2019 was not included because the changes were relatively small compared to the other land use measures, as previously discussed.

The maximum yearly flow had a significant relationship with all three different land use statistics tested. The percent change per year in maximum yearly flow was significantly positively correlated to urban percent change from 2001 to 2019 ($p = 0.04$), as shown in Figure 1. The percent increase per year in maximum flows ranged between 0.2 and 1.5%, while the urban percent increase ranged from 0.2 to 13.9%. The slope of the relationship was 0.068, suggesting that increasing urban land use by 1% corresponds to a 0.068% increase per year in maximum flows. This relationship had one gage (Osage Creek near Elm Springs USGS Site 07195000) with a percent change per year in maximum flow and change in urban area of its watershed that were notably higher than those of every other gage in the comparison.

The percent change per year in maximum flow was also significantly positively correlated to the urban percentage of its watershed ($p = 0.04$). The range in percent changes per year in maximum flows was previously noted, while urban land use in 2019 ranged from 3.3 to 42.3%. The slope of the relationship was 0.024, suggesting that a 1% increase in urban land use from one watershed to another corresponds to a 0.024% increase per year in maximum flows. Again, this relationship had one gage with a percent change per year in maximum flow and percent urban area of its watershed in 2019 that were notably higher than those of every other gage in the comparison (Osage Creek near Elm Springs USGS Site 07195000).

Lastly, the percent change per year in maximum flow was significantly positively correlated to the 2019 HDI of its watershed ($p = 0.04$). The same percent changes per year in maximum flows were compared to 2019 HDI, which ranged from 8.8 to 87.7%. The slope of the relationship was 0.013, suggesting that a 1% increase in HDI from one watershed to another corresponds to a 0.013% yearly increase in maximum flows. This relationship had a well spread distribution of percent change in maximum flow and 2019 HDI.

The percent change per year in minimum flow was positively correlated to the HDI of its watershed in 2019 with moderate significance ($p = 0.06$). The percent change per year in minimum flow ranged from an increase of < 0.1% to an increase of 2.4%. The slope of the relationship was 0.021, suggesting that a 1% increase in HDI

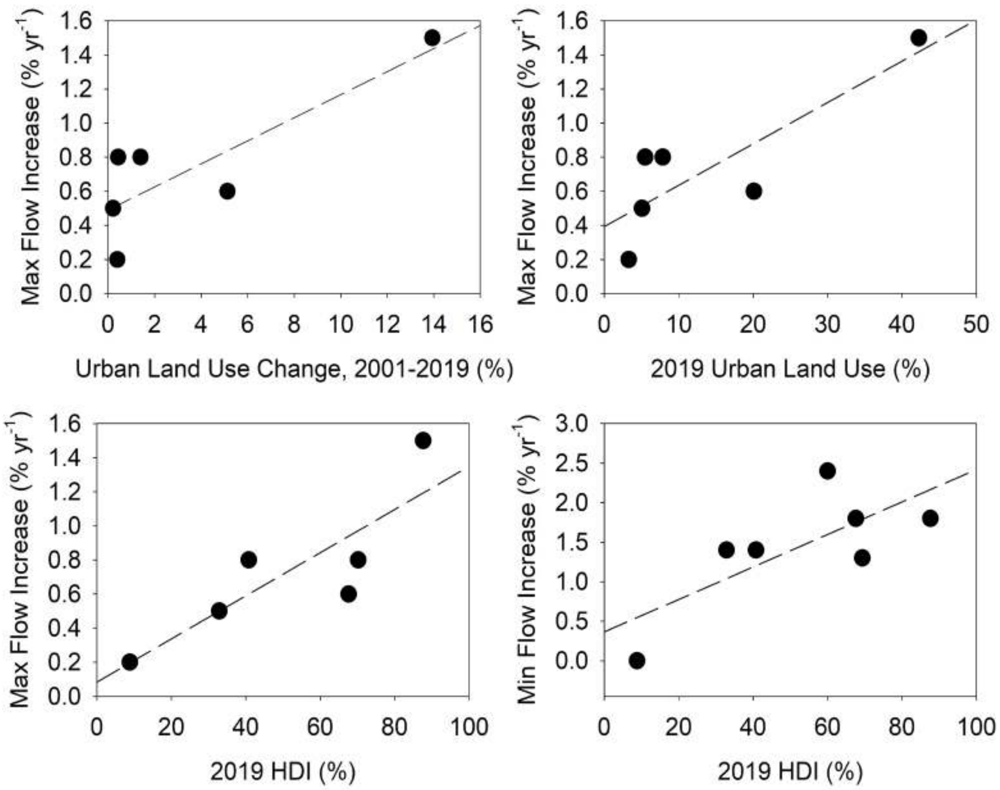

Figure 1. Significant relationships between percent change per year in minimum and maximum flow and watershed land use, including urban, urban plus agricultural (Human Development Index, HDI), and change in urban land use.

from one watershed to another corresponds to a 0.021% yearly increase in minimum flows. This relationship had one gage with a yearly percent change in minimum flow that was notably less than the rest of the gages (Mulberry River near Mulberry USGS site 07252000).

Low Flows

The initial objective of this study was to investigate high flows and flooding; however, we also found interesting trends in low flows. Various ideas exist about the effect of urbanization on baseflow in streams. One idea is that increased groundwater pumping (although not common in NWA) and decreased groundwater recharge caused by more impervious surfaces decrease baseflows (Brown et al. 2005); however, this was not observed in the study site region, as none of the analyzed gages had significant decreases in low flows (minimum, 10th percentile, and 25th percentile). It is assumed that minimum flow, 10th percentile flow, and sometimes 25th percentile flow represented baseflow conditions in these streams.

Another idea is that as populations in urban areas increase, wastewater treatment plant (WWTP) effluent can increase more than groundwater recharge decreases, therefore increasing baseflow in streams (Paul and Meyer 2001). Five out of the nine gages with significant increases in low flows have at least one if not multiple WWTPs in their watershed (Illinois River at Savoy USGS Site 07194800, Illinois River near Watts, OK USGS Site 07195500, Kings River near Berryville USGS Site 07050500, Osage Creek near Elm Springs USGS Site 07195000, and War Eagle Creek near Hindsville USGS Site 07049000).

The four gages with the largest percent increase per year in minimum flow (Illinois River at Savoy USGS Site 07194800, Illinois River near Watts, OK USGS Site 07195500, Osage Creek near Elm Springs USGS site 07195000, and Kings River near Berryville USGS site 07050500) all have at least one if not multiple WWTPs in their watersheds. As the population of the NWA

Table 3. Percent increase per year of annual flow statistics and days exceeding defined flood flows showing those that are moderately significant$^{\#}$ ($p < 0.1$), significant$^{\$}$ ($p < 0.05$), and highly significant* ($p < 0.01$), and the 1.01-year flood flow (as calculated).

Name Site Number	Min	Mean	Max	Percentiles 10th	 25th	 Median	 75th	 90th	1.01-Yr Flood Days	1.01-Yr Flow (cfs)
Flint Creek 07195800			0.8%$^{\#}$							53
Flint Creek 07195855	1.3%$^{\#}$			1.2%$^{\#}$	1.2%$^{\#}$					194
Frog Bayou 07250965							4.8%$^{\$}$	3.5%$^{\$}$	5.4%$^{\$}$	750
Illinois River 07194800	2.4%$^{\#}$			3.6%$^{\$}$	3.7%$^{\#}$					1718
Illinois River 07195500	1.8%*	0.7%$^{\$}$	0.6%$^{\#}$	1.2%*	1.0%*	0.6%$^{\$}$	0.6%$^{\#}$	0.6%$^{\#}$	0.8%$^{\#}$	3360
Jack Creek 07250974				<0.1%$^{\#}$	4.6%$^{\#}$					71
Jones Creek 07250935							5.0%$^{\$}$			107
Kings River 07050500	1.4%*		0.5%$^{\#}$	0.8%$^{\$}$	0.7%$^{\#}$					3906
Lee Creek 07249800									3.9%$^{\#}$	2750
Mulberry River 07252000	<0.1%*	0.5%*	0.2%$^{\$}$	0.5%*	0.5%$^{\#}$		0.5%$^{\$}$	0.6%$^{\$}$	0.5%$^{\$}$	3086
Osage Creek 07195000	1.8%*	1.4%*	1.5%*	1.6%*	1.6%*	1.3%*	1.2%*	1.2%*	1.6%*	408
War Eagle Creek 07049000	1.4%*	0.9%*	0.8%$^{\$}$	1.0%*	0.7%$^{\#}$	0.7%$^{\$}$	0.9%*	0.9%*	1.1%*	2069
West Fork 07048550		3.0%$^{\$}$					3.4%$^{\#}$	3.6%$^{\$}$	3.8%$^{\#}$	1566
White River 07048600					1.3%$^{\$}$		0.6%$^{\#}$			4611

metropolitan area increased from 347,045 in 2000 to 546,725 in 2020 (United States Census Bureau 2022), WWTP effluent discharges have increased to meet the needs of the growing population. For example, Northwest Arkansas Conservation Authority (NACA) WWTP obtained permits to increase effluent from 0.5 mgd (0.8 cfs) to 3.6 mgd (5.5 cfs) in 2009 and then to 7.2 mgd (11.2 cfs) in 2021 (ADEQ 2009; Smoot 2021). Even though there is a moderately significant, positive correlation between minimum flow change and 2019 HDI, the actual cause of the minimum flow increase is likely increased WWTP effluent, not watershed land use. The significant relationship between minimum flow change and 2019 HDI is likely attributed to the fact that HDI and WWTP effluent are both influenced by population growth. It should be noted that potable water for NWA comes from Beaver Lake, which is part of the White River Basin, but then is mostly discharged from WWTPs into the Illinois River watershed, which is essentially an inter-basin transfer of water.

It is interesting to note that urban watersheds that do not receive WWTP effluent but had increases in low flows, thus other factor(s) besides WWTP effluent must outweigh decreases in infiltration due to increased impervious surfaces. Another set of possible factors that would increase low flows is leakage from waterlines, sewers, and septic systems (USEPA 2022). These factors are most applicable in areas with increasing populations, such as the watershed of Flint Creek near West Siloam Springs (USGS Site 07195855) in which water use and wastewater increased, possibly increasing leakage. In Arkansas, 38% of households use septic tanks, although this percent is likely less in the NWA metropolitan area. But, with a failure rate of 10-20% (USEPA 2002), even a smaller percentage of households using septic tanks could increase groundwater and return flows to streams. Although septic tank failure is primarily a water quality issue, it also has an impact on the quantity of soil water and groundwater, and therefore baseflow.

For watersheds that do not have WWTP effluent discharge or a high population causing significant water/wastewater system leakages but do have increases in low flows, the most likely cause of increasing minimum flow is an increase in rainfall that leads to increased infiltration and groundwater recharge. This is consistent with a 2003 study in Iowa (Schilling and Libra 2003), which found increasing rainfall contributed more to streamflow as baseflow than it did as runoff. This could have occurred in the Mulberry River near Mulberry (USGS site 07252000) and Jack Creek near Winfrey (USGS site 07250974). In NWA, total yearly rainfall, based on water year as measured at Drake Field in Fayetteville (NWS 2022), has increased with moderate significance in the long term (1952-2021, p = 0.097) and the near term (2002-2021, p = 0.081). Increased rainfall could be a factor in low flow increases in all analyzed gages, not just the three gages listed above (McCabe and Wolock 2002; Rumsey et al. 2015).

High Flows

Of the gages analyzed, seven gages had at least moderately significant increases in the number of days with flow that met or exceeded the 1.01-year flood and three gages that had at least moderately significant increases in the number of days with flow that met or exceeded the 2-year flood. This has a large impact on channel morphology, as channel forming flow generally corresponds to the 1- to 3-year flood and most closely corresponds to the 1.5-year flood (NRCS 2001; Colorado Water Conservation Board 2006). However, frequencies of these smaller flood events (i.e., bank-full events) might be better analyzed using partial-duration flood series to better understand the occurrence of these events (Edwards et al. 2019).

These increases need to be monitored and controlled because uncontrolled channel morphology can have negative socioeconomic and ecological impacts (Hauer et al. 2011; Abubakar 2013). Such impacts include loss of agricultural land, destruction of utilities, and the alteration and/or destruction of aquatic habitats (Abubakar 2013). Increased erosion of stream banks increases phosphorous loadings because phosphorous is in the streamside soil and is often adsorbed to sediments (Son et al. 2011). Also, the destruction of riparian zones reduces the filtration of phosphorous before it reaches the streams (Tillery et al. 2003). Increased phosphorous loading leads to increased algae blooms and accelerated eutrophication (Tillery et al. 2003; Son et al. 2011). Additionally, as channels move from their natural floodplains, the effects of flooding are amplified due to decreased floodwater buffering and absorption (Pierce et al. 2012; Mondal and Patel 2018). Potential mitigation strategies include restoring riparian buffers, mechanical bank stabilization, and limiting human activity that increases high flows (Harmel et al. 1999; Abubakar 2013), though Mondal and Patel (2018) write that ecological approaches have grown in popularity over artificial mechanical stabilization methods.

The flood frequency analysis yielded a flow for each recurrence interval that is representative of the likelihood that the flow was met or exceeded in any one year based on the period of record. It should be noted, however, that the flood frequency analysis used to calculate the 1.01-, 2-, and 5-year flood flows were based on annual maximum flows, some of which had significant increases over time across selected streams. This means it is likely that the flows associated with these return intervals have increased over time across these sites. This is acceptable for the purposes of this study because the calculated 1.01-, 2-, and 5-year floods were used as thresholds to measure the number of days that met or exceeded those flows; they were not used to predict the likelihood of future flood events. The flow associated with a certain recurrence interval can increase over time due to increased large storm events, climate change, and urbanization (Raff et al. 2009).

Percent change per year in maximum flow was significantly positively correlated to urban land use and HDI in 2019, as well as change in urban land use from 2001 to 2019. Maximum flows show a greater response to increased rainfall in urban-dominated watersheds than rural watersheds (Changnon and Demissie 1996). Both urban-related relationships can be explained by increased runoff-related flow due to increased impervious surfaces, alteration and reduction of vegetation which decreases initial abstraction, and drainage systems that reduce the time it takes runoff to reach streams (USGS 2019). HEC-HMS models have been used to show that increases in streamflow are directly proportional to the rate of urbanization (Amini et al. 2011). It makes sense that urban development and other changes in a watershed produce changes in flow at the mouth of the watershed. A reason that could explain why the percent of urban land use of a watershed at a single point in time was a good predictor of change in maximum flows is that, as discussed previously, the rate of runoff due to increasing precipitation is amplified by urban land use (Changnon and Demissie 1996).

The creation of urban lands is not the only way humans develop landscapes. This study's HDI is comprised of urban and agricultural land use, bringing in the influence of pastures and agricultural land management on changes in stream flow statistics. The strong relationship between 2019 HDI and change in maximum flows is likely due to changes in soil quality and compaction and changes in vegetation in agricultural lands (O'Connell et al. 2007) in addition to the factors caused by urban changes. Undeveloped forests have greater infiltration rates than cultivated fields or grazed pastures (Bharati et al. 2002), meaning a greater amount of precipitation that falls on agricultural land becomes runoff and can contribute to maximum flows than precipitation that falls on undeveloped forest land.

The Osage Creek near Elm Springs (USGS site 07195000) watershed has more than double the 2019 urban land use and change in urban land use than those of the next highest analyzed watersheds. Also, its 2019 HDI is 18% higher than the watershed with the next highest 2019 HDI. For these reasons, it is no surprise that that gage at Osage Creek near Elm Springs showed the largest percent change per year in maximum flows (of those changes that were at least moderately significant) and had highly significant increases in all analyzed flow statistics, except for the number of days with flow exceeding the 5-year flood, which was significant, not highly significant. Additionally, the watershed collects effluent discharge from three major WWTPs: NACA, Rogers, and Springdale, which helps to explain the highly significant increases in low flows in this watershed.

Conclusion

While analyzing changes in flows across their flow regimes at various gages in NWA and northeast Oklahoma, along with the land use in their watersheds, the following conclusions were made:

- All analyzed gages had one or more flow statistics with at least a moderately significant increase, and all flow statistics increased at least moderately significantly at two or more gages.

- There were no decreases of any significance in any flow statistic at any gage.
- In general, the development of urban land did not happen on undeveloped land, but instead happened on land that was previously used for agriculture.
- Increases in yearly maximum flows were positively significantly correlated to 2019 urban land use, 2001 to 2019 change in urban land use, and 2019 HDI.
- Increases in yearly minimum flows were positively correlated to 2019 HDI with moderate significance.
- The growing urban areas need to consider how increasing streamflow influence bank stability and potential flooding and frequency downstream.

The increase in maximum flows and the occurrence of certain floods is concerning because of floods' damage to human life, property, and ecosystems. Knowing the relationships between flooding, flood frequency, land use, and changes over time could help city officials in NWA plan and regulate land development changes in ways that mitigate flooding.

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