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Trends in Peak Flows of Selected Streams in Kansas

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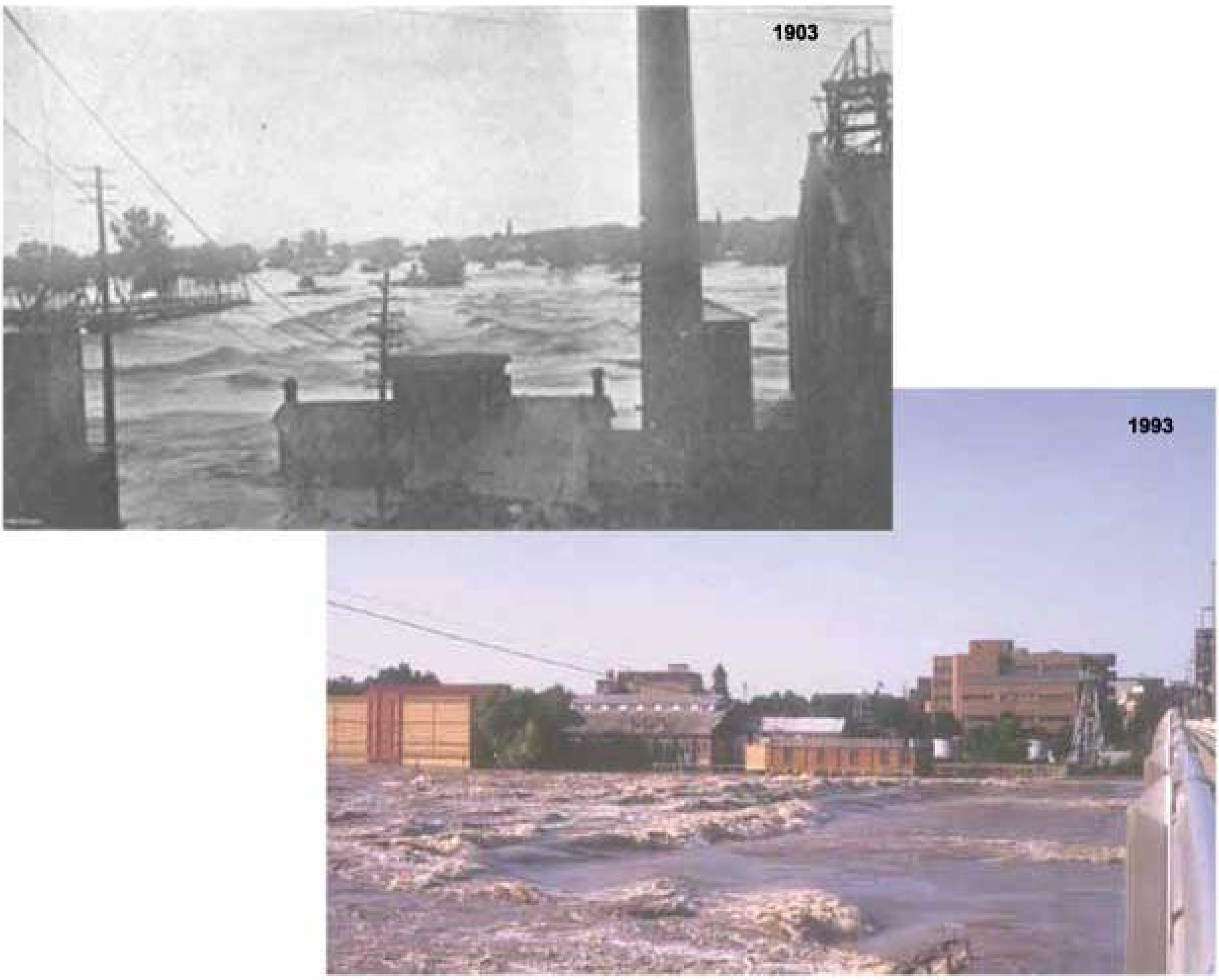

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For additional information about peak flows, please visit this Web site: http://ks.water.usgs.gov/pages/ks-flood

FIGURES

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CONVERSION FACTORS AND ABBREVIATIONS

Multiply	By	To obtain
cubic foot per second (ft /s)	0.02832	cubic meter per second
cubic foot per second per year [(ft /s)/yr]	0.02832	cubic meter per second per year
foot (ft)	0.3048	meter
inch (in.)	2.54	centimeter
mile (mi)	1.609	kilometer
million gallons per day (Mgal/d)	0.04381	cubic meter per second
square mile (miî)	2.590	square kilometer

Abstract

The possibility of a systematic change in flood potential led to an investigation of trends in the magnitude of annual peak flows in Kansas. Efficient design of highway bridges and other flood-plain structures depends on accurate understanding of flood characteristics. The Kendall's tau test was used to identify trends at 40 stream-gaging stations during the 40-year period 1958-97. Records from 13 (32 percent) of the stations showed significant trends at the 95-percent confidence level. Only three of the records (8 percent) analyzed had increasing trends, whereas 10 records (25 percent) had decreasing trends, all of which were for stations located in the western one-half of the State. An analysis of flow volume using mean annual discharge at 29 stations in Kansas resulted in 6 stations (21 percent) with significant trends in flow volumes. All six trends were decreasing and occurred in the western one-half of the State.

The Kendall's tau test also was used to identify peak-flow trends over the entire period of record for 54 stream-gaging stations in Kansas. Of the 23 records (43 percent) showing significant trends, 16 (30 percent) were decreasing, and 7 (13 percent) were increasing. The trend test then was applied to 30-year periods moving in 5-year increments to identify time periods within each station record when trends were occurring.

Systematic changes in precipitation patterns and long-term declines in ground-water levels in some stream basins may be contributing to peak-flow trends. To help explain the cause of the streamflow trends, the Kendall's tau test was applied to total annual precipitation and ground-water levels in Kansas. In western Kansas, the lack of precipitation and presence of decreasing trends in ground-water levels indicated that declining water tables are contributing to decreasing trends in peak streamflow. Declining water tables are caused by ground-water withdrawals and other factors such as construction of ponds and terraces.

Peak-flow records containing trends introduce statistical error into flood-frequency analysis. To examine the effect of trends on flood-frequency analysis, statistically significant trends were added systematically to four nontrending station records. Flood magnitudes estimated on the basis of each data series were compared. The added trends resulted in changes in the 100-year flood magnitudes of as much as 70 percent.

INTRODUCTION

There is evidence that the magnitudes of the annual peak flow for some streams in Kansas are changing. For example, annual peak-flow records for the Marmaton River in east-central Kansas (fig 1) indicated that during the 13-year period, 1985-97, the annual peak flow exceeded the 2-year flood in 9 years, the 5-year flood in 5 years, and the 25-year flood in 3 years. During the previous 13-year period, 1972-84, the annual peak flow exceeded the 2-year flood in only 4 years and the 5-year flood only once. The recurrence intervals of annual peak flows for the Marmaton River near Marmaton were estimated using the Bulletin 17B guidelines for flood-frequency analysis established by the Interagency Advisory Committee on Water Data (1982) and were based on 26 years of record from 1972-97. Recurrence interval, commonly used in hydrology to express the probability of an event, is the time interval in which an event will occur once on the average (Bedient and Huber, 1992). Conversely, in southwest Kansas, annual peak-flow records (1943-98) for Crooked Creek (fig 1) showed that the creek was frequently dry with no peak flows exceeding the 2-year flood magnitude in the last 13 years.

Trends in peak streamflow are of particular interest to State and Federal highway departments as they design highway structures in flood plains. Routine flood-frequency analysis on streams with gaging stations, as well as regional frequency-analysis procedures used at ungaged sites, rely on historical peak-flow records to estimate flood magnitudes. Frequency analysis is based on the assumption that floods are independent and identically distributed in time-that is, temporally uncorrelated and stationary. A trend in streamflow could indicate that floods are not independent, not stationary, or both, introducing an element of error into the flood-frequency analysis.

The purposes of this report, prepared by the U.S. Geological Survey (USGS) in cooperation with the Kansas Department of Transportation, are to: (1) document whether significant trends exist in the magnitudes of annual peak flows at selected stream-gaging stations in Kansas, (2) evaluate possible causes of the trends, and (3) document if these trends have a significant effect on flood magnitudes as indicated by flood-frequency analyses. For the purpose of this report, a trend is considered to be a smooth upward or downward change over several (three to six) decades. This is a relatively small window in time, representing only a part of what actually may be, over a longer period, a continuing trend or a fluctuating or cyclic pattern.

This report focuses primarily on Kansas peak-flow trends and their causes. However, peak-flow records were analyzed for stream-gaging stations in the adjoining States of Oklahoma and Nebraska to improve understanding of the regional pattern associated with trends in Kansas. Several different categories of analysis were used to identify regional and temporal trends in streamflow. First, peak flows from the same 40-year period of record, 1958-97, were considered for selected streams in Kansas, Oklahoma, and Nebraska. Then peak flows over the entire available period of record for Kansas streams were analyzed. In addition, the complete periods of record were divided into moving 30-year blocks to recognize trending cycles in peak flow. Finally, flow volumes at selected Kansas stream-gaging stations were analyzed using mean annual discharge values.

STREAMFLOW TREND ANALYSES

Kendall's Tau Test

Kendall's tau (Kendall and Gibbons, 1990) served as the statistical basis for the trend analyses presented in this report. It is a nonparametric test that can be used to indicate the likelihood of an increasing or decreasing trend over time. A nonparametric test is one that does not require a known or assumed probability distribution for the variables in question. A parametric test, like linear regression, was not considered appropriate for this report because streamflow characteristics are not normally distributed. The Kendall's tau test is rank based and does not depend specifically on the magnitudes of the data values. It is effective for identifying trends in streamflow because extreme values and skewness in the data have little effect on the outcome (Helsel and Hirsch, 1992).

Using the Kendall's tau test, the rank of each peak-flow value is compared to the rank of the values following it in the series. If the second value is consistently higher than the first, the tau coefficient is positive. If the second value is consistently lower, the tau coefficient is negative. An equal number of negative and positive values would suggest that a trend does not exist. Therefore, the tau value is a measure of the correlation between the series and time. In this report, a trend was considered to be significant if the probability (p) value (probability that a true null hypothesis of no trend is erroneously rejected) was less than or equal to 0.05. This represents a 95-percent confidence level. The slope is a measure of the magnitude of the trend.

Past studies suggest that statistically significant trends in streamflow can be difficult to detect due to relatively short periods of record (Chiew and McMahon, 1993). Furthermore, Wahl (1998) showed that, although Kendall's tau test is relatively insensitive to the presence of individual outliers, a sequence of extreme occurrences near the beginning or the end of the period of record could have a significant effect on the outcome of the Kendall's tau test. Therefore, stream-gaging-station records used in this report were examined for multiyear sequences that were wetter or dryer than normal at either end of the period of record. Although several sequences were found, they were minor and did not appear to significantly alter the overall results of the trend analysis.

Peak Flow

All the stations used in the trend analyses are listed in table 1. The first part of the peak-flow analysis used the same 40-year period of record, 1958-97, from 88 stations in Kansas, Oklahoma, and Nebraska (table 2). The second part of the peak-flow analysis used the entire period of record from all stations in Kansas that had more than 38 years of record.

Peak-flow trends were analyzed by first applying the Kendall's tau test to the instantaneous (occurring at a particular instant in time) annual peak-flow values from 40 stream-gaging stations in Kansas, 12 stations in Oklahoma, and 36 stations in Nebraska. Peak-flow data were obtained from the USGS, which operates a stream-gaging-station network throughout the United States. Data are published in annual USGS water-data reports for each State and are available on the Internet (http://water.usgs.gov). This report considered all the stream-gaging stations in the three-State area that measured flows that were unregulated (less than 10 percent of the basin is regulated by a dam) and that provided an uninterrupted 40-year peak-flow record from 1958 through 1997. The 40-year period of record is nearly twice the length of the suspected drought cycle, which is estimated to be 22 years in the Great Plains (Mitchell and others, 1979). The drought of the 1950s was severe from 1952 until 1957, and 1993 was an extremely wet year. Therefore, 1958 was chosen as the beginning year and 1997 the ending year for the trend analyses.

The 88 stream-gaging stations whose records were analyzed are distributed fairly well across the three States and are representative of a range of existing conditions in the central Great Plains. Drainage areas of the associated basins vary in size from 0.89 to 14,320 miî (table 2). Land-surface elevations within the three States generally slope gently downward from west to east. Relatively flat topography, shallow stream channels, and ephemeral (intermittent) flow generally characterize the western parts of the three States. The eastern parts have hilly topography, deep channels, and perennial (continuous) streamflow. Mean annual precipitation ranges from 16 in. in western Nebraska to 56 in. in southeastern Oklahoma (National Oceanic and Atmospheric Administration, 1979). Most of the precipitation is produced by summer thunderstorms, and the quantity is variable, both spatially and temporally (Paulson and others, 1991). Land is used primarily for crop production and livestock grazing, with scattered industrial uses near urbanized areas.

The Kendall's tau analysis of annual peak flow for the 88 stream-gaging stations in Kansas, Oklahoma, and Nebraska indicated both increasing and decreasing trends in peak flows across the three States during the 40-year period (table 2). Some individual station records showed significant trends, and slight regional trends in peak flows occurred as well (fig. 2). Of the 88 sets of records analyzed for trends in peak flow, 22 sets (25 percent) exhibited a trend at the 95-percent confidence level. Records from 4 stream-gaging stations indicated statistically significant increasing trends in peak flows, whereas records from 18 stations indicated statistically significant decreasing trends (table 2). The records with increasing trends were from gaging stations scattered in the eastern or southern part of the three-State area, whereas the decreasing-trend stations were all located in the western or northern part, particularly western Kansas and southwestern Nebraska. Considering only stream-gaging-station records in Kansas, 13 of the 40 peak-flow station records analyzed (32 percent) showed a significant trend. Of the 13 station records that showed a significant trend, 10 indicated decreasing trends occurring in the western one-half of the State, whereas the 3 increasing-trend stations were located in eastern Kansas (see fig. 2).

As the period of record is adjusted, so is the trend test result. The Kendall's tau test also was used to identify trends over the entire available record for 54 stations in Kansas with a record length of more than 38 years (table 3). Some years were missing from the peak-flow series. However, a few missing values within the series has little effect on the test outcome (Helsel and Hirsch, 1992). Of the 54 stations used, 23 station records showed significant trends over their entire record. Sixteen station records had decreasing trends (negative tau and slope), and seven records had increasing trends (positive tau and slope) (fig. 3). Four of the Kansas stations (06889500, 06892000, 07141200, and 07144200; map index numbers 30, 32, 39, and 44) had peak-flow data dating back to at least 1930. Two of these four records showed significant trends, one increasing (station 06889500, map index number 30) and the other decreasing (station 07141200, map index number 39) when tested over the 40-year period of record (table 2). Trends for the same two stations proved significant over the longer period of record as well. When the other two longer records were tested, they too showed significant trends, both increasing; however, these two increasing trends were not evident in the 40-year period (fig. 4and table 2). Graphs showing annual peak flows and 10-year moving averages (with the value of the 10-year average plotted at the middle of the 10-year period) for each of the 54 peak-flow records are given in figures 5(*A*) through 5(*BBB*).

Table 4 shows results of a trend test on records from each of the 54 stream-gaging stations in Kansas using a 30-year period that moves in 5-year increments through the available periods of record. From this table, it is possible to identify time periods within each station record when peak-flow trends were occurring. For example, Crooked Creek near Englewood (07157500, map index number 51) showed a decreasing trend throughout its record. Pawnee River at Rozel (07141200, map index number 39) showed a variable pattern with an increasing trend from 1926-55, then shifted to a decreasing trend from 1956-85. Table 4 also shows time periods when trends were more geographically widespread, such as 1956-85 when 9 of 28 station records were experiencing decreasing trends.

The Marmaton River in southeast Kansas was not included in the trend analyses because the period of record for any one stream-gaging station was not completely within the 1958-97 time period. Although the Marmaton River has been gaged since the 1920s, the stream-gaging station was relocated from Fort Scott to near Marmaton, dividing the 40-year period from 1958-97 into two records. When both station records were combined and adjustments made for the difference in drainage-basin area, the Marmaton River data showed a statistically significant increasing trend in peak streamflow.

Flow Volume

In addition to the peak-flow analysis, flow volume in Kansas was analyzed for trends using mean annual discharge for 29 stream-gaging stations. Mean annual discharge is the average of the individual daily mean discharge values. Fewer stream-gaging stations were studied in this part of the analysis than for the peak-flow analysis because some of the stations had only partial records of daily mean discharge. Regulated streams were not used in the peak-flow analysis because dams and diversions significantly altered peak flows on regulated streams. However, records from four regulated stream-gaging stations with large drainage basins were used in the analysis of flow volumes. Losses from lake evaporation and diversions were not accounted for in total annual flow volume at the regulated stations. Analyzing the flow volumes for the larger drainage basins may provide more reliable indicators of flow trends because they are less susceptible to localized flooding and human-related factors. Larger drainages also have a larger ground-water component that can make them slower to respond to changes in precipitation. Again, the 29 flow-volume stream-gaging stations were distributed evenly and were representative of conditions across Kansas.

When the Kendall's tau test was applied to mean annual discharges in Kansas, a regional pattern similar to the peak-flow analysis resulted (fig. 6). Of the 29 stations studied, records from 6 (21 percent) showed a trend significant at the 95-percent confidence level (table 5). All six trends were negative and occurred in records from stream-gaging stations in the western one-half of Kansas, supporting the previous test results indicating a trend toward decreasing flows in that part of the State. Only one of the four regulated streams with larger drainage basins showed a significant trend. Records from 6 of the 29 stations exhibited a significant decreasing trend in both the annual peak-flow analysis (table 3) and the mean annual discharge analysis (table 5). No station showed a significant increasing trend in flow volume.

Decreasing streamflow volume in western Kansas, described by Jordan (1982) and Angelo (1994) and supported by the mean annual discharge trend analysis, is related to decreasing trends in peak flow. When rain falls on a dry streambed, more rain contributes to saturation of the streambed and less to actual streamflow. Therefore, peak flow would be expected to decrease over a period of time as mean annual discharge decreases.

EVALUATION OF TREND CAUSES

Factors Affecting Peak Flow

Establishing that a statistically significant trend in streamflow occurred over the past 40 years does not indicate that the trend will continue into the future. In evaluating whether the trend is likely to continue, the cause of the trend needs to be determined. Trends in peak streamflow can be caused by a variety of factors, many of which are difficult to relate statistically to the trend due to lack of appropriate data.

The most direct potential cause of an increasing trend in peak flow is an increase in either the frequency, intensity, or amount of rainfall. Increased rainfall frequency may support higher average streamflows, which then are supplemented during intense storms, resulting in higher peak flow. Urbanization, particularly stream channelization and increasing paved surface areas, may result in higher downstream peak flows (Bedient and Huber, 1992). A substantial decrease in upstream water use, although not common, also could affect downstream peak flows.

Decreasing peak-flow trends also can be caused by changes in rainfall patterns, such as decreases in total rainfall or decreases in the intensity or frequency of rainfall. Construction of reservoirs, levees, and diversions may decrease peak flows. Increases in upstream water use are likely to contribute to decreasing streamflows. Ground-water depletion usually decreases streamflow, particularly over a long period of time, because it decreases base flow (ground-water contribution to streamflow). Average annual runoff in Kansas varies from 0.1 in. in the west to about 10 in. in the east (Sophocleous and Wilson, 2000). Terracing, particularly in western Kansas, could reduce available runoff, resulting in decreasing peak flows. In addition, changes in land use and farming practices can decrease streamflow. In the 1930s, the Federal government, primarily through the Soil Conservation Service, initiated a series of programs designed to reduce soil erosion. Land-management practices including contour farming, crop rotation, pasture improvement, highly erodible land repair, and construction of watershed dams all control soil erosion. These practices also reduce and delay surface runoff, which should result in a decrease in peak flows and flow volumes.

Precipitation Trend Analysis

Total precipitation in the United States has increased by 10 percent during the 20th century from 1910 to 1995 (Karl and Knight, 1998). The increase in precipitation has been attributed in part to increasing global temperatures. As the mean surface temperatures of the Earth increase, more evaporation occurs. Warmer temperatures also allow the atmosphere to hold more water that subsequently falls as precipitation. In their analysis of precipitation trends, Karl and Knight (1998) showed a statistically significant increase in the number of annual precipitation occurrences in each of the nine regions covering the entire contiguous United States. The same analysis also revealed an increase in the intensity of excessive rainfall in all nine regions, which has an even greater effect on total precipitation than does increased frequency.

An increasing trend in flood intensities would be expected from increased precipitation. Runoff occurs when rainfall intensity exceeds the infiltration capacity of the soil, which is affected primarily by the existing soil-moisture conditions. The increasing trend in rainfall frequency may not increase flood intensity if the time interval between rainfall allows adequate evapotranspiration to deplete the soil moisture. However, an increase in the intensity of rainfall does result in increased runoff and floods of greater magnitude. Lins and Slack (1999) found that across the United States annual minimum and mean streamflows were increasing significantly but that annual maximum flows were neither increasing nor decreasing nationwide.

The Kendall's tau test was applied to total annual precipitation values for each of the 26 meteorological divisions of the National Weather Service in Kansas, Oklahoma, and Nebraska for 1958-97, the same 40-year period used for the peak-flow analysis described earlier in this report. The precipitation data were from the National Climatic Data Center's database (National Oceanic and Atmospheric Administration, 1998).

When the Kendall's tau test was applied to annual precipitation, trends significant at the 95-percent confidence level (positive tau and slope) were detected for 3 of the 26 divisions (table 6). The three meteorological divisions showing significant increasing trends in annual precipitation were all located in south-central Oklahoma (fig. 7). One of three stream-gaging stations tested for trends in peak flow within those divisions showed a significant increasing trend in peak flow (station 07311500, map index number 68, table 2). The other two stations (07300500 and 07332500, map index numbers 67 and 69, table 2). showed no trend. Karl and Knight's (1998) study of regional precipitation trends in the United States also found no significant increasing trend in monthly median precipitation from 1910-96 in the regions containing Kansas, Oklahoma, and Nebraska. In addition, Karl and Knight (1998) found that the number of precipitation occurrences and the amount of rainfall during intense precipitation increased significantly during the same time period. They suggested that the amount of rainfall received during intense precipitation could result in an increase in peak flows without being reflected in the median precipitation data. Additional analysis of maximum rainfalls for various durations within the study area could determine more conclusively whether increasing streamflow trends in the eastern part of the study area were caused by an increase in the amount of rainfall during intense precipitation.

Table 6. Results of Kendall's tau trend analysis of mean annual precipitation in Kansas, Oklahoma, and Nebraska, 1958-97

[**Bold** indicates significant at 95-percent confidence level (probability value less than or equal to 0.05). (ft /s)/yr, cubic feet per second per year; NA, not available]

Meteorological division number (fig. 7)	Kendall's tau	Probability value	Slope [(ft /s)/yr]
	Kansas		
1401	0.181	0.108	0.085
1402	.054	.637	.038
1403	.051	.654	.063
1404	.074	.514	.033
1405	.014	.913	.008
1406	.053	.646	.049
1407	.066	.561	.038
1408	.055	.628	.034
1409	.104	.358	.098
	Nebraska		
2501	.418	.717	.015
2502	NA	NA	NA
2503	.190	.090	.106
2505	.130	.250	.066
2506	.023	.847	.018
2507	.140	.213	.048
2508	.062	.586	.030
2509	.009	.942	.002
	Oklahoma		
3401	.014	.913	.002
3402	.157	.164	.113
3403	.213	.058	.192
3405	.147	.191	.086
3405	**.263**	**.019**	**.223**
3406	.198	.077	.227
3407	**.260**	**.020**	**.206**
3408	**.282**	**.012**	**.252**
3409	.181	.108	.180

The general lack of significant precipitation trends in all meteorological divisions in western Kansas and Nebraska indicated that the decreasing trends in peak flows apparent in those areas probably were due to factors other than total precipitation. Karl and Knight (1998) found no decrease in rainfall frequency or in rainfall intensity during excessive precipitation in the regions containing Kansas, Oklahoma, and Nebraska. Intensity of light rainfall may have changed; however, that would have little effect on peak flows.

Water-Table Trend Analysis

The Kendall's tau test was applied to winter water levels in 17 wells in Kansas for 1958-97. All the wells with water levels less than 50 ft below land surface for which annual data were available for the majority of the period were included. Wells with water levels less than 50 ft below land surface were used because they measure ground water that is likely to be more directly related to surface flow than water at greater depths. Water-level measurements used in the analysis were made during the winter months because less natural fluctuation normally occurs due to the fact that it is typically the driest season in Kansas. Also, water levels are more stable in winter because they have recovered from irrigation pumping during the previous summer. January measurements were used when available, and when unavailable, the closest February or December measurements were substituted. If no December, January, or February water level was available, the year was skipped. The water-level values used represented the altitude of the water table. A positive tau represented an increase in water-table altitude.

Of the 17 ground-water wells used in the water-table trend analysis, water levels in 13 showed significant trends (table 7). Water levels in 10 wells indicated that the water-table altitude at those locations was declining, whereas water levels in three wells showed that the water table at those locations was rising. The 10 wells with declining water-table altitudes were located in central and western Kansas (fig. 8). Of the two wells analyzed in eastern Kansas, the one located in northeastern Kansas (well W3, fig. 8) showed an increasing trend in water-table altitude, and the well located in southeastern Kansas (well W13, fig. 8) showed a decreasing trend.

Table 7. Results of Kendall's tau trend analysis of winter water levels in 17 shallow wells in Kansas, 1958-97

[**Bold** indicates statistically significant at the 95-percent confidence level (probability value less than or equal to 0.05). (ft /s)/yr, cubic feet per second per year; <, less than]

Map index number (fig. 8)	County and well number	Number of years with missing data	Kendall's tau—	Prob-ability value	Slope [(ft /s)/yr]
W1	**Cheyenne 1**	**2**	**-0.220**	**0.0297**	**-0.0204**
W2	Cheyenne 2	4	-.422	.2970	.0309
W3	**Douglas 1**	**0**	**+.043**	**<.0001**	**+.0150**
W4	Gray 1	9	-.417	.6840	-.2000
W5	**Hamilton 1**	**0**	**-.107**	**.0007**	**-.0171**
W6	**Hamilton 2**	**10**	**-.345**	**.0050**	**-.0642**
W7	**Harvey 1**	**4**	**-.246**	**.0038**	**-.0425**
W8	**Harvey 2**	**0**	**-.354**	**.0082**	**-.0278**
W9	**Kingman 1**	**14**	**+.025**	**.0001**	**+.0017**
W10	Kiowa 1	5	-.142	.8820	-.0639
W11	**Meade 1**	**5**	**+.606**	**<.0001**	**+.1900**
W12	**Meade 2**	**10**	**-.374**	**.0002**	**-.0299**
W13	**Neosho 1**	**0**	**-.460**	**<.0001**	**-.0926**
W14	Reno 1	17	+.014	.9030	+.0017
W15	**Reno 2**	**5**	**-.348**	**.0002**	**-.0512**
W16	**Sedgwick 1**	**0**	**-.297**	**.0046**	**-.0550**
W17	**Sedgwick 2**	**1**	**-.612**	**<.0001**	**-.0683**

—Positive values for Kendall's tau and slope represent increasing water-table altitudes.

Results of water-level trend analysis indicate that declining water levels may be a factor contributing to decreasing trends in peak flow. In general, if shallow ground-water levels are declining, perennial streams (continuous flow) become ephemeral (intermittent flow) with dry streambeds. Consequently, more rainfall is needed to create flow and to attain peak flows comparable to those under previous conditions. Angelo (1994) described areas in western Kansas where streambeds have changed from perennial to ephemeral because the water table declined below the streambed elevation. More detailed study of local ground-water/surface-water relations would be helpful in determining where declining water levels have affected peak flows.

Water Use

One important variable that could not be used in the analysis due to a lack of reliable historic records was water use. Estimates of total water withdrawals in Kansas from 1955 to 1995 are shown in table 8. The estimates were compiled from USGS Circulars, "Estimated Use of Water in the United States," which have been published every 5 years since 1950 (see "References Cited" at the end of this report). According to the estimates, water withdrawals increased by about 200 percent from 1955 through 1980 and then decreased slightly (by about 20 percent) from 1980 to 1995. Irrigation water use, which represents the State's largest category of water use, showed the same trend. Because the majority of irrigation withdrawals were from ground water, the same pattern of increasing withdrawals from 1955 through 1980 (by about 450 percent) and then decreasing withdrawals (by 37 percent) from 1980-95, was evident in the ground-water source category. Irrigation application rates vary from year to year and depend on annual rainfall, surface-water availability, farm commodity prices, application technologies, and conservation practices (Solley and others, 1998).

Table 8. Estimated total water withdrawals in Kansas by water-use category, except hydroelectric, 1955-95

Water-use category	Estimated total water withdrawals (million gallons per day)—								
	1955	**1960**	**1965**	**1970**	**1975**	**1980**	**1985**	**1990**	**1995**
Total withdrawal	2,235	2,800	2,800	3,800	5,800	6,600	5,670	6,080	5,240
Public supply	205	200	280	250	290	290	316	373	370
Rural domestic and livestock	70	94	100	130	130	140	110	139	133
Irrigation	740	1,800	2,300	3,000	5,000	5,600	4,730	4,190	3,380
Industrial	1,220	700	100	360	390	530	510	1,385	1,352
Source of water									
Ground	1,006	1,200	2,300	3,100	5,000	5,600	4,800	4,360	3,510
Surface	1,229	1,600	550	640	810	980	866	1,720	1,720

—Estimates of total water withdrawals from MacKichan (1951, 1957), MacKichan and Kammerer (1961), Murray (1968), Murray and Reeves (1972, 1977), and Solley and others (1983, 1988, 1993, 1998).

Irrigation water use and declines in ground-water levels in western Kansas and Nebraska probably have contributed to decreasing streamflows. The effect of ground-water depletion on surface-water flow is highly variable. Over the short term, irrigation drainage locally may increase both surface-water flow and the height of the water table. However, over the long term, excessive ground-water withdrawals will deplete surface-water supplies to some degree by lowering the water table (Sophocleous, 1998). Under base-flow conditions, the water level in a stream or lake intersects the ground-water level. Flow in some streams in western Kansas has changed from perennial to intermittent because ground-water development has caused the regional water table to decline below the streambed (Angelo, 1994; Sophocleous, 1998). Decreasing streamflows in western Oklahoma also have been attributed to depletion of ground water (Wahl and Wahl, 1988; Wahl and Tortorelli, 1996). In a study of rainfall-runoff relations for two river basins in central and western Kansas, Jordan (1982) found that the amount of runoff from 1967-75 was 50 percent less than the amount of runoff resulting from the same amount of rainfall from 1948-66. That study indicated that one-fourth to one-third of the decrease in streamflow could be attributed to a decrease in base flow that occurred concurrently with an increase in ground-water pumpage. Jordan (1982) attributed the remainder of the decrease to farming practices that increase soil-moisture storage and to construction of ponds and terraces.

EFFECTS OF TRENDS ON FLOOD-FREQUENCY ANALYSIS

Analysis of Flood-Frequency Estimates

Flood-frequency analysis uses annual peak flows to estimate the probabilities for certain flood magnitudes when designing bridges, highways, and other flood-plain structures. Frequency analysis assumes that the data series is stationary; that is, the statistical parameters, such as mean, variance, and skewness coefficient, do not change over time. If significant trends exist in the peak-flow series, the data are not stationary, violating the assumptions of frequency analysis and introducing error into the statistical analysis. Whether the error is large enough to invalidate the frequency analysis results becomes the issue.

The effects of significant trends on flood-frequency analysis were investigated by adding hypothetical trends to four nontrending stream-gaging-station records and comparing estimated flood magnitudes. Flood-frequency analysis was carried out according to procedures outlined in Bulletin 17B of the Interagency Advisory Committee on Water Data (1982). The guidelines presented in Bulletin 17B were established to provide consistency in flood-frequency analysis done by Federal agencies. It uses annual peak-flow series to compute flood-frequency curves by fitting a Pearson type-III distribution to the logarithms of the peak flows. Special techniques are recommended for handling low outliers, zero-flow years, historic peaks, and other aspects of the procedure. As a general rule, frequency analysis is questioned when using a historical record less than 10 years in length and in estimating frequencies of floods greater than twice the length of record (Viessman and Lewis, 1996).

The four stream-gaging-station records used to examine the effects of trends on flood-frequency analysis were Caney River near Elgin (station 07172000, map index number 54), Stranger Creek near Tonganoxie (station 06892000, map index number 32), Pottawatomie Creek near Garnett (station 06914000, map index number 34), and Otter Creek at Climax (station 07167500, map index number 53). These stations were selected because each had a Kendall's tau value near zero and an associated large value for probablility (p), indicating no trend in the data (table 2). Trends were introduced to the records by adding a given hypothetical percentage increase or decrease incrementally to each year of the 40-year record. Increasing trends were added to the two station records that initially had positive tau values (map index numbers 54 and 32, table 2). The other two station records had negative tau values (map index numbers 34 and 53, table 2); therefore, decreasing trends were added to those records.

Tables 9-12 show how annual peak-flow values from 1958-97 were affected by the added trends. The first column after the year shows the annual peak flows with no change. The next flow column shows the peak with a slight trend added. The third flow column shows slightly more trend added. The final flow column shows the peak flows with just enough added trend to result in a Kendall's tau probability level of less than 0.05, indicating statistical significance. The bottoms of the tables show estimated floods that are based on each peak-flow series. The lower and upper ranges of the confidence limits are shown in parentheses for the original peak-flow series. It was determined that a 3-percent increasing trend was needed for the Caney River station (table 9) and the Stranger Creek (table 10) records to attain statistically significant trends. A 1.5-percent decreasing trend was needed for the Pottawatomie Creek station (table 11) and the Otter Creek station (table 12) records.

The comparison of flood magnitudes between a nontrending peak-flow series and the same series with an added 3-percent increasing trend revealed that flood estimates increased by as much as 70 percent. The 10-year flood estimate increased by 62 percent for Stranger Creek (table 10) and 63 percent for Caney River (table 9). The 50-year flood estimates increased by 66 percent (table 10) and 68 percent (table 9), respectively, and the 100-year flood estimates increased by 68 percent and 70 percent, respectively. In all cases for the Stranger Creek and Caney River station records, the flood estimate from the trending series was greater than the upper confidence limit established by the nontrending series, indicating the potential importance of accounting for trends.

Comparing flood magnitudes between the nontrending series and the same series with a 1.5-percent decreasing trend showed that the largest percentage change in flood estimates occurred for 5-year floods, which decreased by 28 percent for both the Pottawatomie Creek and Otter Creek station records. The 25-year flood estimate decreased by 20 percent and 23 percent, respectively. For both records, the flood estimates for the trending series were greater than the lower confidence limit established by the unaltered series for the 25-, 50-, and 100-year floods. The estimates were less than the lower limits, however, for the 5-year flood, again indicating the potential importance of accounting for trends.

The percentage differences derived by adding trends to the peak-flow records and then comparing flood magnitudes estimated using flood-frequency analysis are not intended to be used as "correction factors" for records with streamflow trends. The purpose of the comparison is to quantify the effect of peak-flow trends to consider their importance in flood-frequency analysis. Determining an appropriate method for applying flood-frequency analysis to streamflow records containing peak-flow trends was beyond the scope of this report.

Discussion

Flood risk changes over time. It appears that flood estimates for specific frequencies can change considerably on the basis of period of record used and on whether trends, either cyclic or monotonic, occur in the data. Flood-frequency analysis assumes that future peak-flow conditions will be similar to past conditions.

Determining the appropriate period of record to use when estimating flood recurrence intervals is perhaps a larger issue than previously thought. The traditional approach to flood-frequency estimation involves a tradeoff between bias and variance (National Research Council, 1999). Bias arises when long periods of record are used that include time periods when flood risk is different than during the current planning period. However, long periods of record result in better definition of the variance.

Climate variations may prove to be the most challenging aspect to estimating floods. Although human-related causes of peak-flow trends, such as changes in land and water use, can be projected into the future with reasonable accuracy, climate is much less predictable. As the National Research Council (1999, p. 67-68) explains in its recent study of the American River flood-frequency analysis:

> "Non-stationarities pose a serious challenge to flood frequency and risk analysis, and flood control design and practices. If cyclical or regime-like variations arise due to the natural dynamics of the climate system, a relatively short historical record may not be representative of the succeeding design period. Furthermore, by the time one recognizes that the project operation period has been different from the period of record used for design, the climate system may be ready to switch regimes again. Thus it is unclear whether the full record, the first half of the record, the last half of the record or some other suitably selected portion is most useful for future decisions- ."

A general conclusion, then, is that more uncertainty exists in flood-frequency estimates than that suggested by conventional statistical analysis. Although a large amount of uncertainty is built into the frequency analysis, it is rarely considered in flood-plain decisionmaking processes. The National Research Council (1999) recommends that the existing static flood-risk framework, in which a single flood-frequency distribution is estimated from all available data and applied to an indefinite future period, be replaced with a more dynamic framework. A more appropriate approach would be to consider the length of the record, climatic factors, the length of the planning period, risk and uncertainty, and then follow up with periodic flood-frequency updates.

SUMMARY

The magnitude of the annual peak flow for some streams in Kansas appears to be changing. The Kendall's tau trend test was used to identify and evaluate peak-flow trends in Kansas and in two adjoining States, Oklahoma and Nebraska. Initially, the same 40-year period of record, 1957-98, was used in the analysis. Thirteen (32 percent) of the 40 stream-gaging stations in Kansas that were analyzed showed a significant trend in peak flow. Of the 13 trending station records, 10 indicated decreasing trends occurring in the western one-half of the State. The three increasing-trend stations were located in eastern Kansas.

A similar pattern occurred when station records from Oklahoma and Nebraska were included in the peak-flow analysis. When the same 40-year period of record was analyzed for peak-flow trends at 88 stream-gaging stations in the three-State area, 22 (25 percent) of the station records showed significant trends. Four station records showed increasing trends, and 18 records showed decreasing trends. Nearly all the stations with decreasing trends were located in western Kansas and southwestern Nebraska, whereas most of the stations with increasing trends were scattered across the eastern one-half of the area.

As the period of record is adjusted, so is the trend test result. The Kendall's tau test also was used to identify trends over the entire available period of record for 54 stations in Kansas with a record length of more than 38 years. Of the 54 stations used in this part of the analysis, 23 station records (43 percent) showed significant trends over their entire record. Sixteen station records (30 percent) had decreasing trends, and seven records (13 percent) had increasing trends. The trend test then was applied to 30-year periods moving in 5-year increments through the available period of record to identify time periods within each station record when peak-flow trends were occurring.

In addition to the peak-flow analysis, flow volume in Kansas was analyzed for trends using mean annual discharge for 29 stream-gaging stations. A regional pattern similar to the peak-flow analysis was apparent. Records from six stations showed a significant trend. All six trends were decreasing and occurred in the western one-half of Kansas.

To help evaluate possible causes of the streamflow trends, the Kendall's tau trend analysis was applied to total annual precipitation in the three-State area and to ground-water levels in Kansas. A significant trend in annual precipitation was detected for 3 of the 26 meteorological divisions analyzed in the three-State area. All three trends in precipitation were increasing and occurred in meteorological divisions located in south-central Oklahoma. One of three stream-gaging stations tested for trends in peak flow within the three trending meteorological divisions showed

a significant increasing trend in peak flow.

Although the increasing trends may be caused by changes in precipitation patterns, decreasing streamflow in western Kansas and Nebraska probably are caused by factors other than precipitation. The Kendall's tau test was applied to water levels in 17 ground-water wells in Kansas. Water levels in 13 wells showed significant trends. Water levels in 10 wells, all located in central and western Kansas, indicated that the water table was declining. As the water table declines below streambed elevation, more rainfall is necessary to create flow and to attain peak flows comparable to those under previous conditions. Therefore, declining water tables caused largely by ground-water withdrawals are contributing to decreasing trends in peak streamflow in western Kansas. Decreasing peak streamflow also may be related to other factors such as construction of ponds and terraces.

Peak-flow data are used to estimate probabilities for certain flood magnitudes. Nonstationary data, such as the peak-flow records containing trends, introduce statistical error into the flood-frequency analysis. To examine the effect of trends on flood-frequency analysis, hypothetical trends were systematically added to four nontrending station records. For each record, flood-frequency analysis was conducted on both the unchanged record and the corresponding record with the added trend. The resulting estimated flood magnitudes were compared. The magnitude of the 100-year flood changed by as much as 70 percent. In some cases, flood-frequency estimates calculated using trending peak-flow records fell outside the wide confidence limits established by flood-frequency analysis using the unaltered series, indicating the potential importance of accounting for trends in the analysis.

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