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Development of New Precipitation Frequency Tables for Counties in Kansas Using NOAA Atlas 14

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Averaged across Kansas, precipitation estimates have decreased for most combinations of duration and recurrence interval. The changes vary geographically across Kansas. The changes in Johnson, Sedgwick and Finney Counties were examined in detail. The spatial variability of the precipitation estimates has increased considerably. The changes in the precipitation frequency estimates are not necessarily indicative of actual changes in extreme precipitation characteristics. These changes are largely attributable to the improved statistical methodologies used in Atlas 14 compared to TP-40 and HYDRO-35.

The impacts of these changes on design discharges for bridges, culverts and other drainage structures vary by hydrologic method. Design discharges computed with the Rational formula and the Extended Rational equations for Kansas will increase or decrease by the same percentage as the precipitation input to these equations. Discharges computed with the three-variable regression equations for Kansas will increase or decrease by a slightly larger percentage than the precipitation input. Discharge computed with the USGS flood-frequency regression equations for Kansas are unaffected by the changes in the precipitation frequency estimates. Design discharges computed by flood hydrograph simulation will decrease slightly in most cases for most locations in Kansas.

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Abstract

This report documents the development of the Kansas Department of Transportation's (KDOT) new rainfall tables for counties in Kansas based on *NOAA Atlas 14 Volume 8* (Perica et al. 2013). These new tables provide rainfall depths and intensities for durations from 5 minutes to 24 hours and recurrence intervals from 1 to 500 years. The new tables will replace the KDOT's current rainfall tables (McEnroe 1997), which are based on the U.S. Weather Bureau's *Technical Paper No. 40* (Hershfield 1961) and NOAA's *Technical Memorandum NWS HYDRO-35* (Frederick et al. 1977). This report also provides an overview of the Atlas 14 products, a summary of the methodology used to develop the Atlas 14 estimates, and guidance for use of the new KDOT rainfall tables.

Averaged across Kansas, precipitation estimates have decreased for most combinations of duration and recurrence interval. The changes vary geographically across Kansas. The changes in Johnson, Sedgwick and Finney Counties were examined in detail. In Johnson County, the changes are mixed. In Sedgwick County, precipitation depths generally decreased, with a few exceptions. Depths for Finney County decreased for nearly all durations and recurrence intervals. The spatial variability of the precipitation estimates has increased considerably. The changes in the precipitation frequency estimates are not necessarily indicative of actual changes in extreme precipitation characteristics. These changes are largely attributable to the improved statistical methodologies used in Atlas 14 compared to TP-40 and HYDRO-35.

The impacts of these changes on design discharges for bridges, culverts and other drainage structures vary by hydrologic method. Design discharges computed with the Rational formula and the Extended Rational equations for Kansas will increase or decrease by the same percentage as the precipitation input to these equations. Discharges computed with the three-variable regression equations for Kansas will increase or decrease by a slightly larger percentage than the precipitation input. Discharge computed with the USGS flood-frequency regression equations for Kansas are unaffected by the changes in the precipitation frequency estimates. Design discharges computed by flood hydrograph simulation will decrease slightly in most cases for most locations in Kansas.

Sometime in the future, the extended Rational and three-variable regression equations and the guidelines for flood hydrograph simulation in the Design Manual (KDOT 2011) should be updated for compatibility with the new precipitation frequency estimates.

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Chapter 1: Introduction

The National Weather Service (NWS) Hydrometeorological Design Studies Center recently released *NOAA Atlas 14 Volume 8* (Perica et al. 2013), which provides new precipitation frequency estimates for Kansas and 10 other Midwestern states. The precipitation estimates for Kansas in Atlas 14 Volume 8 supersede the previous estimates for durations from 5 to 60 minutes in NWS's *Technical Memorandum HYDRO-35* (Frederick et al. 1977) and the estimates for longer durations in the U.S. Weather Bureau's *Technical Paper No. 40* (TP-40) (Hershfield 1961). Chapter 2 of this report provides an overview of the Atlas 14 products and a summary of methodology by which NWS developed the Atlas 14 estimates.

Chapter 3 explains the development of the new rainfall tables for counties in Kansas based on Atlas 14 and provides guidance for their use. These new tables provide rainfall depths and intensities for durations from 5 minutes to 24 hours and recurrence intervals from 1 to 500 years. The new tables will replace the KDOT's rainfall tables based on TP-40 and HYDRO-35 (McEnroe 1997). Chapter 4 provides an analysis of the changes in the rainfall frequency estimates by location, duration and recurrence interval. Chapter 5 evaluates the impacts of these changes on KDOT's hydrologic design procedures.

Chapter 2: Overview of NOAA Atlas 14 Volume 8

2.1 Precipitation Frequency Estimates

NOAA Atlas 14, Precipitation-Frequency Atlas of the United States, is an ongoing project of the Hydrometeorological Design Studies Center (HSDC) of the National Weather Service. The recently released Volume 8 (Perica et al. 2013) provides updated precipitation frequency estimates for 11 Midwestern states: Colorado, Iowa, Kansas, Michigan, Missouri, Nebraska, North Dakota, Oklahoma, South Dakota and Wisconsin.

The Atlas 14 precipitation estimates are provided on NWS's Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/) through an interactive map-based tool. The user selects the location of interest on the map or specifies the latitude and longitude. The user also selects the desired output type (depth or intensity), units (English or metric) and time-series type (partial duration or annual maximum – explained in Section 2.2). If the partial-duration time series is selected, the data server returns a table of precipitation estimates for all combinations of 19 durations and 10 average recurrence intervals. The 19 durations are 5, 10, 15, 30 and 60 minutes; 2, 3, 6, 12 and 24 hours; 2, 3, 4, 7, 10, 20, 30, 45 and 60 days, and the 10 average recurrence intervals are 1, 2, 5, 10, 25, 50, 100, 200, 500 and 1000 years. If the annual-maximum time series is selected, the data server returns precipitation estimates for all combinations of the 19 durations and nine annual exceedance probabilities: 0.001, 0.002, 0.005, 0.01, 0.05, 0.02, 0.05, 0.1, 0.2 and 0.5.

The Atlas 14 precipitation estimates are provided on a 30 arc-second spatial grid. The average dimensions of a 30 arc-second grid cell in Kansas are 2360 ft (E-W) by 3030 ft (N-S). The data server also offers complete gridded data sets for all combinations of duration and frequency in ArcGIS format.

2.2 Average Recurrence Interval and Annual Exceedance Probability

Hydrologic frequency can be expressed in terms of average recurrence interval (ARI) or annual exceedance probability (AEP). In Atlas 14, average recurrence interval is defined as the average period of time between occurrences of events that equal or exceed a specified magnitude. Annual exceedance probability is defined as the probability that an event of a specified magnitude will be equaled or exceeded one or more times in a given year. It is important to note that, with ARI defined as stated above, AEP is not the reciprocal of ARI. The relationship between ARI (as defined by NOAA) and AEP can be stated as (Langbein 1949):

$$\mathrm{AEP} = 1 - \exp\left(-\frac{1}{\mathrm{ARI}}\right)$$ **(Equation 2.1)**

$$\mathrm{ARI} = -\frac{1}{\ln(1 - \mathrm{AEP})}$$ **(Equation 2.2)**

Table 2.1 shows the annual exceedance probabilities corresponding to the standard average recurrence intervals tabulated in Atlas 14. For average recurrence intervals of 10 years and greater, AEP is approximately equal to 1/ARI. For shorter average recurrence intervals, this approximation does not hold. Minor events can have average recurrence intervals shorter than one year.

Table 2.1: Relationship Between AEP and ARI

ARI (years)	Corresponding AEP
1000	0.1%
500	0.2%
200	0.5%
100	1.0%
50	2.0%
25	3.9%
10	9.5%
5	18%
2	39%
1	63%

We note that NOAA now uses the term average recurrence interval (ARI) rather than the equivalent terms *recurrence interval* or *return period*. The new term is preferable because the modifier *average* emphasizes the key point that hydrologic events recur irregularly rather than on a fixed schedule.

2.3 Summary of Atlas 14 Methodology

The final report for Atlas 14 Volume 8 (Perica et al. 2013) fully explains the development of the new precipitation frequency estimates. The methodology is summarized here for convenience. In short, frequency analyses were performed on the data records from over 4800 individual field recording stations in the study area. The gridded precipitation estimates were developed through spatial interpolation and smoothing of the results for the individual stations.

NWS initially collected precipitation records for over 16,000 field stations in the study area. These records were examined for length, completeness and consistency. Records for 4832 field stations were ultimately selected for frequency analysis. Table 2.1 shows the numbers of selected daily, hourly and sub-hourly precipitation records and the average record lengths. With a few exceptions, the daily records contained at least 30 years of valid data, and the hourly records contained at least 20 years of valid data. The frequency-analysis data set included 488 field stations in Kansas: 360 daily stations, 89 hourly stations and 39 fifteen-minute stations. Figures 2.1 and 2.2 show the locations of the daily, hourly and sub-hourly field stations in Kansas.

Table 2.2: Field Station Records Used in Frequency Analysis

Recording interval	Number of stations	Median record length (years)
Daily	3382	63
Hourly	992	43
Sub-hourly	458	25

(Adapted from Table 4.4.1, NOAA Atlas 14 Volume 8)

Annual-maximum series (AMS) for durations of 15 minutes and longer (≥ data recording interval) were developed for the selected field stations. The annual maxima were screened for reasonableness with outlier tests. Sampling adjustment factors were applied to maxima obtained from daily and hourly fixed-time observations. No sampling adjustments were applied to maxima obtained from sub-hourly data. Statistical tests of stationarity were applied to daily and hourly AMS of sufficient length. No statistically significant trends were found, so the AMS data were treated as stationary. No annual maximum series were developed for the 10-minute and 5-minute durations due to data limitations.

Frequency analyses were performed by fitting three-parameter generalized extreme value (GEV) probability distributions to the AMS data by the method of L-moments. For durations of 60 minutes and longer, the fitting method used the local 1st-order L-moment and higher-order L-moments computed from the local 1st-order L-moment and regional estimates of three L-moment ratios: L-CV, L-skewness and L-kurtosis. The regional L-moment ratios for each station were computed by averaging station-specific values for 8-16 nearby stations. A different fitting method was used for the 30-minute and 15-minute durations due to data limitations. Frequency-analysis results were adjusted to obtain smooth depth-duration curves for the AEPs of interest. Precipitation estimates for ARIs from 1 year to 1000 years were obtained from the frequency-analysis results using the equivalent AEPs calculated with Eq. 2.1.

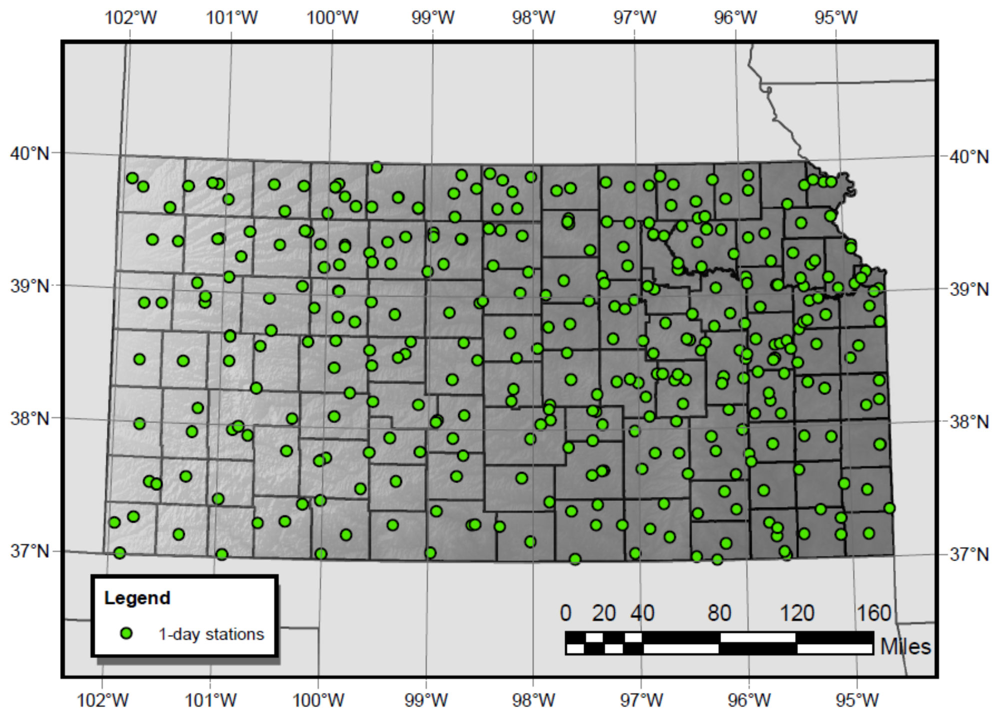

Figure 2.1: Daily Field Stations in Kansas Used in Frequency Analysis

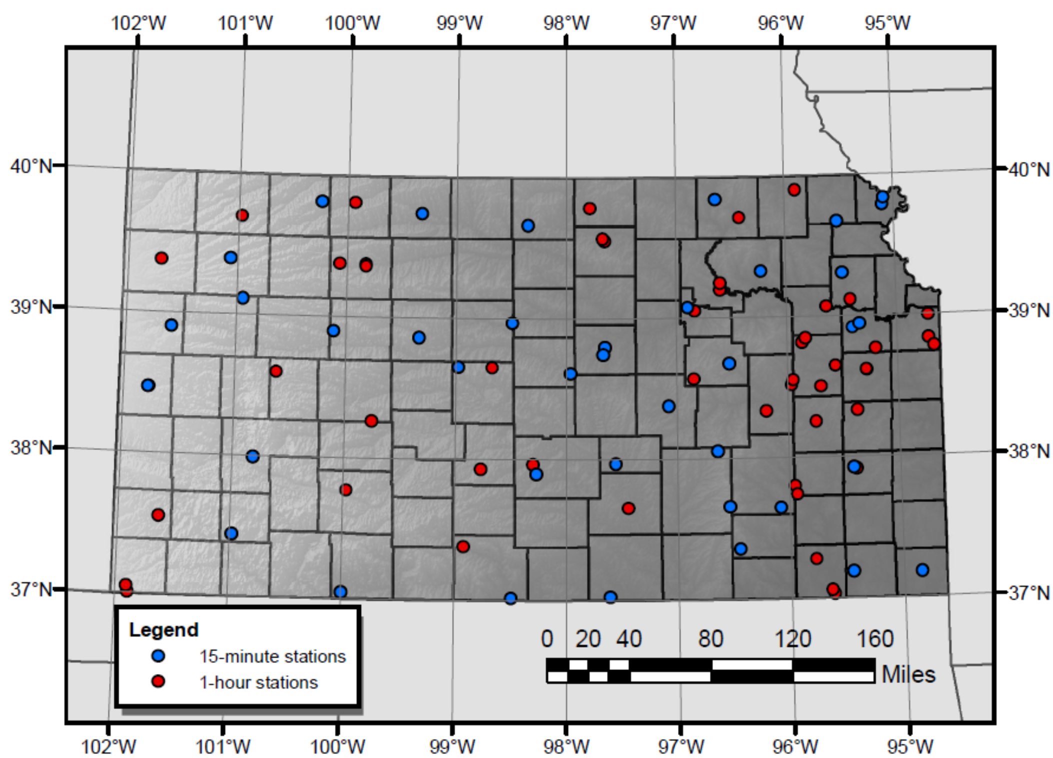

Figure 2.2: Hourly and 15-Minute Field Stations in Kansas Used in Frequency Analysis

Grids of precipitation depth and intensity for all combinations of the selected durations and frequencies were developed from the station-specific results. The grid development process included extensive use of PRISM modeling, a hybrid statistical-geographic approach that considers elevation and terrain characteristics. The grids for the 30-minute and 15-minute durations were developed by a different process than the grids for the longer durations "due to concerns about the soundness of at-station precipitation frequency estimates computed directly from AMS for sub-hourly durations" (Perica et al. 2013). The precipitation frequency grids for the 10-minute and 5-minute durations were generated by a more approximate method due to more severe data limitations. The 10-minute and 5-minute precipitation depths were assumed to equal 82% and 57% of the 15-minute depths throughout the 11-state study area. These percentages were developed from analyses of the relative few available n-minute records.

Chapter 3: Development of New Precipitation Tables

3.1 Spatial Averaging of Precipitation Estimates by County

Atlas 14 provides precipitation estimates on a 30 arc-second grid, with an average grid-cell size of approximately 160 acres. We computed spatially averaged precipitation estimates for each county in Kansas by averaging the precipitation estimates for all grid cells with centroids located within the county boundaries. For example, the values for Shawnee County are averages of the values for the 2188 grid cells located within the county. These spatially averaged values were computed for all combinations of durations up to 24 hours and average recurrence intervals up to 500 years.

3.2 Interpolation Method for Intermediate Durations

NOAA Atlas 14 provides precipitation estimates for durations of 5, 10, 15, 30 and 60 minutes and 2, 3, 6, 12 and 24 hours, plus some longer durations. KDOT requires precipitation estimates for intermediate durations. The KDOT tables provide precipitation estimates for durations from 5 to 60 minutes at 1-minute intervals, from 1 to 3 hours at 5-minute intervals, from 3 to 6 hours at 15-minute intervals, from 6 to 12 hours at 30-minute intervals, and from 12 to 24 hours at 1-hour intervals. We computed the estimates for the intermediate durations by cubic spline interpolation. In the cubic spline method of interpolation, a separate third-order polynomial is fitted to the interval between each pair of adjacent points. The cubic spline method solves for the polynomial coefficients so that the first and second derivatives are continuous at the interior points. An additional condition must be specified for the interval at each end. We required the third derivative to be constant across the last two intervals at each end (the so-called "not a knot" end condition).

3.3 Point-to-Area Conversion for Precipitation Estimates

The rainfall depths and intensities in Atlas 14 and the KDOT tables are values at a point and not average values over a watershed. If the watershed area exceeds a few hundred acres, the average value over the watershed is less than the point value for the same duration and average recurrence interval. The ratio of the areal-average rainfall to the point rainfall is termed the areal reduction factor (ARF). The following equation provides an estimate of the ARF as a function of rainfall duration (D) in minutes and drainage area (A) in mi^2:

$$\mathrm{ARF} = 1 - (0.355\ \mathrm{D}^{-0.428}) \cdot [1 - \exp(-0.015\ \mathrm{A})] \qquad \textbf{(Equation 3.1)}$$

The U.S. Army Corps of Engineers (2000) and McEnroe and Young (2007) fitted Eq. 3.1 to a graphical relationship developed by the U.S. Weather Bureau (1958). To estimate the areal average rainfall for a given area and duration, the corresponding point rainfall is multiplied by the ARF value obtained from Eq. 3.1.

3.4 Estimation of Average Recurrence Interval for a Historical Event

Most rain gages report rainfall amounts at a fixed times (e.g. daily or hourly). The true maximum rainfall amount for a given duration is generally higher than the apparent maximum determined from data recorded at fixed times. For example, the true maximum 60-minute rainfall amount for a given event is likely to be somewhat higher than the maximum hourly rainfall determined from data recorded at clock-hour intervals.

When estimating the average recurrence interval for a historical event, the maximum rainfall depth determined from fixed-time-interval data should be multiplied by a sampling adjustment factor (SAF) computed with Eq. 3.2, in which D is the duration of interest and Δt is the recording interval (Young and McEnroe 2003).

$$\mathrm{SAF} = 1 + 0.13\left(\frac{\mathrm{D}}{\Delta \mathrm{t}}\right)^{-1.5} \qquad \textbf{(Equation 3.2)}$$

The recurrence-interval range for the event of interest is estimated by comparing the adjusted maximum rainfall with the values in the KDOT tables.

<u>Example</u>

A rain gage in Shawnee County records rainfall amounts at 15-minute intervals. Based on these 15-minute data, the largest 15-minute rainfall amount for a certain event was 1.60 inches. The objective is to estimate the average recurrence interval for the maximum 15-minute rainfall.

The first step is to compute the sampling adjustment factor with Eq. 3.2. For D = 15 minutes and Δt = 15 minutes, Eq. 3.2 yields SAF = 1.13. The maximum 15-minute rainfall amount from the 15-minute data is multiplied by this sampling correction factor to obtain an adjusted maximum 15-minute rainfall of 1.81 inches. The KDOT rainfall depth table for Shawnee County shows 15-minute rainfall depths for average recurrence intervals from 1 to 500 years. The adjusted maximum depth of 1.81 inches lies between the 50-year depth of 1.69 inches and the 100-year depth of 1.90 inches. Therefore it is likely that this event had an average recurrence interval in the range of 50 to 100 years.

Chapter 4: Changes in Precipitation Frequency Estimates

4.1 Changes in Precipitation Contours over the 11-State Study Area

The relative changes in local precipitation estimates differ by location, duration and recurrence interval. In general, the spatial variability of the precipitation estimates has increased considerably, as can be seen by comparing the old and new precipitation contours in Figures 4.1 and 4.2. The greater complexity and irregularity of the new precipitation contours stems from changes in statistical methodology rather than an actual increase in the spatial variability of extreme precipitation. In our opinion, greater degree of spatial smoothing should have been applied in developing the gridded precipitation estimates from the estimates for the individual gages.

4.2 Changes in Precipitation Estimates across Kansas

Averaged across Kansas, the new precipitation estimates are generally somewhat smaller than the estimates in KDOT's 1997 rainfall tables. Table 4.1 shows the average percentage changes in the 10-year and 100-year estimates for durations of 15 minutes, 1 hour and 24 hours. Of these six combinations, only the 100-year 24-hour rainfall increased on a statewide-average basis.

Table 4.1: Average Percentage Changes in Precipitation Frequency Across Kansas

Duration	ARI (years)	Average % change
15 minutes	10	-7.1%
15 minutes	100	-2.1%
60 minutes	10	-8.0%
60 minutes	100	-3.7%
24 hours	10	-4.6%
24 hours	100	+3.7%

Figures 4.3 through 4.10 shows how the percentage changes in these six precipitation depths vary geographically across Kansas. The 10-year 15-minute and 10-year 60-minute depths decreased throughout Kansas. The 10-year 24-hour depth also decreased nearly everywhere, especially in the southwest region. The 100-year 15-minute and 100-year 60-minute depths

decreased in some areas and increased in other areas. The 100-year 15-minute depths have generally changed more than the 100-year 60-minute depths. The 100-year 24-hour depths increased throughout most of Kansas.

The changes in the precipitation frequency estimates are not necessarily indicative of actual changes in extreme precipitation characteristics. These changes are largely attributable to the different the statistical methodologies used in Atlas 14 compared to HYDRO-35 and TP-40.

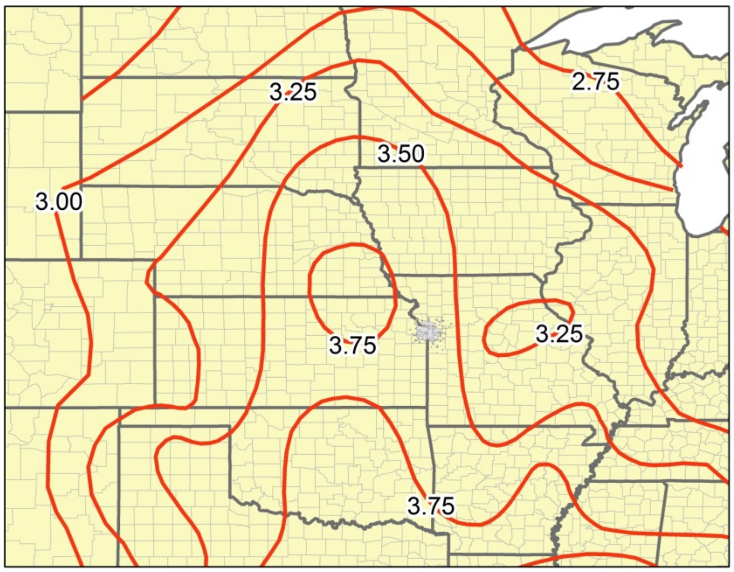

Figure 4.1(a): Old 100-Year 60-Minute Precipitation (inches) from HYDRO-35

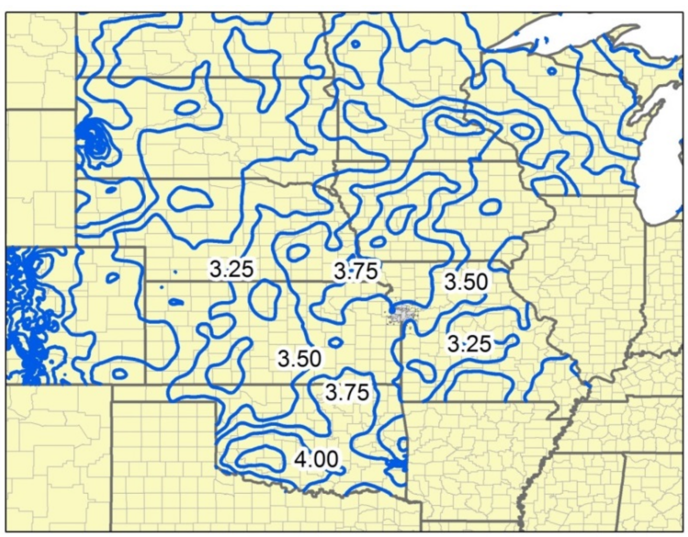

Figure 4.1(b): New 100-Year 60-Minute Precipitation (inches) from Atlas 14

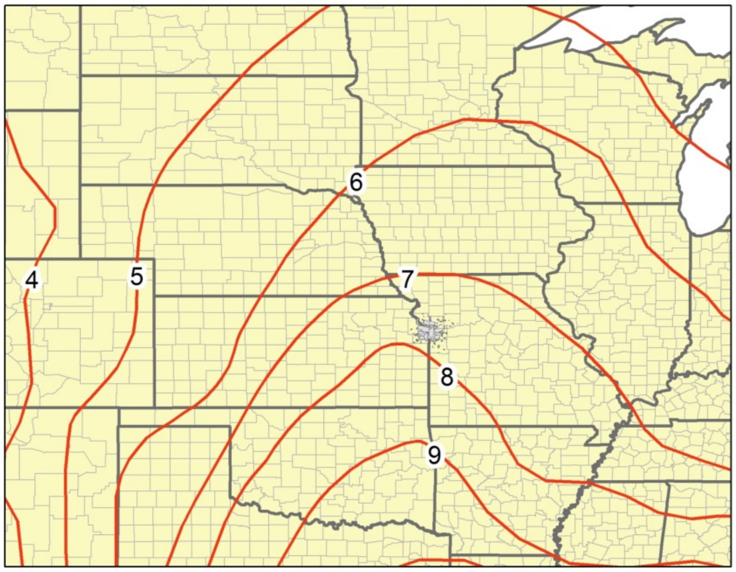

Figure 4.2(a): Old 100-Year 24-Hour Precipitation from TP-40 (inches)

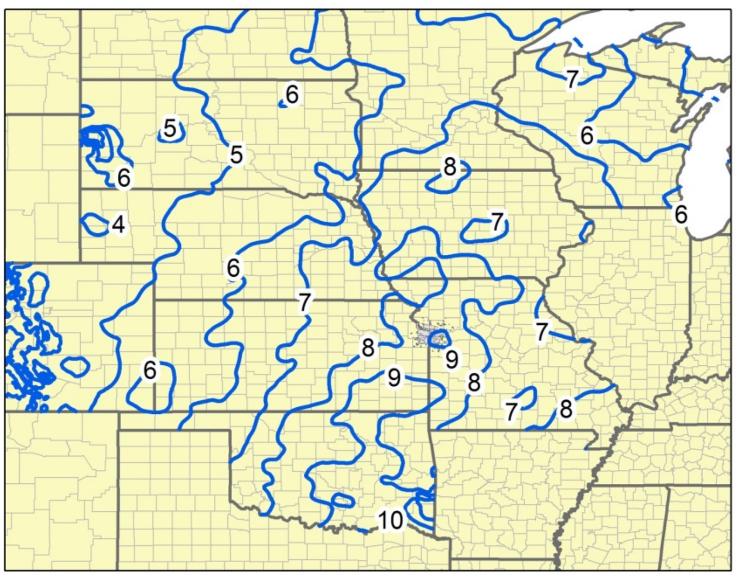

Figure 4.2(b): New 100-Year 24-Hour Precipitation from Atlas 14 (inches)

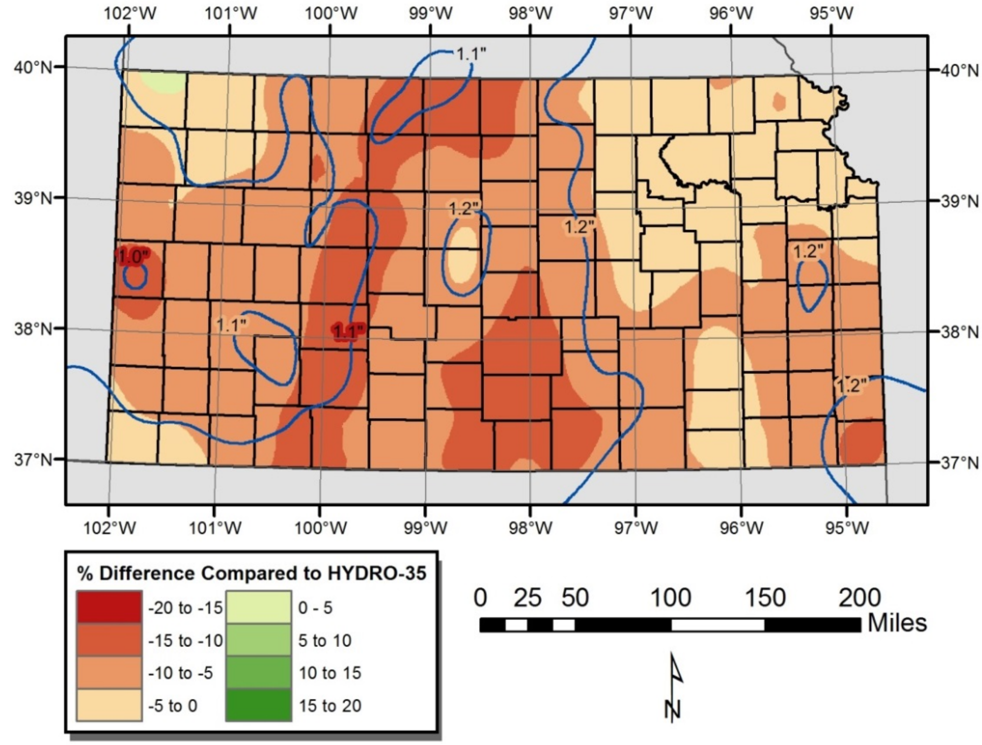

Figure 4.3: Changes in 10-Year 15-Minute Precipitation across Kansas

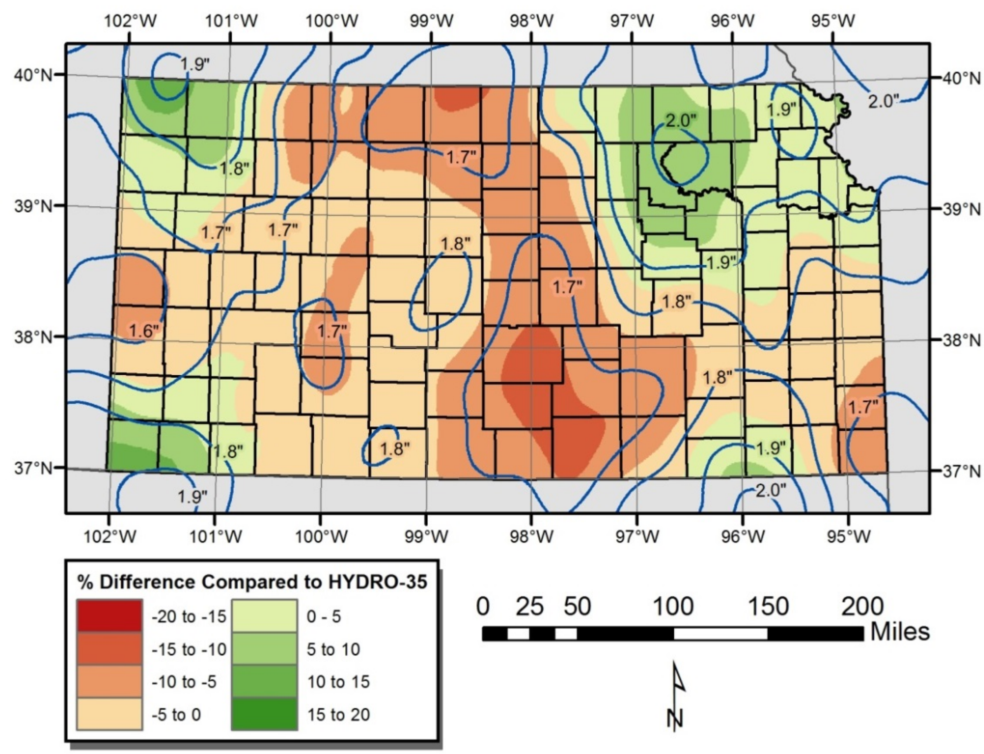

Figure 4.4: Changes in 100-Year 15-Minute Precipitation across Kansas

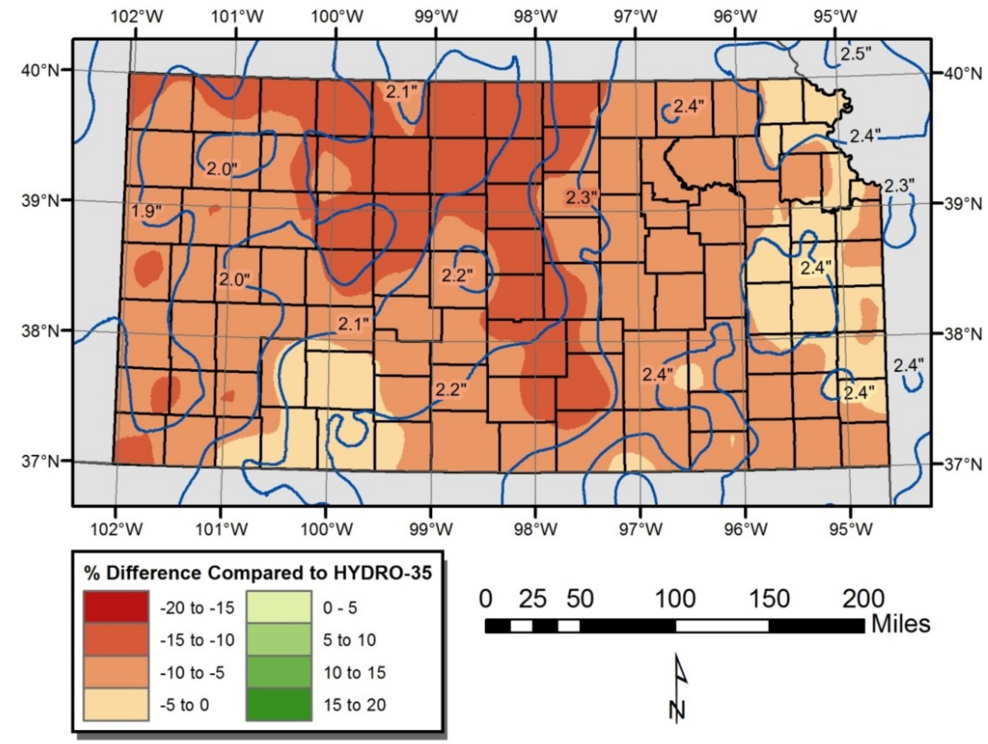

Figure 4.5: Changes in 10-Year 60-Minute Precipitation across Kansas

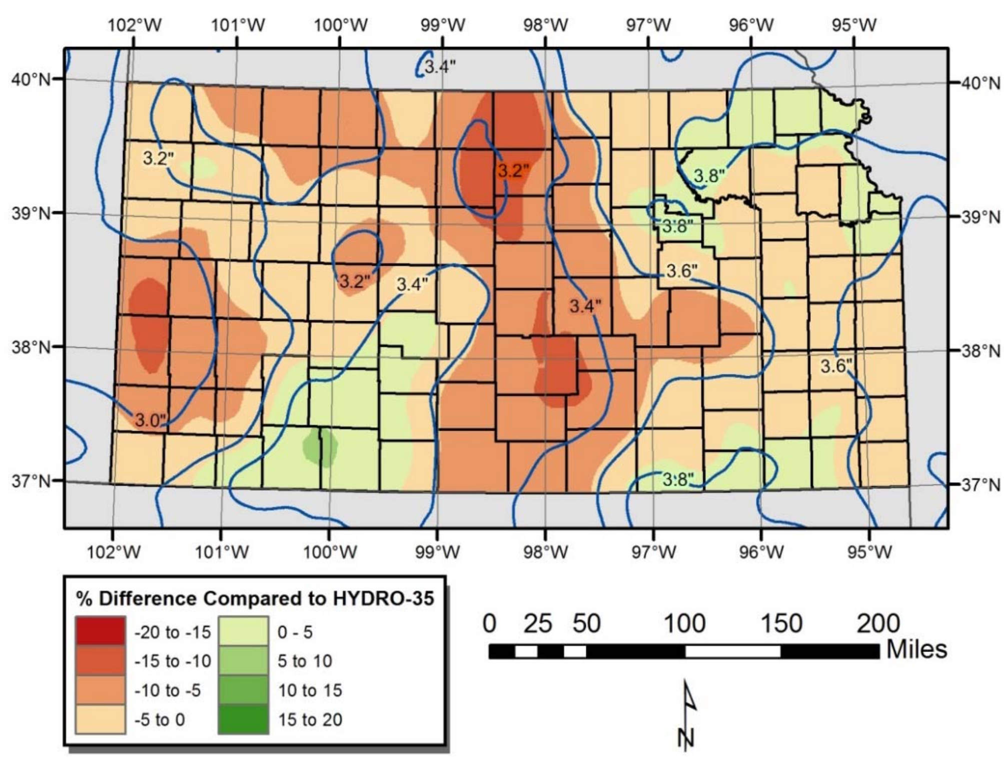

Figure 4.6: Changes in 100-Year 60-Minute Precipitation across Kansas

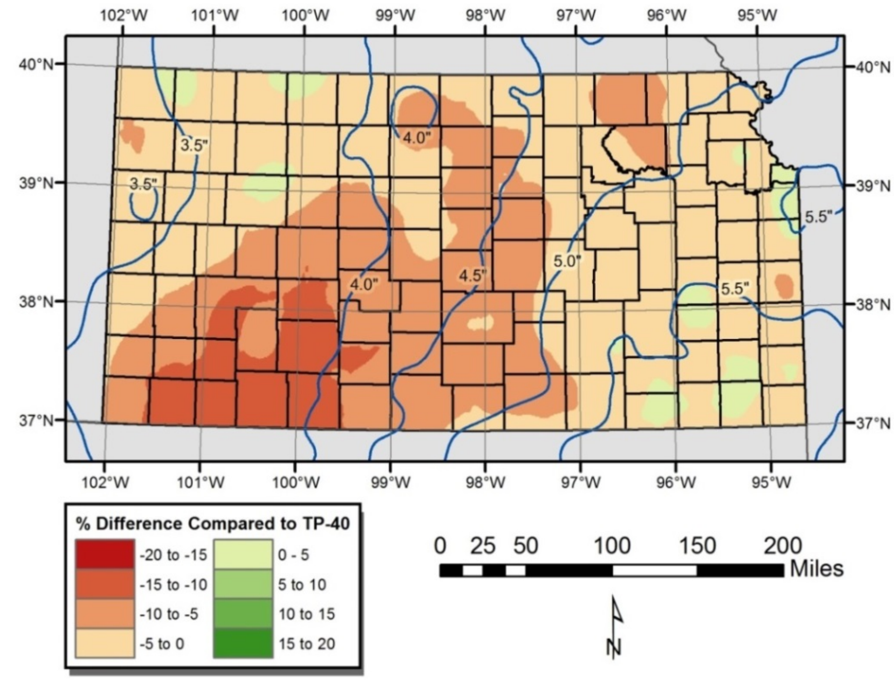

Figure 4.7: Changes in 10-Year 24-Hour Precipitation across Kansas

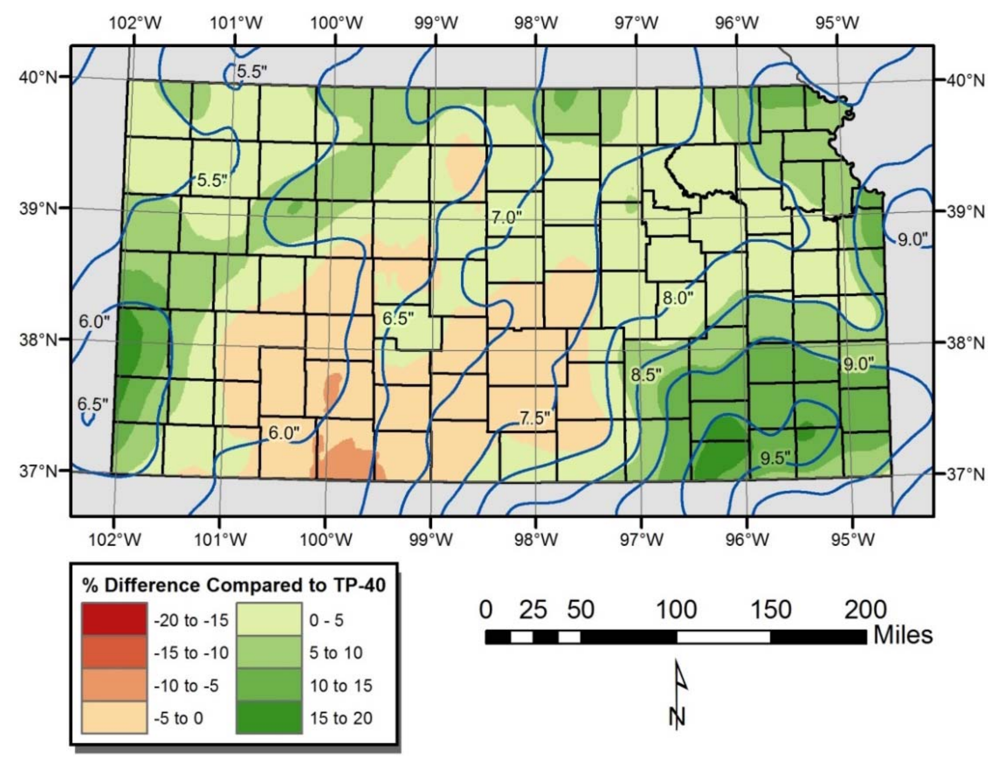

Figure 4.8: Changes in 100-Year 24-Hour Precipitation across Kansas

4.3 Changes in Precipitation Frequency for Johnson County, Kansas

In Johnson County, the changes are mixed, as Tables 4.2 and 4.3 and Figure 4.11 show. Depths for the 5-minute duration increased substantially for all recurrence intervals. 100-year depths for durations from 6 to 24 hours also increased substantially. On the other hand, the 2-year 15-minute depth decreased by more than 10%.

Table 4.2: Changes in 15-Minute, 1-Hour and 24-Hour Precipitation Depths for Johnson County

Recurr. interval (yr)	15-minute precipitation depth (in.)			1-hour precipitation depth (in.)			24-hour precipitation depth (in.)		
	HYDRO-35	Atlas 14	% change	TP-40	Atlas 14	% change	TP-40	Atlas 14	% change
2	0.95	0.85	-10.5%	1.65	1.62	-1.8%	3.60	3.63	0.8%
5	1.15	1.05	-8.7%	2.11	2.03	-3.8%	4.59	4.54	-1.1%
10	1.30	1.21	-6.9%	2.43	2.38	-2.1%	5.29	5.36	1.3%
25	1.52	1.44	-5.3%	2.89	2.86	-1.0%	6.27	6.58	4.9%
50	1.68	1.62	-3.6%	3.25	3.23	-0.6%	7.04	7.60	8.0%
100	1.85	1.80	-2.7%	3.60	3.60	0.0%	7.80	8.68	11.3%

Table 4.3: Changes in 10-Year and 100-Year Precipitation Depths for Johnson County

Duration	10-year precipitation depth (in.)			100-year precipitation depth (in.)		
	TP-40 & HYDRO-35	Atlas 14	% change	TP-40 & HYDRO-35	Atlas 14	% change
5 min	0.60	0.68	13.3%	0.85	1.01	18.8%
10 min	1.02	1.00	-2.0%	1.44	1.47	2.1%
15 min	1.30	1.21	-6.9%	1.85	1.80	-2.7%
30 min	1.86	1.76	-5.4%	2.71	2.61	-3.7%
1 hr	2.43	2.38	-2.1%	3.60	3.60	0.0%
2 hr	3.02	3.00	-0.7%	4.40	4.59	4.3%
3 hr	3.29	3.43	4.3%	4.90	5.32	8.6%
6 hr	3.89	4.12	5.9%	5.80	6.54	12.8%
12 hr	4.64	4.74	2.2%	6.90	7.65	10.9%
24 hr	5.29	5.36	1.3%	7.80	8.68	11.3%

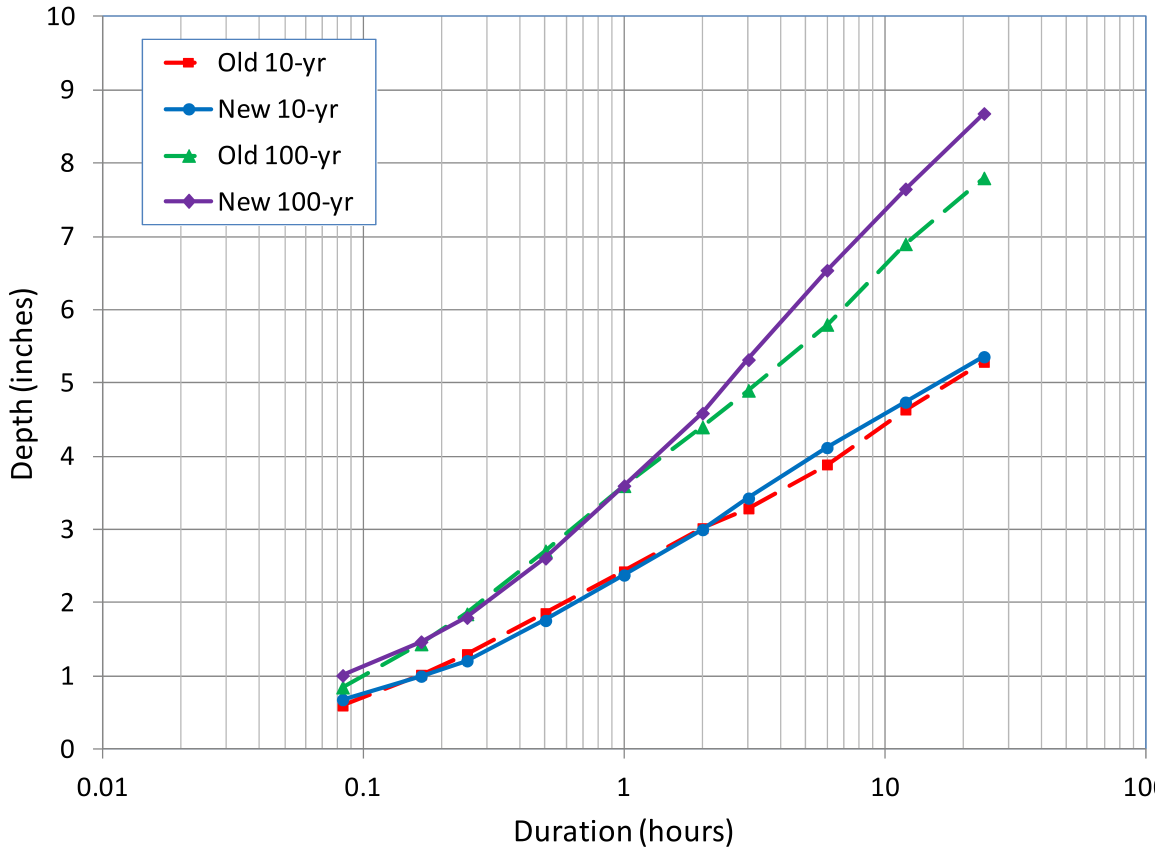

Figure 4.9: Comparison of Old and New 10-Year and 100-Year Precipitation Depths for Johnson County

4.4 Changes in Precipitation Frequency for Sedgwick County, Kansas

In Sedgwick County, precipitation depths generally decreased, as documented in Tables 4.4 and 4.5 and Figure 4.12. Depths for durations of 15, 30 and 60 minutes fell the most in percentage terms. Depths increased only for the 5-minute duration at all recurrence intervals and for durations of 3 to 24 hours at the 100-year recurrence interval.

Table 4.4: Changes in 15-Minute, 1-Hour and 24-Hour Precipitation Depths for Sedgwick County

Recurr. interval (yr)	15-minute precipitation depth (in.)			1-hour precipitation depth (in.)			24-hour precipitation depth (in.)		
	HYDRO -35	Atlas 14	% change	TP-40	Atlas 14	% change	TP-40	Atlas 14	% change
2	0.95	0.87	-8.4%	1.70	1.59	-6.5%	3.50	3.40	-2.9%
5	1.15	1.04	-9.6%	2.17	1.95	-10.1%	4.53	4.24	-6.4%
10	1.30	1.18	-9.2%	2.50	2.26	-9.6%	5.24	4.98	-5.0%
25	1.52	1.38	-9.2%	2.97	2.69	-9.4%	6.24	6.06	-2.9%
50	1.68	1.53	-8.9%	3.34	3.04	-9.0%	7.02	6.93	-1.3%
100	1.85	1.67	-9.7%	3.70	3.40	-8.1%	7.80	7.84	0.5%

Table 4.5: Changes in 10-Year and 100-Year Precipitation Depths for Sedgwick County

Duration	10-year precipitation depth (in.)			100-year precipitation depth (in.)		
	TP-40 & HYDRO-35	Atlas 14	% change	TP-40 & HYDRO-35	Atlas 14	% change
5 min	0.61	0.66	8.2%	0.85	0.94	10.6%
10 min	1.02	0.97	-4.9%	1.44	1.37	-4.9%
15 min	1.30	1.18	-9.2%	1.85	1.67	-9.7%
30 min	1.89	1.70	-10.1%	2.76	2.42	-12.3%
1 hr	2.50	2.26	-9.6%	3.70	3.40	-8.1%
2 hr	3.06	2.81	-8.2%	4.60	4.38	-4.8%
3 hr	3.29	3.17	-3.6%	5.00	5.12	2.4%
6 hr	3.89	3.78	-2.8%	5.90	6.25	5.9%
12 hr	4.54	4.39	-3.3%	6.80	7.11	4.6%
24 hr	5.24	4.98	-5.0%	7.80	7.84	0.5%

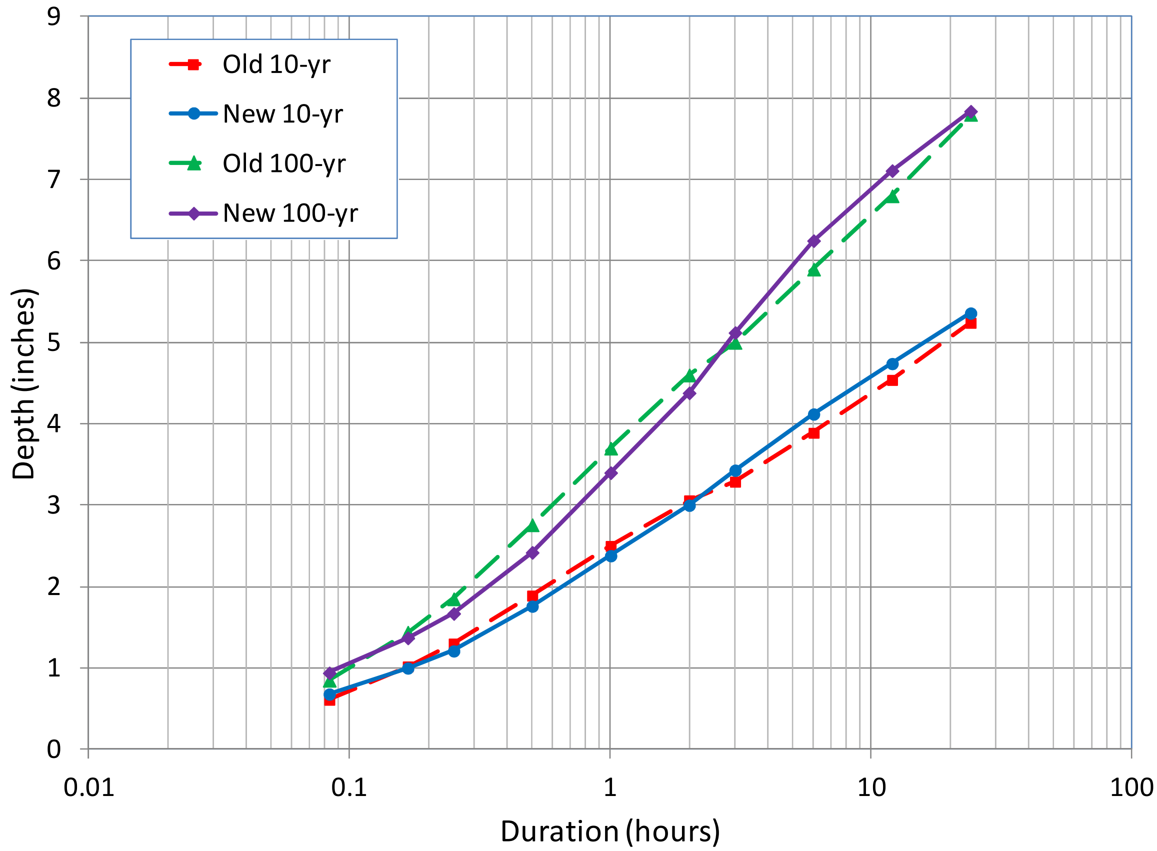

Figure 4.10: Comparison of Old and New 10-Year and 100-Year Precipitation Depths for Sedgwick County

4.5 Changes in Precipitation Frequency for Finney County, Kansas

Precipitation depths for Finney County decreased for nearly all durations and recurrence intervals, as can be seen in Tables 4.6 and 4.7 and Figure 4.13. The 2-year and 5-year depths for the 15-minute duration fell by more than 10%. Only the 100-year 5-minute depth increased substantially.

Table 4.6: Changes in 15-Minute, 1-Hour and 24-Hour Precipitation Depths for Finney County

Recurr. interval (yr)	15-minute precipitation depth (in.)			1-hour precipitation depth (in.)			24-hour precipitation depth (in.)		
	HYDRO-35	Atlas 14	% change	TP-40	Atlas 14	% change	TP-40	Atlas 14	% change
2	0.80	0.72	-10.0%	1.40	1.30	-7.1%	2.40	2.44	1.7%
5	1.03	0.92	-10.7%	1.85	1.67	-9.7%	3.23	3.04	-5.9%
10	1.18	1.10	-6.8%	2.15	1.98	-7.9%	3.79	3.57	-5.8%
25	1.41	1.34	-5.0%	2.58	2.41	-6.6%	4.58	4.34	-5.2%
50	1.58	1.52	-3.8%	2.92	2.75	-5.8%	5.19	4.96	-4.4%
100	1.75	1.72	-1.7%	3.25	3.10	-4.6%	5.80	5.62	-3.1%

Table 4.7: Changes in 10-Year and 100-Year Precipitation Depths for Finney County

Duration	10-year precipitation depth (in.)			100-year precipitation depth (in.)		
	TP-40 & HYDRO-35	Atlas 14	% change	TP-40 & HYDRO-35	Atlas 14	% change
5 min	0.59	0.61	3.4%	0.84	0.96	14.3%
10 min	0.94	0.90	-4.3%	1.38	1.41	2.2%
15 min	1.18	1.10	-6.8%	1.75	1.72	-1.7%
30 min	1.66	1.55	-6.6%	2.49	2.43	-2.4%
1 hr	2.15	1.98	-7.9%	3.25	3.10	-4.6%
2 hr	2.59	2.41	-6.9%	3.90	3.77	-3.3%
3 hr	2.78	2.62	-5.8%	4.20	4.10	-2.4%
6 hr	3.10	2.94	-5.2%	4.70	4.63	-1.5%
12 hr	3.52	3.24	-8.0%	5.40	5.10	-5.6%
24 hr	3.79	3.57	-5.8%	5.80	5.62	-3.1%

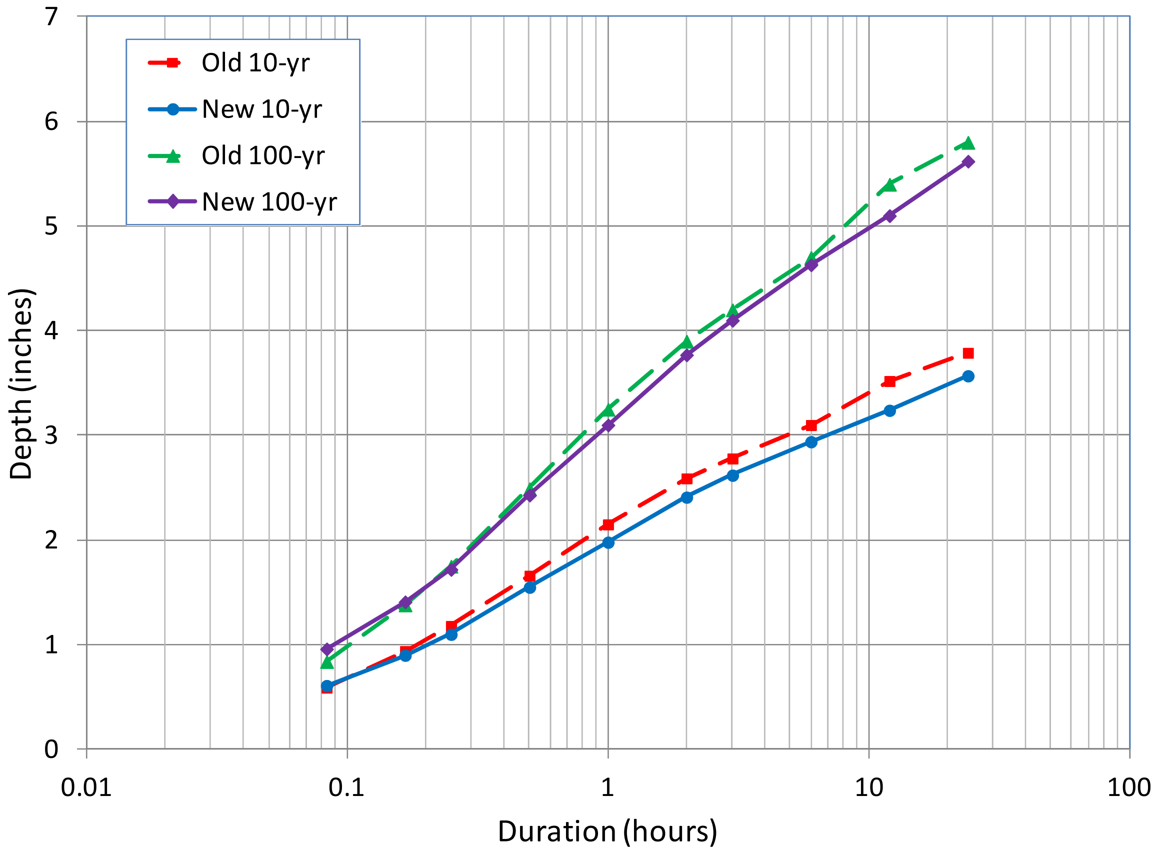

Figure 4.11: Comparison of Old and New 10-Year and 100-Year Precipitation Depths for Finney County

Chapter 5: Impacts on Hydrologic Estimates and Design Procedures

This chapter examines the impacts of the changes in precipitation frequency estimates on KDOT's hydrologic design procedures and discharge estimates. KDOT computes design discharges for bridges, culverts and other drainage structures by a variety of methods. Table 5.1 lists these methods with their limitations and appropriate uses. Recurrence intervals for design can range from 2 years to 100 years, depending on the type of improvement or land use requiring protection from flooding. Recurrence intervals for protection of roadways are 10 years for local routes, 25 years for primary routes and 50 years for interstate highways.

Table 5.1: Guidelines for Selection of Hydrologic Methods

Method	**Limitations and Uses**
Rational method	Drainage area ≤ 640 acres Unregulated stream No analysis of detention storage at structure
Extended Rational method	Drainage area > 640 acres and ≤ 30 mi^2 Unregulated stream
Three-variable regression method	Drainage area > 640 acres and ≤ 30 mi^2 Unregulated stream
USGS regression method for Kansas	Rural areas Drainage area > 640 acres Unregulated stream No analysis of detention storage at structure Generally used for bridge-size structures only
Flood hydrograph simulation method (by specified procedures)	Circumstances in which the other methods are not applicable, or consideration of timing and storage effects is warranted. Examples include determination of peak flow on a stream controlled by a constructed device and/or natural diversion or when detention storage analysis is warranted.

(Source: KDOT 2011)

5.1 Rational Method

The Rational method is used to compute design flows for small bridges, culverts, median drainage systems, urban drainage inlets and storm sewers. In the Rational formula, the T-year discharge is directly proportional to the T-year rainfall intensity with duration equal to the watershed's time of concentration. Therefore an n% change in the relevant rainfall intensity will result in an n% change in the design discharge. Times of concentration (Tc) in urban drainage systems generally range from 5 minutes (for inlets) to 30 minutes. Tc values for median drainage systems are typically 15 minutes of less. Times of concentration can exceed 60 minutes for rural culverts and small bridges in rural watersheds with drainage areas approaching 640 acres.

The new precipitation estimates will result in higher design flows for urban storm-drainage inlets because 10-year, 5-minute rainfall intensities have increased markedly. Design flows for hydraulic structures with times of concentration in the 15-to-60-minute range will be lower in most locations because rainfall intensities for those durations have generally decreased. No changes are required to the guidelines for the Rational method in the KDOT Design Manual.

5.2 Extended Rational and Three-Variable Regression Methods

The extended Rational equations and the three-variable regression equations for Kansas (McEnroe and Young 2007) are applicable to rural watersheds with drainage areas up to 30 mi2. The precipitation input to these equations is the intensity with a duration equal to the watershed's time of concentration and the same recurrence interval as the discharge. In the extended Rational equations, as in the simple Rational formula, the discharge is directly proportional to the rainfall intensity, so a given percentage change in the precipitation input will produce the same percentage change in the discharge estimate. In the three-variable regression equations for Kansas, the exponents on the rainfall intensity term range from 1.02 to 1.3, so the percentage change in the discharge estimate will slightly exceed the percentage change in the precipitation estimate.

Sometime in the future, the extended Rational and three-variable regression equations should be updated by repeating the regression analyses using the new precipitation estimates and updated flood frequency estimates.

5.3 USGS Regression Equations for Kansas

Discharge estimates computed with the USGS flood-frequency regression equations for Kansas (Rasmussen and Perry 2000) are unaffected by the changes in the precipitation frequency estimates. The precipitation input to the USGS regression equations for Kansas is the mean annual precipitation in inches. NOAA Atlas 14 Volume 8 does not address mean annual precipitation. The map of mean annual precipitation for Kansas in the KDOT Design Manual is still valid for use with the USGS regression equations. No changes are required to this section of the KDOT Design Manual.

5.4 Flood Hydrograph Simulation

The guidelines for flood hydrograph simulation (FHS) in the KDOT Design Manual state that the design storm should be a frequency-based hypothetical storm of the type generated by the HEC-HMS Hydrologic Modeling System of the U.S. Army Corps of Engineers (USACE 2000). The KDOT Design Manual (2011) recommends a storm duration of 3, 6, 12 or 24 hours, depending on the hydrologic region (eastern or western) and the recurrence interval of interest. The precipitation inputs needed to generate the design storm are the depths for the durations of 5, 15 and 60 minutes and 2, 3, 6, 12 and 24 hours (only up to the total storm duration).

We investigated the impacts of the precipitation frequency changes on flood hydrographs by simulating 100-year design events on hypothetical 640-acre rural watersheds in Johnson, Sedgwick and Finney Counties. The test watersheds were assumed to have lag times of 36 minutes and runoff curve numbers of 74 for average antecedent moisture conditions. In accordance with the guidelines in the KDOT Design Manual, we used storm durations of 24 hours for Johnson and Sedgwick Counties and 12 hours for Finney County. In Johnson and Sedgwick Counties, the baseline curve number of 74 was increased to 85, the corresponding value for AMC = 2.75.

Table 5.2 compares the computed peak discharges and runoff depths for the 100-year design events on the three test watersheds. The new precipitation estimates produce a slightly higher peak discharge in Johnson County and significantly lower peak discharges in Sedgwick and Finney Counties. The total runoff depth for the 100-year design event increases markedly in Johnson County, remains nearly constant in Sedgwick County and decreases significantly in Finney County.

Table 5.2: Comparison of FHS Results for 100-Year Design Events on Hypothetical 640-Acre Watershed using Old and New Precipitation Estimates

County	Peak discharge (cfs)			Runoff depth (in.)		
	TP-40 & HYDRO-35	Atlas 14	% change	TP-40 & HYDRO-35	Atlas 14	% change
Johnson	2103	2160	2.7%	5.79	6.81	17.6%
Sedgwick	2150	1995	-7.2%	5.96	6.01	0.8%
Finney	1219	1123	-7.9%	2.68	2.44	-9.0%

Sometime in the future, the guidelines for storm duration and antecedent moisture condition in the KDOT Design Manual (2011) should be updated by repeating the analysis using the new precipitation estimates and updated flood frequency estimates.

Chapter 6: Summary and Conclusions

This report documents the development of KDOT's new rainfall tables for counties in Kansas based on NOAA Atlas 14 Volume 8 (Perica et al. 2013) and provides guidelines for their use. These new tables provide rainfall depths and intensities for durations from 5 minutes to 24 hours and recurrence intervals from 1 to 500 years.

Averaged across Kansas, precipitation estimates have decreased for most combinations of duration and recurrence interval. Of the combinations we examined, only the 24-hour depth for the 100-year recurrence interval and the 5-minute depths for all recurrence intervals have increased on a statewide-average basis.

The changes vary geographically across Kansas. The changes in Johnson, Sedgwick and Finney Counties were examined in detail. In Johnson County, the changes are mixed. Depths for the 5-minute duration increased substantially for all recurrence intervals. 100-year depths for durations from 6 to 24 hours also increased substantially. However, the 2-year 15-minute depth decreased by more than 10%. In Sedgwick County, precipitation depths generally decreased. Depths increased only for the 5-minute duration at all recurrence intervals and for durations of 3 to 24 hours at the 100-year recurrence interval. Precipitation depths for Finney County decreased for nearly all durations and recurrence intervals. Only the 100-year 5-minute depth increased substantially. The spatial variability of the precipitation estimates has increased considerably.

The changes in the precipitation frequency estimates are not necessarily indicative of actual changes in extreme precipitation characteristics. These changes are largely attributable to the improved statistical methodologies used in Atlas 14 compared to TP-40 and HYDRO-35.

The impacts of these changes on design discharges for bridges, culverts and other drainage structures vary by hydrologic method. Design discharges computed with the Rational formula and the Extended Rational equations for Kansas will increase or decrease by the same percentage as the precipitation input to these equations. Discharges computed with the three-variable regression equations for Kansas will increase or decrease by a slightly larger percentage than the precipitation input. Discharge computed with the USGS flood-frequency regression equations for Kansas are unaffected by the changes in the precipitation frequency estimates.

Design discharges computed by flood hydrograph simulation will decrease slightly in most cases for most locations in Kansas.

Sometime in the future, the extended Rational and three-variable regression equations and the guidelines for flood hydrograph simulation in the KDOT Design Manual (2011) should be updated for compatibility with the new precipitation frequency estimates.

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