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MAPPING THE RAINFALL EVENT FOR STORMWATER QUALITY CONTROL

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16 Abstract

Stormwater runoff from transportation facilities and urban areas can contain significant concentrations of suspended solids, metals, and oil and grease. In some cases, best management practices (BMPs) are required for treatment of this contaminated runoff. Current Center for Watershed Protection (CWP) guidelines suggest that BMPs be designed to treat 90% of the annual runoff. A survey of state BMP design manuals shows that many states are adopting the 90% runoff guideline. The objective of this study was to determine the daily rainfall depth that should be used for sizing BMPs in Kansas. This report presents two methods for determining this rainfall depth: (a) the 90th percentile daily rainfall and (b) the 90% volume daily rainfall. Records for 623 raingages in and within 100 miles of Kansas were analyzed to determine the design rainfall event using these two methods. Results are presented as contour maps and maps showing the design depths for all Kansas counties.

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Final Report

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and

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PREFACE

The Kansas Department of Transportation's (KDOT) Kansas Transportation Research and New-Developments (K-TRAN) Research Program funded this research project. It is an ongoing, cooperative and comprehensive research program addressing transportation needs of the state of Kansas utilizing academic and research resources from KDOT, Kansas State University and the University of Kansas. Transportation professionals in KDOT and the universities jointly develop the projects included in the research program.

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ABSTRACT

Stormwater runoff from transportation facilities and urban areas can contain significant concentrations of suspended solids, metals, and oil and grease. In some cases, best management practices (BMPs) are required for treatment of this contaminated runoff. Current Center for Watershed Protection (CWP) guidelines suggest that BMPs be designed to treat 90% of the annual runoff. A survey of state BMP design manuals shows that many states are adopting the 90% runoff guideline. The objective of this study was to determine the daily rainfall depth that should be used for sizing BMPs in Kansas. This report presents two methods for determining this rainfall depth: (a) the 90th percentile daily rainfall and (b) the 90% volume daily rainfall. Records for 623 raingages in and within 100 miles of Kansas were analyzed to determine the design rainfall event using these two methods. Results are presented as contour maps and maps showing the design depths for all Kansas counties.

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Chapter 1

Introduction

1.1 Background

Over recent years, increased attention has been given to the problem of non-point source (NPS) pollution from transportation facilities and urban areas. Two regulatory initiatives impact the management of stormwater quality: a) the Total Maximum Daily Load (TMDL) program and b) the National Pollution Discharge Elimination System (NPDES) Phase I and II permitting requirements for urban catchments. As a result of these federal initiatives, many stormwater discharges will require in-situ treatment through structural or non-structural means. Such treatment methods are generally termed best management practices (BMPs). Current Center for Watershed Protection (CWP) guidelines for the treatment of stormwater recommend that BMP facilities be sized to treat 90% of the annual volume of rainfall runoff (CWP 2005). The objective of this study was to determine the design rainfall event for stormwater quality control for the State of Kansas.

1.2 Design Rainfall Events for Stormwater Quality Control

States have adopted various methods for computing the design volume (the water quality volume) for BMPs. A tabular summary of water quality design storms is presented in Table 1.1. This table lists the design storms that have been selected by nine different states. Many states (e.g., Georgia, Maryland, Virginia, New York) have adopted recommendations similar to the CWP guideline. The CWP guideline, however, has been interpreted in two different ways. The two interpretations are defined below.

(a) The CWP Stormwater Manager's Resource Center website defines the water quality design storm as the *90th percentile daily rainfall*. This is the daily rainfall accumulation that is exceeded, on average, in only 10% of the precipitation events in a given year.

(b) The intent of the CWP guideline is to treat runoff from 90% of the annual rainfall. The guideline in (a) does not meet this aim. Another approach is to select the design rainfall accumulation such that 90% of the annual rainfall is contributed by storms of this magnitude or smaller. This approach is called the *90% volume daily rainfall* throughout this report.

The State of Kansas has not selected a guideline for sizing BMPs. As such, both of the interpretations of the water quality design storm are examined in this research.

Table 1.1: Summary of Water Quality Design Storms

State	Water Quality Design Storm	Reference
Georgia	85^{th} Percentile Storm	(Georgia 2001)
Idaho	1/3 of 2-year, 24-hour Storm	(Idaho 2005)
Maryland	90% of Annual Rainfall Volume	(Maryland 2000)
Massachusetts	0.5" or 1.0"	(Massachusetts 1997)
New York	90^{th} Percentile Storm	(New York 2003)
Pennsylvania	90% of Annual Rainfall Volume	(Pennsylvania 1998)
Vermont	90^{th} Percentile Storm	(Vermont 2002)
Virginia	90% of Annual Rainfall Volume	(Virginia 1999)
Washington	6-month, 24-hour Storm	(Washington 2001)

Chapter 2

Data and Methods

2.1 Data Used

The data set collected for this study consisted of daily raingage observations for Kansas and adjacent states. Raingage observations were obtained from the National Climatic Data Center for all daily gages within 100 miles of Kansas. Gages with short record lengths (generally less than 30 years) were excluded from analysis. In all, 623 raingages were used in the analysis. The average length of record for these gages was 55.2 years. Record completeness ranged from 94 to 100%. Figure 2.1 displays the locations of raingages used for this study.

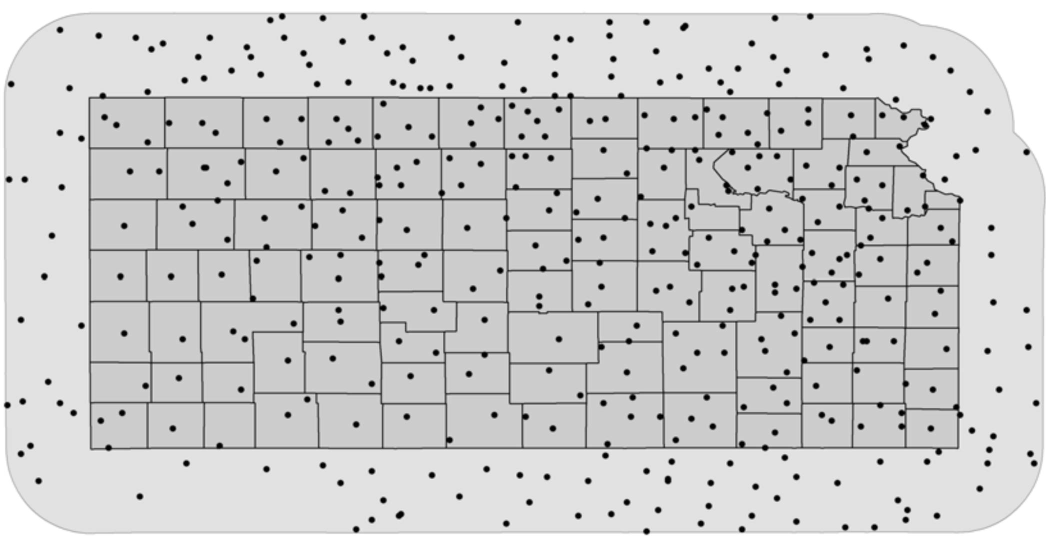

Figure 2.1: Locations of Raingages Used for this Study

2.2 Methodology

The design event depth was determined using the two different approaches outlined in Chapter 1. For the sake of clarity, these approaches are defined again here:

Definition (a): *90th percentile daily rainfall*. This depth represents the daily rainfall accumulation that is exceeded (in an average year) on only 10% of days with rainfall totals in excess of 0.1 inch.

Definition (b): *90% volume daily rainfall*. In an average year, all daily rainfall accumulations less than or equal to this depth add up to 90% of the total annual rainfall (excluding daily accumulations less than 0.1 inch).

Both approaches follow the recommendation of the CWP and exclude rainfall depths less than 0.1 inch. Reporting of depths less than 0.1 inch is inconsistent and may be inaccurate. In addition, events that produce less than 0.1 inch of rainfall rarely contribute runoff.

In this study, the 90th percentile daily rainfall was determined for each raingage by sorting and ranking all historical daily rainfall observations that exceed 0.1 inch. The 90th percentile event was selected from this ranked list and recorded in tabular format along with the station geographic coordinates for input to a geographic information system (GIS) for interpolation. The interpolation is described below.

The 90% volume daily rainfall was determined by sorting and ranking all daily rainfall totals for each raingage. A running sum of rainfall volumes was computed, and the daily rainfall depth that encompassed 90% of the total gage rainfall volume was recorded. Again, these data were stored in tabular format along with the station coordinates for input to a GIS for interpolation.

Figure 2.2 illustrates this methodology with a distribution curve of daily rainfall accumulations for the McPherson gage. This gage (COOPID 145152) has a 102-year record of daily rainfalls.

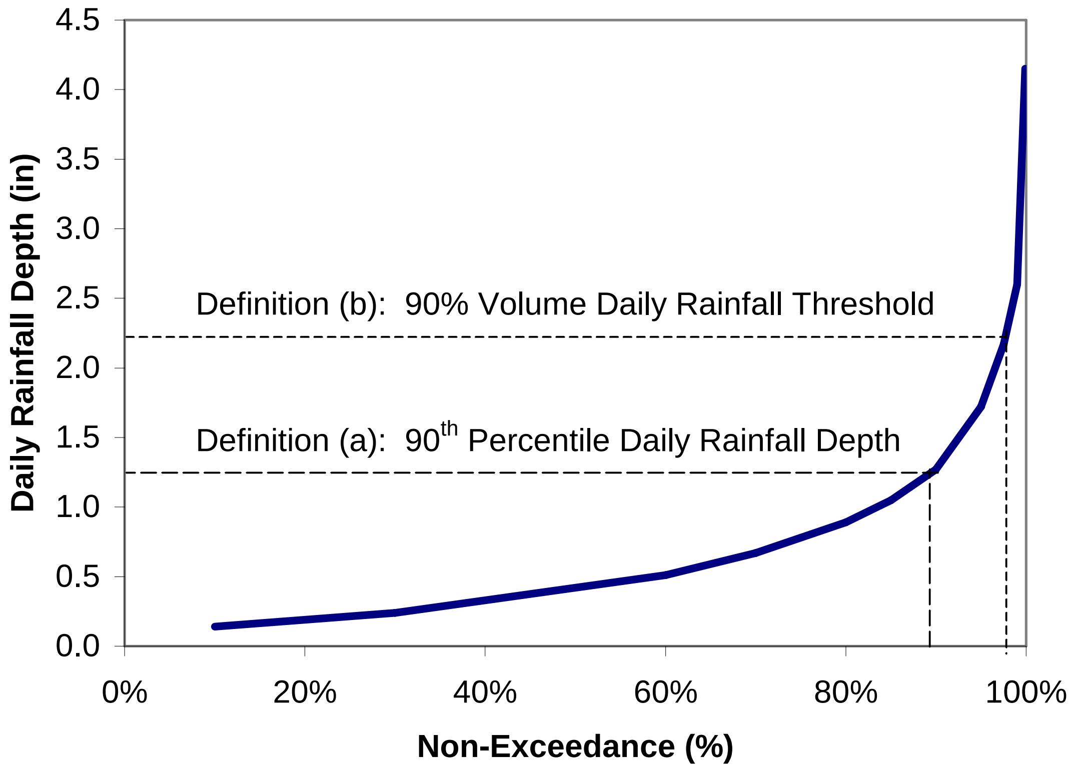

Figure 2.2: Distribution of Daily Rainfall Totals for the McPherson Gage

Several interpolation methods were applied to the two data sets. Methods used included inverse distance weighting squared, ordinary kriging assuming no nugget effect, ordinary kriging assuming a large nugget effect, local polynomial interpolation, and global polynomial interpolation. Cross validation was performed for all five interpolation methods, and results were similar. Of the five interpolation methods evaluated, local polynomial interpolation (LPI) was determined to produce superior maps of the design rainfall depths. LPI does an excellent job of capturing the overall spatial trends of the data sets. Inverse distance weighting and kriging assign too much weight to individual gage results.

Chapter 3

Results

3.1 90th Percentile Daily Rainfall

Figure 3.1 displays contours for the 90th percentile daily rainfall. Results for this map follow the trend of mean annual rainfall, with high values in southeast Kansas and low values in northwest Kansas. Results range from 0.98 to 1.48 inches. These depths represent the daily rainfall depth that is exceeded (on average) on only 10% of days when more than 0.1 inch of rain falls.

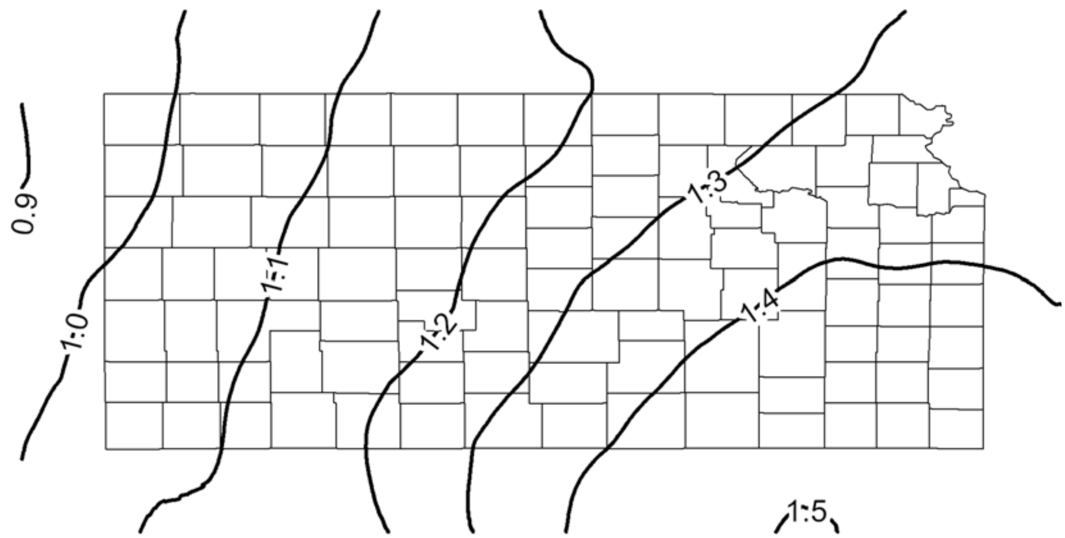

Figure 3.1: 90th Percentile Daily Rainfall Contours (in inches)

3.2 90% Volume Daily Rainfall

Figure 3.2 shows contours for the daily rainfall depth that envelopes the daily rainfalls that produce (on average) 90% of the average annual rainfall volume. These results follow the same trend as in Figure 3.1, but depths for Kansas range from 1.82 to 2.84 inches. These depths are significantly higher than those in Figure 3.1. As such, using this definition of the water quality design storm would lead to much more conservative (and thus more costly) treatment facilities.

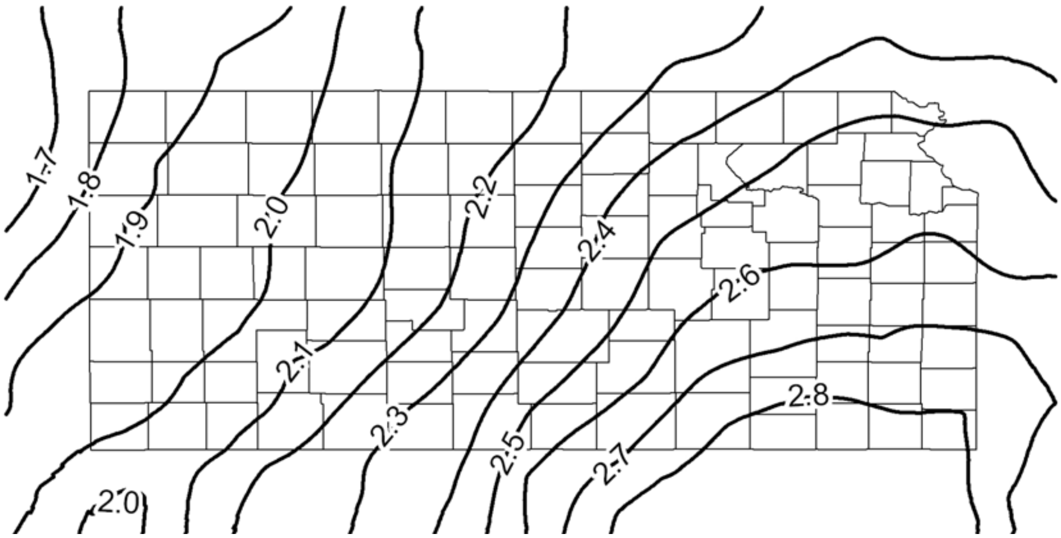

Figure 3.2: 90% Volume Daily Rainfall Contours (in inches)

3.3 County Maps

Figures 3.3 shows the 90th percentile daily rainfall depth for each county in Kansas. The value for each county represents the spatial average. Figure 3.4 shows the 90% volume daily rainfall for each county in Kansas.

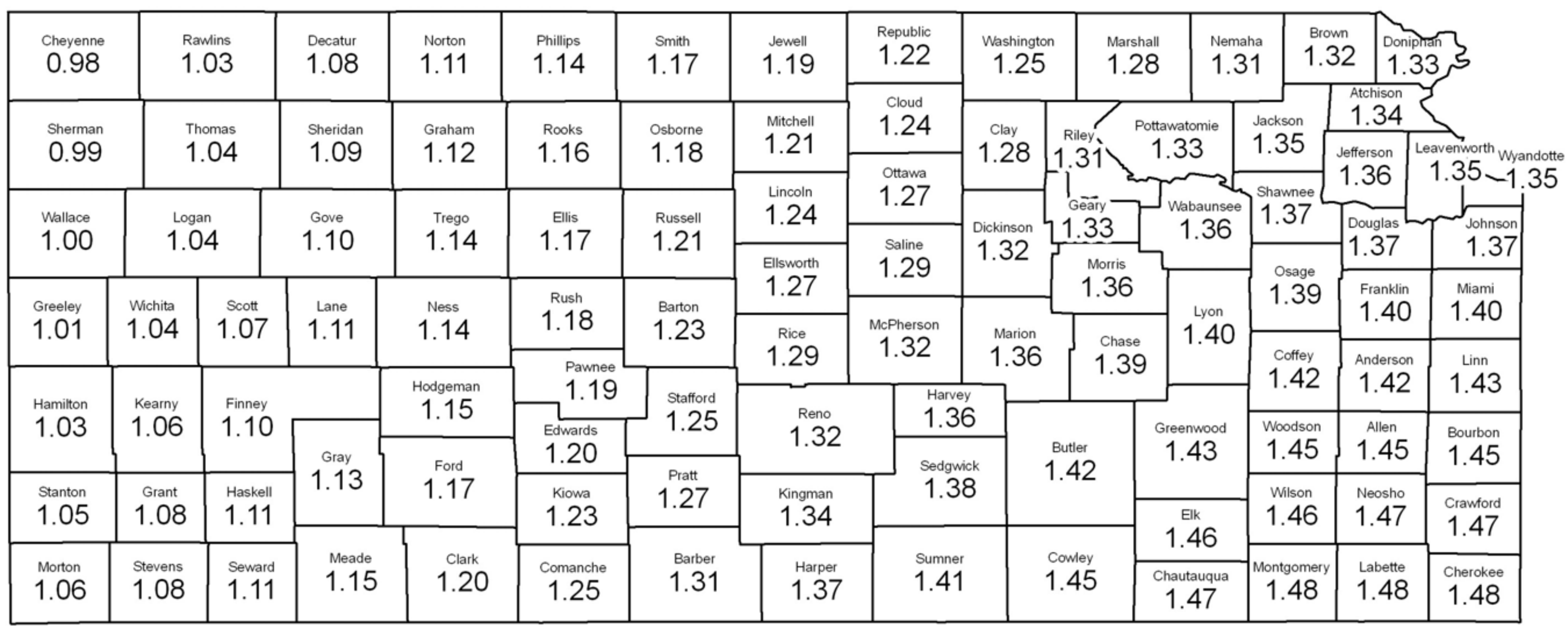

Figure 3.3: 90th Percentile Daily Rainfall Values by County (in inches)

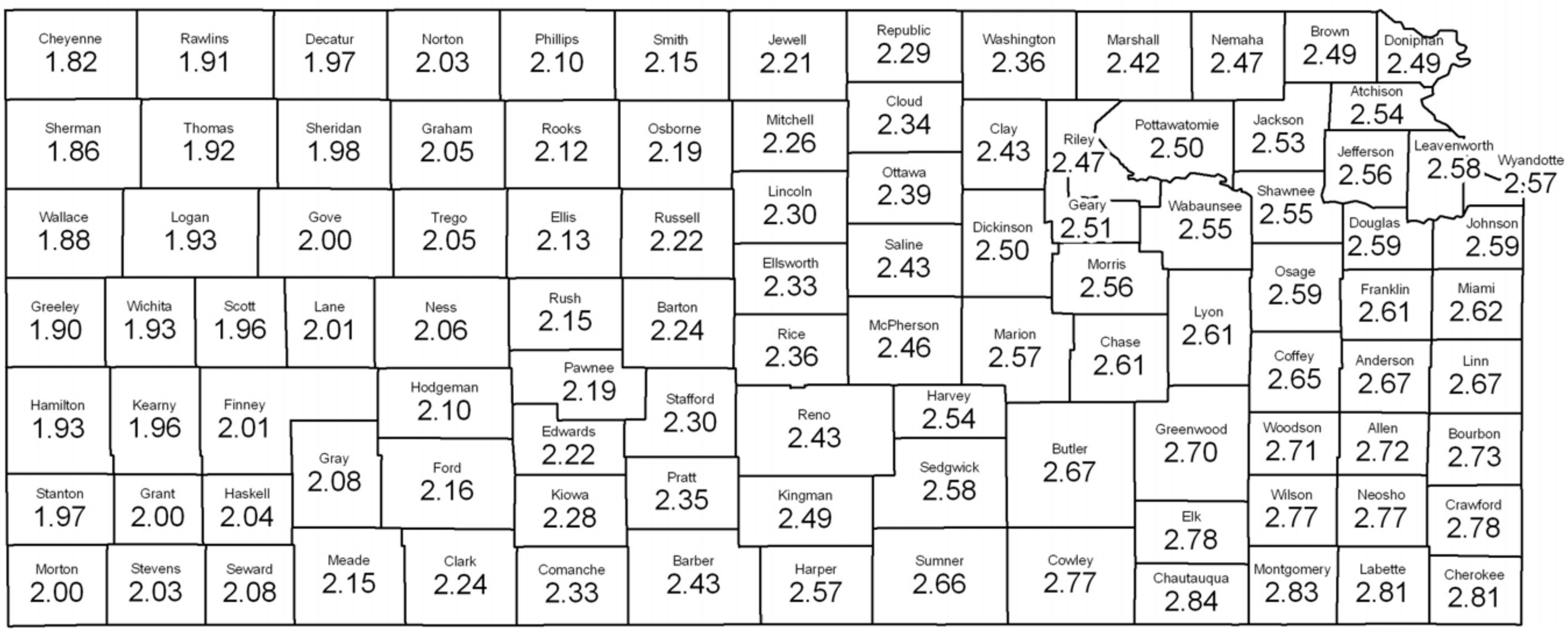

Figure 3.4: 90% Volume Daily Rainfall Values by County (in inches)

3.4 Inter-Annual Variability of Estimates

Figures 3.3 and 3.4 present daily rainfall depths for two different definitions of the water quality event. Note that for each definition, the depth shown in the figures is a daily rainfall accumulation that (a) is exceeded by only 10% of all events for an average year or (b) encompasses 90% of the rainfall volume for an average year. The purpose of this section is to discuss the variability in the results from year to year. An analysis of the 102-year McPherson gage is provided to illustrate inter-annual variation.

Table 3.1 presents the range and quartile values for daily rainfall depths according to the two definitions evaluated in this report. The 90% daily rainfall depth ranges from 0.75 inches (in 1955) to 2.50 inches (in 1976). Likewise, the 90% volume daily rainfall ranges from 1.04 inches (in 1952) to 4.37 inches (in 1980). Note that the median values presented in Table 3.1 are slightly different from those for McPherson County in Figures 3.3 and 3.4. This is for a number of reasons. First, the table presents median values while the figures present mean values. Second, the values in the figures are spatially averaged using a number of gages in the vicinity.

Table 3.1 is a reminder that the depths presented in Figures 3.3 and 3.4 are for an average year, and that a BMP designed to meet the 90^{th} percentile daily rainfall event will not capture and treat 90% of rain events in all years.

3.5 Recurrence Intervals for 90% Volume Daily Rainfall

The rainfall depths reported in Figure 3.4 for the 90% volume daily rainfall are much higher than those reported in Figure 3.3 for the 90^{th} percentile daily rainfall. This section attaches recurrence intervals to the rainfall depths presented in Figure 3.4 for five different assumed rainfall durations. The purpose is to illustrate the magnitude of these rainfall depths and to put them in a frame of reference that is easy to understand. Table 3.2 presents approximate return periods for the ten counties. Note that the 90% volume daily rainfall is a 24-hour event; the return periods for shorter durations are presented for comparison only. On average, the depths reported in Figure 3.4 are equivalent to the 1-year, 24-hour rainfall event. These events are significant, given that the recurrence interval for channel-forming events tend to fall in the 1.5-year to 2.0-year range.

Table 3.1: Variability of Rainfall Depths for McPherson Gage Over 102-Year Record

	90th Percentile Daily Rainfall (in)	**90% Volume Daily Rainfall (in)**
Minimum	0.75	1.04
25th Percentile	1.18	1.68
Median	1.36	2.20
75th Percentile	1.68	2.70
Maximum	2.50	4.37

Table 3.2: Recurrence Intervals for 90% Volume Daily Rainfall Events for Ten Counties

County	**Approximate Recurrence Intervals (Years) for Various Rainfall Durations**				
	1 hour	**3 hours**	**6 hours**	**12 hours**	**24 hours**
Sherman	6.3	3.4	2.3	1.7	1.3
Morton	8.0	3.5	2.5	1.6	1.0
Pawnee	7.7	3.3	2.0	1.2	1.2
Cloud	7.2	3.6	1.9	1.5	1.0
Sedgwick	12.6	4.0	2.3	1.3	<1.0
Shawnee	10.6	3.6	1.9	1.3	<1.0
Coffey	13.9	4.0	1.9	1.1	<1.0
Doniphan	9.8	3.9	2.0	1.1	<1.0
Johnson	15.2	3.8	2.0	1.2	<1.0
Cherokee	20.8	4.3	2.0	1.1	<1.0

Chapter 4

Conclusion

4.1 Conclusion

States across the country have adopted varying definitions of the design storm for stormwater treatment facilities. The prominent definition in use is the 90% rainfall event. This definition in turn has seen two different interpretations or approaches for determining this design event. This study used these two alternate methods for computing the design rainfall event for stormwater quality control. The two approaches are (a) the 90th percentile daily rainfall approach and (b) the 90% volume daily rainfall. The 90th percentile daily rainfall event is much smaller across the state due to the skewed distribution of daily rainfall events. It only takes a few large storms to produce 10% of the annual volume of rainfall. Using the 90% volume daily rainfall guideline would lead to design criteria requiring the treatment of approximately the 1-year, 24-hour storm. The implementation of BMPs for this event magnitude is probably not feasible or realistic.

Values for the two approaches were computed for 623 daily gages in and within 100 miles of Kansas. These values were interpolated and mapped by county. This study does not make a recommendation for which method is appropriate; the authority for regulating BMP design in the State of Kansas resides with the Kansas Department of Health and Environment (KDHE).

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