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# Estimating Design Discharges for Drainage Structures in Western Kansas

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*The University of Kansas*

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**15 Supplementary Notes**

KDOT engineers have expressed concern that the hydrologic methods in the current KDOT Design Manual (Volume I, Part C, 2011) may lead to over-sizing of drainage structures in Western Kansas. Some new structures designed by the current methods are much larger than the previous structures at these locations or existing structures directly upstream or downstream, where the older structures had no known history of overtopping. There are reasons to suspect that current methods may not be well suited to small watersheds in Western Kansas, particularly for areas with high soil permeability.

This report examines the applicability of KDOT's current hydrologic methods to Western Kansas and develops new Rational C values and flood-frequency regression equations for this region. In addition, KDOT's current hydrologic methods are compared with those of nearby state DOTs.

In order to develop new flood-frequency regression equations and recommendations for Rational C values for Western Kansas, we assembled a data set of all USGS gaging stations that met the following criteria: (1) at least 10 years of peak flow records, (2) watershed area less than 100 mi$^2$, (3) unregulated watersheds (no major lakes or reservoirs), and (4) watersheds within 100 miles of the Kansas border and west of 97.5° longitude. The resulting data set contains 156 stations, 62 of which are in Kansas.

Regional flood frequency analyses were performed on this data set using Generalize Least Squares regression in WREG 1.0. Soil permeability was found not to be a significant predictor variable. Regression equations were developed for Western Kansas, but our comparisons show that these equations are not a substantial improvement over existing regression equations. Based on an evaluation of available methods, we recommend the Extended Rational method for watershed areas $> 640$ ac and $< 30$ mi$^2$ and the USGS four-parameter regression equation for watersheds $\geq 30$ mi$^2$ in both Western and Eastern Kansas.

An analysis of Rational C values indicates that C values currently used for design in Western Kansas are too high for recurrence intervals below 100 years. New Rational C values for Western Kansas were developed and checked against regression methods for consistency. Our proposed C values for Western Kansas are lower than the current values for all recurrence intervals below 100 years. We also propose certain adjustments to the Rational C values for Eastern Kansas. We recommend that urban open spaces and pervious surfaces within the right-of-way be considered equivalent to pasture/range rather than cropland in both Western and Eastern Kansas.

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## Final Report

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THE KANSAS DEPARTMENT OF TRANSPORTATION
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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.

# NOTICE

# DISCLAIMER

# Abstract

KDOT engineers have expressed concern that the hydrologic methods in the current KDOT Design Manual (Volume I, Part C, 2011) may lead to over-sizing of drainage structures in Western Kansas. Some new structures designed by the current methods are much larger than the previous structures at these locations or existing structures directly upstream or downstream, where the older structures had no known history of overtopping. There are reasons to suspect that current methods may not be well suited to small watersheds in Western Kansas, particularly for areas with high soil permeability.

This report examines the applicability of KDOT's current hydrologic methods to Western Kansas and develops new Rational C values and flood-frequency regression equations for this region. In addition, KDOT's current hydrologic methods are compared with those of nearby state DOTs.

In order to develop new flood-frequency regression equations and recommendations for Rational C values for Western Kansas, we assembled a data set of all USGS gaging stations that met the following criteria: (1) at least 10 years of peak flow records, (2) watershed area less than 100 $mi^2$, (3) unregulated watersheds (no major lakes or reservoirs), and (4) watersheds within 100 miles of the Kansas border and west of 97.5° longitude. The resulting data set contains 156 stations, 62 of which are in Kansas.

Regional flood frequency analyses were performed on this data set using Generalize Least Squares regression in WREG 1.0. Soil permeability was found not to be a significant predictor variable. Regression equations were developed for Western Kansas, but our comparisons show that these equations are not a substantial improvement over existing regression equations. Based on an evaluation of available methods, we recommend the Extended Rational method for watershed areas $> 640$ ac and $< 30$ $mi^2$ and the USGS four-parameter regression equation for watersheds $\geq 30$ $mi^2$ in both Western and Eastern Kansas.

An analysis of Rational C values indicates that C values currently used for design in Western Kansas are too high for recurrence intervals below 100 years. New Rational C values for Western Kansas were developed and checked against regression methods for consistency. Our proposed C values for Western Kansas are lower than the current values for all recurrence intervals below 100 years. We also propose certain adjustments to the Rational C values for Eastern Kansas. We recommend that urban open spaces and pervious surfaces within the right-of-way be considered equivalent to pasture/range rather than cropland in both Western and Eastern Kansas.

# Acknowledgements

This project was supported by the Kansas Department of Transportation (KDOT) through the Kansas Transportation Research and New-Developments (K-TRAN) Program. James Richardson, P.E., of KDOT served as the project monitor. Brad Rognlie, P.E., and Michael Orth, P.E., of KDOT also provided valuable guidance. The authors sincerely appreciate the contributions of these individuals.

# Table of Contents

# List of Tables

# List of Figures

# Chapter 1: Introduction

KDOT engineers have expressed concern that the hydrologic methods in the current KDOT Design Manual (Volume I, Part C, 2011) may lead to over-sizing of drainage structures in Western Kansas. Some new structures designed by the current methods are much larger than the previous structures at these locations or existing structures directly upstream or downstream, where the older structures had no known history of overtopping. There are reasons to suspect that current methods may not be well suited to small watersheds in Western Kansas, particularly for areas with high soil permeability. The KDOT Design Manual specifies the Rational method for unregulated streams with drainage areas under 640 acres and regional regression equations for unregulated rural streams with larger drainage areas. The Design Manual provides recommended Rational C values for use throughout the State. The recommended values do not account for differences in climate and soil permeability. The Design Manual states that these C values “may be somewhat conservative for western Kansas.”

This report examines the applicability of KDOT’s current hydrologic methods to Western Kansas and develops new Rational C values and flood-frequency regression equations for this region. KDOT’s current hydrologic methods are compared with those of nearby state DOTs. We attempt to develop new regional flood-frequency equations specifically for Western Kansas, and compare these equations with the current statewide equations. We also investigate the issue of Rational runoff coefficients for small watersheds and propose new C values for Western and Eastern Kansas.

In this report, Western Kansas and Eastern Kansas are defined as the western and eastern hydrologic regions shown in Figure 1.1, from the KDOT Design Manual. The Design Manual recommends different storm durations and antecedent moisture conditions for simulation of floods in the western and eastern regions, based on research by McEnroe and Gonzalez (2003).

In Kansas, as in other Plains states, hydrologic characteristics vary greatly from east to west. Figures 1.2 and 1.3 show the patterns of mean annual precipitation and lake evaporation across Kansas. Southeastern Kansas receives two-and-a-half times as much total precipitation as far Western Kansas, while lake evaporation is approximately 50% higher in the southwest than in the northeast. Soil permeability is significantly higher, on average, in the western region than in the eastern region, as can be seen in Figure 1.5, the generalized soil permeability map for Kansas (Rasmussen and Perry 2000). The spatial pattern of soil permeability is quite complex, particularly in the southwestern region. Soil permeability is generally highest in the Arkansas River Lowlands physiographic region, defined in Figure 1.4, and in alluvial river valleys throughout the state.

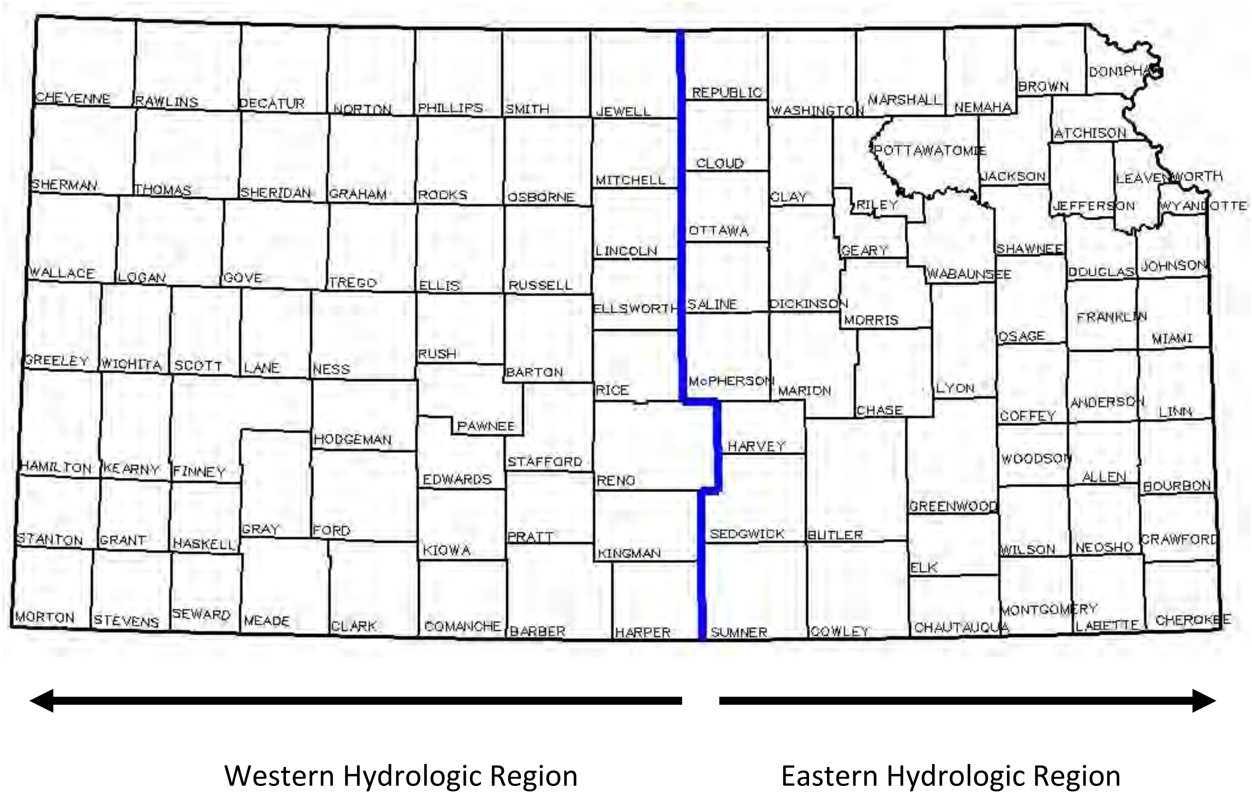
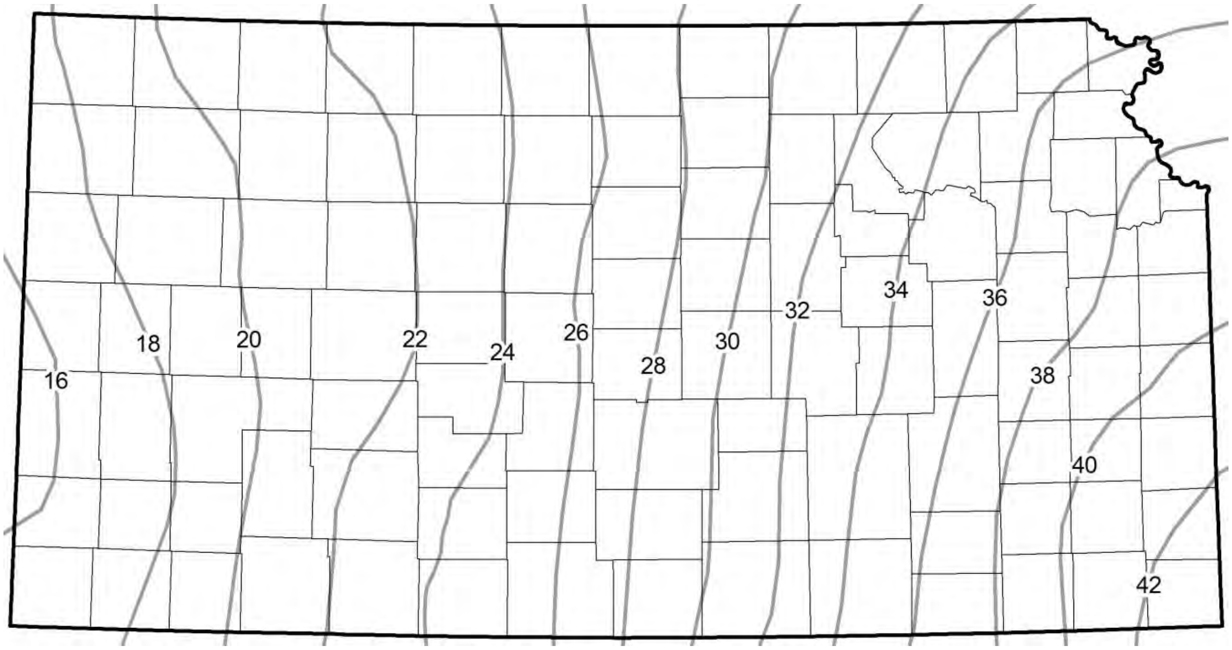
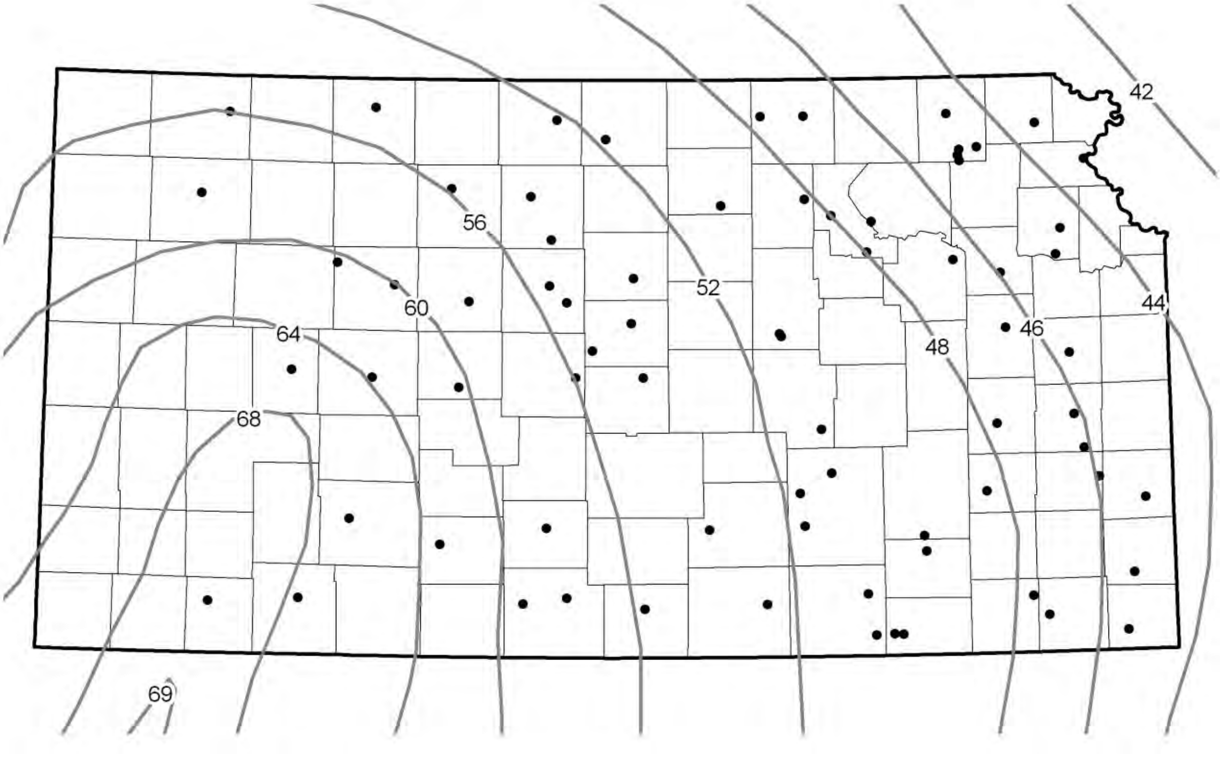


**FIGURE 1.1**
**Western and Eastern Hydrologic Regions of Kansas**



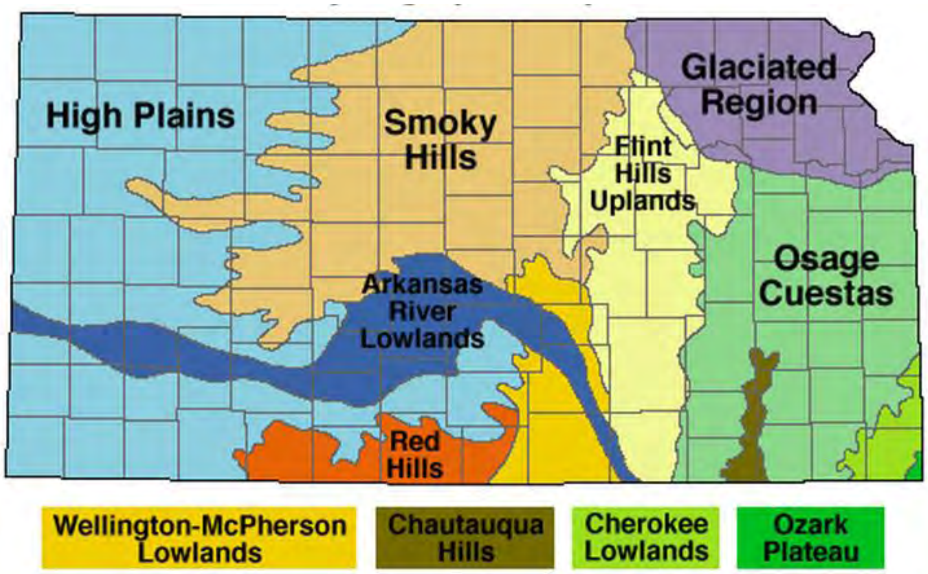
(Source: Rasmussen and Perry 2000)

**FIGURE 1.2**
**Mean Annual Precipitation (inches), Kansas**



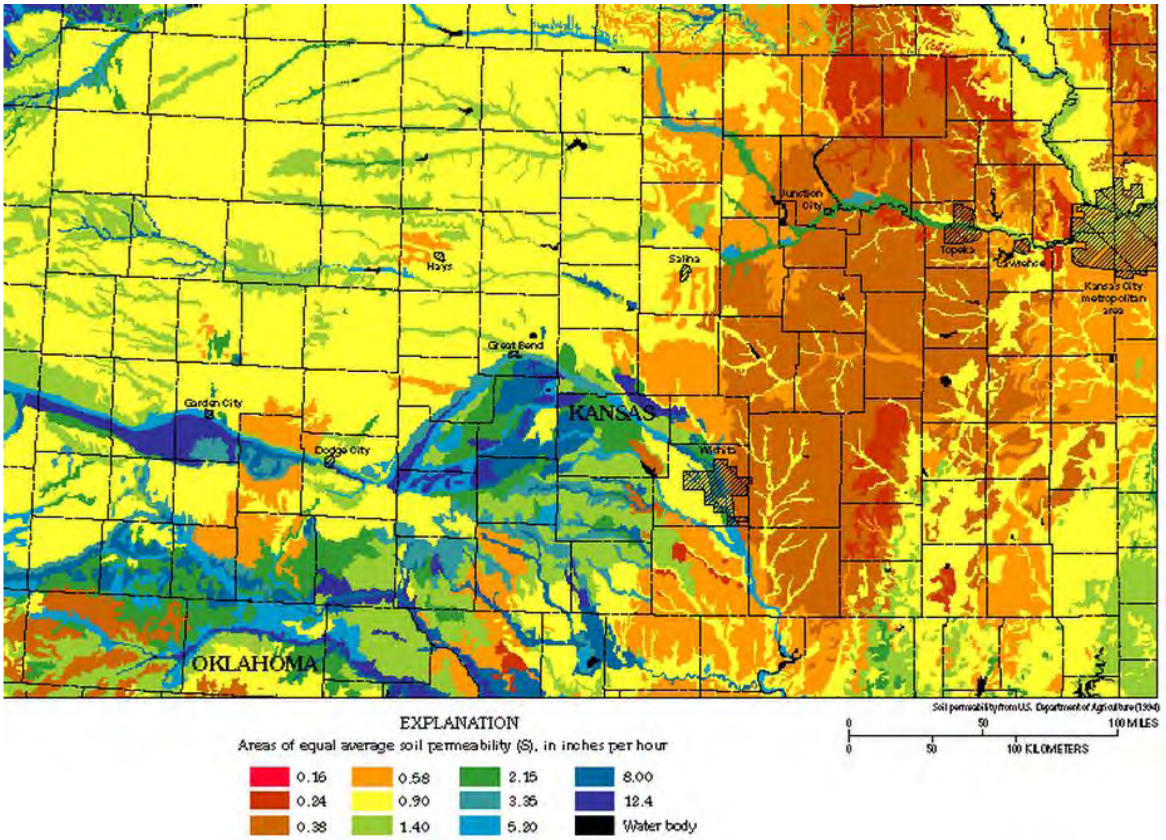
(Source: Farnsworth et al. 1982)

**FIGURE 1.3**
**Mean Annual Lake Evaporation (Inches), Kansas**



(Source: Kansas Geological Survey)

**FIGURE 1.4**
**Generalized Physiographic Regions of Kansas**



(Source: Rasmussen and Perry, 2000)

**FIGURE 1.5**
**Generalized Soil Permeability, Kansas and Surrounding Region**

Rainfall depths for specific durations and recurrence intervals also vary geographically, but to a lesser degree than mean annual precipitation. T-year rainfalls for short durations exhibit much less geographically variability than T-year rainfalls for longer durations. Table 1.1 compares 100-year rainfall depths for three different durations in Rawlins County (northwest Kansas, MAP = 20”) and Allen County (southeast Kansas, MAP = 40”). For the 5-minute duration, the difference is minimal.

**TABLE 1.1**
**Comparison of 100-Year Rainfall Depths for Locations in Western and Eastern Kansas**

| Location | 100-year, 24-hour rainfall (in.) | 100-year, 1-hour rainfall (in.) | 100-year, 5-minute rainfall (in.) |
|---|---|---|---|
| Rawlins Co. (MAP = 20”) | 5.50 | 3.30 | 0.83 |
| Allen Co. (MAP = 40”) | 8.30 | 3.65 | 0.85 |

Flood characteristics for watersheds of a given size vary tremendously across Kansas as a consequence of the differences in climate, topography, soils and vegetation. The USGS statewide flood-frequency equations for watersheds under 30 $mi^2$ (Rasmussen and Perry 2000) can be used to assess the generalized effects of the factors that vary geographically. The two inputs to these equations are drainage area and mean annual precipitation. Mean annual precipitation serves as a surrogate for all relevant factors other than drainage area. Table 1.2 compares 2-year and 100-year discharges for hypothetical 10-$mi^2$ watersheds in Rawlins County (MAP = 20 in.) and Allen County (MAP = 40 in.) computed with the USGS equations. This comparison provides support to some general observations about flood frequency relationships in western and eastern Kansas. First, the relative differences in flood quantiles from west to east exceed the relative differences in mean annual precipitation. Second, the geographic effects are more pronounced for the more frequent floods than for extreme floods. Third, flood frequency curves (discharge versus recurrence interval) have steeper slopes in Western Kansas than in Eastern Kansas.

### TABLE 1.2
### Comparison of Flood Quantiles for Hypothetical 10 mi$^2$ Watersheds in Western and Eastern Kansas

| Location | 2-year discharge* (cfs) | 100-year discharge* (cfs) |
|---|---|---|
| Rawlins Co. (MAP = 20”) | 233 | 4040 |
| Allen Co. (MAP = 40”) | 1658 | 9865 |

* from USGS regression equations for Kansas (Rasmussen and Perry, 2000)

# Chapter 2: Review of Current Hydrologic Methods

## 2.1 Selection of Methods

The KDOT Design Manual, Volume I, Part C (2011) provides the following guidelines for selection of hydrologic methods for calculation of design discharges:

**TABLE 2.1**
**Guidelines for Selection of Hydrologic Methods in KDOT Design Manual, Volume I, Part C (2011)**

| Method | Limitations and Uses |
|---|---|
| Rational method | Drainage area ≤ 640 ac<br>Unregulated stream<br>No analysis of detention storage at structure |
| Extended Rational method | Drainage areas > 640 acres and ≤ 30 $\text{mi}^2$<br>Unregulated stream<br>No analysis of detention storage at structure |
| Three-variable regression method | Drainage areas > 640 acres and ≤ 30 $\text{mi}^2$<br>Unregulated stream<br>No analysis of detention storage at structure |
| USGS regression equations for Kansas | Rural areas<br>Drainage area > 640 ac<br>Unregulated stream<br>No analysis of detention storage at structure<br>Generally used for bridge-size structures only |
| Flood hydrograph simulation (by specified procedures) | Any case in which the other two methods are not applicable, or consideration of timing and storage effects is warranted |

These methods are used to estimate design discharges with recurrence intervals of 2, 5, 10, 25, 50, and 100 years. The Extended Rational and three-variable regression methods are closely related methods that yield similar results (McEnroe and Young 2007). These two methods, like the USGS regression equations, apply only to watersheds that are largely rural. This limitation should be added to the KDOT guidelines.

This report investigates the suitability of the Rational and regression methods for use in Western Kansas. KDOT's flood-hydrograph simulation procedures, which are not considered here, already recommend different calibrated inputs for the Eastern and Western Kansas based on the research of McEnroe and Gonzalez (2003).

## 2.2 Rational Method

### *2.2.1 Drainage-Area Limitations*

The Rational method is generally considered an appropriate hydrologic method for small unregulated watersheds. However, there is no general agreement on an upper limit for drainage area. Table 2.2 compares the upper limits specified by KDOT and the transportation departments of surrounding states.

**TABLE 2.2**
**Drainage-Area Limitations on Use of Rational Method**

| State DOT | Upper limit on drainage area for Rational method |
|---|---|
| Kansas Department of Transportation | 640 acres |
| Nebraska Department of Roads | 640 acres |
| Colorado Department of Transportation | 160 acres |
| Oklahoma Department of Transportation | 640 acres |
| Missouri Department of Transportation | 200 acres |

In our view, a drainage area of 640 acres is an appropriate dividing line between the Rational method and the regression methods. The regression methods cannot be expected to provide reliable discharge estimates for watersheds much smaller than 640 acres because so few gaged watersheds have drainage areas in this lower range, particularly in Western Kansas.

### *2.2.2 Rational Runoff Coefficients*

The runoff coefficient (C value) is a key input to design-discharge estimation by the Rational method. There is no generally accepted method for determination of runoff coefficients. Different engineering organizations provide different guidelines. Land use/cover is generally considered the most important factor. Other factors considered by some organizations include recurrence interval, land slope and soil type (e.g., clayey or sandy). The runoff coefficient is generally assumed to be independent of climatic characteristics. However, our previous research on larger watersheds in Kansas showed that C values are strongly related to mean annual precipitation (McEnroe and Young 2007).

The C values currently recommended by KDOT are shown in Table 2.3. The recommended values, which apply statewide, vary with land use and recurrence interval. The following statement in the KDOT Design Manual allows the designer some leeway to account for other factors:

> The designer may opt to use slightly higher or lower runoff coefficients to account for unusual local conditions. Higher runoff coefficients might be appropriate for soils with very low permeability on steep slopes or thin soils with little water-storage capacity. Lower runoff coefficients might be appropriate for soils with very high permeability and for very flat terrain. The recommended runoff coefficients may be somewhat conservative for western Kansas, where the climate is relatively dry.

**TABLE 2.3**
**Recommended Rational Runoff Coefficients in KDOT Design Manual**

| | Rational runoff coefficient, C | | | |
|---|---|---|---|---|
| Land Use | 2-10 yr | 25 yr | 50 yr | 100 yr |
| Impervious surfaces | 0.95 | 0.95 | 0.95 | 0.95 |
| Pervious surfaces within highway right-of-way | 0.50 | 0.55 | 0.58 | 0.60 |
| Urban open space (lawns, parks, etc.) | 0.50 | 0.55 | 0.58 | 0.60 |
| Cultivated agricultural land | 0.50 | 0.55 | 0.58 | 0.60 |
| Pasture or range | 0.40 | 0.44 | 0.46 | 0.48 |
| Woods | 0.30 | 0.33 | 0.35 | 0.36 |

The KDOT table includes only two urban land-use categories: urban open space and impervious surfaces. The composite C value for any urban watershed can be computed as an average of the values for these two categories, weighted by the percentages of pervious and impervious area.

It is interesting to compare KDOT's recommended C values with those of the neighboring state transportation departments, although these comparisons do not reveal which values are more nearly correct. Table 2.4 through 2.7 show the C values recommended by the Oklahoma Department of Transportation (ODOT), the Nebraska Department of Roads (NDOR), and the Colorado Department of Transportation (CDOT).

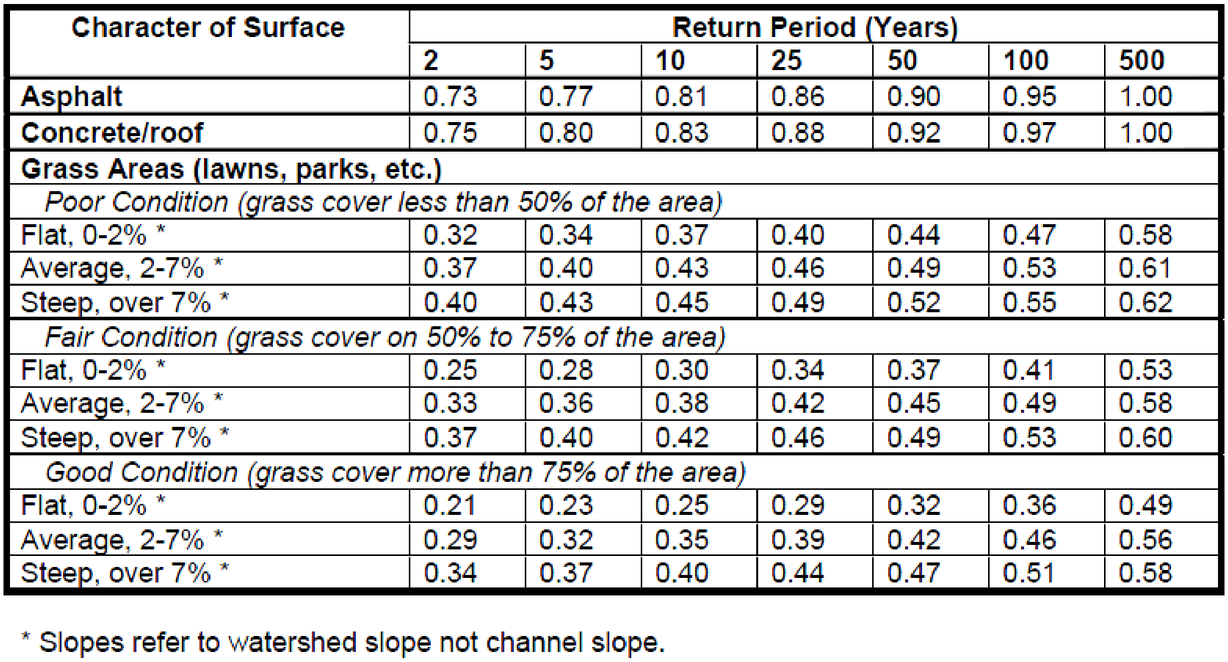
ODOT's recommendations are the least specific, providing ranges of C values for different land uses, with no mention of other relevant factors such as recurrence interval. (The Rational formula used by ODOT does not include a separate adjustment factor for recurrence interval.) The ranges in Table 2.4 are applied throughout Oklahoma. Most of ODOT's ranges encompass KDOT's recommended C values (Table 2.2). KDOT's C values for impervious surfaces and woods slightly exceed ODOT's upper limits.

**TABLE 2.4**
**Rational Runoff Coefficients Used by Oklahoma DOT**

| Surface type | Rational C |
|---|---|
| Paved | 0.7 – 0.9 |
| Gravel | 0.4 – 0.6 |
| Cut or fill slope | 0.5 – 0.7 |
| Grassed areas | 0.1 – 0.7 |
| Residential | 0.3 – 0.7 |
| Woods | 0.1 – 0.3 |
| Cultivated | 0.2 – 0.6 |

The Nebraska Department of Roads specifies C values based on land use/cover, land slope and recurrence interval. Tables 2.5 and 2.6 show NDOR's statewide recommendations for developed and undeveloped areas. NDOR's recommendations differ from KDOT's recommendations in several ways. First, NDOR's C values for all land covers except forest/woodlands are somewhat lower than KDOT's recommendations. Second, in NDOR's tables, $C_2 < C_5 < C_{10}$ (where $C_2$, $C_5$ and $C_{10}$ are the C values for recurrence intervals of 2, 5 and 10 years), whereas KDOT uses the same C values for recurrence intervals of 2, 5 and 10 years. Third, NDOR's table for developed areas breaks out grass areas by condition. The C values for urban grass areas in good, fair and poor condition are similar to those for forest/woodlands, pasture/range and cultivated land, respectively. In KDOT's table, the C values for urban open space are the same as for cultivated land. Fourth, NDOR's tables break out C values by land slope, with significantly higher C values for steeper slopes. KDOT's recommended C values are independent of land slope.

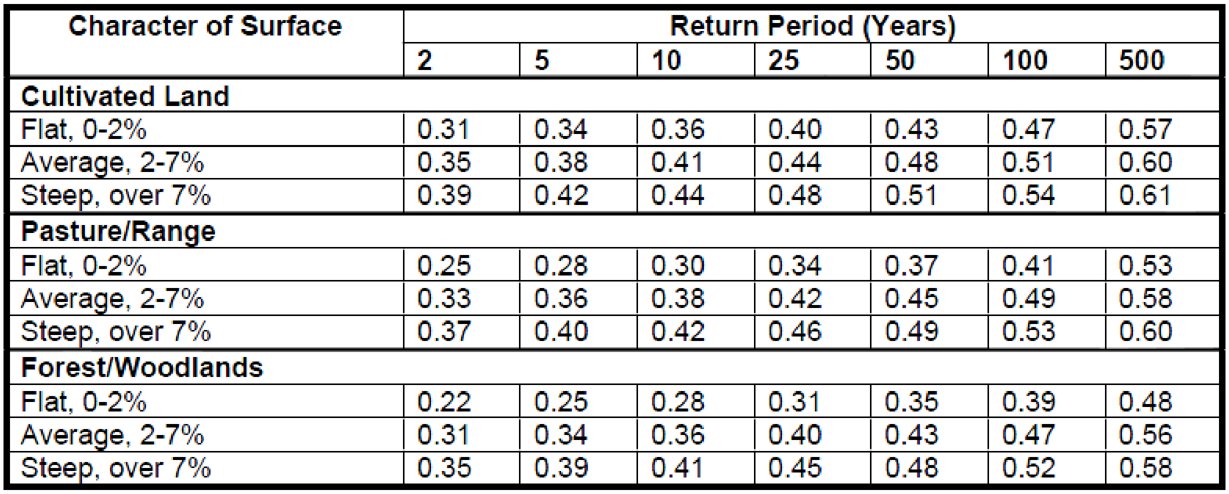
## TABLE 2.5
## Rational C Values for Developed Areas Used by Nebraska Department of Roads



| Character of Surface | Return Period (Years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 25 | 50 | 100 | 500 |
| **Asphalt** | 0.73 | 0.77 | 0.81 | 0.86 | 0.90 | 0.95 | 1.00 |
| **Concrete/roof** | 0.75 | 0.80 | 0.83 | 0.88 | 0.92 | 0.97 | 1.00 |
| **Grass Areas (lawns, parks, etc.)** | | | | | | | |
| *Poor Condition (grass cover less than 50% of the area)* | | | | | | | |
| Flat, 0-2% * | 0.32 | 0.34 | 0.37 | 0.40 | 0.44 | 0.47 | 0.58 |
| Average, 2-7% * | 0.37 | 0.40 | 0.43 | 0.46 | 0.49 | 0.53 | 0.61 |
| Steep, over 7% * | 0.40 | 0.43 | 0.45 | 0.49 | 0.52 | 0.55 | 0.62 |
| *Fair Condition (grass cover on 50% to 75% of the area)* | | | | | | | |
| Flat, 0-2% * | 0.25 | 0.28 | 0.30 | 0.34 | 0.37 | 0.41 | 0.53 |
| Average, 2-7% * | 0.33 | 0.36 | 0.38 | 0.42 | 0.45 | 0.49 | 0.58 |
| Steep, over 7% * | 0.37 | 0.40 | 0.42 | 0.46 | 0.49 | 0.53 | 0.60 |
| *Good Condition (grass cover more than 75% of the area)* | | | | | | | |
| Flat, 0-2% * | 0.21 | 0.23 | 0.25 | 0.29 | 0.32 | 0.36 | 0.49 |
| Average, 2-7% * | 0.29 | 0.32 | 0.35 | 0.39 | 0.42 | 0.46 | 0.56 |
| Steep, over 7% * | 0.34 | 0.37 | 0.40 | 0.44 | 0.47 | 0.51 | 0.58 |

* Slopes refer to watershed slope not channel slope.

## TABLE 2.6
## Rational C Values for Undeveloped Areas Used by Nebraska Department of Roads

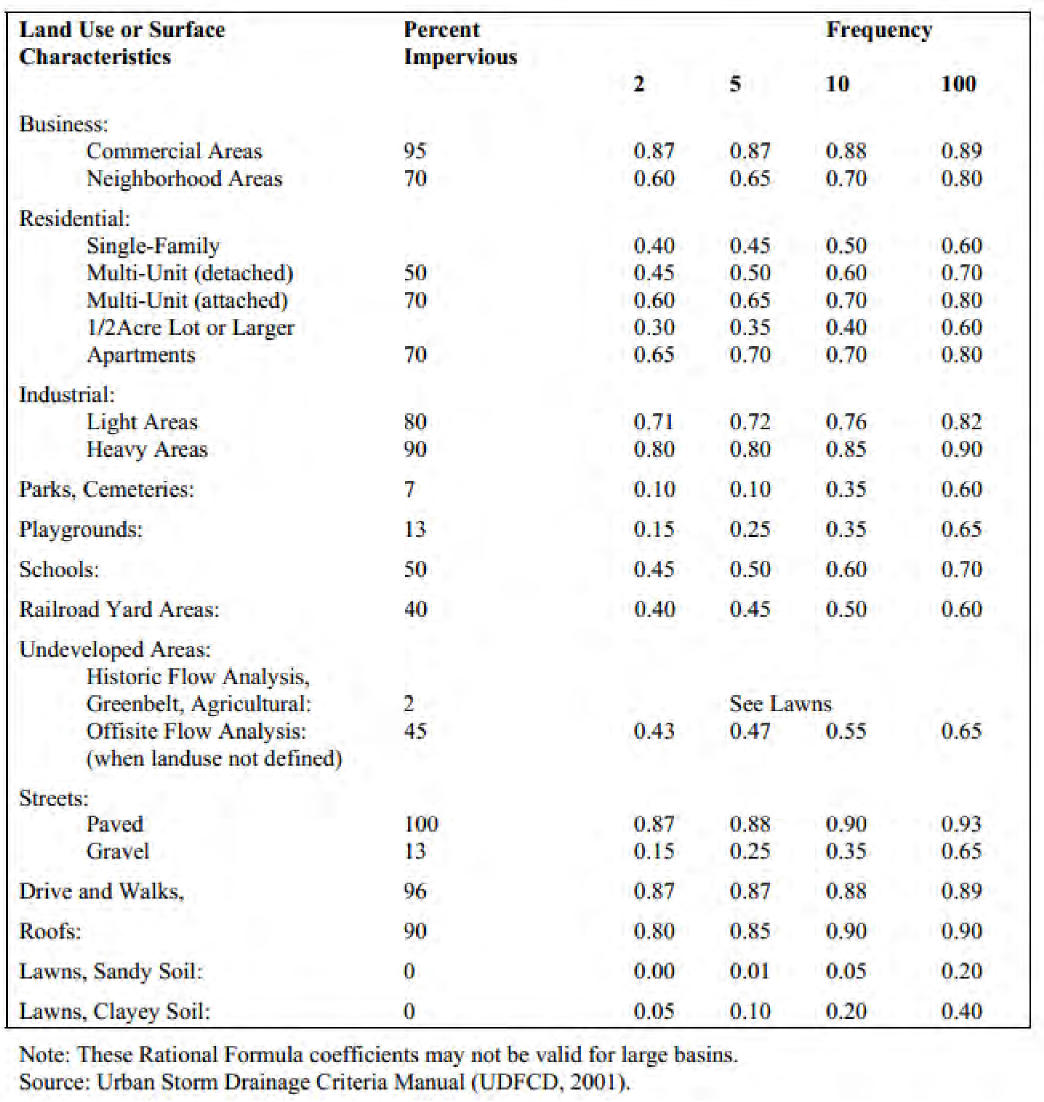


| Character of Surface | Return Period (Years) | | | | | | |
|---|---|---|---|---|---|---|---|
| | 2 | 5 | 10 | 25 | 50 | 100 | 500 |
| **Cultivated Land** | | | | | | | |
| Flat, 0-2% | 0.31 | 0.34 | 0.36 | 0.40 | 0.43 | 0.47 | 0.57 |
| Average, 2-7% | 0.35 | 0.38 | 0.41 | 0.44 | 0.48 | 0.51 | 0.60 |
| Steep, over 7% | 0.39 | 0.42 | 0.44 | 0.48 | 0.51 | 0.54 | 0.61 |
| **Pasture/Range** | | | | | | | |
| Flat, 0-2% | 0.25 | 0.28 | 0.30 | 0.34 | 0.37 | 0.41 | 0.53 |
| Average, 2-7% | 0.33 | 0.36 | 0.38 | 0.42 | 0.45 | 0.49 | 0.58 |
| Steep, over 7% | 0.37 | 0.40 | 0.42 | 0.46 | 0.49 | 0.53 | 0.60 |
| **Forest/Woodlands** | | | | | | | |
| Flat, 0-2% | 0.22 | 0.25 | 0.28 | 0.31 | 0.35 | 0.39 | 0.48 |
| Average, 2-7% | 0.31 | 0.34 | 0.36 | 0.40 | 0.43 | 0.47 | 0.56 |
| Steep, over 7% | 0.35 | 0.39 | 0.41 | 0.45 | 0.48 | 0.52 | 0.58 |

The Colorado DOT's table of C values (Table 2.7) was taken from the design manual of the Urban Drainage and Flood Control District of the Denver metropolitan area. This table provides guidance mainly for urban land uses. The recommended C values vary with recurrence interval, but no values are listed for recurrence intervals of 25 or 50 years. C values are provided for paved streets, gravel streets, lawns with sandy soil, lawns with clayey soil, and roofs.

Composite C values are also provided for various urban land uses based on stated impervious percentages and other unstated assumptions. CDOT's C values are generally lower than KDOT's values. CDOT uses a $C_2$ value of zero for lawns with sandy soil. CDOT's table provides almost no guidance for rural areas. All undeveloped and agricultural areas (whether cultivated land, pasture/range or woodland) are assumed equivalent to urban lawns.

**TABLE 2.7**
**Rational C Values Used by Colorado DOT**



| **Land Use or Surface Characteristics** | **Percent Impervious** | | | **Frequency** | |
|---|---|---|---|---|---|
| | | **2** | **5** | **10** | **100** |
| Business: | | | | | |
| Commercial Areas | 95 | 0.87 | 0.87 | 0.88 | 0.89 |
| Neighborhood Areas | 70 | 0.60 | 0.65 | 0.70 | 0.80 |
| Residential: | | | | | |
| Single-Family | | 0.40 | 0.45 | 0.50 | 0.60 |
| Multi-Unit (detached) | 50 | 0.45 | 0.50 | 0.60 | 0.70 |
| Multi-Unit (attached) | 70 | 0.60 | 0.65 | 0.70 | 0.80 |
| 1/2Acre Lot or Larger | | 0.30 | 0.35 | 0.40 | 0.60 |
| Apartments | 70 | 0.65 | 0.70 | 0.70 | 0.80 |
| Industrial: | | | | | |
| Light Areas | 80 | 0.71 | 0.72 | 0.76 | 0.82 |
| Heavy Areas | 90 | 0.80 | 0.80 | 0.85 | 0.90 |
| Parks, Cemeteries: | 7 | 0.10 | 0.10 | 0.35 | 0.60 |
| Playgrounds: | 13 | 0.15 | 0.25 | 0.35 | 0.65 |
| Schools: | 50 | 0.45 | 0.50 | 0.60 | 0.70 |
| Railroad Yard Areas: | 40 | 0.40 | 0.45 | 0.50 | 0.60 |
| Undeveloped Areas: | | | | | |
| Historic Flow Analysis, Greenbelt, Agricultural: | 2 | | See Lawns | | |
| Offsite Flow Analysis: (when landuse not defined) | 45 | 0.43 | 0.47 | 0.55 | 0.65 |
| Streets: | | | | | |
| Paved | 100 | 0.87 | 0.88 | 0.90 | 0.93 |
| Gravel | 13 | 0.15 | 0.25 | 0.35 | 0.65 |
| Drive and Walks, | 96 | 0.87 | 0.87 | 0.88 | 0.89 |
| Roofs: | 90 | 0.80 | 0.85 | 0.90 | 0.90 |
| Lawns, Sandy Soil: | 0 | 0.00 | 0.01 | 0.05 | 0.20 |
| Lawns, Clayey Soil: | 0 | 0.05 | 0.10 | 0.20 | 0.40 |

Note: These Rational Formula coefficients may not be valid for large basins.
Source: Urban Storm Drainage Criteria Manual (UDFCD, 2001).

## 2.3 Regression Methods

KDOT uses three sets of regression equations to compute design discharges for unregulated rural streams with drainage areas over one square mile: the Extended Rational equations, three-variable regression equations, and USGS regression equations. All three sets of regression equations are applicable statewide.

The Extended Rational and three-variable regression equations were fitted to flood quantile estimates and watershed characteristics for 72 USGS gaging stations with drainage areas under 30 $mi^2$ and record lengths of 20 years or longer. These two sets of equations use the same inputs. The T-year discharge is estimated from the drainage area, the mean annual precipitation over the watershed, and the T-year rainfall intensity for a duration equal to the watershed's time of concentration. The time of concentration is computed from the length and average slope of the main channel using an equation fitted to data for rural watersheds in Kansas (McEnroe and Zhao 2000). Therefore these methods actually incorporate information on five watershed characteristics: drainage area, mean annual precipitation, rainfall intensity, channel length and average channel slope. The Extended Rational equations resemble the common Rational equation in that the discharge is directly proportional to both drainage area and rainfall intensity. Regression equations relate the runoff coefficients to mean annual precipitation. Neither soil permeability nor channel slope was found to be a significant explanatory variable at any recurrence interval. The three-variable equations differ from the Extended Rational equations only in that the exponents on drainage area and rainfall intensity were fitted to the data rather than set to a value of one. The exponents on these terms in the three-variable equations do not differ greatly from one, which supports the validity of the general form of the Rational equation.

The most recent USGS flood-frequency report for Kansas (Rasmussen and Perry 2000) includes two sets of statewide regression equations: one set for drainage areas under 30 $mi^2$ and another set for larger drainage areas. The equations for drainage areas $\geq 30$ $mi^2$ have four inputs: contributing drainage area, mean annual precipitation, average channel slope, and generalized soil permeability (Figure 1.4). The USGS regression equations for the drainage areas under 30 $mi^2$, which are seldom used by KDOT, have considerably larger standard errors of prediction than the equations for the larger drainage areas. The regression equations for the smaller drainage areas have only two inputs: drainage area and mean annual precipitation. The USGS found that soil permeability and channel slope were not significant as explanatory variables for watersheds under 30 $mi^2$.

The Oklahoma Department of Transportation, the Colorado Department of Transportation and the Nebraska Department of Roads all use regression equations to compute design discharges for unregulated rural streams with drainage areas that exceed their limitations on the Rational method. ODOT and CDOT use the applicable USGS regression equations (Lewis 2010; Capesius and Stephens 2009). NDOR uses a set of regression equations developed for NDOR by the University of Nebraska (Cordes and Hotchkiss 1993) rather than the most recent USGS regression equations (Soenksen et al. 1999). The USGS regression equations for Oklahoma are statewide equations with three inputs: contributing drainage area, mean annual precipitation and average channel slope. Soil permeability was considered as a possible explanatory variable but was found to be non-significant. The USGS regression equations for Colorado are regional rather than statewide equations. The USGS has divided Colorado into five hydrologic regions and developed equations for each region. The Plains Region of Colorado adjoins the western border of Kansas. The USGS regression equations for the Plains Region have two inputs: drainage area and the 100-year, 6-hour rainfall depth. NDOR's regression equations are also regional rather than statewide. Region 1 (of five) adjoins most of the northern border of Western Kansas. The regression equations for Region 1 have two inputs: contributing drainage area and mean annual precipitation.

# Chapter 3: Development of Data Set

## 3.1 Selection of Stations

The goal of this study was to develop improved hydrologic methods for small watersheds in Western Kansas, particularly in areas of high soil permeability. From previous studies, it was clear that the number of gaged watersheds in Western Kansas would be insufficient to develop meaningful regression equations. For this reason, we included USGS-gaged watersheds from neighboring states in this study. The search criteria for the stations in our data set were: (1) at least 10 years of peak flow records, (2) watershed area less than 100 $mi^2$, (3) unregulated watersheds (no major lakes or reservoirs), and (4) watersheds within 100 miles of the Kansas border and west of 97.5° longitude. Stations east of 97.5° longitude Kansas were excluded so that the resulting regional flood frequency equations would be representative of conditions predominant in the western part of the state. These conditions include lower mean annual rainfall, higher soil permeability, lower channel slopes, and higher mean annual evapotranspiration.

Our data set contains 156 stations: 62 in Kansas, 56 in Nebraska, 19 in Oklahoma, 14 in Colorado, four in New Mexico and one in Texas. Table A.1 lists the station names and other basic information. Figure 3.1 shows the locations of these stations along with contours of mean annual precipitation.

## 3.2 Watershed Characteristics

The hydrologic methods of interest in this study are regional flood frequency (RFF) analysis and the Rational method. The goal of RFF analysis is to develop equations to predict flood quantiles ($Q_T$) as functions of watershed characteristics. Table 3.1 lists the watershed characteristics obtained for this study and used subsequently in the RFF analysis. A brief description of each characteristic, along with the method used for its determination, follows. The values of these characteristics for all stations in the data set are listed in tables A.2 and A.3.

### *3.2.1 Watershed Area, A*

We originally planned to use published USGS drainage areas for all watersheds in this study. However, we found inconsistencies in reported drainage areas for many watersheds between the USGS's NWIS system and the various state-level RFF studies performed by the USGS. These inconsistencies are understandable; watershed delineation in areas with low relief can be challenging and the resulting delineation often depends on the source of topographic data. As a result, we found it necessary to delineate all 156 watersheds using a consistent and repeatable methodology.

We determined the watershed area for each USGS gage using automated watershed delineation facilitated by ArcHydro 1.4 in ArcGIS 9.3 (Djokic 2008). Each watershed was delineated using three arc-second digital elevation models (DEMs) developed and distributed by the USGS as part of the National Elevation Dataset (NED) (Gesch 2007; Gesch et al. 2002). These DEMs have a grid spacing of three arc-seconds, which is approximately 10 m depending on latitude. Higher-resolution DEMs are available for a number of the watersheds included in this analysis, but it is important to use a consistent resolution, particularly for the determination of main channel length and channel slope. All DEMs were projected into a Universal Transverse Mercator (UTM) map projection (zone 13-15 depending on longitude) based on the North American Datum of 1983 (NAD83) prior to analysis in ArcHydro.

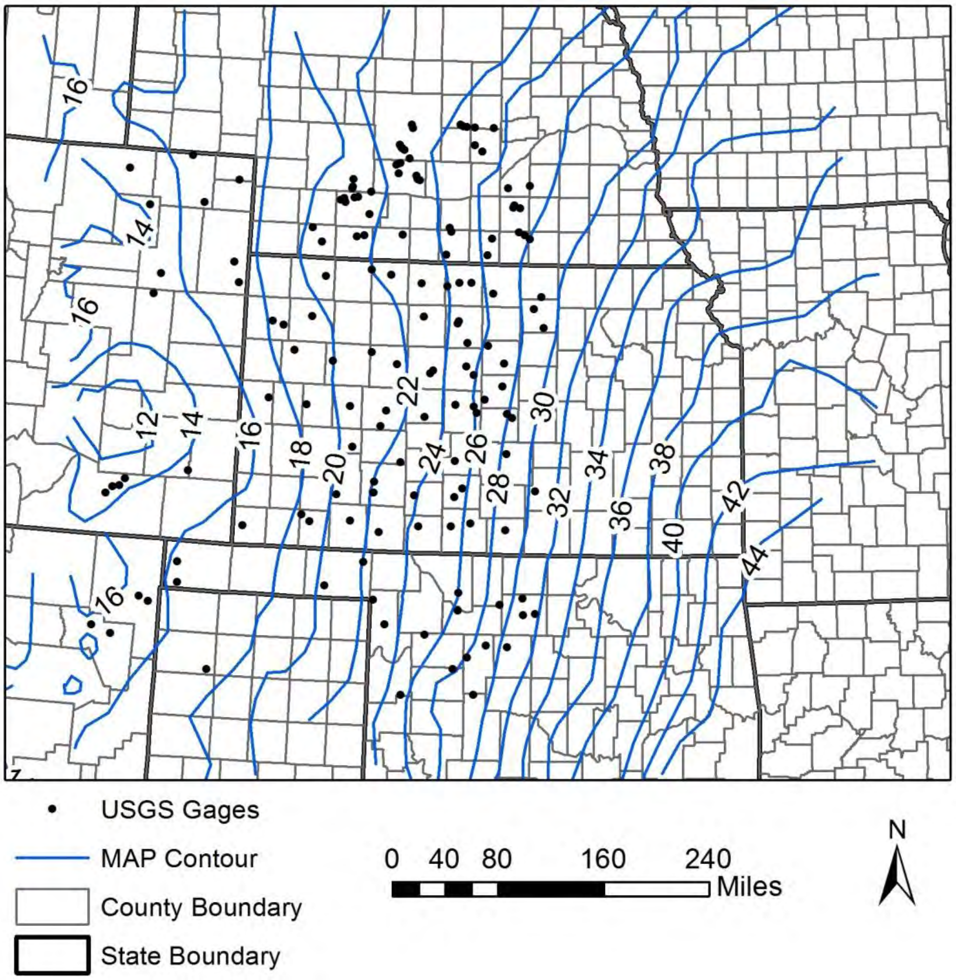


**FIGURE 3.1**
**Locations of Selected Stations and Mean Annual Precipitation (Inches)**

**TABLE 3.1**
**Watershed Characteristics Considered in this Study**

| Characteristic | Units | Description |
|---|---|---|
| A | $mi^2$ | Total watershed area (including non-contributing areas) |
| L | mi | Length of the main channel extended to the watershed boundary. |
| Sl | ft/mi | Slope of the main channel, measured between points 10% and 85% along the channel from the watershed outlet to the drainage divide |
| Sh | none | Basin shape factor ($L^2/A$) |
| $SP_{12}$ | in./hr | Mean soil permeability of the top 12 inches of soil. |
| $SP_{full}$ | in./hr | Mean soil permeability of the entire soil profile |
| $T_c$ | hr | Watershed time of concentration |
| $i_T$ | in./hr | Rainfall intensity for duration = $T_c$ and recurrence interval T |
| MAP | in. | Mean annual precipitation |

### *3.2.2 Main Channel Length, L*

The main channel length for each watershed was computed with ArcHydro 1.4. The main channel length is defined as the longest flow path from the watershed outlet to the drainage divide. As noted above, it is important to use a consistent grid cell size when delineating channel length using GIS tools. Our analysis found that DEMs with smaller grid cell sizes yield significantly longer channel measurements.

### *3.2.3 Main Channel Slope, Sl*

ArcHydro 1.4 was also used to find the slope of the main channel for each watershed. The standard USGS definition of channel slope was used in our investigation. This definition computes the slope (in feet per mile) between points 10% and 85% of the way up the channel as measured from the watershed outlet to the drainage divide.

### *3.2.4 Basin Shape Factor, Sh*

The basin shape factor is a dimensionless indicator of how elongated a watershed is relative to its drainage area. The equation for shape factor is given in Eq. 3-1. It should be noted that the basin shape factor used in the Nebraska USGS RFF report (Soenksen et al. 1999) uses a different definition than the one used here.

$$Sh = \frac{L^2}{A}$$ **Equation 3.1**

### 3.2.5 Soil Permeability, $SP_{12}$ and $SP_{full}$

Previous RFF studies for Kansas have obtained soil permeabilities from Figure 1.5, the map produced by the USGS (Rasmussen and Perry, 2000). A digital GIS version of the USGS map is available for download through the Kansas Data Access and Support Center (DASC, www.kansasgis.org). The soil permeability map available through DASC does not extend past the Kansas border.

In order to determine soil permeability in a consistent manner for all 156 watersheds, we generated soil permeability maps that cover the entire study area. These permeability maps were generated using the U.S. General Soil Map (STATSGO2) produced by the Natural Resources Conservation Service (NRCS) (NRCS 2012). The STATSGO2 dataset includes a representative hydraulic conductivity for each soil horizon for each soil component. These representative hydraulic conductivities were averaged with respect to depth for each soil component and spatially for each soil map unit (made up of several soil components). Two separate soil maps were generated. Figure 3.2 shows the mean soil hydraulic conductivity computed for the top 12 inches of soil. Figure 3.3 shows the soil permeability averaged over the full depth of soil, as was done for the USGS map. These two maps were used in ArcGIS to compute two values of spatially averaged hydraulic conductivity for each watershed ($SP_{12}$ and $SP_{full}$).

### 3.2.6 Time of Concentration, $t_c$

The time of concentration, $t_c$, is the time required for runoff to travel from the most remote point in the watershed to the watershed outlet during a storm event. Time of concentration is an important measure of how quickly runoff reaches the watershed outlet. The $t_c$

for each watershed was estimated using the KU-KDOT equation for rural watersheds (McEnroe and Zhao, 1999):

$$\mathbf{t_c} = 0.176\left(\frac{\mathbf{L}}{\sqrt{\mathbf{Sl}}}\right)^{\mathbf{0.66}} \qquad \textbf{Equation 3.2}$$

in which

$t_c$ = time of concentration (hr)
$L$ = length of main channel, extended to the drainage divide (mi)
$Sl$ = average slope of main channel (ft/ft)

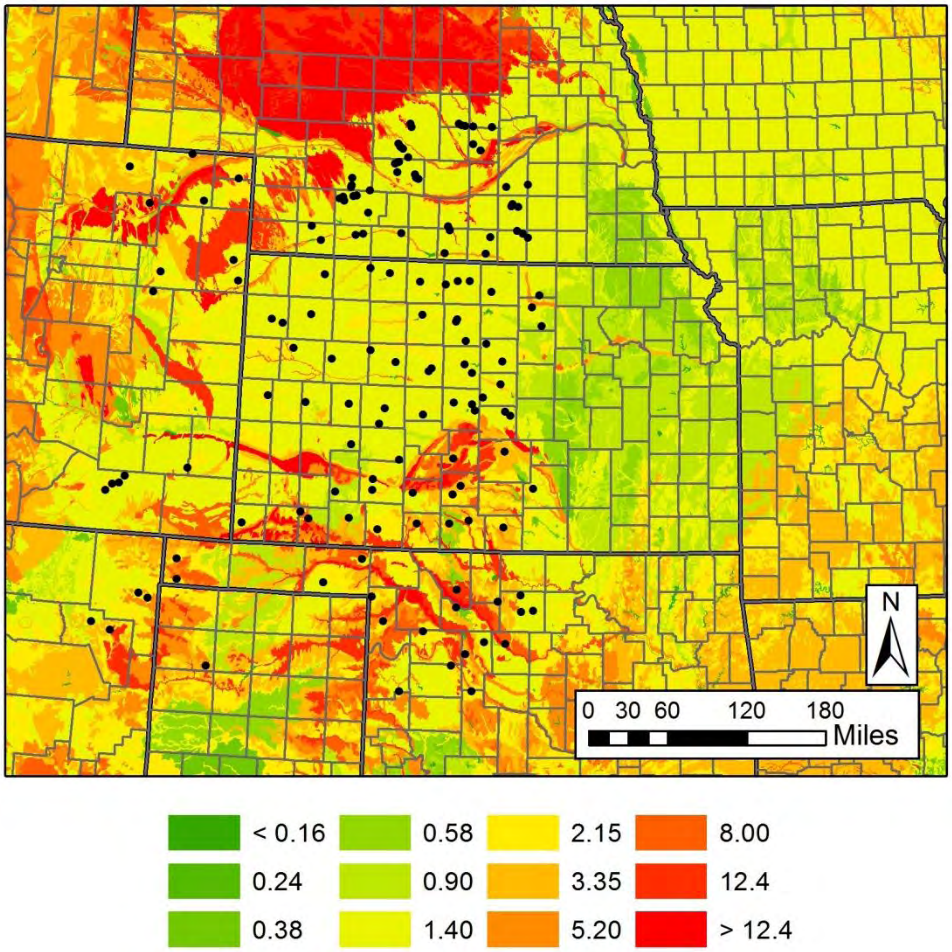


**FIGURE 3.2**
**Mean Soil Permeability (Inches/Hr) of Top Twelve Inches of Soil**

The KU-KDOT equation was developed from an analysis of rainfall and streamflow records for 20 rural watersheds in Kansas ranging in size from 0.81 to 10.0 $mi^2$. Although many of the watersheds in this study fall outside the spatial and size range of the basins used to generate Equation 3.2, we think that this equation is still the best available. It was important to use one consistent equation for $t_c$ for all of the watersheds in the data set.

### *3.2.7 Representative Rainfall Intensity, $i_T$*

The representative rainfall intensity for a given recurrence interval (iT, where T designates the recurrence interval) is the T-year rainfall intensity for a duration equal to tc. The iT values for each watershed were determined for recurrence intervals of 2, 5, 10, 25, 50, and 100 years. For basins in Kansas, Nebraska, and Oklahoma, we digitized the rainfall atlas maps from TP-40 (Hershfield 1961) and HYDRO-35 (Frederick et al. 1977), converted the contours to grid format, and determined the rainfall depths for each recurrence interval at the centroid of each watershed. Interpolation procedures described in TP-40 and HYDRO-35 were used to interpolate between recurrence intervals (where necessary) and between durations. For watersheds in New Mexico, rainfall intensities were obtained via NOAA Atlas 14 (Bonnin et al. 2006) using the online tool available online through the National Weather Service (NWS) Hydrometeorological Design Studies Center (HDSC) Precipitation Frequency Data Server (PFDS) (http://hdsc.nws.noaa.gov/hdsc/pfds/). Rainfall intensities for the Colorado watersheds were determined at the centroids of the watersheds from the maps and interpolation formulas in NOAA Atlas 2 (Miller et al. 1973).

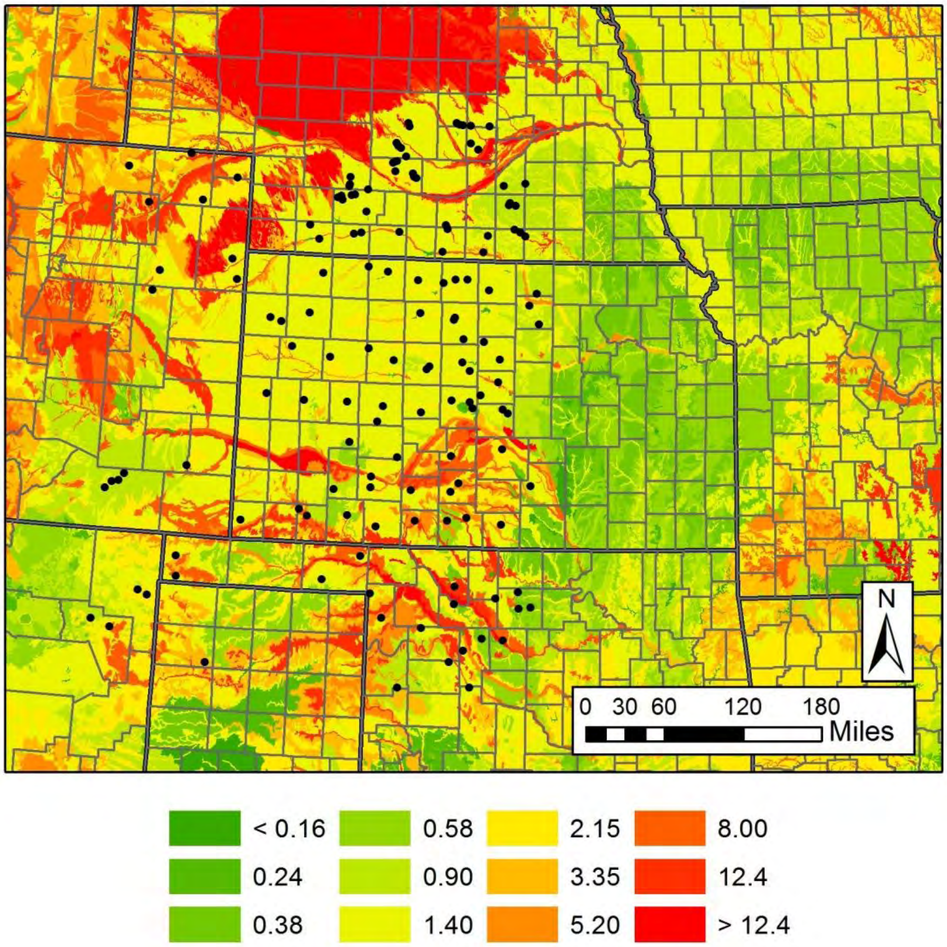


**FIGURE 3.3**
**Mean Soil Permeability (Inches/Hr) of Full Depth of Soil**

### *3.2.8 Mean Annual Precipitation, MAP*

The mean annual precipitation for each watershed was extracted from a digital version of Figure 3.1. This map was generated using the USGS mean annual precipitation map for Kansas, shown in Figure 1.2 (Rasmussen and Perry, 2000). The values of MAP in Figures 1.2 and 3.1 are based on rain-gage data collected during the period 1961–1990 (NOAA climate normals are computed over a time span of three decades). More recent climate normal are available (1981–2010); however, we chose to use the MAP values already in use in the KDOT drainage manual.

The MAP contours from Rasmussen and Perry (2000) were extended further north, south, and west to cover all of the watersheds in the study area by overlaying the USGS contours on a MAP contour map generated from the PRISM rainfall mapping project (Daly et al. 1994; Daly et al. 1997).

## 3.3 Flood Frequency for Individual Stations

A flood frequency analysis was performed for each gage record according to Bulletin 17B methods (Interagency Advisory Committee on Water Data, 1981) using the HEC-SSP 2.0 (Statistical Software Package) program developed by the U.S. Army Corps of Engineers (USACE) Hydraulic Engineering Center (HEC). Documentation for the HEC-SSP program can be found in Brunner and Fleming (2010).

HEC-SSP 2.0 automatically downloads peak flow data from the USGS National Water Information System (NWIS) (USGS 2012) for specified gage stations. The only input required from the user is the regional skew coefficient, which is used by HEC-SSP to compute the weighted skew coefficient. There are two ways to obtain the regional skew coefficient for a particular watershed. First, specific regional skew coefficient maps or equations have been developed for some states. Rassmussen and Perry (2000) present a regional skew-coefficient equation for watersheds located in Kansas. Soenksen (1999) provides a map of regional skew coefficients for Nebraska, and Lewis (2010) provides a map for Oklahoma. Second, in locations where no specific map or equation has been developed, the national map can be used (Interagency Advisory Committee 1981). Regional skew coefficients for watersheds in Colorado and New Mexico were obtained from the national map.

Flood quantiles were computed for recurrence intervals of 2, 5, 10, 25, 50 and 100 years. Table A.4 presents these values for all stations in the data set.

## 3.4 Rational Runoff Coefficients for Individual Stations

Rational runoff coefficients for recurrence intervals of 2, 5, 10, 25, 50 and 100 years were computed for all stations. From the Rational formula, the runoff coefficient for a given recurrence interval, $C_T$, is equal to $Q/(A \cdot i_T)$. Table A.5 presents the computed $C_T$ values.

# Chapter 4: Regional Flood-Frequency Analysis

## 4.1 Background

The goal of regional flood frequency (RFF) analysis is to develop a set of equations to predict flood quantiles ($Q_T$) as functions of watershed characteristics. Equations for RFF analysis are usually developed using least-squares multiple linear regression (MLR) on the log-transformed values of the flood quantiles (the dependent, or response variable) and the watershed characteristics (the independent, or predictor variables).

One important assumption of MLR is that the regression residuals (the differences between the observed and predicted dependent variable) must be independent of each other and identically distributed (the probability density function for each residual is the same). In RFF analysis, there are several factors that might cause this assumption to be violated. First, the estimate of the flood quantile for a particular watershed is highly uncertain, and the degree of uncertainty is dependent on the length of the gage record. MLR gives each data point equal weight in the RFF analysis, regardless of whether the record length is 10 years or 100 years. Second, gage records do not all cover the same period of time. This introduces a potential bias in RFF analysis. For example, if a gage was operated for a 10-year period, and that period happened to be especially eventful (several large floods) due to an underlying climate cycle, climate trend or just randomness, that gage would bias the results of the RFF analysis upwards given year for these watersheds may even be generated by the same storm events. This causes spatial correlation of the gage records, making the regression residuals not truly independent of each other.

Generalized Least Squares (GLS) regression, developed by Stedinger and Tasker (1985), is a more sophisticated regression method that accounts for record lengths and temporal and spatial correlations between gage records. The USGS and others consider GLS the best method currently available for RFF analysis. The RFF analyses in this study were all performed by the GLS method using the Weighted-Multiple-Linear Regression program (WREG v. 1.0) developed by the USGS (Eng et al. 2009).

## 4.2 Examination of Predictor Variables

Before applying GLS regression using the WREG software package, it is important to evaluate the predictor (independent) variables to determine whether they are suitable for use in regression. GLS regression and traditional multiple linear regression require that the predictor variables be independent of each other.

The first two predictors examined were the two soil permeability measures, $SP_{full}$ and $SP_{12}$. $SP_{full}$ is the watershed-average soil permeability averaged over the entire depth of the soil horizon, as used in the current USGS RFF equations for Kansas (Rasmussen and Perry 2000). We suspected that a measure of surface soil permeability might perform better in the regression analysis. Hence, we computed $SP_{12}$, the watershed-average soil permeability averaged over the top twelve inches of soil. Figure 4.1 shows a scatterplot of $SP_{full}$ and $SP_{12}$ for the 156 watersheds. The $R^2$ coefficient for the plot is 0.82, indicating a very high level of correlation ($r = 0.91$) between the two parameters. Test regressions in WREG showed that $SP_{full}$ and $SP_{12}$ perform similarly as predictors of $Q_T$. We see no additional value in using $SP_{12}$ instead of $SP_{full}$. To remain consistent with Rasmussen and Perry (2000), we use $SP_{full}$ in the subsequent regression analyses.

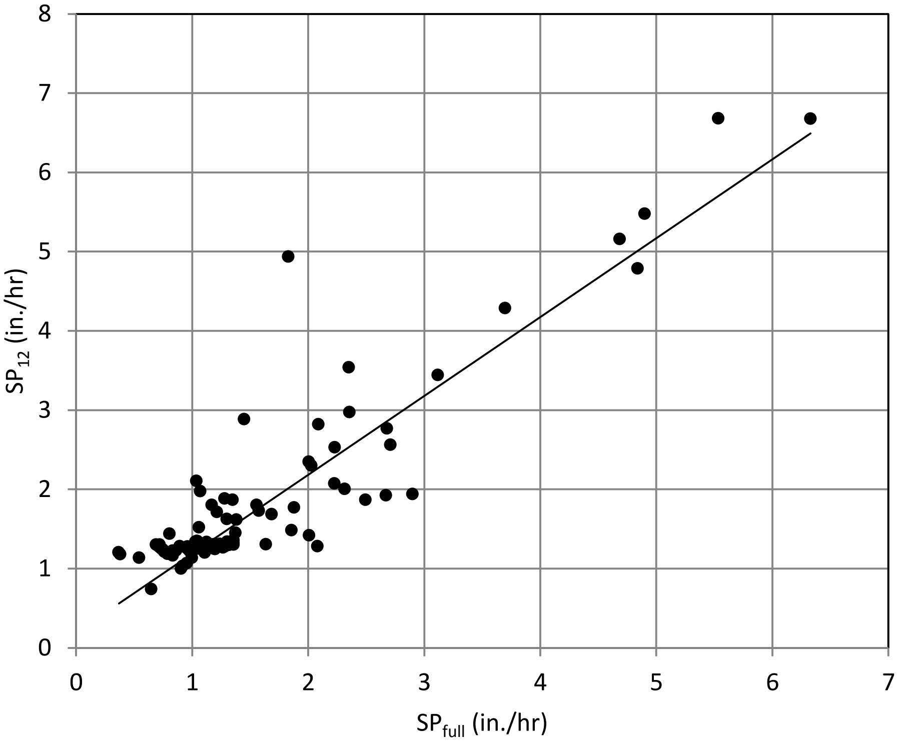


**FIGURE 4.1**
**Scatter Plot of $SP_{12}$ vs. $SP_{full}$ with Linear Trendline**

Table 4.1 displays the correlation matrix for prediction of the log($Q_{25}$). It is evident from the correlation matrix that most of the log-transformed watershed characteristics are highly correlated with one another (multicolinearity). For example, log(A) has a very strong positive correlation with channel length. This correlation makes sense, as larger watersheds will have longer main channels. Similarly, log(A) has a very strong negative correlation with the rainfall intensity. Again, this correlation has good physical basis. The $i_{25}$ varies geographically, but is most highly dependent on the watershed time of concentration ($t_c$), which in turn depends strongly on channel length (Equation 3.1). Drainage area also exhibits statistically significant (95% confidence level) with all of the other watershed characteristics except mean annual precipitation and soil permeability.

### TABLE 4.1

### Correlation Matrix for Prediction of $Q_{25}$ (Cells Highlighted in Yellow Indicate Statistically Significant Correlation Values with 95% Confidence)

| | Correlation Coefficient, r | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $\log(Q_{25})$ | $\log(i_{25})$ | log(A) | log(L) | log(Sh) | log(SL) | log(MAP) | $\log(SP_{full})$ |
| $\log(Q_{25})$ | 1.000 | -0.412 | 0.563 | 0.513 | 0.167 | -0.221 | 0.081 | -0.069 |
| $\log(i_{25})$ | -0.412 | 1.000 | -0.942 | -0.976 | -0.677 | 0.804 | 0.107 | 0.098 |
| log(A) | 0.563 | -0.942 | 1.000 | 0.966 | 0.478 | -0.668 | -0.092 | -0.036 |
| log(L) | 0.513 | -0.976 | 0.966 | 1.000 | 0.690 | -0.717 | -0.081 | -0.062 |
| log(Sh) | 0.167 | -0.677 | 0.478 | 0.690 | 1.000 | -0.564 | -0.018 | -0.109 |
| log(SL) | -0.221 | 0.804 | -0.668 | -0.717 | -0.564 | 1.000 | -0.297 | 0.215 |
| log(MAP) | 0.081 | 0.107 | -0.092 | -0.081 | -0.018 | -0.297 | 1.000 | -0.193 |
| $\log(SP_{full})$ | -0.069 | 0.098 | -0.036 | -0.062 | -0.109 | 0.215 | -0.193 | 1.000 |

The multicolinearity evident in Table 4.1 violates the conditions necessary for application of MLR or GLS regression. Regression requires that all predictor variables be independent of each other. One approach to reconciling multicolinearity is the application of principal components analysis (PCA). The goal of PCA is to find linear combinations of the proposed predictor variables that are independent of one another. These linear combinations of the original proposed predictors are called the principal components (PCs) and can be used in regression analysis as the new predictor variables.

PCA is able to determine how much information content is really available in a dataset. For example, although Table 4.1 lists seven potential predictor variables, the actual information content is less because the predictors are correlated with one another.

PCA was applied in this study using the computer program StatistiXL 1.9. PCA was used to determine how many independent variables can be constructed from the dataset, and to determine which combinations of variables make sense. PCA indicates that three principal components capture 88.4% of the total variability exhibited in the predictors listed in Table 4.1. After investigating potential combinations of variables, we selected the following three potential predictors: $\log(A \cdot i_T)$, log(MAP), and $\log(SP_{full})$.

The predictor $\log(A \cdot i_T)$ was selected based on findings from previous research (McEnroe and Young 2007) and evaluation of PCA output for this study. The product $A \cdot i_T$ captures information about the size of the watershed, the length and slope of the channel, and the extreme rainfall climatology of the watershed location. Table 4.2 shows the correlation matrix for these three predictors. The correlation between log(MAP) and log($SP_{full}$) is statistically significant at the 95% level, but is low enough ($|r|<0.2$) to be considered independent for purposes of linear regression analysis.

**TABLE 4.2**
**Correlation Matrix for Potential Predictor Variables from PCA (Cells Highlighted in Yellow Indicate Statistically Significant Correlation Values with 95% Confidence)**

| | Correlation Coefficient, r | | |
|---|---|---|---|
| | log(MAP) | log($SP_{full}$) | log($A \cdot i_{25}$) |
| log(MAP) | 1.000 | -0.193 | -0.072 |
| log($SP_{full}$) | -0.193 | 1.000 | 0.017 |
| log($A \cdot i_{25}$) | -0.072 | 0.017 | 1.000 |

## 4.3 Generalized Least Squares (GLS) Regression

WREG 1.0 was used to perform GLS regression for regional flood frequency analysis. WREG requires a large quantity of input data, including the watershed characteristics for each watershed (to be used as independent variables), the flood quantile estimates for each gage (to be used as dependent variables), the weighted skew coefficient and log-Pearson Type III frequency factors (K values) used in the flood frequency analyses, and the time series of the annual maxima for each site.

WREG prompts the user to fit a curve to a spatial correlogram (graph of correlation between overlapping station records versus the distance between the gages). This correlation model is used in the GLS regression to account for the correlation between neighboring gages. The correlation model used by WREG requires two fitting parameters: $\alpha$ and $\theta$. For this study, we set $\alpha = 0.0035$ and $\theta = 0.98$ to achieve a reasonable fit to the observed spatial correlations.

WREG also prompts the user for the mean square error (MSE) of the regional skew coefficient ($G_R$) used in the flood frequency analyses. We used the best available method for determining regional skew for each state included in the study, which means that the MSE($G_R$) was different for each state. The MSE for the regional skew equation for gages in Kansas is 0.0366, while the MSE for the national skew coefficient map is 0.3025. We evaluated the sensitivity of WREG to the MSE($G_R$) value input by the user and found that the regression coefficients are insensitive across the range of values from 0.0366 to 0.3025. Because the study centers on Kansas, we input the MSE($G_R$) for the Kansas regional skew equation (0.0366) to WREG.

Table 4.3 presents the final equations produced by the WREG GLS regression analyses. These equations are referred to as the HWK (Hydrology of Western Kansas) equations throughout the remainder of this report. For recurrence intervals of 2, 5 and 10 years, the predictors $A \cdot i_T$ and MAP were both found to be statistically significant and are included in the HWK equations. For higher recurrence intervals, only the predictor $A \cdot i_T$ was statistically significant. Soil permeability was not found to be a statistically significant parameter at any recurrence interval.

In addition to developing equations for all of Western Kansas, we divided the dataset by physiographic region and used WREG to develop separate sets of equations for each region. This analysis did not lead to significant improvements over the equations presented in Table 4.3.

**TABLE 4.3**
**New HWK Regression Equations for Watersheds < 100 mi$^2$ in Western Kansas**

| HWK Regression Equation | Standard Model Error of Prediction, $S_p$ (%) |
|---|---|
| $Q_2 = 0.03311\ (A \cdot i_2)^{0.747}\ (MAP)^{2.414}$ | 90.9 |
| $Q_5 = 1.122\ (A \cdot i_5)^{0.770}\ (MAP)^{1.566}$ | 61.1 |
| $Q_{10} = 5.754\ (A \cdot i_{10})^{0.778}\ (MAP)^{1.181}$ | 55.1 |
| $Q_{25} = 346.7\ (A \cdot i_{25})^{0.778}$ | 57.1 |
| $Q_{50} = 446.7\ (A \cdot i_{50})^{0.792}$ | 60.6 |
| $Q_{100} = 549.5\ (A \cdot i_{100})^{0.801}$ | 65.8 |

## 4.4 Comparison with Other Hydrologic Methods

Table 4.3 lists the standard model error of prediction ($S_p$) in percent, as output by WREG. This measure is comparable to the standard errors presented in Rasmussen and Perry (2000). Table 4.4 lists the $S_p$ values from Table 4.3 along with those for the existing USGS regression equations for Kansas. The USGS values are presented as +/- percentages, whereas WREG only provides the average of the +/- values.

### TABLE 4.4
### Comparison of Standard Model Error of Prediction for HWK and USGS Regression Equations

| T (years) | Standard Model Error of Prediction, Sp (%) | | |
|---|---|---|---|
| | HWK | USGS < 30 $mi^2$ | USGS ≥ 30 $mi^2$ |
| 2 | 90.9 | +64/-39 | +43/-30 |
| 5 | 61.1 | +53/-35 | +36/-26 |
| 10 | 55.1 | +58/-37 | +35/-26 |
| 25 | 57.1 | +58/-37 | +37/-27 |
| 50 | 60.6 | +64/-39 | +39/-28 |
| 100 | 65.8 | +77/-44 | +42/-30 |

The HWK equations exhibit higher standard model errors than the USGS regression equations. This is not surprising, given that the USGS equations were developed using data from across the state, with the majority of stations in the eastern portion of the state, where flood quantiles are less erratic and are more predictable.

Figure 4.2 displays the $Q_{25}$ values predicted by the new HWK equations, the USGS equations (Rasmussen and Perry, 2000), and Extended Rational equations (McEnroe and Young 2007) versus the $Q_{25}$ predicted for each gaged watershed using FFA. Only Kansas gages selected for this study are included in the graph. For Figure 4.2, we used the USGS two-parameter equation for watersheds < 30 $mi^2$ and the full, four-parameter equation for watersheds ≥ 30 $mi^2$.

Figure 4.3 displays a similar graph for the predicted $Q_{100}$ values. All three methods exhibit considerable scatter about the 1:1 line. The USGS and Extended Rational equations tend to over-predict $Q_T$ slightly more than 50% of the data points, while the HWK equations tend to under-predict $Q_T$ 60% of the time.

One should keep in mind that there are considerable uncertainties in the FFA-derived $Q_T$ values used as the x values for Figures 4.2 and 4.3. Still, it appears that the Extended Rational equations work better than the USGS equations for watersheds with small observed $Q_T$ values.

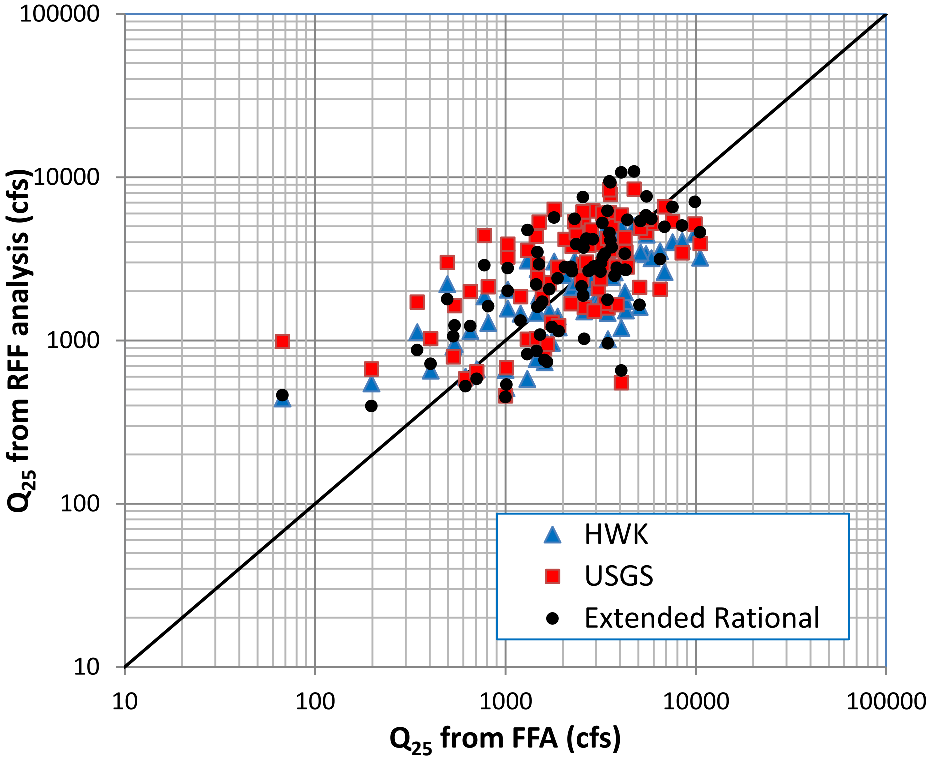


**FIGURE 4.2**
**Comparison of $Q_{25}$ Estimates by Three Methods**

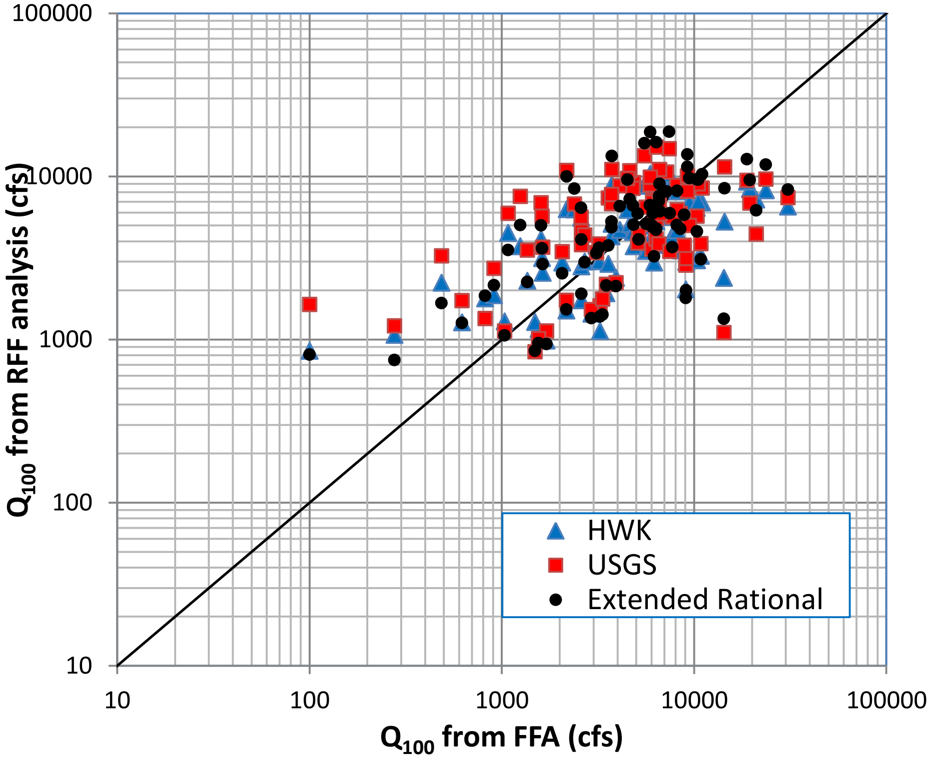


**FIGURE 4.3**
**Comparison of $Q_{100}$ Estimates by Three Methods**

## 4.5 Recommendations

Although considerable effort was expended in the development of the HWK regression equations, it appears that these equations do not represent a substantial improvement over existing KDOT hydrologic methods. Although the HWK equations could be used for design in Western Kansas, recommending use of these equations would complicate the guidelines for selection of hydrologic methods in the KDOT Design Manual (Table 2.1) and could lead to confusion. As such, our recommendations are to use the Extended Rational method for watershed areas > 640 ac and < 30 mi$^2$ and the USGS four-parameter regression equation for watersheds ≥ 30 mi$^2$ in both Western and Eastern Kansas. Figures 4.4 and 4.5 present a graphical evaluation of these recommended methods applied to the Kansas gages in our data set.

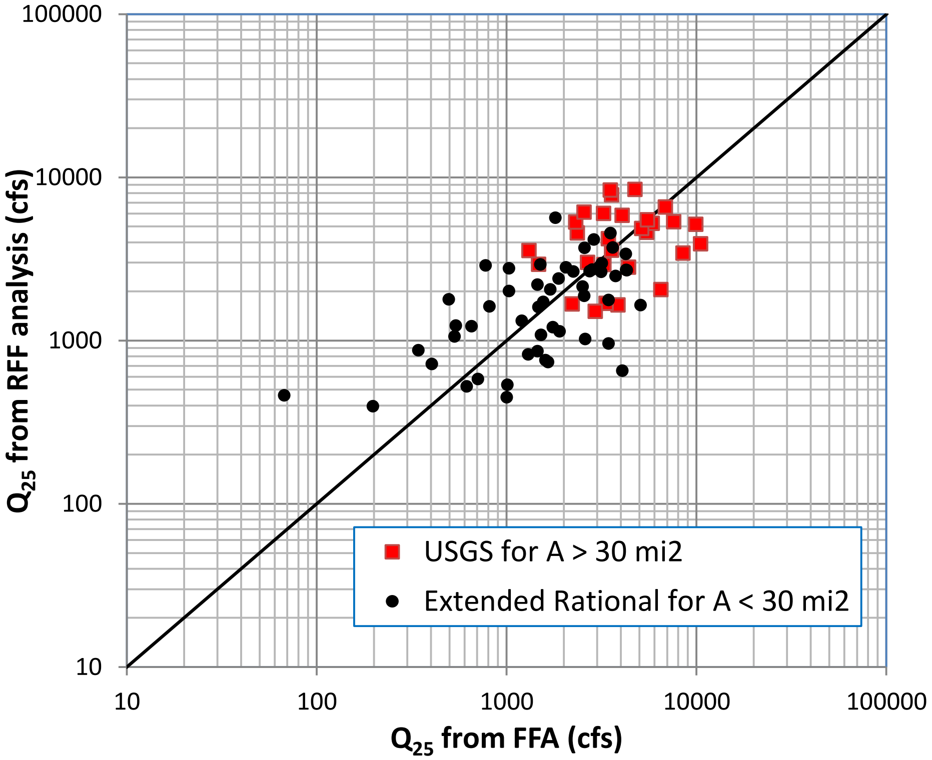


**FIGURE 4.4**
**Evaluation of Recommended Methods for Estimation of $Q_{25}$ in Western Kansas**

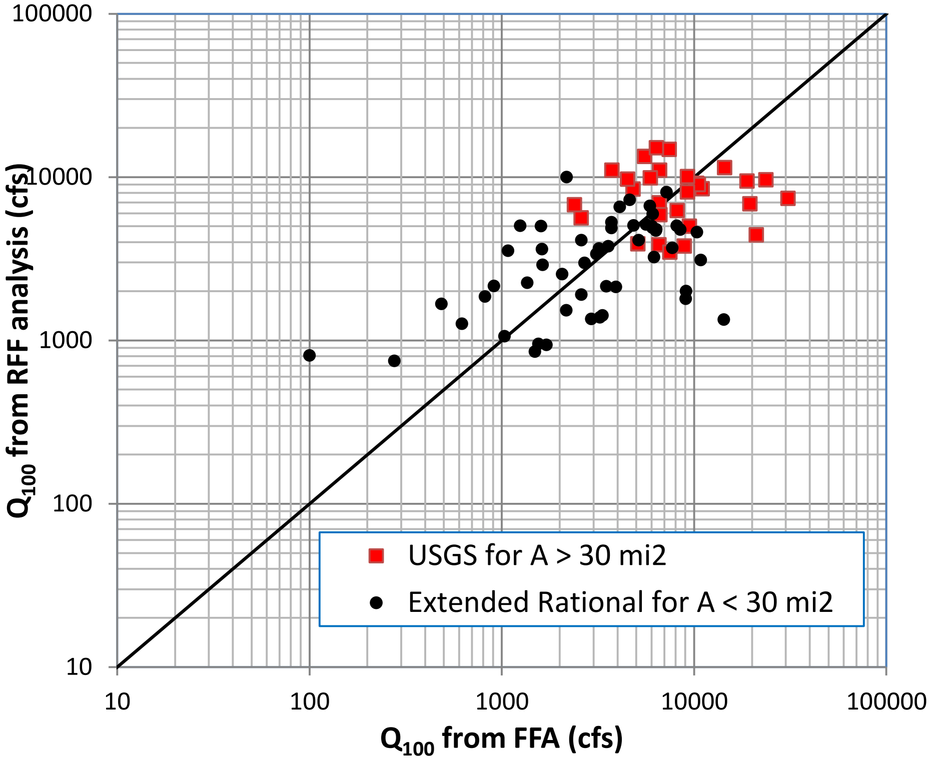


**FIGURE 4.5**
**Evaluation of Recommended Methods for Estimation of $Q_{100}$ in Western Kansas**

# Chapter 5: Rational Runoff Coefficients

This chapter examines Rational runoff coefficients for Western Kansas and proposes changes to KDOT's recommended C values. KDOT applies the Rational method to watersheds with drainage areas of one square mile or less. The data set compiled for this study includes only two stations in Kansas and five stations in adjacent states with drainage areas in this size range. Any statistical analysis of C values for so few stations would not be meaningful. However, an examination of the C values for all stations in the data set leads to some observations that should apply to the small watersheds as well as watersheds up to 100 $mi^2$.

## 5.1 Regional Analysis of Rational Runoff Coefficients

Rational C values vary greatly with recurrence interval. Table 5.1 displays the median C values by recurrence interval for all stations in our regional flood frequency data set. This data set includes stations in Western Kansas and nearby regions of Nebraska, Colorado, Oklahoma, New Mexico and Texas. Table 5.2 displays the median C values for Eastern and Western Kansas from our previous statewide study (McEnroe and Young 2007). The median C values for stations in our data set are somewhat lower than the values for Western Kansas alone because the expanded data set includes more far-western stations outside of Kansas. Runoff coefficients are more strongly dependent on recurrence interval in Western Kansas than in Eastern Kansas. Most of the watersheds in these data sets are much larger than 640 acres, so the median C values may not be directly applicable to very small watersheds. However, the C values for very small watersheds and intermediate-size watersheds should follow similar trends.

**TABLE 5.1**
**Median Values of Rational C for All Stations in the RFF Data Set**

| Recurrence interval (years) | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| Median C value | 0.06 | 0.14 | 0.22 | 0.35 | 0.44 | 0.53 |

**TABLE 5.2**
**Median Values of Rational C for Stations in Eastern and Western Kansas**

| Recurrence interval (years) | 2 | 5 | 10 | 25 | 50 | 100 |
|---|---|---|---|---|---|---|
| Median C, Eastern Kansas | 0.31 | 0.51 | 0.63 | 0.80 | 0.87 | 0.97 |
| Median C, Western Kansas | 0.10 | 0.21 | 0.28 | 0.39 | 0.48 | 0.59 |

(Source: McEnroe and Young 2007)

Contrary to expectations, we found no statistically significant relationship between C values and soil permeability. Figure 5.1 shows the lack of a significant relationship between the 10-year C value ($C_{10}$) and the average soil permeability for the watershed.

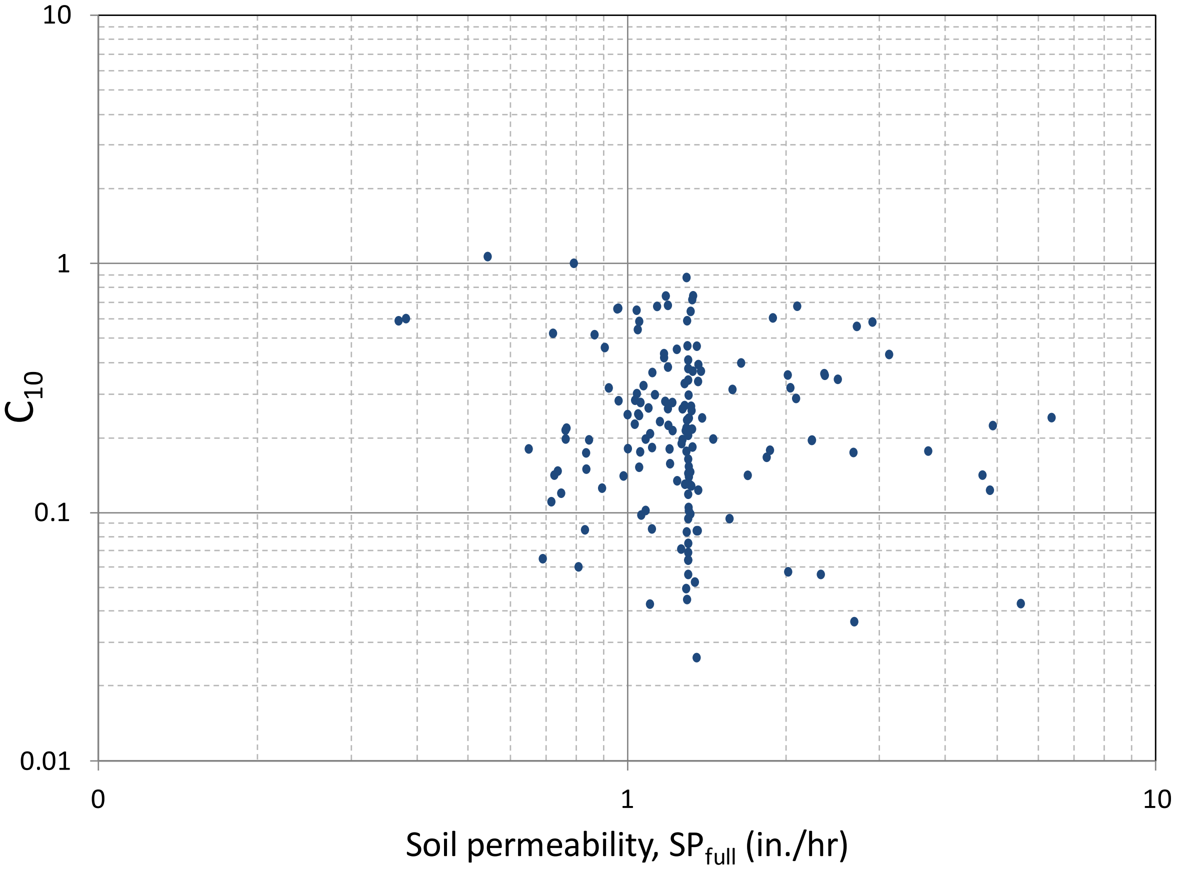


**FIGURE 5.1**
**Relationship between C10 and Soil Permeability**

We also found no statistically significant relationship between C values and channel slope. This finding was expected. Channel slope affects the speed of runoff but not the volume of runoff. In the Rational method, channel slope affects the time of concentration, which affects the rainfall intensity. The runoff coefficient can be considered independent of channel slope.

## 5.2 Comparison of Rational Method and Regression Methods

KDOT recommends the Rational method for drainage areas up to one square mile and three different sets of regional regression equations for areas over one square mile (Table 2.1). Discharges computed by the Rational method and the regional regression equations should not differ greatly for drainage areas in the neighborhood of one square mile.

The following four stations were selected for a comparison of the Rational method and the regional regression equations:

| | |
|---|---|
| 06873300 | Ash Creek Tributary near Stockton, KS |
| 06858700 | North Fork Smoky Hill River Tributary near Winona, KS |
| 06848200 | Prairie Dog Creek Tributary near Norton, KS |
| 06867800 | Cedar Creek Tributary near Bunker Hill, KS |

Table 5.3 provides relevant information for these stations. Drainage areas range from 0.86 to 1.09 mi$^2$ and times of concentration range from 49 to 80 minutes. Crops and grass are the predominant land covers.

**TABLE 5.3**
**Watersheds for Comparison of Discharge Estimates by Different Methods**

| Station ID | 06873300 | 06858700 | 06848200 | 06867800 |
|---|---|---|---|---|
| County | Rooks | Logan | Norton | Russell |
| Mean ann. precip. (in.) | 22.81 | 18.90 | 22.27 | 25.33 |
| Drainage area (mi$^2$) | 0.86 | 0.94 | 1.07 | 1.09 |
| Channel length (mi) | 1.94 | 1.74 | 2.18 | 1.72 |
| Channel slope (ft/mi) | 53.4 | 67.7 | 53.27 | 149.51 |
| Time of concentration (hr) | 74.4 | 63.6 | 80.4 | 48.6 |
| % crops | 48.5 | 90.0 | 58.0 | 13.2 |
| % grass | 51.3 | 10.0 | 41.6 | 86.7 |
| % woods | 0.1 | 0.0 | 0.3 | 0.1 |
| % impervious | 0.1 | 0.0 | 0.1 | 0.0 |

Table 5.4 compares discharge estimates computed with the regional regression equations and the Rational method in the KDOT Design Manual (2011) for the four stations. Figures 5.2 through 5.5 display these comparisons graphically. Because the estimates from the Extended Rational equations and the three-variable equations are very similar, the estimates from the three-variable equations were omitted from the graphs for clarity.

### TABLE 5.4
### Comparison of Discharges from Regional Regression Equations and Rational Method with Current C Values

| | Discharge (cfs) | | | | | |
|---|---|---|---|---|---|---|
| | 2 yr | 5 yr | 10 yr | 25 yr | 50 yr | 100 yr |
| Station 06873300 | | | | | | |
| USGS regression equations | 79 | 220 | 357 | 581 | 779 | 1010 |
| Extended Rational equations | 72 | 197 | 325 | 533 | 730 | 963 |
| Three-variable equations | 70 | 191 | 304 | 491 | 684 | 884 |
| Rational method (current) | 321 | 421 | 488 | 643 | 762 | 880 |
| Station 06858700 | | | | | | |
| USGS regression equations | 49 | 155 | 266 | 457 | 632 | 839 |
| Extended Rational equations | 49 | 152 | 266 | 460 | 649 | 877 |
| Three-variable equations | 47 | 151 | 258 | 445 | 639 | 850 |
| Rational method (current) | 383 | 512 | 602 | 801 | 955 | 1104 |
| Station 06848200 | | | | | | |
| USGS regression equations | 84 | 238 | 390 | 640 | 864 | 1125 |
| Extended Rational equations | 78 | 216 | 361 | 593 | 818 | 1082 |
| Three-variable equations | 75 | 212 | 341 | 557 | 781 | 1014 |
| Rational method (current) | 375 | 493 | 575 | 756 | 899 | 1038 |
| Station 068767800 | | | | | | |
| USGS regression equations | 122 | 317 | 500 | 793 | 1049 | 1344 |
| Extended Rational equations | 170 | 428 | 684 | 1086 | 1461 | 1899 |
| Three-variable equations | 165 | 441 | 692 | 1107 | 1530 | 1964 |
| Rational method (current) | 534 | 684 | 789 | 1032 | 1214 | 1402 |

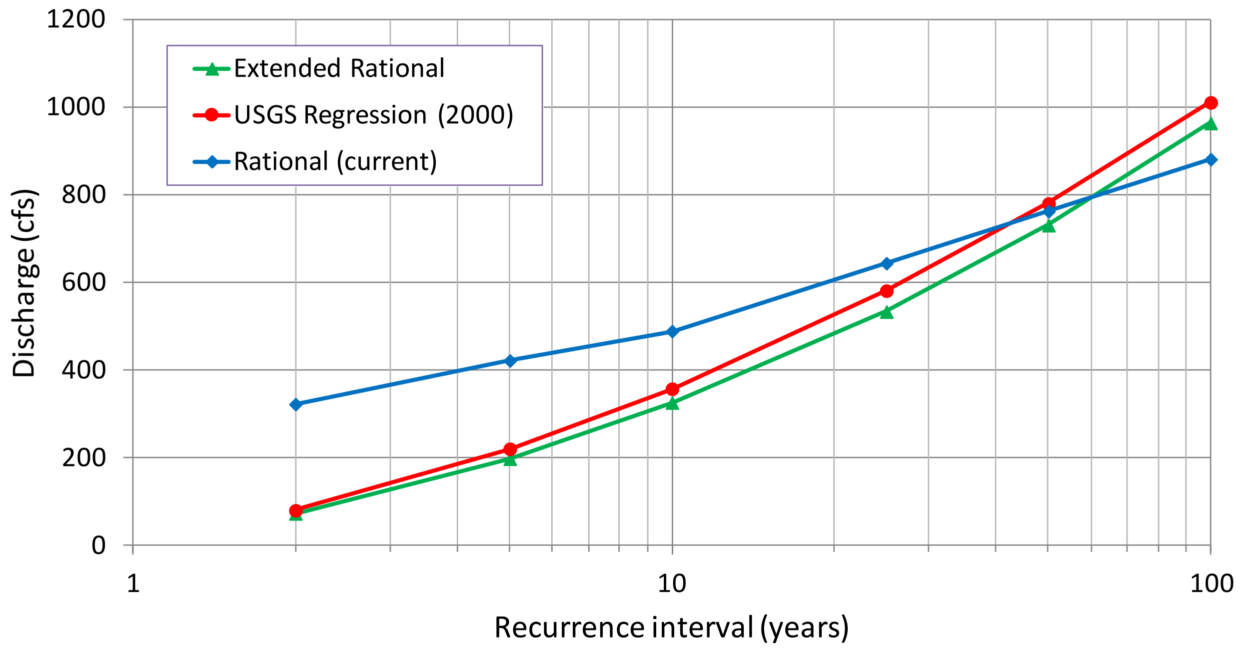


**FIGURE 5.2**
**Discharges for Station 06873300 from Regional Regression Equations and Rational Method with Current C Values**

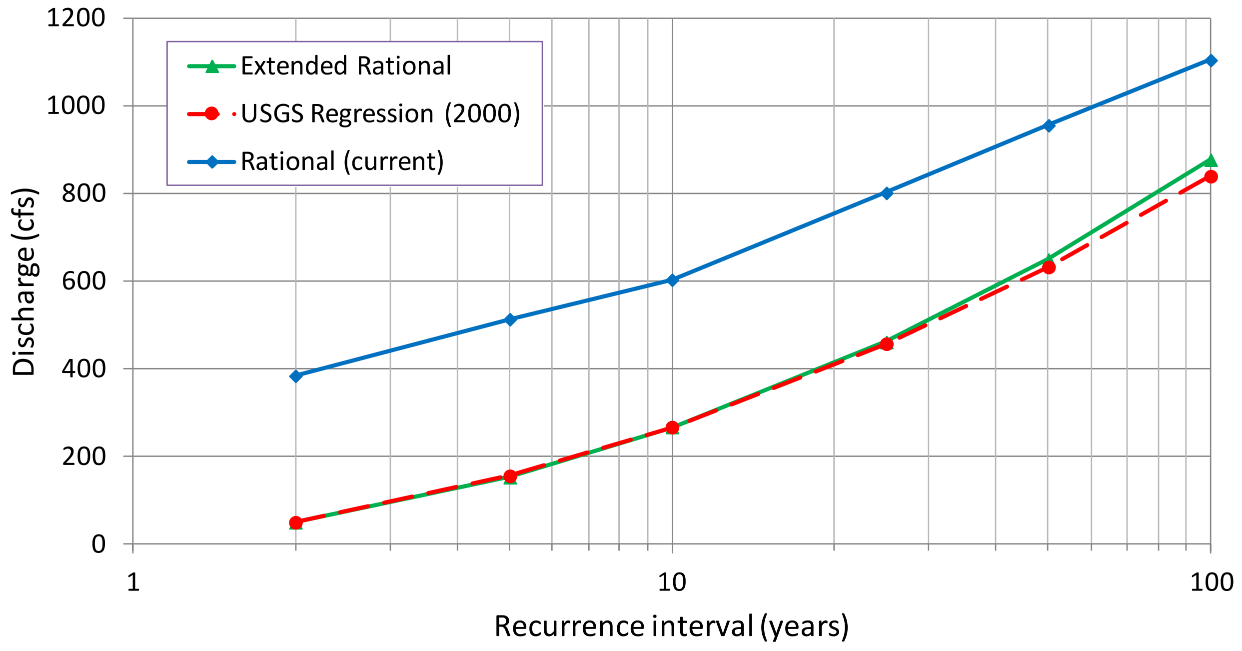


**FIGURE 5.3**
**Discharges for Station 06858700 from Regional Regression Equations and Rational Method with Current C Values**

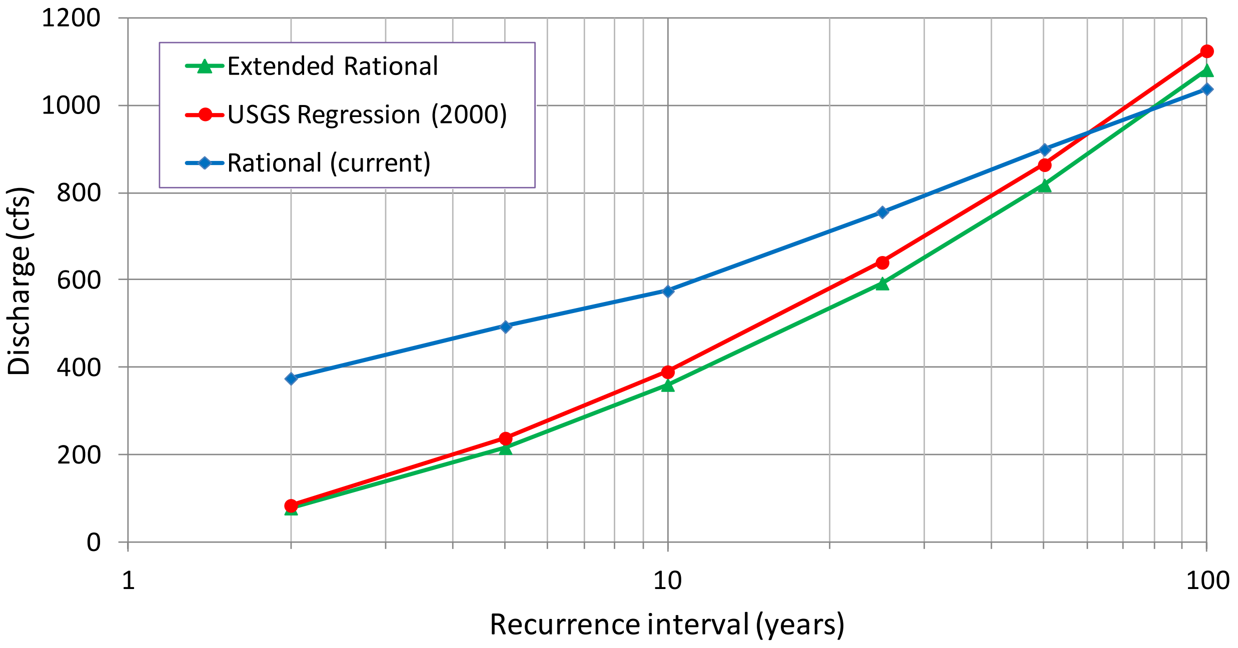


**FIGURE 5.4**
**Discharges for Station 06848200 from Regional Regression Equations and Rational Method with Current C Values**

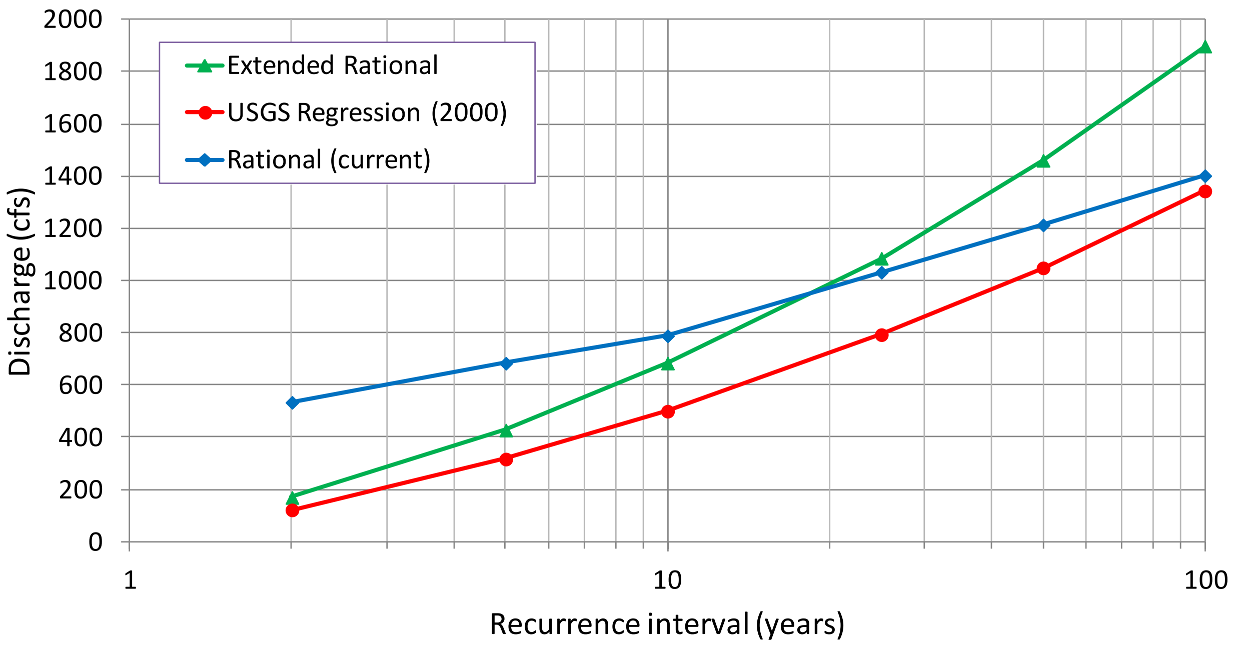


**FIGURE 5.5**
**Discharges for Station 06867800 from Regional Regression Equations and Rational Method with Current C Values**

These comparisons indicate that the Rational method with current C values tends to overestimate discharges for recurrence intervals below 100 years. The shorter the recurrence interval, the greater the apparent overestimation of discharge. The Rational estimates of $Q_{100}$ are consistent, on average, with the $Q_{100}$ estimates from the other methods.

### 5.3 Recommended Runoff Coefficients for Western Kansas

The comparisons in the previous section indicate that the Rational C values currently used by KDOT are too high (except at the 100-year recurrence interval) for small watersheds in Western Kansas. Reducing the $C_{10}$ values by 40% brings the Rational estimates of $Q_{10}$ into line with the regression estimates. The median values for Western Kansas in Table 5-2 suggest the following approximate relationships for the other recurrence intervals:

$$C_2 = 0.40\ C_{10}$$ **Equation 5.1**

$$C_5 = 0.75\ C_{10}$$ **Equation 5.2**

$$C_{25} = 1.50\ C_{10}$$ **Equation 5.3**

$$C_{50} = 1.75\ C_{10}$$ **Equation 5.4**

$$C_{100} = 2.00\ C_{10}$$ **Equation 5.5**

These relationships apply only to pervious surfaces. The recurrence interval of the rainfall has much less impact on C values for impervious surfaces.

KDOT currently assumes that urban open space and pervious areas within the highway right-of-way have the same C values as cultivated agricultural land. This assumption is probably too conservative. Most engineering organizations, including the NRCS, assume that urban open spaces and pervious right-of-way areas have the runoff-producing characteristics as pasture or range. We favor this reasonable and widely accepted assumption. Runoff coefficients for pasture/range are lower than for cropland.

Based on these considerations, we recommend the runoff coefficients in Table 5.5 for small watersheds (less than 640 acres) in Western Kansas. The recommended $C_{10}$ values for grassland, cropland and woods are 60% of the current values. The other C values for these land uses follow from Equations 5.1 through 5.5. Urban open spaces and pervious surfaces within the right-of-way are assumed equivalent to pasture/range. The current C value of 0.95 for impervious surfaces is retained for the 100-year recurrence interval; slightly lower values are applied to shorter recurrence intervals.

Rational discharge estimates for the four small watersheds in Western Kansas were re-computed using the proposed C values in Table 5.5 and compared with the estimates from the three regression methods. Table 5.6 and Figures 5.6 through 5.9 compare these discharge estimates. The Rational method with the recommended C values in Table 5.5 yields discharge estimate that agree well, on average, with the regression estimates for all recurrence intervals.

**TABLE 5.5**
**Proposed Runoff Coefficients for Western Kansas**

| | Rational runoff coefficient, C | | | | | |
|---|---|---|---|---|---|---|
| Land Use | 2 yr | 5 yr | 10 yr | 25 yr | 50 yr | 100 yr |
| Impervious surfaces | 0.80 | 0.86 | 0.90 | 0.93 | 0.94 | 0.95 |
| Pervious surfaces within right-of-way | 0.10 | 0.18 | 0.24 | 0.36 | 0.42 | 0.48 |
| Urban open space (lawns, parks, etc.) | 0.10 | 0.18 | 0.24 | 0.36 | 0.42 | 0.48 |
| Pasture or range | 0.10 | 0.18 | 0.24 | 0.36 | 0.42 | 0.48 |
| Cultivated agricultural land | 0.12 | 0.23 | 0.30 | 0.45 | 0.53 | 0.60 |
| Woods | 0.07 | 0.14 | 0.18 | 0.27 | 0.32 | 0.36 |

## TABLE 5.6
## Comparison of Discharges from Regional Regression Equations and Rational Method with Proposed C Values

| | Discharge (cfs) | | | | | |
|---|---|---|---|---|---|---|
| | 2 yr | 5 yr | 10 yr | 25 yr | 50 yr | 100 yr |
| Station 06873300 | | | | | | |
| USGS regression equations | 79 | 220 | 357 | 581 | 779 | 1010 |
| Extended Rational equations | 72 | 197 | 325 | 533 | 730 | 963 |
| Three-variable equations | 70 | 191 | 304 | 491 | 684 | 884 |
| Rational method (proposed) | 321 | 421 | 488 | 643 | 762 | 880 |
| Station 06858700 | | | | | | |
| USGS regression equations | 49 | 155 | 266 | 457 | 632 | 839 |
| Extended Rational equations | 49 | 152 | 266 | 460 | 649 | 877 |
| Three-variable equations | 47 | 151 | 258 | 445 | 639 | 850 |
| Rational method (proposed) | 383 | 512 | 602 | 801 | 955 | 1104 |
| Station 06848200 | | | | | | |
| USGS regression equations | 84 | 238 | 390 | 640 | 864 | 1125 |
| Extended Rational equations | 78 | 216 | 361 | 593 | 818 | 1082 |
| Three-variable equations | 75 | 212 | 341 | 557 | 781 | 1014 |
| Rational method (proposed) | 375 | 493 | 575 | 756 | 899 | 1038 |
| Station 06867800 | | | | | | |
| USGS regression equations | 122 | 317 | 500 | 793 | 1049 | 1344 |
| Extended Rational equations | 170 | 428 | 684 | 1086 | 1461 | 1899 |
| Three-variable equations | 165 | 441 | 692 | 1107 | 1530 | 1964 |
| Rational method (proposed) | 534 | 684 | 789 | 1032 | 1214 | 1402 |

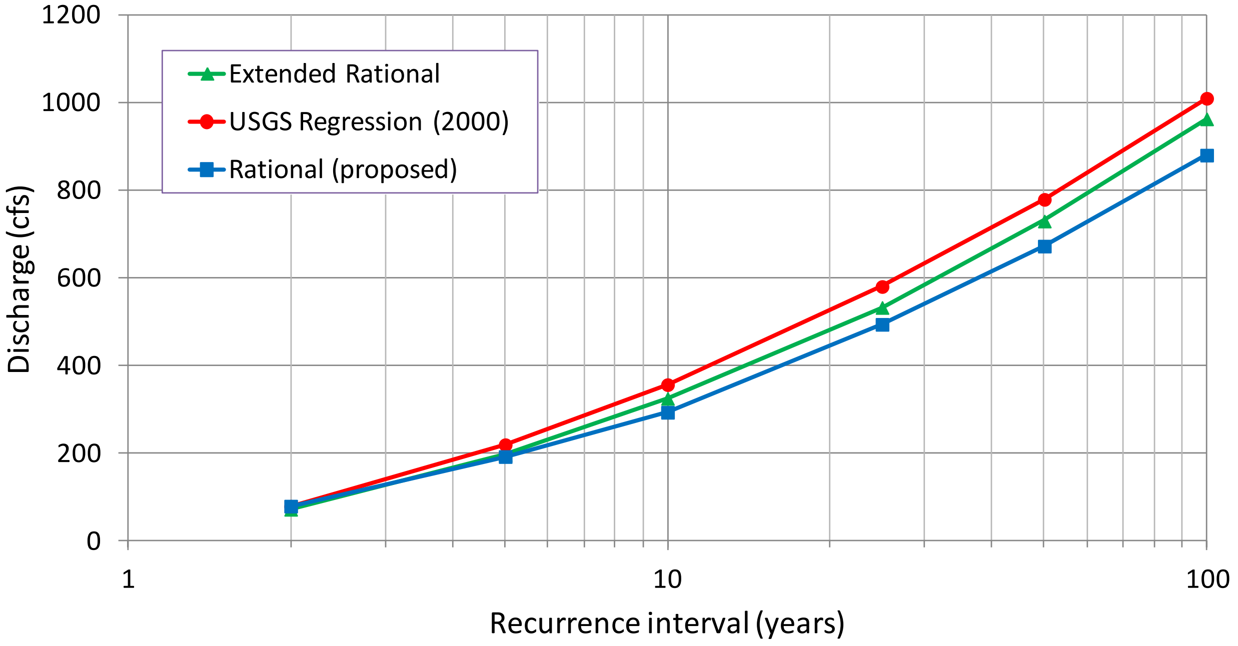


**FIGURE 5.6**
**Discharges for Station 0687330 from Regional Regression Equations and Rational Method with Proposed C Values**

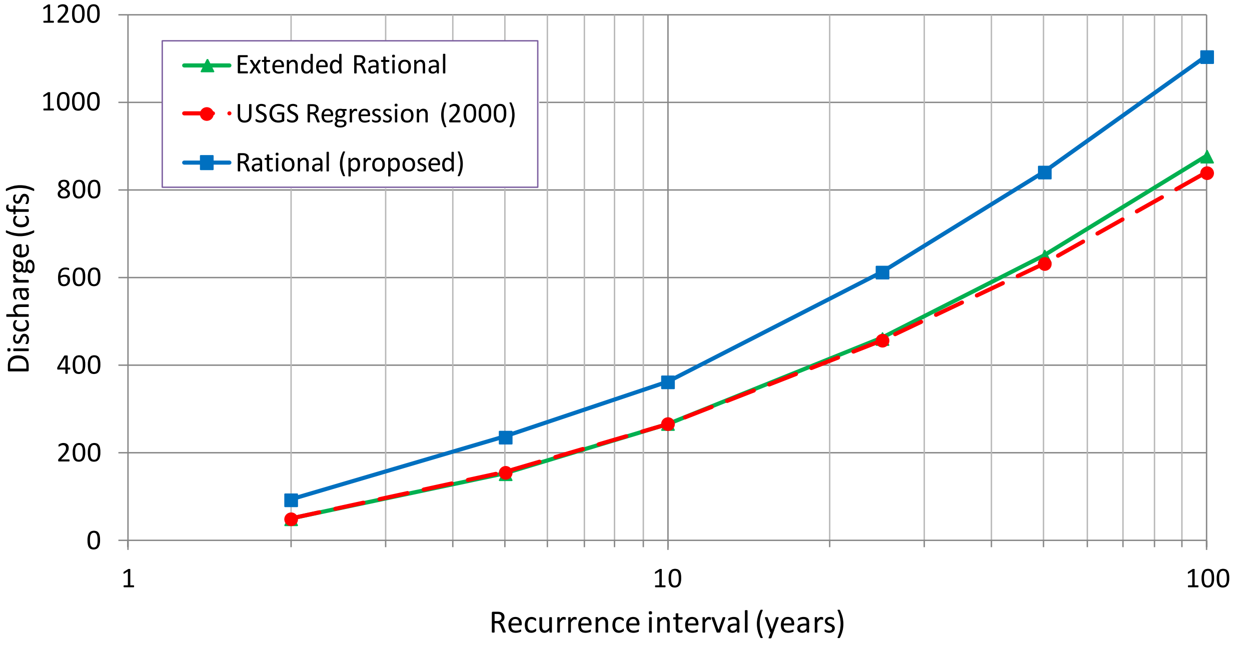


**FIGURE 5.7**
**Discharges for Station 06858700 from Regional Regression Equations and Rational Method with Proposed C Values**

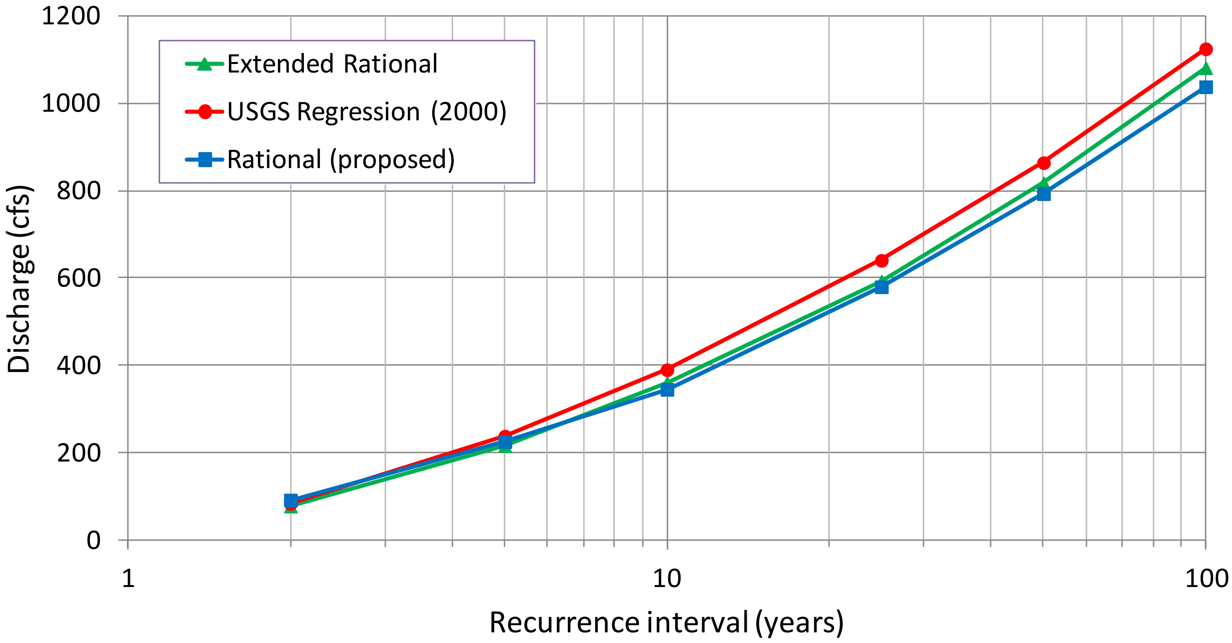


**FIGURE 5.8**
**Discharges for Station 06848200 from Regional Regression Equations and Rational Method with Proposed C Values**

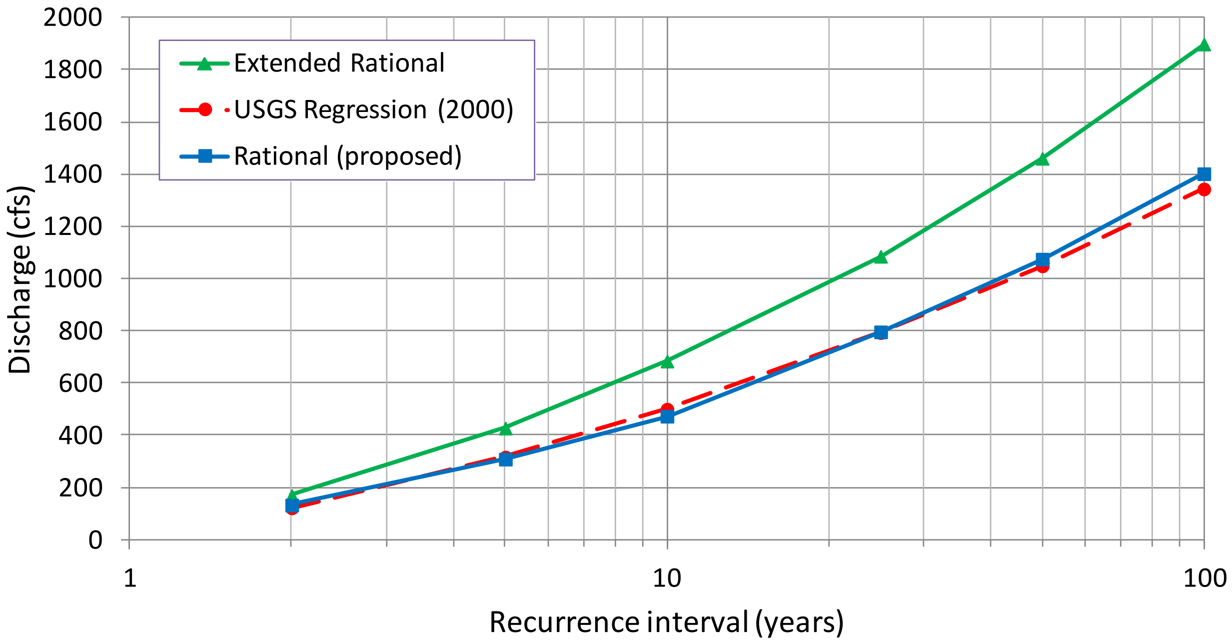


**FIGURE 5.9**
**Discharges for Station 0687800 from Regional Regression Equations and Rational Method with Proposed C Values**

## 5.4 Recommended Runoff Coefficients for Eastern Kansas

We propose certain adjustments to the current statewide C values for use in Eastern Kansas. Table 5.7 shows our proposed C values for Eastern Kansas. The C values for pasture/range, cropland and woods for recurrence intervals of 10 years and greater are the same as the current values. The C values for impervious surfaces are the same values recommended for Western Kansas. Urban open spaces and pervious surfaces within the right-of-way are assumed equivalent to pasture/range rather than cropland. Lower values of $C_2$ and $C_5$ are applied to the pervious land uses. We propose $C_2$ and $C_5$ values equal to 50% and 80% of the $C_{10}$ values. These percentages follow from the median C values for Eastern Kansas in Table 5.2.

**TABLE 5.7**
**Recommended Runoff Coefficients for Eastern Kansas**

| | Rational runoff coefficient, C | | | | | |
|---|---|---|---|---|---|---|
| Land Use | 2 yr | 5 yr | 10 yr | 25 yr | 50 yr | 100 yr |
| Impervious surfaces | 0.80 | 0.86 | 0.90 | 0.93 | 0.94 | 0.95 |
| Pervious surfaces within right-of-way | 0.20 | 0.32 | 0.40 | 0.50 | 0.55 | 0.60 |
| Urban open space (lawns, parks, etc.) | 0.20 | 0.32 | 0.40 | 0.50 | 0.55 | 0.60 |
| Pasture or range | 0.20 | 0.32 | 0.40 | 0.50 | 0.55 | 0.60 |
| Cultivated agricultural land | 0.25 | 0.40 | 0.50 | 0.63 | 0.69 | 0.75 |
| Woods | 0.15 | 0.24 | 0.30 | 0.38 | 0.41 | 0.45 |

# Chapter 6: Conclusions and Summary of Recommendations

This report describes an extensive evaluation of hydrologic methods for small watersheds (< 30 mi$^2$) in Western Kansas. We assembled a data set of all USGS gaging stations that met the following criteria:

(1) at least 10 years of peak flow records,

(2) watershed area less than 100 mi$^2$,

(3) unregulated watersheds (no major lakes or reservoirs), and

(4) watersheds within 100 miles of the Kansas border and west of 97.5° longitude. The data set contains 156 stations, 62 of which are in Kansas.

Regional flood frequency analyses were performed on this data set using Generalize Least Squares regression in WREG 1.0. Soil permeability was found not to be a significant predictor variable. Regression equations were developed for Western Kansas, but our comparisons show that these equations are not a substantial improvement over existing regression equations. We recommend the Extended Rational method for watershed areas > 640 ac and < 30 mi$^2$ and the USGS four-parameter regression equation for watersheds ≥ 30 mi$^2$ in both Western and Eastern Kansas.

An analysis of Rational C values indicates that C values currently used for design in are too high for recurrence intervals below 100 years. New Rational C values for Western Kansas were developed and checked against regression methods for consistency. Our proposed Rational C values for Western Kansas are presented in Table 5.5. The proposed C values are lower than the current values for all recurrence intervals below 100 years. We also propose certain adjustments to the Rational C values for Eastern Kansas in Table 5.7. We recommend that urban open spaces and pervious surfaces within the right-of-way be considered equivalent to pasture/range rather than cropland in both Western and Eastern Kansas.

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# Appendix

## TABLE A.1
## Station Information for Selected Peak-Flow Records

| Station number | Station name | State | County | Years of record | Period of record |
|---|---|---|---|---|---|
| 6687600 | Ash Hollow near Oshkosh | NE | Garden | 10 | 1968-1978 |
| 6759700 | Sand Cr. Tr. near Lindon | CO | Washington | 11 | 1969-1979 |
| 6759900 | Antelope Draw near Union | CO | Morgan | 11 | 1969-1979 |
| 6760200 | Igo Cr. Tr. near Keota | CO | Weld | 11 | 1905-1979 |
| 6760430 | Spring Canyon Cr. near Peetz | CO | Logan | 11 | 1905-1979 |
| 6763200 | Lodgepole Cr. Tr. near Sunol | NE | Cheyenne | 11 | 1968-1978 |
| 6767200 | North Fork Plum Cr. Tr. near Farnam | NE | Lincoln | 27 | 1952-1978 |
| 6768050 | Buffalo Cr. Tr. No.1 near Buffalo | NE | Dawson | 14 | 1965-1978 |
| 6768100 | East Buffalo Cr. near Buffalo | NE | Dawson | 28 | 1951-1978 |
| 6768200 | Buffalo Cr. at Buffalo | NE | Dawson | 17 | 1951-1967 |
| 6768300 | Buffalo Cr. Tr. No. 2 near Buffalo | NE | Dawson | 15 | 1951-1965 |
| 6768400 | West Buffalo Cr. near Buffalo | NE | Dawson | 28 | 1951-1978 |
| 6768500 | Buffalo Cr. near Darr | NE | Dawson | 23 | 1947-1969 |
| 6769100 | Elm Cr. Tr. near Overton | NE | Dawson | 28 | 1951-1978 |
| 6769200 | Elm Cr. near Sumner | NE | Dawson | 28 | 1951-1978 |
| 6769300 | Elm Cr. Tr. No. 2 near Overton | NE | Dawson | 28 | 1951-1978 |
| 6769500 | Elm Cr. near Overton | NE | Dawson | 12 | 1947-1958 |
| 6770600 | Wood R. Tr. near Lodi | NE | Custer | 27 | 1905-1978 |
| 6770700 | Wood R. near Lodi | NE | Custer | 27 | 1952-1978 |
| 6770800 | Wood R. near Oconto | NE | Custer | 28 | 1950-1978 |
| 6770900 | Wood R. at Oconto | NE | Custer | 28 | 1950-1978 |
| 6770910 | Wood R. near Lomax | NE | Custer | 27 | 1952-1978 |
| 6782800 | North Branch Mud Cr. at Broken Bow | NE | Custer | 17 | 1951-1967 |
| 6782900 | Mud Cr. Tr. near Broken Bow | NE | Custer | 29 | 1945-1978 |
| 6784700 | Turkey Cr. near Farwell | NE | Howard | 25 | 1950-1978 |
| 6784800 | Turkey Cr. near Dannebrog | NE | Howard | 21 | 1965-1993 |
| 6789200 | Davis Cr. Tr. No. 2 near North Loup | NE | Valley | 20 | 1951-1970 |
| 6789300 | Davis Cr. near North Loup | NE | Valley | 17 | 1951-1967 |
| 6789400 | Davis Cr. Southwest of North Loup | NE | Valley | 28 | 1951-1978 |
| 6789500 | Davis Cr. near Cotesfield | NE | Greeley | 11 | 1948-1958 |
| 6790900 | Mary's Cr. at Wolbach | NE | Greeley | 16 | 1952-1967 |
| 6821300 | North Fork Arikaree R. Tr. near Shaw | CO | Lincoln | 11 | 1969-1978 |
| 6821400 | North Fork Black Wolf Cr. near Vernon | CO | Yuma | 11 | 1969-1979 |
| 6822600 | Patent Cr. near St. Petersburg | CO | Logan | 11 | 1969-1979 |
| 6826900 | Sand Cr. near Hale | CO | Yuma | 11 | 1969-1979 |
| 6828100 | North Branch Indian Cr. near Max | NE | Dundy | 10 | 1962-1978 |
| 6829700 | Thompson Canyon near Trenton | NE | Hitchcock | 13 | 1966-1978 |
| 6834200 | Spring Cr. Tr. near Amherst | CO | Sedgewick | 11 | 1969-1979 |
| 6835100 | Bobtail Cr. near Palisade | NE | Hitchcock | 13 | 1966-1978 |
| 6838200 | Coon Cr. at Indianola | NE | Red Willow | 37 | 1961-1999 |
| 6838550 | Dry Cr. at Bartley | NE | Red Willow | 37 | 1961-1999 |
| 6839200 | Elkhorn Canyon near Maywood | NE | Frontier | 27 | 1952-1978 |

## TABLE A.1
## Station Information for Selected Peak-Flow Records (Continued)

| Station number | Station name | State | County | Years of record | Period of record |
|---|---|---|---|---|---|
| 6839400 | Elkhorn Canyon Southwest of Maywood | NE | Frontier | 19 | 1952-1970 |
| 6839600 | Frazier Cr. near Maywood | NE | Frontier | 19 | 1952-1970 |
| 6839850 | Fox Cr. North of Curtis | NE | Lincoln | 19 | 1952-1970 |
| 6839900 | Fox Cr. above Cut Canyon near Curtis | NE | Lincoln | 28 | 1951-1978 |
| 6839950 | Cut Canyon near Curtis | NE | Lincoln | 28 | 1951-1978 |
| 6840000 | Fox Cr. at Curtis | NE | Frontier | 34 | 1951-1993 |
| 6840500 | Dry Cr. near Curtis | NE | Frontier | 20 | 1947-1970 |
| 6841500 | Mitchell Cr. above Harry Strunk Lake | NE | Frontier | 25 | 1948-1974 |
| 6844210 | Turkey Cr. at Edison | NE | Furnas | 16 | 1978-1993 |
| 6844700 | South Fork Sappa Cr. near Brewster | KS | Sherman | 22 | 1968-1989 |
| 6844800 | South Fork Sappa Cr. near Goodland | KS | Sherman | 33 | 1957-1989 |
| 6845100 | Long Branch Draw near Norcatur | KS | Norton | 53 | 1957-2010 |
| 6845900 | Little Beaver Cr. Tr. near Mcdonald | KS | Rawlins | 9 | 1957-1966 |
| 6846200 | Beaver Cr. Tr. near Ludell | KS | Rawlins | 33 | 1957-1989 |
| 6847600 | Prairie Dog Cr. Tr. at Colby | KS | Thomas | 55 | 1957-2011 |
| 6848200 | Prairie Dog Cr. Tr. near Norton | KS | Norton | 35 | 1957-1991 |
| 6850200 | Cottonwood Cr. near Bloomington | NE | Franklin | 26 | 1948-1978 |
| 6851100 | West Branch Thompson Cr. at Hildreth | NE | Kearney | 18 | 1953-1970 |
| 6851300 | W. Branch Thompson Cr. Tr. near Hildreth | NE | Franklin | 26 | 1953-1978 |
| 6852000 | Elm Cr. at Amboy | NE | Webster | 40 | 1948-1993 |
| 6853100 | Beaver Cr. near Rosemont | NE | Webster | 40 | 1939-1978 |
| 6855900 | Wolf Cr. near Concordia | KS | Cloud | 19 | 1963-1981 |
| 6856100 | West Cr. near Talmo | KS | Republic | 34 | 1941-1989 |
| 6858700 | North Fork Smoky Hill R. Tr. near Winona | KS | Logan | 16 | 1957-1977 |
| 6860300 | South Branch Hackberry Cr. near Orion | KS | Gove | 12 | 1957-1970 |
| 6863400 | Big Cr. Tr. near Ogallah | KS | Trego | 52 | 1957-2011 |
| 6863700 | Big Cr. Tr. near Hays | KS | Ellis | 52 | 1957-2011 |
| 6863900 | North Fork Big Cr. near Victoria | KS | Ellis | 25 | 1963-1987 |
| 6864300 | Smoky Hill R. Tr. at Dorrance | KS | Russell | 54 | 1957-2011 |
| 6864700 | Spring Cr. near Kanopolis | KS | Ellsworth | 33 | 1957-1989 |
| 6866800 | Saline R. Tr. at Collyer | KS | Trego | 33 | 1957-1989 |
| 6867800 | Cedar Cr. Tr. near Bunker Hill | KS | Russell | 21 | 1957-1977 |
| 6868300 | Coon Cr. Tr. near Luray | KS | Osborne | 55 | 1957-2011 |
| 6868700 | North Branch Spillman Cr. near Ash Grove | KS | Lincoln | 15 | 1963-1977 |
| 6868900 | Bullfoot Cr. Tr. near Lincoln | KS | Lincoln | 31 | 1957-1989 |
| 6871900 | Deer Cr. near Phillipsburg | KS | Phillips | 15 | 1967-1981 |
| 6872100 | M. Cedar Cr. at Kensington | KS | Smith | 22 | 1905-1977 |
| 6872300 | M. Beaver Cr. near Smith Center | KS | Smith | 10 | 1961-1970 |
| 6872600 | Oak Cr. at Bellaire | KS | Smith | 33 | 1957-1989 |
| 6873300 | Ash Cr. Tr. near Stockton | KS | Rooks | 51 | 1957-2011 |
| 6873700 | Kill Cr. near Bloomington | KS | Osborne | 18 | 1964-1981 |
| 6873800 | Kill Cr. Tr. near Bloomington | KS | Osborne | 21 | 1957-1977 |

## Table A.1
## Station Information for Selected Peak-Flow Records (Continued)

| Station number | Station name | State | County | Years of record | Period of record |
|---|---|---|---|---|---|
| 6874500 | East Limestone Cr. near Ionia | KS | Jewell | 38 | 1934-1989 |
| 6876200 | M. Pipe Cr. near Miltonvale | KS | Cloud | 21 | 1957-1977 |
| 6880590 | N. Br. W. Fork Big Blue R. Tr. at Giltner | NE | Hamilton | 11 | 1968-1978 |
| 6880710 | School Cr. Tr. near Harvard | NE | Clay | 19 | 1952-1970 |
| 6880720 | School Cr. near Harvard | NE | Clay | 26 | 1953-1978 |
| 6880730 | School Cr. Tr. No.2 near Harvard | NE | Clay | 26 | 1953-1978 |
| 6880740 | School Cr. near Saronville | NE | Clay | 19 | 1952-1969 |
| 6880775 | Beaver Cr. Tr. near Henderson | NE | York | 11 | 1968-1978 |
| 6883600 | South Fork Big Sandy Cr. near Edgar | NE | Nuckolls | 18 | 1953-1970 |
| 6883700 | South Fork Big Sandy Cr. near Davenport | NE | Nuckolls | 28 | 1950-1978 |
| 6883800 | South Fork Big Sandy Cr. near Carleton | NE | Thayer | 19 | 1952-1970 |
| 7126325 | Taylor Arroyo Bl Rock Cr.ossing | CO | Las Animas | 29 | 1983-2011 |
| 7126390 | Lockwood Canyon Cr. near Thatcher | CO | Las Animas | 28 | 1983-2011 |
| 7126415 | Red Rock Canyon Cr. near Thatcher | CO | Las Animas | 29 | 1983-2011 |
| 7126480 | Bent Canyon Cr. near Timpas | CO | Las Animas | 27 | 1984-2011 |
| 7133200 | Clay Cr. Tr. near Deora | CO | Prowers | 11 | 1969-1979 |
| 7138600 | White Woman Cr. Tr. near Selkirk | KS | Greeley | 39 | 1957-2010 |
| 7138800 | Lion Cr. Tr. near Modoc | KS | Scott | 21 | 1957-1977 |
| 7139700 | Arkansas R. Tr. near Dodge City | KS | Ford | 53 | 1957-2011 |
| 7139800 | Mulberry Cr. near Dodge City | KS | Ford | 22 | 1968-1990 |
| 7140300 | Whitewoman Cr. near Bellefont | KS | Hodgeman | 33 | 1957-1989 |
| 7140600 | Pawnee R. Tr. near Kalvesta | KS | Finney | 33 | 1957-1989 |
| 7140700 | Guzzlers Gulch near Ness City | KS | Ness | 19 | 1962-1980 |
| 7141400 | South Fork Walnut Cr. Tr. near Dighton | KS | Lane | 21 | 1957-1977 |
| 7141600 | Long Branch Cr. near Ness City | KS | Ness | 33 | 1957-1989 |
| 7141800 | Otter Cr. near Rush Center | KS | Rush | 33 | 1956-1989 |
| 7142100 | Rattlesnake Cr. Tr. near Mullinville | KS | Kiowa | 33 | 1957-1989 |
| 7142500 | Spring Cr. near Dillwyn | KS | Stafford | 21 | 1957-1977 |
| 7142700 | Salt Cr. near Partridge | KS | Reno | 33 | 1957-1989 |
| 7142860 | Cow Cr. near Claflin | KS | Barton | 22 | 1967-1988 |
| 7142900 | Blood Cr. near Boyd | KS | Barton | 33 | 1957-1989 |
| 7143100 | Little Cheyenne Cr. Tr. near Claflin | KS | Barton | 55 | 1957-2011 |
| 7143200 | Plum Cr. near Holyrood | KS | Ellsworth | 20 | 1957-1977 |
| 7143500 | Little Arkansas R. near Geneseo | KS | Rice | 21 | 1957-1977 |
| 7143600 | Little Arkansas R. near Little R. | KS | Rice | 26 | 1960-1985 |
| 7144850 | S. Fork of S. Fork Ninnescah R. near Pratt | KS | Pratt | 19 | 1961-1979 |
| 7144900 | S. Fork Ninnescah R. Tr. near Pratt | KS | Pratt | 32 | 1957-1989 |
| 7145300 | Clear Cr. near Garden Plain | KS | Sedgewick | 33 | 1957-1989 |
| 7148700 | Dog Cr. near Deerhead | KS | Barber | 21 | 1957-1977 |
| 7148800 | Medicine Lodge R. Tr. nr. Medicine Lodge | KS | Barber | 21 | 1957-1977 |
| 7150580 | Sand Cr. Tr. near Kremlin | OK | Garfield | 12 | 1964-1975 |
| 7151600 | Rush Cr. near Harper | KS | Harper | 33 | 1957-1989 |

## TABLE A.1
## Station Information for Selected Peak-Flow Records (Continued)

| Station number | Station name | State | County | Years of record | Period of record |
|---|---|---|---|---|---|
| 7152520 | Black Bear Cr. Tr. near Garber | OK | Garfield | 12 | 1964-1974 |
| 7155100 | Cold Springs Cr. near Wheeless | OK | Cimarron | 18 | 1964-1984 |
| 7155900 | North Fork Cimarron R. Tr. near Elkhart | KS | Morton | 33 | 1957-1989 |
| 7156600 | Cimarron R. Tr. near Moscow | KS | Seward | 33 | 1957-1989 |
| 7156700 | Cimarron R. Tr. near Satanta | KS | Seward | 49 | 1957-2010 |
| 7157100 | Crooked Cr. near Copeland | KS | Gray | 33 | 1957-1989 |
| 7157400 | Crooked Cr. Tr. at Meade | KS | Meade | 33 | 1957-1989 |
| 7157550 | West Fork Cr. near Knowles | OK | Beaver | 22 | 1964-1985 |
| 7157700 | Keiger Cr. near Ashland | KS | Clark | 32 | 1957-1989 |
| 7157900 | Cavalry Cr. at Coldwater | KS | Comanche | 28 | 1957-1988 |
| 7158020 | Cimarron R. Tr. near Lone Wolf | OK | Major | 12 | 1964-1974 |
| 7158080 | Sand Cr. Tr. near Waynoka | OK | Woods | 13 | 1951-1974 |
| 7158180 | Salt Cr. Tr. near Okeene | OK | Blaine | 12 | 1964-1975 |
| 7158500 | Preacher Cr. near Dover | OK | Kingfisher | 26 | 1952-1984 |
| 7158550 | Turkey Cr. Tr. near Goltry | OK | Alfalfa | 19 | 1964-1982 |
| 7160350 | Skeleton Cr. at Enid | OK | Garfield | 15 | 1997-2011 |
| 7226200 | Bueyeros Cr. at Bueyeros | NM | Harding | 32 | 1957-2011 |
| 7226300 | Carrizo Cr. near Roy | NM | Harding | 53 | 1955-2010 |
| 7227295 | Sandy Arroyo Tr. near Clayton | NM | Union | 43 | 1952-1996 |
| 7227300 | Sand Draw near Clayton | NM | Union | 16 | 1905-2010 |
| 7227460 | E. Fork Cheyenne Cr. Tr. near Channing | TX | Hartley | 10 | 1965-1974 |
| 7228290 | Rough Cr. near Thomas | OK | Custer | 22 | 1964-1985 |
| 7228450 | Deer Cr. Tr. near Hydro | OK | Caddo | 12 | 1964-1974 |
| 7232650 | Aqua Frio Cr. near Felt | OK | Cimarron | 12 | 1905-1975 |
| 7234050 | North Fork Clear Cr. Tr. near Balko | OK | Beaver | 22 | 1964-1985 |
| 7234290 | Clear Cr. Tr. near Catesby | OK | Ellis | 20 | 1966-1985 |
| 7235700 | Little Wolf Cr. Tr. near Gage | OK | Ellis | 11 | 1964-1973 |
| 7237750 | Cottonwood Cr. near Vici | OK | Dewey | 21 | 1964-1984 |
| 7239050 | North Canadian R. Tr. near Eagle City | OK | Blaine | 12 | 1964-1974 |
| 7321500 | Sandstone Cr. SWS 3 near Elk City | OK | Roger Mills | 14 | 1955-1973 |

## TABLE A.2
## Watershed Characteristics

| Station number | DA ($mi^2$) | CDA ($mi^2$) | MAP (in.) | L (mi) | Sl (ft/mi) | $T_c$ (hr) | SP (in./hr) |
|---|---|---|---|---|---|---|---|
| 6687600 | 48.88 | 48.88 | 16.98 | 14.01 | 10.0 | 7.93 | 1.26 |
| 6759700 | 3.62 | 1.72 | 15.21 | 5.69 | 30.2 | 3.04 | 1.37 |
| 6759900 | 5.24 | 1.34 | 14.33 | 5.32 | 24.8 | 3.11 | 2.68 |
| 6760200 | 1.56 | 1.53 | 14.78 | 4.69 | 85.5 | 1.90 | 2.32 |
| 6760430 | 17.90 | 9.96 | 16.31 | 11.43 | 13.4 | 6.30 | 2.01 |
| 6763200 | 19.17 | 19.17 | 16.57 | 13.16 | 22.5 | 5.83 | 1.86 |
| 6767200 | 1.73 | 1.73 | 21.59 | 3.53 | 32.9 | 2.16 | 1.30 |
| 6768050 | 2.11 | 2.11 | 22.76 | 2.13 | 36.5 | 1.50 | 1.30 |
| 6768100 | 5.19 | 5.19 | 22.65 | 6.76 | 25.8 | 3.59 | 1.30 |
| 6768200 | 30.42 | 30.60 | 22.71 | 14.69 | 26.7 | 5.92 | 1.29 |
| 6768300 | 1.92 | 1.92 | 22.62 | 4.02 | 25.8 | 2.55 | 1.30 |
| 6768400 | 16.66 | 16.66 | 22.58 | 11.49 | 17.6 | 5.78 | 1.29 |
| 6768500 | 63.65 | 63.65 | 22.65 | 23.93 | 13.3 | 10.30 | 1.30 |
| 6769100 | 0.60 | 0.60 | 23.30 | 1.36 | 41.8 | 1.06 | 1.30 |
| 6769200 | 14.85 | 14.85 | 23.22 | 8.31 | 14.6 | 4.96 | 1.30 |
| 6769300 | 5.81 | 5.81 | 23.25 | 4.74 | 21.2 | 3.03 | 1.30 |
| 6769500 | 32.90 | 32.90 | 23.28 | 12.33 | 12.5 | 6.78 | 1.30 |
| 6770600 | 2.06 | 2.06 | 22.82 | 3.07 | 32.9 | 1.97 | 1.34 |
| 6770700 | 19.35 | 19.35 | 22.81 | 12.61 | 13.5 | 6.71 | 1.35 |
| 6770800 | 24.72 | 24.72 | 22.83 | 13.46 | 13.6 | 6.99 | 1.36 |
| 6770900 | 43.95 | 43.95 | 22.84 | 17.14 | 11.4 | 8.70 | 1.35 |
| 6770910 | 79.29 | 79.29 | 22.91 | 29.08 | 8.9 | 13.36 | 1.36 |
| 6782800 | 10.72 | 10.80 | 23.18 | 8.27 | 27.7 | 4.01 | 2.23 |
| 6782900 | 5.93 | 5.93 | 23.24 | 5.29 | 50.3 | 2.45 | 1.69 |
| 6784700 | 27.57 | 27.57 | 24.76 | 18.01 | 11.2 | 9.02 | 1.33 |
| 6784800 | 65.81 | 65.81 | 24.97 | 32.40 | 8.6 | 14.53 | 1.32 |
| 6789200 | 6.77 | 6.77 | 24.22 | 6.10 | 24.0 | 3.43 | 1.32 |
| 6789300 | 21.12 | 21.12 | 24.29 | 9.96 | 16.7 | 5.35 | 1.32 |
| 6789400 | 31.25 | 31.25 | 24.33 | 17.61 | 10.6 | 9.07 | 1.32 |
| 6789500 | 81.04 | 81.04 | 24.49 | 34.28 | 8.7 | 15.02 | 1.32 |
| 6790900 | 7.55 | 7.55 | 25.57 | 5.73 | 24.5 | 3.27 | 1.30 |
| 6821300 | 6.58 | 1.45 | 15.02 | 9.06 | 27.3 | 4.27 | 1.30 |
| 6821400 | 16.37 | 16.37 | 17.37 | 9.86 | 32.0 | 4.29 | 1.27 |
| 6822600 | 2.27 | 2.27 | 16.67 | 4.47 | 24.3 | 2.78 | 2.08 |
| 6826900 | 19.98 | 10.60 | 17.28 | 10.10 | 26.3 | 4.65 | 1.31 |
| 6828100 | 3.54 | 3.54 | 19.57 | 4.06 | 85.7 | 1.73 | 1.29 |
| 6829700 | 9.14 | 9.14 | 20.69 | 6.29 | 31.8 | 3.19 | 1.29 |
| 6834200 | 45.75 | 13.10 | 17.10 | 24.59 | 12.6 | 10.67 | 5.54 |
| 6835100 | 29.64 | 29.64 | 20.09 | 13.80 | 29.6 | 5.50 | 1.28 |
| 6838200 | 68.41 | 68.41 | 21.44 | 33.68 | 10.0 | 14.17 | 1.30 |
| 6838550 | 41.76 | 41.76 | 21.66 | 23.54 | 13.3 | 10.17 | 1.30 |

Note: DA = drainage area, CDA = contributing drainage area, MAP = mean annual precipitation, L = main-channel length, Tc = time of concentration, SP = generalized soil permeability

## TABLE A.2
## Watershed Characteristics (Continued)

| Station number | DA (mi$^2$) | CDA (mi$^2$) | MAP (in.) | L (mi) | Sl (ft/mi) | $T_c$ (hr) | SP (in./hr) |
|---|---|---|---|---|---|---|---|
| 6839200 | 6.97 | 6.97 | 20.81 | 4.77 | 50.6 | 2.28 | 1.30 |
| 6839400 | 13.78 | 12.90 | 20.85 | 9.25 | 25.3 | 4.44 | 1.31 |
| 6839600 | 11.36 | 11.36 | 20.95 | 6.05 | 32.0 | 3.11 | 1.32 |
| 6839850 | 13.53 | 13.53 | 20.91 | 6.32 | 33.1 | 3.16 | 1.30 |
| 6839900 | 31.30 | 31.30 | 20.92 | 13.56 | 20.6 | 6.12 | 1.30 |
| 6839950 | 25.47 | 25.47 | 20.79 | 17.29 | 18.3 | 7.47 | 1.30 |
| 6840000 | 77.20 | 77.20 | 20.93 | 27.90 | 14.8 | 10.99 | 1.31 |
| 6840500 | 21.61 | 21.61 | 21.23 | 12.67 | 20.1 | 5.90 | 1.33 |
| 6841500 | 52.13 | 52.13 | 21.54 | 30.48 | 11.6 | 12.62 | 1.36 |
| 6844210 | 78.78 | 78.78 | 22.53 | 42.04 | 10.2 | 16.31 | 1.31 |
| 6844700 | 85.65 | 74.00 | 18.16 | 33.65 | 11.2 | 13.65 | 1.29 |
| 6844800 | 21.12 | 4.98 | 17.94 | 13.24 | 13.4 | 6.94 | 1.29 |
| 6845100 | 31.97 | 31.70 | 21.90 | 16.45 | 12.7 | 8.15 | 1.30 |
| 6845900 | 8.17 | 2.12 | 19.36 | 5.91 | 37.2 | 2.91 | 1.26 |
| 6846200 | 10.68 | 10.20 | 20.60 | 7.33 | 33.9 | 3.46 | 1.27 |
| 6847600 | 8.09 | 7.53 | 19.62 | 6.91 | 18.1 | 4.09 | 1.29 |
| 6848200 | 1.07 | 1.02 | 22.27 | 2.18 | 53.3 | 1.34 | 1.30 |
| 6850200 | 15.76 | 15.76 | 24.18 | 13.34 | 22.8 | 5.85 | 1.28 |
| 6851100 | 41.80 | 18.40 | 24.27 | 14.90 | 5.8 | 9.92 | 1.11 |
| 6851300 | 11.42 | 8.20 | 24.45 | 9.28 | 10.2 | 6.01 | 1.20 |
| 6852000 | 51.71 | 51.71 | 26.24 | 29.07 | 9.9 | 12.90 | 1.64 |
| 6853100 | 0.75 | 0.75 | 26.59 | 1.96 | 36.8 | 1.41 | 1.18 |
| 6855900 | 56.53 | 56.00 | 28.60 | 17.99 | 9.9 | 9.39 | 1.00 |
| 6856100 | 39.98 | 42.00 | 28.83 | 30.44 | 8.7 | 13.88 | 0.86 |
| 6858700 | 0.94 | 1.13 | 18.90 | 1.74 | 67.7 | 1.06 | 1.29 |
| 6860300 | 59.49 | 49.60 | 19.64 | 37.52 | 10.2 | 15.12 | 1.29 |
| 6863400 | 4.90 | 4.81 | 21.66 | 7.78 | 18.7 | 4.38 | 1.19 |
| 6863700 | 6.06 | 6.19 | 23.04 | 8.88 | 17.8 | 4.86 | 0.98 |
| 6863900 | 52.98 | 54.00 | 22.94 | 27.95 | 8.8 | 13.08 | 1.24 |
| 6864300 | 5.51 | 5.39 | 25.84 | 5.01 | 25.9 | 2.94 | 1.06 |
| 6864700 | 9.70 | 9.84 | 27.36 | 9.00 | 19.5 | 4.75 | 1.04 |
| 6866800 | 3.54 | 3.13 | 21.02 | 3.82 | 31.6 | 2.30 | 1.19 |
| 6867800 | 1.09 | 0.99 | 25.33 | 1.72 | 149.5 | 0.81 | 1.08 |
| 6868300 | 6.54 | 6.53 | 25.12 | 5.16 | 44.0 | 2.52 | 1.11 |
| 6868700 | 27.03 | 26.10 | 25.96 | 16.17 | 15.2 | 7.61 | 1.00 |
| 6868900 | 2.89 | 2.64 | 27.21 | 5.17 | 30.7 | 2.84 | 1.05 |
| 6871900 | 67.64 | 65.00 | 22.83 | 22.65 | 15.3 | 9.48 | 1.36 |
| 6872100 | 59.79 | 58.90 | 23.96 | 29.62 | 9.8 | 13.12 | 1.21 |
| 6872300 | 72.84 | 71.00 | 24.61 | 26.92 | 11.8 | 11.56 | 1.24 |
| 6872600 | 5.38 | 4.75 | 25.23 | 6.35 | 23.7 | 3.54 | 1.20 |
| 6873300 | 0.86 | 0.89 | 22.81 | 1.94 | 53.4 | 1.24 | 1.19 |

Note: DA = drainage area, CDA = contributing drainage area, MAP = mean annual precipitation, L = main-channel length, Tc = time of concentration, SP = generalized soil permeability

## TABLE A.2
## Watershed Characteristics (Continued)

| Station number | DA ($mi^2$) | CDA ($mi^2$) | MAP (in.) | L (mi) | Sl (ft/mi) | $T_c$ (hr) | SP (in./hr) |
|---|---|---|---|---|---|---|---|
| 6873700 | 51.64 | 52.00 | 24.20 | 20.17 | 14.8 | 8.88 | 1.15 |
| 6873800 | 1.43 | 1.45 | 24.46 | 2.89 | 41.6 | 1.75 | 1.14 |
| 6874500 | 26.64 | 25.60 | 26.49 | 17.81 | 12.5 | 8.64 | 1.18 |
| 6876200 | 9.71 | 10.20 | 29.23 | 9.48 | 21.2 | 4.79 | 0.90 |
| 6880590 | 5.12 | 5.08 | 26.59 | 8.74 | 9.9 | 5.84 | 0.72 |
| 6880710 | 19.64 | 19.64 | 27.02 | 14.28 | 6.2 | 9.41 | 0.75 |
| 6880720 | 39.52 | 37.70 | 27.00 | 15.75 | 6.7 | 9.78 | 0.74 |
| 6880730 | 14.55 | 13.90 | 26.99 | 10.24 | 9.9 | 6.48 | 0.72 |
| 6880740 | 89.04 | 49.70 | 27.01 | 25.54 | 6.8 | 13.41 | 0.73 |
| 6880775 | 1.28 | 1.28 | 27.25 | 2.97 | 6.3 | 3.33 | 0.69 |
| 6883600 | 13.64 | 13.64 | 27.40 | 11.90 | 4.9 | 9.01 | 0.76 |
| 6883700 | 34.20 | 34.20 | 27.52 | 22.07 | 4.8 | 13.69 | 0.76 |
| 6883800 | 56.79 | 56.79 | 27.66 | 30.71 | 4.6 | 17.25 | 0.77 |
| 7126325 | 48.54 | 48.54 | 13.49 | 16.64 | 31.9 | 6.06 | 0.83 |
| 7126390 | 48.93 | 48.93 | 13.31 | 17.16 | 32.7 | 6.14 | 1.06 |
| 7126415 | 48.83 | 48.83 | 13.31 | 14.57 | 40.3 | 5.14 | 0.89 |
| 7126480 | 56.32 | 56.32 | 13.00 | 22.36 | 34.8 | 7.16 | 0.83 |
| 7133200 | 2.45 | 2.45 | 14.55 | 3.38 | 84.7 | 1.53 | 2.90 |
| 7138600 | 26.33 | 30.41 | 16.76 | 18.64 | 15.1 | 8.37 | 1.10 |
| 7138800 | 8.21 | 1.19 | 18.60 | 10.67 | 10.2 | 6.58 | 1.08 |
| 7139700 | 9.34 | 8.66 | 21.98 | 9.36 | 14.2 | 5.42 | 1.38 |
| 7139800 | 77.48 | 73.80 | 21.71 | 27.63 | 9.3 | 12.73 | 1.30 |
| 7140300 | 18.39 | 14.00 | 22.56 | 12.64 | 11.5 | 7.08 | 1.05 |
| 7140600 | 26.81 | 6.89 | 20.42 | 14.22 | 8.4 | 8.50 | 0.65 |
| 7140700 | 57.49 | 58.20 | 21.14 | 32.92 | 10.6 | 13.70 | 1.19 |
| 7141400 | 1.43 | 1.43 | 20.41 | 3.30 | 16.2 | 2.61 | 1.05 |
| 7141600 | 29.59 | 28.00 | 21.40 | 23.33 | 11.1 | 10.74 | 1.11 |
| 7141800 | 17.41 | 17.00 | 22.79 | 13.06 | 14.3 | 6.73 | 1.09 |
| 7142100 | 10.00 | 10.30 | 23.82 | 10.42 | 11.0 | 6.33 | 1.05 |
| 7142500 | 48.53 | 14.30 | 24.55 | 22.47 | 7.0 | 12.21 | 4.90 |
| 7142700 | 93.95 | 72.00 | 27.79 | 29.32 | 6.6 | 14.84 | 3.70 |
| 7142860 | 43.26 | 43.00 | 25.79 | 16.90 | 7.1 | 10.05 | 1.04 |
| 7142900 | 62.62 | 61.00 | 24.37 | 19.49 | 10.2 | 9.82 | 1.05 |
| 7143100 | 1.53 | 1.48 | 26.09 | 3.24 | 20.5 | 2.38 | 1.03 |
| 7143200 | 19.13 | 19.00 | 26.49 | 11.86 | 11.0 | 6.90 | 1.03 |
| 7143500 | 24.51 | 25.00 | 27.73 | 10.59 | 13.1 | 6.04 | 0.83 |
| 7143600 | 71.96 | 71.00 | 27.92 | 19.29 | 8.8 | 10.24 | 0.84 |
| 7144850 | 21.59 | 21.00 | 25.24 | 13.31 | 10.7 | 7.50 | 2.01 |
| 7144900 | 1.59 | 1.48 | 25.67 | 2.65 | 23.7 | 1.99 | 2.09 |
| 7145300 | 5.24 | 5.03 | 30.42 | 5.49 | 18.3 | 3.51 | 1.17 |
| 7148700 | 5.03 | 5.31 | 25.50 | 3.95 | 65.2 | 1.85 | 2.49 |

Note: DA = drainage area, CDA = contributing drainage area, MAP = mean annual precipitation, L = main-channel length, Tc = time of concentration, SP = generalized soil permeability

## TABLE A.2
## Watershed Characteristics (Continued)

| Station number | DA (mi$^2$) | CDA (mi$^2$) | MAP (in.) | L (mi) | Sl (ft/mi) | $T_c$ (hr) | SP (in./hr) |
|---|---|---|---|---|---|---|---|
| 7148800 | 2.15 | 2.04 | 26.38 | 3.35 | 35.9 | 2.02 | 1.35 |
| 7150580 | 7.24 | 7.21 | 30.64 | 8.22 | 15.6 | 4.83 | 0.38 |
| 7151600 | 11.89 | 12.00 | 28.64 | 11.39 | 20.3 | 5.48 | 1.88 |
| 7152520 | 0.92 | 0.97 | 31.71 | 2.33 | 30.2 | 1.69 | 0.37 |
| 7155100 | 10.58 | 11.00 | 16.01 | 11.66 | 27.3 | 5.05 | 1.28 |
| 7155900 | 50.00 | 10.00 | 16.44 | 24.42 | 16.1 | 9.79 | 1.10 |
| 7156600 | 19.68 | 8.00 | 18.16 | 11.56 | 23.6 | 5.27 | 2.03 |
| 7156700 | 3.03 | 2.41 | 18.96 | 4.82 | 32.8 | 2.65 | 3.12 |
| 7157100 | 54.42 | 44.00 | 19.97 | 18.94 | 12.8 | 8.92 | 0.92 |
| 7157400 | 8.46 | 6.57 | 20.99 | 9.69 | 31.7 | 4.25 | 0.95 |
| 7157550 | 4.46 | 4.22 | 21.98 | 5.15 | 55.8 | 2.32 | 4.68 |
| 7157700 | 34.35 | 34.00 | 22.40 | 21.52 | 26.6 | 7.63 | 1.56 |
| 7157900 | 41.72 | 39.00 | 24.20 | 17.96 | 11.4 | 8.96 | 2.67 |
| 7158020 | 4.13 | 4.26 | 26.15 | 5.99 | 37.1 | 2.94 | 1.58 |
| 7158080 | 1.76 | 1.61 | 25.96 | 2.54 | 63.3 | 1.40 | 1.12 |
| 7158180 | 8.33 | 8.23 | 28.51 | 10.36 | 15.5 | 5.63 | 0.54 |
| 7158500 | 13.80 | 14.50 | 30.36 | 10.58 | 14.7 | 5.81 | 6.33 |
| 7158550 | 4.92 | 5.08 | 28.94 | 6.67 | 14.9 | 4.26 | 1.04 |
| 7160350 | 67.92 | 70.30 | 30.48 | 18.70 | 13.1 | 8.78 | 2.36 |
| 7226200 | 34.18 | 34.00 | 15.97 | 18.74 | 49.0 | 5.69 | 1.17 |
| 7226300 | 96.96 | 68.00 | 16.00 | 25.92 | 28.5 | 8.44 | 0.81 |
| 7227295 | 1.35 | 1.35 | 15.98 | 2.58 | 51.5 | 1.51 | 1.83 |
| 7227300 | 51.38 | 51.38 | 15.98 | 24.85 | 29.2 | 8.14 | 1.45 |
| 7227460 | 1.61 | 1.60 | 17.19 | 2.71 | 89.7 | 1.30 | 2.71 |
| 7228290 | 9.08 | 10.40 | 27.67 | 7.20 | 38.2 | 3.29 | 0.96 |
| 7228450 | 2.23 | 2.31 | 29.36 | 3.74 | 54.2 | 1.90 | 1.07 |
| 7232650 | 33.10 | 31.00 | 16.01 | 20.80 | 18.9 | 8.36 | 1.21 |
| 7234050 | 4.16 | 4.22 | 20.33 | 4.95 | 25.6 | 2.93 | 0.96 |
| 7234290 | 8.59 | 8.57 | 22.45 | 4.90 | 33.9 | 2.65 | 4.84 |
| 7235700 | 17.54 | 17.80 | 23.12 | 9.26 | 22.7 | 4.61 | 1.30 |
| 7237750 | 11.63 | 11.50 | 25.01 | 7.90 | 54.2 | 3.11 | 2.23 |
| 7239050 | 0.53 | 0.52 | 27.99 | 1.39 | 92.2 | 0.83 | 2.35 |
| 7321500 | 0.67 | 0.62 | 25.32 | 1.77 | 92.4 | 0.97 | 0.79 |

Note: DA = drainage area, CDA = contributing drainage area, MAP = mean annual precipitation, L = main-channel length, Tc = time of concentration, SP = generalized soil permeability

## TABLE A.3
## Representative Rainfall Intensities

| Station number | $i_2$ (in./hr) | $i_5$ (in./hr) | $i_{10}$ (in./hr) | $i_{25}$ (in./hr) | $i_{50}$ (in./hr) | $i_{100}$ (in./hr) |
|---|---|---|---|---|---|---|
| 06687600 | 0.20 | 0.27 | 0.32 | 0.38 | 0.42 | 0.48 |
| 06759700 | 0.45 | 0.62 | 0.74 | 0.89 | 1.01 | 1.13 |
| 06759900 | 0.41 | 0.58 | 0.68 | 0.84 | 0.93 | 1.05 |
| 06760200 | 0.60 | 0.86 | 1.03 | 1.28 | 1.45 | 1.64 |
| 06760430 | 0.27 | 0.34 | 0.38 | 0.45 | 0.51 | 0.55 |
| 06763200 | 0.25 | 0.34 | 0.42 | 0.49 | 0.54 | 0.65 |
| 06767200 | 0.75 | 1.00 | 1.20 | 1.43 | 1.61 | 1.81 |
| 06768050 | 1.03 | 1.38 | 1.63 | 1.95 | 2.20 | 2.45 |
| 06768100 | 0.49 | 0.65 | 0.77 | 0.90 | 1.05 | 1.16 |
| 06768200 | 0.31 | 0.42 | 0.49 | 0.55 | 0.66 | 0.71 |
| 06768300 | 0.66 | 0.88 | 1.04 | 1.24 | 1.41 | 1.59 |
| 06768400 | 0.33 | 0.43 | 0.52 | 0.57 | 0.69 | 0.74 |
| 06768500 | 0.19 | 0.26 | 0.31 | 0.36 | 0.39 | 0.45 |
| 06769100 | 1.40 | 1.85 | 2.17 | 2.60 | 2.93 | 3.27 |
| 06769200 | 0.38 | 0.50 | 0.59 | 0.67 | 0.80 | 0.87 |
| 06769300 | 0.57 | 0.76 | 0.89 | 1.06 | 1.21 | 1.37 |
| 06769500 | 0.29 | 0.38 | 0.45 | 0.51 | 0.60 | 0.65 |
| 06770600 | 0.82 | 1.09 | 1.31 | 1.56 | 1.74 | 1.96 |
| 06770700 | 0.29 | 0.38 | 0.45 | 0.51 | 0.60 | 0.65 |
| 06770800 | 0.27 | 0.37 | 0.44 | 0.49 | 0.58 | 0.63 |
| 06770900 | 0.22 | 0.30 | 0.36 | 0.41 | 0.46 | 0.52 |
| 06770910 | 0.15 | 0.21 | 0.25 | 0.29 | 0.31 | 0.36 |
| 06782800 | 0.44 | 0.59 | 0.69 | 0.80 | 0.94 | 1.04 |
| 06782900 | 0.67 | 0.90 | 1.06 | 1.26 | 1.43 | 1.61 |
| 06784700 | 0.24 | 0.31 | 0.37 | 0.43 | 0.48 | 0.54 |
| 06784800 | 0.15 | 0.20 | 0.24 | 0.29 | 0.31 | 0.36 |
| 06789200 | 0.53 | 0.70 | 0.82 | 0.96 | 1.10 | 1.23 |
| 06789300 | 0.36 | 0.47 | 0.56 | 0.63 | 0.75 | 0.81 |
| 06789400 | 0.23 | 0.31 | 0.36 | 0.42 | 0.47 | 0.53 |
| 06789500 | 0.15 | 0.19 | 0.23 | 0.27 | 0.30 | 0.34 |
| 06790900 | 0.56 | 0.74 | 0.87 | 1.02 | 1.15 | 1.30 |
| 06821300 | 0.34 | 0.46 | 0.54 | 0.66 | 0.74 | 0.84 |
| 06821400 | 0.43 | 0.56 | 0.66 | 0.79 | 0.89 | 1.00 |
| 06822600 | 0.49 | 0.68 | 0.82 | 0.98 | 1.12 | 1.25 |
| 06826900 | 0.36 | 0.49 | 0.59 | 0.74 | 0.83 | 0.92 |
| 06828100 | 0.83 | 1.13 | 1.37 | 1.62 | 1.79 | 2.05 |
| 06829700 | 0.50 | 0.68 | 0.80 | 0.95 | 1.10 | 1.24 |
| 06834200 | 0.19 | 0.25 | 0.29 | 0.34 | 0.38 | 0.42 |
| 06835100 | 0.30 | 0.42 | 0.49 | 0.56 | 0.66 | 0.73 |
| 06838200 | 0.14 | 0.19 | 0.23 | 0.27 | 0.30 | 0.34 |
| 06838550 | 0.19 | 0.26 | 0.31 | 0.36 | 0.40 | 0.46 |
| 06839200 | 0.68 | 0.91 | 1.10 | 1.30 | 1.46 | 1.66 |

## TABLE A.3
## Representative Rainfall Intensities (Continued)

| Station number | $i_2$ (in./hr) | $i_5$ (in./hr) | $i_{10}$ (in./hr) | $i_{25}$ (in./hr) | $i_{50}$ (in./hr) | $i_{100}$ (in./hr) |
|---|---|---|---|---|---|---|
| 06839400 | 0.38 | 0.52 | 0.62 | 0.71 | 0.84 | 0.92 |
| 06839600 | 0.52 | 0.70 | 0.82 | 0.98 | 1.13 | 1.27 |
| 06839850 | 0.51 | 0.69 | 0.80 | 0.96 | 1.11 | 1.25 |
| 06839900 | 0.29 | 0.39 | 0.47 | 0.52 | 0.63 | 0.67 |
| 06839950 | 0.25 | 0.34 | 0.40 | 0.45 | 0.53 | 0.58 |
| 06840000 | 0.17 | 0.23 | 0.28 | 0.33 | 0.36 | 0.41 |
| 06840500 | 0.31 | 0.42 | 0.49 | 0.55 | 0.66 | 0.71 |
| 06841500 | 0.16 | 0.22 | 0.26 | 0.30 | 0.33 | 0.38 |
| 06844210 | 0.13 | 0.18 | 0.21 | 0.25 | 0.27 | 0.31 |
| 06844700 | 0.14 | 0.19 | 0.22 | 0.26 | 0.29 | 0.34 |
| 06844800 | 0.26 | 0.35 | 0.42 | 0.49 | 0.56 | 0.63 |
| 06845100 | 0.24 | 0.32 | 0.38 | 0.44 | 0.50 | 0.56 |
| 06845900 | 0.54 | 0.73 | 0.87 | 1.04 | 1.18 | 1.35 |
| 06846200 | 0.48 | 0.64 | 0.76 | 0.90 | 1.03 | 1.17 |
| 06847600 | 0.42 | 0.56 | 0.67 | 0.78 | 0.90 | 1.01 |
| 06848200 | 1.16 | 1.54 | 1.82 | 2.16 | 2.43 | 2.72 |
| 06850200 | 0.35 | 0.46 | 0.54 | 0.62 | 0.73 | 0.79 |
| 06851100 | 0.21 | 0.29 | 0.34 | 0.40 | 0.44 | 0.50 |
| 06851300 | 0.34 | 0.45 | 0.53 | 0.61 | 0.72 | 0.77 |
| 06852000 | 0.18 | 0.24 | 0.28 | 0.33 | 0.36 | 0.42 |
| 06853100 | 1.20 | 1.58 | 1.85 | 2.19 | 2.47 | 2.75 |
| 06855900 | 0.25 | 0.33 | 0.38 | 0.45 | 0.51 | 0.57 |
| 06856100 | 0.18 | 0.24 | 0.28 | 0.34 | 0.37 | 0.42 |
| 06858700 | 1.27 | 1.71 | 2.01 | 2.42 | 2.73 | 3.06 |
| 06860300 | 0.14 | 0.19 | 0.22 | 0.26 | 0.29 | 0.33 |
| 06863400 | 0.44 | 0.59 | 0.69 | 0.81 | 0.94 | 1.04 |
| 06863700 | 0.42 | 0.56 | 0.66 | 0.76 | 0.88 | 0.98 |
| 06863900 | 0.17 | 0.23 | 0.28 | 0.33 | 0.36 | 0.41 |
| 06864300 | 0.65 | 0.87 | 1.02 | 1.19 | 1.35 | 1.52 |
| 06864700 | 0.45 | 0.60 | 0.70 | 0.82 | 0.94 | 1.05 |
| 06866800 | 0.74 | 0.99 | 1.18 | 1.39 | 1.56 | 1.77 |
| 06867800 | 1.79 | 2.32 | 2.68 | 3.20 | 3.60 | 3.99 |
| 06868300 | 0.73 | 0.97 | 1.15 | 1.34 | 1.51 | 1.70 |
| 06868700 | 0.29 | 0.39 | 0.45 | 0.53 | 0.61 | 0.68 |
| 06868900 | 0.69 | 0.92 | 1.08 | 1.26 | 1.42 | 1.60 |
| 06871900 | 0.21 | 0.29 | 0.34 | 0.40 | 0.44 | 0.50 |
| 06872100 | 0.17 | 0.23 | 0.27 | 0.32 | 0.35 | 0.40 |
| 06872300 | 0.19 | 0.25 | 0.30 | 0.36 | 0.39 | 0.44 |
| 06872600 | 0.55 | 0.72 | 0.85 | 1.00 | 1.13 | 1.27 |
| 06873300 | 1.28 | 1.68 | 1.97 | 2.34 | 2.64 | 2.94 |
| 06873700 | 0.24 | 0.32 | 0.38 | 0.45 | 0.50 | 0.57 |
| 06873800 | 0.99 | 1.32 | 1.56 | 1.84 | 2.07 | 2.32 |

## TABLE A.3
## Representative Rainfall Intensities (Continued)

| Station number | $i_{2}$ (in./hr) | $i_{5}$ (in./hr) | $i_{10}$ (in./hr) | $i_{25}$ (in./hr) | $i_{50}$ (in./hr) | $i_{100}$ (in./hr) |
|---|---|---|---|---|---|---|
| 06874500 | 0.26 | 0.35 | 0.41 | 0.48 | 0.54 | 0.60 |
| 06876200 | 0.46 | 0.60 | 0.70 | 0.82 | 0.93 | 1.03 |
| 06880590 | 0.37 | 0.48 | 0.56 | 0.65 | 0.76 | 0.82 |
| 06880710 | 0.24 | 0.32 | 0.38 | 0.45 | 0.49 | 0.56 |
| 06880720 | 0.23 | 0.30 | 0.36 | 0.42 | 0.47 | 0.52 |
| 06880730 | 0.33 | 0.44 | 0.51 | 0.59 | 0.68 | 0.75 |
| 06880740 | 0.17 | 0.23 | 0.27 | 0.32 | 0.35 | 0.39 |
| 06880775 | 0.59 | 0.78 | 0.91 | 1.06 | 1.20 | 1.35 |
| 06883600 | 0.26 | 0.34 | 0.40 | 0.47 | 0.52 | 0.59 |
| 06883700 | 0.18 | 0.24 | 0.28 | 0.33 | 0.36 | 0.41 |
| 06883800 | 0.14 | 0.19 | 0.23 | 0.27 | 0.30 | 0.33 |
| 07126325 | 0.25 | 0.34 | 0.40 | 0.48 | 0.54 | 0.61 |
| 07126390 | 0.25 | 0.34 | 0.41 | 0.49 | 0.56 | 0.63 |
| 07126415 | 0.29 | 0.40 | 0.48 | 0.59 | 0.67 | 0.75 |
| 07126480 | 0.22 | 0.30 | 0.36 | 0.44 | 0.50 | 0.56 |
| 07133200 | 1.00 | 1.37 | 1.64 | 1.99 | 2.25 | 2.54 |
| 07138600 | 0.22 | 0.29 | 0.35 | 0.41 | 0.46 | 0.52 |
| 07138800 | 0.29 | 0.40 | 0.47 | 0.55 | 0.63 | 0.70 |
| 07139700 | 0.37 | 0.50 | 0.60 | 0.70 | 0.80 | 0.89 |
| 07139800 | 0.17 | 0.23 | 0.28 | 0.33 | 0.37 | 0.42 |
| 07140300 | 0.30 | 0.41 | 0.48 | 0.57 | 0.65 | 0.72 |
| 07140600 | 0.25 | 0.34 | 0.40 | 0.47 | 0.53 | 0.60 |
| 07140700 | 0.16 | 0.22 | 0.26 | 0.31 | 0.34 | 0.39 |
| 07141400 | 0.67 | 0.89 | 1.06 | 1.25 | 1.42 | 1.60 |
| 07141600 | 0.20 | 0.27 | 0.32 | 0.39 | 0.43 | 0.49 |
| 07141800 | 0.31 | 0.42 | 0.50 | 0.58 | 0.67 | 0.75 |
| 07142100 | 0.34 | 0.46 | 0.54 | 0.64 | 0.74 | 0.82 |
| 07142500 | 0.20 | 0.28 | 0.33 | 0.39 | 0.43 | 0.49 |
| 07142700 | 0.18 | 0.24 | 0.28 | 0.33 | 0.37 | 0.42 |
| 07142860 | 0.23 | 0.31 | 0.36 | 0.43 | 0.48 | 0.55 |
| 07142900 | 0.22 | 0.30 | 0.36 | 0.42 | 0.47 | 0.54 |
| 07143100 | 0.80 | 1.07 | 1.26 | 1.48 | 1.67 | 1.87 |
| 07143200 | 0.33 | 0.43 | 0.51 | 0.59 | 0.68 | 0.76 |
| 07143500 | 0.37 | 0.49 | 0.57 | 0.66 | 0.77 | 0.85 |
| 07143600 | 0.23 | 0.31 | 0.37 | 0.43 | 0.48 | 0.54 |
| 07144850 | 0.31 | 0.41 | 0.48 | 0.57 | 0.65 | 0.72 |
| 07144900 | 0.94 | 1.25 | 1.49 | 1.74 | 1.99 | 2.21 |
| 07145300 | 0.61 | 0.84 | 0.98 | 1.15 | 1.29 | 1.46 |
| 07148700 | 0.98 | 1.30 | 1.54 | 1.81 | 2.06 | 2.31 |
| 07148800 | 0.95 | 1.25 | 1.48 | 1.74 | 1.98 | 2.22 |
| 07150580 | 0.49 | 0.68 | 0.80 | 0.92 | 1.03 | 1.17 |
| 07151600 | 0.43 | 0.58 | 0.68 | 0.78 | 0.89 | 1.00 |

## TABLE A.3
## Representative Rainfall Intensities (Continued)

| Station number | $i_2$ (in./hr) | $i_5$ (in./hr) | $i_{10}$ (in./hr) | $i_{25}$ (in./hr) | $i_{50}$ (in./hr) | $i_{100}$ (in./hr) |
|---|---|---|---|---|---|---|
| 07152520 | 1.19 | 1.52 | 1.79 | 2.10 | 2.38 | 2.66 |
| 07155100 | 0.33 | 0.45 | 0.53 | 0.62 | 0.70 | 0.78 |
| 07155900 | 0.21 | 0.28 | 0.33 | 0.39 | 0.43 | 0.50 |
| 07156600 | 0.36 | 0.49 | 0.58 | 0.68 | 0.78 | 0.86 |
| 07156700 | 0.66 | 0.88 | 1.05 | 1.23 | 1.40 | 1.57 |
| 07157100 | 0.23 | 0.31 | 0.37 | 0.43 | 0.49 | 0.55 |
| 07157400 | 0.45 | 0.61 | 0.72 | 0.85 | 0.97 | 1.09 |
| 07157550 | 0.77 | 1.04 | 1.24 | 1.45 | 1.65 | 1.84 |
| 07157700 | 0.28 | 0.38 | 0.44 | 0.52 | 0.59 | 0.66 |
| 07157900 | 0.25 | 0.34 | 0.40 | 0.48 | 0.54 | 0.60 |
| 07158020 | 0.69 | 0.96 | 1.12 | 1.32 | 1.50 | 1.69 |
| 07158080 | 1.27 | 1.66 | 1.94 | 2.30 | 2.60 | 2.90 |
| 07158180 | 0.43 | 0.59 | 0.70 | 0.81 | 0.91 | 1.03 |
| 07158500 | 0.42 | 0.58 | 0.68 | 0.80 | 0.89 | 1.01 |
| 07158550 | 0.53 | 0.74 | 0.87 | 1.01 | 1.13 | 1.29 |
| 07160350 | 0.29 | 0.40 | 0.46 | 0.54 | 0.60 | 0.68 |
| 07226200 | 0.28 | 0.37 | 0.43 | 0.53 | 0.61 | 0.69 |
| 07226300 | 0.19 | 0.25 | 0.29 | 0.35 | 0.41 | 0.46 |
| 07227295 | 0.91 | 1.19 | 1.41 | 1.72 | 1.96 | 2.21 |
| 07227300 | 0.22 | 0.29 | 0.34 | 0.42 | 0.48 | 0.54 |
| 07227460 | 1.16 | 1.56 | 1.80 | 2.17 | 2.45 | 2.72 |
| 07228290 | 0.62 | 0.87 | 1.02 | 1.21 | 1.37 | 1.54 |
| 07228450 | 1.05 | 1.38 | 1.63 | 1.92 | 2.19 | 2.47 |
| 07232650 | 0.21 | 0.29 | 0.35 | 0.41 | 0.45 | 0.52 |
| 07234050 | 0.62 | 0.83 | 0.99 | 1.16 | 1.32 | 1.49 |
| 07234290 | 0.69 | 0.94 | 1.11 | 1.31 | 1.49 | 1.67 |
| 07235700 | 0.45 | 0.61 | 0.72 | 0.84 | 0.96 | 1.07 |
| 07237750 | 0.63 | 0.87 | 1.02 | 1.21 | 1.38 | 1.55 |
| 07239050 | 1.91 | 2.44 | 2.81 | 3.33 | 3.74 | 4.14 |
| 07321500 | 1.63 | 2.13 | 2.47 | 2.96 | 3.33 | 3.71 |

## TABLE A.4
## Flood Quantiles from Frequency Analyses for Individual Stations

| Station number | $Q_2$ (cfs) | $Q_5$ (cfs) | $Q_{10}$ (cfs) | $Q_{25}$ (cfs) | $Q_{50}$ (cfs) | $Q_{100}$ (cfs) |
|---|---|---|---|---|---|---|
| 06687600 | 28 | 240 | 715 | 2250 | 4670 | 8944 |
| 06759700 | 85 | 316 | 630 | 1320 | 2134 | 3292 |
| 06759900 | 23 | 52 | 82 | 138 | 195 | 270 |
| 06760200 | 12 | 33 | 58 | 109 | 166 | 247 |
| 06760430 | 29 | 117 | 252 | 589 | 1035 | 1740 |
| 06763200 | 286 | 616 | 916 | 1393 | 1821 | 2314 |
| 06767200 | 23 | 70 | 125 | 229 | 336 | 473 |
| 06768050 | 14 | 65 | 141 | 307 | 496 | 753 |
| 06768100 | 11 | 69 | 163 | 382 | 638 | 990 |
| 06768200 | 101 | 283 | 472 | 796 | 1104 | 1469 |
| 06768300 | 23 | 103 | 208 | 421 | 646 | 933 |
| 06768400 | 29 | 121 | 244 | 492 | 758 | 1102 |
| 06768500 | 219 | 704 | 1265 | 2321 | 3403 | 4769 |
| 06769100 | 48 | 113 | 168 | 249 | 316 | 387 |
| 06769200 | 38 | 182 | 386 | 819 | 1298 | 1933 |
| 06769300 | 156 | 332 | 475 | 677 | 838 | 1007 |
| 06769500 | 271 | 1532 | 3570 | 8419 | 14306 | 22687 |
| 06770600 | 7 | 40 | 90 | 200 | 323 | 487 |
| 06770700 | 20 | 77 | 146 | 275 | 404 | 563 |
| 06770800 | 109 | 437 | 843 | 1620 | 2406 | 3377 |
| 06770900 | 109 | 437 | 843 | 1619 | 2404 | 3373 |
| 06770910 | 190 | 602 | 1049 | 1831 | 2576 | 3459 |
| 06782800 | 57 | 372 | 921 | 2286 | 3987 | 6441 |
| 06782900 | 39 | 234 | 566 | 1386 | 2416 | 3920 |
| 06784700 | 231 | 1135 | 2406 | 5057 | 7918 | 11612 |
| 06784800 | 764 | 1392 | 1857 | 2481 | 2961 | 3450 |
| 06789200 | 120 | 467 | 904 | 1767 | 2674 | 3833 |
| 06789300 | 449 | 1241 | 2016 | 3265 | 4377 | 5628 |
| 06789400 | 217 | 822 | 1563 | 2979 | 4424 | 6227 |
| 06789500 | 741 | 1200 | 1517 | 1923 | 2226 | 2527 |
| 06790900 | 221 | 695 | 1237 | 2244 | 3266 | 4547 |
| 06821300 | 84 | 460 | 1060 | 2486 | 4225 | 6716 |
| 06821400 | 254 | 749 | 1343 | 2534 | 3848 | 5629 |
| 06822600 | 19 | 124 | 339 | 1005 | 2045 | 3896 |
| 06826900 | 58 | 367 | 975 | 2787 | 5518 | 10229 |
| 06828100 | 412 | 1426 | 2731 | 5459 | 8541 | 12775 |
| 06829700 | 290 | 698 | 1099 | 1781 | 2428 | 3206 |
| 06834200 | 35 | 160 | 358 | 845 | 1471 | 2422 |
| 06835100 | 418 | 1548 | 3069 | 6370 | 10208 | 15604 |
| 06838200 | 78 | 292 | 562 | 1103 | 1682 | 2435 |
| 06838550 | 53 | 274 | 623 | 1450 | 2463 | 3926 |
| 06839200 | 204 | 643 | 1169 | 2201 | 3306 | 4762 |

## TABLE A.4
## Flood Quantiles from Frequency Analyses for Individual Stations (Continued)

| Station number | $Q_{2}$ (cfs) | $Q_{5}$ (cfs) | $Q_{10}$ (cfs) | $Q_{25}$ (cfs) | $Q_{50}$ (cfs) | $Q_{100}$ (cfs) |
|---|---|---|---|---|---|---|
| 06839400 | 504 | 1802 | 3481 | 6985 | 10919 | 16286 |
| 06839600 | 729 | 2332 | 4258 | 8059 | 12140 | 17522 |
| 06839850 | 113 | 678 | 1649 | 4116 | 7297 | 12066 |
| 06839900 | 239 | 789 | 1424 | 2610 | 3810 | 5309 |
| 06839950 | 345 | 650 | 901 | 1270 | 1583 | 1926 |
| 06840000 | 387 | 1160 | 1993 | 3466 | 4892 | 6613 |
| 06840500 | 905 | 2800 | 5039 | 9408 | 14067 | 20184 |
| 06841500 | 486 | 1592 | 2892 | 5374 | 7943 | 11218 |
| 06844210 | 322 | 707 | 1041 | 1543 | 1970 | 2438 |
| 06844700 | 51 | 380 | 1004 | 2668 | 4864 | 8176 |
| 06844800 | 55 | 384 | 988 | 2570 | 4631 | 7719 |
| 06845100 | 238 | 586 | 922 | 1477 | 1988 | 2586 |
| 06845900 | 140 | 475 | 860 | 1565 | 2262 | 3114 |
| 06846200 | 200 | 725 | 1350 | 2523 | 3703 | 5159 |
| 06847600 | 183 | 475 | 755 | 1206 | 1609 | 2066 |
| 06848200 | 184 | 365 | 508 | 709 | 869 | 1036 |
| 06850200 | 218 | 480 | 703 | 1033 | 1309 | 1608 |
| 06851100 | 154 | 460 | 776 | 1313 | 1809 | 2386 |
| 06851300 | 212 | 472 | 697 | 1033 | 1316 | 1625 |
| 06852000 | 1097 | 2432 | 3714 | 5864 | 7900 | 10350 |
| 06853100 | 192 | 433 | 656 | 1014 | 1338 | 1713 |
| 06855900 | 910 | 1771 | 2494 | 3577 | 4504 | 5532 |
| 06856100 | 737 | 2145 | 3764 | 6874 | 10159 | 14452 |
| 06858700 | 247 | 505 | 712 | 1005 | 1243 | 1492 |
| 06860300 | 295 | 978 | 1770 | 3255 | 4762 | 6648 |
| 06863400 | 107 | 631 | 1478 | 3459 | 5809 | 9077 |
| 06863700 | 60 | 196 | 354 | 655 | 965 | 1358 |
| 06863900 | 297 | 1751 | 4238 | 10537 | 18655 | 30829 |
| 06864300 | 195 | 580 | 990 | 1704 | 2388 | 3206 |
| 06864700 | 390 | 1306 | 2353 | 4274 | 6180 | 8514 |
| 06866800 | 163 | 559 | 1026 | 1909 | 2809 | 3938 |
| 06867800 | 116 | 253 | 367 | 534 | 672 | 820 |
| 06868300 | 308 | 983 | 1748 | 3162 | 4582 | 6347 |
| 06868700 | 344 | 1087 | 1938 | 3531 | 5156 | 7201 |
| 06868900 | 95 | 226 | 347 | 542 | 716 | 915 |
| 06871900 | 1205 | 3429 | 5787 | 9939 | 13964 | 18844 |
| 06872100 | 561 | 1641 | 2860 | 5148 | 7509 | 10529 |
| 06872300 | 767 | 1384 | 1870 | 2564 | 3134 | 3747 |
| 06872600 | 94 | 267 | 459 | 815 | 1177 | 1636 |
| 06873300 | 28 | 131 | 282 | 619 | 1012 | 1557 |
| 06873700 | 181 | 1147 | 2899 | 7580 | 13888 | 23701 |
| 06873800 | 209 | 581 | 961 | 1608 | 2214 | 2928 |

## TABLE A.4
## Flood Quantiles from Frequency Analyses for Individual Stations (Continued)

| Station number | $Q_2$ (cfs) | $Q_5$ (cfs) | $Q_{10}$ (cfs) | $Q_{25}$ (cfs) | $Q_{50}$ (cfs) | $Q_{100}$ (cfs) |
|---|---|---|---|---|---|---|
| 06874500 | 606 | 1313 | 1933 | 2885 | 3710 | 4632 |
| 06876200 | 535 | 1274 | 1990 | 3187 | 4308 | 5638 |
| 06880590 | 258 | 624 | 968 | 1523 | 2023 | 2598 |
| 06880710 | 34 | 221 | 566 | 1510 | 2806 | 4856 |
| 06880720 | 264 | 769 | 1320 | 2314 | 3298 | 4512 |
| 06880730 | 175 | 361 | 524 | 777 | 1000 | 1253 |
| 06880740 | 515 | 1328 | 2143 | 3526 | 4831 | 6384 |
| 06880775 | 19 | 35 | 49 | 68 | 83 | 100 |
| 06883600 | 80 | 333 | 686 | 1457 | 2350 | 3589 |
| 06883700 | 242 | 737 | 1300 | 2358 | 3446 | 4829 |
| 06883800 | 322 | 1001 | 1779 | 3241 | 4739 | 6637 |
| 07126325 | 191 | 888 | 1855 | 3867 | 6051 | 8893 |
| 07126390 | 70 | 502 | 1235 | 2934 | 4885 | 7483 |
| 07126415 | 328 | 1055 | 1869 | 3345 | 4797 | 6569 |
| 07126480 | 139 | 551 | 1095 | 2220 | 3457 | 5105 |
| 07133200 | 103 | 588 | 1490 | 4077 | 7880 | 14336 |
| 07138600 | 29 | 125 | 249 | 497 | 755 | 1080 |
| 07138800 | 91 | 182 | 252 | 345 | 416 | 488 |
| 07139700 | 143 | 485 | 853 | 1478 | 2050 | 2702 |
| 07139800 | 90 | 588 | 1429 | 3443 | 5861 | 9236 |
| 07140300 | 182 | 708 | 1384 | 2743 | 4199 | 6092 |
| 07140600 | 258 | 740 | 1234 | 2064 | 2833 | 3727 |
| 07140700 | 427 | 1246 | 2103 | 3575 | 4965 | 6608 |
| 07141400 | 56 | 108 | 147 | 199 | 238 | 277 |
| 07141600 | 63 | 440 | 1116 | 2831 | 4999 | 8162 |
| 07141800 | 396 | 949 | 1456 | 2249 | 2945 | 3724 |
| 07142100 | 380 | 1190 | 2033 | 3447 | 4736 | 6208 |
| 07142500 | 306 | 1171 | 2257 | 4388 | 6618 | 9462 |
| 07142700 | 1152 | 2158 | 2950 | 4068 | 4976 | 5940 |
| 07142860 | 514 | 1682 | 3019 | 5488 | 7960 | 11020 |
| 07142900 | 955 | 2302 | 3550 | 5523 | 7268 | 9238 |
| 07143100 | 88 | 191 | 278 | 405 | 511 | 623 |
| 07143200 | 574 | 1200 | 1744 | 2579 | 3305 | 4120 |
| 07143500 | 956 | 1318 | 1543 | 1811 | 2000 | 2182 |
| 07143600 | 1167 | 2306 | 3277 | 4748 | 6021 | 7446 |
| 07144850 | 670 | 1568 | 2377 | 3626 | 4710 | 5914 |
| 07144900 | 331 | 712 | 1021 | 1458 | 1808 | 2171 |
| 07145300 | 598 | 1073 | 1421 | 1884 | 2238 | 2597 |
| 07148700 | 272 | 938 | 1699 | 3079 | 4427 | 6055 |
| 07148800 | 135 | 507 | 948 | 1757 | 2549 | 3501 |
| 07150580 | 446 | 1230 | 2210 | 4304 | 6782 | 10374 |
| 07151600 | 1197 | 2276 | 3108 | 4258 | 5168 | 6114 |

## TABLE A.4
## Flood Quantiles from Frequency Analyses for Individual Stations (Continued)

| Station number | $Q_2$ (cfs) | $Q_5$ (cfs) | $Q_{10}$ (cfs) | $Q_{25}$ (cfs) | $Q_{50}$ (cfs) | $Q_{100}$ (cfs) |
|---|---|---|---|---|---|---|
| 07152520 | 78 | 305 | 618 | 1306 | 2110 | 3243 |
| 07155100 | 76 | 393 | 966 | 2598 | 5003 | 9126 |
| 07155900 | 63 | 719 | 2203 | 6499 | 12320 | 21076 |
| 07156600 | 466 | 1395 | 2307 | 3754 | 5008 | 6381 |
| 07156700 | 107 | 450 | 873 | 1659 | 2430 | 3349 |
| 07157100 | 365 | 1874 | 4024 | 8508 | 13325 | 19500 |
| 07157400 | 295 | 1287 | 2572 | 5084 | 7659 | 10857 |
| 07157550 | 91 | 287 | 497 | 860 | 1204 | 1609 |
| 07157700 | 358 | 675 | 913 | 1233 | 1479 | 1730 |
| 07157900 | 394 | 1121 | 1859 | 3093 | 4228 | 5542 |
| 07158020 | 540 | 773 | 922 | 1104 | 1235 | 1362 |
| 07158080 | 162 | 406 | 646 | 1051 | 1431 | 1881 |
| 07158180 | 700 | 2172 | 3966 | 7597 | 11612 | 17058 |
| 07158500 | 177 | 702 | 1445 | 3121 | 5134 | 8032 |
| 07158550 | 338 | 995 | 1769 | 3296 | 4948 | 7154 |
| 07160350 | 3291 | 5444 | 7139 | 9591 | 11646 | 13900 |
| 07226200 | 648 | 2126 | 3974 | 7769 | 12001 | 17768 |
| 07226300 | 425 | 808 | 1082 | 1433 | 1689 | 1939 |
| 07227295 | 44 | 121 | 202 | 349 | 493 | 671 |
| 07227300 | 132 | 866 | 2198 | 5717 | 10385 | 17523 |
| 07227460 | 96 | 449 | 1037 | 2591 | 4743 | 8242 |
| 07228290 | 738 | 2240 | 3921 | 7019 | 10141 | 14043 |
| 07228450 | 298 | 534 | 748 | 1099 | 1428 | 1825 |
| 07232650 | 125 | 649 | 1565 | 4055 | 7558 | 13298 |
| 07234050 | 43 | 286 | 737 | 1967 | 3647 | 6290 |
| 07234290 | 168 | 443 | 747 | 1317 | 1911 | 2682 |
| 07235700 | 451 | 1508 | 2731 | 5012 | 7312 | 10174 |
| 07237750 | 451 | 1007 | 1484 | 2190 | 2779 | 3415 |
| 07239050 | 97 | 218 | 343 | 571 | 804 | 1104 |
| 07321500 | 359 | 728 | 1061 | 1596 | 2085 | 2656 |

## TABLE A.5
## Rational Runoff Coefficients from Frequency Analyses for Individual Stations

| Station number | C2 (cfs) | C5 (cfs) | C10 (cfs) | C25 (cfs) | C50 (cfs) | C100 (cfs) |
|---|---|---|---|---|---|---|
| 06687600 | 0.00 | 0.03 | 0.07 | 0.19 | 0.35 | 0.59 |
| 06759700 | 0.08 | 0.22 | 0.37 | 0.64 | 0.91 | 1.25 |
| 06759900 | 0.02 | 0.03 | 0.04 | 0.05 | 0.06 | 0.08 |
| 06760200 | 0.02 | 0.04 | 0.06 | 0.09 | 0.11 | 0.15 |
| 06760430 | 0.01 | 0.03 | 0.06 | 0.11 | 0.18 | 0.27 |
| 06763200 | 0.09 | 0.15 | 0.18 | 0.23 | 0.27 | 0.29 |
| 06767200 | 0.03 | 0.06 | 0.09 | 0.14 | 0.19 | 0.24 |
| 06768050 | 0.01 | 0.04 | 0.06 | 0.12 | 0.17 | 0.23 |
| 06768100 | 0.01 | 0.03 | 0.06 | 0.13 | 0.18 | 0.26 |
| 06768200 | 0.02 | 0.03 | 0.05 | 0.07 | 0.09 | 0.11 |
| 06768300 | 0.03 | 0.10 | 0.16 | 0.28 | 0.37 | 0.48 |
| 06768400 | 0.01 | 0.03 | 0.04 | 0.08 | 0.10 | 0.14 |
| 06768500 | 0.03 | 0.07 | 0.10 | 0.16 | 0.21 | 0.26 |
| 06769100 | 0.09 | 0.16 | 0.20 | 0.25 | 0.28 | 0.31 |
| 06769200 | 0.01 | 0.04 | 0.07 | 0.13 | 0.17 | 0.23 |
| 06769300 | 0.07 | 0.12 | 0.14 | 0.17 | 0.19 | 0.20 |
| 06769500 | 0.05 | 0.19 | 0.38 | 0.79 | 1.14 | 1.66 |
| 06770600 | 0.01 | 0.03 | 0.05 | 0.10 | 0.14 | 0.19 |
| 06770700 | 0.01 | 0.02 | 0.03 | 0.04 | 0.05 | 0.07 |
| 06770800 | 0.03 | 0.08 | 0.12 | 0.21 | 0.26 | 0.34 |
| 06770900 | 0.02 | 0.05 | 0.08 | 0.14 | 0.19 | 0.23 |
| 06770910 | 0.02 | 0.06 | 0.08 | 0.12 | 0.16 | 0.19 |
| 06782800 | 0.02 | 0.09 | 0.19 | 0.42 | 0.62 | 0.91 |
| 06782900 | 0.02 | 0.07 | 0.14 | 0.29 | 0.44 | 0.64 |
| 06784700 | 0.06 | 0.21 | 0.37 | 0.67 | 0.94 | 1.23 |
| 06784800 | 0.12 | 0.16 | 0.18 | 0.21 | 0.23 | 0.23 |
| 06789200 | 0.05 | 0.15 | 0.26 | 0.43 | 0.56 | 0.72 |
| 06789300 | 0.09 | 0.19 | 0.27 | 0.38 | 0.43 | 0.51 |
| 06789400 | 0.05 | 0.13 | 0.22 | 0.36 | 0.47 | 0.59 |
| 06789500 | 0.10 | 0.12 | 0.13 | 0.14 | 0.14 | 0.14 |
| 06790900 | 0.08 | 0.19 | 0.30 | 0.46 | 0.59 | 0.72 |
| 06821300 | 0.06 | 0.24 | 0.47 | 0.90 | 1.35 | 1.91 |
| 06821400 | 0.06 | 0.13 | 0.20 | 0.31 | 0.41 | 0.53 |
| 06822600 | 0.03 | 0.12 | 0.29 | 0.70 | 1.26 | 2.14 |
| 06826900 | 0.01 | 0.06 | 0.13 | 0.29 | 0.52 | 0.87 |
| 06828100 | 0.22 | 0.56 | 0.88 | 1.48 | 2.11 | 2.75 |
| 06829700 | 0.10 | 0.18 | 0.23 | 0.32 | 0.38 | 0.44 |
| 06834200 | 0.01 | 0.02 | 0.04 | 0.09 | 0.13 | 0.20 |
| 06835100 | 0.07 | 0.20 | 0.33 | 0.60 | 0.81 | 1.13 |
| 06838200 | 0.01 | 0.03 | 0.06 | 0.09 | 0.13 | 0.16 |
| 06838550 | 0.01 | 0.04 | 0.07 | 0.15 | 0.23 | 0.32 |
| 06839200 | 0.07 | 0.16 | 0.24 | 0.38 | 0.51 | 0.64 |

# TABLE A.5
## Rational Runoff Coefficients from Frequency Analyses for Individual Stations (Continued)

| Station number | Q2 (cfs) | Q5 (cfs) | Q10 (cfs) | Q25 (cfs) | Q50 (cfs) | Q100 (cfs) |
|---|---|---|---|---|---|---|
| 06839400 | 0.15 | 0.39 | 0.64 | 1.12 | 1.48 | 2.01 |
| 06839600 | 0.19 | 0.46 | 0.72 | 1.14 | 1.48 | 1.90 |
| 06839850 | 0.03 | 0.11 | 0.24 | 0.50 | 0.76 | 1.12 |
| 06839900 | 0.04 | 0.10 | 0.15 | 0.25 | 0.30 | 0.39 |
| 06839950 | 0.09 | 0.12 | 0.14 | 0.17 | 0.18 | 0.20 |
| 06840000 | 0.05 | 0.10 | 0.14 | 0.21 | 0.28 | 0.33 |
| 06840500 | 0.21 | 0.49 | 0.74 | 1.24 | 1.54 | 2.06 |
| 06841500 | 0.09 | 0.22 | 0.33 | 0.53 | 0.73 | 0.88 |
| 06844210 | 0.05 | 0.08 | 0.10 | 0.12 | 0.14 | 0.16 |
| 06844700 | 0.01 | 0.04 | 0.08 | 0.18 | 0.30 | 0.44 |
| 06844800 | 0.02 | 0.08 | 0.18 | 0.39 | 0.62 | 0.91 |
| 06845100 | 0.05 | 0.09 | 0.12 | 0.16 | 0.19 | 0.22 |
| 06845900 | 0.05 | 0.12 | 0.19 | 0.29 | 0.37 | 0.44 |
| 06846200 | 0.06 | 0.16 | 0.26 | 0.41 | 0.52 | 0.65 |
| 06847600 | 0.08 | 0.16 | 0.22 | 0.30 | 0.34 | 0.39 |
| 06848200 | 0.23 | 0.35 | 0.41 | 0.48 | 0.52 | 0.56 |
| 06850200 | 0.06 | 0.10 | 0.13 | 0.17 | 0.18 | 0.20 |
| 06851100 | 0.03 | 0.06 | 0.09 | 0.12 | 0.15 | 0.18 |
| 06851300 | 0.08 | 0.14 | 0.18 | 0.23 | 0.25 | 0.29 |
| 06852000 | 0.19 | 0.31 | 0.40 | 0.53 | 0.66 | 0.75 |
| 06853100 | 0.33 | 0.57 | 0.74 | 0.97 | 1.13 | 1.30 |
| 06855900 | 0.10 | 0.15 | 0.18 | 0.22 | 0.25 | 0.27 |
| 06856100 | 0.16 | 0.35 | 0.52 | 0.80 | 1.07 | 1.34 |
| 06858700 | 0.32 | 0.49 | 0.59 | 0.69 | 0.76 | 0.81 |
| 06860300 | 0.06 | 0.14 | 0.21 | 0.33 | 0.43 | 0.53 |
| 06863400 | 0.08 | 0.34 | 0.68 | 1.36 | 1.98 | 2.78 |
| 06863700 | 0.04 | 0.09 | 0.14 | 0.22 | 0.28 | 0.36 |
| 06863900 | 0.05 | 0.22 | 0.45 | 0.94 | 1.52 | 2.19 |
| 06864300 | 0.09 | 0.19 | 0.28 | 0.41 | 0.50 | 0.60 |
| 06864700 | 0.14 | 0.35 | 0.54 | 0.84 | 1.06 | 1.31 |
| 06866800 | 0.10 | 0.25 | 0.38 | 0.61 | 0.79 | 0.98 |
| 06867800 | 0.09 | 0.16 | 0.20 | 0.24 | 0.27 | 0.29 |
| 06868300 | 0.10 | 0.24 | 0.36 | 0.56 | 0.72 | 0.89 |
| 06868700 | 0.07 | 0.16 | 0.25 | 0.38 | 0.49 | 0.61 |
| 06868900 | 0.07 | 0.13 | 0.17 | 0.23 | 0.27 | 0.31 |
| 06871900 | 0.13 | 0.28 | 0.39 | 0.57 | 0.73 | 0.87 |
| 06872100 | 0.09 | 0.19 | 0.28 | 0.42 | 0.56 | 0.69 |
| 06872300 | 0.09 | 0.12 | 0.13 | 0.15 | 0.17 | 0.18 |
| 06872600 | 0.05 | 0.11 | 0.16 | 0.24 | 0.30 | 0.37 |
| 06873300 | 0.04 | 0.14 | 0.26 | 0.48 | 0.70 | 0.96 |
| 06873700 | 0.02 | 0.11 | 0.23 | 0.51 | 0.84 | 1.27 |
| 06873800 | 0.23 | 0.48 | 0.67 | 0.96 | 1.17 | 1.38 |

## TABLE A.5
## Rational Runoff Coefficients from Frequency Analyses for Individual Stations (Continued)

| Station number | Q2 (cfs) | Q5 (cfs) | Q10 (cfs) | Q25 (cfs) | Q50 (cfs) | Q100 (cfs) |
|---|---|---|---|---|---|---|
| 06874500 | 0.14 | 0.22 | 0.28 | 0.35 | 0.40 | 0.45 |
| 06876200 | 0.19 | 0.34 | 0.46 | 0.63 | 0.74 | 0.88 |
| 06880590 | 0.21 | 0.39 | 0.52 | 0.72 | 0.82 | 0.97 |
| 06880710 | 0.01 | 0.05 | 0.12 | 0.27 | 0.45 | 0.70 |
| 06880720 | 0.05 | 0.10 | 0.15 | 0.22 | 0.28 | 0.34 |
| 06880730 | 0.06 | 0.09 | 0.11 | 0.14 | 0.16 | 0.18 |
| 06880740 | 0.05 | 0.10 | 0.14 | 0.20 | 0.24 | 0.28 |
| 06880775 | 0.04 | 0.06 | 0.06 | 0.08 | 0.08 | 0.09 |
| 06883600 | 0.04 | 0.11 | 0.20 | 0.35 | 0.51 | 0.70 |
| 06883700 | 0.06 | 0.14 | 0.21 | 0.33 | 0.44 | 0.54 |
| 06883800 | 0.06 | 0.14 | 0.22 | 0.33 | 0.44 | 0.55 |
| 07126325 | 0.02 | 0.08 | 0.15 | 0.26 | 0.36 | 0.47 |
| 07126390 | 0.01 | 0.05 | 0.10 | 0.19 | 0.28 | 0.38 |
| 07126415 | 0.04 | 0.08 | 0.12 | 0.18 | 0.23 | 0.28 |
| 07126480 | 0.02 | 0.05 | 0.08 | 0.14 | 0.19 | 0.25 |
| 07133200 | 0.07 | 0.27 | 0.58 | 1.31 | 2.23 | 3.60 |
| 07138600 | 0.01 | 0.03 | 0.04 | 0.07 | 0.10 | 0.12 |
| 07138800 | 0.06 | 0.09 | 0.10 | 0.12 | 0.13 | 0.13 |
| 07139700 | 0.06 | 0.16 | 0.24 | 0.35 | 0.43 | 0.51 |
| 07139800 | 0.01 | 0.05 | 0.10 | 0.21 | 0.32 | 0.45 |
| 07140300 | 0.05 | 0.15 | 0.24 | 0.41 | 0.55 | 0.72 |
| 07140600 | 0.06 | 0.13 | 0.18 | 0.25 | 0.31 | 0.36 |
| 07140700 | 0.07 | 0.16 | 0.22 | 0.32 | 0.40 | 0.46 |
| 07141400 | 0.09 | 0.13 | 0.15 | 0.17 | 0.18 | 0.19 |
| 07141600 | 0.02 | 0.08 | 0.18 | 0.39 | 0.62 | 0.88 |
| 07141800 | 0.11 | 0.20 | 0.26 | 0.35 | 0.39 | 0.45 |
| 07142100 | 0.17 | 0.40 | 0.58 | 0.84 | 1.00 | 1.19 |
| 07142500 | 0.05 | 0.14 | 0.22 | 0.36 | 0.49 | 0.62 |
| 07142700 | 0.11 | 0.15 | 0.18 | 0.21 | 0.22 | 0.24 |
| 07142860 | 0.08 | 0.20 | 0.30 | 0.46 | 0.60 | 0.73 |
| 07142900 | 0.11 | 0.19 | 0.25 | 0.33 | 0.38 | 0.43 |
| 07143100 | 0.11 | 0.18 | 0.23 | 0.28 | 0.31 | 0.34 |
| 07143200 | 0.14 | 0.23 | 0.28 | 0.35 | 0.39 | 0.44 |
| 07143500 | 0.16 | 0.17 | 0.17 | 0.17 | 0.17 | 0.16 |
| 07143600 | 0.11 | 0.16 | 0.19 | 0.24 | 0.27 | 0.30 |
| 07144850 | 0.16 | 0.28 | 0.36 | 0.46 | 0.52 | 0.59 |
| 07144900 | 0.34 | 0.56 | 0.67 | 0.82 | 0.89 | 0.96 |
| 07145300 | 0.29 | 0.38 | 0.43 | 0.49 | 0.52 | 0.53 |
| 07148700 | 0.09 | 0.22 | 0.34 | 0.53 | 0.67 | 0.81 |
| 07148800 | 0.10 | 0.30 | 0.46 | 0.73 | 0.94 | 1.15 |
| 07150580 | 0.20 | 0.39 | 0.60 | 1.01 | 1.42 | 1.91 |
| 07151600 | 0.37 | 0.52 | 0.60 | 0.71 | 0.77 | 0.80 |

## TABLE A.5
## Rational Runoff Coefficients from Frequency Analyses for Individual Stations (Continued)

| Station number | Q2 (cfs) | Q5 (cfs) | Q10 (cfs) | Q25 (cfs) | Q50 (cfs) | Q100 (cfs) |
|---|---|---|---|---|---|---|
| 07152520 | 0.11 | 0.34 | 0.59 | 1.05 | 1.51 | 2.07 |
| 07155100 | 0.03 | 0.13 | 0.27 | 0.61 | 1.05 | 1.72 |
| 07155900 | 0.01 | 0.08 | 0.21 | 0.52 | 0.89 | 1.33 |
| 07156600 | 0.10 | 0.23 | 0.32 | 0.44 | 0.51 | 0.59 |
| 07156700 | 0.08 | 0.26 | 0.43 | 0.70 | 0.90 | 1.10 |
| 07157100 | 0.05 | 0.17 | 0.32 | 0.56 | 0.79 | 1.02 |
| 07157400 | 0.12 | 0.39 | 0.66 | 1.11 | 1.46 | 1.85 |
| 07157550 | 0.04 | 0.10 | 0.14 | 0.21 | 0.26 | 0.31 |
| 07157700 | 0.06 | 0.08 | 0.09 | 0.11 | 0.11 | 0.12 |
| 07157900 | 0.06 | 0.12 | 0.17 | 0.24 | 0.29 | 0.34 |
| 07158020 | 0.30 | 0.31 | 0.31 | 0.32 | 0.31 | 0.30 |
| 07158080 | 0.11 | 0.22 | 0.30 | 0.41 | 0.49 | 0.58 |
| 07158180 | 0.30 | 0.69 | 1.07 | 1.76 | 2.39 | 3.10 |
| 07158500 | 0.05 | 0.14 | 0.24 | 0.44 | 0.65 | 0.90 |
| 07158550 | 0.20 | 0.43 | 0.65 | 1.04 | 1.38 | 1.77 |
| 07160350 | 0.26 | 0.32 | 0.35 | 0.41 | 0.44 | 0.47 |
| 07226200 | 0.10 | 0.27 | 0.42 | 0.67 | 0.90 | 1.17 |
| 07226300 | 0.04 | 0.05 | 0.06 | 0.07 | 0.07 | 0.07 |
| 07227295 | 0.06 | 0.12 | 0.17 | 0.23 | 0.29 | 0.35 |
| 07227300 | 0.02 | 0.09 | 0.20 | 0.42 | 0.66 | 0.99 |
| 07227460 | 0.08 | 0.28 | 0.56 | 1.16 | 1.88 | 2.94 |
| 07228290 | 0.20 | 0.44 | 0.66 | 1.00 | 1.28 | 1.57 |
| 07228450 | 0.20 | 0.27 | 0.32 | 0.40 | 0.46 | 0.52 |
| 07232650 | 0.03 | 0.10 | 0.21 | 0.47 | 0.79 | 1.21 |
| 07234050 | 0.03 | 0.13 | 0.28 | 0.64 | 1.04 | 1.59 |
| 07234290 | 0.04 | 0.09 | 0.12 | 0.18 | 0.23 | 0.29 |
| 07235700 | 0.09 | 0.22 | 0.34 | 0.53 | 0.68 | 0.84 |
| 07237750 | 0.10 | 0.15 | 0.19 | 0.24 | 0.27 | 0.30 |
| 07239050 | 0.15 | 0.26 | 0.36 | 0.51 | 0.63 | 0.79 |
| 07321500 | 0.51 | 0.80 | 1.00 | 1.26 | 1.46 | 1.67 |

# K-TRAN

## KANSAS TRANSPORTATION RESEARCH
## AND
## NEW-DEVELOPMENT PROGRAM

Kansas
Department of Transportation