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Estimation of Potential Runoff-Contributing Areas in the Kansas-Lower Republican River Basin, Kansas

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Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

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CONVERSION FACTORS, ABBREVATIONS, AND VERTICAL DATUM

Multiply	By	To obtain
inch (in.)	2.54	centimeter
inch per hour (in/hr)	2.54	centimeter per hour
kilometer (km)	0.6214	mile
meter (m)	3.281	foot
mile (mi)	1.609	kilometer
square kilometer (km^2)	0.3861	square mile
square mile (mi^2)	2.59	square kilometer

Sea level: In this report, "sea level" refers to the National Geodetic Vertical Datum of 1929--a geodetic datum derived from a general adjustment of the first-order level nets of the United States and Canada, formerly called Sea Level Datum of 1929.

Abstract

Digital soils and topographic data were used to estimate and compare potential runoff-contributing areas for 19 selected subbasins representing soil, slope, and runoff variability within the Kansas-Lower Republican (KLR) River Basin. Potential runoff-contributing areas were estimated separately and collectively for the processes of infiltration-excess and saturation-excess overland flow using a set of environmental conditions that represented high, moderate, and low potential runoff. For infiltration-excess overland flow, various rainfall intensities and soil permeabilities were used. For saturation-excess overland flow, antecedent soil-moisture conditions and a topographic wetness index were used.

Results indicated that the subbasins with relatively high potential runoff are located in the central part of the KLR River Basin. These subbasins are Black Vermillion River, Clarks Creek, Delaware River upstream from Muscotah, Grasshopper Creek, Mill Creek (Wabaunsee County), Soldier Creek, Vermillion Creek (Pottawatomie County), and Wildcat Creek. The subbasins with relatively low potential runoff are located in the western one-third of the KLR River Basin, with one exception, and are Buffalo Creek, Little Blue River upstream from Barnes, Mill Creek (Washington County), Republican River between Concordia and Clay Center, Republican River upstream from Concordia, Wakarusa River downstream from Clinton Lake (exception), and White Rock Creek. The ability to distinguish the subbasins as having relatively high or low potential runoff was possible mostly due to the variability of soil

permeability across the KLR River Basin.

Introduction

The State of Kansas is required by the Federal Clean Water Act of 1972 to develop a total maximum daily load (TMDL) for basins throughout the State. A TMDL is an estimate of the maximum pollutant load (material transported during a specified time period) from point and nonpoint sources that a receiving water can accept without exceeding water-quality standards (U.S. Environmental Protection Agency, 1991). Requisite for the development of TMDL's is an understanding of potential source areas of storm runoff that are the most likely contributors of nonpoint-source pollution within a basin.

A study by the U.S. Geological Survey (USGS), in cooperation with the Kansas Department of Health and Environment, was begun in 1998 to estimate the spatial extent and pattern of potential runoff-contributing areas for selected subbasins in the Kansas-Lower Republican (KLR) River Basin (fig. 1). The specific study objectives were to:

1. Estimate potential runoff-contributing areas resulting from infiltration-excess overland flow;
2. Estimate potential runoff-contributing areas resulting from saturation-excess overland flow; and
3. Compare potential runoff among selected subbasins within the KLR River Basin.

The purpose of this report is to present the results of the study to estimate the spatial extent and pattern of potential runoff-contributing areas for selected subbasins in the KLR River Basin. The methods presented in this report may be applicable nationwide as related to the development of TMDL's and the targeting and implementation of best-management practices (BMP's).

Background

Runoff-contributing areas within basins primarily are the result of two processes, both of which produce overland flow. The first process is infiltration-excess overland flow (fig. 2*A*), which occurs when precipitation intensity exceeds the rate of water infiltration into the soil. This process may be dominant in basins where the land surface has been disturbed (for example, plowed cropland) or where natural vegetation is sparse. The second process is saturation-excess overland flow (fig. 2*B*), which occurs when precipitation falls on temporarily or permanently saturated land-surface areas that have developed from "outcrops" of the water table at the land surface (Hornberger and others, 1998). A temporary water table can develop during a storm when antecedent soil-moisture conditions in a basin are high. The saturated areas where saturation-excess overland flow develops expand during a storm and shrink during extended dry periods (Dunne and others, 1975).

Both runoff processes would be expected to affect the load of water-quality constituents in streams. The identification of potential runoff-contributing areas in a basin can provide guidance for the targeting of BMP's to reduce runoff and meet TMDL requirements. Implementation of BMP's within potential runoff-contributing areas is likely to be more effective at reducing loads compared to areas less likely to contribute runoff.

The spatial extent and pattern of runoff-contributing areas are affected by climate, soil, and terrain characteristics. Contributing areas of infiltration-excess overland flow are determined by the interaction of rainfall intensity and soil permeability. The least-permeable soils in a basin are the most likely to contribute infiltration-excess overland flow. As rainfall intensity increases, areas with more moderate soil permeability also may contribute overland flow.

Contributing areas of saturation-excess overland flow are determined by the interaction of basin antecedent soil-moisture conditions and topography. The effect of topography on saturation-excess overland flow can be quantified by an index called the topographic wetness index (TWI) (Wolock and McCabe, 1995). The TWI is computed as ln(a/S) for all points in a basin, where "ln" is the natural logarithm, "a" is the upslope area per unit contour length, and "S" is the slope at that point. The locations in a basin with the highest TWI values (large upslope areas and gentle slopes) are the most likely to contribute saturation-excess overland flow. When antecedent soil-moisture conditions are dry, only areas with the highest TWI values may be saturated and potentially contribute overland flow. When antecedent soil-moisture conditions are wet, areas with lower TWI values may be saturated and potentially contribute overland flow.

Description of Kansas-Lower Republican River Basin

The KLR River Basin is an area of about 10,600 mi² in northeast and north-central Kansas (fig. 1). Terrain in the basin generally is typified by gentle to moderate slopes of less than 12 percent (Kansas Water Resources Board, 1959, 1961). Soil permeability ranges from about 0.3 to 6.9 in/hr, with a mean of about 0.8 in/hr, and is generally lower in the central and eastern parts of the basin. Soil permeability also is relatively higher in the flood plains of the KLR main stem and its major tributaries (U.S. Department of Agriculture, 1993). Principal tributaries to the KLR main stem include White Rock Creek, Big Blue River, Mill Creek (Wabaunsee County), Vermillion Creek (Pottawatomie County), Soldier Creek, Delaware River, Wakarusa River, and Stranger Creek. Major Federal reservoirs in the basin include Milford Lake on the Republican River, Tuttle Creek Lake on the Big Blue River, Perry Lake on the Delaware River, and Clinton Lake on the Wakarusa River (fig. 1). Land use is predominantly agricultural, with cropland, grassland, and woodland accounting for about 42, 47, and 7 percent of the basin, respectively (Kansas Applied Remote Sensing Program, 1993).

Long-term (1961-90) mean annual precipitation ranges from about 29 in. at Mankato, Kansas, in the northwest part of the basin to about 39 in. at Lawrence, Kansas, in the southeast (National Oceanic and Atmospheric Administration, 1996). The recurrence intervals for storms of various durations and rainfall intensities (estimated from maps in Hershfield, 1961) are presented in table 1.

Table 1. Recurrence intervals, durations, and rainfall intensities for storms in the Kansas-Lower Republican River Basin
[Source of data: Hershfield, 1961. **Bold** values represent hypothetical storms chosen for analysis in this report]

Recurrence interval (years)	**Rainfall intensity, in inches per hour, for various storm durations**						
	0.5-hour	**1-hour**	**2-hour**	**3-hour**	**6-hour**	**12-hour**	**24-hour**
1	2.2	1.4	0.8	0.6	0.3	0.2	0.1
2	2.6	1.7	1.0	0.7	0.4	0.2	0.1
5	3.4	**2.2**	**1.3**	**0.9**	**0.5**	0.3	0.2
10	4.2	**2.5**	**1.5**	**1.1**	**0.6**	0.4	0.2
25	4.6	**2.9**	**1.8**	**1.2**	**0.7**	0.4	0.2
50	5.4	3.3	2.0	1.4	0.8	0.5	0.3
100	6.0	3.8	2.2	1.6	0.9	0.5	0.3

ESTIMATION OF POTENTIAL RUNOFF-CONTRIBUTING AREAS

Within the KLR River Basin, 19 subbasins representing soil, slope, and runoff variability were selected for analysis (fig. 1). The selected subbasin boundaries were obtained from a statewide data base of 11- and 14-digit hydrologic unit (basin) boundaries that was developed at a scale of 1:24,000 (U.S. Department of Agriculture, Natural Resources Conservation Service, 1997). For all selected subbasins, potential runoff-contributing areas were estimated separately and collectively for the processes of infiltration-excess and saturation-excess overland flow. Geographic-information-system (GIS) techniques and available digital data were used to perform the spatial analyses required to estimate potential runoff-contributing areas. All analyses were done using the GRID module of the ARC/INFO GIS software package. The digital data used in the analyses were in a grid (raster) format with a grid cell size of 1 km^2. The digital data used included the U.S. Department of Agriculture's 1:250,000-scale State soils geographic data base (STATSGO) (U.S. Department of Agriculture, 1993) and the USGS 1-km-resolution digital elevation model (DEM) (Verdin and Greenlee, 1996). These two digital data sets are suitable for use in comparing potential runoff among basins hundreds of square miles in size. Thus, in this study emphasis is placed on a comparison of potential runoff-contributing areas between, rather than within, individual subbasins.

Infiltration-Excess Overland Flow

The potential for infiltration-excess overland flow was estimated using STATSGO-derived soil-permeability digital data. In the STATSGO data set, soil permeability represents the infiltration rate when the soil is saturated (Soil Survey Staff, 1997). In general, there is an inverse relation between soil permeability and the potential for infiltration-excess overland flow. Using GIS techniques and a digital map of KLR River subbasin boundaries, the soil-permeability data were extracted from the STATSGO data base for each subbasin (fig. 3). The mean soil permeability then was computed for each subbasin.

An equal-interval approach was used to select three threshold soil-permeability values that represent a range of rainfall intensities. Within the KLR River Basin, soil permeability ranges from about 0.3 to 6.9 in/hr. However, because about 94 percent of the KLR River Basin has a soil permeability of 1.3 in/hr or less, the effective range used for the selected subbasins in this study was 0.3 to 1.3 in/hr. Thus, the threshold soil-permeability values, representing high, moderate, and low rainfall intensities, were set at 1.05, 0.80, and 0.55 in/hr, respectively. The higher soil-permeability thresholds imply a more intense storm during which areas with higher soil permeabilities potentially may contribute infiltration-excess overland flow. The threshold soil-permeability values were used to compare the subbasins on the basis of the percentage of each subbasin with soil permeabilities that were less than or equal to the threshold value and thus potentially contribute infiltration-excess overland flow.

In addition to an estimation and comparison of potential runoff-contributing areas for the selected KLR River subbasins, an understanding of the relative magnitudes of potential storm runoff was of interest. Twelve hypothetical storms were selected to cover a range of storm durations and rainfall intensities for which BMP's may be effective in reducing runoff. The storms included those with recurrence intervals of 5, 10, and 25 years, and durations of 1, 2, 3, and 6 hours (table 1). Total rainfall for these storms is in the 2- to 4-in. range. Potential rainfall excess, used as an indicator of storm-runoff potential, was computed as rainfall intensity minus mean soil permeability for all selected subbasins and all 12 hypothetical storms. Mean potential rainfall excess was computed as the average for the selected subbasins for each hypothetical storm.

Saturation-Excess Overland Flow

The potential for saturation-excess overland flow was estimated using DEM-derived TWI digital data. In general, there is a direct relation between TWI and the potential for saturation-excess overland flow. Derivation of the TWI digital data followed the approach described by Wolock and McCabe (1995). Elevation differences among the grid cells in the DEM (fig.4) were compared and used to create a flow-direction grid (Jenson and Domingue, 1988). The flow-direction grid was used to derive a flow-accumulation grid by computing the number of upslope cells that drain into each cell. The upslope area per unit contour length (a) for each cell in the flow-accumulation grid is computed as:

(1)
a = (number of upslope cells + 0.5) x (grid-cell length).

Using the DEM and the flow-direction grid, the magnitude of the slope (S) is computed for each cell as:

(2)
S = (change in elevation between neighboring grid cells) / (horizontal distance between centers of neighboring grid cells).

The resultant slope (gradient) grid then was used in combination with the flow-accumulation grid to compute TWI for each cell as:

(3)
TWI = ln (a / S).

Using GIS techniques and a digital map of KLR River subbasin boundaries, the TWI grid data were extracted for each selected subbasin (fig. 5). The mean TWI was computed for each selected subbasin. An equal-interval approach was used to select three threshold TWI values that represented a range of wet-to-dry antecedent soil-moisture conditions. Within the KLR River Basin, the TWI ranged from 8.7 to 26.8. However, because about 95 percent of the KLR River Basin had a TWI of 19 or less, the effective range used for the selected subbasins in this study was 8.7 to 19. Thus, the threshold TWI values, representing wet, moderate, and dry antecedent soil-moisture conditions, were set at 11.3, 13.9, and 16.4, respectively. The lower TWI thresholds imply wetter antecedent soil-moisture conditions during which areas with lower TWI values potentially may contribute saturation-excess overland flow. The threshold TWI values were used to compare the selected subbasins on the basis of the percentage of each subbasin that had TWI values greater than or equal to the threshold value and thus potentially contribute saturation-excess overland flow.

Combined Infiltration-Excess and Saturation-Excess Overland Flows

The combined potential for runoff in the selected KLR River subbasins due to infiltration-excess and saturation-excess overland flows was estimated by combining the previously described hypothetical conditions. A high potential runoff condition was created by combining high rainfall intensity (soil permeability less than or equal to 1.05 in/hr) with wet antecedent soil-moisture (TWI greater than or equal to 11.3) conditions. A moderate potential runoff condition was created by combining moderate rainfall intensity (soil permeability less than or equal to 0.80 in/hr) with moderate antecedent soil-moisture (TWI greater than or equal to 13.9) conditions. A low potential runoff condition was created by combining the low rainfall intensity (soil permeability less than or equal to 0.55 in/hr) with dry antecedent soil-moisture (TWI greater than or equal to 16.4) conditions. The combined conditions were used to compare the selected subbasins on the basis of the percentage of each subbasin that potentially contributes runoff by one or both overland flow processes.

POTENTIAL RUNOFF-CONTRIBUTING AREAS

Infiltration-Excess Overland Flow

Mean soil permeability for the selected KLR River subbasins ranged from about 0.4 to 1.4 in/hr (table 2). The frequency distribution of the mean soil permeabilities is shown in figure 6. Of the 19 subbasins, 11 (58 percent) had a relatively low mean soil permeability of 0.6 in/hr or less. These subbasins have a relatively high potential for infiltration-excess overland flow and are located in the eastern half of the KLR River Basin (fig. 1). The subbasins with high potential for infiltration-excess overland flow are Big Blue River upstream from Tuttle Creek Lake (subbasin 1), Black Vermillion River (subbasin 2), Clarks Creek (subbasin 4), Delaware River upstream from Muscotah (subbasin 5), Grasshopper Creek (subbasin 7), Mill Creek (subbasin 9, Wabaunsee County), Soldier Creek (subbasin 13), Stranger Creek (subbasin 14), Vermillion Creek (subbasin 15, Pottawatomie County), Wakarusa River upstream from Clinton Lake (subbasin 17), and Wildcat Creek (subbasin 19). Four (21 percent) of the 19 subbasins had a relatively high mean soil permeability of 1.1 in/hr or more. These subbasins have a relatively low potential for infiltration-excess overland flow and are located in the western half of the KLR River Basin (fig. 1). The subbasins with low potential for infiltration-excess overland flow are Buffalo Creek (subbasin 3), Republican River between Concordia and Clay Center (subbasin 11), Republican River upstream from Concordia (subbasin 12), and White Rock Creek (subbasin 18).

Table 2. Mean soil permeability and potential contributing areas of infiltration-excess overland flow for selected rainfall intensities and selected Kansas-Lower Republican River subbasins

		Potential contributing area, in percent of the subbasin, for selected rainfall intensities		
Sub-basin number (fig. 1)	**Mean P**	**High rainfall intensity (P^1)**	**Moderate rainfall intensity (P^2)**	**Low rainfall intensity (P^3)**
1	0.6	91.4	88.0	43.6
2	0.4	99.6	99.6	90.0
3	1.1	68.2	10.4	0
4	0.5	99.2	99.2	79.0
5	0.4	93.6	93.6	93.6
6	0.7	99.1	87.0	34.2
7	0.4	91.0	91.0	91.0
8	0.8	80.1	75.3	0
9	0.5	100.0	93.2	93.2

10	0.9	70.7	32.9	0
11	1.2	75.5	42.8	0
12	1.4	49.1	27.5	0
13	0.6	86.1	82.2	82.1
14	0.5	90.5	83.5	61.9
15	0.6	94.1	94.1	75.4
16	0.8	78.0	45.6	14.7
17	0.6	86.5	86.5	64.7
18	1.3	1.0	1.0	0
19	0.6	95.7	95.7	79.0

P^1, soil permeability, in inches per hour, less than or equal to 1.05
P^2, soil permeability, in inches per hour, less than or equal to 0.80
P^3, soil permeability, in inches per hour, less than or equal to 0.55

The potential contributing areas of infiltration-excess overland flow for high rainfall-intensity conditions (soil permeability less than or equal to 1.05 in/hr) ranged from 1 percent of the subbasin for White Rock Creek (subbasin 18) to 100 percent for Mill Creek (subbasin 9, Wabaunsee County) (table 2). Excluding the White Rock Creek subbasin, the range of potential contributing areas was 49.1 (Republican River upstream from Concordia, subbasin 12) to 100 percent. Of the 19 subbasins, 15 (79 percent) had potential contributing areas of infiltration-excess overland flow of 75 percent or more. For all three rainfall intensities, the percentages of potential contributing area were inversely related to the mean soil permeability of the subbasins. Thus, the subbasins with the highest mean soil permeability had the lowest percentage of potential contributing areas of infiltration-excess overland flow. The spatial extent and pattern of potential contributing and noncontributing areas of infiltration-excess overland flow for high rainfall-intensity conditions are shown in figure 7.

For moderate rainfall-intensity conditions (soil permeability less than or equal to 0.80 in/hr), the potential contributing areas of infiltration-excess overland flow ranged from 1 percent of the subbasin for White Rock Creek (subbasin 18) to 99.6 percent for the Black Vermillion River (subbasin 2) (table 2). Of the 19 subbasins, 13 (68 percent) had potential contributing areas of infiltration-excess overland flow of 75 percent or more. The other six subbasins, which had potential contributing areas of infiltration-excess overland flow of less than 50 percent, were Buffalo Creek (subbasin 3), Mill Creek (subbasin 10, Washington County), Republican River between Concordia and Clay Center (subbasin 11), Republican River upstream from Concordia (subbasin 12), Wakarusa River downstream from Clinton Lake (subbasin 16), and White Rock Creek (subbasin 18). The spatial extent and pattern of potential contributing and noncontributing areas of infiltration-excess overland flow for moderate rainfall-intensity conditions are shown in figure 8.

The potential contributing areas of infiltration-excess overland flow for low rainfall-intensity conditions (soil permeability less than or equal to 0.55 in/hr) ranged from 0 to 93.6 percent (table 2). Of the 19 subbasins, 8 (42 percent) had potential contributing areas of infiltration-excess overland flow of 75 percent or more. These subbasins were the Black Vermillion River (subbasin 2), Clarks Creek (subbasin 4), Delaware River upstream from Muscotah (subbasin 5), Grasshopper Creek (subbasin 7), Mill Creek (subbasin 9, Wabaunsee County), Soldier Creek (subbasin 13), Vermillion Creek (subbasin 15, Pottawatomie County), and Wildcat Creek (subbasin 19). In contrast, 6 (32 percent) of the subbasins had no potential contributing area. These subbasins were Buffalo Creek (subbasin 3), Little Blue River upstream from Barnes (subbasin 8), Mill Creek (subbasin 10, Washington County), Republican River between Concordia and Clay Center (subbasin 11), Republican River upstream from Concordia (sub-basin 12), and White Rock Creek (subbasin 18). The spatial extent and pattern of potential contributing and noncontributing areas of infiltration-excess overland flow for low rainfall-intensity conditions are shown in figure 9.

Potential rainfall excess for the selected KLR River subbasins ranged from -0.9 to 2.5 in/hr (table 3) for the 12 hypothetical storms. A negative value for potential rainfall excess indicates that mean soil permeability exceeds rainfall intensity and storm-runoff potential is minimal. For all recurrence intervals, potential rainfall excess was inversely related to mean soil permeability and directly related to rainfall intensity. The 1-hour storms have the highest potential for infiltration-excess overland flow, with mean potential rainfall excesses for the 5-, 10-, and 25-year storms of 1.5, 1.8, and 2.2 in/hr, respectively. Also, the 25-year/2-hour storm had a mean potential rainfall excess of 1.1 in/hr. Storms having moderate potential for infiltration-excess overland flow, with mean potential rainfall excesses in the 0.4- to 0.8-in/hr range, were the 5-year/2-hour, 10-year/2-hour, 10-year/3-hour, and 25-year/3-hour storms. Storms with minimal potential for infiltration-excess overland flow, with mean potential rainfall excesses of 0.2 in/hr or less, were the 5-year/3-hour, 5-year/6-hour, 10-year/6-hour, and 25-year/6-hour storms. Overall, for the conditions analyzed, the 1- and 2-hour storms have the highest potential for infiltration-excess overland flow. The 3- and 6-hour storms have low to moderate and minimal potential for infiltration-excess overland flows, respectively.

Table 3. Potential rainfall excess for selected Kansas-Lower Republican River subbasins.

Subbasin number (fig. 1)	Potential rainfall excess, in inches per hour, for selected storm recurrence intervals/durations											
	5-year/ 1-hour	5-year/ 2-hour	5-year/ 3-hour	5-year/ 6-hour	10-year/ 1-hour	10-year/ 2-hour	10-year/ 3-hour	10-year/ 6-hour	25-year/ 1-hour	25-year/ 2-hour	25-year/ 3-hour	25-year/ 6-hour
1	1.6	0.7	0.3	-0.1	1.9	0.9	0.5	0	2.3	1.2	0.6	0.1
2	1.8	0.9	0.5	0.1	2.1	1.1	0.7	0.2	2.5	1.4	0.8	0.3
3	1.1	0.2	-0.2	-0.6	1.4	0.4	0	-0.5	1.8	0.7	0.1	-0.4
4	1.7	0.8	0.4	0	2.0	1.0	0.6	0.1	2.4	1.3	0.7	0.2
5	1.8	0.9	0.5	0.1	2.1	1.1	0.7	0.2	2.5	1.4	0.8	0.3
6	1.5	0.6	0.2	-0.2	1.8	0.8	0.4	-0.1	2.2	1.1	0.5	0
7	1.8	0.9	0.5	0.1	2.1	1.1	0.7	0.2	2.5	1.4	0.8	0.3
8	1.4	0.5	0.1	-0.3	1.7	0.7	0.3	-0.2	2.1	1.0	0.4	-0.1
9	1.7	0.8	0.4	0	2.0	1.0	0.6	0.1	2.4	1.3	0.7	0.2
10	1.3	0.4	0	-0.4	1.6	0.6	0.2	-0.3	2.0	0.9	0.3	-0.2
11	1.0	0.1	-0.3	-0.7	1.3	0.3	-0.1	-0.6	1.7	0.6	0	-0.5
12	0.8	-0.1	-0.5	-0.9	1.1	0.1	-0.3	-0.8	1.5	0.4	-0.2	-0.7
13	1.6	0.7	0.3	-0.1	1.9	0.9	0.5	0	2.3	1.2	0.6	0.1
14	1.7	0.8	0.4	0	2.0	1.0	0.6	0.1	2.4	1.3	0.7	0.2
15	1.6	0.7	0.3	-0.1	1.9	0.9	0.5	0	2.3	1.2	0.6	0.1
16	1.4	0.5	0.1	-0.3	1.7	0.7	0.3	-0.2	2.1	1.0	0.4	-0.1
17	1.6	0.7	0.3	-0.1	1.9	0.9	0.5	0	2.3	1.2	0.6	0.1
18	0.9	0	-0.4	-0.8	1.2	0.2	-0.2	-0.7	1.6	0.5	-0.1	-0.6
19	1.6	0.7	0.3	-0.1	1.9	0.9	0.5	0	2.3	1.2	0.6	0.1
Mean rainfall excess	**1.5**	**0.6**	**0.2**	**-0.2**	**1.8**	**0.8**	**0.4**	**-0.1**	**2.2**	**1.1**	**0.5**	**0**

Saturation-Excess Overland Flow

Mean TWI's for the selected KLR River subbasins ranged from 12.0 to 13.0 (table 4). The frequency distribution of mean TWI's is shown in figure 10. Of the 19 subbasins, 13 (68 percent) had a mean TWI of 12.6 or more. These subbasins have relatively high potential for saturation-excess overland flow and are located throughout the KLR River Basin (fig. 1). In general, the percentages of potential contributing area were directly related to the mean TWI's for the selected subbasins for all three antecedent soil-moisture conditions. Thus, the subbasins with the highest mean TWI's had the highest percentage of area potentially contributing saturation-excess overland flow.

Table 4. Mean topographic wetness index (TWI) and potential contributing areas of saturation-excess overland flow for selected antecedent soil-moisture conditions and selected

Kansas-Lower Republican River subbasins

Sub-basin number (fig. 1)	Mean TWI	Potential contributing area, in percent of the subbasin, for selected antecedent soil-moisture conditions		
		Wet (TWI[1])	**Moderate (TWI[2])**	**Dry (TWI[3])**
1	12.7	52.2	25.9	12.8
2	12.5	50.4	24.5	11.0
3	12.9	62.2	28.1	12.4
4	12.6	52.8	25.8	13.2
5	12.7	52.5	27.5	14.4
6	12.3	48.1	22.1	10.1
7	12.4	52.1	21.5	9.5
8	12.8	57.6	24.5	11.7
9	12.0	42.8	21.1	10.9
10	12.6	53.4	25.6	12.8
11	13.0	60.3	28.9	12.9
12	13.0	63.5	25.5	9.9
13	12.7	57.5	25.5	12.1
14	12.8	57.4	29.1	13.8
15	12.2	48.2	21.0	10.2
16	12.9	54.5	30.8	17.6
17	12.6	53.7	26.7	11.3
18	12.7	55.5	27.4	13.1
19	12.4	48.3	23.7	9.0

TWI[1] , greater than or equal to 11.3
TWI[2] , greater than or equal to 13.9
TWI[3] , greater than or equal to 16.4

The potential contributing areas of saturation-excess overland flow for wet antecedent soil-moisture conditions (TWI greater than or equal to 11.3) ranged from 42.8 percent of the subbasin for Mill Creek (subbasin 9, Wabaunsee County) to 63.5 percent for the Republican River upstream from Concordia (subbasin 12) (table 4). In addition to the Republican River upstream from Concordia, the Buffalo Creek and the Republican River between Concordia and Clay Center subbasins (subbasins 3 and 11) also had potential contributing areas in excess of 60 percent. Subbasins with potential contributing areas of saturation-excess overland flow of less than 50 percent were Fancy Creek (subbasin 6), Mill Creek (subbasin 9, Wabaunsee County), Vermillion Creek (subbasin 15, Pottawatomie County), and Wildcat Creek (subbasin 19). The spatial extent and pattern of potential contributing and noncontributing areas of saturation-excess overland flow for wet antecedent soil-moisture conditions are shown in figure 11.

For moderate antecedent soil-moisture conditions (TWI greater than or equal to 13.9), the potential contributing areas for saturation-excess overland flow ranged from 21.0 percent of the subbasin for Vermillion Creek (subbasin 15, Pottawatomie County) to 30.8 percent for the Wakarusa River downstream from Clinton Lake (subbasin 16) (table 4). The spatial extent and pattern of potential contributing and noncontributing areas of saturation-excess overland flow for moderate antecedent soil-moisture conditions are shown in figure 12.

Potential contributing areas of saturation-excess overland flow for dry antecedent soil-moisture conditions (TWI greater than or equal to 16.4) ranged from 9.0 percent of the subbasin for Wildcat Creek (subbasin 19) to 17.6 percent for the Wakarusa River downstream from Clinton Lake (subbasin 16) (table 4). As shown in figure 13, the spatial extent and pattern of potential contributing areas of saturation-excess overland flow for dry antecedent soil-moisture conditions are limited mostly to areas along the main stream and larger tributaries within each subbasin.

Combined Infiltration-Excess and Saturation-Excess Overland Flows

For high potential runoff conditions (soil permeability less than or equal to 1.05 in/hr, TWI greater than or equal to 11.3), 17 of 19 (89 percent) selected subbasins had combined potential contributing areas of 85 percent or more (table 5). The two exceptions, located in the extreme northwest corner of the KLR River Basin, were the Republican River upstream from Concordia (subbasin 12, 78.8 percent) and White Rock Creek (subbasin 18, 55 percent). The spatial extent and pattern of combined potential contributing and noncontributing areas for high potential runoff conditions are shown in figure 14.

Table 5. Potential contributing areas for combined infiltration- and saturation-excess overland flows for selected Kansas-Lower Republican River subbasins

Subbasin number (fig. 1)	Potential contributing area, in percent of the subbasin, for selected potential runoff conditions		
	High potential runoff [1]	Moderate potential runoff [2]	Low potential runoff [3]
1	96.8	92.8	51.3
2	99.4	99.4	91.9
3	85.3	35.5	12.4
4	97.6	97.6	82.8
5	97.5	96.5	95.6
6	98.8	90.1	40.1
7	96.3	95.0	93.4
8	91.3	83.2	11.7
9	99.3	94.9	94.2
10	88.6	53.6	12.8
11	91.9	60.2	12.9
12	78.8	45.7	9.2
13	97.5	89.5	86.4
14	97.6	91.5	69.2
15	97.3	95.2	79.4
16	93.4	65.0	29.8
17	92.4	90.5	70.8
18	55.0	27.6	12.9
19	99.2	98.1	75.9

[1] High potential runoff = soil permeability less than or equal to 1.05 inches per hour and topographic wetness index greater than or equal to 11.3.
[2] Moderate potential runoff = soil permeability less than or equal to 0.80 inches per hour and topographic wetness index greater than or equal to 13.9.
[3] Low potential runoff = soil permeability less than or equal to 0.55 inches per hour and topographic wetness index greater than or equal to 16.4.

Combined potential contributing areas for moderate potential runoff conditions (soil permeability less than or equal to 0.80 in/hr, TWI greater than or equal to 13.9) ranged from 27.6 percent of the subbasin for White Rock Creek (subbasin 18) to 99.4 percent for the Black Vermillion River (subbasin 2). Of the 19 subbasins, 12 (63 percent) had combined potential contributing areas of 85 percent or more (table 5). The seven exceptions were Buffalo Creek (subbasin 3, 35.5 percent), Little Blue River upstream from Barnes (subbasin 8, 83.2 percent), Mill Creek (subbasin 10, Washington County) (53.6 percent), Republican River between Concordia and Clay Center (subbasin 11, 60.2 percent), Republican River upstream from Concordia (subbasin 12, 45.7 percent), Wakarusa River downstream from Clinton Lake (subbasin 16, 65 percent), and White Rock Creek (subbasin 18, 27.6 percent). The spatial extent and pattern of combined potential contributing and noncontributing areas for moderate potential runoff conditions are shown in figure 15.

For low potential runoff conditions (soil permeability less than or equal to 0.55 in/hr, TWI greater than or equal to 16.4), combined potential contributing areas ranged from 9.2 percent of the subbasin for the Republican River upstream from Concordia (subbasin 12) to 95.6 percent for the Delaware River upstream from Muscotah (subbasin 5) (table 5). Five of the 19 subbasins (26 percent) had combined potential contributing areas of 85 percent or more-Black Vermillion River (subbasin 2), Delaware River upstream from Muscotah (subbasin 5), Grasshopper Creek (subbasin 7), Mill Creek (subbasin 9, Wabaunsee County), and Soldier Creek (subbasin 13). Six of the 19 subbasins (32 percent) had combined potential contributing areas of less than 15 percent-Buffalo Creek (subbasin 3), Little Blue River upstream from Barnes (subbasin 8), Mill Creek (subbasin 10, Washington County), Republican River between Concordia and Clay Center (subbasin 11), Republican River upstream from Concordia (subbasin 12), and White Rock Creek (subbasin 18). The spatial extent and pattern of combined potential contributing and noncontributing areas for low potential runoff conditions are shown in figure 16.

SUMMARY AND CONCLUSIONS

Digital soils and topographic data were used to estimate and compare potential runoff-contributing areas for 19 selected subbasins within the Kansas-Lower Republican (KLR) River Basin. Potential runoff-contributing areas were estimated separately and collectively for the processes of infiltration-excess and saturation-excess overland flow using a set of environmental conditions that represented high, moderate, and low potential runoff. For infiltration-excess overland flow, various rainfall intensities and soil permeabilities were used. For saturation-excess overland flow, antecedent soil-moisture conditions and a topographic wetness index were used.

Results indicated that the subbasins with relatively high potential runoff are located in the central part of the KLR River Basin. These subbasins are Black Vermillion River, Clarks Creek, Delaware River upstream from Muscotah, Grasshopper Creek, Mill Creek (Wabaunsee County), Soldier Creek, Vermillion Creek (Pottawatomie County), and Wildcat Creek. The subbasins with relatively low potential runoff are located in the western one-third of the KLR River Basin, with one exception, and are Buffalo Creek, Little Blue River upstream from Barnes, Mill Creek (Washington County), Republican River between Concordia and Clay Center, Republican River upstream from Concordia, Wakarusa River downstream from Clinton Lake (exception), and White Rock Creek.

The ability to distinguish the subbasins as having relatively high or low potential runoff was possible mostly due to the variability of soil permeability across the KLR River Basin. Due to this variability, the subbasins had a wide range of potential contributing areas for infiltration-excess overland flow, particularly for low potential runoff conditions. In contrast, the topographic wetness index had a relatively uniform distribution across the KLR River Basin. Thus, the selected subbasins had a narrow range of potential contributing areas for saturation-excess overland flow. The results of the analyses to estimate the combined potential contributing areas for the two runoff processes closely paralleled the results for infiltration-excess overland flow.

This study had some limitations. The digital data sets used were only suitable for use in a comparison of areas hundreds of square miles in size. Thus, the analysis emphasized a comparison of potential runoff-contributing areas between, rather than within, individual subbasins. Improved results will be possible with more spatially detailed digital soils and topographic data sets. Such data sets are currently (1999) being developed and will include the U.S. Department of Agriculture's 1:24,000-scale soil survey geographic data base (SSURGO) and the USGS 30-m-resolution DEM. When available, these data sets will enable a comparison of potential runoff-contributing areas for areas tens of square miles in size. Then, a comparison of areas within individual subbasins will be possible.

In addition, the estimation of potential runoff-contributing areas was limited in that only soil and topographic characteristics were considered. The incorporation of additional factors such as land use and climatic variability may improve the results. For example, an overlay analysis to determine the location of cropland with respect to potential contributing areas may identify the most likely source areas of certain nonpoint-source pollutants within a subbasin. Such information may provide additional guidance for the targeting of BMP's.

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