ESTIMATION OF POTENTIAL RUNOFF-CONTRIBUTING AREAS

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Abstract: *Digital topographic, soil, and land-use information was used to estimate potential runoff-contributing areas in Kansas. The results were used to compare selected subbasins representing slope, soil, land-use, and runoff variability across the State. Potential runoff-contributing areas were estimated collectively for the processes of infiltration-excess and saturation-excess overland flow using a set of environmental conditions that represented very high, high, moderate, low, very low, and extremely low potential for runoff (in relative terms). Various rainfall-intensity and soil-permeability values were used to represent the threshold conditions at which infiltration-excess overland flow may occur. Antecedent soil-moisture conditions and a topographic wetness index (TWI) were used to represent the threshold conditions at which saturation-excess overland flow may occur. Land-use patterns were superimposed over the potential runoff-contributing areas for each set of environmental conditions.*

Results indicated that the very low potential-runoff conditions (soil permeability less than or equal to 1.14 inches per hour and TWI greater than or equal to 14.4) provided the best statewide ability to quantitatively distinguish subbasins as having relatively high, moderate, or low potential for runoff on the basis of the percentage of potential runoff-contributing areas within each subbasin. The very low and (or) extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 inch per hour and TWI greater than or equal to 16.3) provided the best ability to qualitatively compare potential for runoff among areas within individual subbasins. The majority of the subbasins with relatively high potential for runoff are located in the eastern half of the State where soil permeability generally is less and precipitation typically is greater. The ability to distinguish the subbasins as having relatively high, moderate, or low potential for runoff was mostly due to the variability of soil permeability across the State. The spatial distribution of potential contributing areas, in combination with the superimposed land-use patterns, may be used to help identify and prioritize subbasin areas for the implementation of best-management practices to manage runoff and meet Federally mandated total maximum daily load requirements.

INTRODUCTION

The State of Kansas is required by the Federal Clean Water Act of 1972 to develop a total maximum daily load (TMDL) for water bodies 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 1999 to estimate the spatial extent and pattern of potential runoff-contributing areas in Kansas. The specific study objectives were to:

(1) Estimate potential runoff-contributing areas for infiltration-excess and saturation-excess overland flows;

(2) Describe land-use patterns that may affect the potential for runoff; and

(3) Compare the potential for runoff between and within subbasins throughout the State.

This paper presents the methods and results of the study to estimate the spatial extent and pattern of potential runoff-contributing areas in Kansas using the Lower Arkansas River Basin as a representative example. The methods presented in this paper may be applicable nationwide as related to the development of TMDL's and the identification and prioritization of areas for the implementation of best-management practices (BMP's). This study was made possible in part by support from the Kansas State Water Plan Fund.

BACKGROUND

Runoff-contributing areas within river basins primarily are the result of two processes, both of which produce overland flow. The first process is infiltration-excess overland flow, 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, 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, although possibly in different ways due to different flow paths. 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 constituent 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 permeability also may contribute overland flow.

Contributing areas of saturation-excess overland flow are determined by the interaction of basin topography and antecedent soil-moisture conditions. 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.

Land use is another important factor that affects runoff within a basin, both physically and chemically. Physically, such characteristics as vegetative cover, soil permeability, and the amount and connectivity of impervious surfaces combine to determine the relative magnitudes of runoff for various types of land use. For example, cropland and urban land uses are typified by higher runoff volumes than grassland and woodland. Increased runoff from cropland is attributable to several factors, including the removal of native vegetation and soil compaction, which decrease surface permeability. Increased runoff from urban areas is mostly due to the substantial increase in the percentage of impervious surfaces (for example, streets, parking lots, roofed structures). In contrast, decreased runoff from undisturbed grassland and woodland areas is due to such factors as the interception of falling precipitation by the vegetation and accumulated organic debris on the surface, as well as the dense network of roots that increases soil porosity. Chemically, land use is an important determinant of the sources, types, and amounts of contaminants that affect the water quality of runoff. The chemical effects of land use on runoff are not addressed in this paper.

Potential runoff-contributing areas with high percentages of cropland and (or) urban land uses would be expected to have higher potential for runoff compared to areas of similar soils and topography with high percentages of grassland and (or) woodland. Moreover, areas classified as noncontributing on the basis of soil and topographic characteristics may contribute runoff if the land use is mostly cropland and (or) urban. Thus, the importance of including land use in an assessment of the potential for runoff is evident. Implementation of BMP's in potential runoff-contributing areas with high percentages of cropland and (or) urban land uses is likely to be more effective at reducing runoff compared to similar areas with high percentages of grassland and (or) woodland.

ESTIMATION OF POTENTIAL RUNOFF-CONTRIBUTING AREAS

In Kansas, subbasins representing slope, soil, land-use, and runoff variability were selected for analysis. 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). 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 ArcInfo GIS software package. (Any use of trade, product, or firm names is for descriptive purposes only and does not constitute endorsement by the U.S. Geological Survey.)

In this study, digital topographic and soil data, as well as digital land-use data, were used to estimate and compare potential runoff-contributing areas in Kansas. The digital data included the U.S. Department of Agriculture's 1:24,000-scale soil data base (U.S. Department of Agriculture, Natural Resources Conservation Service, 1996), the USGS 100-m-resolution digital elevation model (DEM) (U.S. Geological Survey, 1993), and 1:100,000-scale, land-cover data (Kansas Applied Remote Sensing Program, 1993). The soil and land-cover data were converted from polygon to grid format with a 10,000-m^2 (0.01-km^2) grid-cell size to match the resolution of the 100-m DEM. These three digital data sets are suitable for comparing potential runoff among areas tens of square kilometers in size. This statement is based on the fact that areas tens of square kilometers in size have sufficient numbers of unique 1:24,000-scale soil mapping units and elevation data points to compute representative mean values for the purpose of comparing areas. Thus, in this paper emphasis is placed on a comparison of potential contributing areas both between and within the subbasins that ranged in size from about 150 to 6,600 km^2.

The potential for infiltration-excess overland flow was estimated using the 1:24,000-scale soil-permeability digital data. A depth-weighted, mean soil permeability was used. In general, there is an inverse relation between soil permeability and the potential for infiltration-excess overland flow. Using GIS techniques, a statewide grid of depth-weighted, mean soil permeability was assembled from the soil data base.

An equal-interval approach was used to select six threshold soil-permeability values that represent the rainfall intensity at which infiltration-excess overland flow may occur. In Kansas, soil permeability ranges from 0 to 17.6 in/hr. However, because about 93 percent of the State has a soil permeability of 4.0 in/hr or less, the effective range used in this study was 0 to 4.0 in/hr. Thus, the threshold soil-permeability values, representing very high, high, moderate, low, very low, and extremely low rainfall intensity (in relative terms), were set at 3.43, 2.86, 2.29, 1.71, 1.14, and 0.57 in/hr, respectively.

In general, lower rainfall intensities occur more frequently than higher rainfall intensities. For central Kansas, Hershfield (1961) estimated that 1-hour storms with rainfall intensities of 1.4 and 3.4 in/hr have recurrence intervals of 1 and 50 years, respectively. The higher soil-permeability thresholds imply a more intense storm during which areas with higher soil permeability potentially may contribute infiltration-excess overland flow. The threshold soil-permeability values were used to compare subbasins on the basis of the percentage of each subbasin with soil-permeability values that were less than or equal to the threshold value and thus potentially contribute infiltration-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 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 was computed as:

$$a = (\text{number of upslope cells} + 0.5) \times (\text{grid-cell length}). \quad (1)$$

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

$$S = (\text{change in elevation between neighboring grid cells}) / (\text{horizontal distance between centers of neighboring grid cells}). \quad (2)$$

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

$$\mathrm{TWI} = \ln\,(a\,/\,S). \tag{3}$$

Using GIS techniques, a statewide grid of TWI data was created.

An equal-interval approach was used to select six threshold TWI values that represented a range of wet-to-dry, antecedent soil-moisture conditions. For this analysis, the TWI grid cells that represent the streams were excluded because the TWI is considered a characteristic of the land surface that contributes runoff to the streams. In Kansas, the TWI (with grid cells representing the streams excluded) ranges from 4.5 to 18.3. Because the TWI had a normal distribution, the full range of values was used in this study. Thus, the threshold TWI values, representing very wet, wet, moderate, dry, very dry, and extremely dry antecedent soil-moisture conditions, were set at 6.5, 8.4, 10.4, 12.4, 14.4, and 16.3, 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 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.

The combined potential for runoff due to infiltration-excess and saturation-excess overland flows was estimated by merging the previously described hypothetical environmental conditions. A very high potential-runoff condition was created by combining very high rainfall intensity (soil permeability less than or equal to 3.43 in/hr) with very wet antecedent soil-moisture (TWI greater than or equal to 6.5) conditions. A high potential-runoff condition was created by combining high rainfall intensity (soil permeability less than or equal to 2.86 in/hr) with wet antecedent soil-moisture (TWI greater than or equal to 8.4) conditions. A moderate potential-runoff condition was created by combining moderate rainfall intensity (soil permeability less than or equal to 2.29 in/hr) with moderate antecedent soil-moisture (TWI greater than or equal to 10.4) conditions. A low potential-runoff condition was created by combining the low rainfall intensity (soil permeability less than or equal to 1.71 in/hr) with dry antecedent soil-moisture (TWI greater than or equal to 12.4) conditions. A very low potential-runoff condition was created by combining the very low rainfall intensity (soil permeability less than or equal to 1.14 in/hr) with very dry antecedent soil-moisture (TWI greater than or equal to 14.4) conditions. An extremely low potential-runoff condition was created by combining the extremely low rainfall intensity (soil permeability less than or equal to 0.57 in/hr) with extremely dry antecedent soil-moisture (TWI greater than or equal to 16.3) conditions. The combined conditions were used to compare subbasins on the basis of the percentage of each subbasin that potentially contributes runoff by one or both overland-flow processes. Also, the combined conditions were used to assess the spatial distribution of potential contributing areas within the subbasins.

Land use was addressed in two ways. First, the land-use composition of each subbasin was estimated as the percentage of each subbasin categorized as cropland, grassland, woodland, and urban land uses. This information may be used to quantitatively assess land-use differences between subbasins. Second, for each set of environmental conditions, the grid cells classified as potential contributing areas were color-coded by land-use type. The resulting maps provide information on the spatial distribution of potential contributing areas within a subbasin as well as the land-use patterns within the potential contributing areas. This information may be used to help identify and prioritize subbasin areas for implementation of BMP’s.

RESULTS

Results of this study indicated that the sets of environmental conditions that represented higher potential-runoff conditions generally were not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The inability to distinguish subbasins for the higher potential-runoff conditions was due to the fact that the percentage of contributing areas was in excess of 90 percent for virtually every subbasin. Thus, in this paper, only the results for the low, very low, and extremely low potential-runoff conditions are presented. The results are useful for the purpose of comparing potential runoff-contributing areas between and within subbasins. However, the results are not intended to be used for the purpose of inferring the magnitude of potential runoff within a given area. Complete results for the statewide analysis are presented in Juracek (in press). In this paper, only the results for the Lower Arkansas River Basin in south-central Kansas are provided as an example.

The ability to distinguish subbasins of the Lower Arkansas River Basin as having relatively high, moderate, or low potential for runoff was good for the low potential-runoff conditions and very good for the very low (figure 1) and extremely low potential-runoff conditions. Potential contributing areas for the very low potential-runoff conditions (soil permeability less than or equal to 1.14 in/hr, TWI greater than or equal to 14.4) ranged from 15.4 percent of the subbasin for Sandy and Little Sandy Creeks (subbasin 10) to 94.7 percent for Sun and Turkey Creeks (subbasin 12). Of the 12 subbasins in the Lower Arkansas River Basin, 1 had potential contributing areas in more than 90 percent of the subbasin, 3 had potential contributing areas in 70 to 90 percent of each subbasin, 2 had potential contributing areas in 50 to 70 percent of each subbasin, 2 had potential contributing areas in 30 to 50 percent of each subbasin, and 4 had potential contributing areas in 10 to 30 percent of each subbasin (table 1).

For extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to16.3), potential contributing areas ranged from 6.5 percent of the subbasin for Sandy and Little Sandy Creeks (subbasin 10) to 73.8 percent for Sand and Emma Creeks (subbasin 9). Of the 12 subbasins, 1 had potential contributing areas in 70 to 90 percent of the subbasin, 1 had potential contributing areas in 50 to 70 percent of the

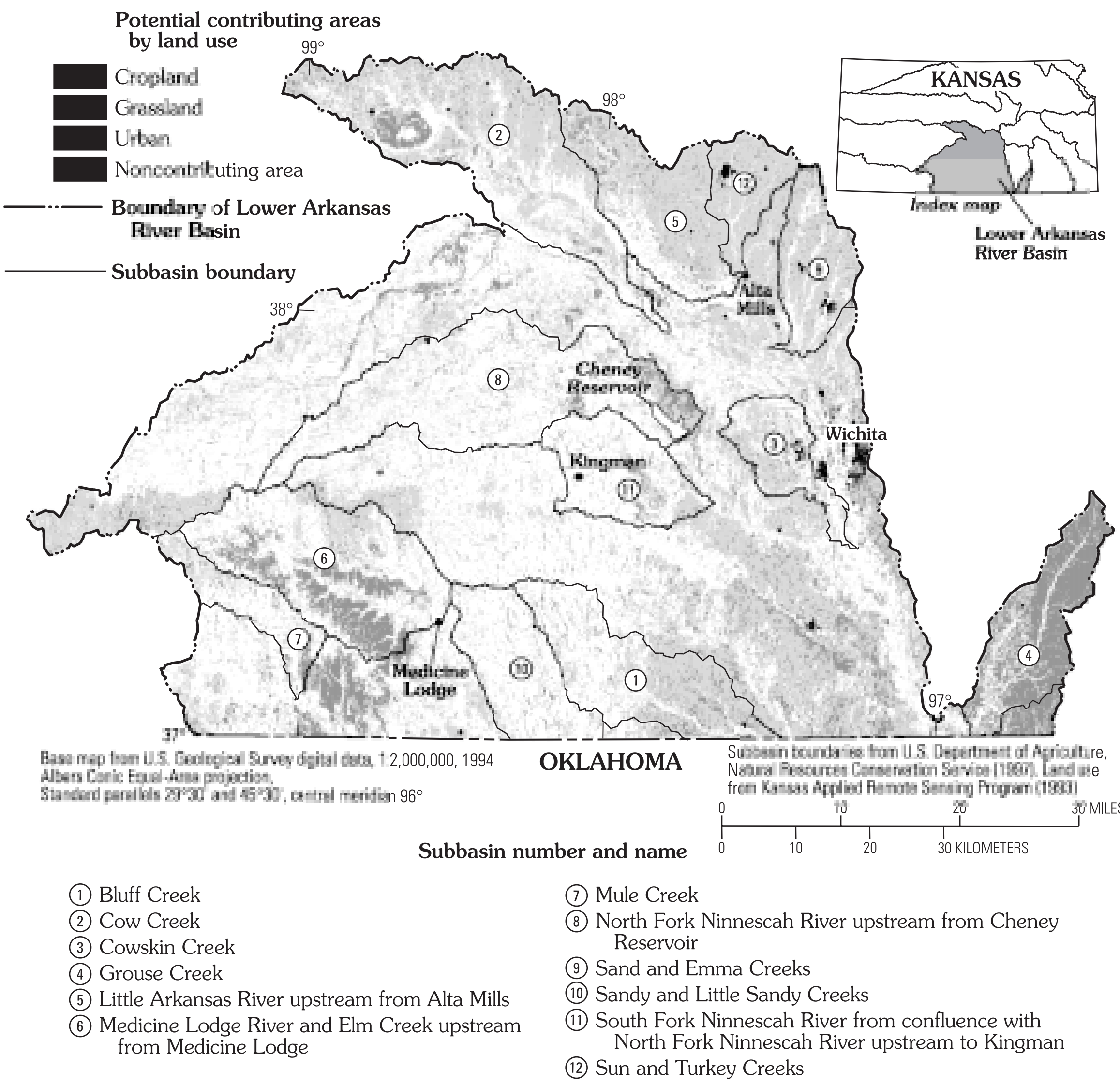

Figure 1. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows for very low potential-runoff conditions in the Lower Arkansas River Basin, Kansas.

Table 1. Potential contributing areas for combined infiltration- and saturation-excess overland flows, and land use for selected subbasins in the Lower Arkansas River Basin, south-central Kansas

[P, soil permeability, in inches per hour; TWI, topographic wetness index. Land-use data from Kansas Applied Remote Sensing Program (1993)]

Subbasin number (fig. 1)	Mean P	Mean TWI	Potential contributing area, in percentage of subbasin, for selected potential-runoff conditions			Land use, in percentage of subbasin			
			Low potential runoff	Very low potential runoff	Extremely low potential runoff	Cropland	Grassland	Woodland	Urban
1	1.4	10.8	85.9	49.4	33.1	69.8	29.1	0.7	0.3
2	1.6	10.9	88.3	62.0	14.8	76.7	20.0	.9	1.4
3	1.9	11.4	89.5	54.1	17.7	76.1	14.9	1.0	6.7
4	.5	10.2	100	86.0	61.9	10.9	85.3	3.2	.1
5	2.4	11.0	86.4	71.5	24.3	66.5	31.8	1.2	.3
6	2.5	10.0	74.8	39.1	25.3	23.2	75.5	1.0	.2
7	2.9	9.9	71.8	28.9	11.7	23.6	75.8	.6	0
8	5.0	11.1	60.7	25.0	9.9	72.7	24.5	1.0	.2
9	.5	11.2	98.2	79.4	73.8	86.6	9.3	1.1	2.4
10	3.4	10.6	66.0	15.4	6.5	44.9	54.6	.4	.1
11	2.9	10.9	77.3	22.3	13.7	57.9	37.8	3.0	0.6
12	.5	11.1	100	94.7	31.6	90.0	6.3	.7	2.7

subbasin, 2 had potential contributing areas in 30 to 50 percent of each subbasin, 6 had potential contributing areas in 10 to 30 percent of each subbasin, and 2 had potential contributing areas in less than 10 percent of each subbasin (table 1).

The subbasins were categorized as having relatively high, moderate, or low potential for runoff using the average percentage of contributing areas for very low and extremely low potential-runoff conditions. The very low and extremely low potential-runoff conditions are meaningful because they provide the best ability to distinguish subbasins and because the 1.14 and 0.57 in/hr rainfall intensities occur more frequently than the higher rainfall intensities. A subbasin was categorized as having relatively high potential for runoff if the average percentage of contributing areas for the very low and extremely low potential-runoff conditions was greater than 70 percent. A subbasin was categorized as having relatively low potential for runoff if the average percentage of contributing areas for the very low and extremely low potential-runoff conditions was less than 30 percent. The subbasins having relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) are Grouse Creek (subbasin 4) and Sand and Emma Creeks (subbasin 9). The subbasins having relatively low potential for runoff (average percentage of contributing areas less than 30 percent) are Mule Creek (subbasin 7), the North Fork Ninnescah River upstream from Cheney Reservoir (subbasin 8), Sandy and Little Sandy Creeks (subbasin 10), and the South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 11). The remaining subbasins have a relatively moderate potential for runoff (average percentage of contributing areas between 30 and 70 percent).

The spatial distribution of potential contributing areas for very low potential-runoff conditions varies considerably across the Lower Arkansas River Basin (figure 1). For Bluff Creek (subbasin 1) and the South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 11), most of the potential contributing areas are located in the downstream half of the subbasins. For Cow Creek (subbasin 2), Cowskin Creek (subbasin 3), and the Medicine Lodge River and Elm Creek upstream from Medicine Lodge (subbasin 6), the potential contributing areas are widespread with several areas of concentration. Potential contributing areas for the Little Arkansas River upstream from Alta Mills (subbasin 5) are widespread and uniformly distributed with the notable exception of a large noncontributing area located in the downstream half of the subbasin. For Mule Creek (subbasin 7), most of the potential contributing areas are located in the upstream and downstream one-thirds of the subbasin. Potential contributing areas for the North Fork Ninnescah River upstream from Cheney Reservoir (subbasin 8) are widely scattered with the exception of a large potential contributing area immediately north of Cheney Reservoir. Elsewhere, the potential contributing areas are widespread with a generally uniform distribution for Grouse Creek (subbasin 4), Sand and Emma Creeks (subbasin 9), and Sun and Turkey Creeks (subbasin 12). For Sandy and Little Sandy Creeks (subbasin 10), the potential contributing areas are generally sparse and widely scattered.

Land use in the subbasins of the Lower Arkansas River Basin is dominated by cropland or grassland. Cropland ranges from 10.9 percent of the subbasin for Grouse Creek (subbasin 4) to 90.0 percent for Sun and Turkey Creeks (subbasin 12). Grassland ranges from 6.3 percent of the subbasin for Sun and Turkey Creeks (subbasin 12) to 85.3 percent for Grouse Creek (subbasin 4) (table 1). The spatial pattern of land use in the potential contributing areas varies among the subbasins (figure 1). Throughout the Lower Arkansas River Basin and statewide, the use of BMP's may be most effective at reducing runoff if implemented in the potential contributing areas where cropland and (or) urban land uses are widespread.

SUMMARY AND CONCLUSIONS

Digital topographic, soil, and land-use information was used to estimate and compare potential runoff-contributing areas for subbasins throughout Kansas. Potential contributing areas were estimated collectively for the processes of infiltration-excess and saturation-excess overland flow using a set of environmental conditions that represented very high, high, moderate, low, very low, and extremely low potential for runoff (in relative terms). Various rainfall-intensity and soil-permeability values were used to represent the threshold conditions at which infiltration-excess overland flow may occur. Antecedent soil-moisture conditions and a topographic wetness index (TWI) were used to represent the threshold conditions at which saturation-excess overland flow may occur.

Statewide results indicated that nearly all subbasins had a large percentage of potential runoff-contributing areas for the low to very high potential-runoff conditions. Thus, the ability to distinguish subbasins as having relatively high, moderate, or low potential for runoff for those conditions was very limited. The best statewide ability to quantitatively distinguish subbasins as having relatively high, moderate, or low potential for runoff, on the basis of the percentage of potential runoff-contributing areas within each subbasin, was provided by the very low potential-runoff conditions (soil permeability less than or equal to 1.14 inches per hour and TWI greater than or equal to 14.4). The best ability to qualitatively compare potential for runoff among areas within individual subbasins was provided by the very low and (or) extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 inch per hour and TWI greater than or equal to 16.3). These results are evident in the example provided by the Lower Arkansas River Basin.

The ability to distinguish subbasins, as well as areas within subbasins, as having relatively high, moderate, or low potential for runoff was mostly due to the variability of soil permeability across the State. Because of this variability, the percentage of potential contributing areas for infiltration-excess overland flow varied considerably among the subbasins, especially for the very low potential-runoff conditions. In contrast, the topographic wetness index had a more spatially consistent distribution that typically followed the drainage networks within the subbasins. Because of this uniformity, the relative differences among subbasins in the percentage of potential contributing areas for saturation-excess overland flow remained typically small across the range of potential-runoff conditions despite substantial within-subbasin differences as the potential contributing areas expanded or contracted in response to changing conditions.

Together, the potential contributing areas for infiltration-excess and saturation-excess overland flows provide an understanding of how the spatial distribution of such areas may change in response to changes in environmental conditions. Under low potential-runoff conditions characterized by low antecedent soil moisture and low rainfall intensity, potential contributing areas for infiltration-excess and saturation-excess overland flows are limited to areas of lower soil permeability and saturated areas adjacent to rivers and streams, respectively. As antecedent soil moisture and rainfall intensity increase, the spatial distribution of the potential contributing areas for both infiltration-excess and saturation-excess overland flows increases. Under high potential-runoff conditions characterized by high antecedent soil moisture and high rainfall intensity, the distinction between infiltration-excess and saturation-excess overland flow becomes less meaningful as the ground becomes increasingly saturated and the potential contributing areas for both runoff processes coalesce.

In general, subbasins in eastern Kansas have higher potential for runoff than subbasins in western Kansas for the very low potential-runoff conditions. In eastern Kansas soil permeability generally is less, and precipitation typically is greater. The spatial distribution of potential contributing areas within the individual subbasins showed considerable variability, as is apparent in the Lower Arkansas River Basin. In many subbasins, the flood plains were determined to be mostly noncontributing areas for overland flow due to relatively high soil permeability. However, such areas may still represent a risk to in-stream water quality as contaminants may reach the streams through subsurface flow.

Land use in Kansas is predominantly cropland and grassland. The spatial pattern of land use varies regionally as well as between and within the subbasins. Potential runoff-contributing areas with high percentages of cropland and (or) urban land uses would be expected to have higher potential for runoff compared to similar areas with high percentages of grassland and (or) woodland. Implementation of BMP's in potential runoff-contributing areas with high percentages of cropland and (or) urban land uses is likely to be more effective at reducing runoff compared to similar areas with high percentages of grassland and (or) woodland. The spatial distribution of potential contributing areas, in combination with the superimposed land-use patterns, may be used to help identify and prioritize subbasin areas for the implementation of BMP's to reduce runoff and meet Federally mandated TMDL requirements.

This study had some limitations. The potential runoff-contributing areas that were determined may over or under estimate actual contributing areas for a particular location and precipitation event. A variety of factors may account for differences between potential and actual contributing areas including vegetation (type and density), soil compaction, impervious surfaces, BMP's, and climatic variability. Such factors were not addressed in this study.

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