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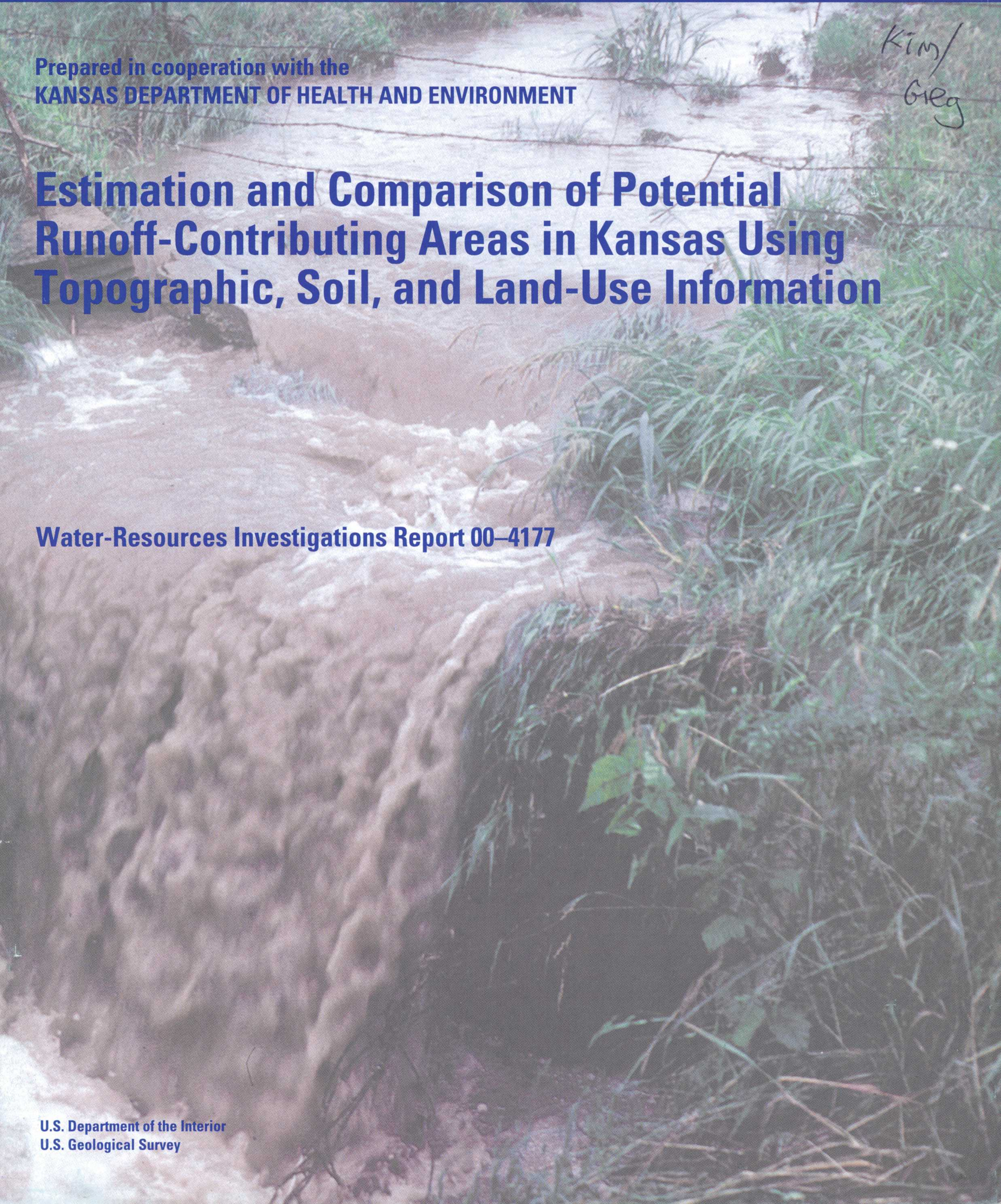

Prepared in cooperation with the
KANSAS DEPARTMENT OF HEALTH AND ENVIRONMENT

Estimation and Comparison of Potential Runoff-Contributing Areas in Kansas Using Topographic, Soil, and Land-Use Information

Water-Resources Investigations Report 00–4177

U.S. Department of the Interior
U.S. Geological Survey

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By KYLE E. JURACEK

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Lawrence, Kansas
2000

U.S. Department of the Interior
Bruce Babbitt, Secretary

U.S. Geological Survey
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Box 25286, Federal Center
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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 meter (m^2)	10.76	square foot
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.

Estimation and Comparison of Potential Runoff-Contributing Areas in Kansas Using Topographic, Soil, and Land-Use Information

By Kyle E. Juracek

Abstract

Digital topographic, soil, and land-use information was used to estimate potential runoff-contributing areas in Kansas. The results were used to compare 91 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, in relative terms, very high, high, moderate, low, very low, and extremely low potential for runoff. 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 subbasins with relatively high potential for runoff are located in the eastern half of the State where soil permeability is generally less and precipitation is typically greater. The ability to distinguish subbasins as having relatively high, moderate, or low potential for runoff was possible 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 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 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 selected subbasins throughout the State.

This study is a refinement of recently completed studies by Juracek (1999a,b), which also estimated potential runoff-contributing areas in Kansas. As compared to the previous studies, this study used more spatially detailed topographic and soil information and also incorporated land-use information. This study was made possible in part by support from the Kansas State Water Plan Fund.

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 91 selected subbasins in Kansas (fig. 1). The methods presented in this report may be applicable nationwide as related to the development of TMDL's and the identification and prioritization of subbasin areas for the implementation of best-management practices (BMP's).

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 (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).

Historically, infiltration-excess overland flow has been assumed to be the most important runoff process in Midwestern agricultural areas. More recently, saturation-excess overland flow has been considered an important runoff process and is the subject of ongoing research (Western and others, 1999).

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, characteristics such 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 (Novotny and Chesters, 1981; Novotny, 1995). 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 report.

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 topography and soils with high percentages of grassland and (or) woodland. Moreover, areas classified as noncontributing on the basis of topographic and soil 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.

The spatial distribution of land-use types within a basin also may be important. For example, in a basin with a land-use mix of 75 percent grassland and 25 percent cropland, it might be assumed that chemicals used in crop production are not a major water-quality issue. However, if most of that cropland is located next to the streams, the short flow paths between the fields and the streams may result in substantial amounts of field-applied chemicals entering the streams by overland and (or) subsurface flows unless effective BMP's are implemented (Suszkiw and others, 1998).

Description of Kansas

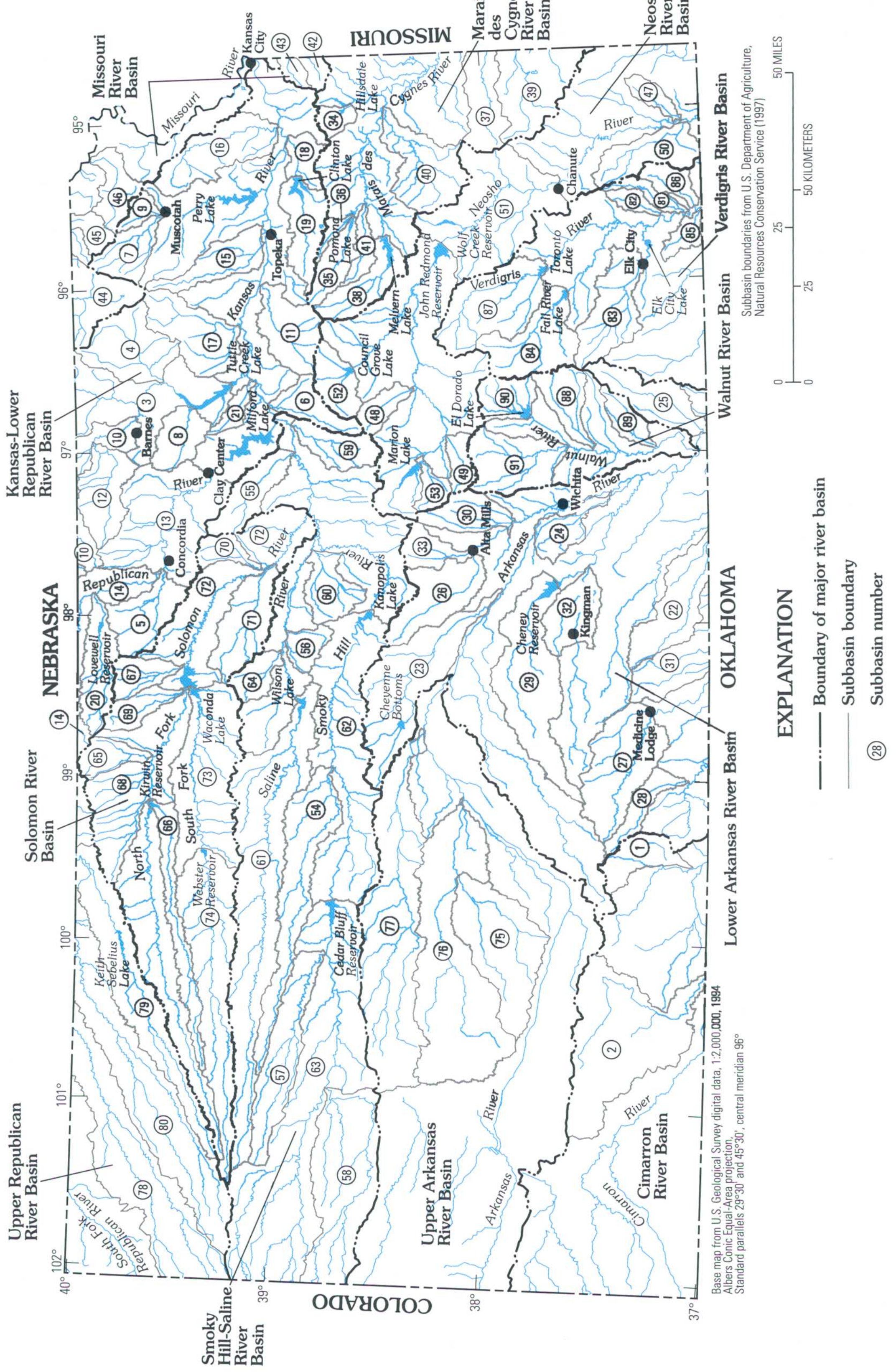
Kansas encompasses an area of about 82,000 mi^2. Major river basins in Kansas are the Cimarron, Kansas-Lower Republican, Lower Arkansas, Marais des Cygnes, Missouri, Neosho, Smoky Hill-Saline, Solomon, Upper Arkansas, Upper Republican, Verdigris, and Walnut (fig. 1). Numerous Federal reservoirs are located throughout the eastern two-thirds of the State. Land use is predominantly agricultural with cropland, grassland, and woodland accounting for 53.0, 42.7, and 2.5 percent of the State, respectively. On the flood plains, grassland appears to dominate in western Kansas, whereas cropland dominates in eastern Kansas (fig. 3). Urban land use accounts for about 1 percent of the State (Kansas Applied Remote Sensing Program, 1993).

Terrain varies throughout Kansas and includes flat plains, rolling hills, sandhills, and steep slopes (Moody and others, 1986). Depth-weighted, mean soil permeability ranges from 0 to about 17.6 in/hr, with a mean of about 1.6 in/hr. The highest soil-permeability values occur in the Cimarron and Upper and Lower Arkansas River Basins of southwest and south-central Kansas. Soil permeability also is generally higher in the western half of the State. Across the State, soil permeability is typically higher in the flood plains of the major rivers and streams (fig. 4) (U.S. Department of Agriculture, Natural Resources Conservation Service, 1996). Mean annual precipitation ranges from about 15 in. or less in extreme western Kansas to about 40 in. in the southeast (Paulson and others, 1991).

The major river basins having relatively high potential for runoff are the Kansas-Lower Republican, Marais des Cygnes, Missouri, Neosho, Verdigris, and Walnut. These basins are located in eastern Kansas where soil permeability generally is less and precipitation typically is greater. The major river basins having relatively low potential for runoff are the Cimarron, Lower Arkansas, Smoky Hill-Saline, Solomon, Upper Arkansas, and Upper Republican. These basins are located in western Kansas where soil permeability generally is higher and precipitation typically is less (Juracek, 1999b).

ESTIMATION OF POTENTIAL RUNOFF-CONTRIBUTING AREAS

Within the State, 91 subbasins representing slope, soil, land-use, 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


NEBRASKA
OKLAHOMA
MISSOURI
COLORADO
Upper Republican River Basin
Solomon River Basin
Kansas-Lower Republican River Basin
Missouri River Basin
Smoky Hill-Saline River Basin
Upper Arkansas River Basin
Lower Arkansas River Basin
Cimarron River Basin
Walnut River Basin
Verdigris River Basin
Neosho River Basin
Marais des Cygnes River Basin
Kansas City
Topeka
Muscotah
Barnes
Clay Center
Concordia
Alta Mills
Wichita
Kingman
Medicine Lodge
Chanute
Elk City
Perry Lake
Clinton Lake
Pomona Lake
Melvern Lake
Hillsdale Lake
Tuttle Creek Lake
Milford Lake
Council Grove Lake
Marion Lake
El Dorado Lake
John Redmond Reservoir
Wolf Creek Reservoir
Toronto Lake
Fall River Lake
Elk City Lake
Cheney Reservoir
Kanopolis Lake
Wilson Lake
Waconda Lake
Lovewell Reservoir
Kirwin Reservoir
Webster Reservoir
Keith Sebelius Lake
Cedar Bluff Reservoir
Cheyenne Bottoms
Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°
Subbasin boundaries from U.S. Department of Agriculture, Natural Resources Conservation Service (1997)
0 25 50 MILES
0 25 50 KILOMETERS
EXPLANATION
Boundary of major river basin
Subbasin boundary
28 Subbasin number

EXPLANATION (continued)

Subbasins selected for analysis

Cimarron River Basin

(1) Cavalry Creek
(2) Crooked Creek

Kansas-Lower Republican River Basin

(3) Big Blue River upstream from Tuttle Creek Lake
(4) Black Vermillion River
(5) Buffalo Creek
(6) Clarks Creek
(7) Delaware River upstream from Muscotah
(8) Fancy Creek
(9) Grasshopper Creek
(10) Little Blue River upstream from Barnes
(11) Mill Creek (Wabaunsee County)
(12) Mill Creek (Washington County)
(13) Republican River between Concordia and Clay Center
(14) Republican River upstream from Concordia
(15) Soldier Creek
(16) Stranger Creek
(17) Vermillion Creek (Pottawatomie County)
(18) Wakarusa River downstream from Clinton Lake
(19) Wakarusa River upstream from Clinton Lake
(20) White Rock Creek
(21) Wildcat Creek

Lower Arkansas River Basin

(22) Bluff Creek
(23) Cow Creek
(24) Cowskin Creek
(25) Grouse Creek
(26) Little Arkansas River upstream from Alta Mills
(27) Medicine Lodge River and Elm Creek upstream from Medicine Lodge
(28) Mule Creek
(29) North Fork Ninnescah River upstream from Cheney Reservoir
(30) Sand and Emma Creeks
(31) Sandy and Little Sandy Creeks
(32) South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman
(33) Sun and Turkey Creeks

Marais des Cygnes River Basin

(34) Big Bull Creek upstream from Hillsdale Lake
(35) Dragoon Creek upstream from Pomona Lake
(36) Hundred and Ten Mile Creek upstream from Pomona Lake
(37) Little Osage River
(38) Marais des Cygnes River upstream from Melvern Lake
(39) Marmaton River
(40) Pottawatomie Creek
(41) Salt Creek

Missouri River Basin

(42) Blue River
(43) Indian and Tomahawk Creeks
(44) South Fork Big Nemaha River
(45) Walnut Creek
(46) Wolf River

Neosho River Basin

(47) Cherry Creek
(48) Diamond Creek
(49) Doyle Creek
(50) Labette Creek
(51) Neosho River between John Redmond Reservoir and Chanute
(52) Neosho River upstream from Council Grove Lake
(53) South Cottonwood River

Smoky Hill-Saline River Basin

(54) Big Creek
(55) Chapman Creek
(56) Elkhorn and Bullfoot Creeks
(57) Hackberry Creek
(58) Ladder Creek
(59) Lyon Creek
(60) Mulberry Creek
(61) Saline River upstream from Wilson Lake
(62) Smoky Hill River between Cedar Bluff Reservoir and Kanopolis Lake
(63) Smoky Hill River upstream from Cedar Bluff Reservoir
(64) Spillman Creek

Solomon River Basin

(65) Beaver Creek
(66) Bow Creek
(67) Limestone Creek (Jewell County)
(68) North Fork Solomon River between Kirwin Reservoir and Waconda Lake
(69) Oak Creek
(70) Pipe Creek
(71) Salt Creek
(72) Solomon River downstream from Waconda Lake
(73) South Fork Solomon River between Webster Reservoir and Waconda Lake
(74) South Fork Solomon River upstream from Webster Reservoir

Upper Arkansas River Basin

(75) Buckner Creek
(76) Pawnee River
(77) Walnut Creek

Upper Republican River Basin

(78) Beaver Creek
(79) Prairie Dog Creek
(80) Sappa Creek

Verdigris River Basin

(81) Big Hill Creek
(82) Drum Creek
(83) Elk River upstream from Elk City
(84) Fall River upstream from Fall River Lake
(85) Onion Creek
(86) Pumpkin Creek
(87) Verdigris River upstream from Toronto Lake

Walnut River Basin

(88) Little Walnut River
(89) Timber Creek
(90) Walnut River upstream from El Dorado Lake
(91) Whitewater River

Figure 1. Location of major river basins and selected subbasins in Kansas.

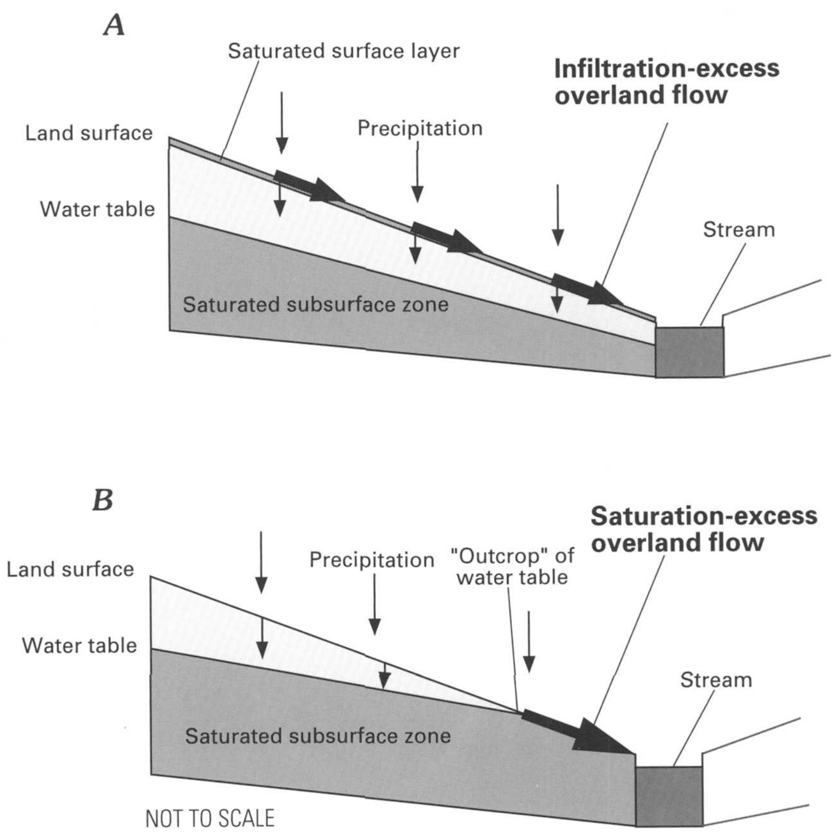


Figure 2. Schematic diagrams illustrating *(A)* infiltration-excess overland flow and *(B)* saturation-excess overland flow.

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 (ESRI, 2000).

Previously, Juracek (1999a,b) estimated potential runoff-contributing areas in Kansas using digital topographic and soil data in a grid (raster) format with a grid-cell size of 1 km^2. The digital data included the U.S. Department of Agriculture's (USDA) 1:250,000-scale, State soils geographic (STATSGO) data base (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 comparing potential runoff among areas hundreds of square kilometers in size. This statement is based on the fact that areas hundreds of square kilometers in size have sufficient numbers of unique STATSGO soil mapping units and elevation data points to compute representative mean values for the purpose of comparing areas. Thus, in Juracek (1999a,b) emphasis was placed on a comparison of potential contributing areas between, rather than within, the individual subbasins that ranged in size from about 150 to 6,600 km^2.

In this study, more spatially detailed 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 USDA's 1:24,000-scale soil data base (U.S. Department of Agriculture, Natural Resources Conservation Service, 1996), the USGS 100-m-resolution 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 study emphasis was placed on a comparison of potential contributing areas both between and within individual subbasins.

The soil information used in this study is currently being used by the USDA's Natural Resources Conservation Service to create a certified version of the 1:24,000-scale soil survey geographic (SSURGO) data base (U.S. Department of Agriculture, 1995) for Kansas. The quality of the soil information used in this study is the same as the quality of the soil information in the certified SSURGO data base (P.R. Finnell, Natural Resources Conservation Service, written commun., 2000).

The potential for infiltration-excess overland flow was estimated using the 1:24,000-scale soil-permeability digital data. As in Juracek (1999a,b), a depth-weighted, mean soil permeability was used. In the soil data base, soil permeability represents the infiltration rate when the soil is saturated (Soil Survey Staff, 1999). 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 (fig. 4). A modified version of the statewide, depth-weighted, mean soil permeability digital data set (Juracek, 2000a) is available from the Kansas GIS Data Access and Support Center in Lawrence, Kansas.

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 the selected 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 the 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:

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

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

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

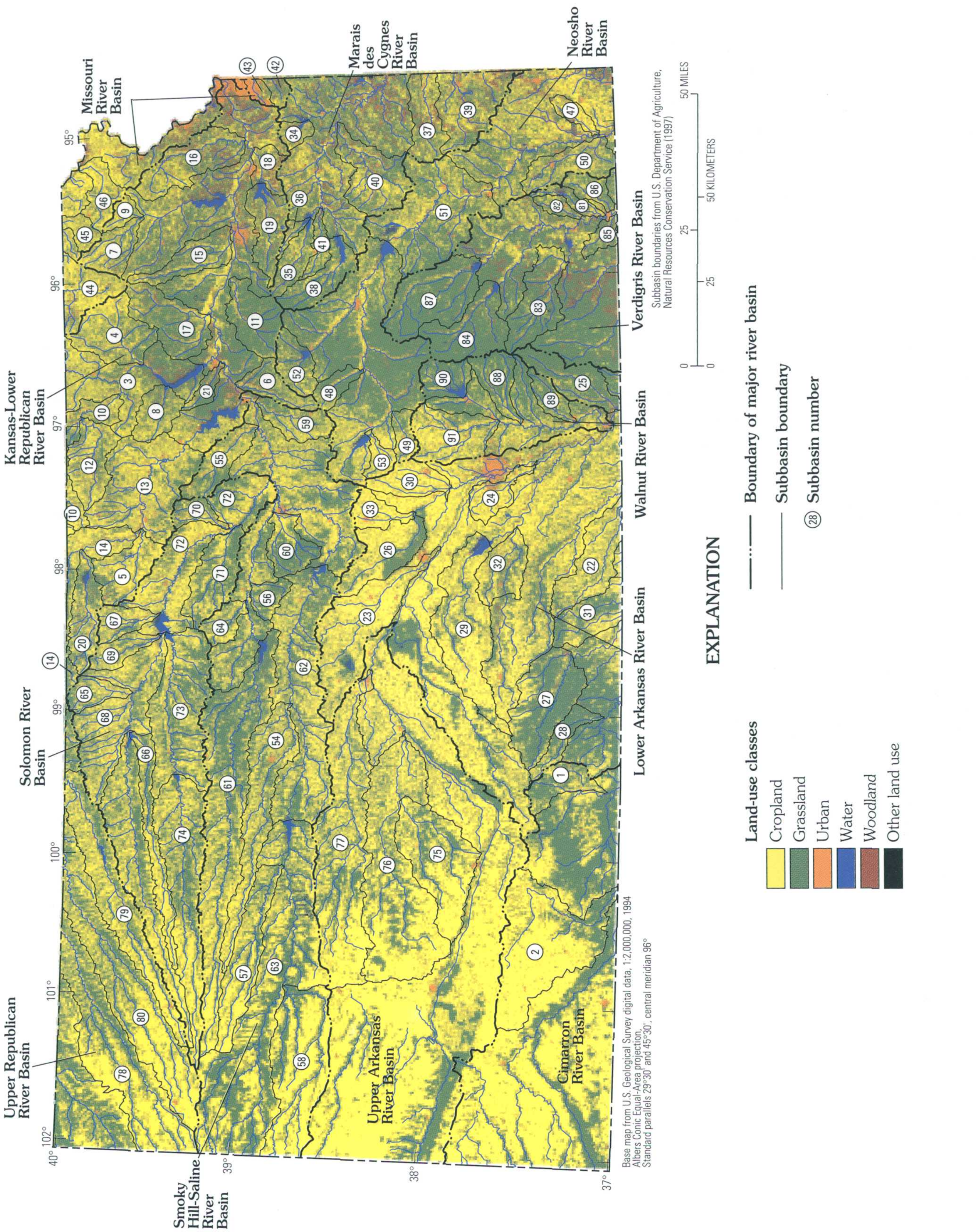
The resultant slope (gradient) grid then was used in combination with the flow-accumulation grid to compute TWI for each cell as:

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

Using GIS techniques, a statewide grid of TWI data was created (fig. 5).

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 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.

The combined potential for runoff in Kansas and the selected subbasins 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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Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°
Subbasin boundaries from U.S. Department of Agriculture,
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0 25 50 MILES
0 25 50 KILOMETERS
Land-use classes
Cropland
Grassland
Urban
Water
Woodland
Other land use
EXPLANATION
Boundary of major river basin
Subbasin boundary
28 Subbasin number

EXPLANATION (continued)

Subbasins selected for analysis

Cimarron River Basin

1 Cavalry Creek
2 Crooked Creek

Kansas-Lower Republican River Basin

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21 Wildcat Creek

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Smoky Hill-Saline River Basin

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Solomon River Basin

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72 Solomon River downstream from Waconda Lake
73 South Fork Solomon River between Webster Reservoir and Waconda Lake
74 South Fork Solomon River upstream from Webster Reservoir

Upper Arkansas River Basin

75 Buckner Creek
76 Pawnee River
77 Walnut Creek

Upper Republican River Basin

78 Beaver Creek
79 Prairie Dog Creek
80 Sappa Creek

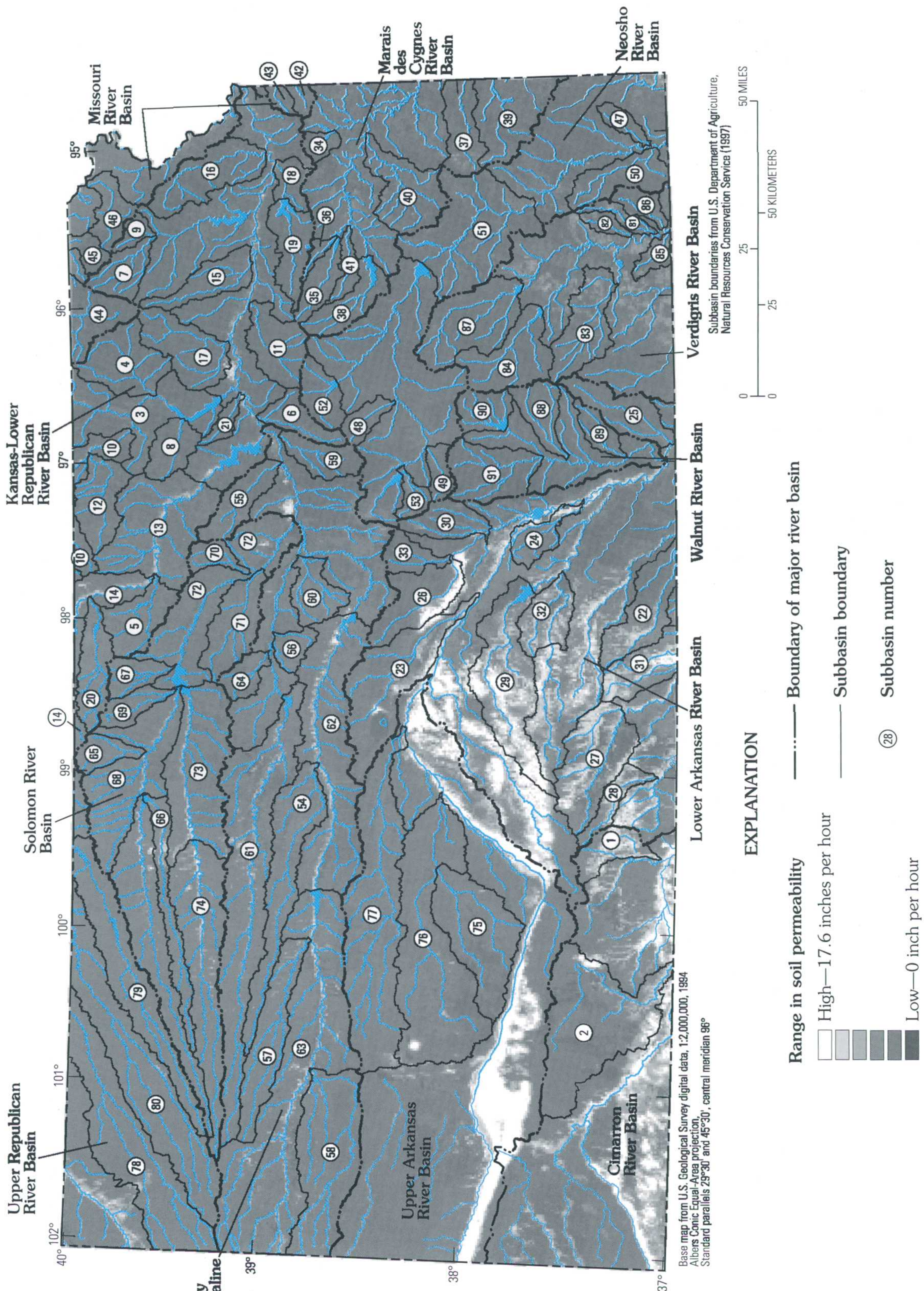
Verdigris River Basin

81 Big Hill Creek
82 Drum Creek
83 Elk River upstream from Elk City
84 Fall River upstream from Fall River Lake
85 Onion Creek
86 Pumpkin Creek
87 Verdigris River upstream from Toronto Lake

Walnut River Basin

88 Little Walnut River
89 Timber Creek
90 Walnut River upstream from El Dorado Lake
91 Whitewater River

Figure 3. Land use in Kansas, 1988–90 (source of data: Kansas Applied Remote Sensing Program, 1993).


Upper Republican River Basin
Smoky Hill-Saline River Basin
Solomon River Basin
Kansas-Lower Republican River Basin
Missouri River Basin
Marais des Cygnes River Basin
Neosho River Basin
Verdigris River Basin
Walnut River Basin
Lower Arkansas River Basin
Upper Arkansas River Basin
Cimarron River Basin
102°
101°
100°
99°
98°
97°
96°
95°
40°
39°
38°
37°
Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°
Subbasin boundaries from U.S. Department of Agriculture,
Natural Resources Conservation Service (1997)
0 25 50 MILES
0 25 50 KILOMETERS
EXPLANATION
Range in soil permeability
High—17.6 inches per hour
Low—0 inch per hour
Boundary of major river basin
Subbasin boundary
28 Subbasin number

EXPLANATION (continued)

Subbasins selected for analysis

Cimarron River Basin

1 Cavalry Creek
2 Crooked Creek

Kansas-Lower Republican River Basin

3 Big Blue River upstream from Tuttle Creek Lake
4 Black Vermillion River
5 Buffalo Creek
6 Clarks Creek
7 Delaware River upstream from Muscotah
8 Fancy Creek
9 Grasshopper Creek
10 Little Blue River upstream from Barnes
11 Mill Creek (Wabaunsee County)
12 Mill Creek (Washington County)
13 Republican River between Concordia and Clay Center
14 Republican River upstream from Concordia
15 Soldier Creek
16 Stranger Creek
17 Vermillion Creek (Pottawatomie County)
18 Wakarusa River downstream from Clinton Lake
19 Wakarusa River upstream from Clinton Lake
20 White Rock Creek
21 Wildcat Creek

Lower Arkansas River Basin

22 Bluff Creek
23 Cow Creek
24 Cowskin Creek
25 Grouse Creek
26 Little Arkansas River upstream from Alta Mills
27 Medicine Lodge River and Elm Creek upstream from Medicine Lodge
28 Mule Creek
29 North Fork Ninnescah River upstream from Cheney Reservoir
30 Sand and Emma Creeks
31 Sandy and Little Sandy Creeks
32 South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman
33 Sun and Turkey Creeks

Marais des Cygnes River Basin

34 Big Bull Creek upstream from Hillsdale Lake
35 Dragoon Creek upstream from Pomona Lake
36 Hundred and Ten Mile Creek upstream from Pomona Lake
37 Little Osage River
38 Marais des Cygnes River upstream from Melvern Lake
39 Marmaton River
40 Pottawatomie Creek
41 Salt Creek

Missouri River Basin

42 Blue River
43 Indian and Tomahawk Creeks
44 South Fork Big Nemaha River
45 Walnut Creek
46 Wolf River

Neosho River Basin

47 Cherry Creek
48 Diamond Creek
49 Doyle Creek
50 Labette Creek
51 Neosho River between John Redmond Reservoir and Chanute
52 Neosho River upstream from Council Grove Lake
53 South Cottonwood River

Smoky Hill-Saline River Basin

54 Big Creek
55 Chapman Creek
56 Elkhorn and Bullfoot Creeks
57 Hackberry Creek
58 Ladder Creek
59 Lyon Creek
60 Mulberry Creek
61 Saline River upstream from Wilson Lake
62 Smoky Hill River between Cedar Bluff Reservoir and Kanopolis Lake
63 Smoky Hill River upstream from Cedar Bluff Reservoir
64 Spillman Creek

Solomon River Basin

65 Beaver Creek
66 Bow Creek
67 Limestone Creek (Jewell County)
68 North Fork Solomon River between Kirwin Reservoir and Waconda Lake
69 Oak Creek
70 Pipe Creek
71 Salt Creek
72 Solomon River downstream from Waconda Lake
73 South Fork Solomon River between Webster Reservoir and Waconda Lake
74 South Fork Solomon River upstream from Webster Reservoir

Upper Arkansas River Basin

75 Buckner Creek
76 Pawnee River
77 Walnut Creek

Upper Republican River Basin

78 Beaver Creek
79 Prairie Dog Creek
80 Sappa Creek

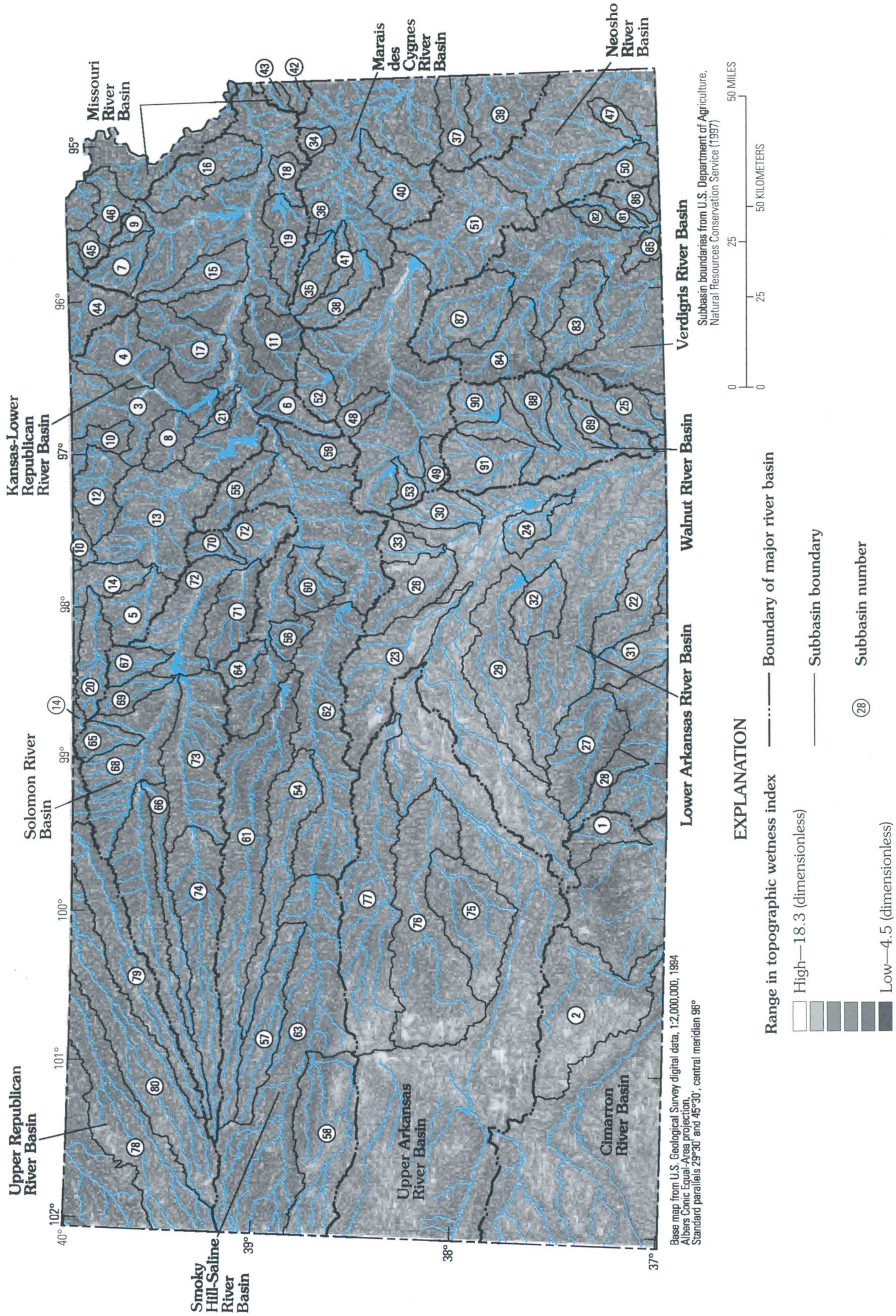
Verdigris River Basin

81 Big Hill Creek
82 Drum Creek
83 Elk River upstream from Elk City
84 Fall River upstream from Fall River Lake
85 Onion Creek
86 Pumpkin Creek
87 Verdigris River upstream from Toronto Lake

Walnut River Basin

88 Little Walnut River
89 Timber Creek
90 Walnut River upstream from El Dorado Lake
91 Whitewater River

Figure 4. Depth-weighted, mean soil permeability in Kansas (source of data: U.S. Department of Agriculture, Natural Resources Conservation Service, 1996).



Upper Republican River Basin
Solomon River Basin
Kansas-Lower Republican River Basin
Missouri River Basin
Marais des Cygnes River Basin
Neosho River Basin
Verdigris River Basin
Walnut River Basin
Lower Arkansas River Basin
Upper Arkansas River Basin
Cimarron River Basin
Smoky Hill-Saline River Basin
40°
39°
38°
37°
102°
101°
100°
99°
98°
97°
96°
95°
Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°
Subbasin boundaries from U.S. Department of Agriculture,
Natural Resources Conservation Service (1997)
0 25 50 MILES
0 25 50 KILOMETERS
EXPLANATION
Range in topographic wetness index
High—18.3 (dimensionless)
Low—4.5 (dimensionless)
Boundary of major river basin
Subbasin boundary
28 Subbasin number

EXPLANATION (continued)

Subbasins selected for analysis

Cimarron River Basin

1 Cavalry Creek
2 Crooked Creek

Kansas-Lower Republican River Basin

3 Big Blue River upstream from Tuttle Creek Lake
4 Black Vermillion River
5 Buffalo Creek
6 Clarks Creek
7 Delaware River upstream from Muscotah
8 Fancy Creek
9 Grasshopper Creek
10 Little Blue River upstream from Barnes
11 Mill Creek (Wabaunsee County)
12 Mill Creek (Washington County)
13 Republican River between Concordia and Clay Center
14 Republican River upstream from Concordia
15 Soldier Creek
16 Stranger Creek
17 Vermillion Creek (Pottawatomie County)
18 Wakarusa River downstream from Clinton Lake
19 Wakarusa River upstream from Clinton Lake
20 White Rock Creek
21 Wildcat Creek

Lower Arkansas River Basin

22 Bluff Creek
23 Cow Creek
24 Cowskin Creek
25 Grouse Creek
26 Little Arkansas River upstream from Alta Mills
27 Medicine Lodge River and Elm Creek upstream from Medicine Lodge
28 Mule Creek
29 North Fork Ninnescah River upstream from Cheney Reservoir
30 Sand and Emma Creeks
31 Sandy and Little Sandy Creeks
32 South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman
33 Sun and Turkey Creeks

Marais des Cygnes River Basin

34 Big Bull Creek upstream from Hillsdale Lake
35 Dragoon Creek upstream from Pomona Lake
36 Hundred and Ten Mile Creek upstream from Pomona Lake
37 Little Osage River
38 Marais des Cygnes River upstream from Melvern Lake
39 Marmaton River
40 Pottawatomie Creek
41 Salt Creek

Missouri River Basin

42 Blue River
43 Indian and Tomahawk Creeks
44 South Fork Big Nemaha River
45 Walnut Creek
46 Wolf River

Neosho River Basin

47 Cherry Creek
48 Diamond Creek
49 Doyle Creek
50 Labette Creek
51 Neosho River between John Redmond Reservoir and Chanute
52 Neosho River upstream from Council Grove Lake
53 South Cottonwood River

Smoky Hill-Saline River Basin

54 Big Creek
55 Chapman Creek
56 Elkhorn and Bullfoot Creeks
57 Hackberry Creek
58 Ladder Creek
59 Lyon Creek
60 Mulberry Creek
61 Saline River upstream from Wilson Lake
62 Smoky Hill River between Cedar Bluff Reservoir and Kanopolis Lake
63 Smoky Hill River upstream from Cedar Bluff Reservoir
64 Spillman Creek

Solomon River Basin

65 Beaver Creek
66 Bow Creek
67 Limestone Creek (Jewell County)
68 North Fork Solomon River between Kirwin Reservoir and Waconda Lake
69 Oak Creek
70 Pipe Creek
71 Salt Creek
72 Solomon River downstream from Waconda Lake
73 South Fork Solomon River between Webster Reservoir and Waconda Lake
74 South Fork Solomon River upstream from Webster Reservoir

Upper Arkansas River Basin

75 Buckner Creek
76 Pawnee River
77 Walnut Creek

Upper Republican River Basin

78 Beaver Creek
79 Prairie Dog Creek
80 Sappa Creek

Verdigris River Basin

81 Big Hill Creek
82 Drum Creek
83 Elk River upstream from Elk City
84 Fall River upstream from Fall River Lake
85 Onion Creek
86 Pumpkin Creek
87 Verdigris River upstream from Toronto Lake

Walnut River Basin

88 Little Walnut River
89 Timber Creek
90 Walnut River upstream from El Dorado Lake
91 Whitewater River

Figure 5. Topographic wetness index (TWI) data for Kansas.

(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 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 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 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 the selected 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 runoff-contributing areas within the selected subbasins.

The combined conditions used do not, nor were they intended to, represent all possible combinations of environmental conditions. For example, such common conditions as high-intensity rainfall on dry soils and low-intensity rainfall on wet soils were not included. However, because variability in soil permeability (rainfall intensity) has been shown to be more important than the TWI (soil moisture) for the purpose of distinguishing subbasins as having relatively high or low potential for runoff in Kansas (Juracek, 1999a,b), the omission of these conditions is not considered a shortcoming for the purpose of this study.

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, urban, and woodland 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 (figs. 6–41) 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.

Initially, the 14-digit hydrologic units were considered as a basis for assessing the spatial distribution of potential contributing areas within the subbasins. The number of 14-digit hydrologic units within a subbasin ranged from 1 for Hundred and Ten Mile Creek upstream from Pomona Lake (subbasin 36) to 61 for Smoky Hill River upstream from Cedar Bluff Reservoir (subbasin 63) (fig. 1). The mean number of 14-digit hydrologic units per subbasin was 13. Because the variability in the spatial distribution of potential contributing areas within the subbasins generally did not justify such discretization, the 14-digit hydrologic units were not used in this study. Instead, the terms "half," "third," or "fourth" were typically sufficient to describe the within-subbasin distribution of potential contributing areas.

POTENTIAL RUNOFF-CONTRIBUTING AREAS

Results of this study, as well as Juracek (1999a,b), indicated that the sets of environmental conditions that represented higher potential for runoff generally were not useful for the purpose of distinguishing subbasins as having relatively high 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 report, 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.

Important implications of the results include the relations between land use and the potential for runoff. For example, potential runoff-contributing areas with high percentages of cropland and (or) urban land uses would be expected to have a higher potential for runoff than similar areas with high percentages of grassland and (or) woodland. The appearance of shades of a specific color in figures 6–41 is an unavoidable result of the methods used to create the figures and is not of any interpretive significance. Thus, for example, light and dark green both indicate grassland.

Cimarron River Basin

In the Cimarron River Basin, the ability to distinguish subbasins as having relatively high or low potential for runoff was good for the low (fig. 6), very low (fig. 7), and extremely low (fig. 8) potential-runoff conditions (table 1). However, 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) provided the best ability to distinguish subbasins. For these conditions, Crooked Creek (subbasin 2) had substantially more potential contributing areas (65.8 percent) than Cavalry Creek (subbasin 1, 15.2 percent). In the Crooked Creek subbasin, most of the potential contributing areas are located in the upstream two-thirds of the subbasin. In the Cavalry Creek subbasin, the potential contributing areas are sparse and scattered, with a somewhat greater concentration in the upstream half of the subbasin (fig. 7). A statewide version of the digital data set that represents potential runoff-contributing areas for very low potential-runoff conditions (Juracek, 2000b) is available from the Kansas GIS Data Access and Support Center in Lawrence, Kansas.

Land use is substantially different within the two Cimarron River subbasins. In the Crooked Creek subbasin, land use is predominately cropland (81.2 percent) with little grassland (table 1). Accordingly, land use for the potential contributing areas in the subbasin is mostly cropland. Thus, potential for runoff for the potential contributing areas in the Crooked Creek subbasin may be higher than if the subbasin was predominantly grassland and (or) woodland. In contrast, land use in the Cavalry Creek subbasin is mostly grassland (63.6 percent) but with considerable cropland (35.6 percent) (table 1). In the upstream half of the subbasin, grassland appears to dominate. Thus,

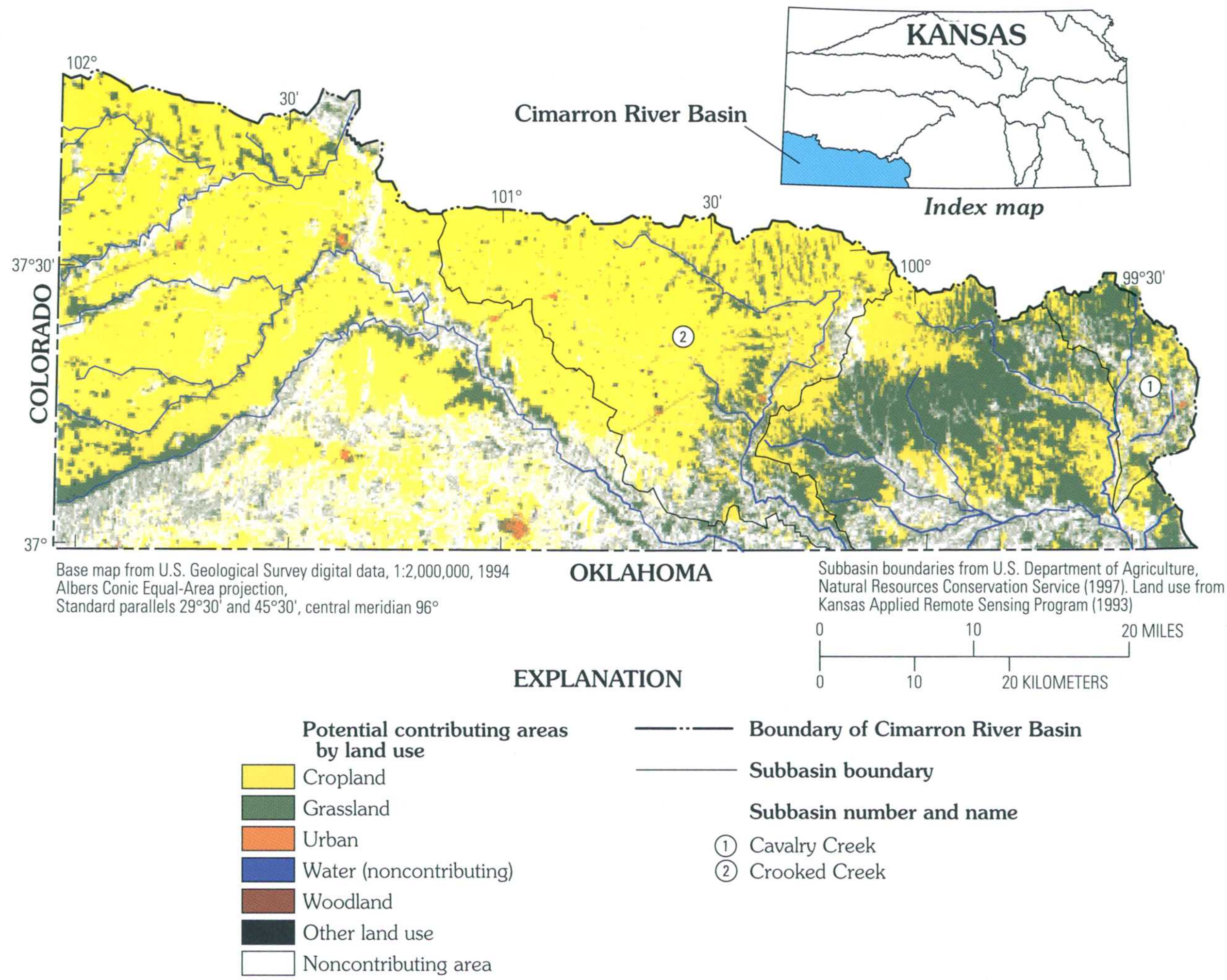


Figure 6. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Cimarron River Basin for low potential-runoff conditions.

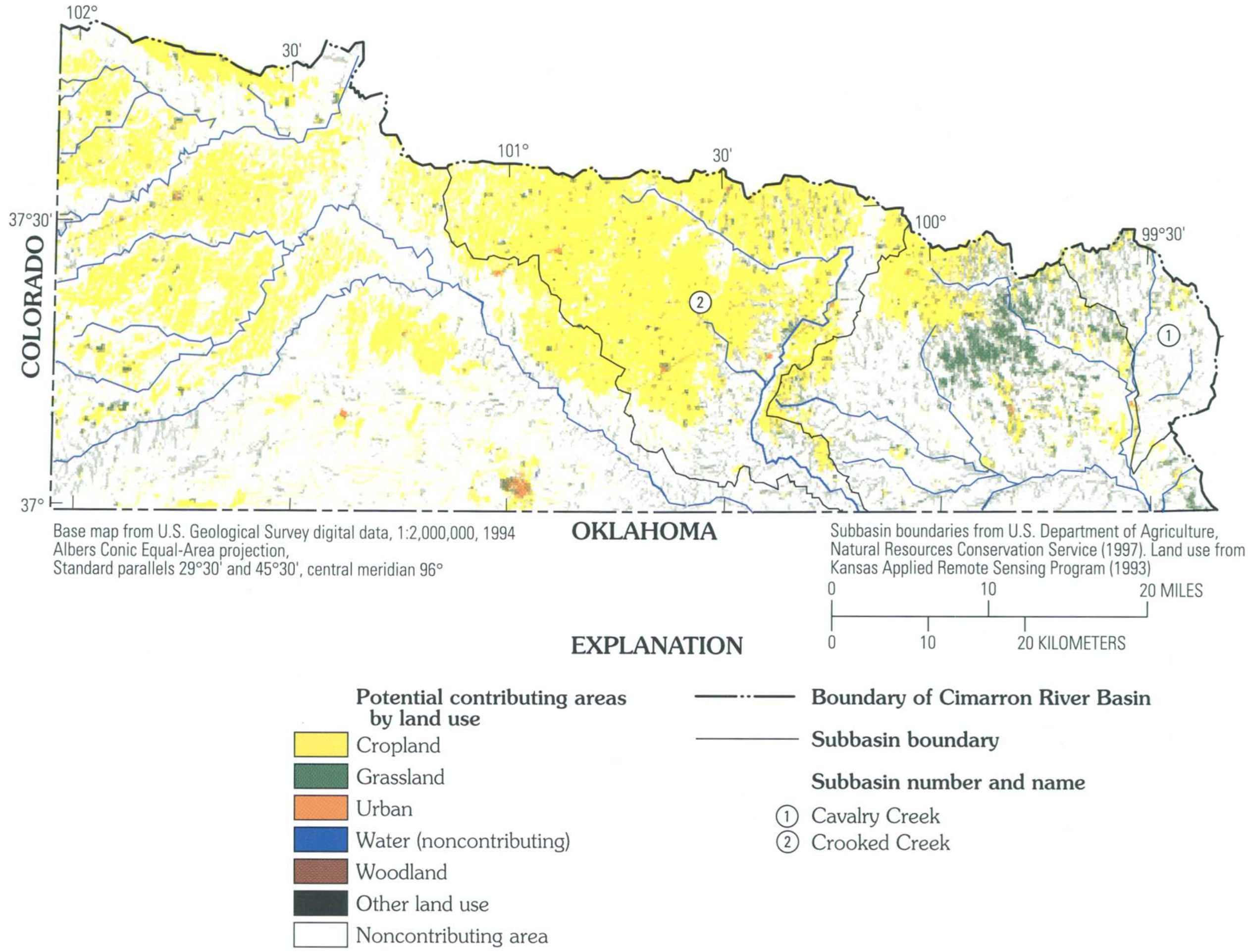


Figure 7. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Cimarron River Basin for very low potential-runoff conditions.

potential for runoff for the potential contributing areas in this part of the subbasin may be less than if the same areas were mostly cropland. In the downstream half of the subbasin, land use in the potential contributing areas appears to be a more balanced mix of cropland and grassland (fig. 6).

Kansas-Lower Republican River Basin

In the Kansas-Lower Republican River Basin, all 19 subbasins had potential contributing areas in greater than 90 percent of each subbasin for low potential-runoff conditions (fig. 9, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low (fig. 10), and especially the extremely low (fig. 11), potential-runoff conditions provided good ability to distinguish subbasins.

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 27.5 percent of the subbasin for White Rock Creek (subbasin 20) to 95.4 percent of the subbasin for Mill Creek (subbasin 11, Wabaunsee County). Of the 19 subbasins in the Kansas-Lower Republican River Basin, 4 had potential contributing areas in more than 90 percent of each subbasin, 12 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, and 1 had potential contributing areas in less than 30 percent of the subbasin (table 1).

For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), potential contributing areas ranged from 2.5 percent of the subbasin for the Republican River upstream from Concordia

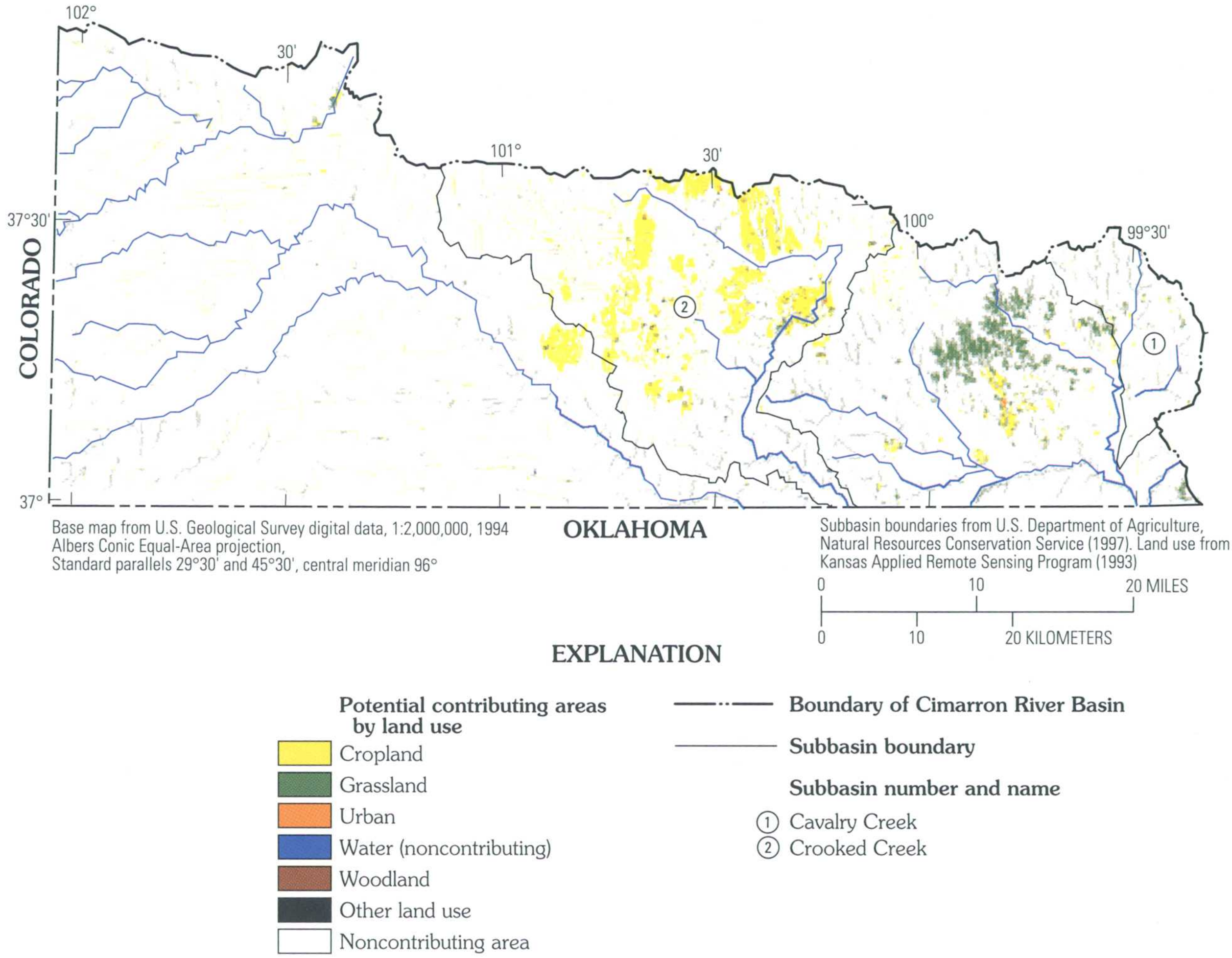


Figure 8. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Cimarron River Basin for extremely low potential-runoff conditions.

(subbasin 14) to 89.7 percent of the subbasin for Mill Creek (subbasin 11, Wabaunsee County). Of the 19 subbasins, 8 had potential contributing areas in 70 to 90 percent of each subbasin, 3 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, 1 had potential contributing areas in 10 to 30 percent of the subbasin, and 5 had potential contributing areas in less than 10 percent of each subbasin (table 1).

Using the very low and extremely low potential-runoff conditions, the subbasins were categorized as having either relatively high, moderate, or low potential for runoff. 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 in/hr 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 are located in the eastern two-thirds of the Kansas-Lower Republican River Basin and are the Big Blue River upstream from Tuttle Creek Lake (subbasin 3), the Black Vermillion River (subbasin 4), Clarks Creek (subbasin 6), the Delaware River upstream from Muscotah (subbasin 7), Grasshopper Creek (subbasin 9), Mill Creek (subbasin 11, Wabaunsee County), Soldier Creek (subbasin 15), Stranger Creek (subbasin 16), Vermillion Creek (subbasin 17, Pottawatomie County), the Wakarusa River upstream from Clinton Lake (subbasin 19), and Wildcat Creek

Table 1. Potential contributing areas for combined infiltration- and saturation-excess overland flows, and land use for selected subbasins in Kansas

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

			Potential contributing area, in percentage of subbasin, for selected potential-runoff conditions			Land use, in percentage of subbasin			
Subbasin number (fig. 1)	Mean P	Mean TWI	Low potential runoff[1]	Very low potential runoff[2]	Extremely low potential runoff[3]	Cropland	Grassland	Woodland	Urban
				Cimarron River Basin					
1	3.8	10.3	70.8	15.2	2.8	35.6	63.6	0.3	0.4
2	1.8	11.1	89.8	65.8	15.3	81.2	18.3	0	.2
				Kansas-Lower Republican River Basin					
3	.5	9.9	99.7	83.9	66.7	41.3	48.9	6.9	.3
4	.4	9.9	99.9	86.5	81.0	54.9	41.3	3.2	.3
5	1.0	10.2	99.2	71.9	9.8	65.9	29.6	3.7	.4
6	.4	9.9	100	90.6	84.5	30.9	62.6	6.2	.1
7	.4	10.0	100	89.8	84.3	52.7	41.2	5.6	.2
8	.6	9.9	100	88.5	41.0	43.4	52.6	3.5	.1
9	.4	10.2	100	91.9	87.8	65.3	30.6	2.0	1.2
10	.9	10.1	98.3	76.6	15.8	56.8	37.4	4.9	.2
11	.5	9.3	100	95.4	89.7	10.5	84.6	3.9	.2
12	.9	10.0	100	72.4	9.1	54.0	40.3	5.1	.3
13	1.1	10.2	97.4	66.6	6.0	61.2	33.5	4.4	.5
14	1.6	10.4	92.9	51.2	2.5	60.1	35.2	3.7	.2
15	0.5	10.2	99.5	88.9	66.7	30.0	62.8	6.0	.5
16	.5	10.1	99.3	89.6	75.1	39.3	48.3	11.1	.5
17	.5	9.7	99.4	89.5	82.5	24.7	68.4	6.5	.2
18	.7	10.1	97.2	76.0	49.6	38.1	40.3	15.0	4.6
19	.5	10.0	100	88.0	67.3	28.5	57.0	9.4	.5
20	1.2	10.0	99.7	27.5	4.8	44.5	48.3	5.9	.1
21	.6	9.9	99.2	91.7	72.1	21.8	65.0	8.4	4.2
				Lower Arkansas River Basin					
22	1.4	10.8	85.9	49.4	33.1	69.8	29.1	.7	.3
23	1.6	10.9	88.3	62.0	14.8	76.7	20.0	.9	1.4
24	1.9	11.4	89.5	54.1	17.7	76.1	14.9	1.0	6.7
25	.5	10.2	100	86.0	61.9	10.9	85.3	3.2	.1
26	2.4	11.0	86.4	71.5	24.3	66.5	31.8	1.2	.3
27	2.5	10.0	74.8	39.1	25.3	23.2	75.5	1.0	.2
28	2.9	9.9	71.8	28.9	11.7	23.6	75.8	.6	0
29	5.0	11.1	60.7	25.0	9.9	72.7	24.5	1.0	.2
30	.5	11.2	98.2	79.4	73.8	86.6	9.3	1.1	2.4
31	3.4	10.6	66.0	15.4	6.5	44.9	54.6	.4	.1

Table 1. Potential contributing areas for combined infiltration- and saturation-excess overland flows, and land use for selected subbasins in Kansas—Continued

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[1]	Very low potential runoff[2]	Extremely low potential runoff[3]	Cropland	Grassland	Woodland	Urban
			Lower Arkansas River Basin—Continued						
32	2.9	10.9	77.3	22.3	13.7	57.9	37.8	3.0	0.6
33	.5	11.1	100	94.7	31.6	90.0	6.3	.7	2.7
			Marais des Cygnes River Basin						
34	.5	10.3	100	75.9	63.4	38.6	48.3	7.1	.8
35	.4	10.1	100	91.2	74.7	34.3	58.6	4.2	1.0
36	.4	10.0	100	88.5	71.7	44.3	47.2	4.2	.3
37	.6	10.1	98.4	76.0	55.8	37.9	48.1	13.3	.2
38	.4	10.2	99.6	91.1	79.3	19.4	73.8	2.7	.1
39	.6	10.2	99.1	76.5	54.6	38.8	47.2	12.2	.8
40	.5	10.2	98.9	83.6	71.8	37.1	53.7	7.8	.6
41	.4	10.1	100	88.1	70.3	38.1	56.5	4.0	.9
			Missouri River Basin						
42	.8	10.1	100	57.4	45.8	27.5	57.0	11.3	2.5
43	.8	9.9	100	65.4	49.7	13.8	29.4	6.0	50.3
44	.4	9.9	100	87.6	82.2	66.8	26.6	5.9	.4
45	.6	10.2	100	82.0	71.5	64.8	31.6	2.2	.8
46	.9	10.1	100	54.0	38.2	70.8	25.5	2.9	.6
			Neosho River Basin						
47	.6	10.8	99.9	74.3	66.7	68.1	20.2	8.9	.8
48	.4	10.0	100	93.7	74.4	18.9	78.1	2.7	.1
49	.4	10.5	99.9	85.7	77.6	50.7	46.8	1.8	.4
50	.5	10.6	99.6	81.6	73.3	41.4	51.6	3.4	2.2
51	.5	10.5	99.8	82.5	73.1	37.6	56.8	2.9	1.0
52	.3	10.2	100	97.2	84.8	29.8	64.1	3.5	.2
53	.5	10.6	100	72.1	66.2	77.6	19.9	1.7	.7
			Smoky Hill-Saline River Basin						
54	1.2	10.3	99.7	49.1	6.1	62.3	36.0	.6	.8
55	.9	10.1	99.8	67.7	17.5	43.8	52.3	3.4	.2
56	1.1	9.7	100	33.9	2.7	31.6	66.7	1.1	0
57	1.3	10.3	99.4	14.7	2.3	67.9	31.7	.1	.1
58	1.3	10.5	99.1	32.9	2.2	74.4	25.5	0	0
59	.3	10.2	100	91.9	84.0	47.6	48.6	2.7	.5
60	1.1	10.0	99.1	40.8	12.9	27.8	68.0	1.9	1.6
61	1.4	10.0	97.6	27.2	6.8	47.5	50.9	.7	.1
62	1.4	10.2	96.9	56.7	5.1	51.5	46.5	1.0	.3
63	1.7	10.1	94.8	19.9	6.1	50.6	48.2	.1	0

Table 1. Potential contributing areas for combined infiltration- and saturation-excess overland flows, and land use for selected subbasins in Kansas—Continued

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[1]	Very low potential runoff[2]	Extremely low potential runoff[3]	Cropland	Grassland	Woodland	Urban
Smoky Hill-Saline River Basin—Continued									
64	.9	10.0	100	65.6	9.8	54.1	44.3	1.1	0
Solomon River Basin									
65	1.2	10.0	99.9	33.3	1.5	51.5	45.2	2.5	.5
66	1.5	10.2	96.0	4.6	1.0	70.0	28.8	1.0	0
67	1.1	10.1	99.6	57.9	8.7	58.0	38.3	3.4	.1
68	1.2	10.0	99.0	33.5	2.6	59.7	38.0	1.8	.3
69	1.1	10.0	99.9	59.2	5.7	54.9	42.4	2.3	.1
70	1.0	10.0	100	60.4	10.5	44.7	50.7	4.0	.2
71	1.0	9.9	100	55.1	9.7	43.8	54.5	1.3	0
72	1.0	10.3	99.5	67.3	11.2	60.4	34.7	2.7	.4
73	1.3	10.0	97.5	54.6	6.1	50.0	48.7	.9	.2
74	1.6	10.2	97.2	6.9	1.6	61.1	37.8	.6	.2
Upper Arkansas River Basin									
75	.9	10.5	99.9	66.4	18.5	68.7	30.7	.1	.2
76	1.1	10.6	98.8	67.3	8.8	71.1	28.3	.1	0
77	1.1	10.5	99.4	60.4	3.5	69.6	29.5	.2	.6
Upper Republican River Basin									
78	1.3	10.3	99.0	5.5	1.4	65.0	34.6	.2	.1
79	1.3	10.2	99.8	5.4	2.1	67.0	31.8	.6	.4
80	1.3	10.3	99.9	4.9	1.3	67.7	31.7	.3	.2
Verdigris River Basin									
81	.7	10.3	90.4	66.5	60.8	33.0	57.1	6.6	.6
82	.8	10.2	90.1	64.6	57.3	31.5	61.9	4.7	1.3
83	.7	10.3	94.7	76.1	67.1	15.1	78.0	5.4	.3
84	.4	9.9	100	95.6	84.0	4.4	90.3	3.3	.3
85	1.0	10.3	81.5	54.5	49.0	24.6	65.9	6.6	2.6
86	.5	10.6	99.1	80.0	73.8	33.4	62.6	2.5	.3
87	.4	10.2	99.7	93.9	82.1	6.6	88.9	2.9	.1
Walnut River Basin									
88	.5	10.3	100	88.0	64.8	15.1	82.3	1.9	.1
89	.5	10.7	100	86.5	62.8	23.1	71.9	2.7	.7
90	.4	10.7	100	91.9	82.0	11.9	80.9	1.1	.1
91	.3	10.9	100	92.3	87.0	64.6	32.3	1.9	.5

[1]Low potential runoff = soil permeability less than or equal to 1.71 inches per hour and topographic wetness index greater than or equal to 12.4
[2]Very low potential runoff = soil permeability less than or equal to 1.14 inches per hour and topographic wetness index greater than or equal to 14.4
[3]Extremely low potential runoff = soil permeability less than or equal to 0.57 inch per hour and topographic wetness index greater than or equal to 16.3.

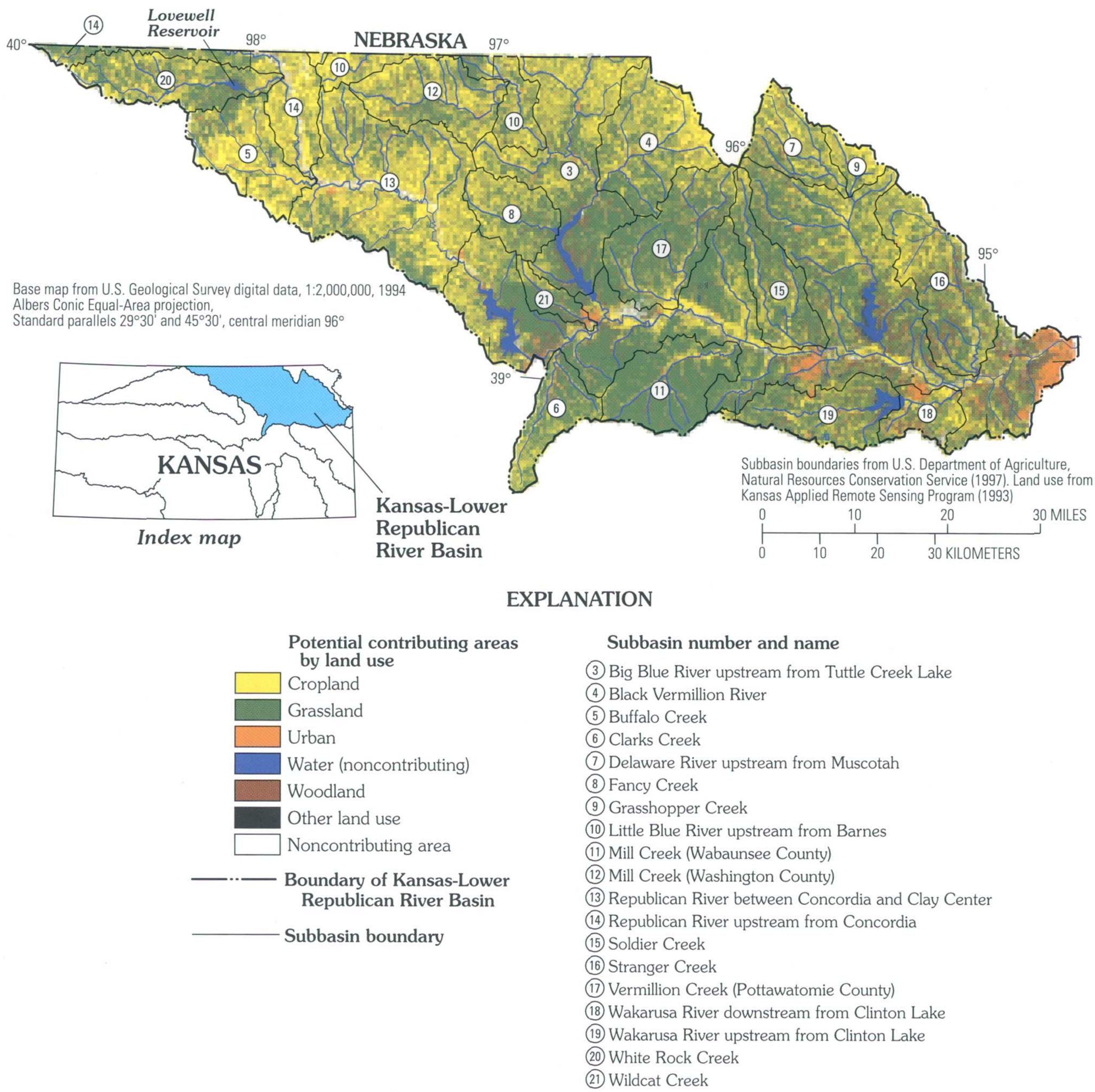
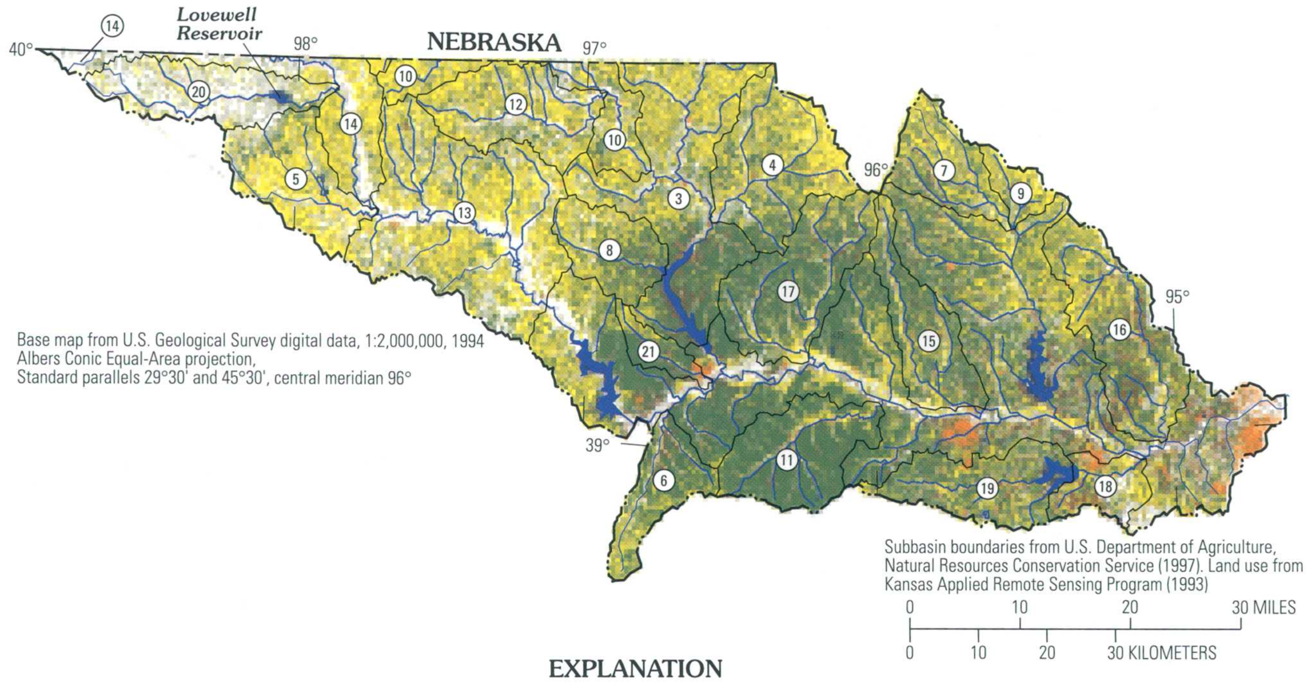


Figure 9. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Kansas-Lower Republican River Basin for low potential-runoff conditions.

(subbasin 21). The subbasins having relatively low potential for runoff are located in the western one-third of the Kansas-Lower Republican River Basin and are the Republican River upstream from Concordia (subbasin 14) and White Rock Creek (subbasin 20) (figs. 10, 11; table 1). The remaining subbasins have relatively moderate potential for runoff (average percentage of contributing areas between 30 and 70 percent).

With a few exceptions noted in the following sentences, the potential contributing areas for very low potential-runoff conditions are widespread with a generally uniform spatial distribution within the individual subbasins. One exception is the Republican River upstream from Concordia (subbasin 14), for which most of the potential contributing areas are located in the downstream half of the subbasin. Another exception is White Rock Creek (subbasin 20), for which potential contributing areas are scattered except for a



EXPLANATION

Potential contributing areas by land use

- Cropland
- Grassland
- Urban
- Water (noncontributing)
- Woodland
- Other land use
- Noncontributing area

Boundary of Kansas-Lower Republican River Basin

Subbasin boundary

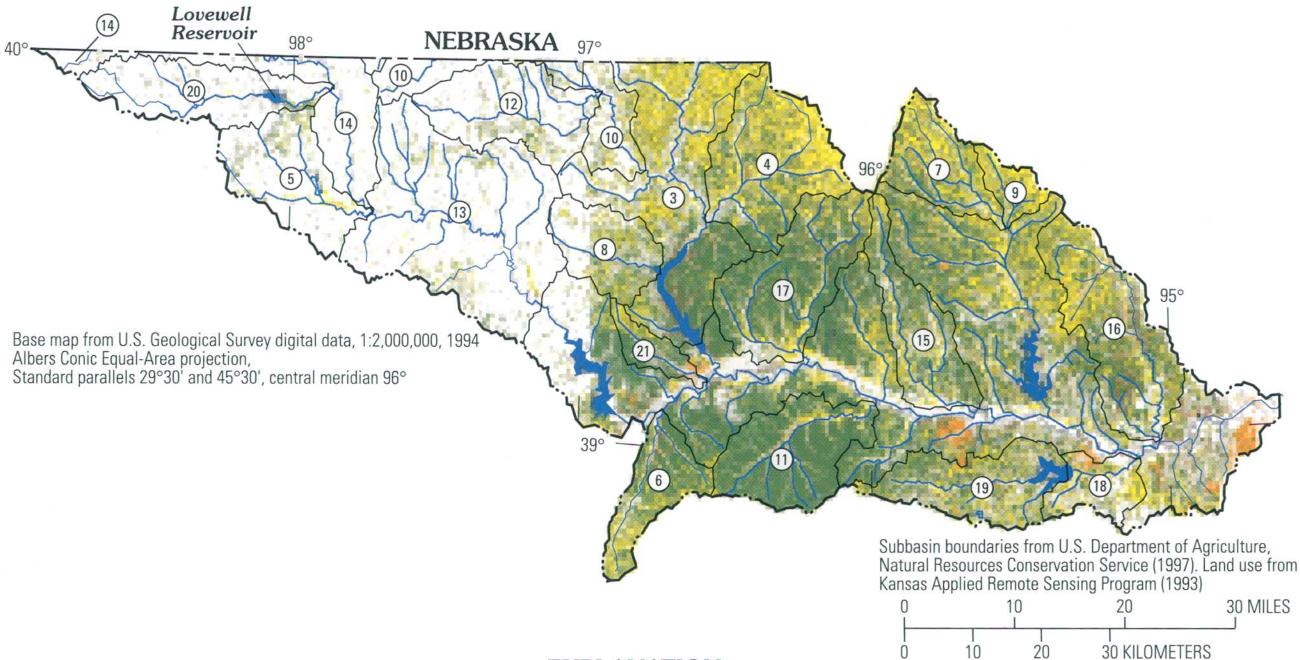
Subbasin number and name

3 Big Blue River upstream from Tuttle Creek Lake
4 Black Vermillion River
5 Buffalo Creek
6 Clarks Creek
7 Delaware River upstream from Muscotah
8 Fancy Creek
9 Grasshopper Creek
10 Little Blue River upstream from Barnes
11 Mill Creek (Wabaunsee County)
12 Mill Creek (Washington County)
13 Republican River between Concordia and Clay Center
14 Republican River upstream from Concordia
15 Soldier Creek
16 Stranger Creek
17 Vermillion Creek (Pottawatomie County)
18 Wakarusa River downstream from Clinton Lake
19 Wakarusa River upstream from Clinton Lake
20 White Rock Creek
21 Wildcat Creek

Figure 10. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Kansas-Lower Republican River Basin for very low potential-runoff conditions.

substantial concentration in the extreme eastern part of the subbasin downstream from Lovewell Reservoir. For the Wakarusa River downstream from Clinton Lake (subbasin 18), the potential contributing areas appear to be somewhat more concentrated in the upstream half of the subbasin. Flood plains are mostly noncontributing areas, and this pattern is particularly evident for the Republican River between Concordia and Clay Center (subbasin 13), and the Republican River upstream from Concordia (subbasin 14), and to a lesser extent for the Big Blue River upstream from Tuttle Creek Lake (subbasin 3), the Little Blue River upstream from Barnes (subbasin 10), and Mill Creek (subbasin 12, Washington County) (fig. 10).

The spatial distribution of potential contributing areas for the extremely low potential-runoff conditions shows a generally sparse and scattered pattern for Buffalo Creek (subbasin 5), the Little Blue River upstream from Barnes (subbasin 10), Mill Creek (subbasin 12, Washington County), the Republican River between



EXPLANATION

Potential contributing areas by land use

- Cropland
- Grassland
- Urban
- Water (noncontributing)
- Woodland
- Other land use
- Noncontributing area

Boundary of Kansas-Lower Republican River Basin

Subbasin boundary

Subbasin number and name

③ Big Blue River upstream from Tuttle Creek Lake
④ Black Vermillion River
⑤ Buffalo Creek
⑥ Clarks Creek
⑦ Delaware River upstream from Muscotah
⑧ Fancy Creek
⑨ Grasshopper Creek
⑩ Little Blue River upstream from Barnes
⑪ Mill Creek (Wabaunsee County)
⑫ Mill Creek (Washington County)
⑬ Republican River between Concordia and Clay Center
⑭ Republican River upstream from Concordia
⑮ Soldier Creek
⑯ Stranger Creek
⑰ Vermillion Creek (Pottawatomie County)
⑱ Wakarusa River downstream from Clinton Lake
⑲ Wakarusa River upstream from Clinton Lake
⑳ White Rock Creek
㉑ Wildcat Creek

Figure 11. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Kansas-Lower Republican River Basin for extremely low potential-runoff conditions.

Concordia and Clay Center (subbasin 13), the Republican River upstream from Concordia (subbasin 14), and White Rock Creek (subbasin 20). For Fancy Creek (subbasin 8), most of the potential contributing areas are located in the eastern half of the subbasin (although, because the break corresponds to a county boundary, which may affect the continuity of some types of data, the distinction is suspect). Likewise, most of the potential contributing area for the Big Blue River upstream from Tuttle Creek Lake (subbasin 3) appears to be located in the eastern two-thirds of the subbasin. For the remaining subbasins, potential contributing areas are widespread and distributed relatively uniformly within the individual subbasins (fig. 11).

Land use is quite variable among the subbasins (table 1). Cropland ranges from 10.5 percent of the subbasin for Mill Creek (subbasin 11, Wabaunsee County) to 65.9 percent for Buffalo Creek (subbasin 5). Grassland ranges from 29.6 percent of the subbasin for Buffalo Creek (subbasin 5) to 84.6 percent for Mill Creek (subbasin 11, Wabaunsee County). Several subbasins, in particular Stranger Creek (subbasin 16, 11.1 percent) and the Wakarusa River downstream from Clinton Lake (subbasin 18, 15.0 percent), have considerable woodland (table 1). Subbasins dominated by cropland are Buffalo Creek (subbasin 5, 65.9 percent), Grasshopper Creek (subbasin 9, 65.3 percent), the Little Blue River upstream from Barnes (subbasin 10, 56.8 percent), the Republican River between Concordia and Clay Center (subbasin 13, 61.2 percent), and the Republican River upstream from Concordia (subbasin 14, 60.1 percent). Subbasins dominated by grassland are Clarks Creek (subbasin 6, 62.6 percent), Mill Creek (subbasin 11, Wabaunsee County, 84.6 percent), Soldier Creek (subbasin 15, 62.8 percent), Vermillion Creek (subbasin 17, Pottawatomie County, 68.4 percent), the Wakarusa River upstream from Clinton Lake (subbasin 19, 57.0 percent), and Wildcat Creek (subbasin 21, 65.0 percent). The remaining subbasins are characterized mostly by a generally uniform mix of cropland and grassland (table 1).

The potential runoff-contributing areas within several subbasins exhibit pronounced land-use patterns. The potential contributing areas for the Big Blue River upstream from Tuttle Creek Lake (subbasin 3) are mostly grassland and woodland in the downstream half of the subbasin, whereas cropland is widespread in the upstream half. Thus, potential for runoff is likely higher in the upstream half of this subbasin. For the Black Vermillion River (subbasin 4) and the Little Blue River upstream from Barnes (subbasin 10), cropland is more widespread in the potential contributing areas in the upstream half of both subbasins. Cropland dominates the potential contributing areas in the Buffalo Creek subbasin (subbasin 5), with the exception of the upstream one-fourth of the subbasin where substantial grassland is located. For Clarks Creek (subbasin 6), the potential contributing areas are dominated by grassland with a minority cropland located mostly in the flood plains and the upstream half of the subbasin. For Fancy Creek (subbasin 8), potential contributing areas are dominated by grassland in the downstream half of the subbasin, whereas in the upstream half land use is a generally uniform mix of cropland and grassland. Land use in the potential contributing areas of the Mill Creek subbasin (subbasin 11, Wabaunsee County) is typified by grassland except for cropland in the flood plains (fig. 9).

The potential contributing areas in the Republican River upstream from Concordia subbasin (subbasin 14) are mostly cropland in the downstream half of the subbasin and mostly grassland in the upstream half. Potential contributing areas for Soldier Creek (subbasin 15) and Vermillion Creek (subbasin 17, Pottawatomie County) are dominated by grassland except in the flood plains where the minority cropland is more prevalent. Potential contributing areas for Stranger Creek (subbasin 16) are mostly grassland and woodland in uplands of the downstream half of the subbasin with cropland dominant in the flood plains. In comparison, potential contributing areas in the upstream half of the Stranger Creek subbasin are characterized by a more uniform mix of cropland and grassland. For Wildcat Creek (subbasin 21), potential contributing areas in the middle half of the subbasin are mostly grassland, whereas considerable cropland and urban land use are located in the upstream and downstream one-fourth of the subbasin, respectively (fig. 9).

Lower Arkansas River Basin

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 (fig. 12) and very good for the very low and extremely low potential-runoff conditions (figs. 13 and 14). 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 31) to 94.7 percent for Sun and Turkey Creeks (subbasin 33). 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 31) to 73.8 percent for Sand and Emma Creeks

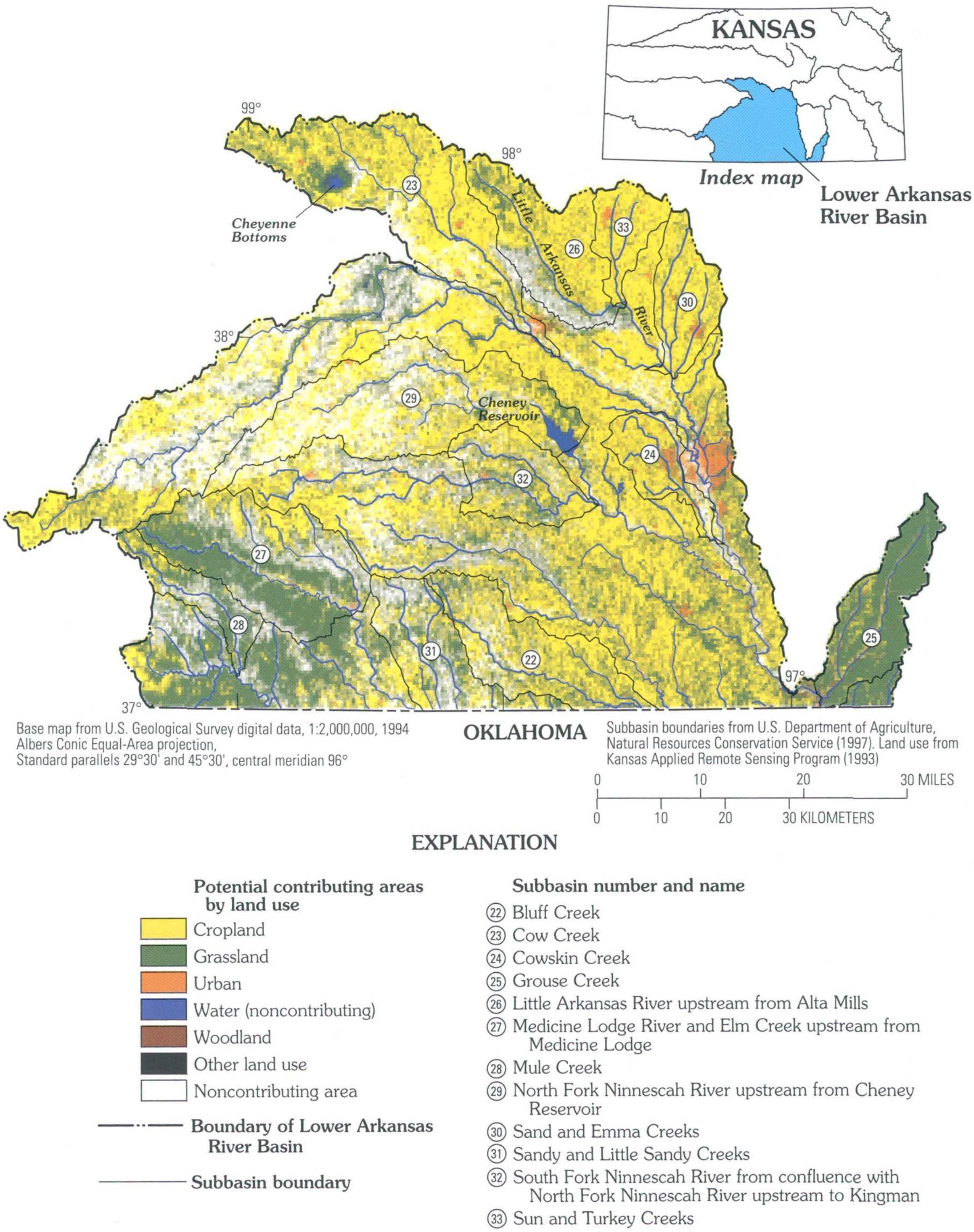


Figure 12. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Lower Arkansas River Basin for low potential-runoff conditions.

(subbasin 30). 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 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).

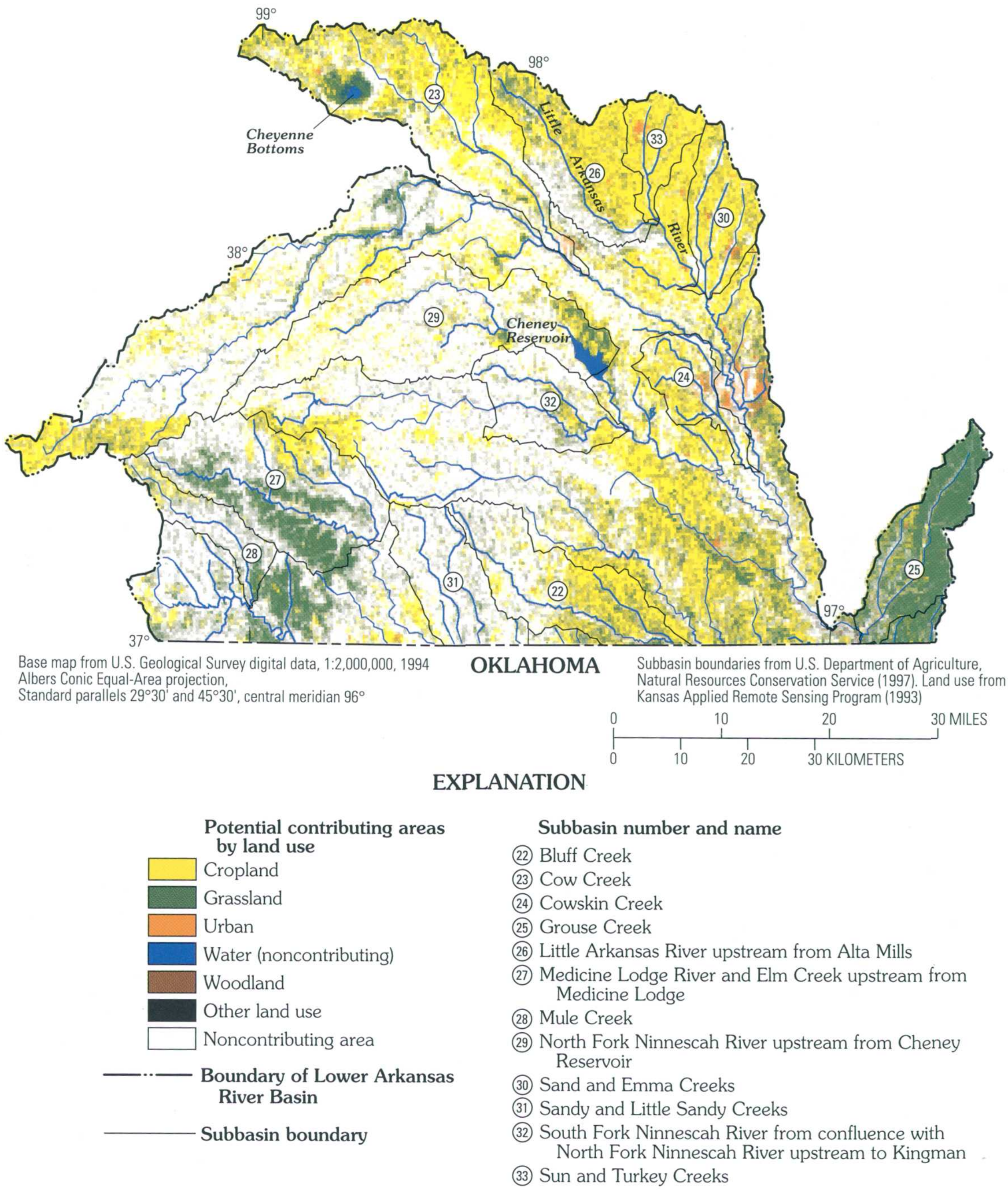
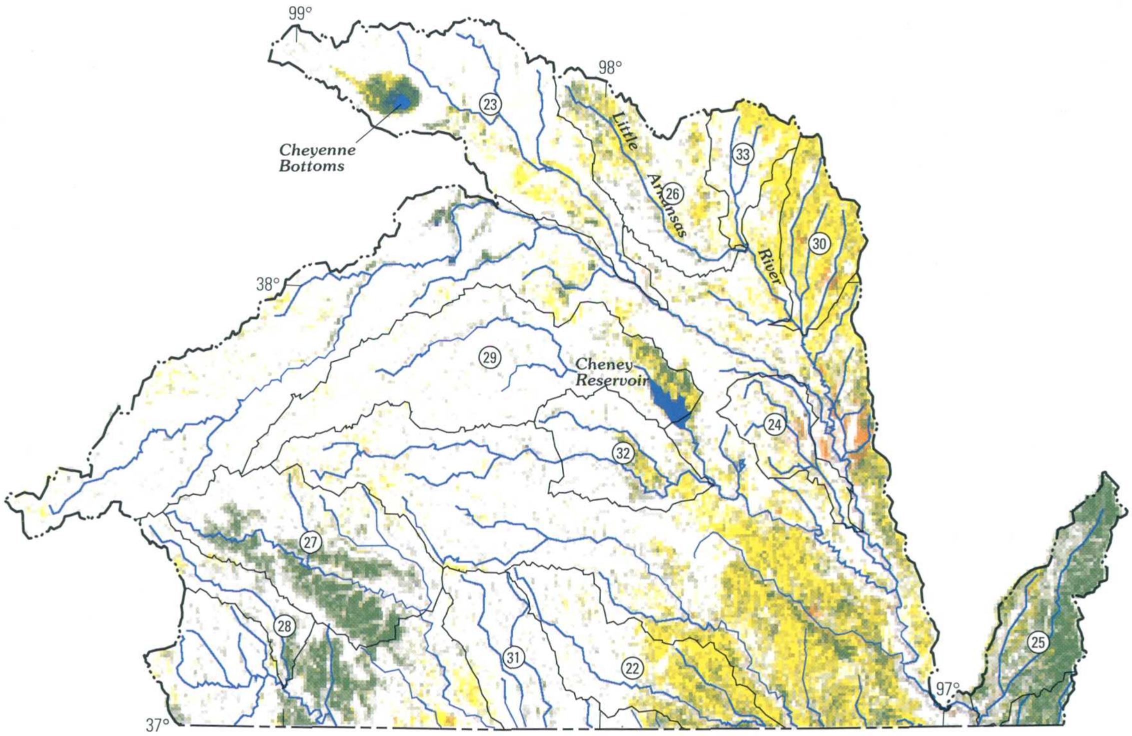


Figure 13. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Lower Arkansas River Basin for very low potential-runoff conditions.

As before, 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 subbasins having relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) are Grouse Creek (subbasin 25) and Sand and Emma Creeks (subbasin 30). The subbasins having relatively low potential for runoff (average percentage of contributing areas less than 30 percent) are Mule Creek (subbasin 28), the North Fork Ninnescah River upstream from Cheney Reservoir (subbasin 29), Sandy and Little Sandy Creeks (subbasin 31), and the South Fork Ninnescah



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

Subbasin boundaries from U.S. Department of Agriculture, Natural Resources Conservation Service (1997). Land use from Kansas Applied Remote Sensing Program (1993)

0 10 20 30 MILES
0 10 20 30 KILOMETERS

EXPLANATION

Potential contributing areas by land use

- Cropland
- Grassland
- Urban
- Water (noncontributing)
- Woodland
- Other land use
- Noncontributing area

Boundary of Lower Arkansas River Basin

Subbasin boundary

Subbasin number and name

- 22 Bluff Creek
- 23 Cow Creek
- 24 Cowskin Creek
- 25 Grouse Creek
- 26 Little Arkansas River upstream from Alta Mills
- 27 Medicine Lodge River and Elm Creek upstream from Medicine Lodge
- 28 Mule Creek
- 29 North Fork Ninnescah River upstream from Cheney Reservoir
- 30 Sand and Emma Creeks
- 31 Sandy and Little Sandy Creeks
- 32 South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman
- 33 Sun and Turkey Creeks

Figure 14. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Lower Arkansas River Basin for extremely low potential-runoff conditions.

River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 32) (figs. 13 and 14). 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 (fig. 13). For Bluff Creek (subbasin 22) and the South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 32), most of the potential contributing areas are located in the downstream half of the subbasins. For Cow Creek (subbasin 23), Cowskin Creek (subbasin 24), and the Medicine Lodge River and Elm Creek upstream from Medicine Lodge (subbasin 27), the potential contributing areas are widespread with several areas of concentration. Potential contributing areas for the Little Arkansas River upstream from Alta Mills (subbasin 26) are widespread and uniformly distributed with the notable exception of a large noncontributing area located in the downstream half of the subbasin south of the Little Arkansas River. For Mule Creek (subbasin 28), 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 29) 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 25), Sand and Emma Creeks (subbasin 30), and Sun and Turkey Creeks (subbasin 33). For Sandy and Little Sandy Creeks (subbasin 31), the potential contributing areas are generally sparse and widely scattered (fig. 13).

For extremely low potential-runoff conditions (fig. 14), the spatial distribution of potential contributing areas was similar (to what was observed for the very low potential-runoff conditions) for Bluff Creek (subbasin 22), Grouse Creek (subbasin 25), the North Fork Ninnescah River upstream from Cheney Reservoir (subbasin 29), Sand and Emma Creeks (subbasin 30), Sandy and Little Sandy Creeks (subbasin 31), and the South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 32). For Cow Creek (subbasin 23) and the Little Arkansas River upstream from Alta Mills (subbasin 26), the potential contributing areas are scattered with several areas of concentration. A notable area of concentration in the Cow Creek subbasin is Cheyenne Bottoms in the upstream end of the subbasin. For the Medicine Lodge River and Elm Creek upstream from Medicine Lodge (subbasin 27), most of the potential contributing areas are located in the southern half of the subbasin. Potential contributing areas for Sun and Turkey Creeks (subbasin 33) are predominantly in the upstream one-third of the subbasin. For Cowskin Creek (subbasin 24), the potential contributing areas are scattered throughout the subbasin. Potential contributing areas for Mule Creek (subbasin 28) are generally sparse and scattered with the exception of one area of concentration in the downstream one-fourth of the subbasin (fig. 14).

Land use in the subbasins typically is dominated by cropland or grassland (table 1). Cropland ranges from 10.9 percent of the subbasin for Grouse Creek (subbasin 25) to 90.0 percent for Sun and Turkey Creeks (subbasin 33). Grassland ranges from 6.3 percent of the subbasin for Sun and Turkey Creeks (subbasin 33) to 85.3 percent for Grouse Creek (subbasin 25). Subbasins dominated by cropland are Bluff Creek (subbasin 22, 69.8 percent), Cow Creek (subbasin 23, 76.7 percent), Cowskin Creek (subbasin 24, 76.1 percent), the Little Arkansas River upstream from Alta Mills (subbasin 26, 66.5 percent), the North Fork Ninnescah River upstream from Cheney Reservoir (subbasin 29, 72.7 percent), Sand and Emma Creeks (subbasin 30, 86.6 percent), the South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 32, 57.9 percent), and Sun and Turkey Creeks (subbasin 33, 90.0 percent). Subbasins dominated by grassland are Grouse Creek (subbasin 25, 85.3 percent), the Medicine Lodge River and Elm Creek upstream from Medicine Lodge (subbasin 27, 75.5 percent), and Mule Creek (subbasin 28, 75.8 percent) (table 1).

The spatial pattern of land use in the potential contributing areas varies among the subbasins. The potential contributing areas for Cow Creek (subbasin 23) and the Little Arkansas River upstream from Alta Mills (subbasin 26) are predominantly cropland with a minority grassland concentrated mostly in the upstream one-third of both subbasins (fig. 12). The potential contributing areas for Cowskin Creek (subbasin 24), Sand and Emma Creeks (subbasin 30), and Sun and Turkey Creeks (subbasin 33) are characterized by widespread cropland with a minority grassland scattered throughout each subbasin. Considerable urban land use also is located in the potential contributing areas in the east-central part of the Cowskin Creek subbasin (subbasin 24). Widespread cropland with scattered grassland also typifies the potential contributing areas for Bluff Creek (subbasin 22), the North Fork Ninnescah River upstream from Cheney Reservoir (subbasin 29), and the South Fork Ninnescah River from confluence with North Fork Ninnescah River upstream to Kingman (subbasin 32). For Sandy and Little Sandy Creeks (subbasin 31), the potential contributing areas are a generally uniform mix of cropland and grassland throughout. Potential contributing areas for Mule Creek (subbasin 28) are predominantly grassland with a minority cropland located mostly in the upstream one-third of the subbasin. Potential contributing areas for the Medicine Lodge River and Elm Creek upstream from Medicine Lodge (subbasin 27) are predominantly grassland except for a sizeable area in the north-central part of the subbasin, which is mostly cropland. For Grouse Creek (subbasin 25), the potential contributing areas are mostly grassland with much of the small percentage of cropland located in the flood plains (fig. 12).

Marais des Cygnes River Basin

In the Marais des Cygnes River Basin, all eight subbasins had potential contributing areas in virtually 100 percent of each subbasin for low potential-runoff conditions (fig. 15, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low (fig. 16) and extremely low (fig. 17) potential-runoff conditions provided some ability to distinguish subbasins. However, the range in percentage of potential contributing areas among the subbasins for these two sets of environmental conditions was somewhat narrow (table 1).

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 75.9 percent of the subbasin for Big Bull Creek upstream from Hillsdale Lake (subbasin 34) to 91.2 percent for Dragoon Creek upstream from Pomona Lake (subbasin 35). For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), potential contributing areas ranged from 54.6 percent of the subbasin for the Marmaton River (subbasin 39) to 79.3 percent for the Marais des Cygnes River upstream from Melvern Lake (subbasin 38) (table 1).

Using the average percentage of contributing areas for very low and extremely low potential-runoff conditions, the subbasins were categorized as having relatively high, moderate, or low potential for runoff. The subbasins having relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) are Big Bull Creek upstream from Hillsdale Lake (subbasin 34), Dragoon Creek upstream

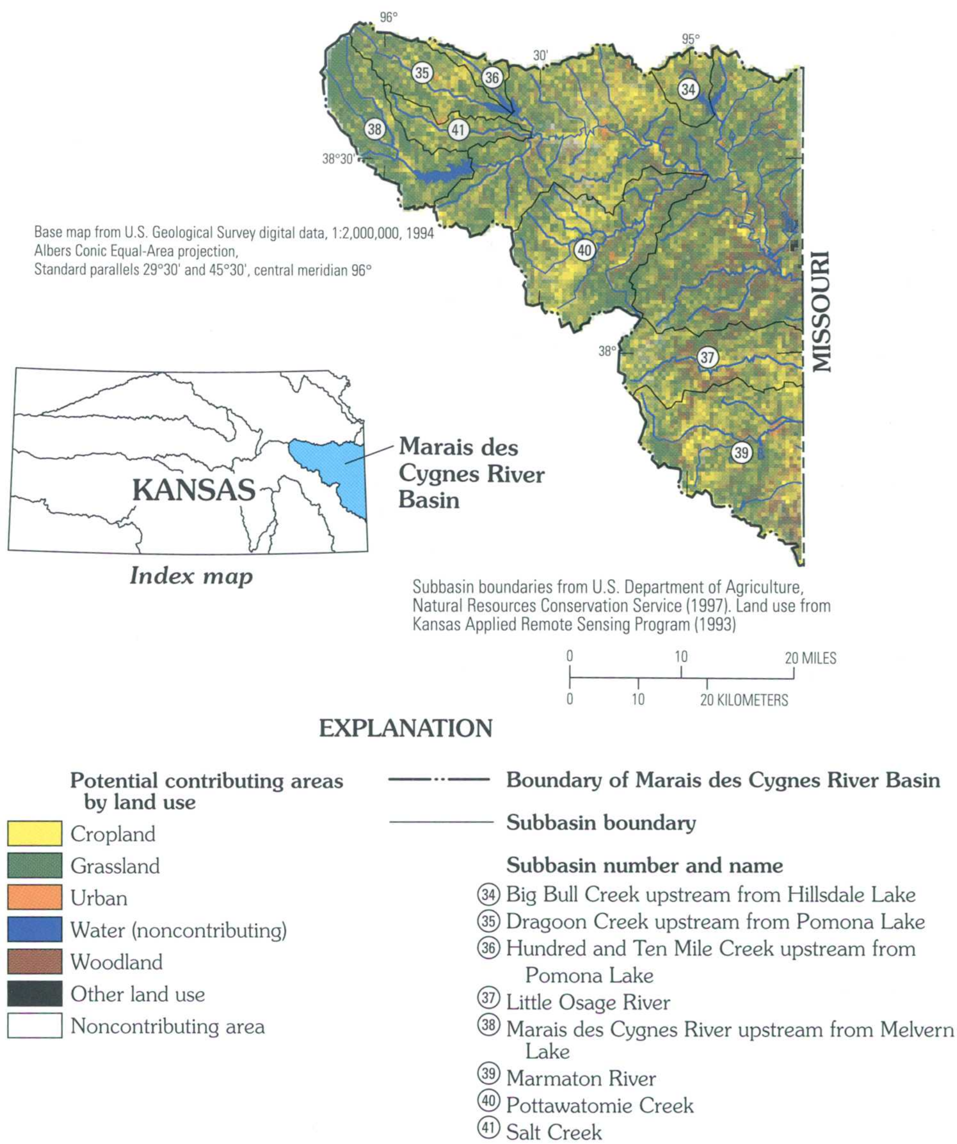


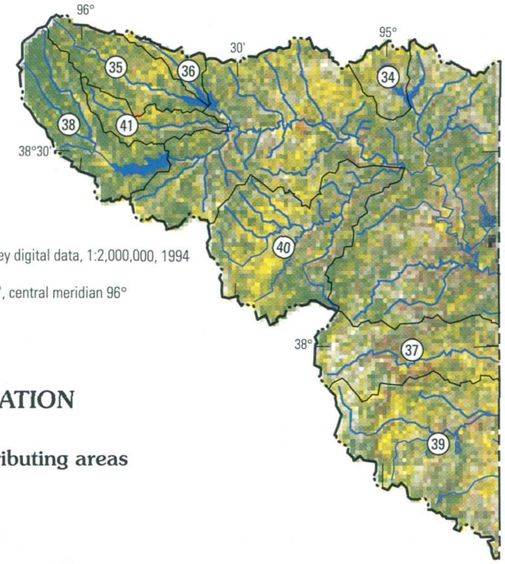
Figure 15. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Marais des Cygnes River Basin for low potential-runoff conditions.

from Pomona Lake (subbasin 35), Hundred and Ten Mile Creek upstream from Pomona Lake (subbasin 36), the Marais des Cygnes River upstream from Melvern Lake (subbasin 38), Pottawatomie Creek (subbasin 40), and Salt Creek (subbasin 41). Potential for runoff was relatively moderate (average percentage of contributing areas between 30 and 70 percent) for the Little Osage River (subbasin 37) and the Marmaton River (subbasin 39). None of the subbasins have relatively low potential for runoff (average percentage of contributing areas less than 30 percent).

The spatial distribution of potential contributing areas for the very low potential-runoff conditions was widespread and generally uniform across the Marais des Cygnes River Basin (fig. 16). However, within two of the subbasins there was some variability. For Big Bull Creek upstream from Hillsdale Lake (subbasin 34), the potential contributing areas are somewhat more concentrated in the upstream half of the subbasin. For the Little Osage River (subbasin 37), the potential contributing areas are more widespread in the downstream half of the subbasin (fig. 16).

For the extremely low potential-runoff conditions, the spatial distribution of potential contributing areas is similar (to what was observed for the very low potential-runoff conditions) for the majority of the subbasins (fig. 17). The upstream versus downstream contrasts previously noted for Big Bull Creek upstream from Hillsdale Lake (subbasin 34) and the Little Osage River (subbasin 37) are now more pronounced. The potential contributing areas for Dragoon Creek upstream from Pomona Lake (subbasin 35), Hundred and Ten Mile Creek upstream from Pomona Lake (subbasin 36), the Marais des Cygnes River upstream from Melvern Lake (subbasin 38), and Salt Creek (subbasin 41), although somewhat less widespread than for the very low potential-runoff conditions, are still distributed generally uniformly. For Pottawatomie Creek (subbasin 40), potential contributing areas are more widespread in the upstream one-third of the subbasin. For the Marmaton River (subbasin 39), the potential contributing areas are widespread with several areas of concentration (fig. 17).

Across the Marais des Cygnes River Basin, grassland is the predominant land use. Grassland ranges from 47.2 percent of the subbasin for both Hundred and Ten Mile Creek upstream from Pomona Lake (subbasin 36) and the Marmaton River (subbasin 39) to 73.8 percent for the Marais des Cygnes River upstream from Melvern Lake (subbasin 38). Cropland ranges from 19.4 percent of the subbasin for the Marais des Cygnes River upstream from Melvern Lake (subbasin 38) to 44.3 percent for Hundred and



Base map from U.S. Geological Survey digital data, 1:2,000,000, 1994
Albers Conic Equal-Area projection,
Standard parallels 29°30' and 45°30', central meridian 96°

Subbasin boundaries from U.S. Department of Agriculture, Natural Resources Conservation Service (1997). Land use from Kansas Applied Remote Sensing Program (1993)

0 10 20 MILES
0 10 20 KILOMETERS

EXPLANATION

Potential contributing areas by land use

Cropland
Grassland
Urban
Water (noncontributing)
Woodland
Other land use
Noncontributing area

Boundary of Marais des Cygnes River Basin

Subbasin boundary

Subbasin number and name

(34) Big Bull Creek upstream from Hillsdale Lake
(35) Dragoon Creek upstream from Pomona Lake
(36) Hundred and Ten Mile Creek upstream from Pomona Lake
(37) Little Osage River
(38) Marais des Cygnes River upstream from Melvern Lake
(39) Marmaton River
(40) Pottawatomie Creek
(41) Salt Creek

Figure 16. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Marais des Cygnes River Basin for very low potential-runoff conditions.

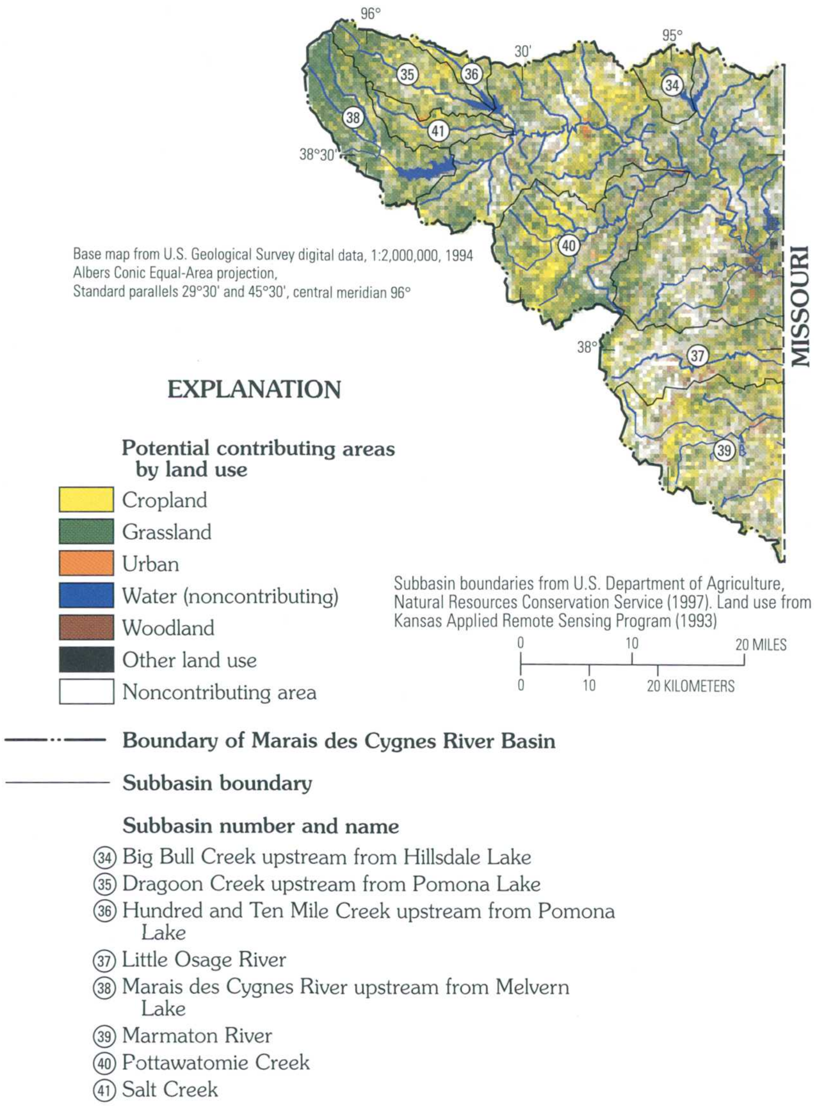


Figure 17. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Marais des Cygnes River Basin for extremely low potential-runoff conditions.

Ten Mile Creek upstream from Pomona Lake (subbasin 36). Several subbasins, in particular the Little Osage River (subbasin 37, 13.3 percent) and the Marmaton River (subbasin 39, 12.2 percent), have substantial areas of woodland (table 1, fig. 15).

Overall, potential runoff-contributing areas in the Marais des Cygnes River Basin are typified by a mix of grassland and cropland with grassland prevalent (figs. 15–17). For Big Bull Creek upstream from Hillsdale Lake (subbasin 34) and Salt Creek (subbasin 41), potential contributing areas are characterized by a generally uniform mix of grassland and cropland with grassland in the majority. For Hundred and Ten Mile Creek upstream from Pomona Lake (subbasin 36) and Pottawatomie Creek (subbasin 40), cropland is more widespread in the potential contributing areas in the upstream half of both subbasins. For Dragoon Creek upstream from Pomona Lake (subbasin 35), the minority cropland is somewhat more concentrated in the middle one-third of the subbasin. Potential contributing areas for the Little Osage River (subbasin 37) are characterized by a generally uniform mix of grassland and cropland in the upstream half of the subbasin, with a concentration of woodland in the middle one-third of the subbasin. Considerable cropland is located in the downstream half of the Little Osage River subbasin. Grassland dominates the potential contributing areas throughout the Marais des Cygnes River subbasin upstream from Melvern Lake (subbasin 38), with much of the small percentage of cropland located in the flood plains. For the Marmaton River (subbasin 39), a subtle banding pattern is apparent that repeats for both the upstream and downstream halves of the subbasin. Within both halves, cropland is more widespread in the potential contributing areas in the downstream part, whereas grassland is more widespread in the upstream part (fig. 15).

Missouri River Basin

In the Missouri River Basin, all five subbasins had potential contributing areas in 100 percent of each subbasin for low potential-runoff conditions (fig. 18, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low (fig. 19) and extremely low (fig. 20) potential-runoff conditions both provided good ability to distinguish subbasins.

The range in 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) was from 54.0 percent of the subbasin for the Wolf River (subbasin 46) to 87.6 percent for the South Fork Big Nemaha River (subbasin 44). For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), potential contributing areas ranged from 38.2 percent for the Wolf River (subbasin 46) to 82.2 percent for the South Fork Big Nemaha River (subbasin 44) (table 1).

Using the average percentage of contributing areas for the very low and extremely low potential-runoff conditions, the subbasins were categorized as having relatively high, moderate, or low potential for runoff. The subbasins having relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) are the South Fork Big Nemaha River (subbasin 44) and Walnut Creek (subbasin 45). Potential for runoff was relatively moderate (average percentage of contributing areas between 30 and 70 percent) for the Blue River (subbasin 42), Indian and Tomahawk Creeks (subbasin 43), and the Wolf River (subbasin 46). None of the subbasins had relatively low potential for runoff (average percentage of contributing areas less than 30 percent).

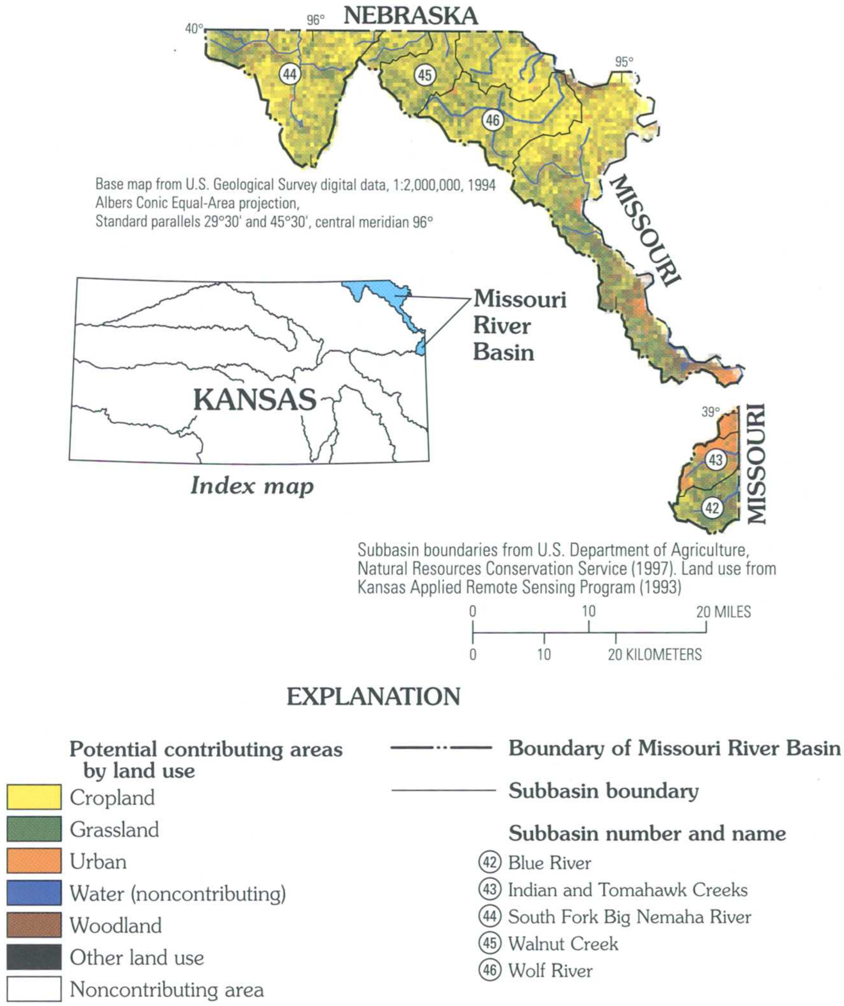


Figure 18. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Missouri River Basin for low potential-runoff conditions.

The spatial distribution of potential contributing areas for the very low potential-runoff conditions exhibited pronounced patterns within the subbasins (fig. 19). For the South Fork Big Nemaha River (subbasin 44), the potential contributing areas cover most of the subbasin. For the Blue River (subbasin 42) and Indian and Tomahawk Creeks (subbasin 43), the potential contributing areas are widespread with a uniform distribution throughout both subbasins. The potential contributing areas are located mostly in the upstream two-thirds of the subbasin for both Walnut Creek (subbasin 45) and the Wolf River (subbasin 46) (fig. 19). For the extremely low potential-runoff conditions, the spatial distribution of potential contributing areas within the subbasins was similar (fig. 20).

Land use is quite variable for the potential runoff-contributing areas in the subbasins as three different types of land use are dominant in one or more cases. Cropland is the major land use for the South Fork Big Nemaha River (subbasin 44, 66.8 percent), Walnut Creek (subbasin 45, 64.8 percent), and the Wolf River (subbasin 46, 70.8 percent). Grassland is the major land use for the Blue River (subbasin 42, 57.0 percent), whereas urban land use is dominant for Indian and Tomahawk Creeks (subbasin 43, 50.3 percent). The Blue River (subbasin 42, 11.3 percent) also has substantial woodland (table 1, fig. 18).

Potential runoff-contributing areas for the South Fork Big Nemaha River (subbasin 44) and Walnut Creek (subbasin 45) are characterized by a generally uniform mix of cropland and grassland throughout both subbasins with cropland in the majority. Potential contributing areas for the Wolf River (subbasin 46) also are dominated by cropland with a minority grassland concentrated mostly in the upstream half of the subbasin. For the Blue River (subbasin 42), potential contributing areas are dominated by grassland, along

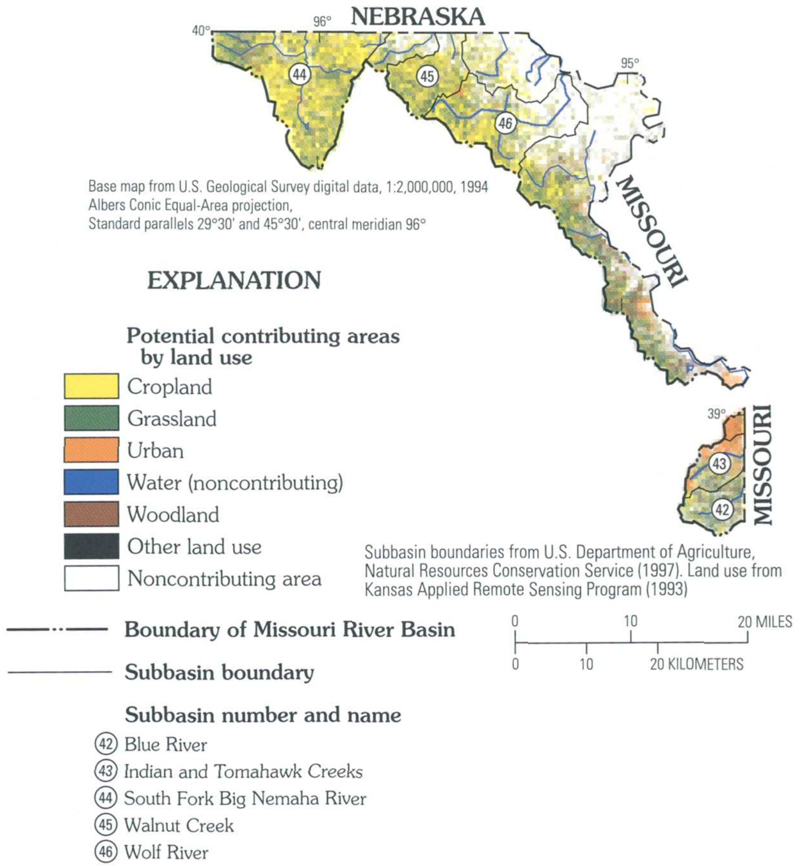


Figure 19. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Missouri River Basin for very low potential-runoff conditions.

with woodland, in the downstream two-thirds of the subbasin, whereas considerable cropland is located in the upstream one-third. Potential contributing areas for Indian and Tomahawk Creeks (subbasin 43) are dominated by urban land use, with the exception of the south-central part of the subbasin where a mix of grassland and cropland is located (fig. 18).

Neosho River Basin

In the Neosho River Basin, all seven subbasins had potential contributing areas in virtually 100 percent of each subbasin for low potential-runoff conditions (fig. 21, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low (fig. 22) and, to a lesser degree, the extremely low (fig. 23) potential-runoff conditions provided some ability to distinguish subbasins. However, the range in percentage of potential contributing areas among the subbasins for these two sets of environmental conditions was somewhat narrow (table 1).

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 72.1 percent of the subbasin for the South Cottonwood River (subbasin 53) to 97.2 percent for the Neosho River upstream from Council Grove Lake (subbasin 52). For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), potential contributing areas ranged from 66.2 percent of the subbasin for the South Cottonwood River (subbasin 53) to 84.8 percent for the Neosho River upstream from Council Grove Lake (subbasin 52) (table 1).

Using the average percentage of contributing areas for the very low and extremely low potential-runoff conditions, the subbasins were categorized as having relatively high, moderate, or low potential for runoff. The subbasins having relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) are Cherry Creek (subbasin 47), Diamond Creek (subbasin 48), Doyle Creek (subbasin 49), Labette Creek (subbasin 50), the Neosho River between John Redmond Reservoir and Chanute (subbasin 51), and the Neosho River upstream from Council Grove Lake (subbasin 52). Potential for runoff was relatively moderate (average percentage of contributing areas between 30 and 70 percent) for the South Cottonwood River (subbasin 53). None of the subbasins had relatively low potential for runoff (average percentage of contributing areas less than 30 percent). For both the very low and extremely low potential-runoff conditions, the potential contributing areas were widespread with a generally uniform distribution within each subbasin (figs. 22 and 23).

The dominant land uses in the Neosho River Basin are grassland and cropland. Grassland ranges from 19.9 percent of the subbasin for the South Cottonwood River (subbasin 53) to 78.1 percent for Diamond Creek (subbasin 48). Cropland ranges from 18.9 percent of the subbasin for Diamond Creek (subbasin 48) to 77.6 percent for the South Cottonwood River (subbasin 53). Subbasins dominated by grassland are Diamond Creek (subbasin 48, 78.1 percent), the Neosho River between John Redmond Reservoir and Chanute (subbasin 51, 56.8 percent), and the Neosho River upstream from Council Grove Lake (subbasin 52, 64.1 percent). Subbasins dominated by cropland are Cherry Creek (subbasin 47, 68.1 percent) and the South Cottonwood River (subbasin 53, 77.6 percent) (table 1).

Land-use patterns, although dominated by grassland and cropland (figs. 21–23), vary considerably within the potential runoff-contributing areas in the subbasins. For Cherry Creek (subbasin 47) and the South Cottonwood River (subbasin 53), potential contributing areas are dominated by cropland with a small percentage of grassland concentrated mostly in the upstream half of both subbasins. Grassland dominates the potential contributing areas for Diamond Creek (subbasin 48) with a small percentage of cropland concentrated mostly in the upstream one-third of the subbasin and in the flood plain. For Doyle Creek (subbasin 49), potential contributing areas are typified by a generally uniform mix of cropland and grassland in the upstream half of the subbasin, whereas in the downstream half grassland prevails. For Labette Creek (subbasin 50), potential contributing areas are characterized by a generally uniform mix of grassland and cropland with grassland in the majority. Grassland dominates the potential contributing areas for the Neosho River upstream from Council Grove Lake (subbasin 52) with a minority cropland scattered throughout the subbasin. Potential contributing areas for the Neosho River between John Redmond Reservoir and Chanute (subbasin 51) are typified by a mix of cropland and grassland, with cropland dominant in the flood plains and grassland prevalent elsewhere (fig. 21).

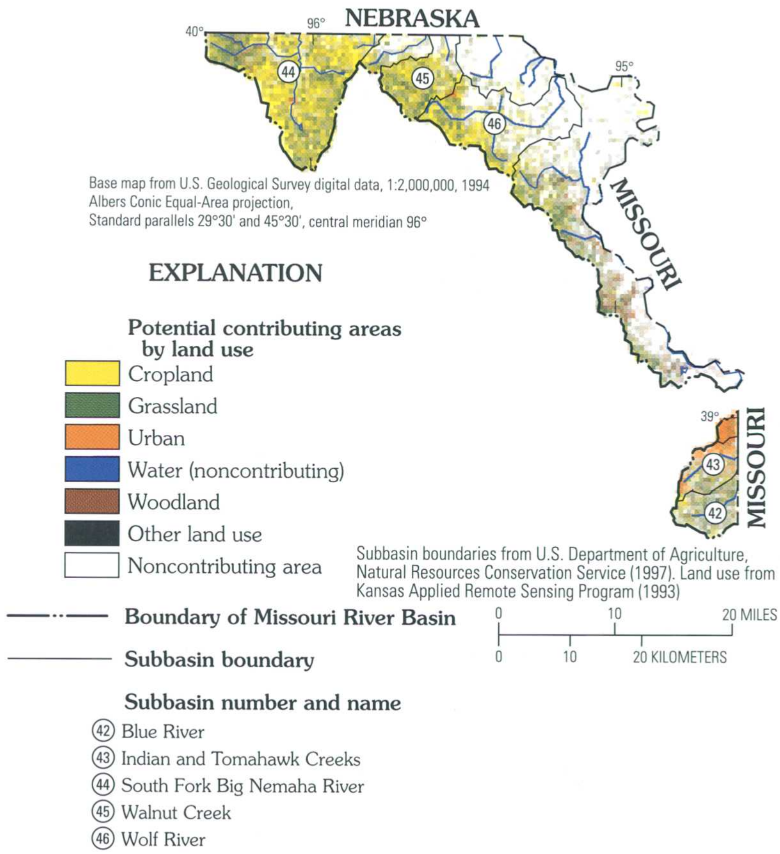


Figure 20. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Missouri River Basin for extremely low potential-runoff conditions.

Smoky Hill-Saline River Basin

In the Smoky Hill-Saline River Basin, all 11 subbasins had potential contributing areas in more than 90 percent of each subbasin for the low potential-runoff conditions (fig. 24, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low potential-runoff conditions (fig. 25) provided very good ability to distinguish subbasins. For the extremely low potential-runoff conditions (fig. 26), the ability to distinguish subbasins was very limited.

The range in 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) was from 14.7 percent for Hackberry Creek (subbasin 57) to 91.9 percent for Lyon Creek (subbasin 59). Of the 11 subbasins in the Smoky Hill-Saline River Basin, 1 had potential contributing areas in more than 90 percent of the subbasin, 3 had potential contributing areas in 50 to 70 percent of each subbasin, 4 had potential contributing areas in 30 to 50 percent of each subbasin, and 3 had potential contributing areas in 10 to 30 percent of each subbasin.

For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI

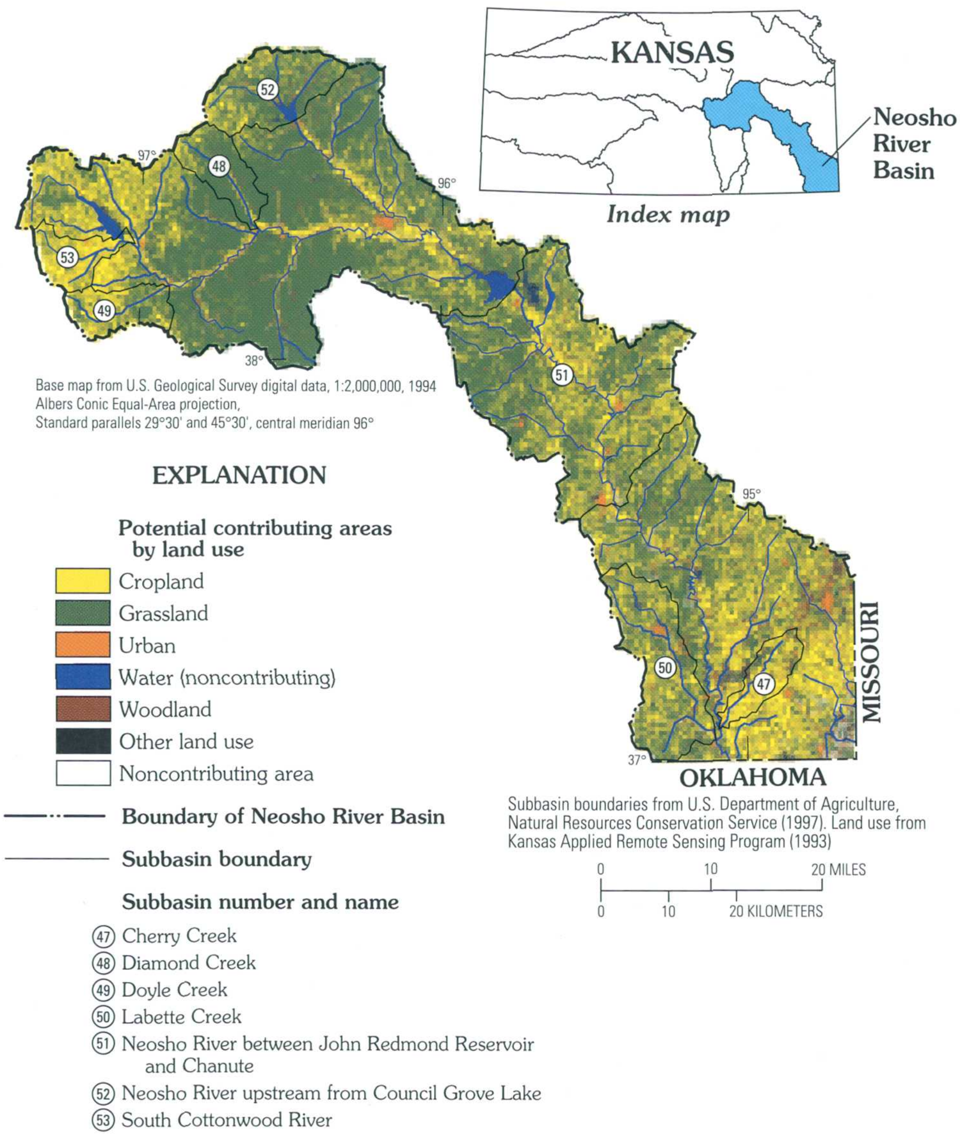


Figure 21. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Neosho River Basin for low potential-runoff conditions.

greater than or equal to 16.3), 10 of 11 subbasins had potential contributing areas in less than 20 percent of each subbasin. The exception was Lyon Creek (subbasin 59), which had potential contributing areas in 84.0 percent of the subbasin (table 1).

Using the average percentage of contributing areas for the very low and extremely low potential-runoff conditions, the subbasins were categorized as having relatively high, moderate, or low potential for runoff. The only subbasin having relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) is Lyon Creek (subbasin 59), which is located in the extreme eastern part of the Smoky Hill-Saline River Basin. The subbasins having relatively low potential for runoff (average percentage of contributing areas less than 30 percent) are Big Creek (subbasin 54), Elkhorn and Bullfoot Creeks (subbasin 56), Hackberry Creek (subbasin 57), Ladder Creek (subbasin 58), Mulberry Creek (subbasin 60), the Saline River upstream from Wilson Lake (subbasin 61), and the Smoky Hill River upstream from Cedar Bluff Reservoir (subbasin 63). The remaining three subbasins have relatively moderate potential for runoff (average percentage of contributing areas between 30 and 70 percent).

The spatial distribution of potential contributing areas for the very low potential-runoff conditions showed considerable variability among the subbasins (fig. 25). For Big Creek (subbasin 54), the potential contributing areas are widespread throughout the subbasin with the exception of the middle and extreme upstream parts where substantial noncontributing areas are located. For Chapman Creek (subbasin 55), potential contributing areas are prevalent in the downstream half of the subbasin but less widespread in the upstream half. An unusual pattern exists for Elkhorn and Bullfoot Creeks (subbasin 56) where most of the potential contributing areas are located around the fringe of the subbasin. For Hackberry Creek (subbasin 57), most of the potential contributing areas are located in the downstream half of the subbasin north of Hackberry Creek. For Ladder Creek (subbasin 58), most of the potential contributing areas are located in the south half of the subbasin. Potential contributing areas for Mulberry Creek (subbasin 60) are scattered, with the largest concentration located in the downstream one-third of the subbasin. Likewise, most of the potential contributing areas are located in the downstream one-third of the subbasin for the Saline River upstream from Wilson Lake (subbasin 61). For the Smoky Hill River between Cedar Bluff Reservoir and Kanopolis Lake (subbasin 62), the potential contributing areas are widespread with a generally uniform distribution throughout the subbasin. For the Smoky Hill River upstream from Cedar Bluff Reservoir (subbasin 63), the potential contributing areas are scattered with a somewhat larger concentration in the downstream half of the subbasin. Most of the potential contributing areas are located in the upstream half of the subbasin for Spillman Creek (subbasin 64). For Lyon Creek (subbasin 59), the potential contributing areas cover almost the entire subbasin. Throughout the Smoky Hill-Saline River Basin, the flood plains are typically noncontributing areas (fig. 25).

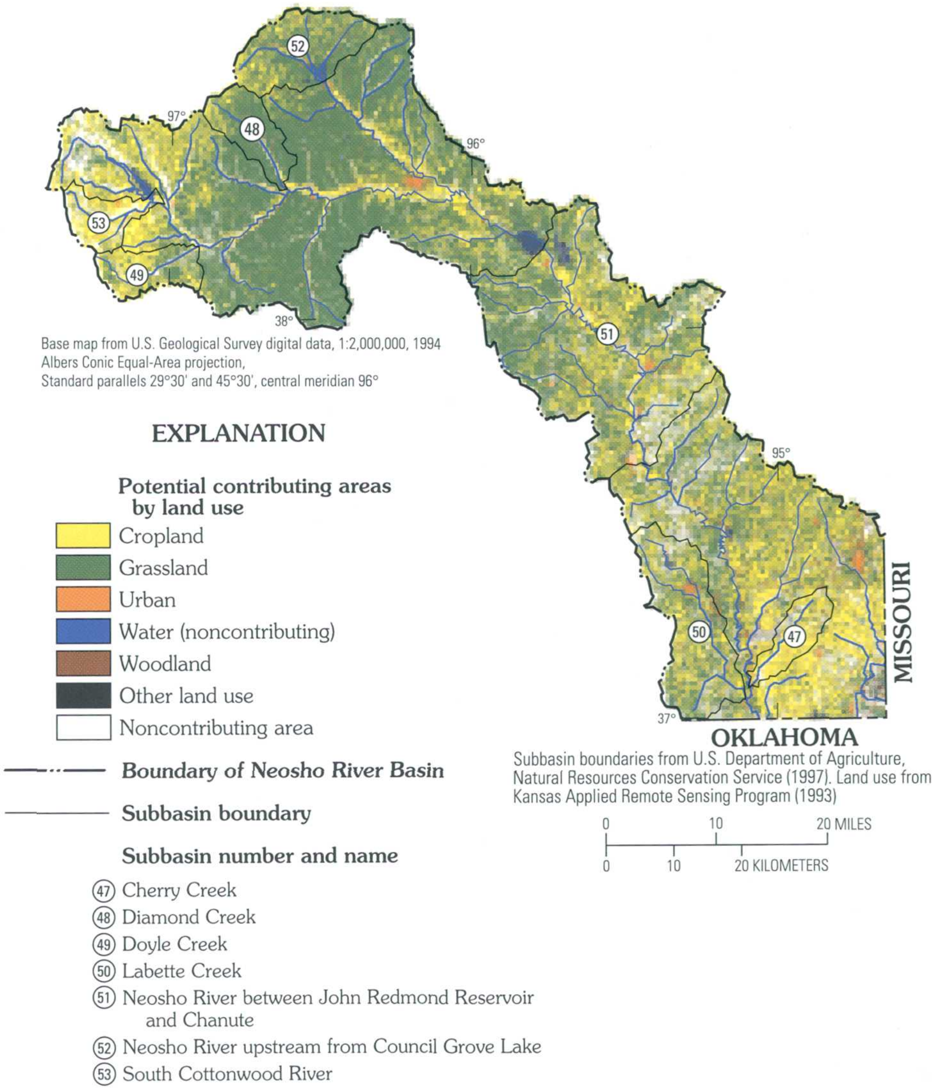


Figure 22. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Neosho River Basin for very low potential-runoff conditions.

With a few exceptions noted in the following sentences, the spatial distribution of potential contributing areas for the extremely low potential-runoff conditions is generally sparse and widely scattered for most of the Smoky Hill-Saline River Basin (fig. 26). The most notable exception is Lyon Creek (subbasin 59) for which potential contributing areas cover most of the subbasin. Other subbasin areas with a somewhat larger concentration of potential contributing areas are the upstream one-fourth of the Smoky Hill River between Cedar Bluff Reservoir and Kanopolis Lake (subbasin 62); the downstream one-third of Big Creek (subbasin 54), the Saline River upstream from Wilson Lake (subbasin 61), and Mulberry Creek (subbasin 60); the downstream half and extreme upstream part of Chapman Creek (subbasin 55), and the upstream and downstream one-fourths of Spillman Creek (subbasin 64). For the Smoky Hill River upstream from Cedar Bluff Reservoir (subbasin 63), the potential contributing areas are somewhat more concentrated in clusters located throughout the subbasin (fig. 26).

Land use in the Smoky Hill-Saline River Basin is dominated by cropland and grassland. Cropland ranges from 27.8 percent of the subbasin for Mulberry Creek (subbasin 60) to 74.4 percent for Ladder Creek (subbasin 58). Grassland ranges from 25.5 percent of the subbasin for Ladder Creek (subbasin 58) to 68.0 percent for Mulberry Creek (subbasin 60). Subbasins dominated by cropland are Big Creek (subbasin 54, 62.3 percent), Hackberry Creek (subbasin 57, 67.9 percent), and Ladder Creek (subbasin 58, 74.4 percent). Subbasins dominated by grassland are

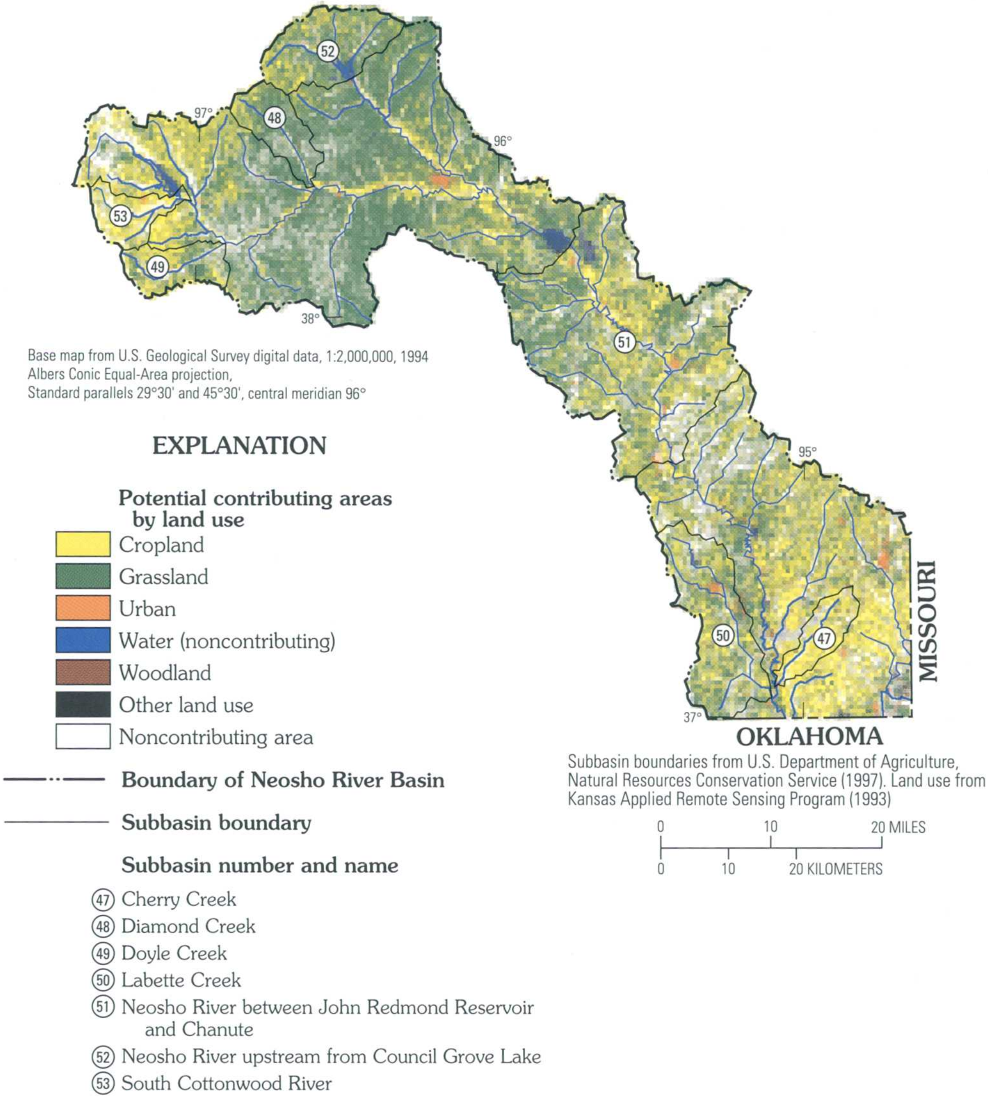


Figure 23. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Neosho River Basin for extremely low potential-runoff conditions.

Elkhorn and Bullfoot Creeks (subbasin 56, 66.7 percent) and Mulberry Creek (subbasin 60, 68.0 percent). The remaining six subbasins have a mix of cropland and grassland with neither particularly dominant (table 1).

The spatial pattern of land use in the potential contributing areas varies among the subbasins (fig. 24). For Big Creek (subbasin 54), the potential contributing areas are dominated by cropland with most of the grassland located in the downstream half of the subbasin. For Chapman Creek (subbasin 55), potential contributing areas in the downstream half of the subbasin are typified by a generally uniform mix of cropland and grassland, whereas grassland dominates in the upstream half. For Elkhorn and Bullfoot Creeks (subbasin 56), potential contributing areas are mostly grassland with a minority cropland located mostly in the downstream half of the subbasin and in the flood plains. Cropland is prevalent in the potential contributing areas for Hackberry Creek (subbasin 57) and Ladder Creek (subbasin 58), particularly in the upstream half of both subbasins. For Lyon Creek (subbasin 59), potential contributing areas are characterized by a generally uniform mix of grassland and cropland, with grassland somewhat more widespread in the downstream half of the subbasin. Potential contributing areas for Mulberry Creek (subbasin 60) are dominated by grassland in the upstream two-thirds of the subbasin, whereas cropland prevails in the downstream one-third. A gradational pattern exists for the Saline River upstream from Wilson Lake (subbasin 61) in which the potential contributing areas grade from grassland dominated in the downstream one-third of the subbasin to cropland dominated in the upstream one-third. Potential contributing areas for the Smoky Hill River between Cedar Bluff Reservoir and Kanopolis Lake (subbasin 62) are a generally uniform mix of cropland and grassland except in the downstream one-third and extreme upstream end of the subbasin where concentrations of grassland are located. For the Smoky Hill River upstream from Cedar Bluff Reservoir (subbasin 63) and Spillman Creek (subbasin 64), potential contributing areas are generally a uniform mix of cropland and grassland. However, for the Smoky Hill River upstream from Cedar Bluff Reservoir, the land use in the upstream three-fourths of the subbasin is a more

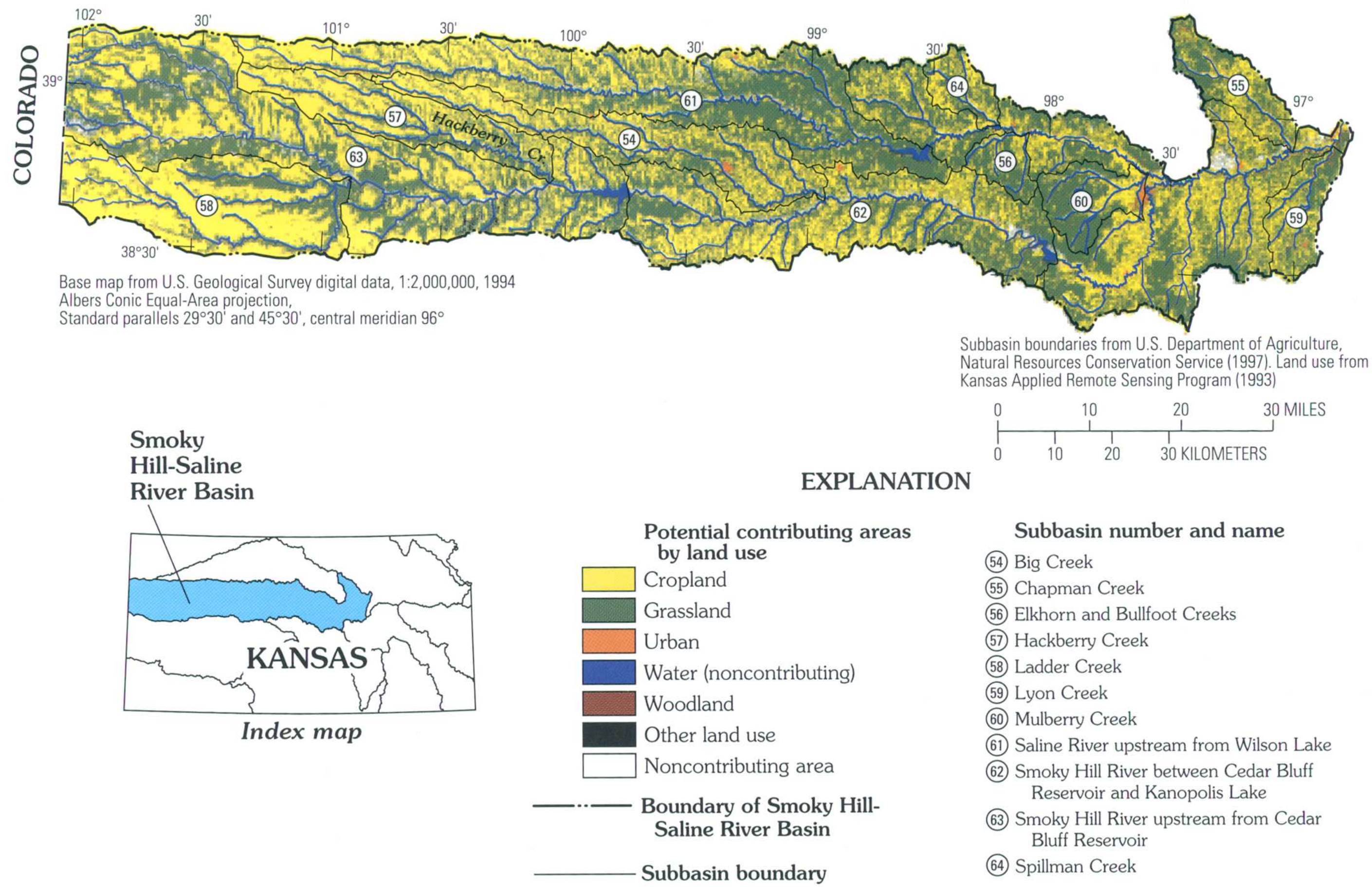


Figure 24. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Smoky Hill-Saline River Basin for low potential-runoff conditions.

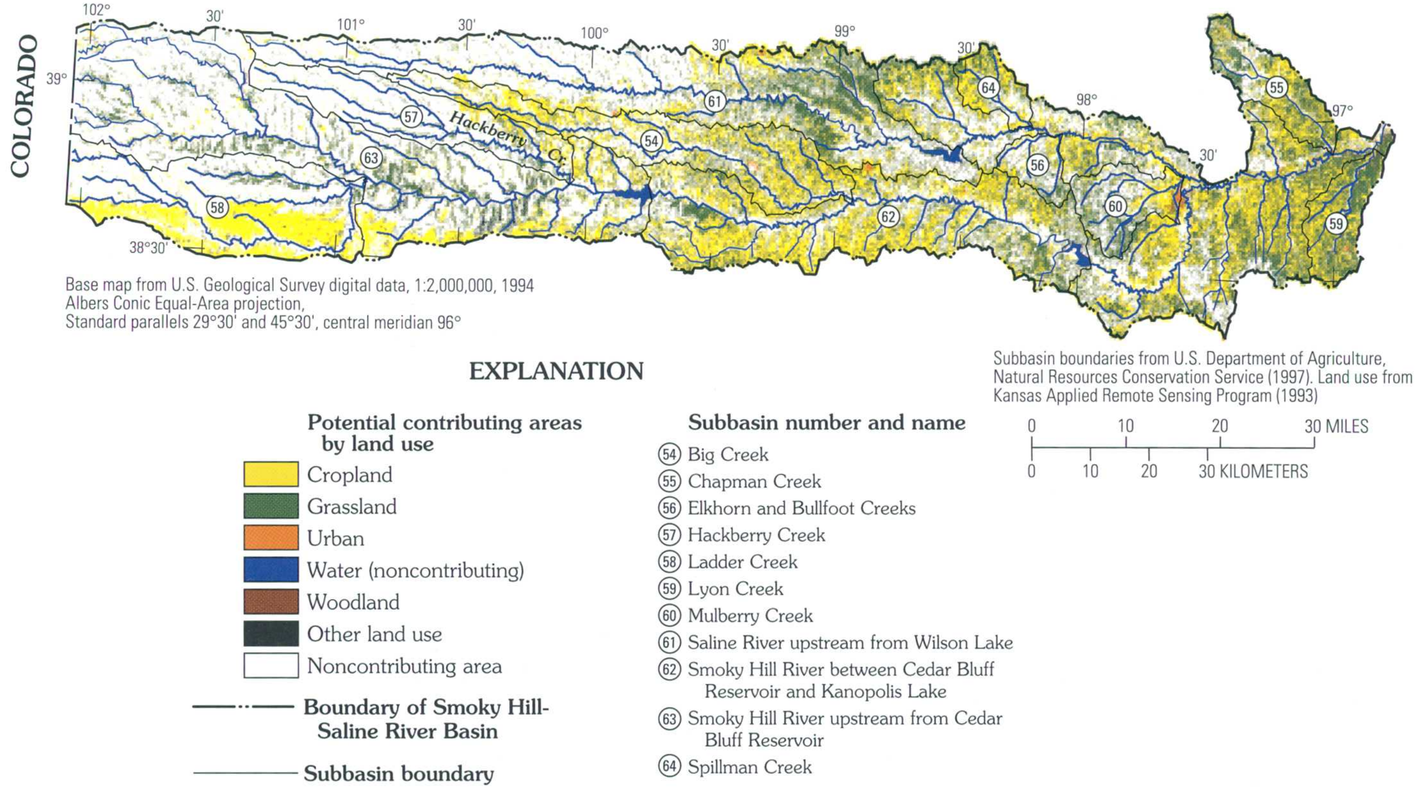


Figure 25. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Smoky Hill-Saline River Basin for very low potential-runoff conditions.

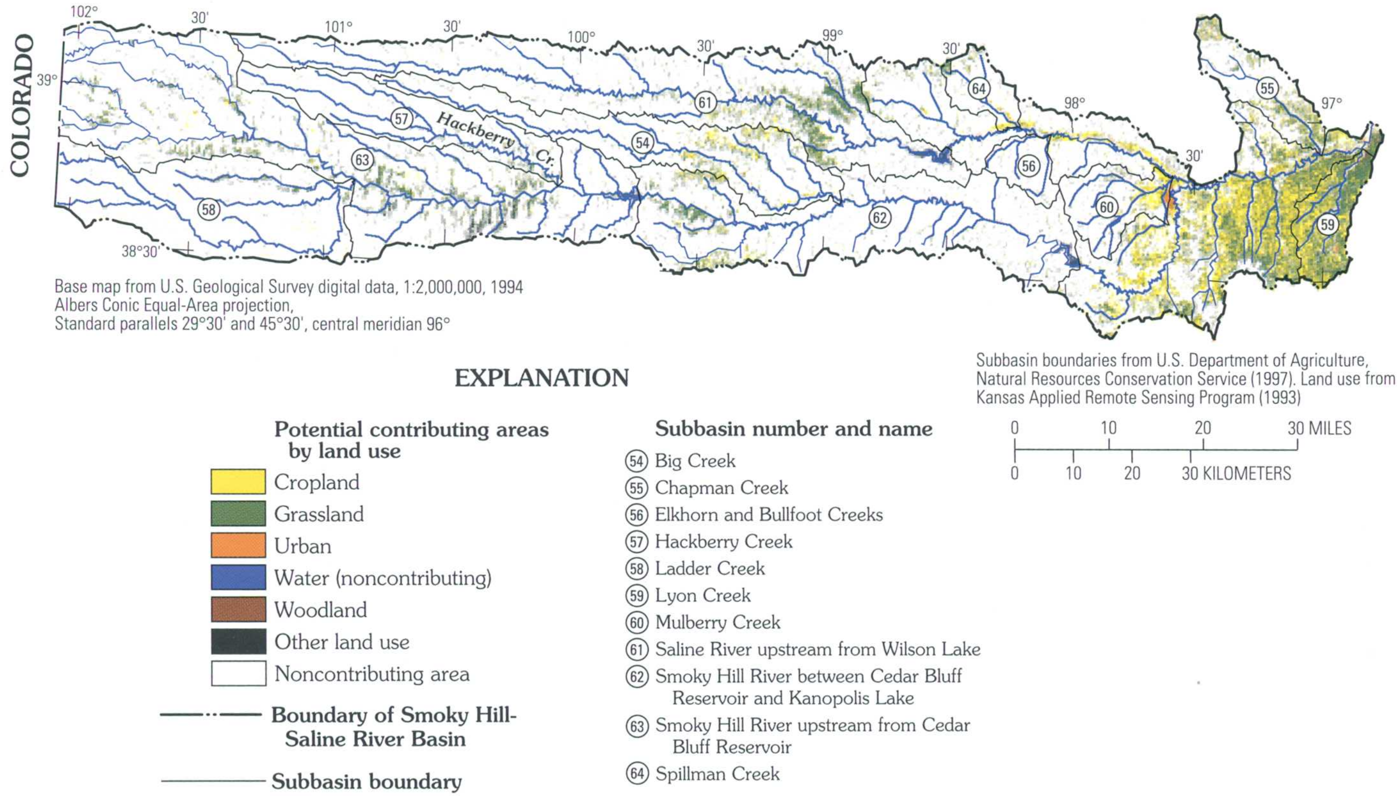


Figure 26. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Smoky Hill-Saline River Basin for extremely low potential-runoff conditions.

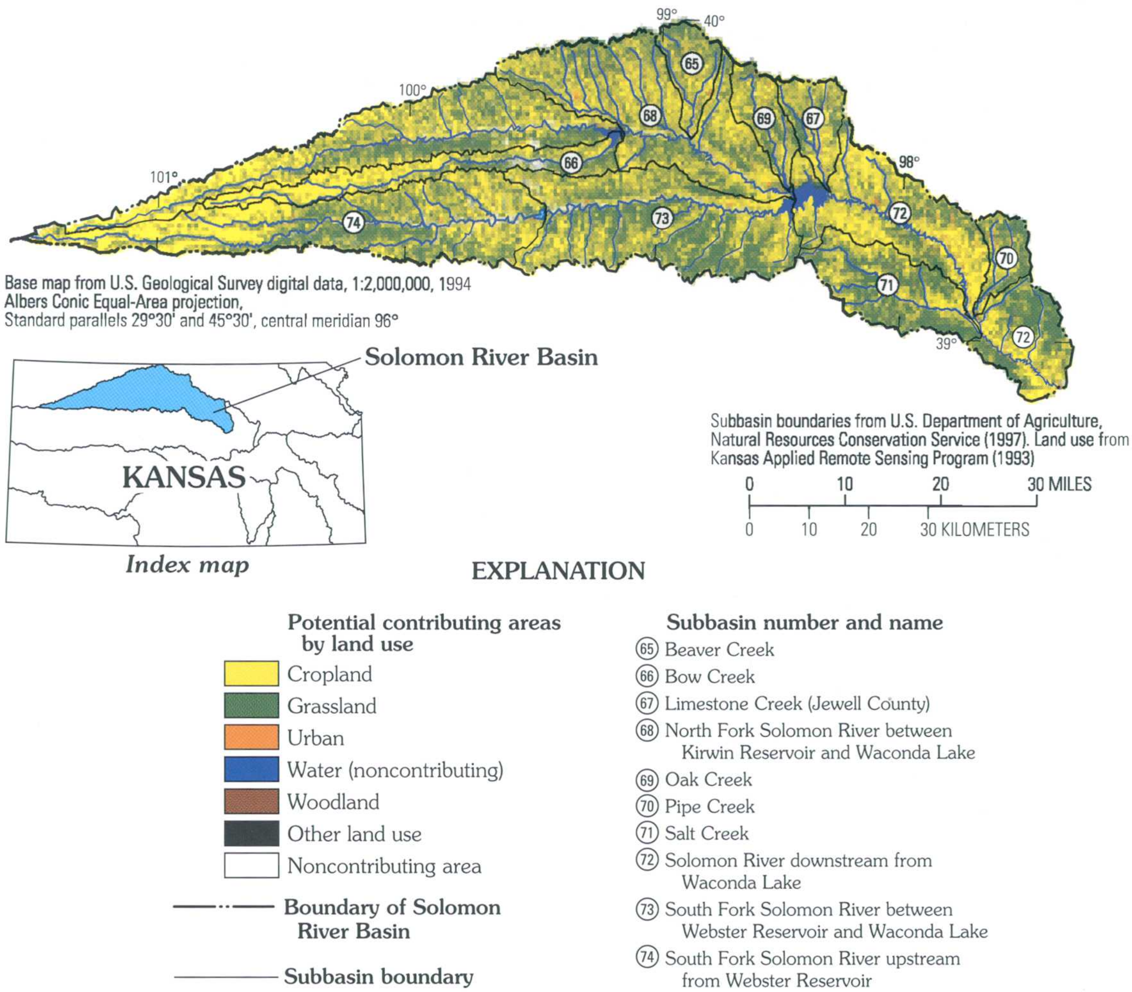


Figure 27. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Solomon River Basin for low potential-runoff conditions.

coarse-grained pattern characterized by large, alternating areas of grassland and cropland (fig. 24).

Solomon River Basin

In the Solomon River Basin, all 10 subbasins had potential contributing areas in virtually 100 percent of each subbasin for the low potential-runoff conditions (fig. 27, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low potential-runoff conditions (fig. 28) provided good ability to distinguish subbasins. However, the extremely low potential-runoff conditions (fig. 29) were not useful for distinguishing subbasins as all 10 subbasins had potential contributing areas of about 10 percent or less.

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 4.6 percent of the subbasin for Bow Creek (subbasin 66) to 67.3 percent for the Solomon River downstream from Waconda Lake (subbasin 72). Of the 10 subbasins in the Solomon River Basin, 6 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 2 had potential contributing areas in less than 10 percent of each subbasin (table 1).

Using the average percentage of contributing areas for the very low and extremely low potential-runoff conditions, the subbasins were categorized as having relatively high, moderate, or low potential for runoff. No subbasins had relatively high potential for runoff (average percentage of contributing areas greater than

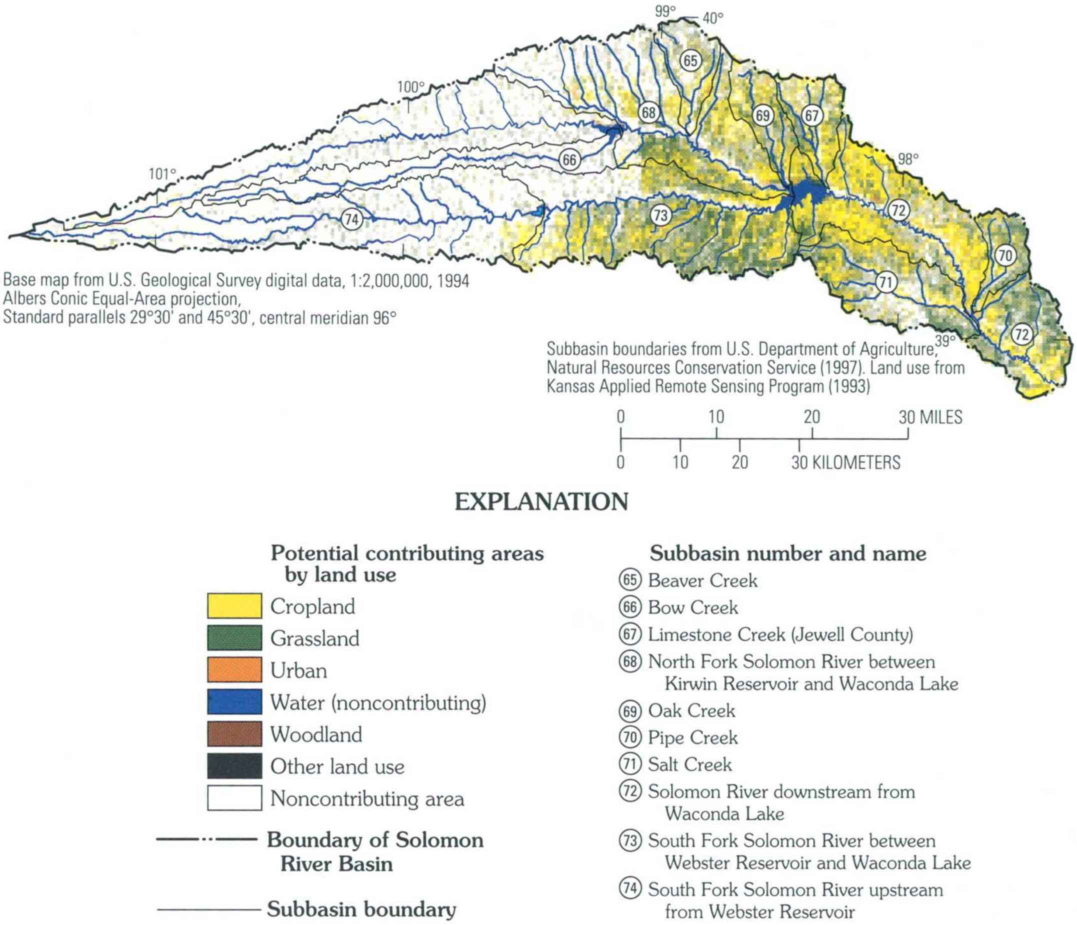
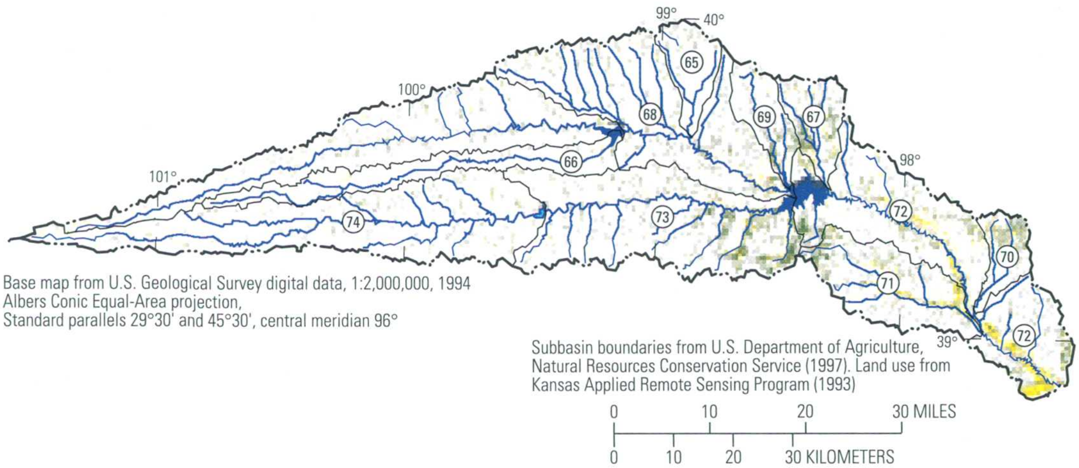


Figure 28. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Solomon River Basin for very low potential-runoff conditions.

70 percent). The subbasins with relatively low potential for runoff (average percentage of contributing areas less than 30 percent) were Beaver Creek (subbasin 65), Bow Creek (subbasin 66), the North Fork Solomon River between Kirwin Reservoir and Waconda Lake (subbasin 68), and the South Fork Solomon River upstream from Webster Reservoir (subbasin 74). Potential for runoff was relatively moderate for the remaining subbasins (average percentage of contributing areas between 30 and 70 percent).

The spatial distribution of potential contributing areas for the very low potential-runoff conditions indicates that most potential contributing areas are located in the eastern half of the Solomon River Basin (fig. 28). For Bow Creek (subbasin 66) and the South Fork Solomon River upstream from Webster Reservoir (subbasin 74), the potential contributing areas are generally sparse and widely scattered. Potential contributing areas are widespread, with a generally uniform distribution, for Oak Creek (subbasin 69), Pipe Creek (subbasin 70), and the Solomon River downstream from Waconda Lake (subbasin 72). For Beaver Creek (subbasin 65), the potential contributing areas are scattered with a generally uniform distribution. For Limestone Creek (subbasin 67, Jewell County), the potential contributing areas are widespread with a somewhat larger concentration in the downstream half of the subbasin. Most of the potential contributing areas for the North Fork Solomon River between Kirwin Reservoir and Waconda Lake (subbasin 68) are located in the downstream half of the subbasin. For Salt Creek (subbasin 71), the potential contributing areas are more widespread in the upstream and downstream one-thirds of the subbasin. Potential contributing areas are widespread with a generally uniform distribution for the South Fork Solomon River between Webster Reservoir and Waconda Lake (subbasin 73) except for a large noncontributing area located in the north half of the upstream half of the subbasin (fig. 28).



EXPLANATION

Potential contributing areas by land use

- Cropland
- Grassland
- Urban
- Water (noncontributing)
- Woodland
- Other land use
- Noncontributing area

Boundary of Solomon River Basin

Subbasin boundary

Subbasin number and name

65 Beaver Creek
66 Bow Creek
67 Limestone Creek (Jewell County)
68 North Fork Solomon River between Kirwin Reservoir and Waconda Lake
69 Oak Creek
70 Pipe Creek
71 Salt Creek
72 Solomon River downstream from Waconda Lake
73 South Fork Solomon River between Webster Reservoir and Waconda Lake
74 South Fork Solomon River upstream from Webster Reservoir

Figure 29. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Solomon River Basin for extremely low potential-runoff conditions.

With a few exceptions noted in the following sentences, the spatial distribution of potential contributing areas for the extremely low potential-runoff conditions is sparse and widely scattered for most of the Solomon River Basin (fig. 29). For Limestone Creek (subbasin 67, Jewell County) and Oak Creek (subbasin 69), the potential contributing areas are somewhat more widespread in the downstream halves of the subbasins. For the South Fork Solomon River between Webster Reservoir and Waconda Lake (subbasin 73), the potential contributing areas are more widespread in the downstream one-third of the subbasin. Potential contributing areas are more widespread in the upstream half of the subbasin for Pipe Creek (subbasin 70). For Salt Creek (subbasin 71), many of the potential contributing areas are located in the extreme upstream part of the subbasin and the flood plains. Likewise, many of the potential contributing areas are located in the flood plains for the Solomon River downstream from Waconda Lake (subbasin 72) (fig. 29).

Land use in the Solomon River Basin is dominated by cropland and grassland (table 1). Cropland ranges from 43.8 percent of the subbasin for Salt Creek (subbasin 71) to 70.0 percent for Bow Creek (subbasin 66). Grassland ranges from 28.8 percent of the subbasin for Bow Creek (subbasin 66) to 54.5 percent for Salt Creek (subbasin 71). Subbasins dominated by cropland are Bow Creek (subbasin 66, 70.0 percent), Limestone Creek (subbasin 67, Jewell County, 58.0 percent), the North Fork Solomon River between Kirwin Reservoir and Waconda Lake (subbasin 68, 59.7 percent), the Solomon River downstream from Waconda Lake (subbasin 72, 60.4 percent), and the South Fork Solomon River upstream from Webster Reservoir (subbasin 74, 61.1 percent). For the remaining subbasins, land use is a mix of cropland and grassland with neither particularly dominant (table 1).

The spatial distribution of cropland and grassland in the potential contributing areas varies considerably among the subbasins (fig. 27). For Beaver Creek (subbasin 65), grassland is more prevalent in the potential contributing areas in the upstream half of the subbasin, whereas cropland dominates in the downstream half. Potential contributing areas for Bow Creek (subbasin 66) and the South Fork Solomon River upstream from Webster Reservoir (subbasin 74) are dominated by cropland with most of the minority grassland located in the downstream halves of the subbasins. In potential contributing areas for Limestone Creek (subbasin 67, Jewell County) and Oak Creek (subbasin 69), cropland is the majority land use, with substantial areas of grassland located mostly in the middle halves of both subbasins. A generally uniform mix of cropland and grassland characterizes the potential contributing areas for the North Fork Solomon River between Kirwin Reservoir and Waconda Lake (subbasin 68) and Salt Creek (subbasin 71), with cropland dominant in the former subbasin and grassland dominant in the later. In potential contributing areas for Pipe Creek (subbasin 70), grassland is more prominant in the upstream and eastern parts of the subbasin. In potential contributing areas for the Solomon River downstream from Waconda Lake (subbasin 72), cropland is prevalent with most of the minority grassland located in the middle and downstream parts of the subbasin. Potential contributing areas consist of a generally uniform mix of cropland and grassland for the South Fork Solomon River between Webster Reservoir and Waconda Lake (subbasin 73) (fig. 27).

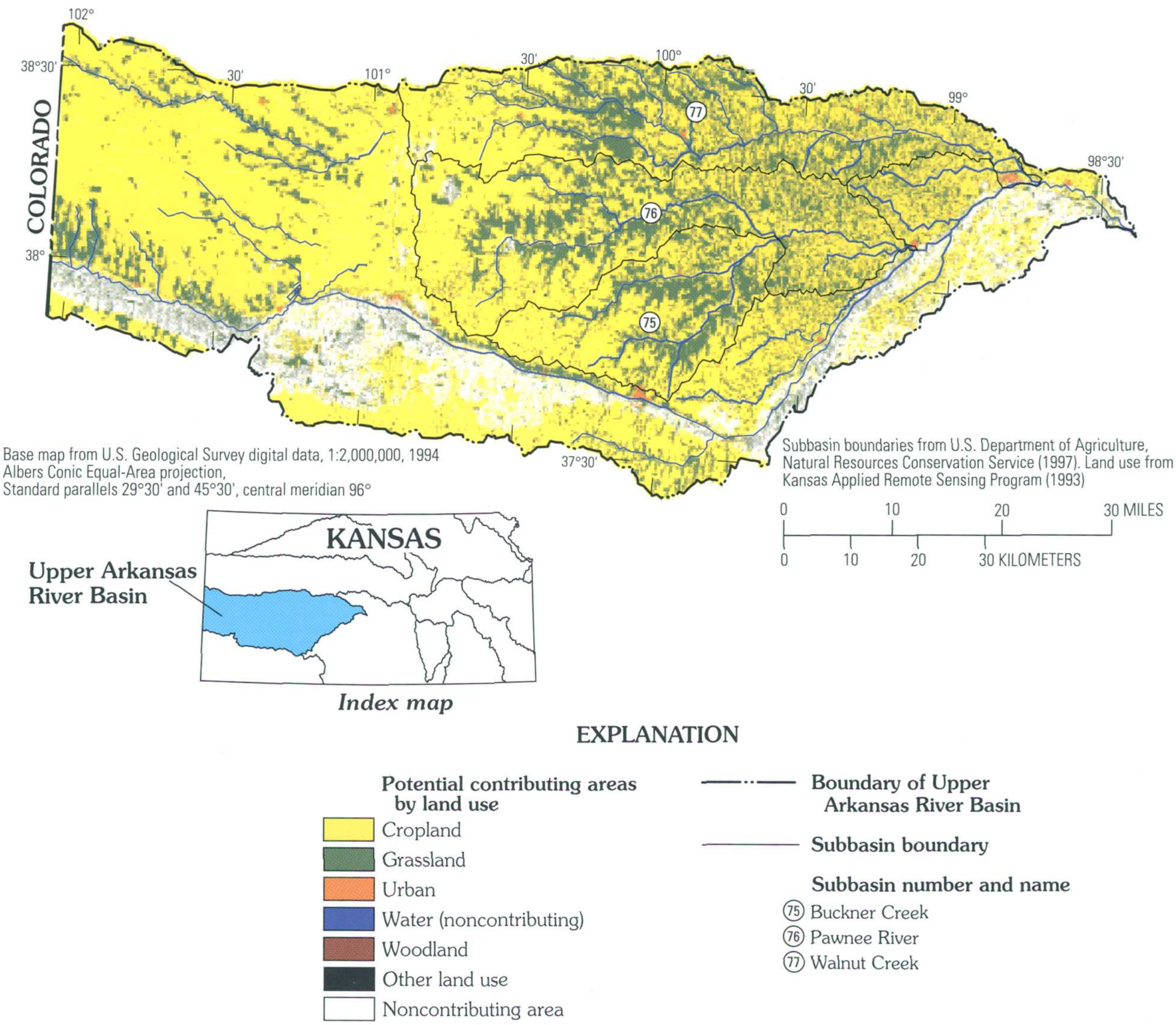


Figure 30. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Upper Arkansas River Basin for low potential-runoff conditions.

Upper Arkansas River Basin

In the Upper Arkansas River Basin, all three subbasins had potential contributing areas in virtually 100 percent of each subbasin for low potential-runoff conditions (fig. 30, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. The very low potential-runoff conditions (fig. 31) provided very limited ability to distinguish subbasins as the potential contributing areas for all three subbasins ranged between 60 and 70 percent. Likewise, the extremely low potential-runoff conditions (fig. 32) provided limited ability to distinguish subbasins as the potential contributing areas for all three subbasins were less than 20 percent (table 1).

The spatial distribution of 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) was similar for the three subbasins (fig. 31). In each case, the potential contributing areas are widespread, with substantial potential contributing areas concentrated in the upstream one-fourth to one-third of each subbasin. For the Pawnee River (subbasin 76), potential contributing areas also cover most of the downstream one-third of the subbasin. In all three subbasins the flood plains are mostly noncontributing areas (fig. 31), with a couple exceptions noted in the following paragraph.

For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), potential contributing areas are generally sparse and scattered (fig. 32). Exceptions include the upstream half of the subbasin for Buckner Creek (subbasin 75), the downstream one-fourth and an isolated area in the southern part of the upstream one-third of the Pawnee River subbasin

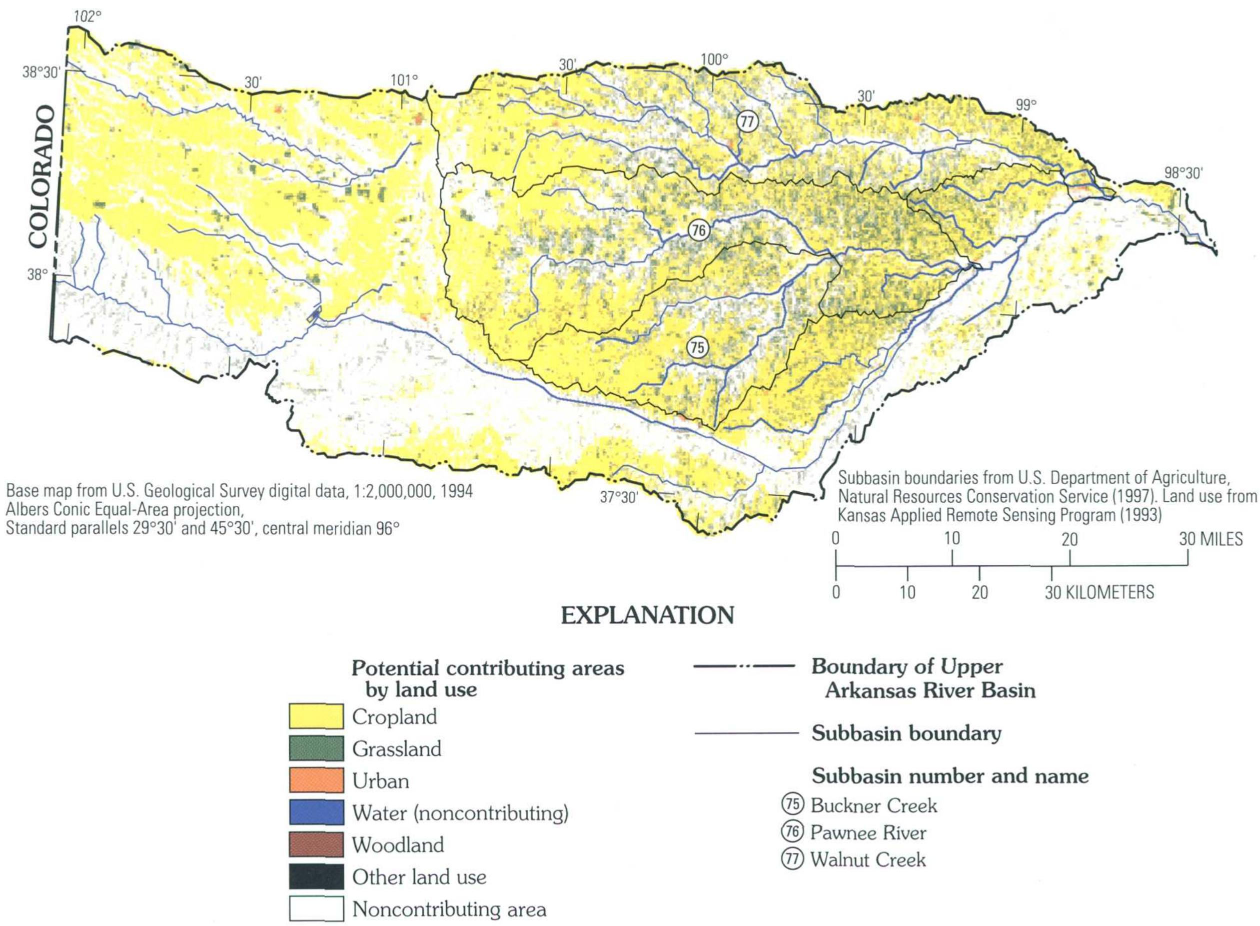


Figure 31. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Upper Arkansas River Basin for very low potential-runoff conditions.

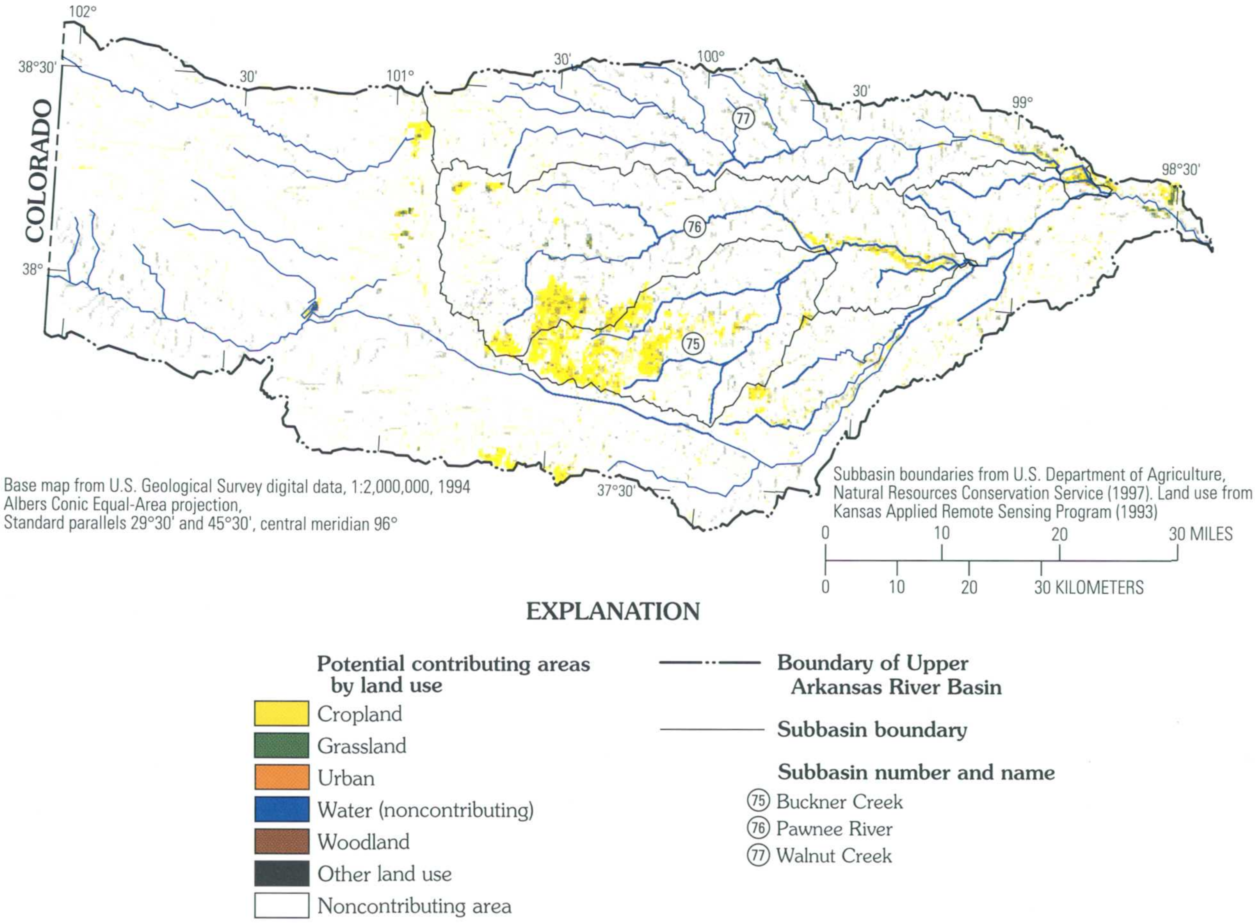


Figure 32. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Upper Arkansas River Basin for extremely low potential-runoff conditions.

(subbasin 76), and the downstream one-fourth of the Walnut Creek subbasin (subbasin 77) where potential contributing areas are more widespread. The potential contributing areas in the downstream one-fourth of the Pawnee River and Walnut Creek subbasins appear to be concentrated in the flood plains (fig. 32).

The subbasins are very similar in terms of land use. In each case, cropland and grassland account for about 70 and 30 percent of the subbasin, respectively (table 1). In the potential contributing areas the minority grassland is interspersed more or less uniformly throughout each subbasin with the exception of the upstream one-fourth of each subbasin where cropland is more extensive (fig. 30).

Upper Republican River Basin

In the Upper Republican River Basin, none of the three sets of environmental conditions were useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. For the low potential-runoff conditions (fig. 33), all three subbasins had potential contributing areas in virtually 100 percent of each subbasin (table 1). For the very low and extremely low potential-runoff conditions (figs. 34 and 35), the potential contributing areas for all three subbasins were about 5 percent or less (table 1). The inability to distinguish subbasins is due to the uniformity of soil permeability throughout most of the Upper Republican River Basin (fig. 4). Within the three subbasins, the depth-weighted, mean soil permeability is about 1.3 in/hr with few exceptions. The spatial distribution of potential contributing areas for the very low and extremely low potential-runoff conditions was sparse and widely scattered throughout all three subbasins.

The subbasins are very similar in terms of land use. In each case, cropland and grassland account for about two-thirds and one-third of the land use, respectively (table 1). Potential contributing areas are characterized by a generally uniform mix of cropland and

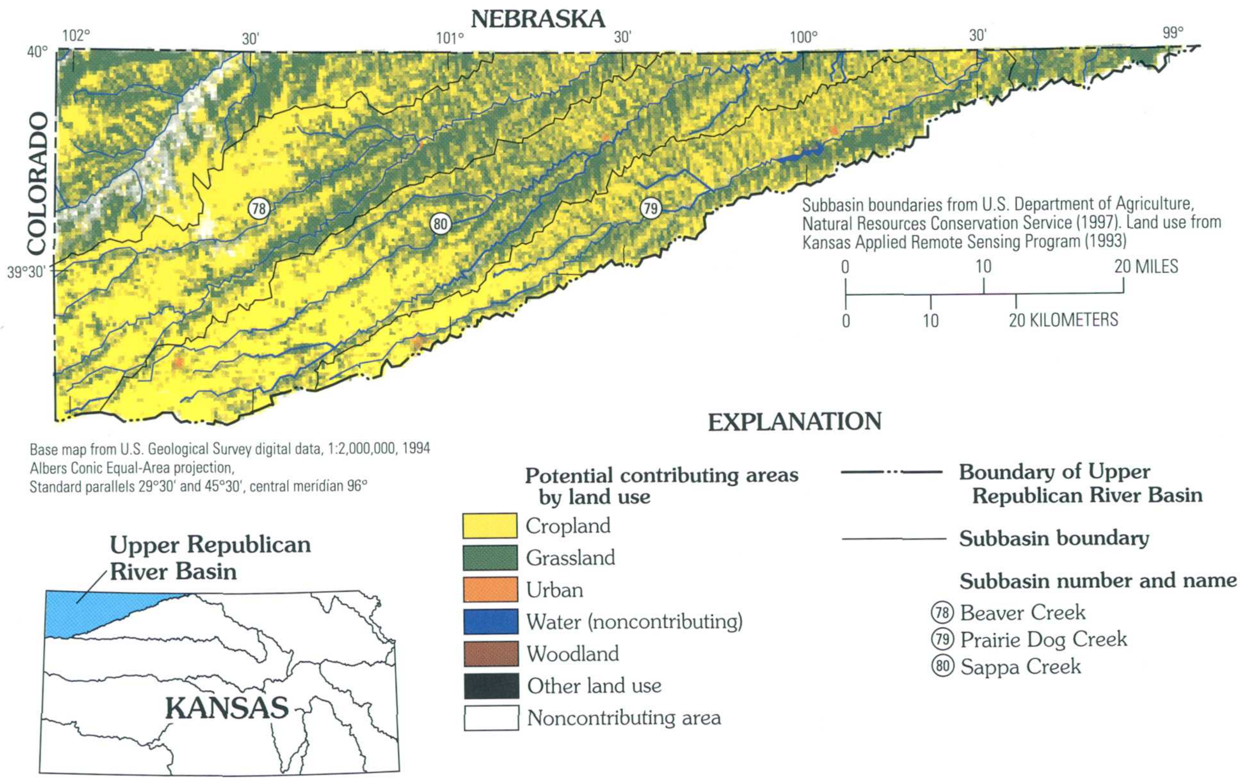


Figure 33. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Upper Republican River Basin for low potential-runoff conditions.

grassland in the downstream two-thirds with cropland prevalent in the upstream one-third of each subbasin (fig. 33).

Verdigris River Basin

The ability to distinguish subbasins of the Verdigris River Basin as having relatively high, moderate, or low potential for runoff was very limited for the low potential-runoff conditions (fig. 36) but good for the very low and extremely low potential-runoff conditions (figs. 37 and 38). 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 54.5 percent of the subbasin for Onion Creek (subbasin 85) to 95.6 percent for the Fall River upstream from Fall River Lake (subbasin 84). Of the seven subbasins in the Verdigris River Basin, two had potential contributing areas in more than 90 percent of each subbasin, two had potential contributing areas in 70 to 90 percent of each subbasin, and three had potential contributing areas in 50 to 70 percent of each subbasin (table 1).

For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), potential contributing areas ranged from 49.0 percent for Onion Creek (subbasin 85) to 84 percent for the Fall River upstream from Fall River Lake (subbasin 84). Of the seven subbasins in the Verdigris River Basin, three had potential contributing areas in 70 to 90 percent of each subbasin, three had potential contributing areas in 50 to 70 percent of each subbasin, and one had potential contributing areas in 30 to 50 percent of the subbasin (table 1).

Using the average percentage of contributing areas for the very low and extremely low potential-runoff conditions, the subbasins were categorized as having relatively high, moderate, or low potential for runoff. The subbasins with relatively high potential for runoff (average percentage of contributing areas greater than 70 percent) were the Elk River upstream from Elk City (subbasin 83), the Fall River upstream from Fall River Lake (subbasin 84), Pumpkin Creek (subbasin 86), and the Verdigris River upstream from Toronto Lake (subbasin 87). The remaining subbasins had relatively moderate potential for runoff (average percentage of

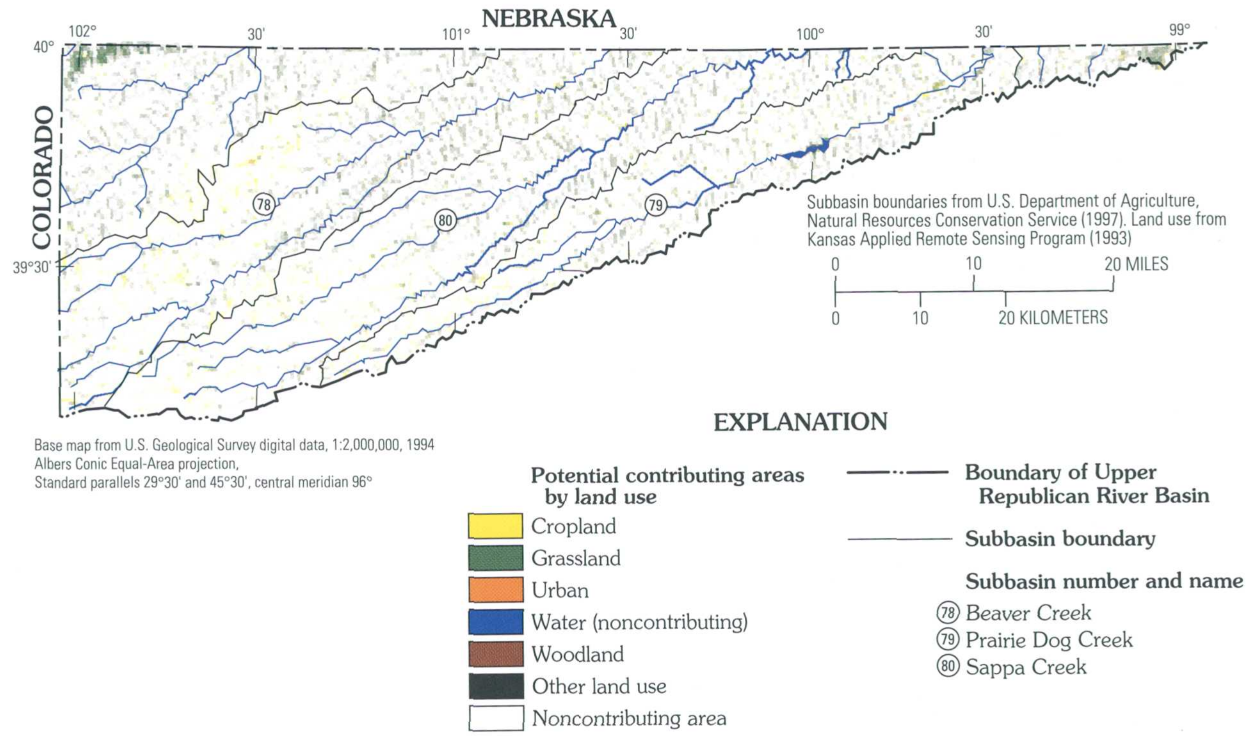


Figure 34. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Upper Republican River Basin for very low potential-runoff conditions.

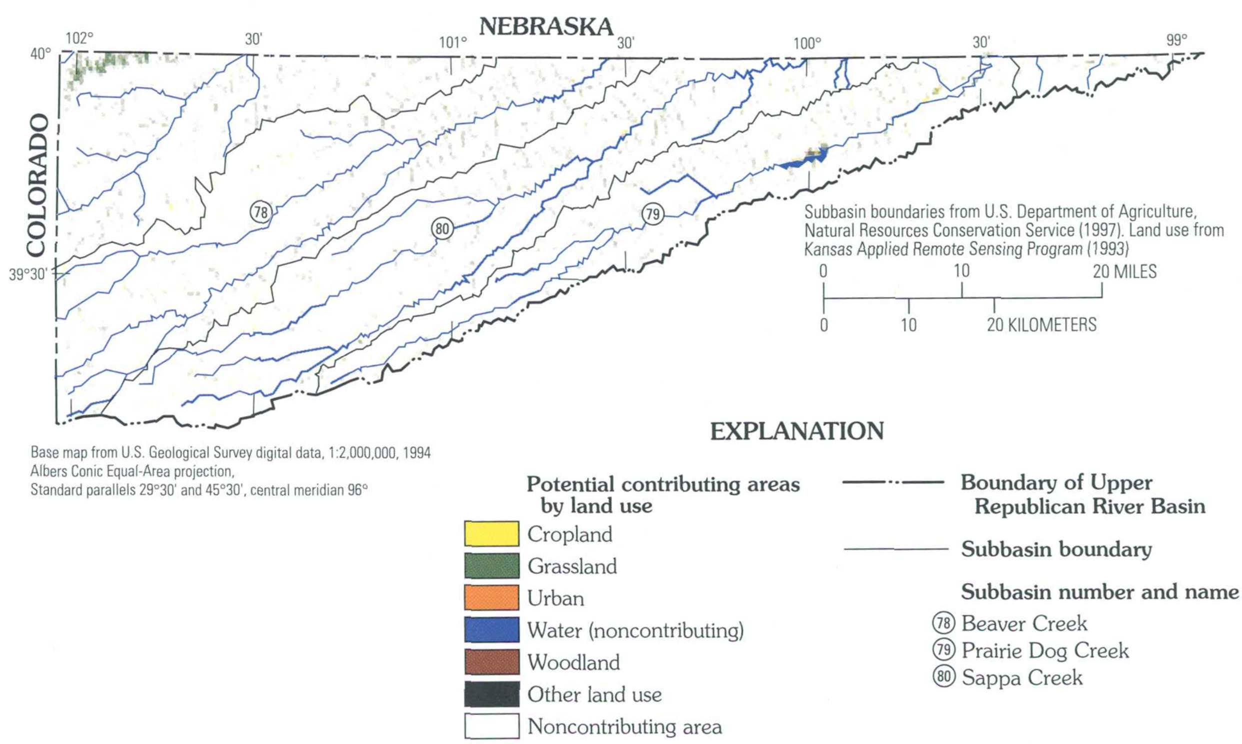


Figure 35. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Upper Republican River Basin for extremely low potential-runoff conditions.

contributing areas between 30 and 70 percent). None of the subbasins had relatively low potential for runoff (average percentage of contributing areas less than 30 percent).

The spatial distribution of potential contributing areas for the very low potential-runoff conditions varied considerably among the subbasins (fig. 37). For Big Hill Creek (subbasin 81), most of the potential contributing areas are located in the upstream and downstream one-thirds of the subbasin. For the Elk River upstream from Elk City (subbasin 83), the potential contributing areas are widespread with noncontributing areas more abundant in the downstream three-fourths of the subbasin. Similarly, for Pumpkin Creek (subbasin 86), the potential contributing areas are widespread with noncontributing areas more abundant in the downstream half of the subbasin. Potential contributing areas are located mostly in the upstream half of the subbasin for Onion Creek (subbasin 85). For Drum Creek (subbasin 82), the potential contributing areas are widespread with a generally uniform distribution. Potential contributing areas cover virtually the entire subbasins for the Fall River upstream from Fall River Lake (subbasin 84) and the Verdigris River upstream from Toronto Lake (subbasin 87). For the extremely low potential-runoff conditions, the spatial distribution of potential contributing areas was very similar (to what was observed for the very low potential-runoff conditions), with noncontributing areas somewhat more common throughout the subbasins (fig. 38).

The prevailing land use in the Verdigris River Basin is grassland, especially in the western half of the basin (table 1). Grassland ranges from 57.1 percent of the subbasin for Big Hill Creek (subbasin 81) to 90.3 percent for the Fall River upstream from Fall River Lake (subbasin 84). Cropland ranges from 4.4 percent of the subbasin for the Fall River upstream from Fall River Lake (subbasin 84) to 33.4 percent for Pumpkin Creek (subbasin 86) (table 1).

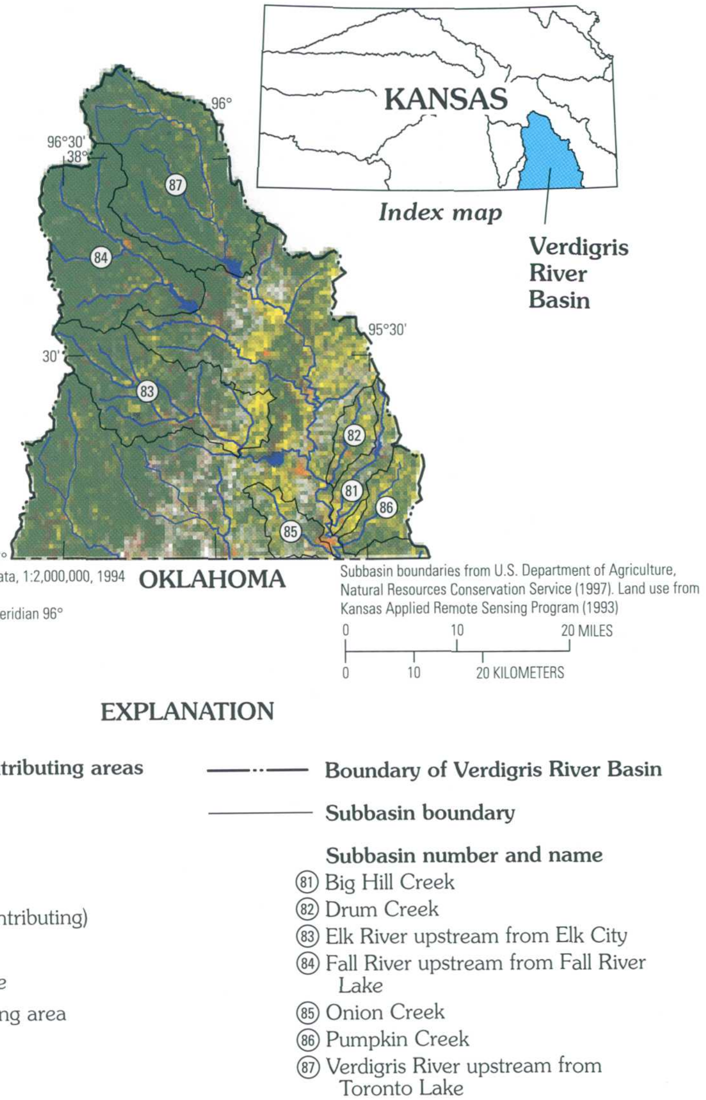


Figure 36. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Verdigris River Basin for low potential-runoff conditions.

Land-use patterns in the potential contributing areas, although dominated by grassland, vary considerably among the subbasins (fig. 36). For Big Hill Creek (subbasin 81), the minority cropland is located mostly in the potential contributing areas in the upstream and downstream one-thirds of the subbasin. For the Elk River upstream from Elk City

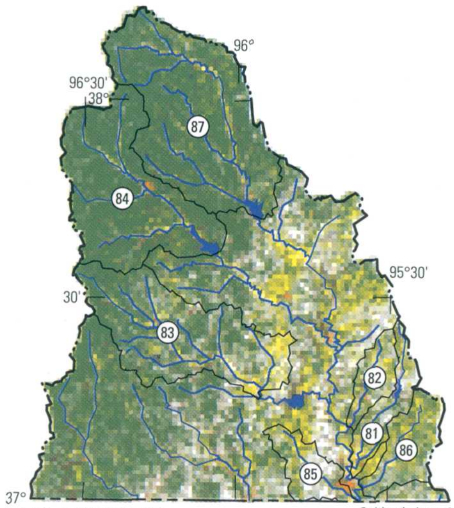


Figure 37. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Verdigris River Basin for very low potential-runoff conditions.

(subbasin 83), most of the minority cropland is located in the potential contributing areas in the downstream one-fourth of the subbasin and in the flood plains. Likewise, most of the minority cropland is located in the potential contributing areas in the flood plains for the Fall River upstream from Fall River Lake (subbasin 84) and the Verdigris River upstream from Toronto Lake (subbasin 87). For Onion Creek (subbasin 85), the minority cropland is located mostly in the potential contributing areas in the upstream half of the subbasin and in the flood plain. The minority cropland is interspersed generally uniformly throughout the potential contributing areas for Drum Creek (subbasin 82) and Pumpkin Creek (subbasin 86).

Walnut River Basin

In the Walnut River Basin, all four subbasins had potential contributing areas in 100 percent of each subbasin for the low potential-runoff conditions (fig. 39, table 1). Thus, this set of environmental conditions was not useful for the purpose of distinguishing subbasins as having relatively high, moderate, or low potential for runoff. Likewise, the very low potential-runoff conditions (fig. 40) were not useful for distinguishing subbasins as the potential contributing areas for all the subbasins were about 90 percent (table 1). The extremely low potential-runoff conditions (fig. 41) provided some ability to distinguish subbasins. For the extremely low potential-runoff conditions, potential contributing areas ranged from 62.8 percent of the subbasin for Timber Creek (subbasin 89) to 87.0 percent for the Whitewater River (subbasin 91) (table 1).

The spatial distribution of 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) is consistent among the subbasins. In each case, the potential contributing areas are widespread throughout the subbasin, with the noncontributing areas located mostly in the flood plains (fig. 40). For the extremely low potential-runoff conditions (soil permeability less than or equal to 0.57 in/hr, TWI greater than or equal to 16.3), the spatial distribution of potential contributing areas is similar (to what was observed for the very low potential-runoff conditions). However, for the Little Walnut River (subbasin 88) and Timber Creek (subbasin 89), the noncontributing areas are substantially more widespread than for the very low potential-runoff conditions (fig. 41).

Land use in the Walnut River Basin is primarily a mix of grassland and cropland with the cropland located mostly in the western half of the basin (fig. 39, table 1). Subbasins dominated by grassland are the Little Walnut River (subbasin 88, 82.3 percent), Timber Creek (subbasin 89, 71.9 percent), and the Walnut River upstream from El Dorado Lake (subbasin 90, 80.9 percent). Cropland is dominant in the Whitewater River subbasin (subbasin 91, 64.6 percent).

The land-use patterns in the potential contributing areas exhibit both similarities and differences among the subbasins. Potential contributing areas for all four subbasins are typified by a concentration of cropland in the flood plains. For Timber Creek (subbasin 89), the remaining cropland is somewhat more concentrated in the potential contributing areas in the downstream half of the subbasin. For the Whitewater River (subbasin 91), most of the minority grassland is located in the potential contributing areas in the eastern half of the subbasin (fig. 39).

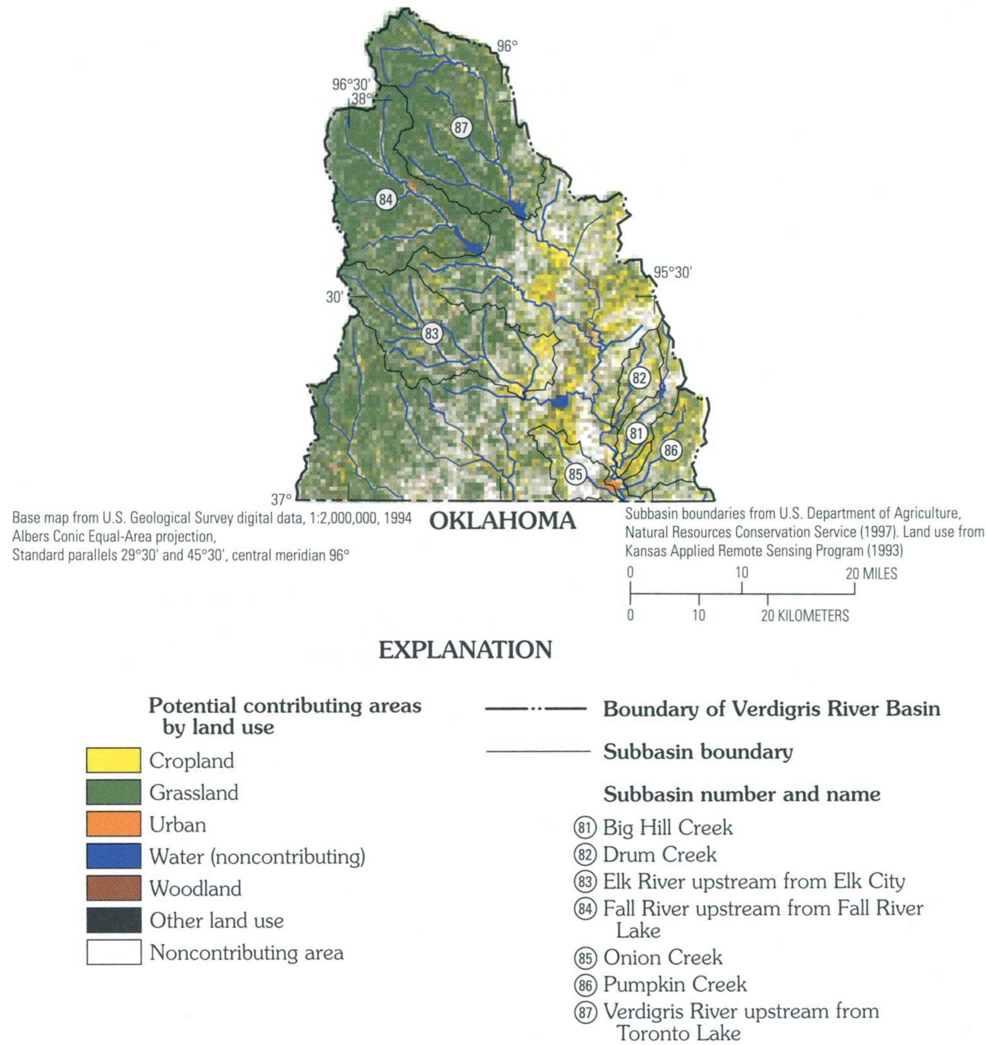


Figure 38. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Verdigris River Basin for extremely low potential-runoff conditions.

SUMMARY AND CONCLUSIONS

Digital topographic, soil, and land-use information was used to estimate and compare potential runoff-contributing areas for 91 selected subbasins in 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, in relative terms, very high, high, moderate, low, very low, and extremely low potential for runoff. 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 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

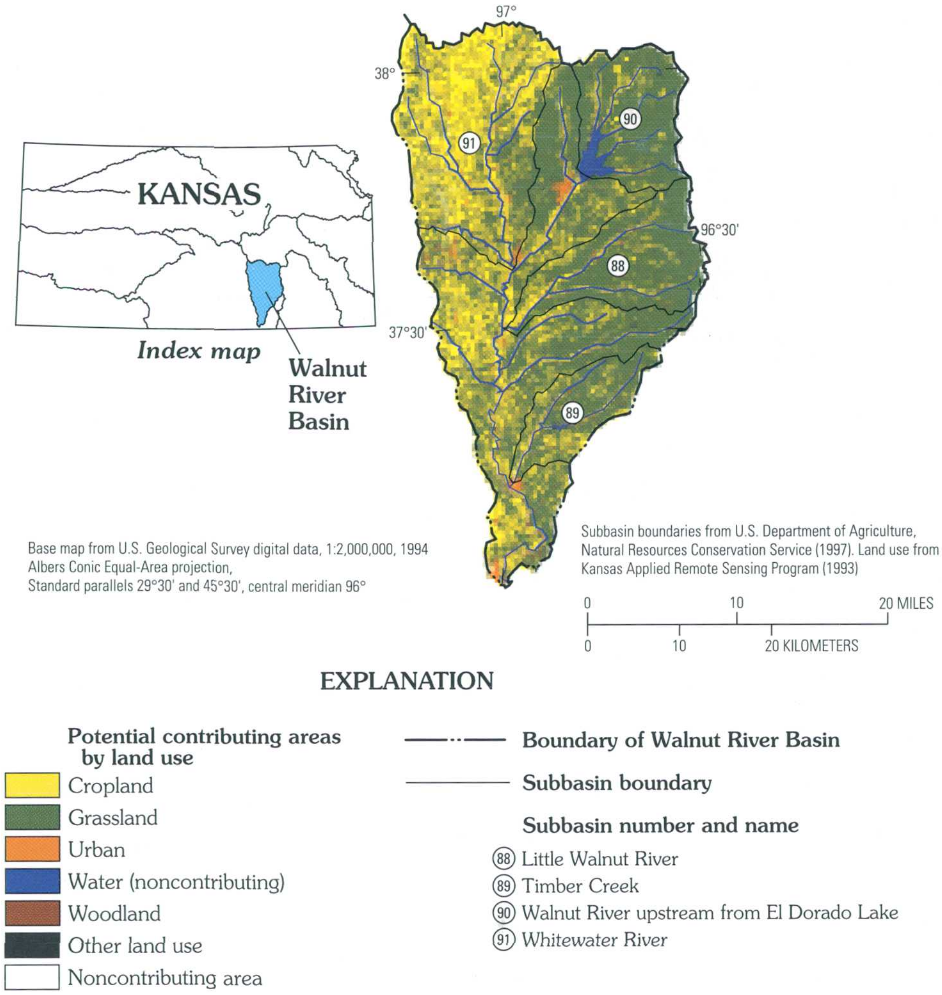


Figure 39. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Walnut River Basin for low potential-runoff conditions.

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). Within the major river basins, the ability to distinguish subbasins as having relatively high, moderate, or low potential for runoff varied. For the Cimarron, Neosho, Smoky Hill-Saline, and Solomon River Basins, the best ability to distinguish subbasins was provided by the very low potential-runoff conditions. For the Cimarron Basin good ability to distinguish subbasins also was provided by the low (soil permeability less than or equal to 1.71 inches per hour and TWI greater than or equal to 12.4) and extremely low (soil permeability less than or equal to 0.57 inch per hour and TWI greater than or equal to 16.3) potential-runoff conditions. For the Kansas-Lower Republican, Lower Arkansas, Marais des Cygnes, Missouri, and Verdigris River Basins, the best ability to distinguish subbasins was provided by both the very low and extremely low potential-runoff conditions. The extremely low potential-runoff conditions provided the best ability to distinguish subbasins for the Upper Arkansas and Walnut River Basins. For the Upper Republican River Basin, none of the potential-runoff conditions provided the ability to distinguish subbasins. 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.

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 between and within subbasins 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 typically remained 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 flows becomes less meaningful as the ground becomes increasingly saturated and the potential contributing areas for both runoff processes coalesce.

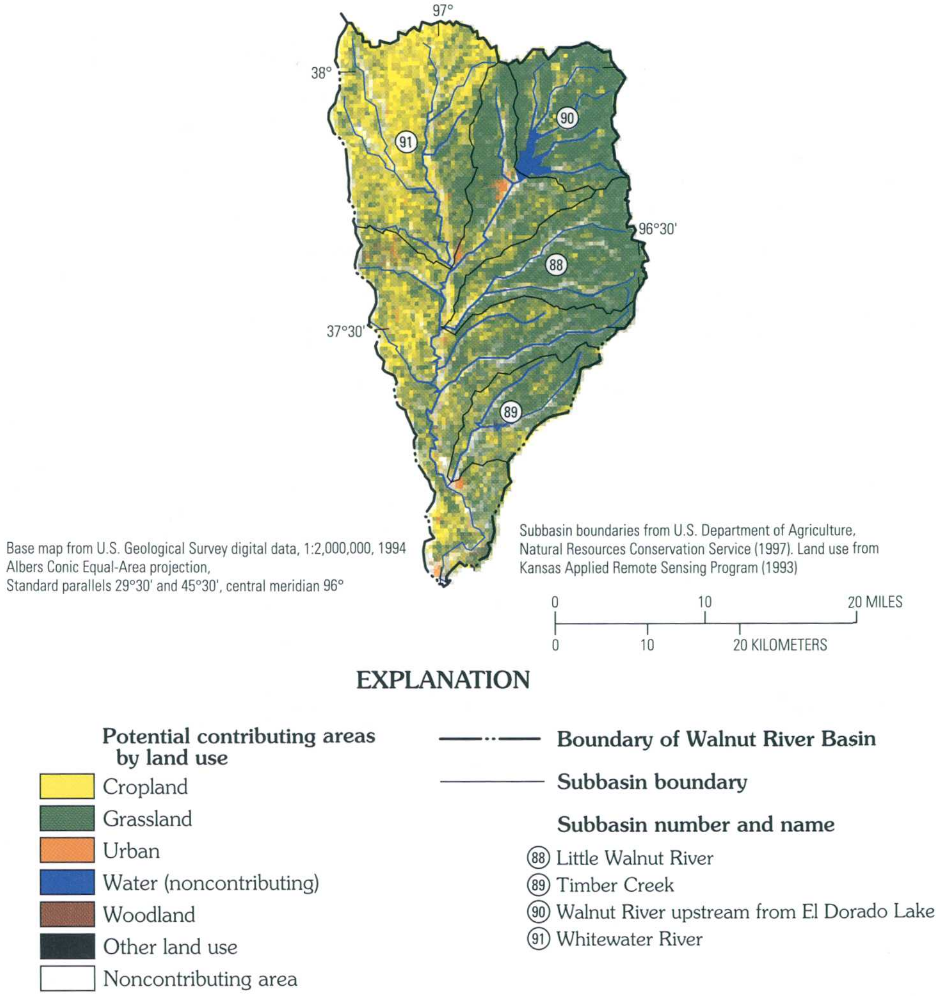


Figure 40. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Walnut River Basin for very low potential-runoff conditions.

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. 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 than 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 pattern, 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 overestimate or underestimate 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, land use immediately adjacent to streams, and climatic variability. Such factors were not addressed in this study but may have important implications for future water-resource management.

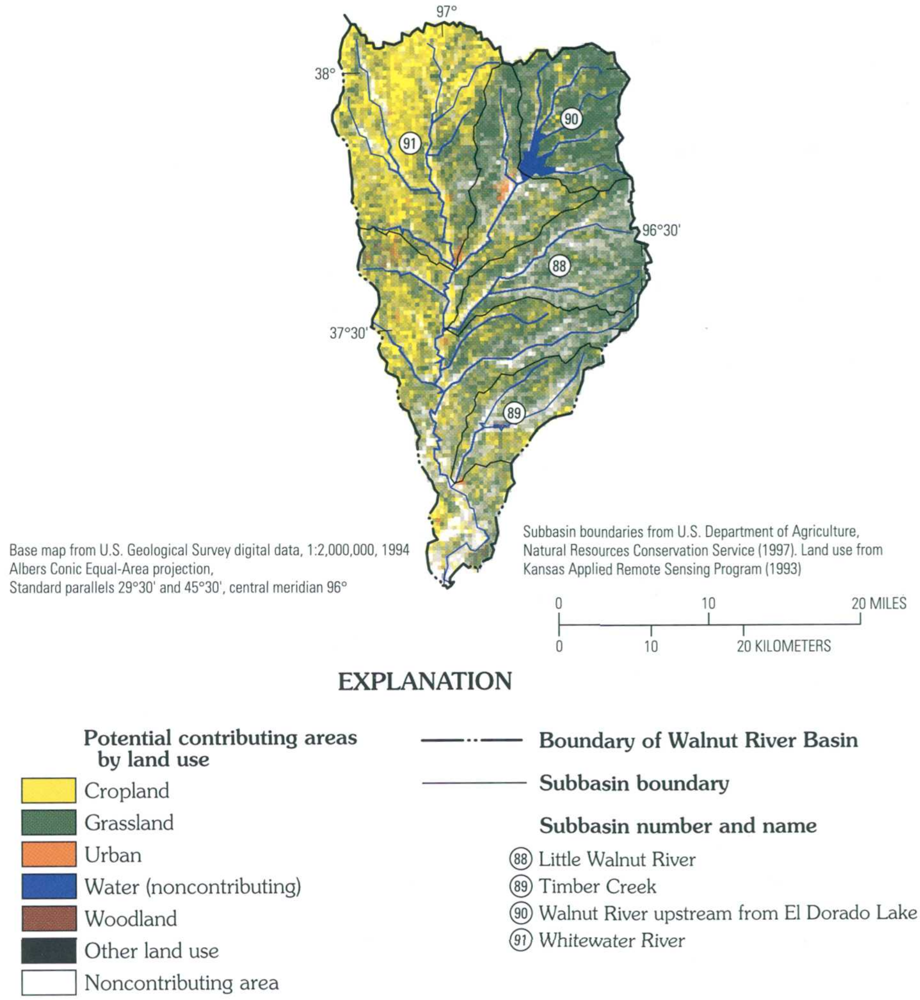


Figure 41. Potential contributing and noncontributing areas of combined infiltration- and saturation-excess overland flows in Walnut River Basin for extremely low potential-runoff conditions.

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