KANSAS REFERENCE STREAMS:

SELECTION OF SUITABLE CANDIDATES, IMPENDING THREATS TO REFERENCE STATURE, AND RECOMMENDATIONS FOR LONG-TERM CONSERVATION

Kansas Department of Health and Environment
Bureau of Environmental Field Services
and Bureau of Water

Cover photograph: Salt Fork Arkansas River, southwestern Barber County, Kansas
Photographer: Diana Lehmann, Kansas Department of Health and Environment

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Executive Summary

Reference streams, or the highest quality streams in a given region, play a critical role in modern water pollution control programs. Knowledge obtained through their study is applied in the characterization of the baseline ecological condition, the development of surface water quality criteria, the identification of water quality-impaired streams, the performance of statewide water quality assessments, and the formulation of restoration goals for environmentally degraded water bodies. With these considerations in mind, the Kansas Department of Health and Environment (KDHE) recently undertook a systematic inventory of candidate reference streams in Kansas.

In July 2009, KDHE began to assemble a large suite of existing geographical databases, each relevant to the identification and study of reference ecosystems. A human disturbance index was developed using these databases and subsequently applied in the evaluation and ranking of the state's nearly 100,000 watersheds and corresponding stream reaches. Predictive computer models also were developed relating watershed disturbance scores to the prevailing diversity of native fishes, freshwater mussels, and aquatic insects. Results were summarized and interpreted for the state as a whole and for five quantitative ecoregions delineated as part of this study.

Disturbance scores varied significantly among quantitative ecoregions, but the lowest scores in each ecoregion were associated with the headwater catchments of large grassland areas. Watersheds with exceptionally low scores were relegated primarily to the Flint Hills, Smoky Hills, and Gypsum Hills and to a few isolated areas in northwestern and extreme southwestern Kansas. Heavily disturbed watersheds were prevalent in far eastern Kansas and in the central and southwestern portions of the state. Geographical location and stream size were significant predictors of species richness. However, regression models incorporating disturbance score as an independent variable revealed a consistent, inverse relationship between the number of species inhabiting a given stream and the level of human activity occurring in the surrounding catchment.

Governmental planning documents, statistical abstracts, permit applications, unpublished databases, and published and unpublished reports were examined for environmental and societal trends bearing on the future integrity of reference streams in Kansas. Based on this assessment, the following disturbance factors exhibited a significant potential for degrading the quality of reference streams over time: urban and residential sprawl; transportation and utility infrastructure development; mineral resource extraction; dam construction; conversion of native (and restored) grassland to other uses; feedlot proliferation and expansion; surface water and groundwater diversions; and nonnative species infestations. Climate change and other regional and global factors could exacerbate the effects of these disturbances.

In the months and years ahead, and as permitted by the availability of staff and other resources, KDHE will endeavor to finalize the reference stream selection process initiated in this study. Watersheds with low disturbance scores will be targeted for field-based validation studies. Final reference stream selections will be based on four primary factors: watershed disturbance score; field assessment results; site accessibility (i.e., willing landowner participation); and perceived future disturbance risk. Verified reference streams will be incorporated into KDHE's long-term water quality monitoring program and sampled on a four- to eight-year rotational schedule.

The importance assigned to reference streams implies that a concerted effort should be made to maintain (and possibly improve) the condition of these aquatic ecosystems. Pursuant to the Kansas surface water quality standards, some reference streams may merit designation as exceptional state waters or outstanding national resource waters. Total maximum daily loads (TMDLs) could, and probably should, be developed for selected reference streams based on the antidegradation provisions of the existing standards. Similarly, the establishment of minimum desirable stream flows for selected reference streams would reduce some of the environmental concerns resulting from the planned development of additional impoundments and water diversions in Kansas.

Several governmental agencies administer programs that promote the voluntary adoption of agricultural best management practices and/or the restoration and protection of riparian areas and adjacent surface waters. Some of these programs also offer financial incentives to participating landowners. To date, available funding has been used primarily to improve conditions in heavily degraded watersheds. In the future, a portion of these funds could be reserved for the protection and improvement of reference streams and other high quality surface waters. Various private organizations also work closely with landowners to preserve and protect unique natural areas, a concept that could be extended readily to reference streams.

The conservation and protection of reference ecosystems should be included among the shared goals of all natural resource agencies in Kansas. Landowners, interest groups, and the general public should be kept apprised of governmental decisions affecting the condition of these ecosystems. The next revision of the *Kansas Water Plan* seemingly would provide an ideal opportunity for public and interagency dialogue on this issue. Recommended changes to the *Kansas Water Plan*, underscoring the ecological and regulatory importance of reference streams, would facilitate the level of cooperation needed to effectively manage and maintain these exceptional waters.

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1. Introduction

This report was prepared by the Kansas Department of Health and Environment (KDHE) and submitted to the United States Environmental Protection Agency (EPA) in partial fulfillment of the terms of a stimulus grant awarded under the American Recovery and Reinvestment Act of 2009. It addresses the occurrence and distribution of reference stream reaches within Kansas, the importance of these reaches in environmental regulatory and restoration programs, and the need to identify and conserve reference-caliber aquatic ecosystems within the state. The development of a statewide inventory of reference water bodies was established previously as a long-term departmental goal (KDHE 2005). The availability of federal stimulus monies allowed this goal to be pursued on an expedited basis.

1.1 Role of reference streams

The Federal Water Pollution Control Act of 1972 sought to "restore and maintain the chemical, physical, and biological integrity of the Nation's waters." This historic and sweeping environmental statute did not define the key term, integrity, but congressional records indicate that legislators drafting the original bill considered naturalness and integrity to be redundant expressions (Davis 1995). Elaborating on this concept, Frey (1977) defined biological integrity as the "capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a composition and diversity comparable to that of the *natural* habitats of the region" (emphasis added). Karr and Dudley (1981) modified the latter portion of Frey's definition to read: "having a species composition, diversity, and functional organization comparable to that of the natural habitats of the region." Today, this modified definition is deeply ingrained within the environmental regulatory and scientific community (Stoddard et al. 2006).

The concept of reference condition is closely linked to the notions of biological integrity and naturalness (Reynoldson and Wright 2000; Hawkins 2006). Environmental researchers often use data from comparatively unaltered (reference) water bodies to approximate the baseline or pre-disturbance condition in other aquatic ecosystems. Stoddard et al. (2006) suggested that water bodies exhibiting comparatively little alteration could be placed into one of two categories: *minimally disturbed* systems (those largely unaffected by human actions); and *least disturbed* systems (those exhibiting the best remaining condition in a region widely impacted by human actions). They also used the term *best attainable* to describe a hypothetical condition resulting from the implementation of all appropriate best management practices and best practicable technologies. The term *historical* was used by the same authors to denote a biological condition occurring at some specified point in the past (e.g., immediately prior to European settlement). These terms and definitions have been widely adopted by aquatic ecologists and environmental regulators in the United States (e.g., Paulsen et al. 2008; Bellucci et al. 2009).

Candidate reference waters often are identified by aquatic biologists, hydrologists, and other specialists using a combination of available monitoring data and best professional judgement (e.g., Suplee et al. 2005; Baker et al. 2009). Most state and federal environmental agencies maintain probabilistic or targeted water quality monitoring programs, allowing data obtained from selected streams, lakes, and wetlands to be applied in the characterization of the reference condition. Because funding and logistical constraints limit the number of water bodies that can

be included in governmental monitoring programs, some agencies have attempted to screen large regions for reference-caliber aquatic systems using geographical information system (GIS) methods and available landscape databases. Such an approach does not rely on the *a priori* availability of site-specific data, produces a more complete inventory of prospective reference systems, and can be used to quantitatively assess the prevailing level of human disturbance in individual watersheds (Wang et al. 2008).

The emergence of modeling techniques for estimating taxonomic completeness (defined as the proportion of expected taxa actually observed during monitoring activities, or O/E) has enhanced the ability of scientists and regulators to detect human-induced changes in biological condition (Moss et al. 1987; Hawkins et al. 2000; Clarke et al. 2003; Hawkins 2006). However, the accuracy of any assessment employing such techniques is fundamentally dependent on the quality of the reference systems selected within the geographical region of interest. To obtain the greatest possible benefit from the O/E method and comparable modeling techniques, reference waters must be chosen in the most objective, systematic, and reproducible manner possible. The development and adoption of a standardized protocol for screening large areas (e.g., states, ecoregions) would lead to more comprehensive inventories of candidate reference systems, improve the representativeness of the resulting baseline data, and amplify the scientific benefits stemming from the O/E modeling method and other advanced bioassessment approaches.

KDHE administers several statewide environmental monitoring programs, including both targeted and probabilistic stream biological monitoring programs (KDHE 2010a). Efforts are underway within the department to adopt the O/E modeling method for bioassessment purposes. However, these efforts have been hindered, to date, by the small number of identified reference systems within or adjacent to the state. The department previously has acknowledged the need to identify additional reference systems and to reevaluate the condition of all previously selected water bodies (KDHE 2005). Urban sprawl and ongoing industrial and agricultural development threaten to degrade the state's remaining reference-caliber waters (Angelo 1994; Angelo et al. 2003; KDHE 2010a). Recent pipeline ruptures and chemical spills in Kansas (e.g., NTSB 2007) and plans to develop additional reservoirs within the state (KWA 2010) likewise underscore the pressing need to identify the most promising candidate reference systems, to confirm (or refute) their reference stature, and to safeguard them from further chemical, physical, and biological degradation.

1.2 Scope of report

As an initial step in the identification and conservation of reference stream reaches in Kansas, this report uses a large suite of existing geographical databases and an integrative statistical approach to develop a landscape-based watershed disturbance index. Each of the state's nearly 100,000 watersheds is ranked on the basis of anthropogenic alteration, and results are interpreted in the context of a quantitative ecoregional framework. Predictive computer models are presented relating human disturbance scores to the prevailing diversity of native fishes, freshwater mussels, and aquatic insects. Modeling results, watershed disturbance rankings, and other available sources of information are used to identify the most promising candidate reference streams, to ascertain the most serious threats to these water bodies, and to formulate recommendations for reducing these threats.

2. Methods

2.1 Delineation of stream reaches and watersheds

Stream reaches in this study were defined on the basis of tributary confluences, an approach applied successfully by earlier investigators (e.g., Brenden et al. 2006; Wang et al. 2008). All reaches, and their corresponding allocated and accumulated watersheds, were delineated using the 1:100,000 scale NHDPlus dataset and supporting CA3T software (NHDPlus 2005). Allocated watersheds included all land surfaces adjoining (draining directly into) the defined reaches, whereas accumulated watersheds included entire upstream drainage areas. Ninety meter riparian corridors also were delineated for all reaches using ArcGIS (ESRI 2009). NHDPlus provided two different estimates of annual average flow for individual stream reaches (Vogel et al. 1999; RTI 2001). Estimates based on the unit runoff method (UROM) were available for all reaches and were selected for use in this study (see NHDPlus 2010). The UROM estimates allowed streams throughout Kansas to be partitioned and evaluated according to size (discussed below).

2.2 Delineation of quantitative ecoregions

Ecoregions are relatively homogenous geographical areas defined and differentiated in the context of some combination of landscape characteristics (e.g., climate, physiography, soils, vegetation, geology). Hargrove and Hoffman (2005) argued that most previously developed ecoregional frameworks were not suitable for statistical extrapolation, primarily because boundaries between ecoregions were established on the basis of subjective expert opinion (see Bailey 1976, 1983; Omernik 1987, 1995; Bailey et al. 1994; Abell et al. 2000). They presented an alternative method for delineating ecoregions based on multivariate clustering and visualization techniques. These techniques were adapted for use in this study.

Specifically, statewide geographical databases were obtained for 13 environmental variables, each germane to the characterization and classification of watersheds and each comparatively unvarying under conditions of human disturbance (Table 1). These databases were converted to 30 meter raster coverages, and arithmetic means and standard deviations for the corresponding variables were calculated for all allocated watersheds. Applying varimax rotation, a principal components analysis (PCA) was performed on the standardized residuals (for both means and standard deviations) to produce 26 orthogonal component axes. Ecoregional boundaries were determined by subjecting the watershed data space coordinates to *k*-means non-hierarchical clustering, where *k* refers to a predetermined number of clusters (Hartigan 1975). Watersheds grouped into the same data space cluster were assigned to the same ecoregion. Nine different *k* scenarios were evaluated as part of this study (k = 3, 4, 5, 10, 50, 100, 250, 500, and 1,000).

To enhance visualization, the first, second, and third principal component scores for each watershed were extracted and converted to color intensity units using a 0–255 scale, red-green-blue (RGB) color triplet. Average RGB values, representing the centroid position in three-dimensional data space, were calculated for each watershed cluster (i.e., ecoregion). Adjoining ecoregions exhibiting comparable topographic, climatic, and edaphic conditions were mapped in similar (average RGB) colors, depicting a gradual spatial transition in environmental character. Adjoining ecoregions with markedly different conditions were mapped in dissimilar colors, revealing a more abrupt transition in environmental character (Hargrove and Hoffman 2005).

Table 1. Variables considered in quantitative ecoregional analysis (see also appendices A and B). Variable names ending in "m" and "sd" refer to watershed means and standard deviations, respectively.

Variable name	Variable description	Variable name	Variable description
Climatological		Edaphic (cont.)	
AMPm	Annual mean precipitation	SPHm	Soil pH
AMPsd		SPHsd	
FFDm	Frost-free days per year	SPSm	Soil percent sand
FFDsd		SPSsd	
ISRm	Incident solar radiation	WTDm	Water table depth
ISRsd		WTDsd	
Edaphic		Topographic	
SAWCm	Soil available water capacity	LSAm	Land surface aspect
SAWCsd		LSAsd	
SCECm	Soil cation exchange capacity	LSEm	Land surface elevation
SCECsd		LSEsd	
SKSATm	Soil hydraulic conductivity	LSSm	Land surface slope
SKSATsd		LSSsd	
SOMm	Soil organic matter		
SOMsd			

2.3 Disturbance index development

A statewide disturbance index was developed using available geographical databases for 20 measures of landscape alteration (Table 2). These databases were converted to 30 meter raster coverages, and arithmetic means for the 20 measures were calculated separately for allocated and accumulated watersheds (corresponding to near-field and far-field influences on stream biota). Means were normalized to [0, 1] using a linear scaling function, and a PCA was performed on all 40 indicators using varimax rotation (Smith et al. 2003). Orthogonal components with eigenvalues of 1.0 or more were extracted for further analysis. Loadings were converted to absolute values and used as weighting coefficients for their respective indicators. The weighted sum of all 40 indicators was calculated for each extracted component, then the average of these weighted sums was used as an integrated disturbance index for watershed ranking purposes. Based on the index scores, watersheds were assigned to seven groups (septiles) containing an equal number of watersheds (unless prohibited by ties). Each group was mapped in a different color, ranging from green (best condition) to red (worst condition) (Smith et al. 2003).

Environmental variables also were integrated by summing the normalized values for all 40 indicators within each watershed. Watersheds were grouped into septiles based on the summed values and again mapped using a green (best condition) to red (worst condition) color scheme. The resulting map was compared with the original, PCA-based map as a check against the occurrence of distorting data anomalies. To the extent the two maps agreed with one another, the PCA results were considered unaffected by such anomalies (Smith et al. 2003). Agreement between maps was defined as the percentage of watersheds assigned to the same disturbance class. Differences between paired watershed septile (1–7) scores were evaluated using the non-parametric Wilcoxon signed rank test ($\alpha = 0.05$).

Table 2. Variables considered in watershed disturbance analysis (see also appendices C and D). Variable names ending in "al" and "ac" refer to allocated and accumulated catchments, respectively.

Variable name	Variable description
CAFOal	Density of confined livestock (animal units)
CAFOac	
CROPal	Ratio of cropland area to total land area
CROPac	
CROPRIal	Ratio of cropland area to total land area within 90-meter riparian corridor
CROPRIac	
DAMSal	Density of registered and unregistered dams
DAMSac	
GRAZINal	Density of grazing cattle
GRAZINac	
H2OWELal	Density of permitted groundwater diversions
H2OWELac	
IMPOUNal	Ratio of inundated land area to total land area
IMPOUNac	
LANDFIal	Density of active and inactive permitted landfills
LANDFIac	
MINESal	Density of active and inactive permitted mines and quarries
MINESac	
NPDESal	Total permitted wastewater output divided by catchment area
NPDESac	
OILWELal	Density of registered active and inactive oil and natural gas wells
OILWELac	
PESTICal	Combined annual application rate for all pesticides
PESTICac	
PIPECRal	Density of stream/industrial pipeline intersections
PIPECRac	
POPULAal	Density of human residents
POPULAac	
RAILCRal	Density of stream/railroad intersections
RAILCRac	
ROADCRal	Density of stream/road intersections
ROADCRac	
SUPERFal	Density of active and inactive Superfund sites
SUPERFac	
SURFDIal	Density of permitted surface water diversions
SURFDIac	
URBANal	Ratio of urban land area to total land area
URBANac	
URBANRal	Ratio of urban land area to total land area within 90-meter riparian corridor
URBANRac	

2.4 Modeling the effects of disturbance on taxonomic richness

Taxonomic richness databases were compiled for three different groups of organisms based on biological surveys performed from 1990 through 2007 by KDHE and the Kansas Department of Wildlife and Parks. These groups included native fishes (KDWP 2009), freshwater mussels (Angelo et al. 2009), and aquatic insects belonging to the orders Ephemeroptera, Plecoptera, and Trichoptera (EPT) (KDHE 2007, 2010b). All fish and mussel records were resolved to the species level, whereas insect records were resolved to the genus or species level. Collectively, biological data were available in some form for 1,820 stream reaches or 1.8% of the reaches represented in the NHDPlus database. Data pertaining specifically to fishes, mussels, and EPT were available for 908, 1,763, and 225 stream reaches, respectively (Table 3).

Table 3. Number of inter-confluence stream reaches with available biological data, presented for state as a whole and for component quantitative ecoregions (see Quantitative Results, Figure 1).

	----------Ecoregion----------					
Faunal group(s)	ER1	ER2	ER3	ER4	ER5	Statewide
EPT	9	48	28	38	102	225
Fishes	101	148	194	180	285	908
Mussels	217	368	264	328	586	1,763
EPT + fishes	2	9	10	10	20	51
EPT + mussels	9	44	28	31	84	196
Fishes + mussels	101	143	193	176	276	889
EPT + fishes + mussels	2	9	10	10	20	51

Biological surveys were performed at some monitoring sites on more than one occasion during the 18-year assessment period. In such cases, median richness was applied as the point estimator for the corresponding stream reach. Data also were obtained in several instances from two or more sites within a given reach. In these instances, the (grand) median richness across sites was calculated and applied to the reach. Richness databases for the three faunal groups were merged with the watershed disturbance database described previously. Stream flow (Q) values were log transformed ($\log_{10} Q + 1$), and data for all watershed variables were standardized ($(x - \bar{x}) \div sd$) prior to the onset of model development (Frank and Althoen 1995).

Independent variables in the preliminary regression models included longitude, latitude, stream flow, and PCA-based disturbance score. Data for the individual disturbance indicators (rather than the integrated disturbance score) then were used to develop alternative models using best-subsets regression. Disturbance indicators were incorporated as free variables, whereas longitude, latitude, and flow were incorporated as fixed variables. Separate models were developed for the state as a whole and for individual quantitative ecoregions ($k = 5$). Models were fitted initially with variance inflation factor (VIF) values, and independent variables with VIF > 5.0 were eliminated from further modeling iterations. To choose among the various competing models, we employed two criteria: Mallow's $C_p \leq (p + 1)$ (where p represented the number of independent variables); and largest possible R^2_{adj} (coefficient of determination adjusted for the number of independent variables). Independent variables were trimmed from the resulting models if their associated p-values exceeded 0.05.

Final models were chosen based on their ability to accurately predict responses to new observations, as measured by the predicted R^2 statistic (predicted residual sum of squares expressed as a percentage of the total sum of squares) (see Ott and Longnecker 2001; Minitab 2010). Models with fewer variables but meeting the above C_p and R^2_{adj} criteria were retained preferentially over equally predictive but more complex models.

2.5 Reference stream threat assessment

Governmental planning documents, statistical abstracts, permit applications, and similar sources of information were examined for environmental and societal trends bearing upon the future condition of candidate reference streams. The following indicators were considered in this qualitative analysis: human population growth; urban/residential encroachment; point source proliferation and expansion; industrial facility and infrastructure development (including pipeline and utility corridor development); mineral resource extraction; road construction; dam construction; conversion of native (and restored) grassland to other uses; proliferation/expansion of feedlots; stream channelization; riparian corridor degradation; surface water and alluvial groundwater diversions; and exotic species infestations. Specific sources of information included in the threat assessment are identified later in this report.

3. Quantitative results

3.1 Ecoregional delineations

Kansas ecoregions (k = 5) identified during this study are depicted in random colors in Figure 1. In the underlying PCA analysis, the first, second, and third principal components accounted for 53% of the total variability in the watershed data. The first component was defined largely by spatial variability in AMPm, LSEm, and ISRm (each related to elevation or climate), the second component by variability in LSSsd, LSEsd, LSSm, and ISRsd (each related to topographical relief and roughness), and the third component by variability in SKSATsd, SPSsd, SAWCm, SKSATm, and SPSm (each related to soil water retention capacity) (Table 4). Figure 2 illustrates the application of RGB colors to the coordinate scores for the cluster (ecoregional) centroids and the subsequent combining of these colors into a single similarity map (k = 5). Figure 3 presents eight additional similarity maps, each developed under a different k scenario (k = 3, 4, 10, 50, 100, 250, 500, and 1,000). Maps developed for each of the 26 underlying indicators are presented in Appendix B.

The quantitative ecoregional maps presented in this report superficially resemble maps developed by previous researchers using best professional judgment or BPJ (e.g., Chapman et al. 2001; Appendix E). A pronounced east-to-west zonation is apparent in both the quantitative and BPJ-based maps, and certain geographical areas stand out in both cases (e.g., Southwestern Tablelands, Flint Hills). However, boundaries between regions differ markedly from map to map (e.g., eastern margin of Western High Plains) and several minor features in the BPJ-based maps (Level IV features in Chapman et al.) are depicted more prominently in the quantitative maps (e.g., Rolling Sand Plains, Great Bend Sand Prairie, Smoky Hills). Major ecoregions in the BPJ-based maps (Level III features in Chapman et al.) are presented as contiguous land surfaces, whereas some quantitative (k = 5) ecoregions are fractured into many separate parts. Such differences bear heavily on the selection and distribution of candidate reference streams.

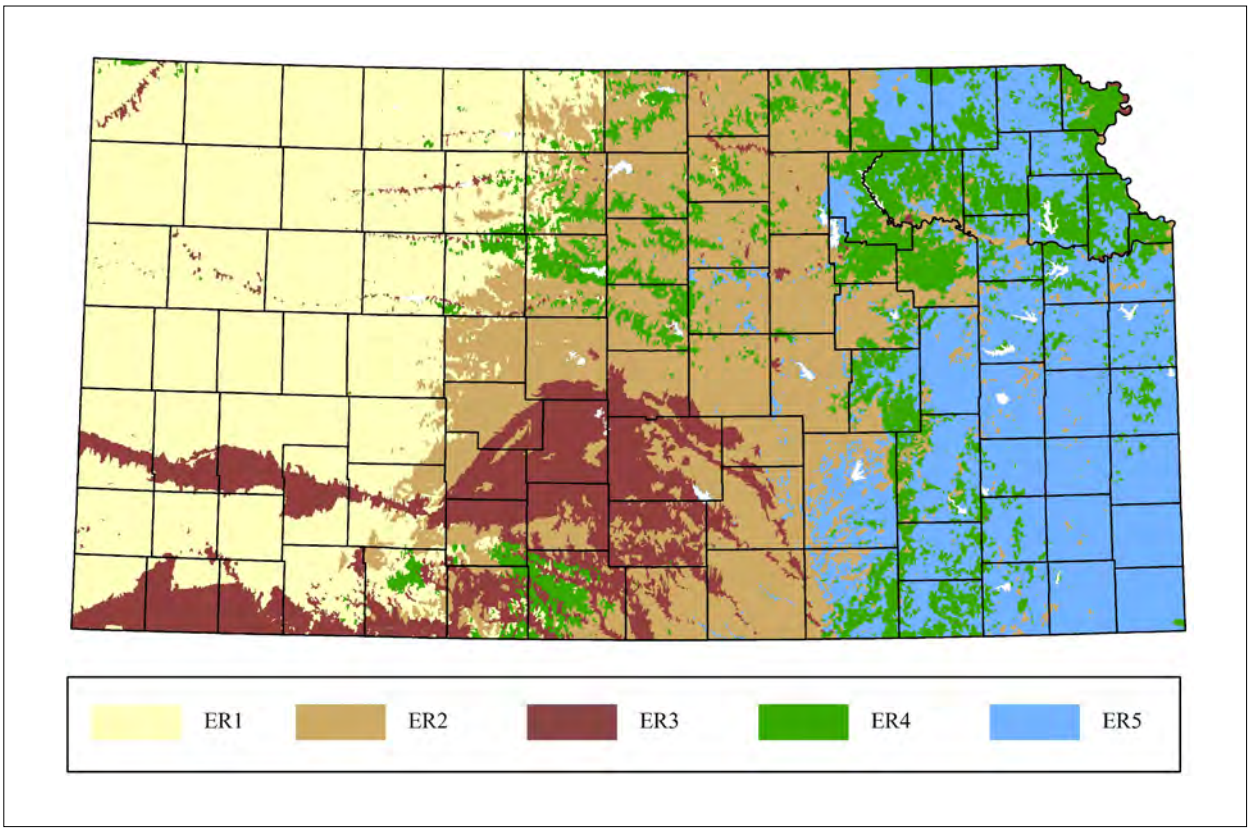


Figure 1. Kansas quantitative ecoregional map (k = 5). White polygons depict major reservoirs and wetland complexes; black lines depict county boundaries.

Table 4. First, second, and third principal component scores obtained from ecoregional PCA. Variables used in this analysis are defined in Table 1 and Appendix A.

	----------Axis----------				----------Axis----------		
Variable	PC1	PC2	PC3	Variable	PC1	PC2	PC3
Climatological				Edaphic (cont.)			
AMPm	0.370	−0.098	−0.049	SPHm	−0.230	0.159	0.024
AMPsd	0.141	−0.072	−0.059	SPHsd	−0.036	0.060	−0.057
FFDm	0.269	−0.136	−0.211	SPSm	−0.177	0.103	−0.296
FFDsd	0.018	−0.018	0.016	SPSsd	−0.012	0.191	−0.331
ISRm	−0.362	0.089	0.074	WTDm	−0.213	0.091	0.077
ISRsd	0.117	0.390	0.181	WTDsd	0.094	0.015	−0.083
Edaphic				Topographic			
SAWCm	−0.130	−0.118	0.324	LSAm	0.083	0.013	0.050
SAWCsd	0.175	0.171	−0.277	LSAsd	0.061	0.155	−0.027
SCECm	0.268	−0.101	0.202	LSEm	−0.365	0.088	0.074
SCECsd	0.239	0.134	−0.174	LSEsd	0.113	0.423	0.200
SKSATm	−0.172	0.095	−0.316	LSSm	0.112	0.422	0.205
SKSATsd	−0.033	0.145	−0.383	LSSsd	0.120	0.430	0.169
SOMm	0.253	−0.140	0.228				
SOMsd	0.175	0.166	−0.163				

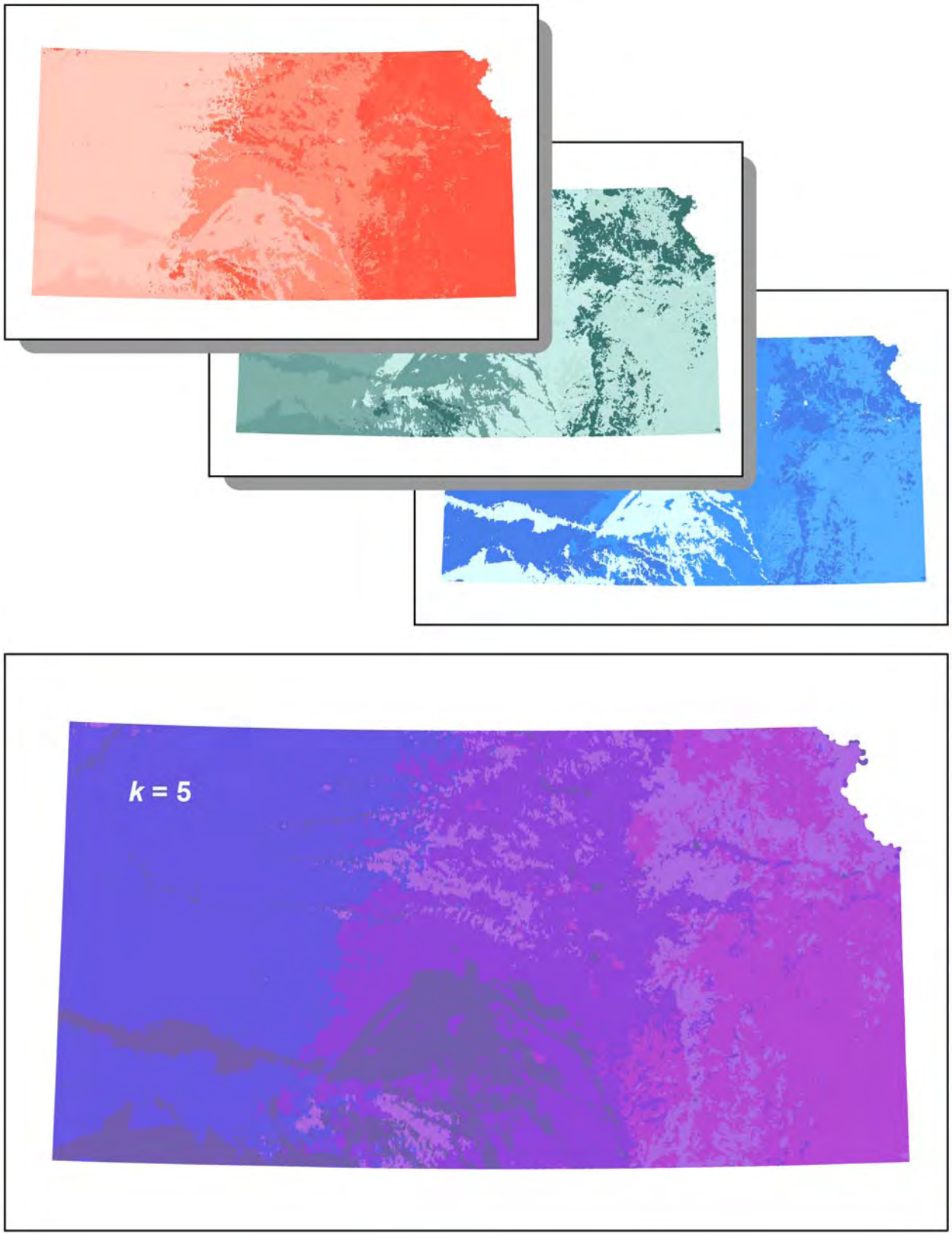


Figure 2. Application of RGB colors to the first, second, and third principal components and subsequent combining of these colors to form a similarity map. Ecoregions with comparable climatological, topographic, and edaphic conditions are depicted in similar colors (cf. Figure 1).

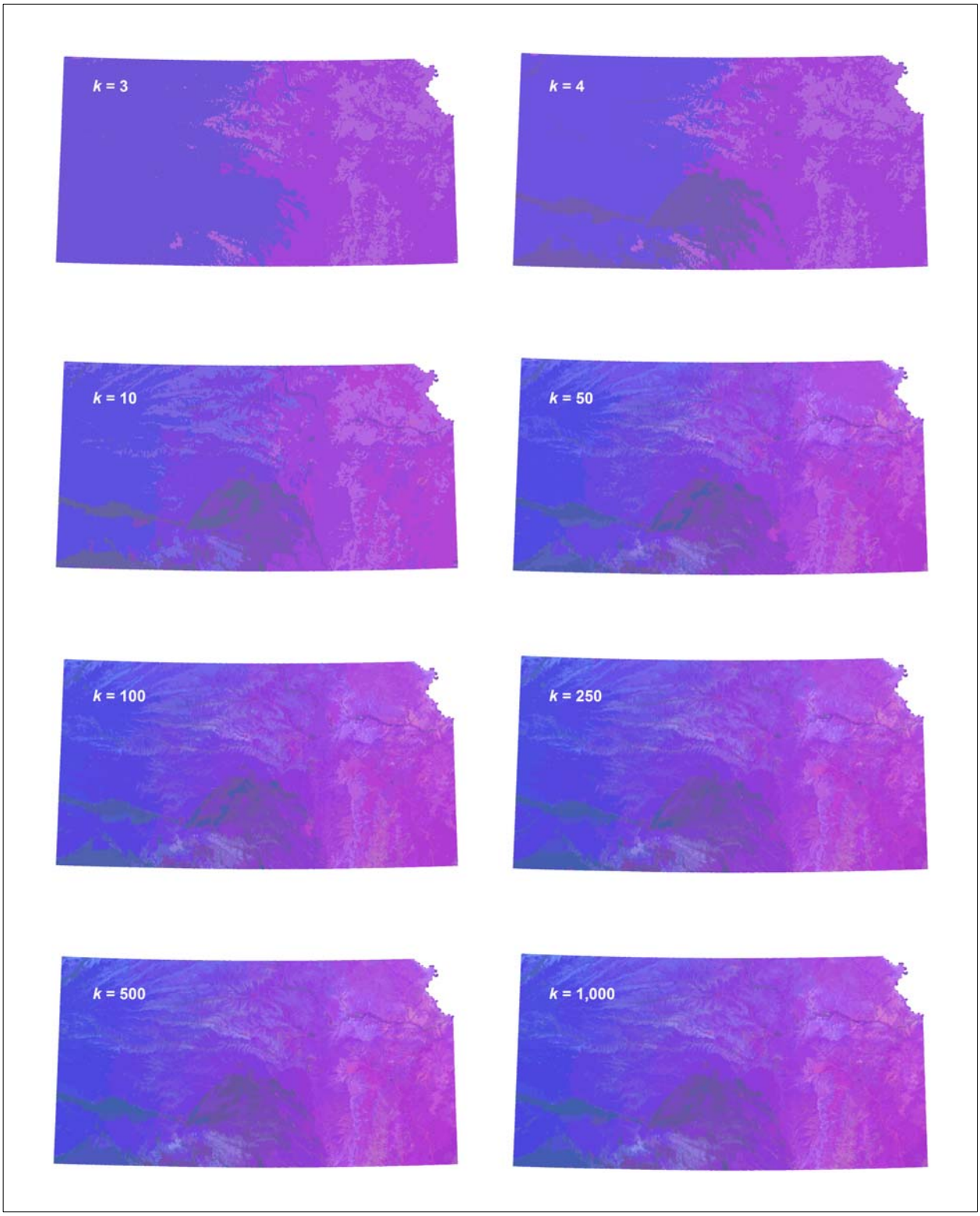


Figure 3. Eight additional similarity maps, each developed under a different *k* scenario. Note rapid convergence of visual patterns with increasing *k* value. Modeling efforts in this study were based on the five-ecoregion scenario presented previously. Available biological data did not warrant the application of a higher degree of geographical partitioning.

3.2 Watershed disturbance rankings

In the PCA-based disturbance analysis, the first 17 principal components had eigenvalues of 1.0 or greater and collectively captured 70% of the variability in the watershed data. Statewide disturbance maps created using the PCA-based method and the summation-based method were visually similar (Figure 4) and statistically equivalent with respect to watershed septile assignments ($p = 0.37$). For 98% of the watersheds, septile assignments under the two mapping approaches were either identical or differed by only one unit. Watersheds with low PCA-based disturbance scores were relegated primarily to physiographic areas known (regionally) as the Flint Hills, Smoky Hills, and Gypsum Hills and to a few isolated areas in northwestern and extreme southwestern Kansas. Heavily disturbed watersheds were prevalent in far eastern Kansas and in the southwestern and central portions of the state. Figure 5 highlights the state's least disturbed watersheds using six (progressively less stringent) evaluation scenarios (best 2.5%, 5.0%, 10%, 15%, 20%, and 25%). Figure 6 illustrates the location of least disturbed watersheds based on within-ecoregion rankings (best 10% only).

PCA-based disturbance scores are summarized for the state as a whole and for individual ecoregions in Table 5. Disturbance scores varied significantly among ecoregions ($p < 0.001$, Kruskal-Wallis), with median values ranging from 0.076 (ER4) to 0.140 (ER5). As shown in Table 6, watersheds with very low disturbance scores were associated most commonly with smaller headwater streams ($Q < 0.28$ m^3 s^{-1} or 10 ft^3 s^{-1}).

Table 5. Watershed disturbance score summary for Kansas and component ecoregions ($k = 5$).

			----------Percentile----------				
Region	N	Mean ± SD	10th	25th	50th	75th	90th
ER1	24,460	0.097 ± 0.034	0.054	0.074	0.095	0.118	0.142
ER2	27,951	0.120 ± 0.036	0.073	0.097	0.119	0.142	0.163
ER3	7,469	0.084 ± 0.035	0.045	0.057	0.081	0.104	0.130
ER4	15,311	0.088 ± 0.043	0.044	0.056	0.076	0.110	0.154
ER5	23,620	0.136 ± 0.051	0.064	0.095	0.140	0.174	0.198
State	98,811	0.110 ± 0.045	0.055	0.076	0.106	0.140	0.171

Table 6. Number of watersheds with disturbance scores ranking in the lowest 10th percentile statewide, partitioned by stream flow class (KDHE 2010a) and quantitative ecoregion ($k = 5$).

Mean flow	----------Ecoregion----------					
(m^3 s^{-1})	ER1	ER2	ER3	ER4	ER5	Statewide
< 0.28	2,483	897	1,248	3,437	1,189	9,254
0.28–2.8	20	27	155	55	39	296
> 2.8	21	6	255	22	27	331
Total	2,524	930	1,658	3,514	1,255	9,881

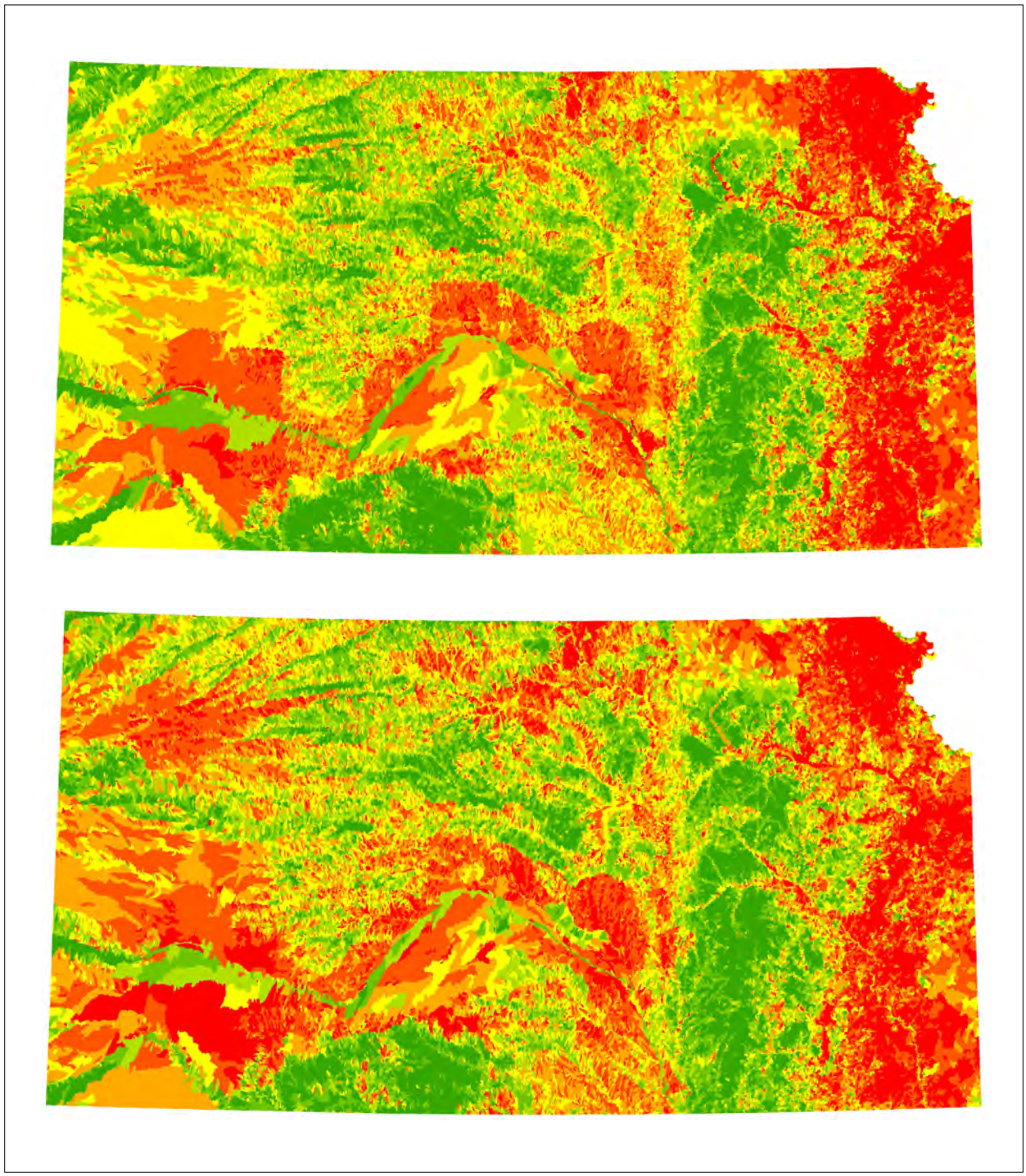


Figure 4. Anthropogenic disturbance maps developed using the PCA-based method (top) and the summation-based method (bottom). Watersheds were assigned to one of seven groups based on calculated disturbance scores. Each group was mapped in a different color, ranging from green (least disturbed condition) to red (most disturbed condition). Forty disturbance indicators were applied in this analysis (Table 2).

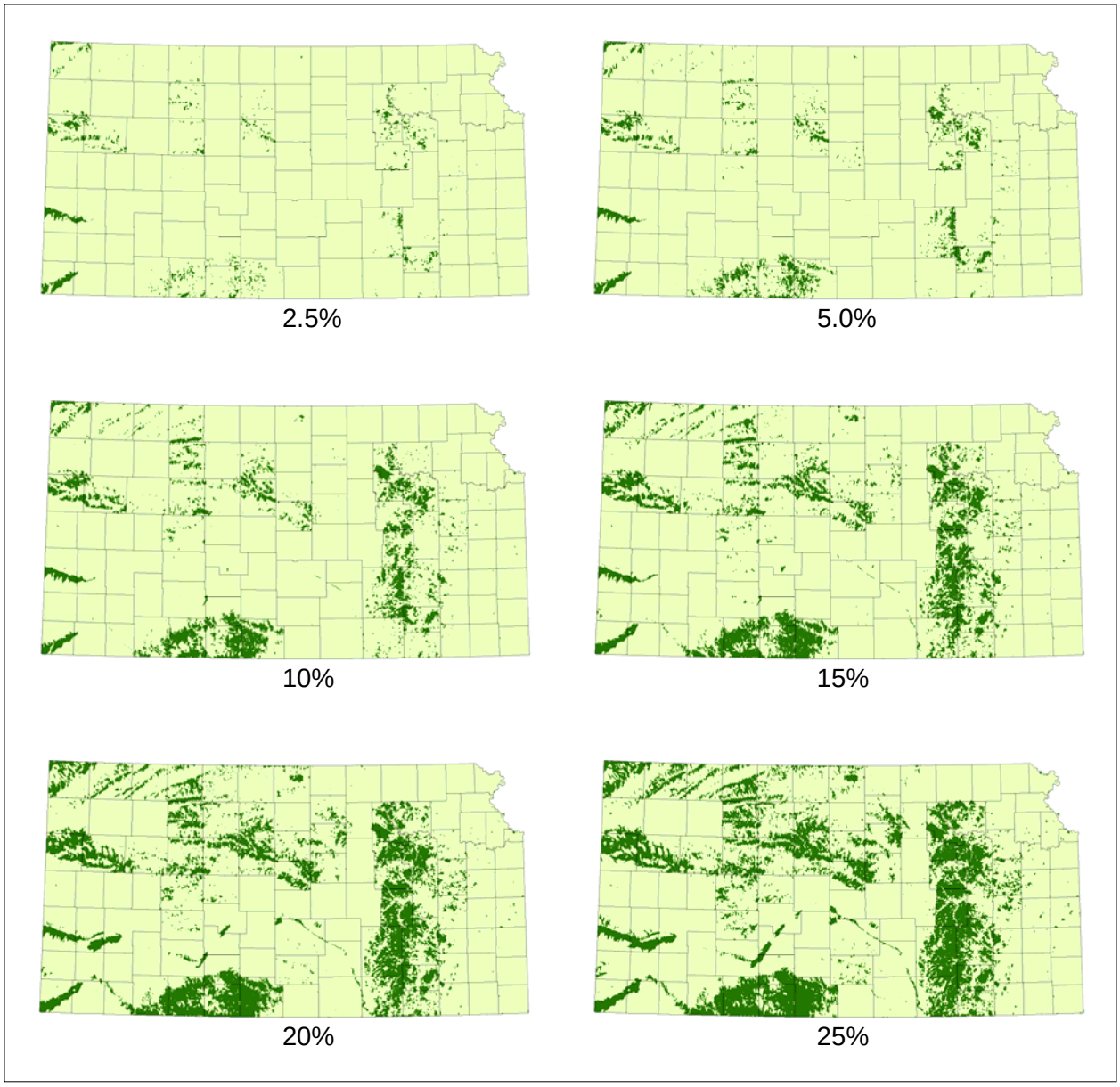


Figure 5. Location of least disturbed watersheds in Kansas. Rankings are based on the PCA-derived disturbance index. Six watershed evaluation scenarios are illustrated (best 2.5%, 5.0%, 10%, 15%, 20%, and 25%).

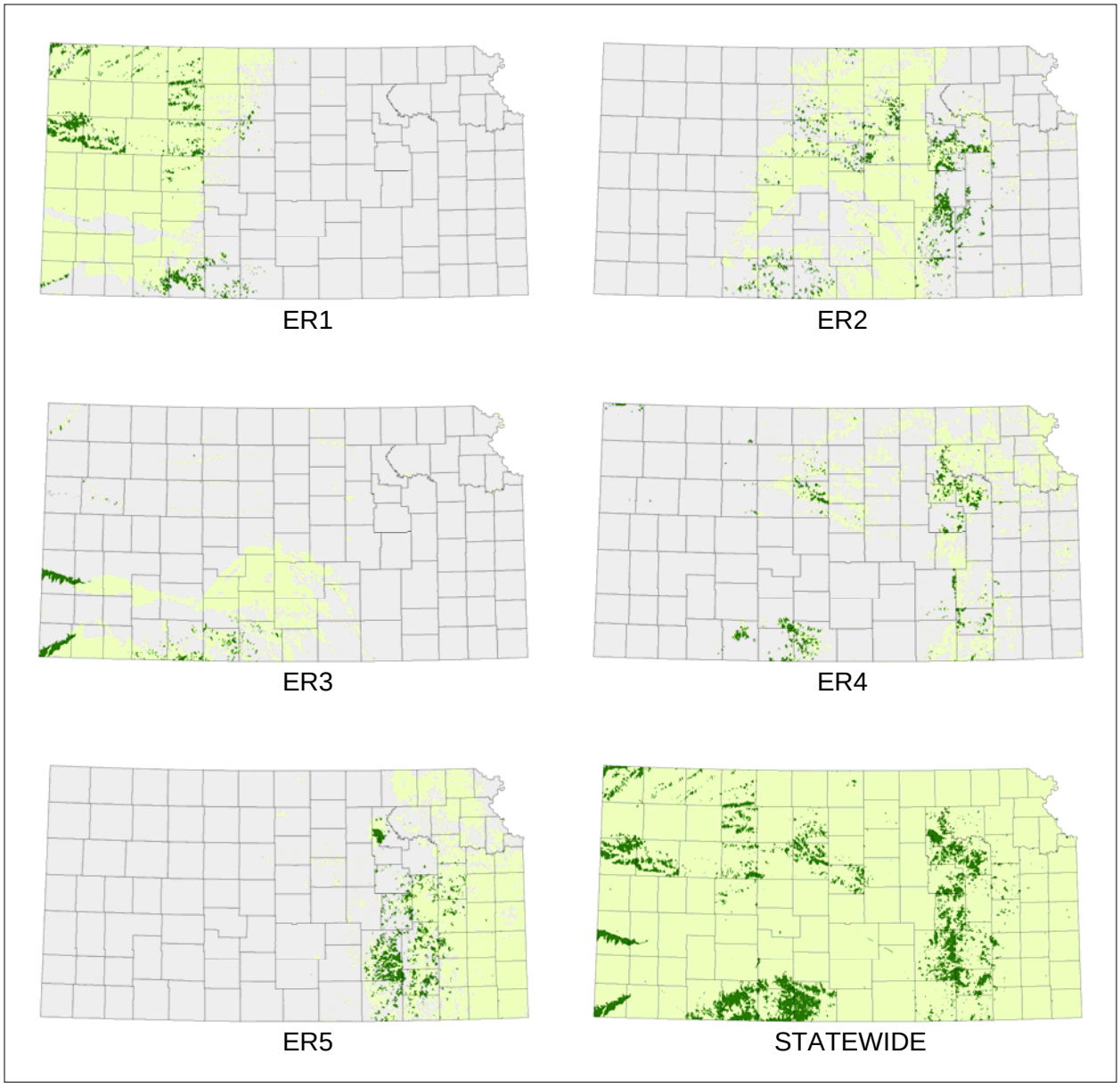


Figure 6. Location of least disturbed watersheds within individual quantitative ecoregions ($k = 5$). Rankings are based on the PCA-derived disturbance index. Highlighted watersheds rank in the lowest (best) 10th percentile within their respective ecoregions. The statewide (10th percentile) map from Figure 5 is shown for comparison.

3.3 Species richness models

Table 7 presents the statewide regression models developed using longitude, latitude, stream flow, and disturbance score as independent variables. Based on the (rising or falling) slopes calculated for these variables, species richness appeared to increase (a) from west to east, (b) from north to south, (c) with increasing annual average stream flow, and (d) with declining watershed disturbance. The strongest regression models (i.e., those addressing fishes, mussels + EPT, and fishes + mussels) accounted for only 39–42% of the observed variability in species richness but were well fitted, yielding R^2_{pred} values of 37–42%. Longitude and flow generally represented the strongest predictive variables in these models, followed by latitude and disturbance index. Incorporation of the same independent variables in the ecoregional ($k = 5$) models improved predictive ability in some instances, but only marginally so (e.g., the ER5 model for fishes + mussels yielded an R^2_{pred} of 44%). Ecoregional models developed for some faunal group combinations were based on fewer than 40 observations (e.g., ER5 model for fishes + mussels + EPT). These models produced moderate to high R^2_{adj} values (40–67%) but low R^2_{pred} values (0–37%) and received no further consideration in this study.

Table 7. Statewide species richness models incorporating longitude (xcoord), latitude (ycoord), stream flow (Q), and PCA-based disturbance score (DScore) as independent variables. Intercepts for all models pass through the origin, owing to the data standardization procedures described previously. In models identified by an asterisk, DScore represents a significant predictor of species richness ($p \leq 0.05$).

Faunal group(s)	N	Regression model (based on standardized watershed data)	R^2_{adj} (%)	R^2_{pred} (%)
EPT	225	$0.301xcoord + 0.010ycoord + 0.427(\log_{10} Q + 1) - 0.212DScore^*$	26.5	24.6
Fishes (F)	908	$0.656xcoord - 0.205ycoord + 0.313(\log_{10} Q + 1) - 0.204DScore^*$	40.3	39.8
Mussels (M)	1,763	$0.289xcoord - 0.062ycoord + 0.362(\log_{10} Q + 1) - 0.038DScore$	23.9	23.6
EPT + F	51	$0.576xcoord - 0.298ycoord + 0.100(\log_{10} Q + 1) - 0.210DScore$	36.0	28.1
EPT + M	196	$0.327xcoord - 0.073ycoord + 0.499(\log_{10} Q + 1) - 0.150DScore^*$	39.0	37.0
F + M	889	$0.655xcoord - 0.185ycoord + 0.356(\log_{10} Q + 1) - 0.171DScore^*$	42.3	41.9
EPT + F + M	51	$0.546xcoord - 0.296ycoord + 0.139(\log_{10} Q + 1) - 0.140DScore$	35.9	28.8

Efforts to further enhance predictive ability and to identify important disturbance variables using best-subsets regression produced ambiguous results. For example, the strongest statewide model (fishes + mussels) produced an R^2_{adj} of 48% and an R^2_{pred} of 47%. However, five of the nine disturbance variables in the final model had positive slopes, and all nine variables collectively accounted for only 6.5% of the calculated R^2_{pred} value. Longitude, latitude, and stream flow represented the strongest predictive variables in all statewide models, whereas stream flow alone usually represented the strongest predictive variable in the ecoregional models. No single disturbance variable was represented in all best-subsets models. Overall, the best-subsets models were less amenable to ecological interpretation than the preliminary models, in that disturbance effects in the latter were integrated into a single predictive variable (DScore) exhibiting a consistently inverse relationship with species richness.

4. Threat assessment results

As mentioned previously, governmental planning documents, statistical abstracts, permit applications, unpublished databases, and published and unpublished reports were examined for environmental and societal trends bearing upon the future condition of reference streams in Kansas. This review endeavored to determine (a) the most serious threats to the integrity of these streams and (b) regions of the state most vulnerable to declines in aquatic biological diversity. The following paragraphs briefly summarize the findings and concerns stemming from this review. Information is organized under eight headings: urban and residential sprawl; expanding transportation and utility infrastructure; escalating mineral resource extraction; proliferation of dams and reservoirs; conversion of grassland to other uses; industrialization of livestock industry; growing anthropogenic demand for water; and introduction and spread of nonnative species.

4.1 Urban and residential sprawl

Findings: The state's resident human population grew by approximately 4.2% from April 2000 to April 2008 (IPSR 2009). Most of this growth occurred in major cities and urban counties and along major transportation corridors. For example, the population of Johnson County in northeastern Kansas grew by 18%, and that of neighboring Douglas County grew by 15% (Appendix F). The state's total population is projected to grow by an additional 4.8% by 2020, whereas the populations of Johnson and Douglas counties are projected to grow by 31% and 20%, respectively. Butler, Jackson, Leavenworth, Miami, and Osage counties also are expected to experience disproportionate (≥15%) growth during this period (IPSR 2009).

Concerns: In watersheds undergoing rapid urban and residential development, native aquatic communities often succumb to: increases in land imperviousness and accompanying changes in catchment hydrology; the proliferation and expansion of wastewater and storm water discharges and resulting increase in contaminant loadings to streams; the construction of bridges, culverts, and levees and channelization and rip-rapping of water courses; the elimination of riparian habitat and fluvial wetlands; and other major disturbances (Booth and Jackson 1997; Wang et al. 2001; Wilkison et al. 2002; Brown et al. 2005; Lee et al. 2005; Walsh et al. 2005; Rasmussen et al. 2009). Watersheds adjacent to rapidly growing urban and residential areas generally are most susceptible to the development of new suburbs, commercial areas, and industrial complexes. Of the seven counties mentioned in the above paragraph, Butler and Osage appear to contain the greatest number of least disturbed watersheds and candidate reference streams (Figures 5 and 6).

4.2 Expanding transportation and utility infrastructure

Findings: Total road mileage in Kansas increased by about 3.9% from 2003 to 2007 (IPSR 2009). The state now contains roughly 103,000 stream/road intersections or about one road crossing per every 1.9 km (1.2 mi) of stream, on average (Appendix D). Industrial pipeline crossings are less prevalent in Kansas (one crossing per every 4.6 km (2.9 mi) of stream, on average), but new pipelines continue to be built in the state. This is exemplified by the recently approved Keystone Pipeline, which eventually will transport 1.5 million barrels of crude oil per day from Canada through Kansas to points in southern Illinois (eastern branch) and northern Oklahoma (southern branch) (Wichita Eagle 2010). Other large pipelines have been constructed

in Kansas in recent years to convey natural gas from production facilities in Wyoming and Colorado to markets in the Midwest. This trend probably will continue as natural gas production intensifies in Wyoming and Colorado (Ronnebaum 2007; EIA 2010). Kansas also is one of the nation's most rapidly developing wind energy centers (KEIN 2010), and a new coal-fired electrical generating facility has been proposed for construction in Finney County (ENS 2010). Projected increases in electrical generation capacity likely will necessitate some further expansion in the state's electrical transmission grid.

Concerns: Some level of stream channelization usually accompanies the creation of new road crossings, resulting in the cumulative and permanent loss of fish and wildlife habitat. Smaller bridges and low water crossings also tend to employ culverts or raised aprons that can impede the migration of fish and other aquatic organisms (Warren and Pardew 1998). Roads, railroads, and pipelines frequently are used to transport crude oil, anhydrous ammonia, solvents, fertilizers, pesticides, and other potentially harmful substances. Spills resulting from leaking pipelines or from transportation-related accidents can have devastating impacts on streams and their biological communities (e.g., NTSB 2007; ENS 2009). Additionally, the establishment of utility corridors across streams frequently involves the clearing of woody riparian vegetation. This activity can temporarily increase sediment runoff and cause permanent reductions in the availability of woody debris (i.e., fish and aquatic invertebrate habitat). New road construction in Kansas is occurring primarily in the aforementioned, rapidly growing counties. In contrast, many pipelines now under construction or planned for the future will cut across comparatively undeveloped regions and could pose a more serious threat to the state's reference streams.

4.3 Escalating mineral resource extraction

Findings: From 2006 through 2008, crude oil production in Kansas increased by 11% to about 40 million barrels annually, and the number of active oil wells in the state increased by 2.5% to approximately 45,000. Counties gaining at least 100 new or re-activated oil wells included Barber, Franklin, Haskell, Miami, and Woodson. During this same period, natural gas production in Kansas increased by 0.9% to about 11 billion m^3 yr^{-1} (14 billion yd^3 yr^{-1}), and the number of active gas wells increased by 13% to approximately 25,400. Counties gaining at least 100 new or re-activated gas wells included Barber, Cheyenne, Labette, Miami, Montgomery, Neosho, and Wilson (IPSR 2009). From 2004 to 2006, coal, salt, and gypsum mines in Kansas experienced limited growth, whereas sand and gravel production increased by 22% to about 12 million metric tons annually (IPSR 2009). Sand and gravel currently are being dredged in appreciable quantities from the Arkansas, Big Blue, Cottonwood, Kansas, Missouri, Neosho, and Walnut rivers and from some smaller streams in Kansas (Brady et al. 1998; KDWP 2008; Scott Satterthwaite, KDHE, pers. comm. 2010).

Concerns: During the first half of the 20th century, water pollution resulting from crude oil production and the accompanying release of brine nearly annihilated the native fauna of many streams in Kansas (e.g., Iola Register 1920; Jones 1950). The advent of environmental laws controlling the production of oil and disposal of brine led to gradual improvements in the quality of most impacted water bodies (Yu et al. 1993; KDHE 2010a). Still, oil production remains a matter of concern in the selection of reference streams, owing primarily to the potential for leaking pipelines and major spills. Of the counties recently experiencing a marked increase in the number of active oil wells, Barber and Cheyenne contain the largest concentrations of least

disturbed watersheds and candidate reference streams (Figure 5). The dredging of streams for sand and gravel also remains a controversial practice in some regions of the state. Dredging operations can lead to the local eradication of mussels and other benthic organisms and to changes in stream hydrology and morphology extending well upstream and downstream of the zone of sand/gravel extraction (e.g., Bull and Scott 1974; Cross et al. 1982; Lyttle 1993; Kondolf 1994; KDWP 2008). Virtually all reference streams are vulnerable to future dredging operations.

4.4 Proliferation of dams and reservoirs

Findings: The state's total number of dams (registered and unregistered) and associated impoundments has been estimated conservatively at 120,000 (KSBA 1992). This figure is dominated overwhelmingly by water bodies smaller than 0.8 ha (2.0 ac) and includes privately owned farm ponds and other smaller impoundments. According to the National Inventory of Dams (USACE 2005), Kansas contains approximately 5,900 larger earthen dams and associated impoundments, most located in the eastern third of the state. Twenty-nine impoundments exceed 2.6 km^2 (1.0 mi^2) in surface area, and most of these were developed 40 to 50 years ago for flood control, water supply, and recreational purposes. Although some public agencies and private organizations have expressed renewed interest in the development of large reservoirs (e.g., KWA 2010), recent dam construction has focused primarily on the creation of smaller reservoirs or "watershed impoundments." From 1974 to 2008, more than 900 watershed impoundments were developed in Kansas under the auspices of state and federally administered financial assistance programs. Several hundred additional impoundments are planned for the near future, ostensibly for flood control, grade stabilization, and water quality improvement purposes. Many will be located in the Flint Hills in Chase, Lyon, and Wabaunsee counties (KWA 2010).

Concerns: Dams (large and small) constitute major impediments to the movement and migration of fish and other aquatic organisms (Cross 1967; Watters 1996; Vaughn and Taylor 1999; Dean et al. 2002). Reservoirs formed by these structures also play a major role in the introduction and spread of non-indigenous fish, shellfish, and hydrophytic plants, including certain forms clearly harmful to native aquatic species (Gido et al. 2002; Mammoliti 2002; Eberle 2007; Angelo et al. 2009; KDHE 2010a). Reservoirs designed and operated for flood control tend to retain storm water runoff during late spring and early summer, thereby diminishing the seasonal peak flows associated with spawning in some native fishes (Cross and Moss 1987; Eberle 2007). In years of excessive precipitation, large reservoirs often discharge vast quantities of accumulated water well into the late summer or early fall, seasons normally characterized by low stream flow and important for mussel reproduction (Murray and Leonard 1962). These prolonged discharges can destabilize the downstream benthic substrate, displacing juvenile mussels, hampering interactions between larval mussels and fishes serving as their biological hosts, and in some cases eliminating entire mussel assemblages (Vaughn and Taylor 1999; Angelo et al. 2009). Plans to develop numerous new impoundments in the Flint Hills are especially worrisome, in that this physiographic region contains many of the state's least disturbed watersheds and most promising candidate reference streams (Figure 5).

4.5 Conversion of grassland to other uses

Findings: As of 2009, approximately 1.3 million ha (3.1 million ac) in Kansas were enrolled in the federal Conservation Reserve Program (CRP). This land had been restored previously to

native vegetation to reduce soil erosion, protect surface water quality, and conserve regional wildlife. Contracts for 0.6 million ha (1.6 million ac) are scheduled to expire during 2010–2012, and only 7.5% of this land will be eligible for re-enrollment in CRP (Wichita Eagle 2009). This limitation is expected to result in the retroversion of tens of thousands of acres to cropland. The prevalence of grassland in Kansas also may be impacted in the future by ongoing demographic changes. From 2000 to 2008, 82 (mostly rural) counties in Kansas experienced measurable declines in population. Prominent examples included Kiowa County (−23%), Wallace County (−20%), and Lane County (−19%) (IPSR 2009). Since 1970, the state has experienced a 27% decrease in its number of farms and ranches and a 29% increase in the average size of its farms and ranches (IPSR 2009). At least two-thirds of the largest grassland tracts in the Flint Hills (contiguous areas ≥ 777 ha or 3.0 mi^2) are owned by nonresidents or absentee landowners (Kindsher and Scott 1997). Mounting economic pressures could lead to the selling of some of these tracts to residential, commercial, or industrial development interests.

Concerns: The onset of row crop production during the middle and late 1800s resulted in widespread soil erosion, and many of the state's most productive mussel beds and fish spawning areas were blanketed in silt during this period (Mead 1896; Metcalf 1966; see also Doze 1924, Franzen and Leonard 1943; Angelo et al. 2003). Although much emphasis was placed subsequently on the mitigation of this problem (Devlin 2000), stream siltation remains a pervasive concern and an important limiting factor for fishes, mussels, gill-breathing insects, and other aquatic organisms (Cross 1967; Cross and collins 1995; Obermeyer et al. 1995; Hoke 1996, 2005; Angelo et al. 2009; KDHE 2010). Upcoming reductions in CRP acreage undoubtedly will lead to increased sediment yields in many watersheds, to the general detriment of the state's stream-dwelling flora and fauna. Also, given the demographic changes described previously, future land use decisions in Kansas could be driven increasingly by short-term commercial motives rather than by the traditional long-term interests of family farmers and ranchers. This is clearly cause for concern: the fate of the state's highest quality streams cannot be separated readily from the fate of its native grassland regions.

4.6 Industrialization of livestock industry

Findings: Kansas contains approximately 1,800 permitted feedlots, 1,600 additional feedlots certified by KDHE as posing no significant water pollution potential, and an unknown number of smaller feeding operations. Of the permitted feedlots, about 450 support more than 1,000 animal units (AU), 130 support more than 10,000 AU, and two support more than 100,000 AU (KDHE 2010c). An AU may account for more than (or for less than) a single animal, depending on the livestock species and its potential for waste generation (K.S.A. 65-171d(c)(3)). Many large feedlots (> 10,000 AU) are located in western Kansas, where water pumped from the High Plains Aquifer currently supports the production of vast quantities of feed grain (Schloss et al. 2000). Although manure generated by feedlots normally is applied at agronomic rates to the surrounding cropland, severe water pollution can result from the improper storage or application of this material (EPA 2010). Wastewater retention structures maintained by larger feedlots are designed to accommodate the largest 24-hour storm events predicted to occur every 25 years, on average (KDHE 2006). However, natural disasters (e.g., floods, tornadoes), mechanical failures, and operator error may lead to unplanned discharges from these structures (KDHE 2010d).

Concerns: Prior to the enactment of state and federal laws regulating the disposal of livestock waste, pollution from feedlots and slaughterhouses (primarily in the form of unionized ammonia and oxidizable solids) devastated the fish and invertebrate communities of many streams in Kansas (Cross and Braasch 1968; Gray 1968; Prophet 1969; Cross and Cavin 1971; Prophet and Edwards 1973). For example, the Cottonwood River received large quantities of feedlot runoff and ranked as one of the state's most heavily contaminated water bodies during the 1960s (Prophet 1969). Although water quality conditions have improved in recent decades, some segments of the Cottonwood River now support only half their original number of mussel species (Angelo et al. 2009). Of the 1,223 separate fish kill events recorded in Kansas from 1978 to 2007, 67 events (5.5%) were linked to pollution emanating from feedlot operations (Haslouer 1979, 1983; KDHE 2010d). Most candidate reference streams identified in the present study are far removed from major feedlots but could be affected by future feedlot development. Moreover, poultry manures originating from large facilities in Arkansas, Missouri, and Oklahoma are being applied increasingly to both grassland and cropland in southeastern Kansas (KWO and KDHE 2009). This activity currently is unregulated and could pose a significant threat to the region's highest quality streams.

4.7 Growing anthropogenic demand for water

Findings: Actual water usage in Kansas varies from year to year depending on weather conditions, market and regulatory forces, and other factors. On average, the state diverts about 8.4 billion m^3 (6.8 million ac-ft) of water annually. Groundwater diversions comprise about 72% of this amount and are associated primarily with irrigation withdrawals. Surface water diversions account for the remaining 28% and are dominated by cooling water withdrawals for electrical power generation (Sophocleous 1998; Sophocleous and Wilson 2000). From 1995 to 2005, irrigation usage in Kansas increased by 7%, public water supply usage grew by 12%, and industrial, mining, and thermoelectric withdrawals increased by 6% (Kenny and Hansen 2004). Similarly, from 1990 to 2000, groundwater utilization by the livestock and meat processing industries in southwestern Kansas grew by 50%, and surface water withdrawals for crude oil production, natural gas production, and sand dredging increased by 19% statewide (Kenny and Hansen 2004). The following table itemizes water usage in Kansas during 2005.

Table 8. Estimated water withdrawals in Kansas during calendar year 2005 by water use category (adapted from Kenny et al. 2009; Joan Kenny, U.S. Geological Survey, pers. comm. 2010). Values are expressed in units of million m^3 (and thousand ac-ft) and may not add precisely to totals owing to independent rounding.

Water source:	Water use category: Public	Domestic	Commercial	Irrigation	Livestock	Industrial	Mining	Thermoelectric	Total
Surface water	335 (272)	< 0.1 (< 0.1)	0.2 (0.1)	158 (128)	37.3 (30.3)	8.8 (7.1)	6.4 (5.2)	1,817 (1,474)	2,363 (1,916)
Ground-water	221 (179)	20.6 (16.7)	5.6 (4.5)	3,626 (2,941)	119 (96.7)	49.1 (39.8)	14.0 (11.3)	18.5 (15.0)	4,075 (3,305)
Total	556 (451)	20.6 (16.7)	5.8 (4.7)	3,784 (3,069)	157 (127)	57.9 (46.9)	20.4 (16.5)	1,835 (1,489)	6,437 (5,221)

Concerns: Many streams in western Kansas have experienced a progressive reduction in flow since the mid 1970s. Trends are most dramatic in the Arkansas, Cimarron, and Smoky Hill river basins, where a shift toward irrigated crop production has contributed to the lowering of the groundwater table and largely eliminated base flow contributions from shallow aquifers. A continued emphasis on the production of corn and other water intensive crops threatens to reduce stream flow over an even wider geographical area (Angelo 1994; Sophocleous and Wilson 2000; Angelo et al. 2003). Diminished flow, and the transformation of many streams from perennial systems to intermittent or ephemeral systems, has contributed to the regional or local extirpation of several native fish and shellfish species (Cross et al. 1985; Cross and Moss 1987; Eberle et al. 1997; Haslouer et al. 2005; Eberle 2007; Angelo et al. 2009). Most of the state's candidate reference streams are located in grassland regions and currently afforded some protection from the threat of imminent water depletion. However, possible future diversions of water from these streams (or their supporting springs and alluvial aquifers) could lead to rapid dewatering and a decline in the diversity and representativeness of the resident biological communities.

4.8 Introduction and spread of nonnative species

Findings: Non-indigenous plants and animals currently are found in nearly every stream in Kansas. Watercress (*Rorippa nasturtium-aquaticum*), common carp (*Cyprinus carpio*), and a few other widespread forms were introduced intentionally during the 19th century to enhance food availability and/or recreational fishing opportunities (Cross 1967; Barkley 1986). The subsequent arrival of many other species occurred by accident, by gradual migration from other regions, or by willful release to the waters of the state. Salt cedar (*Tamarix* spp.) now forms dense thickets along many streams in western and central Kansas, purple loosestrife (*Lythrum salicaria*) has become the dominant herbaceous species in many fluvial wetlands, and Eurasian watermilfoil (*Myriophyllum spicatum*), a highly invasive plant sold in the aquarium trade, has been discovered in several streams in western Kansas (KDHE 2010a). Similarly, the Asian clam (*Corbicula fluminea*) maintains sizeable populations in numerous rivers and creeks throughout the state, and the zebra mussel (*Dreissena polymorpha*) recently has gained a foothold in at least five major river basins (Angelo et al. 2009). Several other invasive (or potentially invasive) aquatic organisms have been documented in the state (e.g., Cross and Collins 1995; Distler 2003). The discovery of additional species is anticipated in the near future (Goeckler 2005).

Concerns: The arrival of invasive plants and animals can lead to the rapid demise of many native or previously established species. For example, zebra mussels attach themselves in large numbers to the shells of other bivalves, competing for food and interfering with normal respiration, movement, and valve closure. These animals already have decimated native mussel communities in large areas of eastern North America (e.g., Strayer and Smith 1996; Ricciardi et al. 1998). Salt cedar often crowds out native trees, shrubs, and nonwoody plants, jeopardizing the wildlife dependent on this vegetation for food and shelter (Tomaso 1998). Eurasian watermilfoil propagates via seeds and vegetative fragments and can spread rapidly between water bodies by attaching to boat propellers, boat trailers, and fishing gear. Once introduced into a reservoir or stream, it tends to form dense mats that can eliminate native plants and disrupt the natural feeding behavior of fish (KDHE 2010a). KDWP has implemented a program for limiting the spread of invasive aquatic species, but the logistical, budgetary, and regulatory challenges confronting this program are admittedly daunting (Goeckler 2005). Virtually all candidate reference streams in Kansas are vulnerable to future infestations of nonnative organisms.

5. Discussion

5.1 Historical perspectives

Prior to the settlement of this region, natural environmental variables exerted a dominant influence on the structure of aquatic biological communities. Stream hydrology, morphology, and substrate composition largely determined the distributions of many native aquatic species (e.g., Cross 1967). Recurring floods and droughts and gradual fluctuations in climate operated over different time scales to produce ongoing changes in community composition (Weaver and Albertson 1936; Bryson 1980; Kay 1998). In some areas, wildfires impeded the development of riparian vegetation and the amount of woody debris available for aquatic macroinvertebrate colonization (Higgins 1984). Aboriginal cultures also exerted localized influences on stream communities, primarily through the seasonal harvest of aquatic plants and animals (e.g., Wedel 1959; Warren 1974) and the use of fire for controlling brush near river encampments (e.g., Williams 2001). The arrival of French trappers in the early 1700s triggered a steep decline in beaver and otter populations and ushered in a new era of rapid environmental change (Choate 1987; Hoffman and Genoways 2005). Towns and cities began to develop along many streams during the mid 1800s; farms and ranches were established throughout the state by 1880; and declines in stream flow were reported in some major streams only a decade later (e.g., Barry 1972; Warman 1903). By the close of the 19th century, the sanitary condition of many rivers and creeks had degraded visibly (e.g., Dobak 1996). Several fish, shellfish, and waterfowl species no longer occurred in locations where once they had been abundant (Mead 1896; Scammon 1906; Metcalf 1966; Slater 2006).

As noted previously, watersheds across the state experienced many additional disturbances over the course of the 20th century. Today, even the most isolated streams in Kansas differ in major respects from the historical (pre-settlement) reference condition. Virtually all have been influenced by the introduction of livestock, the proliferation of carp, the eradication of river otter, the construction of dams and roads, and other seemingly ubiquitous disturbances. Many fishes, mussels, and gill-breathing snails have been extirpated from all or nearly all of their former ranges in Kansas (Cross 1967; Angelo et al. 2002, 2003, 2009; Haslouer et al. 2005). Air and water pollution from urban, industrial, and agricultural areas has contributed to the accumulation of mercury, lead, DDT, and other contaminants in fluvial sediment and the tissues of aquatic plants and animals (Havlik and Marking 1987; Juracek 2004; Angelo et al. 2007; KDHE 2010e). Furthermore, climate change may be gradually increasing the state's surface water temperatures (Kaushal et al. 2010), altering seasonal streamflow patterns (Milly et al. 2005), shortening the growth and spawning seasons for some native fish and shellfish species (Eaton and Scheller 1996), exacerbating the effects of certain chemical pollutants on aquatic life (see EPA 1999), and facilitating the invasion and proliferation of exotic plants and animals (Rahel and Olden 2008). Given these considerations, virtually all reference streams in Kansas should be regarded as *least disturbed* systems rather than *minimally disturbed* systems (see Stoddard et al. 2006).

5.2 Programmatic perspectives

In this study, the effects of individual disturbance variables on biological communities were difficult to gauge using only the best-subsets models. However, preliminary models incorporating the PCA-based disturbance score (DScore) did confirm a general relationship between (a) the

number of species inhabiting a given stream and (b) the level of human activity occurring in the surrounding catchment. These findings were not entirely unexpected. Aquatic biological communities are sensitive to a wide range of anthropogenic stressors, each operating over different spatial and temporal scales. Therefore, disturbance measures integrating the effects of many stressors should serve as superior predictors of biological condition. The models developed in this study could be modified and improved with some additional effort. For example, data for the various disturbance and biological measures were obtained from different (but overlapping) time periods. Future models conceivably could be strengthened by adhering to a more consistent data collection window. Given that biological responses to anthropogenic disturbances often involve some form of threshold effect (Brenden et al. 2008), improvements also could result from the application of non-linear regression techniques or other alternative statistical approaches (e.g., Céréghino and Compin 2003; Santoul et al. 2004; Sickle et al. 2006). Despite these limitations, the screening models developed in this study seemingly supported the application of DScore in the ranking of watersheds and identification of candidate reference streams.

In the months and years ahead, and as permitted by the availability of staff and other resources, KDHE will endeavor to finalize the stream selection process initiated in this study. Watersheds with low disturbance scores (e.g., lowest 10th percentile) will be grouped by both quantitative ecoregion and stream flow category and targeted for computer-assisted desktop reconnaissance. All watersheds lacking evident local stressors will be subjected to more rigorous, field-based evaluations. Final reference stream selections will be based on four primary factors: watershed disturbance score; field assessment results; site accessibility (i.e., willing landowner participation); and future disturbance risk. Streams chosen in this manner will be incorporated into KDHE's long-term water quality monitoring programs, allowing physical habitat, water chemistry, and biological data to be obtained from each water body on a four- to eight-year rotational basis. Ultimately, these data will be applied in (a) the characterization of the baseline ecological condition, (b) the development of biological criteria (and other criteria) on a statewide, ecoregional, and site-specific basis, (c) the establishment of diagnostic thresholds for water quality-impaired streams, (d) the performance of statewide water quality assessments, and (e) the formulation of restoration goals for environmentally degraded water bodies. The importance assigned to reference streams implies that every reasonable effort should be made to monitor, maintain, and possibly improve their condition over time. Recommendations for protecting these high quality waters are presented in the following section.

5.3 Reference steam conservation strategies

5.3.1 Available regulatory tools

The Kansas surface water quality standards (K.A.R. 28-16-28b et seq.) provide nearly all aquatic ecosystems in the state some basic level of water quality protection. However, only *classified* waters receive the full range of benefits provided under these regulations. All such waters and their designated uses are listed in the Kansas surface water register, which is updated periodically to reflect the results of use attainability analyses (UAAs) performed by the department (KDHE 2009). To qualify for listing, stream reaches must meet certain minimal flow requirements, maintain permanent pools that provide for the biological recolonization of intermittently flowing segments, support populations of threatened or endangered species, or receive discharges from federally permitted wastewater treatment facilities (K.A.R. 28-16-

28d(a)). Many small reaches identified in this study have not been evaluated with respect to their classification status. These reaches currently are not represented in the surface water register, implying that field-based reconnaissance activities will need to incorporate UAAs in certain instances. Over time, these analyses may add significantly to the state's list of classified waters.

Under the antidegradation provisions of the surface water quality standards, classified waters are partitioned into different protective tiers. The highest tier (Tier 3) includes *outstanding national resource waters* (ONRWs), a designation reserved primarily for aquatic ecosystems located in large parks, game preserves, and wildlife refuges or otherwise possessing "unique recreational or ecological value" (KDHE 2006). New or expanded discharges of wastewater and other anthropogenic disturbances that could permanently degrade water quality are prohibited in ONRWs. *Exceptional state waters* (referred to as Tier 2.5 waters) exhibit "remarkable quality" or "significant recreational or ecological value" and likewise are provided an enhanced level of protection under the standards. Although new or expanded discharges to these waters could be authorized by KDHE, permit limits would provide for the maintenance and protection of the existing water quality and existing beneficial uses. Presumably, many reference streams would qualify for inclusion in Tier 2.5, whereas only a select few would merit entry into Tier 3.

Pursuant to section 401 of the Clean Water Act (CWA), KDHE routinely evaluates the water pollution potential of the following activities: any proposed project requiring a federal license under sections 402 and 404 of the CWA; any project requiring a wastewater discharge permit pursuant to K.S.A. 65-165; any water development project subject to the provisions of K.S.A. 82a-325 et seq.; and any project undertaken by another state agency that (in the opinion of the KDHE) could cause a water quality impact (K.A.R. 28-16-28f(c)). KDHE's purview in this regard extends to the disposal of dredged materials, the construction or sewage treatment plants and extension of sewage lines, the development of watershed impoundments, large reservoirs, and other water-related projects, and the construction of highways and other major public works. Following project evaluation, KDHE must (a) certify, in writing, that the proposed action will comply with all applicable surface water quality standards, (b) identify changes to the project needed to ensure compliance with the standards, or (c) deny certification. Any approved project influencing (or potentially influencing) an ONRW or an exceptional state water must meet the relatively stringent antidegradation requirements considered previously.

Pursuant to section 303(d) of the CWA, KDHE routinely determines the maximum amount of a pollutant that can be released into a given water body, from all sources, while still meeting the requirements of the Kansas surface water quality standards. These established amounts are known as total maximum daily loads or TMDLs. Traditionally, TMDLs have been used to reduce contaminant loadings in classified waters identified as "water quality impaired" (KDHE 2010). However, TMDLs also could be used to protect reference streams and other unimpaired waters from future increases in contaminant concentrations (CWA section 303(d)(3)). Under K.S.A. 65-171d, the Secretary of KDHE also has the authority to establish critical water quality management areas (CWQMAs). These include watersheds (or portions thereof) in which

> "...application of minimum state or national wastewater and water quality management practices and procedures cannot be reasonably expected to result in attainment of water quality goals, attainment of water quality standards, protection of resources of the state, prevention of excessive sediment deposition in stream beds, lakes or reservoirs, or

prevention of destruction of fishery habitat; or an area in which additional treatment and control of pollutants can result in additional cost effective benefits" (K.A.R. 28-16-69).

If needed to achieve important water quality (i.e., antidegradation) goals, the CWQMA designation could be applied selectively to watersheds harboring reference streams. Such an action would require the development of a written water quality management plan delineating the boundaries of the proposed CWQMA and establishing an implementation schedule for the control of the pollutant source(s). A formal cost-benefit analysis also would be required as part of this action (K.S.A. 65-171d).

Reference stream reaches are threatened by many factors falling outside the general purview of the CWA and the regulatory jurisdiction of KDHE. For example, dewatering of some reaches could result from the granting of water appropriation permits under the authority of the Chief Engineer, Division of Water Resources, Kansas Department of Agriculture (K.S.A. 82a-701 et seq.). The Chief Engineer considers the public interest when evaluating requests to divert water, but this official has no legal mandate for including environmental considerations in allocation decisions. The Kansas Legislature has established minimum desirable streamflows (MDSs) for some streams to help preserve or enhance base flows for specific beneficial uses (e.g., water quality maintenance, aquatic life protection, recreation, general aesthetics, domestic uses, protection of existing water rights) (K.S.A. 82a-928(i)). With the establishment of an MDS, the Chief Engineer withholds from appropriation the water needed to maintain the desired minimum flow. However, Kansas is a prior appropriation state, and all MDS allocations are subordinate to more senior water rights. Any material change in this system would require major revisions in the laws and policies now informing water appropriation decisions (see Sherow 2002).

Diversions of water also occur through the impoundment of streams and storage of inflows. Impoundments can alter downstream hydrology by attenuating peak flows and, in many cases, base flows (e.g., Metcalf 1983; Eberle 2007). Except for a requirement to pass through inflows when needed to satisfy senior water rights, Kansas law does little to mitigate the hydrological changes caused by impoundments. Dam construction projects typically are subject to CWA section 401 certification requirements, but these requirements focus on water quality-related issues and seldom protect streams from the hydrological disturbances accompanying dam construction. Most proposed dam projects also undergo interagency review pursuant to the Kansas Water Projects Environmental Coordination Act (K.S.A. 82a-325 et seq.). However, recommendations shared by the reviewing agencies generally are non-binding on the permitting agencies (K.S.A. 82a-327(d)). The establishment of minimum desirable stream flows for selected reference streams would reduce the environmental impacts resulting from the development of future impoundments and water diversions, but they would not eliminate these impacts. All MDS actions also would require legislative approval and authorization (K.S.A. 82a-703c).

5.3.2 Incentive-based approaches

Public lands comprise less than 1% of the state's total surface area (NRCM 2000), meaning that nearly all candidate reference streams identified in the present study flow through private property. These streams also are restricted largely to rural settings, implying that zoning ordinances are unlikely to play a major role in their protection. Given these realities, financial incentives may offer the most promising mechanisms for preventing the degradation of reference

water bodies. The State Conservation Commission (SCC) administers a suite of cost-share programs of potential interest to landowners implementing agricultural best management practices. For example, the Water Quality Buffer Initiative provides funds to restore grassy and woody corridors along streams (SCC 2009b). This program effectively supplements the Environmental Quality Incentives Program (administered by the Natural Resources Conservation Service) and the aforementioned Conservation Reserve Program (administered by the Farm Service Agency or FSA). Additional funding is available through SCC's Non-Point Source Pollution Control Program and Riparian and Wetland Protection Program (SCC 2009a). In theory, some of the monies allocated to these programs could be reserved for the protection and maintenance of high quality streams.

The Conservation Reserve Enhancement Program (CREP) is a voluntary land retirement program administered by FSA. CREP has helped many farmers protect environmentally sensitive land, decrease soil erosion, restore wildlife habitat, and enhance groundwater and surface water quality. Resources provided through this program are intended to address high-priority conservation concerns. In western Kansas, for example, funds have been used to retire marginal cropland and reduce water usage along the Arkansas River (KWO 2010). Additionally, several private organizations work closely with landowners to conserve unique natural areas, primarily through the establishment of property easements or through willing-seller land acquisitions (e.g., KLT 2010; TNC 2010). Many of the watersheds identified in the present study contain unspoiled landscapes and diverse plant and animal assemblages. Therefore, they may warrant the attention of these conservation groups.

5.3.3 Interagency planning and cooperation

The conservation and protection of reference ecosystems should be included among the shared goals of all natural resource agencies in Kansas. Landowners, interest groups, and the general public should be apprised of governmental decisions and actions potentially affecting the condition of these resources. The next revision of the *Kansas Water Plan* seemingly would provide an ideal opportunity for articulating these shared goals and obtaining public feedback. Pursuant to K.S.A. 82a-901 et seq., this planning tool establishes a multi-agency framework for addressing water-related issues in the state. Responsibility for its preparation and maintenance rests chiefly with the Kansas Water Office (KWO 2009). The development of the *Kansas Water Plan* is guided by two key statutory objectives: the improvement of public water supply systems and the prevention of water pollution. Several statutory "policies" further define the functions and responsibilities of KWO and other water-oriented state agencies. These policies include:

> "...the identification of minimum desirable streamflows to preserve, maintain or enhance baseflows for in-stream water uses relative to water quality, fish, wildlife, aquatic life, recreation, general aesthetics and domestic uses and for the protection of existing water rights" (K.S.A. 82a-928(i)); and
>
> "...the maintenance of the surface waters of the state within the water quality standards adopted by the secretary of health and environment as provided by K.S.A. 65-164 to 65-171t, inclusive, and amendments thereto" (K.S.A. 82a-928(j)).

As currently structured, the *Kansas Water Plan* sets forth management policies applicable to the entire state and to specific regions of the state (i.e., major river basins). In the section of the plan dealing with statewide policies (and in some basin plans), the local Watershed Restoration and Protection Strategy (WRAPS) program is identified as the primary mechanism for addressing water quality issues on a watershed-to-watershed basis (WRAPS 2010). This section could be expanded in the future to explain the role of reference streams as environmental "benchmarks" and their relevance in the sub-basins served by WRAPS. High priority TMDLs currently are listed in each of the river basin plans, directing the attention of natural resource agencies to specific water bodies and specific impairments. In the future, verified reference stream reaches also could be (a) listed in the corresponding basin plans, (b) recognized therein as high priority resources requiring protection, (c) acknowledged for their role in the development of meaningful water quality criteria and water quality assessments, and (d) targeted for the establishment of TMDLs and minimum desirable streamflows. Such changes in the *Kansas Water Plan* would underscore the ecological and regulatory importance of reference streams. Moreover, they would encourage governmental agencies, WRAPS groups, and the general public to work together to maintain the condition of these exceptional resources.

References

Abell, R.A., D.M. Olson, E. Dinerstein, P.T. Hurley, J.T. Diggs, W. Eichbaum, S. Walters, W. Wettengel, T. Allnutt, C.J. Loucks and P. Hedao. 2000. Freshwater ecoregions of North America. Island Press, Washington, D.C.

Angelo, R.T. 1994. Impacts of declining stream flow on surface water quality. *In*: Proceedings of the Eleventh Annual Conference on Water and the Future of Kansas, Kansas State University, Manhattan, KS.

Angelo, R.T., M.S. Cringan, D.L. Chamberlain, A.J. Stahl, S.G. Haslouer and C.A. Goodrich. 2007. Residual effects of lead and zinc mining on freshwater mussels in the Spring River Basin (Kansas, Missouri, and Oklahoma, USA). Science of the Total Environment 384:467–496.

Angelo, R.T., M.S. Cringan and J.E. Fry. 2002. Distributional revisions and new and amended occurrence records for prosobranch snails in Kansas. Transactions of the Kansas Academy of Science 105:246–257.

Angelo, R.T., M.S. Cringan and S.G. Haslouer. 2003. Response of stream biological communities to agricultural disturbances in Kansas: an historical overview with comments on the potential for aquatic ecosystem restoration. *In*: Baker, D. (ed.): Proceedings of the Central Plains Bioassessment and Biocriteria Symposium, University of Kansas, Lawrence, KS.

Angelo, R.T., M.S. Cringan, E. Hays, C.A. Goodrich, E.J. Miller, M.A. VanScoyoc and B.R. Simmons. 2009. Historical changes in the occurrence and distribution of freshwater mussels in Kansas. Great Plains Research 19:89–126.

Bailey, R.G. 1976. Ecoregions of the United States. 1:7,500,000 scale map. Forest Service, U.S. Department of Agriculture, Ogden, UT.

Bailey, R.G. 1983. Delineation of ecosystem regions. Environmental Management 7:365–373.

Bailey, R.G., P.E. Avers, T. King and W.H. McNab. 1994. Ecoregions and subregions of the United States. 1:7,500,000 scale map with table. Forest Service, U.S. Department of Agriculture, Ogden UT.

Baker, D.S., D.G. Huggins and R. Everhart. 2009. Identification and characterization of reference conditions within USEPA Region 7 using EMAP methodology. Kansas Biological Survey, University of Kansas, Lawrence, KS.

Barkley, T.M. (ed.). 1986. Flora of the Great Plains. University Press of Kansas, Lawrence KS.

Barry, L. 1972. The beginning of the West: annals of the Kansas gateway to the American West 1540–1854. Kansas State Historical Society, Topeka, KS.

Bellucci, C., M. Beauchene and M. Becker. 2009. Physical, chemical, and biological attributes of least disturbed watersheds in Connecticut. Bureau of Water Protection and Land Reuse, Connecticut Department of Environmental Protection, Hartford, CT.

Booth, D.B. and C.R. Jackson. 1997. Urbanization of aquatic systems: impacts, solutions, and prognoses. Northwest Environmental Journal 7:93–118.

Brady, L.L., D.A. Grisafe, J.R. McCauley, G.C. Ohlmacher, H.A.M. Quinodoz and K.A. Nelson. 1998. The Kansas River corridor: its geologic setting, land use, economic geology, and hydrology. Kansas Geological Survey Open-file Report.

Brenden, T.O., R.D. Clark, A.R. Cooper, P.W. Seelbach, L. Wang, S.S. Aichele et al. 2006. A GIS framework for collecting, managing, and analyzing multi-scale variables across large regions for river conservation and management. *In*: Hughes, R.M., L. Wang and P.W. Seelbach (eds.): Landscape influences on stream habitats and biological assemblages. American Fisheries Society, Symposium 48, Bethesda, MD.

Brenden, T.O., L. Wang and Z. Su. 2008. Quantitative identification of disturbance thresholds in support of aquatic resource management. Environmental Management 42:821–832.

Brown, L.R., R.H. Gray, R.M. Hughes and M.R. Meador. 2005. Introduction to the effects of urbanization on stream ecosystems. *In*: Brown, L.R., R.H. Gray, R.M. Hughes, and M.R. Meador (eds.): Effects of urbanization on stream ecosystems. American Fisheries Society, Symposium 47, Bethesda, MD.

Bryson, R.A. 1980. Ancient climes on the Great Plains. Natural History 89:64–73.

Bull, W.B. and K.M. Scott. 1974. Impact of mining gravel from urban stream beds in the south-western United States. Geology 2:171–174.

Céréghino, R. and A. Compin. 2003. Predicting the species richness of aquatic insects using a limited number of environmental variables. Journal of the North American Benthological Society 22:442–456.

Chapman, S.S., J.M. Omernik, J.A. Freeouf, D.G. Huggins, J.R. McCauley, C.C. Freeman, G. Steinauer, R.T. Angelo and R.L. Schlepp. 2001. Ecoregions of Nebraska and Kansas. 1:1,950,000 scale map with color poster, descriptive text, summary tables, and photographs. U.S. Geological Survey, Reston VA.

Choate, J.R. 1987. Post-settlement history of mammals in western Kansas. The Southwestern Naturalist 32:157–168.

Clarke, R.T., J.F. Wright and M.T. Furse. 2003. RIVPACS models for predicting the expected macroinvertebrate fauna and assessing the ecological quality of rivers. Ecological Modelling 160:219–233.

Cross, F.B. 1967. Handbook of fishes of Kansas. University of Kansas Museum of Natural History Miscellaneous Publication No. 45.

Cross, F.B. and M. Braasch. 1968. Qualitative changes in the fish fauna of the upper Neosho River System, 1952–1967. Transactions of the Kansas Academy of Science 71:350–60.

Cross, F.B. and L.M. Cavin. 1971. Effects of pollution, especially from feedlots, on fishes in the upper Neosho River Basin. Kansas Water Resources Research Institute, Manhattan, KS.

Cross, F.B. and J.T. Collins. 1995. Fishes in Kansas (2nd edition). University of Kansas Natural History Museum Public Education Series No. 14.

Cross, F.B., F.J. DeNoyelles, S.C. Leon, S.W. Campbell, S.L. Dewey, B.D. Heacock, D. Weirick. 1982. Report on the Impacts of Commercial Dredging on the Fishery of the Lower Kansas River. U.S. Army Corps of Engineers, Kansas City, MO.

Cross, F.B. and R.E. Moss. 1987. Historic changes in fish communities and aquatic habitats in plains streams of Kansas. *In*: Matthews, W.J. and D.C. Heins (eds.): Community and evolutionary ecology of North American stream fishes. University of Oklahoma Press, Norman, OK.

Cross, F.B., R.E. Moss and J.T. Collins. 1985. Assessment of dewatering impacts on stream fisheries in the Arkansas and Cimarron Rivers. Kansas Fish and Game Commission, Pratt, KS.

Davis, W.S. 1995. Biological assessment and criteria: building on the past. *In*: Davis, W.S. and T.P. Simon (eds.): Biological assessment and criteria: tools for water resource planning and decision making. CRC Press, Boca Raton, FL.

Dean, J., D. Edds, D. Gillette, J. Howard, S. Sherraden and J. Tiemann. 2002. Effects of lowhead dams on freshwater mussels in the Neosho River, Kansas. Transactions of the Kansas Academy of Science 105:232–40.

Devlin, D.L. 2000. Water quality protection: best management practices for farmland. Kansas Agricultural Experiment Station and Cooperative Extension Service, Kansas State University, Manhattan, KS.

Distler, D.A. 2003. Occurrence of the mystery snail *Cipangopaludina chinensis* (Gastropoda: Viviparidae) in the Walnut River Basin, Kansas. Transactions of the Kansas Academy of Science 106:215.

Dobak, W.A. 1996. “One of the nastiest rivers that I know of...” — municipal and rural sanitation in nineteenth century Kansas. Kansas History 19:52–63.

Doze, J.B. 1924. Fifth biennial report. Kansas State Fish and Game Department, Pratt, KS.

Eaton, J.G. and R.M. Scheller. 1996. Effects of climate warming on fish thermal habitat in streams of the United States. Limnology and Oceanography 4 l:1109–1115.

Eberle, M.E. 2007. Homogenization of fish faunas and concurrent anthropogenic impacts on plains streams in western Kansas: 1854–2003. Fort Hays Studies 4:1–78.

Eberle, M., S. Hoofer, N. Mandrak and T. Wenke. 1997. Assessment of fish communities in western Kansas streams during 1994–1996. Department of Biological Sciences, Fort Hays State University, Hays, KS.

EIA. 2010. Natural gas pipelines in the central region. Energy Information Administration, U.S. Department of Energy. (Viewable online at http://www.eia.doe.gov/pub/oil_gas/natural_gas/analysis_publications/ngpipeline/central.html.)

ENS. 2009. Ammonia spills in Nebraska, Kansas cost pipeline firms $3.65 M. Environmental News Service article dated August 14, 2009. (Viewable online at http://www.ens-newswire.com/ens/aug2009/2009-08-14-093.html).

ENS. 2010. Sunflower Electric reapplies for coal-fired power plant expansion. Environmental News Service article dated January 14, 2010. (Vviewable online at http://www.ens-newswire.com/ens/ jan2010/2010-01-14-092.html.)

EPA. 1999. Aquatic life ambient water quality criteria for ammonia update. U.S. Environmental Protection Agency. Fact sheet. (Viewable online at http://www.epa.gov/waterscience/criteria/ammonia/technical.html.)

EPA. 2010. Civil enforcement actions taken against beef feedlots in Iowa, Kansas and Nebraska for violations of Clean Water Act. U.S. Environmental Protection Agency. News release dated May 5, 2010. (Viewable online at http://yosemite.epa.gov/opa/admpress.nsf/names/r07_2010-5- 24_beef_feedlots_civil_action_ks_ne_ia.)

ESRI. 2009. PC ArcGIS version 9.3.1. Environmental System Research Institute, Redlands, CA.

Frank, H. and S.C. Althoen. 1995. Statistics: concepts and applications. Cambridge University Press, Cambridge, Great Britain.

Franzen, D.S. and A.B. Leonard. 1943. The Mollusca of the Wakarusa River Valley. University of Kansas Science Bulletin 29:363–439.

Frey, D.G. 1977. Biological integrity of water: an historical approach. *In*: Ballantine, R.K. and L.J. Guarraia (eds.): The integrity of water. Symposium proceedings. U.S. Environmental Protection Agency, Washington, D.C.

Gido, K.B., C.S. Guy, T.R. Strakosh, R.J. Bernot, K.J. Hase and M.A. Shaw. 2002. Long-term changes in the fish assemblages of the Big Blue River Basin 40 years after the construction of Tuttle Creek Reservoir. Transactions of the Kansas Academy of Science 105:193–208.

Goeckler, J.M. 2005. Kansas aquatic nuisance species management plan. Kansas Department of Wildlife and Parks, Emporia, KS.

Gray, M.W. 1968. Water pollution and agriculture. Supplement to the Transactions of the Kansas Academy of Science 70:30–38.

Hargrove, W.W. and F.M. Hoffman. 2005. Potential of multivariate quantitative methods for delineation and visualization of ecoregions. Environmental Management 34:S39-S60.

Hartigan, J.A. 1975. Clustering algorithms. Wiley, New York, NY.

Haslouer, S.G. 1979. Natural and pollution caused fishkills in Kansas during 1978. Transactions of the Kansas Academy of Science 82:197–204.

Haslouer, S.G. 1983. Natural and pollution caused fishkills in Kansas during 1979–1980. Transactions of the Kansas Academy of Science 86:136–143.

Haslouer, S.G., M.E. Eberle, D.R. Edds, K.B. Gido, C.S. Mammoliti, J.R. Triplett, J.T. Collins, D.A. Distler, D.G. Huggins and W. J. Stark. 2005. Current status of native fish species in Kansas. Transactions of the Kansas Academy of Science 108:32–46.

Havlik, M.E. and L.L. Marking. 1987. Effects of contaminants on naiad mollusks (Unionidae): a review. Resource Publication 164. U.S. Fish & Wildlife Service, Washington, DC.

Hawkins, C.P. 2006. Quantifying biological integrity by taxonomic completeness: evaluation of a potential indicator for use in regional- and global-scale assessments. Ecological Applications 16:1251–1266.

Hawkins, C.P., R.H. Norris, J.N. Hogue and J.W, Feminella. 2000. Development and evaluation of predictive models for measuring the biological integrity of streams. Ecological Applications 10:1456-1477.

Higgins, K. F. 1984. Lightning fires in North Dakota grasslands and in pine-savanna lands of South Dakota and Montana. Journal of Range Management 37:100–103.

Hoffman, J.D. and H.H. Genoways. 2005. Recent records of formerly extirpated carnivores in Nebraska. The Prairie Naturalist 37:225–244.

Hoke, E. 1996. The unionid mollusks of the Big and Little Nemaha River Basins of southeastern Nebraska and northeastern Kansas. Transactions of the Nebraska Academy of Sciences 23:37–57.

Hoke, E. 2005. The unionid mussels (Mollusca: Bivalvia: Unionidae) of the Big Blue River Basin of northeastern Kansas and southeastern Nebraska. Transactions of the Nebraska Academy of Sciences 30:33–57.

Iola Register. 1920. Watch oil on river: button company men interested in stream protection: contamination will kill or retard growth of mussels essential to industry. News article dated August 6, 1920.

IPSR. 2009. Kansas statistical abstract 2009. Institute for Policy and Social Research. University of Kansas Press, Lawrence, KS.

Jones, O.S. 1950. Fresh water protection from pollution arising in the oil fields. University of Kansas Publications, Lawrence, KS.

Juracek, K.E. 2004. Sedimentation and occurrence and trends of selected chemical constituents in bottom sediment of 10 small reservoirs, eastern Kansas. U.S. Geological Survey Scientific Investigations Report. USGS, Lawrence, KS.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspectives on water quality goals. Environmental Management 5:55–68.

Kaushal, S.S., G.E. Likens, N.A. Jaworski, M.L. Pace, A.M. Sides, D. Seekell, T. Belt, D.H. Secor and R.L. Wingate. 2010. Rising stream and river temperatures in the United States. Frontiers in Ecology and the Environment (e-View release dated March 23, 2010).

Kay, M. 1998. The Great Plains setting. *In*: Wood, W.R. (ed.): Archaeology on the Great Plains. University of Kansas Press, Lawrence, KS.

KDHE. 2005. Kansas water quality monitoring and assessment strategy. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2006. Design standards for confined feeding facilities. Bureau of Water, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2007. Kansas stream probabilistic monitoring program quality assurance management plan. *In*: Division of Environment quality management plan. Part III: program level quality assurance management plans. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2009. Kansas surface water register. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2010a. Kansas integrated water quality assessment, 2010. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2010b. Kansas stream biological monitoring program quality assurance management plan. *In*: Division of Environment quality management plan. Part III: program level quality assurance management plans. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2010c. Unpublished database for permitted (and certified) confined animal feeding operations. Bureau of Water, Kansas Department of Health and Environment, Topeka, KS.

KDHE. 2010d. Unpublished fish kill database. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDHE, 2010e. Unpublished fish tissue contaminant database. Bureau of Environmental Field Services, Kansas Department of Health and Environment, Topeka, KS.

KDWP 2008. Programmatic management for gravel excavation for the Neosho and Cottonwood rivers in Kansas. Kansas Department of Wildlife and Parks, Emporia, KS.

KDWP. 2009. Unpublished fisheries database. Environmental Services Section, Kansas Department of Wildlife and Parks, Pratt, KS.

KEIN. 2010. Kansas wind energy. Kansas Energy Information Network. (Viewable online at http://www.kansasenergy.org/wind_projects.htm.)

Kenny, J.F., N.L. Barber, S.S. Hutson, K.S. Linsey, J.K. Lovelace and M.A. Maupin. 2009. Estimated use of water in the United States in 2005. U.S. Geological Survey Circular.

Kenny, J.F. and C.V. Hansen. 2004. Water use in Kansas, 1990–2000. U.S. Geological Survey Fact Sheet.

Kindscher, K. and N. Scott. 1997. Land ownership and tenure of the largest land parcels in the Flint Hills, USA. Natural Areas Journal 17:131–135.

KLT. 2010. Kansas Land Trust. Organizational website. (Viewable at http://www.klt.org/.)

Kondolf, G.M. 1994. Geomorphic and environmental effects of instream gravel mining. Landscape Urban Planning 28:225–243.

KSBA. 1992. Dam safety guidebook: Kansas edition. Division of Water Resources, Kansas State Board of Agriculture, Topeka, Kansas.

KWA. 2010. Reservoir roadmap. Kansas Water Authority, Topeka, KS.

KWO. 2009. Kansas water plan. Kansas Water Office, Topeka, KS. (Viewable online at http://www.kwo.org/Kansas%20Water%20Plan/Kansas%20Water%20Plan.htm.)

KWO. 2010. Water plan projects initiative: conservation reserve enhancement program (CREP). Kansas Water Office. (Viewable online at http://www.kwo.org/kwa/wppi/wppi.htm#HPA.)

KWO and KDHE. 2009. Summary of Kansas Neosho Basin assessment: activities and issues. Kansas Water Office and Kansas Department of Health and Environment, Topeka, KS.

Lee, C.J., D.P. Mau and T.J. Rasmussen. 2005. Effects of nonpoint and selected point contaminant sources on Johnson County streams, northeastern Kansas, October 2002 through June 2004. U.S. Geological Survey Scientific Investigations Report.

Lyttle, M.M.. 1993. Impacts of gravel mining on fish communities in three Ozark streams. Master's thesis. University of Arkansas, Fayetteville, AR.

Mammoliti, C.S. 2002. The effects of small watershed impoundments on native stream fishes: a focus on the Topeka shiner and hornyhead chub. Transactions of the Kansas Academy of Science 105:219–231.

Mead, J.R. 1896. A dying river. Transactions of the Kansas Academy of Science 14:111–112.

Metcalf, A.L. 1966. Fishes of the Kansas River system in relation to zoogeography of the Great Plains. University of Kansas Museum of Natural History Publications 17:23–189.

Metcalf, A.L. 1983. Mortality in unionacean mussels in a year of drought. Transactions of the Kansas Academy of Science 86:89–92.

Milly, P.C.D., K.A. Dunne1 and A.V. Vecchia. 2005. Global pattern of trends in streamflow and water availability in a changing climate. Nature 43817:347–350.

Minitab. 2010. Interpreting the predicted R-squared in the regression output. Minitab, Inc. Company website. (Viewable at http://www.minitab.com/en-US/support/answers/ answer.aspx?ID =983&langType=1033.)

Moss, D.M., M.T. Furse, J.F. Wright and P.D. Armitage. 1987. The prediction of the macro-invertebrate fauna of unpolluted running-water sites in Great Britain using environmental data. Freshwater Biology 17:41–52.

Murray, H.D., and A.B. Leonard. 1962. Handbook of unionid Mussels in Kansas. University of Kansas Museum of Natural History, Lawrence, KS.

NHDPlus. 2005. National hydrography dataset plus, edition 1.0. Office of Water, U.S. Environmental Protection Agency/ U.S. Geological Survey. (Accessible online at http://www.fws.gov/r5gomp/gom/bd/NEAHCP/nhd_plus_metadata.htm.)

NHDPlus. 2010. NHDPlus user guide. Office of Water, U.S. Environmental Protection Agency/ U.S. Geological Survey. (Viewable online at ftp://ftp.horizon-systems.com/NHDPlus/ documentation/NHDPLUS_UserGuide.pdf.)

NRCM. 2000. Public land ownership by state. Natural Resources Council of Maine. (Viewable online at http://www.nrcm.org/documents/publiclandownership.pdf.)

NTSB. 2007. Pipeline rupture and leak with vapor cloud six miles west of Kingman, Kansas. Pipeline Accident Brief 07/02. National Transportation Safety Board, Washington, D.C.

Obermeyer, B.K., D.R. Edds and C.W. Prophet. 1995. Distribution and abundance of federal "candidate" mussels (Unionidae) in southeast Kansas. Kansas Department of Wildlife and Parks, Pratt, KS.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118–125.

Omernik, J.M., 1995. Ecoregions: a spatial framework for environmental management. *In*: Davis, W.S. and T.P. Simon (eds.): Biological assessment and criteria: tools for water resource planning and decision making. CRC Press, Boca Raton, FL.

Ott, R.L. and M. Longnecker. 2001. An introduction to statistical methods and data analysis. Wadsworth Group, Pacific Grove, CA.

Paulsen, S.G., A. Mayio, D.V. Peck, J.L. Stoddard, E. Tarquinio, S.M. Holdsworth, J.V. Sickle, L.L. Yuan, C.P. Hawkins, A.T. Herlihy, P.R. Kaufmann, M.T. Barbour, D.P. Larsen and A.R. Olson. 2008. Condition of stream ecosystems in the U.S.: an overview of the first national assessment. Journal of the North American Benthological Society 27:812–821.

Prophet, C.W. 1969. River pollution by feedlot runoff. Proceedings of the Oklahoma Academy of Science 48:207–09.

Prophet, C.W. and N.L. Edwards. 1973. Benthic macroinvertebrate community structure in a Great Plains stream receiving feedlot runoff. Water Resources Bulletin 9:583–89.

Rahel, F.J. and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. Conservation Biology 22:521–533.

Rasmussen, T.J., B.C. Poulton and J.L. Graham. 2009. Quality of streams in Johnson County, Kansas, and relations to environmental variables, 2003–07. U.S. Geological Survey Scientific Investigations Report.

Reynoldson, T.B. and J.F. Wright. 2000. The reference condition: problems and solutions. *In*: Wright, J.F., D.W. Sutcliffe and M.T. Furse (eds.): Assessing the biological quality of freshwaters: RIVPACS and other techniques. Freshwater Biological Association, Ambleside, Tasmania.

Ricciardi, A., R.J. Neves and J.B. Rasmussen. 1998. Impending extinctions of North American freshwater mussels (Unionoida) following the zebra mussel (*Dreissena polymorpha*) invasion. Journal of Animal Ecology 67:613–619.

Ronnebaum, E. 2007. Largest pipeline in U.S. crosses northeast Kansas. The Kansas Lifeline. November issue:50–53.

RTI. 2001. The national water pollution control assessment model (NWPCAM) version 2. Research Triangle Institute, Research Triangle Park, NC.

Santoul, F., A. Soulard, J. Figuerola, R. Céréghino and S. Mastrorillo. 2004. Environmental factors influencing local fish species richness and differences between hydroregions in south-western France. International Review of Hydrobiology 89:79–87.

Scammon, R.E. 1906. The Unionidae of Kansas. Pt. 1: an illustrated catalogue of the Kansas Unionidae. University of Kansas Science Bulletin 3:279–373, plates 52–86.

SCC. 2009a. Stream/riparian initiative. State Conservation Commission. Topeka, KS. Agency website. (Viewable at http://www.scc.ks.gov/index.php?option=com_content&view =category&id =154&Itemid=86.)

SCC. 2009b. Water quality buffer initiative. State Conservation Commission. Topeka, KS. (Program website: http://www.scc.ks.gov/index.php?option=com_content&view= category&id=210&Itemid=205.)

Schloss, J.A., R.W. Buddemeier and B.B. Wilson (eds). 2000. An atlas of the Kansas High Plains Aquifer. Educational Series No. 14. Kansas Geological Survey, Lawrence, KS.

Sherow, J.E. 2002. The art of water and the art of living. Kansas History 25:52–71.

Sickle, J.V., D.D. Huff and C.P. Hawkins. 2006. Selecting discriminant function models for predicting the expected richness of aquatic macroinvertebrates. Freshwater Biology 51:359–372.

Slater, G.L. 2006. Trumpeter swan (*Cygnus buccinator*): a technical conservation assessment. Forest Service, U.S. Department of Agriculture, Golden, CO. (Viewable online at http://www.fs.fed.us/r2/projects/scp/assessments/trumpeterswan.pdf.)

Smith , E.R., L.T. Tran and R.V. O'Neill. 2003. Regional vulnerability assessment for the Mid-Atlantic Region: evaluation of integration methods and assessment results. EPA/600/R-03/082. Office of Research and Development, U.S. Environmental Protection Agency, Washington, D.C.

Sophocleous, M.A. (ed). 1998. Perspectives on sustainable development of water resources in Kansas. Bulletin No. 239. Kansas Geological Survey, Lawrence, Kansas.

Sophocleous, M.A. and B.B. Wilson. 2000. Surface water in Kansas and its interactions with groundwater. *In*: Schloss, J.A., R.W. Buddemeier and B.B. Wilson (eds.): An Atlas of the Kansas High Plains Aquifer. Educational Series No. 14. Kansas Geological Survey, Lawrence, KS.

Stoddard, J.L., D.P. Larsen, C.P. Hawkins, R.K. Johnson and R.H. Norris. 2006. Setting expectations for the ecological conditions of streams: the concept of reference condition. Ecological Applications 16:1267–1276.

Strayer, D.L. and L.C. Smith. 1996. Relationships between zebra mussels (*Dreissena polymorpha*) and unionid clams during the early stages of zebra mussel invasion of the Hudson River. Freshwater Biology 36:771–779.

Suplee, M., R.S. de Suplee, D. Feldman and T. Laidlaw. 2005. Identification and assessment of Montana reference streams: a follow-up and expansion of the 1992 benchmark biology study. Montana Department of Environmental Quality, Helena, MT.

TNC. 2010. The Nature Conservancy in Kansas. Organizational website. (Viewable at http://www.nature.org/wherewework/northamerica/states/kansas/.)

Tomaso, J.M. 1998. Impact, biology, and ecology of salt cedar (*Tamarix* spp.) in the southwestern United States. Weed Technology 12:326–336.

USACE. 2005. National inventory of dams. Army Topographic Engineering Center, U.S. Army Corps of Engineers, Alexandria, VA. (Viewable online at http://crunch.tec. army.mil/nid/ webpages/nid.cfm.)

Vaughn, C.C. and C.M. Taylor. 1999. Impoundments and the decline of freshwater mussels: a case study of an extinction gradient. Conservation Biology 13:912–20.

Vogel, R.M., I.W. Wilson and C. Daly. 1999. Regional regression models of annual streamflow for the United States. Journal of Irrigation and Drainage Engineering 125:148–157.

Walsh, C.R., A.H. Roy, J.W. Feminella, P.D. Cottingham, P.M. Groffman and R.P. Morgan. 2005. The urban stream syndrome: current knowledge and a search for a cure. Journal of the North American Benthological Society 24:706–723.

Wang, L., T. Brenden, P. Seelbach, A. Cooper, D. Allan, R. Clark and M. Wiley. 2008. Landscape based identification of human disturbance gradients and reference conditions for Michigan streams. Environmental Monitoring and Assessment 141:1–17.

Wang, L., J. Lyons, P. Kanehl and R. Bannerman. 2001. Impacts of urbanization on stream habitat and fish across multiple spatial scales. Environmental Management 28:255–266.

Warman, P.C. 1903. Catalog of published writings. *In*: John Wesley Powell: proceedings of a meeting commemorative of his distinguished service. Proceedings of the Washington Academy of Sciences 5:131–187.

Warren, M.L. and M.G. Pardew. 1998. Road crossings as barriers to small-stream fish movement. Transactions of the American Fisheries Society 127:637–644.

Warren, R.E. 1974. Pre-Columbian unionacean (Mollusca, Pelecypoda) distribution in north-central Kansas. Proceedings of the Nebraska Academy of Sciences and Affiliated Societies 84:17.

Watters, G.T. 1996. Small dams as barriers to freshwater mussels (Bivalvia, Unionoida) and their hosts. Biological Conservation 75:79–85.

Weaver, J. E. and F. W. Albertson. 1936. Effects of great drought on the prairies of Iowa, Nebraska, and Kansas. Ecology 17:567–639.

Wedel, W.R. 1959. An introduction to Kansas archeology. Bureau of American Ethnology, Smithsonian Institution, Washington, D.C.

Wichita Eagle. 2009. CRP land in Kansas to expire: acreage on brink. News article dated July 12, 2009. (Viewable online at http://findarticles.com/p/articles/mi_qn4179/is_ 20090712/ ai_n32167468/.)

Wichita Eagle. 2010. Two weeks added to Keystone pipeline comment period. News article dated June 9, 2010. (Viewable online at http://www.kansas.com/2010/06/09/1351868/ keystone-pipeline-operating-in.html.)

Wilkison, D.H., D.J. Armstrong and D.W. Blevins. 2002. Effects of wastewater and combined sewer overflows on water quality in the Blue River Basin, Kansas City, Missouri and Kansas, July 1998–October 2000. U.S. Geological Survey Water-Resources Investigations Report.

Williams, G.W. 2001. References on the American Indian use of fire in ecosystems. Forest Service, U.S. Department of Agriculture, Washington, D.C. (Viewable online at http://www. wildlandfire.com/docs/biblio_indianfire.htm.)

WRAPS. 2010. Kansas watershed restoration and protection strategy: Project directory. (Viewable online at http://www.kswraps.org/projects.)

Yu, Y.S., S. Zou and D. Whittemore. 1993. Non-parametric trend analysis of water quality data of rivers in Kansas. Journal of Hydrology 150:61–80.

Appendix A. Descriptions of variables considered in quantitative ecoregional analysis. Variable names ending in "m" and "sd" refer to watershed means and standard deviations, respectively.

Variable	Data source	Description
AMPm AMPsd	NOAA (2000)	Annual mean precipitation. Data were derived from monthly totals recorded from 1971 to 2000. The average total values for all sampling points were interpolated using the simple kriging method. The interpolated surface then was used to calculate neighborhood statistics for the mean and standard deviation.
FFDm FFDsd	KSU (2009)	Frost-free days per year. Data were obtained from a point coverage for towns and cities in Kansas. The coverage was interpolated using the simple kriging method. The interpolated surface then was used to calculate neighborhood statistics for the standard deviation and mean.
ISRm ISRsd	USGS (1999)	Incident solar radiation. Estimates were based on statewide elevation data and the hemispherical viewshed algorithm developed by Rich et al. (1994).
SAWCm SAWCsd	USDA (2009)	Soil available water capacity. This variable represented total inches of water in the soil profile. Data were derived from the SSURGO soil database. The representative value was used to calculate neighborhood statistics for the mean and standard deviation.
SCECm SCECsd	USDA (2009)	Soil cation exchange capacity. This variable represented the amount of readily exchangeable cations adsorbed by soil particles at pH 7.0. Data were obtained from the SSURGO soil database. The representative value was used to calculate the mean and standard deviation.
SKSATm SKSATsd	USDA (2009)	Soil hydraulic conductivity. This variable represented the amount of water moving vertically through a unit area of saturated soil in unit time under unit hydraulic gradient. Data were obtained from the SSURGO soil database. The representative value was used to calculate neighborhood statistics for the mean and standard deviation.
SOMm SOMsd	USDA (2009)	Soil organic matter. This variable represented the amount of decomposed plant and animal residue occurring in soil. Data were obtained from the SSURGO soil database. The representative value was used to calculate statistics for the mean and standard deviation.
SPHm SPHsd	USDA (2006)	Soil pH. This variable represented the pH value associated with the soil layer or horizon. Data were obtained from the STATSGO2 soil database. The minimum value was used to calculate the mean and standard deviation.

Appendix A. Descriptions of variables considered in quantitative ecoregional analysis (continued).

Variable	Data source	Description
SPSm SPSsd	USDA (2009)	Soil percent sand. This variable represented the amount of of sand (0.05–2.0 mm particles) in soil, expressed as a weight percentage. Data were obtained from the SSURGO soil database. The representative value was used to calculate neighborhood statistics for the mean and standard deviation.
WTDm WTDsd	USDA (2009)	Water table depth. This variable represented the depth to a a seasonally high water table. Data were obtained from the SSURGO soil database. The maximum value was used to calculate neighborhood statistics for the mean and standard deviation.
LSAm LSAsd	USGS (1999)	Land surface aspect. Refer to entry for LSEm and LSEsd, below.
LSEm LSEsd	USGS (1999)	Land surface elevation. This variable represented elevation above sea level. Aside from its application as a stand alone descriptor, the variable was used in the calculation of slope and aspect. Data were obtained from the National Elevation Dataset. The raster was applied in the calculation of neighborhood statistics for the mean and standard deviation.
LSSm LSSsd	USGS (1999)	Land surface slope. Refer to entry for LSEm and LSEsd, above.

Agency and database acronyms:
KSU = Kansas State University (K-State) Research and Extension, Weather Data Library
NOAA = National Oceanic and Atmospheric Administration, National Weather Service
SSURGO = Soil Survey Geographic Database (maintained by NRCS)
STATSGO2 = U.S. General Soil Map (maintained by NRCS)
USDA = U.S. Department of Agriculture, Natural Resources Conservation Service (NRCS)
USGS = U.S. Geological Survey

References:

Rich, P.M., R. Dubayah, W.A. Hetrick and S.C. Saving. 1994. Using viewshed models to calculate intercepted solar radiation: applications in ecology. American Society for Photogrammetry and Remote Sensing Technical Papers, pp. 524–529.

Appendix B. Statewide maps for individual variables considered in quantitative ecoregional analysis. Watersheds were assigned to seven groups (septiles) containing an equal number of watersheds (unless prohibited by ties). Each group was mapped in a different color, ranging from green (lowest value) to red (highest value).

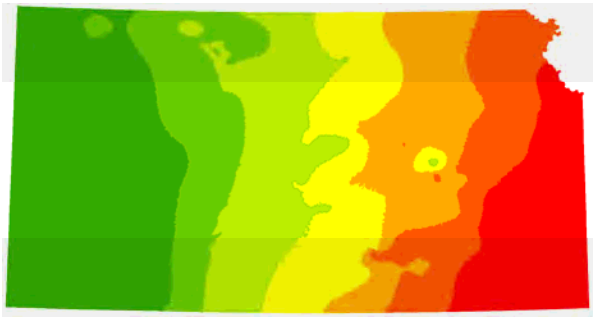


Figure B.1. Mean annual precipitation in allocated catchments (AMPm).

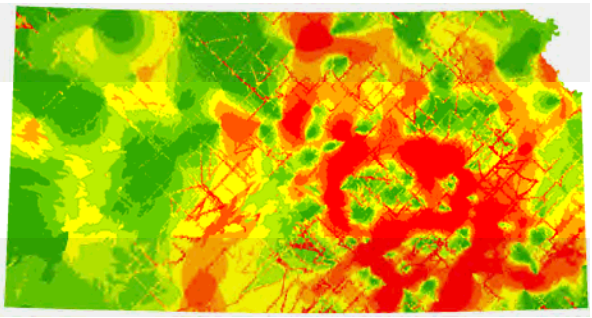


Figure B.2. Standard deviation of mean annual precipitation in allocated catchments (AMPsd).

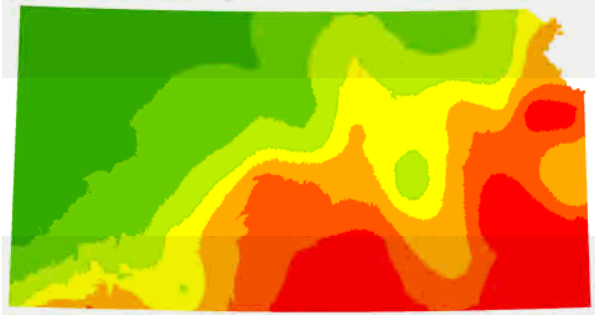


Figure B.3. Mean frost-free days per year in allocated catchments (FFDm).

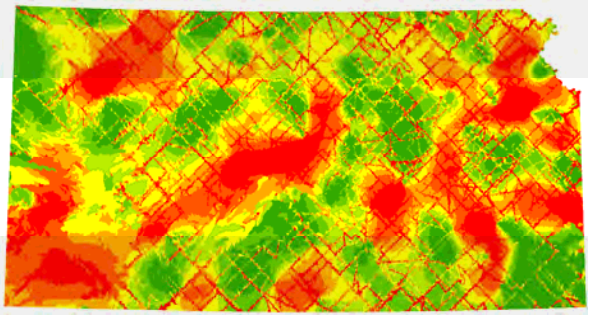


Figure B.4. Standard deviation of mean frost-free days per year in allocated catchments (FFDsd).

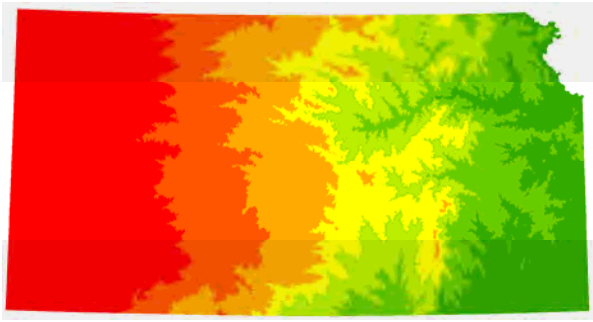


Figure B.5. Mean incident solar radiation in allocated catchments (ISRm).

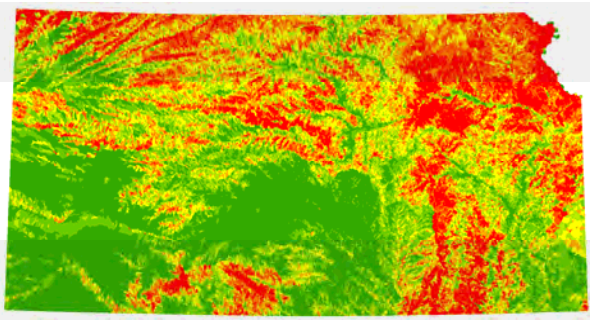


Figure B.6. Standard deviation of mean incident solar radiation in allocated catchments (ISRsd).

Appendix B. Statewide maps for individual variables considered in quantitative ecoregional analysis (continued).

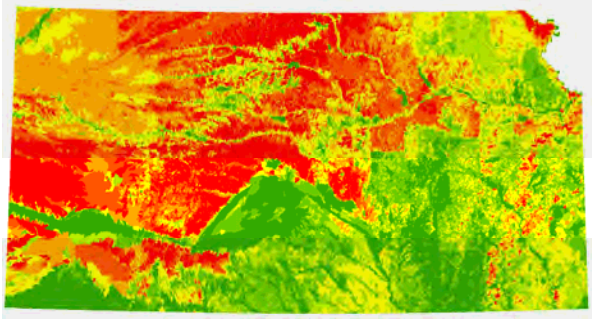


Figure B.7. Mean soil available water capacity in allocated catchments (SAWCm).

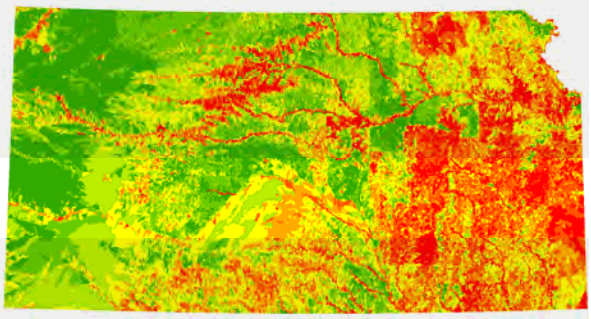


Figure B.8. Standard deviation of mean soil available water capacity in allocated catchments (SAWCsd).

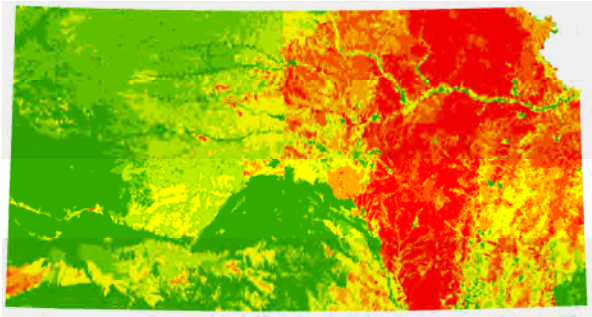


Figure B.9. Mean soil cation exchange capacity in allocated catchments (SCECm).

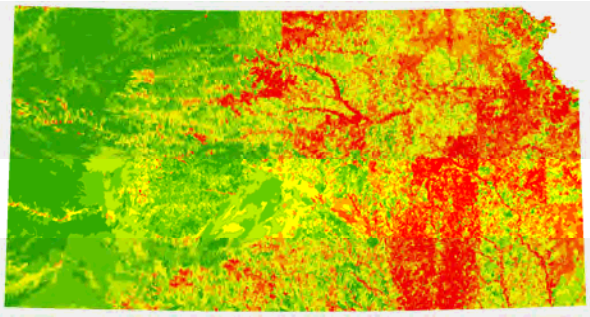


Figure B.10. Standard deviation of mean soil cation exchange capacity in allocated catchments (SCECsd).

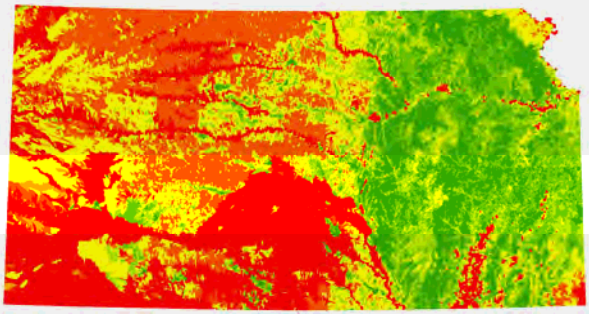


Figure B.11. Mean soil hydraulic conductivity in allocated catchments (SKSATm).

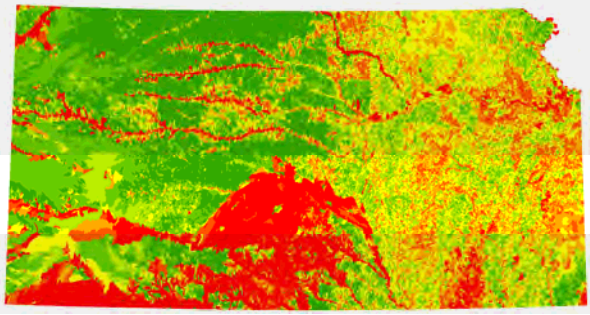


Figure B.12. Standard deviation of mean soil hydraulic conductivity in allocated catchments (SKSATsd).

Appendix B. Statewide maps for individual variables considered in quantitative ecoregional analysis (continued).

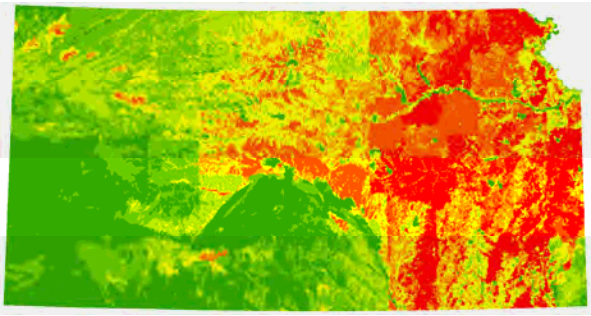


Figure B.13. Mean soil organic matter in allocated catchments (SOMm).

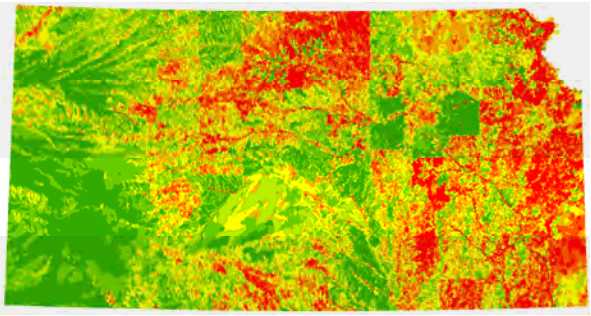


Figure B.14. Standard deviation of mean soil organic matter in allocated catchments (SOMsd).

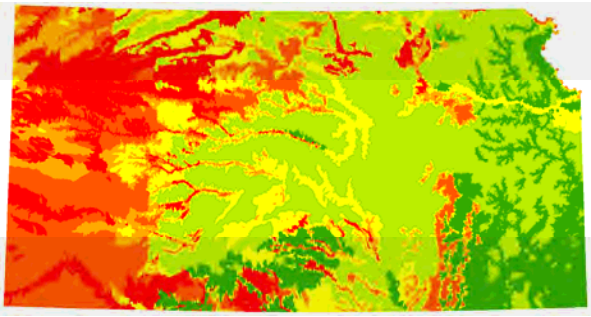


Figure B.15. Mean soil pH in allocated catchments (SPHm).

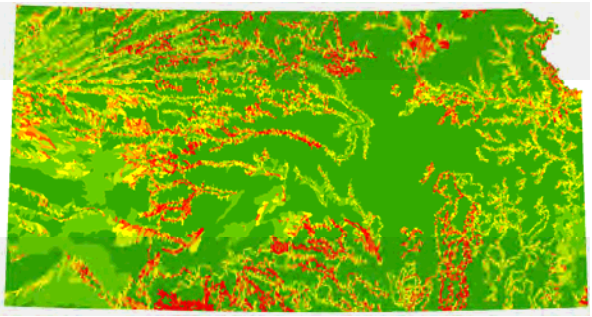


Figure B.16. Standard deviation of mean soil pH in allocated catchments (SPHsd).

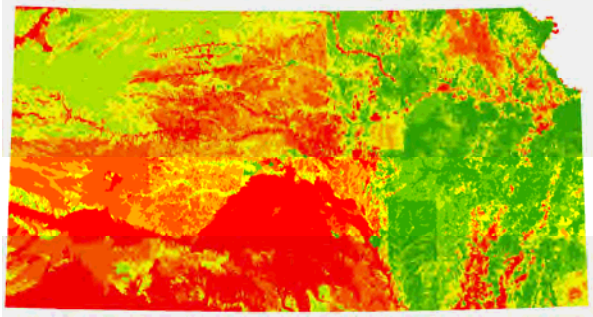


Figure B.17. Mean soil percent sand in allocated catchments (SPSm).

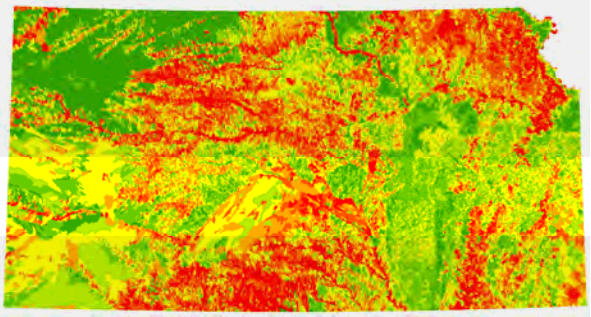


Figure B.18. Standard deviation of mean soil percent sand in allocated catchments (SPSsd).

Appendix B. Statewide maps for individual variables considered in quantitative ecoregional analysis (continued).

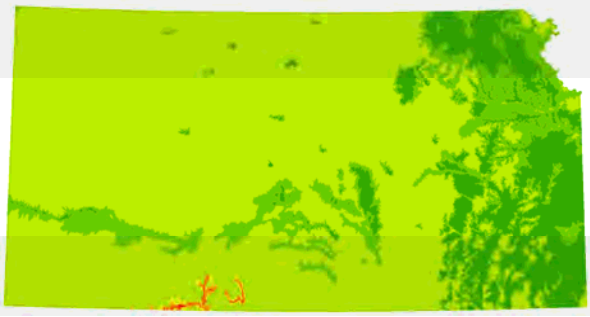


Figure B.19. Mean water table depth in allocated catchments (WTDm).

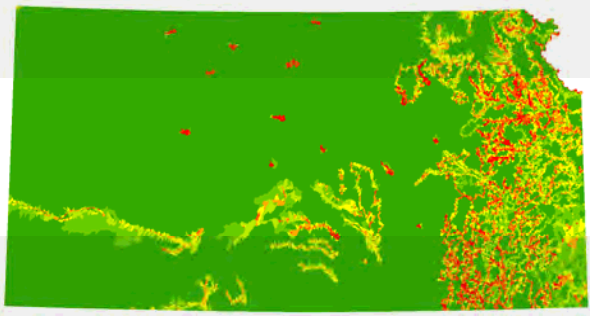


Figure B.20. Standard deviation of mean water table depth in allocated catchments (WTDsd).

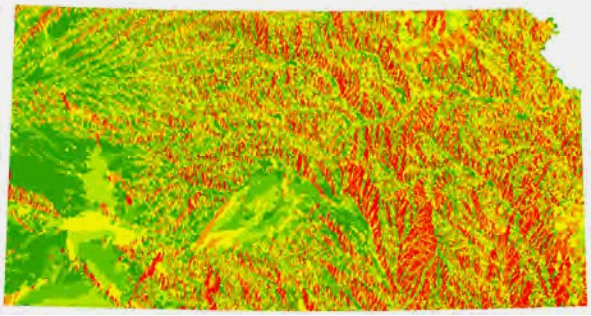


Figure B.21. Mean land surface aspect in allocated catchments (LSAm).

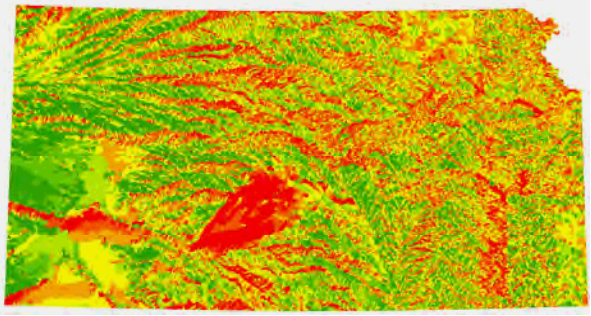


Figure B.22. Standard deviation of mean land surface aspect in allocated catchments (LSAsd).

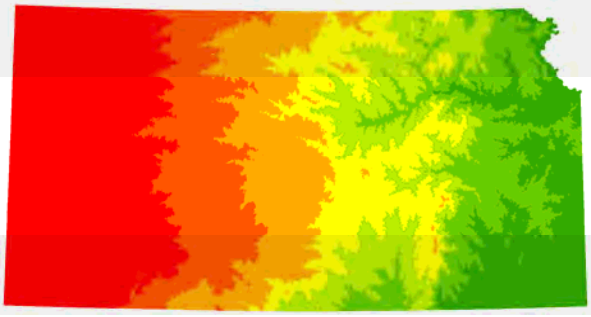


Figure B.23. Mean land surface elevation in allocated catchments (LSEm).

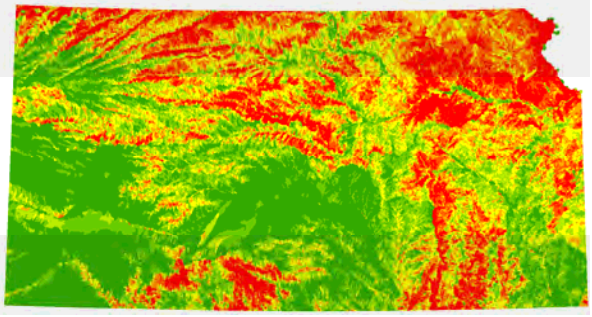


Figure B.24. Standard deviation of mean land surface elevation in allocated catchments (LSEsd).

Appendix B. Statewide maps for individual variables considered in quantitative ecoregional analysis (continued).

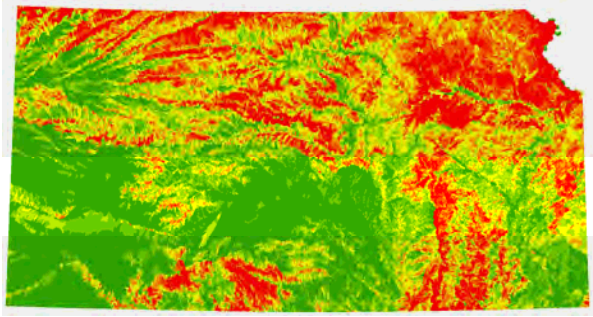


Figure B.25. Mean land surface slope in allocated catchments (LSSm).

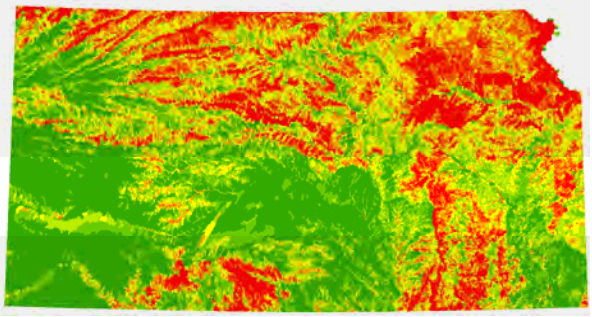


Figure B.26. Standard deviation of mean land surface slope in allocated catchments (LSSsd).

Appendix C. Descriptions of variables considered in watershed disturbance analysis. Variable names ending in "al" and "ac" refer to allocated and accumulated catchments, respectively.

Variable	Data source	Description
CAFOal CAFOac	CDPHE (2009) KDHE (2009) NDEQ (2009)	Density of confined livestock. This variable represented the total number of animal units within the catchment divided by the area of catchment.
CROPal CROPac	USGS (2001)	Ratio of cropland area to total land area. Land cover data were derived from the 2001 NLCD.
CROPRIal CROPRIac	USGS (2001)	Ratio of cropland area to total land area within 90-meter riparian corridor. Data were derived from the NLCD.
DAMSal DAMSac	EPA/USGS (2005)	Density of registered and unregistered dams. Data were derived from 1:100,000 NHD.
GRAZINNal GRAZINNac	USDA (2002) USGS (2001)	Density of grazing cattle. Density was calculated by intersecting county-level cattle statistics with the NLCD grassland and pasture/hay classes.
H20WELal H20WELac	CWCB (2009) KDWR (2009) MSDIS (2006) NDNR (2009)	Density of permitted groundwater diversions. Density was calculated as the total number of groundwater wells within the catchment divided by the area of catchment.
IMPOUNal IMPOUNac	EPA/USGS (2005)	Ratio of inundated land area to total land area. Total inundated area was derived from the 1:100,000 NHD.
LANDFIal LANDFIac	MORAP (2008)	Density of active and inactive permitted landfills in catchment. Both solid waste and hazardous waste landfills were included in density estimate.
MINESal MINESac	MORAP (2008)	Density of active and inactive permitted mines and quarries within catchment.
NPDESal NPDESac	KDHE (2010)	Total federally permitted wastewater output divided by catchment area.
OILWELal OILWELac	COGCC (2007) KGS (2009) MORAP (2008)	Density of registered active and inactive oil and natural gas wells in catchment.
PESTICal PESTICac	MORAP (2008)	Combined annual application rate for all pesticides. Estimates were obtained by integrating county level U.S. Agricultural Census Data and the NLCD.
PIPECRal PIPECRac	KAG (2010)	Density of stream/industrial pipeline intersections within catchment.

Appendix C. Descriptions of variables considered in watershed disturbance analysis (continued).

Variable	Data source	Description
POPULAal POPULAac	DASC (2000) MSDIS (2000) NDNR (2000)	Density of human residents. The watershed catchment shapefile was intersected with the CY2000 census block shapefile to create sub-blocks within catchment. The total human population of each sub-block was distributed across the block and then redistributed within catchment.
RAILCRal RAILCRac	MORAP (2008)	Density of stream/railroad intersections within catchment area.
ROADCRal ROADCRac	MORAP (2008)	Density of stream/road intersections within catchment area.
SUPERFal SUPERFac	MORAP (2008)	Density of active and inactive Superfund sites within catchment area.
SURFDIal SURFDIac	CWCB (2009) KDWR (2009) NDNR (2009)	Density of permitted surface water diversions. Density was calculated as the total number of diversions within the catchment divided by the area of catchment.
URBANal URBANac	USGS (2001)	Ratio of urban area to total land area within catchment. Land cover data were derived from the NLCD.
URBANRal URBANRac	USGS (2001)	Ratio of urban area to total land area within 90-meter riparian corridor. Land cover data were derived from the NLCD.

Agency and database acronyms:
CDPHE = Colorado Department of Public Health and Environment
COGCC = Colorado Oil and Gas Conservation Commission
CWCB = Colorado Water Conservation Board and Colorado Division of Water Resources
DASC = (Kansas) Data Access and Support Center
EPA = U.S. Environmental Protection Agency
KAG = Kansas Adjutant General's Department
KDHE = Kansas Department of Health and Environment
KGS = Kansas Geological Survey
MORAP = Missouri Resource Assessment Partnership
MSDIS = Missouri Spatial Data Information Service
NDEQ = Nebraska Department of Environmental Quality
NDNR = Nebraska Department of Natural Resources
NHD = National Hydrography Dataset (maintained by EPA and USGS)
NLCD = National Land Cover Database (maintained by USGS Land Cover Institute)
USDA = U.S. Department of Agriculture, National Agricultural Statistics Service
USGS = U.S. Geological Survey

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis. Watersheds were assigned to seven groups (septiles) containing an equal number of watersheds (unless prohibited by ties). Each group was mapped in a different color, ranging from green (best condition) to red (worst condition).

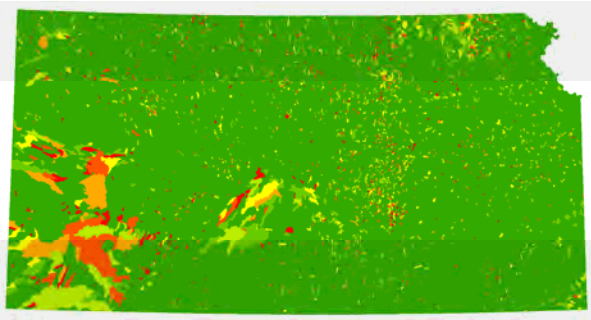


Figure D.1. Density of confined livestock (i.e., permitted animal units) in allocated catchments (CAFOal).

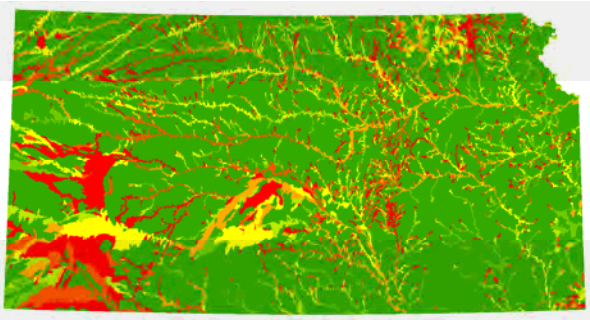


Figure D.2. Density of confined livestock (i.e., permitted animal units) in accumulated catchments (CAFOac).

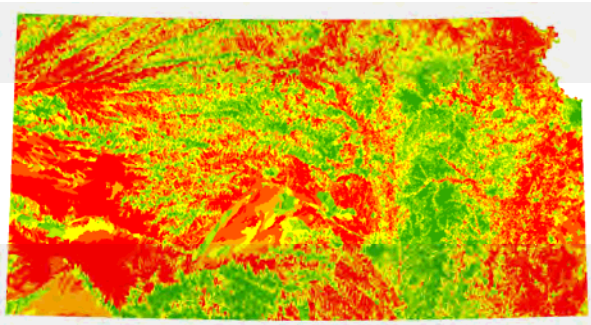


Figure D.3. Ratio of cropland area to total land area in allocated catchments (CROPal).

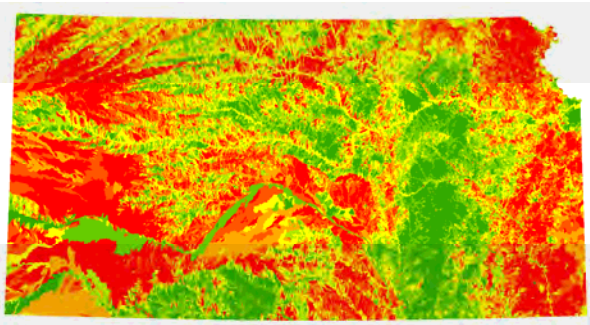


Figure D.4. Ratio of cropland area to total land area in accumulated catchments (CROPac).

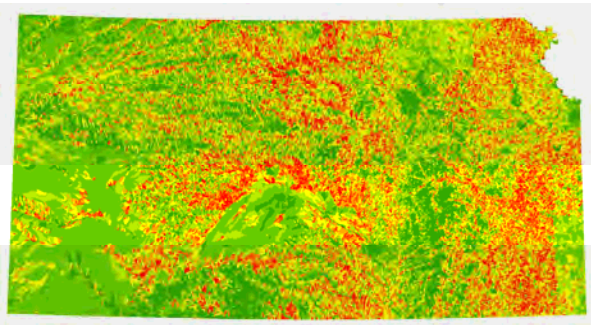


Figure D.5. Ratio of cropland area to total land area within 90-meter riparian corridor in allocated catchments (CROPRIal).

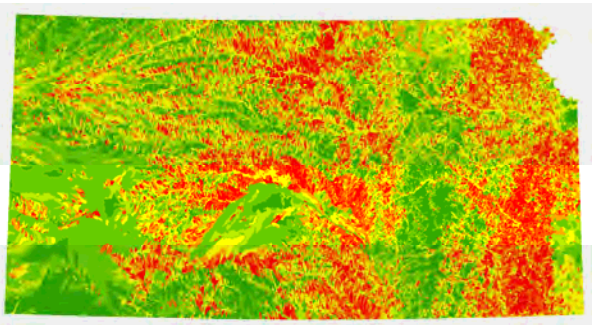


Figure D.6. Ratio of cropland area to total land area within 90-meter riparian corridor in accumulated catchments (CROPRIac).

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis (continued).

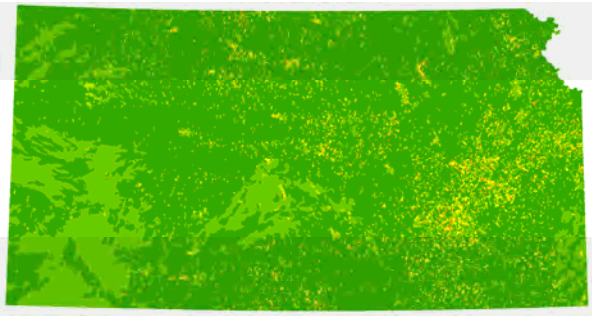


Figure D.7. Density of registered and unregistered dams in allocated catchments (DAMSal).

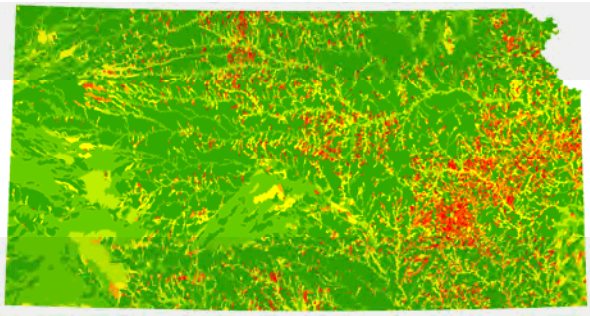


Figure D.8. Density of registered and unregistered dams in accumulated catchments (DAMSac).

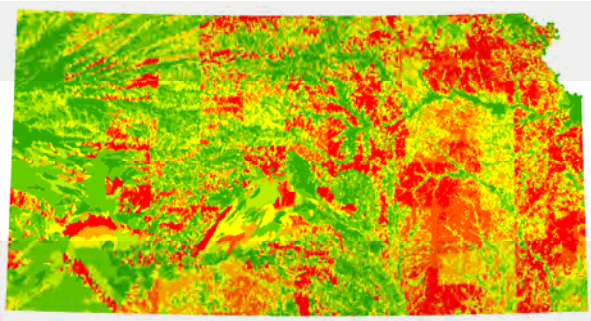


Figure D.9. Density of grazing cattle in allocated catchments (GRAZINal).

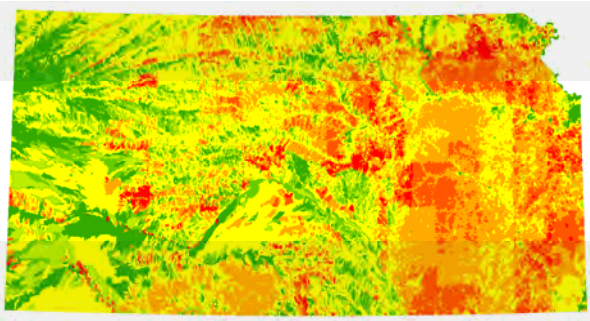


Figure D.10. Density of grazing cattle in accumulated catchments (GRAZINac).

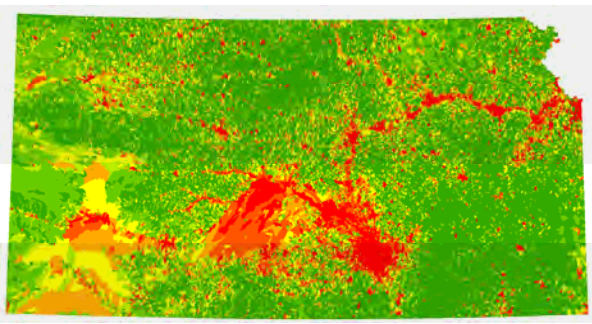


Figure D.11. Density of permitted groundwater diversions in allocated catchments (H2OWELal).

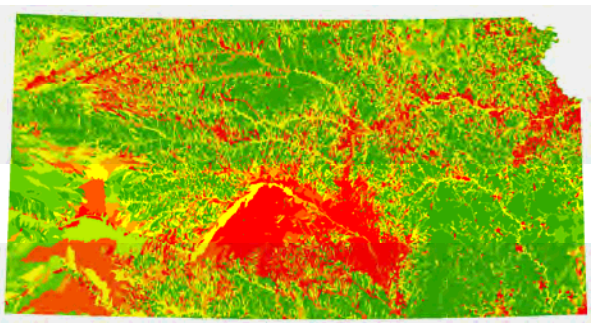


Figure D.12. Density of permitted groundwater diversions in accumulated catchments (H2OWELac).

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis (continued).

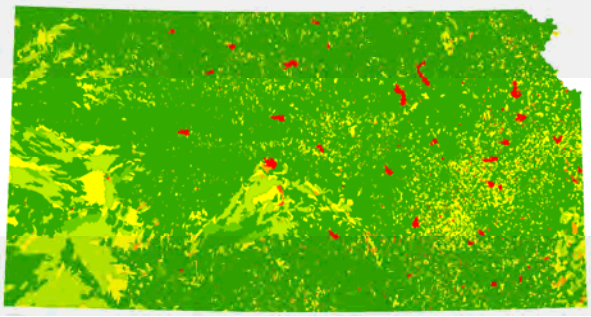


Figure D.13. Ratio of inundated land area to total land area in allocated catchments (IMPOUNal).

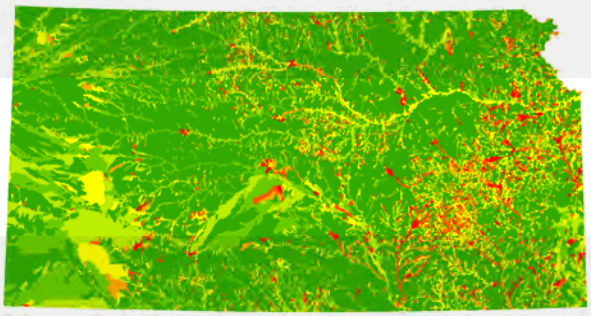


Figure D.14. Ratio of inundated land area to total land area in accumulated catchments (IMPOUNac).

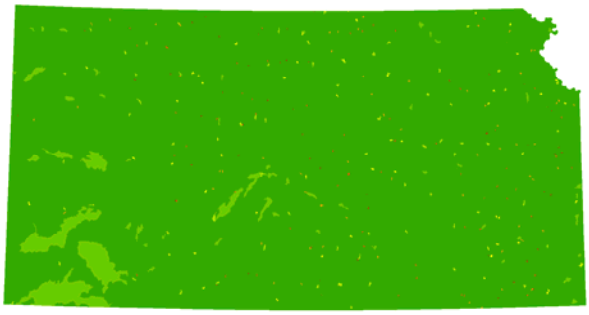


Figure D.15. Density of active and inactive permitted landfills in allocated catchments (LANDFIal).

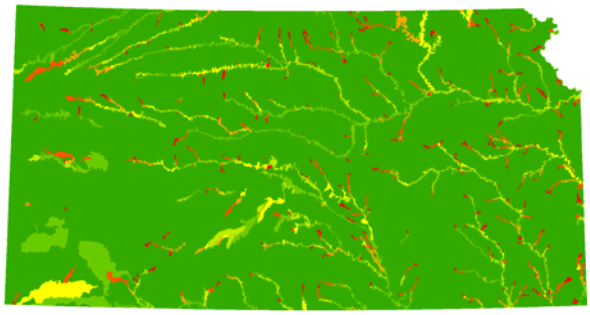


Figure D.16. Density of active and inactive permitted landfills in accumulated catchments (LANDFIac).

Figure D.17. Density of active and inactive permitted mines and quarries in allocated catchments (MINESal).

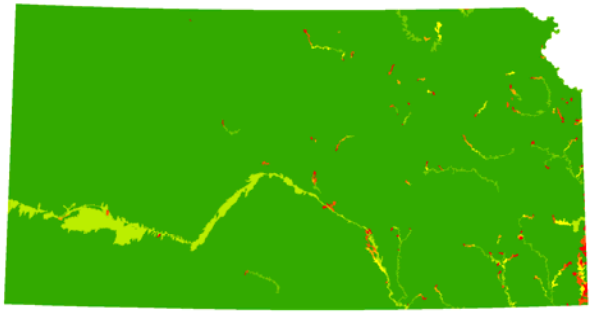


Figure D.18. Density of active and inactive permitted mines and quarries in accumulated catchments (MINESac).

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis (continued).

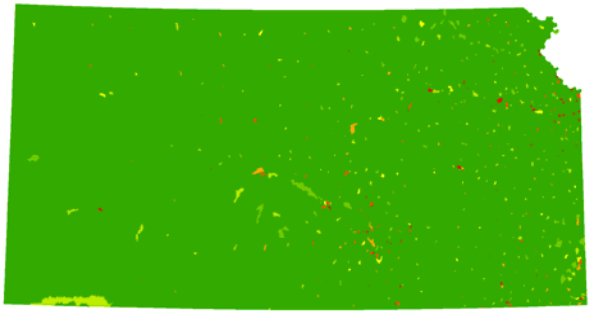


Figure D.19. Total permitted wastewater output divided by catchment area in allocated catchments (NPDESal).

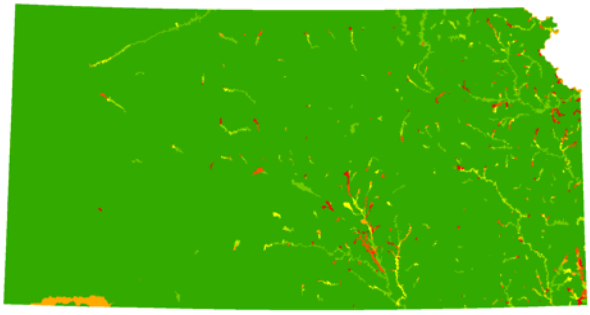


Figure D.20. Total permitted wastewater output divided by catchment area in accumulated catchments (NPDESac).

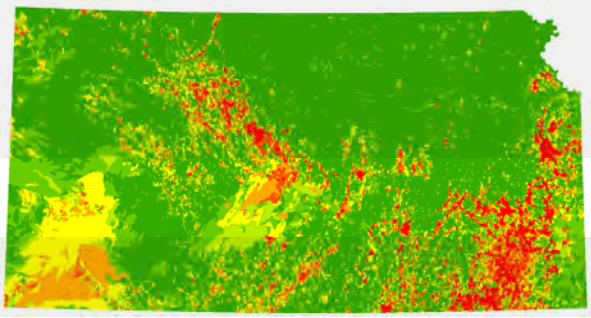


Figure D.21. Density of registered active and inactive oil and natural gas wells in allocated catchments (OILWELal).

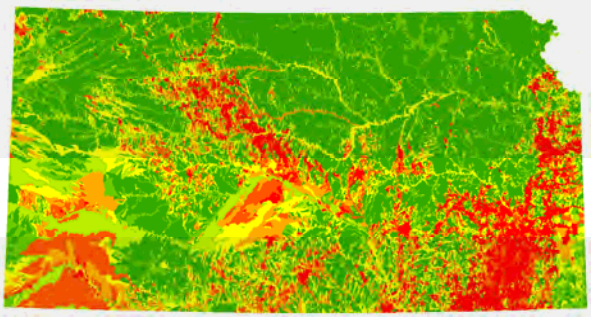


Figure D.22. Density of registered active and inactive oil and natural gas wells in accumulated catchments (OILWELac).

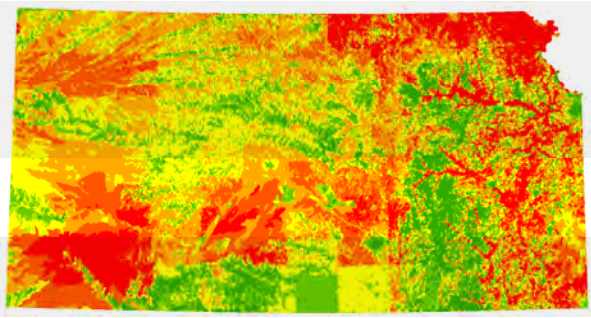


Figure D.23. Combined annual application rate for all pesticides in allocated catchments (PESTICal).

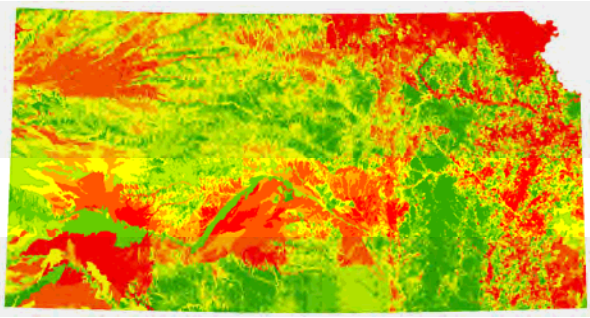


Figure D.24. Combined annual application rate for all pesticides in accumulated catchments (PESTICac).

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis (continued).

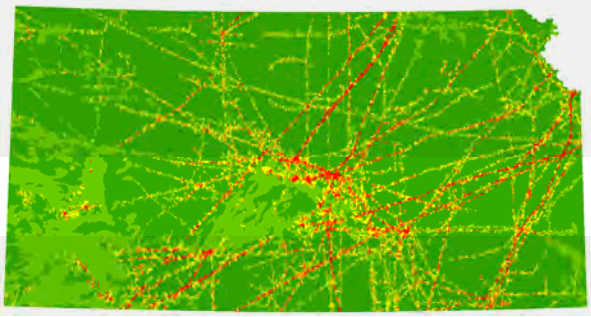


Figure D.25. Density of stream/industrial pipeline intersections in allocated catchments (PIPECRal).

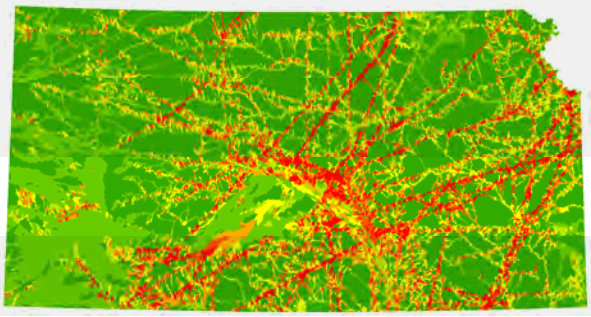


Figure D.26. Density of stream/industrial pipeline intersections in accumulated catchments (PIPECRac).

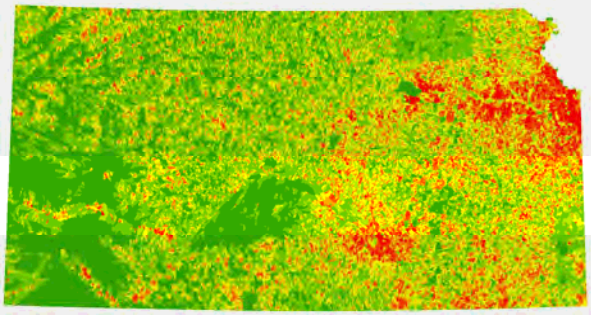


Figure D.27. Density of human residents in allocated catchments (POPULAal).

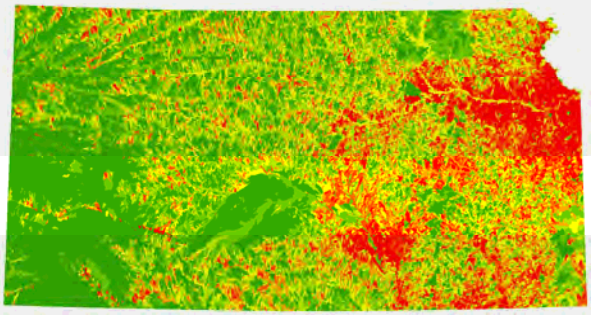


Figure D.28. Density of human residents in accumulated catchments (POPULAac).

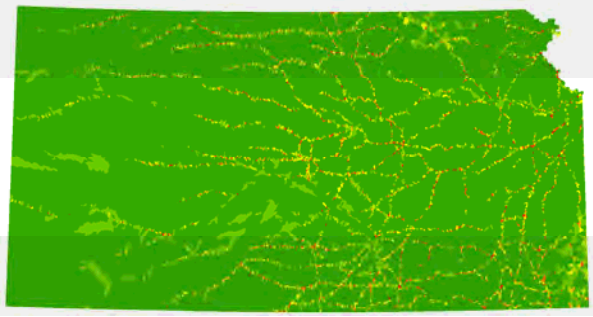


Figure D.29. Density of stream/railroad intersections in allocated catchments (RAILCRal).

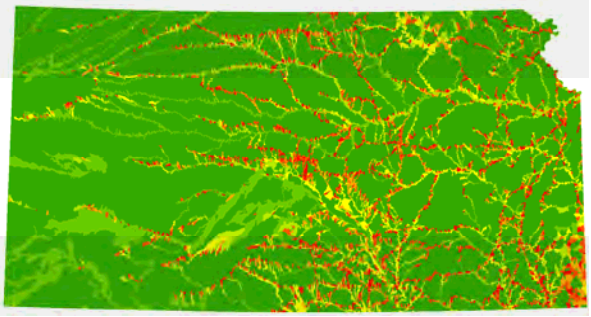


Figure D.30. Density of stream/railroad intersections in accumulated catchments (RAILCRac).

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis (continued).

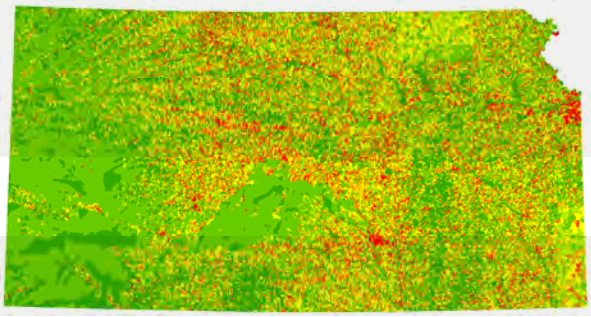


Figure D.31. Density of stream/road intersections in allocated catchments (ROADCRal).

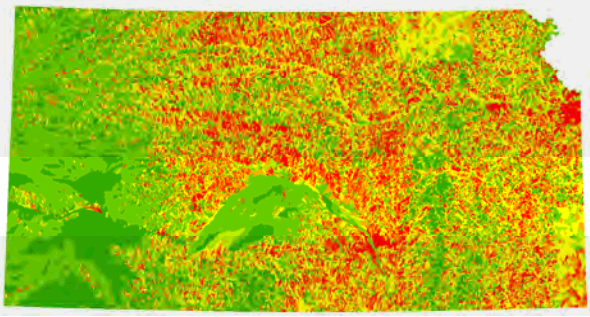


Figure D.32. Density of stream/road intersections in accumulated catchments (ROADCRac).

Figure D.33. Density of active and inactive Superfund sites in allocated catchments (SUPERFal).

Figure D.34. Density of active and inactive Superfund sites in accumulated catchments (SUPERFac).

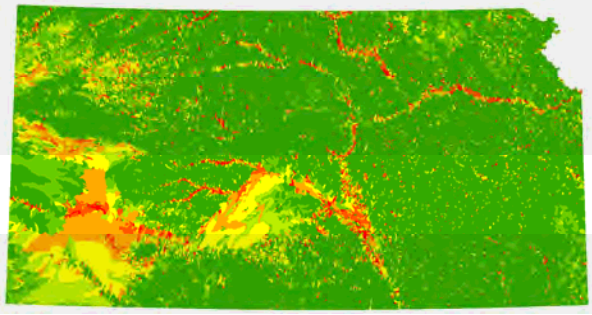


Figure D.35. Density of permitted surface water diversions in allocated catchments (SURFDIal).

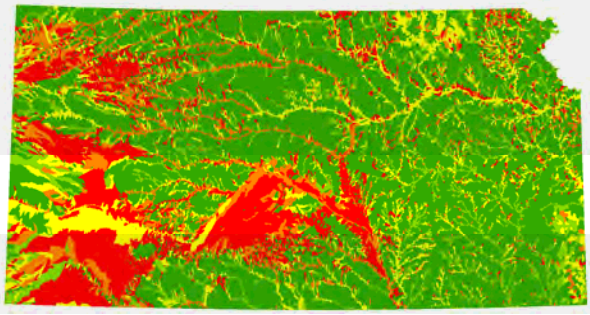


Figure D.36. Density of permitted surface water diversions in accumulated catchments (SURFDIac).

Appendix D. Statewide maps for individual variables considered in watershed disturbance analysis (continued).

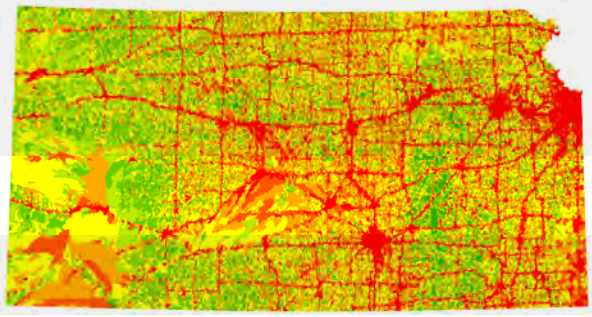


Figure D.37. Ratio of urban land area to total land area in allocated catchments (URBANal).

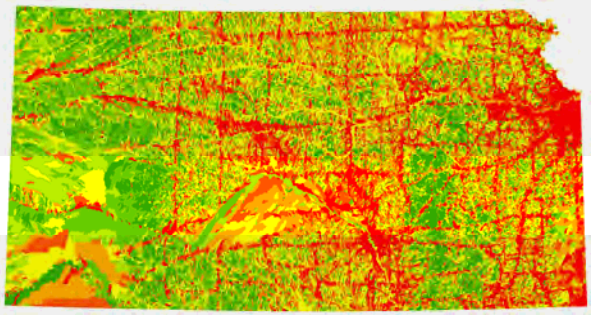


Figure D.38. Ratio of urban land area to total land area in accumulated catchments (URBANac).

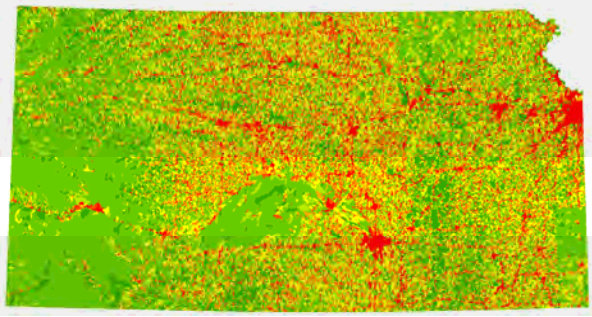


Figure D.39. Ratio of urban land area to total land area within 90-meter riparian corridor in allocated catchments (URBANRal).

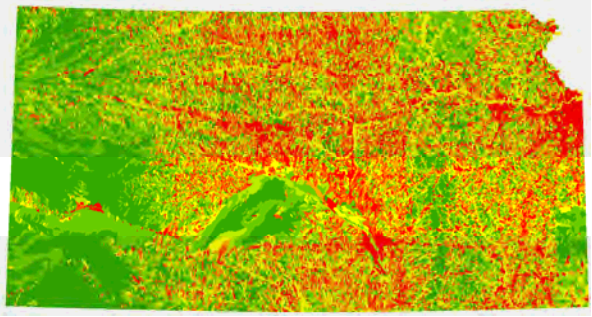
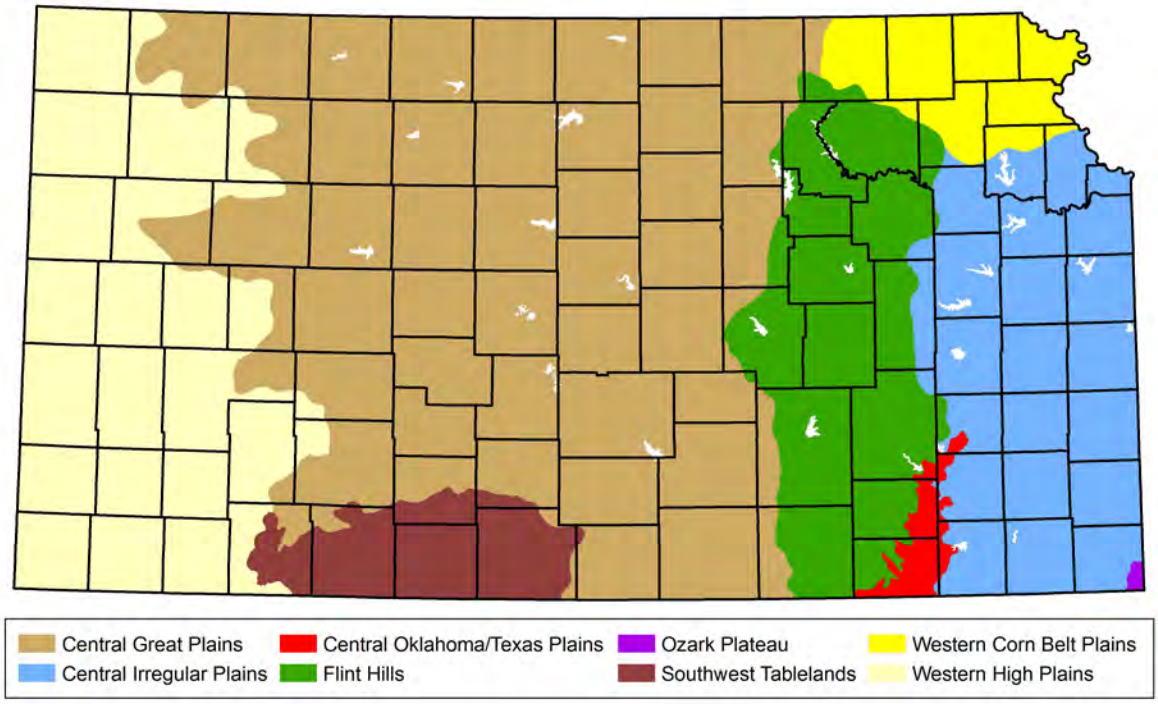
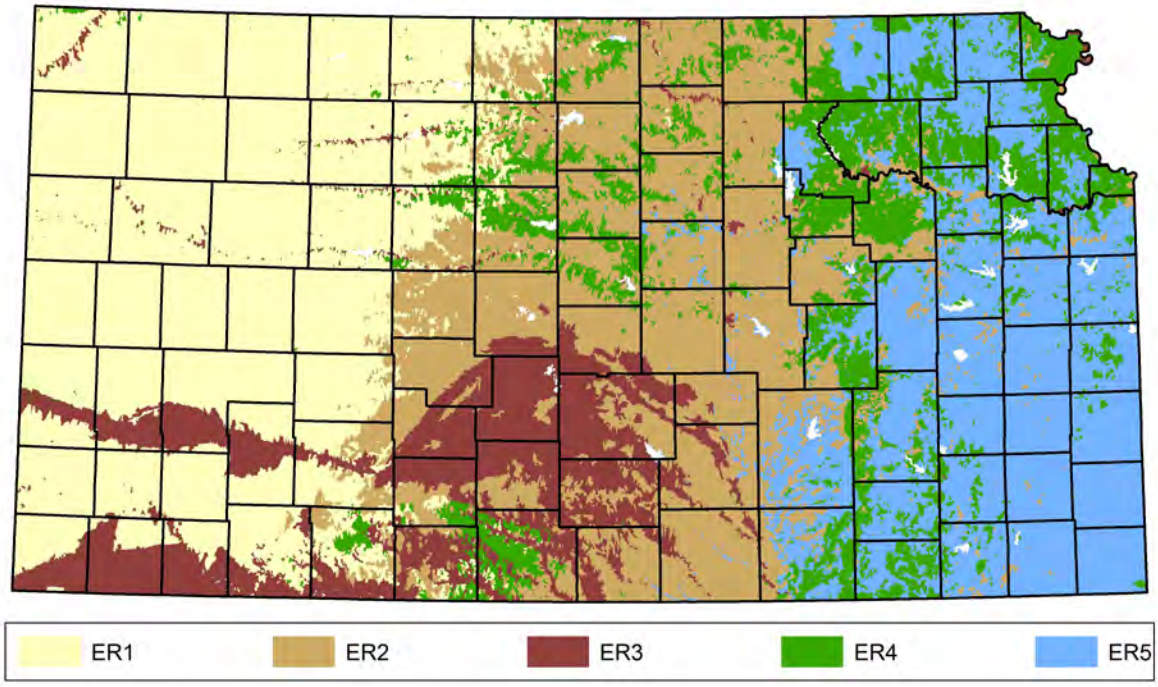
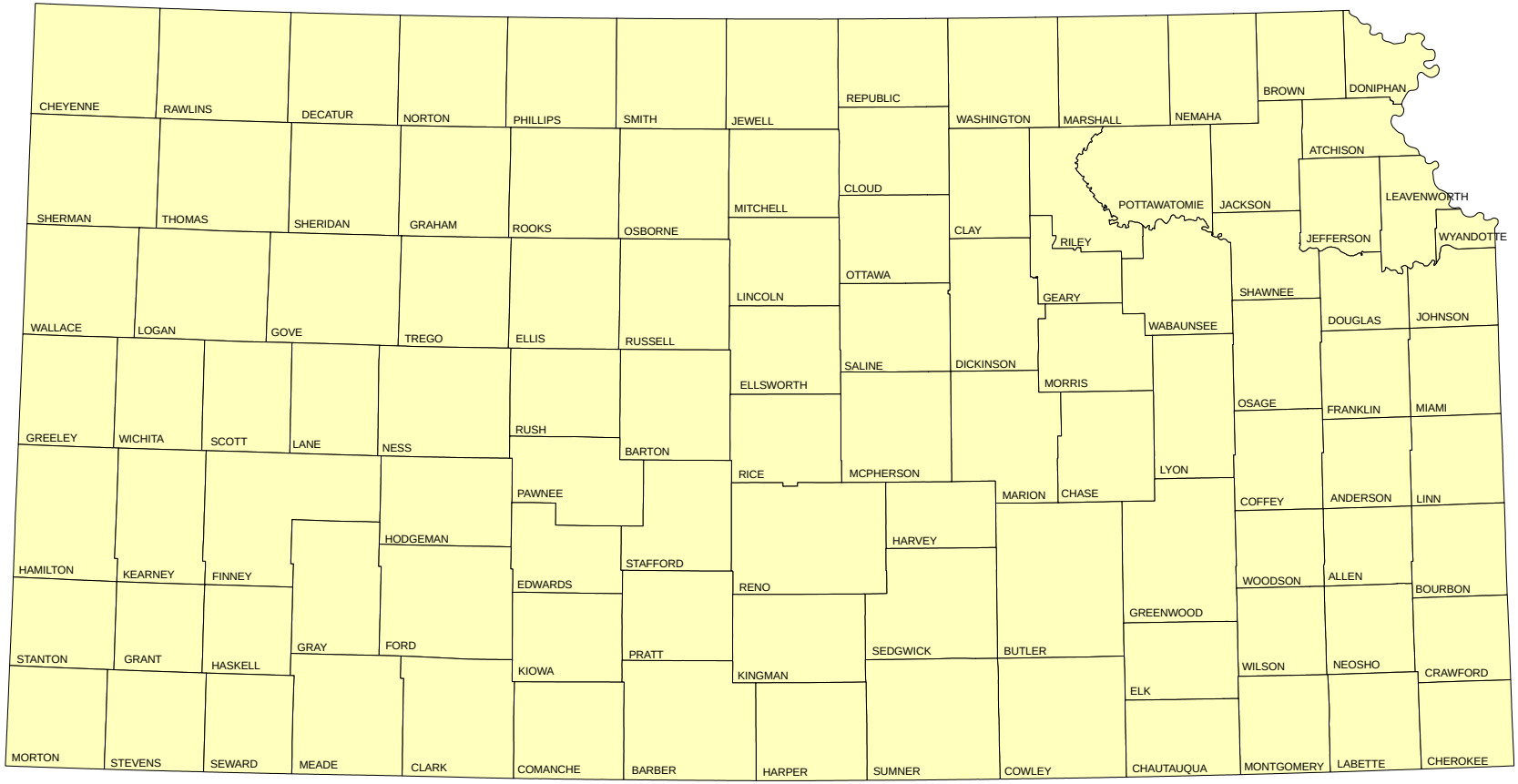


Figure D.40. Ratio of urban land area to total land area within 90-meter riparian corridor in accumulated catchments (URBANRac).

Appendix E. Comparison of Chapman et al. (2001) Level III ecoregions (upper map) to the quantitative (k = 5) ecoregions delineated in this study (lower map). Level IV ecoregions are not shown in upper map. White polygons depict major reservoirs and wetland complexes; black lines depict county boundaries.





Appendix F. Map of Kansas depicting locations of all 105 counties.