science for a changing world

Prepared in cooperation with the Missouri Department of Natural Resources

Comparison of Hydrologic and Water-Quality Characteristics of Two Native Tallgrass Prairie Streams with Agricultural Streams in Missouri and Kansas

Scientific Investigations Report 2009–5213

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

Cover. East Drywood Creek at Prairie State Park, Missouri. Photo provided by Prairie State Park, Missouri Department of Natural Resources.

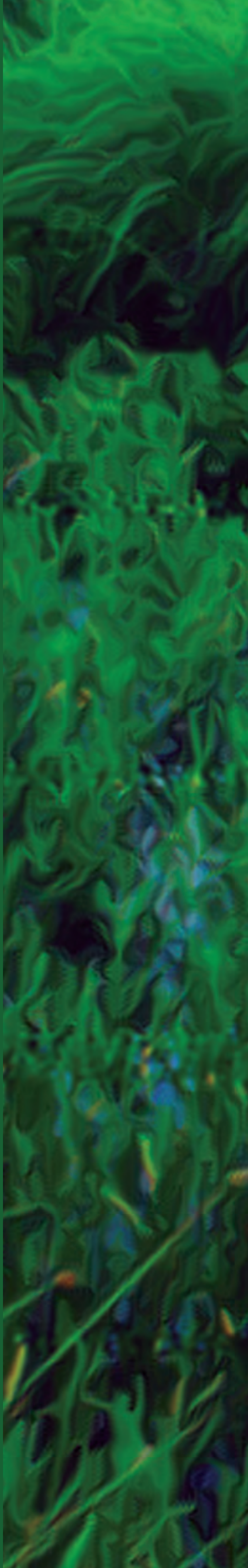
Comparison of Hydrologic and Water-Quality Characteristics of Two Native Tallgrass Prairie Streams with Agricultural Streams in Missouri and Kansas

By David C. Heimann

Prepared in cooperation with the Missouri Department of Natural Resources

Scientific Investigations Report 2009-5213

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



U.S. Department of the Interior
KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

This and other USGS information products are available at http://store.usgs.gov/
U.S. Geological Survey
Box 25286, Denver Federal Center
Denver, CO 80225

To learn about the USGS and its information products visit http://www.usgs.gov/
1-888-ASK-USGS

Suggested citation:
Heimann, D.C., 2009, Comparison of Hydrologic and Water-Quality Characteristics of Two Native Tallgrass Prairie Streams with Agricultural Streams in Missouri and Kansas: U.S. Geological Survey Scientific Investigations Report 2009-5213, 39 p.

Contents

Figures

Tables

Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25,400.	micrometer (µm)
foot (ft)	0.3048	meter (m)
	Area	
acre	4,047	square meter (m^2)
square mile (mi^2)	259.0	hectare (ha)
	Volume	
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:
°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:
°C=(°F-32)/1.8

Elevation data are referenced to the North American Vertical Datum of 1988 (NAVD 88).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Comparison of Hydrologic and Water-Quality Characteristics of Two Native Tallgrass Prairie Streams with Agricultural Streams in Missouri and Kansas

By David C. Heimann

Abstract

This report presents the results of a study by the U.S. Geological Survey, in cooperation with the Missouri Department of Natural Resources, to analyze and compare hydrologic and water-quality characteristics of tallgrass prairie and agricultural basins located within the historical distribution of tallgrass prairie in Missouri and Kansas. Streamflow and water-quality data from two remnant, tallgrass prairie basins (East Drywood Creek at Prairie State Park, Missouri, and Kings Creek near Manhattan, Kansas) were compared to similar data from agricultural basins in Missouri and Kansas.

Prairie streams, especially Kings Creek in eastern Kansas, received a higher percentage of base flow and a lower percentage of direct runoff than similar-sized agricultural streams in the region. A larger contribution of direct runoff from the agricultural streams made them much flashier than prairie streams. During 22 years of record, the Kings Creek base-flow component averaged 66 percent of total flow, but base flow was only 16 to 26 percent of flows at agricultural sites of various record periods. The large base-flow component likely is the result of greater infiltration of precipitation in prairie soils and the resulting greater contribution of groundwater to streamflow. The 1- and 3-day annual maximum flows were significantly greater at three agricultural sites than at Kings Creek. The effects of flashier agricultural streams on native aquatic biota are unknown, but may be an important factor in the sustainability of some native aquatic species.

There were no significant differences in the distribution of dissolved-oxygen concentrations at prairie and agricultural sites, and some samples from most sites fell below the 5 milligrams per liter Missouri and Kansas standard for the protection of aquatic life. More than 10 percent of samples from the East Drywood Creek prairie stream were less than this standard. These data indicate low dissolved-oxygen concentrations during summer low-flow periods may be a natural phenomenon for small prairie streams in the Osage Plains.

Nutrient concentrations including total nitrogen, ammonia, nitrate, and total phosphorus were significantly less in base-flow and runoff samples from prairie streams than from agricultural streams. The total nitrogen concentration at all sites other than one of two prairie sampling sites were, on occasion, above the U.S. Environmental Protection Agency recommended criterion for total nitrogen for the prevention of nutrient enrichment, and typically were above this recommended criterion in runoff samples at all sites. Nitrate and total phosphorus concentrations in samples from the prairie streams generally were below the U.S. Environmental Protection Agency recommended nutrient criteria in base-flow and runoff samples, whereas samples from agricultural sites generally were below the criteria in base-flow samples and generally above in runoff samples. The lower concentrations of nutrient species in prairie streams is likely because prairies are not fertilized like agricultural basins and prairie basins are able to retain nutrients better than agricultural basins. This retention is enhanced by increased infiltration of precipitation into the prairie soils, decreased surface runoff, and likely less erosion than in agricultural basins.

Streamflow in the small native prairie streams had more days of zero flow and lower streamflow yields than similar-sized agricultural streams. The prairie streams were at zero flow about 50 percent of the time, and the agricultural streams were at zero flow 25 to 35 percent of the time. Characteristics of the prairie basins that could account for the greater periods of zero flow and lower yields when compared to agricultural streams include greater infiltration, greater interception and evapotranspiration, shallower soils, and possible greater seepage losses in the prairie basins. Another difference between the prairie and agricultural streams was the duration of extreme low flows (flows within the lowest 10^{th} percentile). The long-term extreme low-flow duration was a median of 112 days for the prairie stream, Kings Creek, but was not greater than a median of 16 days at any of the agricultural sites. This extended duration of low flows indicates a prolonged period of groundwater contributions to streamflow from the prairie stream compared to the agricultural streams.

Introduction

Before 19th century cultivation, most of the agricultural Midwest, including western and northern Missouri, was covered by tallgrass prairie (fig. 1). About 95 percent of the original tallgrass prairie in the United States has been converted to other land covers (Samson and Knopf, 1994), and less than one percent of the original tallgrass prairie in Missouri remains (Schroeder, 1982; Samson and Knopf, 1994). Rarer still are sizeable reaches of native tallgrass prairie streams (Dodds and others, 2004) with homogenous prairie basins, as many remaining prairies are small patchwork remnants located within basins dominated by altered land uses. The few, small, homogenous prairie basins that remain provide the opportunity to examine the hydrology, water quality, and ecology of an aquatic ecosystem that once dominated much of Missouri. The nature and extent that alterations in land cover have changed the hydrology, water quality, and habitat under which native biota have developed can be quantified through comparisons of existing stream characteristics of native prairie and altered basins.

Studies have shown that the cultivation and conversion of tallgrass prairies to agricultural land uses have resulted in modifications of physical and chemical soil characteristics that have led to changes in the hydrology. Brye (2003) determined the conversion from prairie to cultivated land cover resulted in soil textural changes, specifically a reduction in the sand-sized fraction and an increase in the clay-sized fraction, resulting in hydraulic changes in the soil. Tomko and Hall (1986) detected a loss of organic carbon and an increase in bulk density in prairie soils following cultivation. Fuentes and others (2004) detected an order of magnitude reduction in hydraulic conductivity associated with cultivation of natural prairies in the state of Washington. These changes persisted decades following cultivation. Several studies in Wisconsin and Canada have detected substantial increases in runoff and peak flows from cultivated land cover when compared with those from prairie land cover (Sartz, 1969; Sartz, 1970; Knox, 1977; Knox, 2001; van der Kamp and others, 2001; Gerla, 2007).

In addition to changes in soil characteristics, cultivation may result in changes in the water budget of basins that formerly were native prairie. Prairie grasses had greater interception storage and precipitation reaching the soil was less for prairie soils than for cultivated cropland (Brye and others, 2000). Despite increased rates of evapotranspiration, soil moisture was greater in a restored prairie compared with cultivated sites. Lauwo (2007) stated that moisture stored in the Konza prairie soil is retained as a result of the dense prairie grass residue acting as a mulch layer. The water-conserving photosynthetic process of native prairie warm-season (C4) grasses (Jones, 1983; Pearcy and Ehleringer, 1984) also could lead to greater soil moisture and more sustained base flows in comparison to converted, cool-season (C3) pasture grasses and forbs. Restoration efforts using native C4 plants over C3 plants resulted in advantages in developing soil aggregates (Jastrow, 1987), which can help reverse some of the soil and hydrologic changes that can result from cultivation. Since 1985, the acreage of warm-season prairie grasses has increased because of the U.S. Department of Agriculture's Conservation Reserve Program (Sullivan and others, 2004) and efforts by states and conservation groups to preserve and restore tallgrass prairies. These policies and trends toward preservation and restoration of remnant prairies are increasing the planting and extent of native prairie plant species, which may have an effect on the modern-day hydrologic regime and water-quality characteristics of streams of western Missouri and eastern Kansas.

Soil erosion and yields of nutrients and contaminants (Kemp and Dodds, 2002), such as phosphorus, nitrate, ammonia, and agricultural pesticides, also are expected to be greater for land altered for agricultural uses than for native prairies because fertilizers and pesticides generally are not used on established prairies. Soil erosion also increases as a result of increased runoff from exposed soils under cultivation (Knox, 2001). A stream draining a remnant native tallgrass prairie, therefore, might serve as a reference stream for water quality because the only anthropomorphic chemicals in the basin originate from atmospheric deposition and possible occasional spot spraying for invasive species.

Purpose and Scope

Few studies have compared the hydrologic and water-quality characteristics of native-prairie and agricultural basins in the tall grass prairie region of the agricultural Midwestern United States. To address this need, a study was conducted by the U.S. Geological Survey (USGS) in cooperation with the Missouri Department of Natural Resources to analyze and compare existing streamflow and water-quality data from remnant prairie basins (East Drywood Creek at Prairie State Park, Missouri; Kings Creek near Manhattan, Kansas; fig. 1) with similar data from comparable-sized agricultural basins in Missouri and Kansas. Specific study objectives included the following:

1. characterize and compare the hydrology (hydrograph separation, flow duration, rainfall-streamflow relations, and ecological flow characteristics) of native prairie streams with similar-sized agricultural streams within the historical tallgrass prairie region of Missouri and Kansas, and
2. characterize and compare water quality (field measurements, nutrients, major ions, and pesticide characteristics) of native prairie streams with similar-sized agricultural streams within the tallgrass prairie region of Missouri and Kansas.

This report summarizes the analyses of the hydrologic and water-quality characteristics of selected prairie and agricultural streams. Streamflow data collected during 1957 through 2008 from the two native prairie basins and six agricultural basins were used for hydrologic comparisons. Data collected during 1980 through 2009 from nine basins

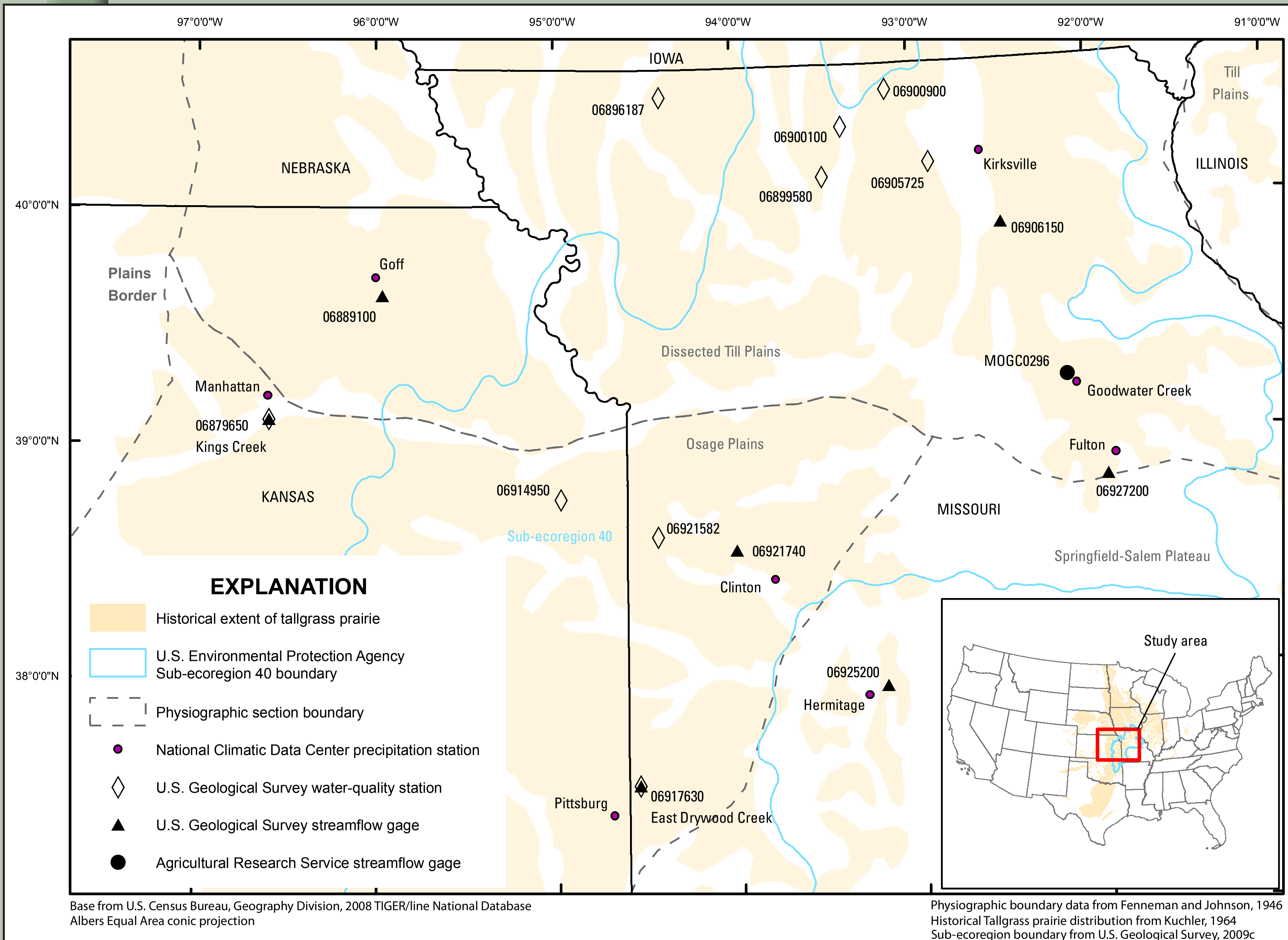


Figure 1. Location of hydrologic, water-quality, and precipitation monitoring stations used in study, physiographic section boundaries, and historical distribution of tallgrass prairie in the conterminous United States.

(two native prairie and seven agricultural basins) were used for the water-quality comparisons. Most of the streamflow and water-quality data were not collected to specifically address the objectives of the study described in this report, and the frequency of sampling and period of record at the selected sites are, therefore, not necessarily concurrent.

Characteristics of Study Area

Streamflow data from six agricultural (basins having greater than 50 percent agricultural land cover) streamflow-gaging stations in Missouri and Kansas were selected for hydrologic comparisons with East Drywood Creek at Prairie State Park, Missouri (USGS streamflow-gaging station number 06917630) and Kings Creek near Manhattan, Kansas (USGS streamflow-gaging station number 06879650, fig. 1; table 1). Data from seven agricultural water-quality monitoring stations (fig. 1; table 2) were selected for comparisons with the East Drywood Creek and Kings Creek data. The primary selection criteria for comparison sites included those that were located within the historical distribution of native tallgrass prairie or tallgrass prairie savannah in Missouri and Kansas (fig. 1), were similar in drainage area to East Drywood Creek [3.38 square miles (mi^2)] and Kings Creek (4.09 mi^2), and, when possible, that had a period of streamflow or water-quality record that overlapped all or part of the East Drywood Creek (2002-2008 water years) and Kings Creek (1980 to 2008 water years) period of record. A secondary selection criterion was that the sites be located within the same physiographic section as East Drywood Creek and Kings Creek--the Osage Plains physiographic section (fig. 1). Few suitable comparison sites met this secondary criterion; therefore, basins also were selected from adjacent physiographic sections. The historical vegetation includes tallgrass prairie in all represented physiographic sections (Thom and Wilson, 1980), and all are underlain by sedimentary rocks including sandstones, limestones, and shales (Fenneman, 1938; Nigh and Schroeder, 2002). Local relief generally is less in the Osage Plains [generally less than 100 feet (ft)] than in the Dissected Till Plains (less than 150 ft) or the Springfield-Salem Plateau (200 to 350 ft; Nigh and Schroeder, 2002).

East Drywood Creek at Prairie State Park, Missouri, drains a native prairie basin located within Prairie State Park in west central Missouri. The park, established in 1980 (Larson, 1983), contains 3,942 acres, which includes the 3,646-acre Regal Tallgrass Prairie Natural Area (Miller, 2008). Prairie State Park is Missouri’s largest remaining contiguous prairie, and the 3.38-mi^2 East Drywood Creek headwater basin within the park is the largest native prairie basin in Missouri. East Drywood Creek at Prairie State Park also is listed as an “Outstanding State Resource Water” by the State of Missouri Clean Water Commission (Missouri Department of Natural Resources, 2008). Small areas of Prairie State Park were strip mined but have since been restored to prairie cover (Miller, 2007). Prairie State Park also includes 148 acres of cultivated land that were plowed before the 1930’s, but have since been restored (Larson, 1983). There also is light bison grazing (130 bison on 2,686 acres), elk grazing (40 elk on 400 acres), and managed burning within the park (Miller, 2007). This remnant tallgrass prairie likely remained prairie because the shallow soils overlying sandstone and shale (Larson, 1983) were unsuitable for cultivation.

The other remnant tallgrass prairie basin used in this study is the Kings Creek Basin in the Konza Prairie Biological Station in northeastern Kansas. Kings Creek near Manhattan, Kansas (fig. 1) is a USGS hydrologic benchmark streamflow-gaging station (Mast and Turk, 1999) at the outlet of a 4.09-mi^2 predominantly, native-prairie basin. The Kings Creek Basin is the largest homogenous prairie basin in the Konza Prairie preserve. Here, too, the remnant prairie remained because the shallow soils overlying limestone and shale (Macpherson, 1996) were unsuitable for cultivation. Soils in the basin are characterized by high infiltration capacity, high water storage, and high content of shrinking-swelling clays. During dry periods, large cracks allow for high infiltration and little runoff, and the deeper soils developed in the alluvium and the fractured limestone act as an aquifer (Lauwo, 2007). Management of the prairie within the Konza Prairie Biological Station includes light grazing of bison and prescribed burning.

The basins associated with the agricultural streamflow- and water-quality monitoring locations used in this study are located within the former distribution of native tallgrass prairie in northern Missouri and eastern Kansas (fig. 1). These basins once were predominantly tallgrass prairie and prairie savannah, but the most current (2001) land cover primarily is agriculture (table 3). Several of the “agricultural” basins also have some urban development, which can increase runoff and peak-flow characteristics of the basin. The 2001 land-cover estimates in table 3 may overestimate the degree of development present during the actual period of hydrologic record used in the analyses. Soils in the Goodwater Creek at weir 11 near Centralia, Missouri, [U.S. Department of Agriculture, Agricultural Research Service (ARS) station number MOGC0296] basin (fig. 1; table 1) are loess deposits of high silt and clay content that form a natural claypan layer (Bockhold and others, 2006). The physical setting of the seven USGS water-quality and streamflow stations (tables 1 and 2; fig. 1) in the Dissected Till Plains of northern Missouri consists of loess soils overlying shale, limestone, and sandstones (Gann and others, 1973). The Big Bull Creek near Edgerton, Kansas (USGS station number 06914950; table 2) basin contains rich calcareous loam soils overlying shale and limestone (Miller, 1966), whereas soils in the Soldier Creek near Goff, Kansas (USGS station number 06889100; table 1) basin generally are silty clay loam overlying shale, sandstone, and limestone (Abel, 2005).

In addition to the land-cover differences between the prairie and agriculture sites used in the hydrologic analyses, there also are differences in the hydraulic properties of the native soils at the prairie and some agricultural sites. Soils in both prairie basins are classified as hydrologic soil group

Table 1. Prairie and agricultural basin streamflow-gaging stations used in hydrologic analyses.

U.S. Geological Survey or Agricultural Research Service* Station identification	Site	Prairie/ agricultural basin	Drainage area, in square miles	Total years of complete water year record	Total period of record, in water years	Primary soil series in basin (percent slope)	Hydrologic soil group of primary soil series[a]	Mean saturated hydraulic Conductivity (K_{sat}) of primary soil series profile, in micrometers per second
06921740	Brushy Creek near Blairstown, Missouri	Agricultural	1.15	15	1961-1975	Snead silty clay (5-14)	C	1.00
06889100	Soldier Creek near Goff, Kansas	Agricultural	2.06	22	1965-1986	Wymore silty clay loam (1-3)	D	1.32
06917630	East Drywood Creek at Prairie State Park, Missouri	Prairie	3.38	7	2002-2008	Barden Silt loam (1-5)	C	2.13
06927200	Big Hollow near Fulton, Missouri	Agricultural	4.05	15	1958-1972	Mexico Silt loam (1-4)	D	1.85
06879650	Kings Creek near Manhattan, Kansas	Prairie	4.09	29	1980-2008	Benfield Florence complex (5-30)	C	1.52
06925200	Starks Creek at Preston, Missouri	Agricultural	4.18	20	1957-1976	Eldon gravelly silt loam (8-15)	C	2.62
MOGC0296*	Goodwater Creek at weir 11 near Centralia, Missouri	Agricultural	4.67	30	1972-2001	Mexico Silt loam (1-4)	D	1.85
06906150	Long Branch Creek near Atlanta, Missouri	Agricultural	23.0	13	1996-2008	Armstrong loam (5-9)	C	1.58

[a] Hydrologic soil group classification from U.S. Department of Agriculture (2009)-- Group C soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils with moderately fine to fine structure. These soils have a slow rate of water transmission. Group D soils have a very low infiltration rate (high runoff potential) when thoroughly wet. These soils consist chiefly of clay soils with a high shrink-swelling potential, soils with a permanent high water table, soils with a claypan or clay layer at or near the surface and shallow soils over nearly impervious material. These soils have a very slow rate of water transmission.

Table 2. Prairie and agricultural basin water-quality monitoring stations, sample constituents, and period of record used in water-quality analyses.

[-- no data or data not used in analyses; USGS, U.S. Geological Survey]

U.S. Geological Survey water quality station identification	Site	Prairie/ agricultural basin	Drainage area, square miles	Specific conductance, in microsiemens per centimeter at 25 degrees celsius (parameter code 00095): Period of record used	Specific conductance: Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	Prairie	3.38	11/1993-1/2009	29
06879650	Kings Creek near Manhattan, Kansas	Prairie	4.09	4/1980-7/2003	112
--[a]	Kings Creek downstream from USGS gage	Prairie	4.20	--	--
06905725	Mussel Fork near Mystic, Missouri	Agricultural	24.0	11/1997-1/2009	101
06914950	Big Bull Creek near Edgerton, Kansas	Agricultural	28.70	--	--
06899580	No Creek near Dunlap, Missouri	Agricultural	34.0	11/1997-1/2009	102
06900100	Little Medicine Creek near Harris, Missouri	Agricultural	66.5	11/1997-1/2009	105
06900900	Locust Creek near Unionville, Missouri	Agricultural	77.5	10/1999-1/2009	81
06896187	Middle Fork Grand River near Grant City, Missouri	Agricultural	82.4	11/1999-1/2009	48
06921582	South Grand River near Freeman, Missouri	Agricultural	150	--	--

U.S. Geological Survey water quality station identification	Site	Dissolved oxygen, in milligrams per liter (parameter code 00300): Period of record used	Dissolved oxygen: Sample size	Field pH, in standard units (parameter code 00400): Period of record used	Field pH: Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	11/1993-1/2009	26	11/1993-1/2009	30
06879650	Kings Creek near Manhattan, Kansas	6/1980-7/2003	47	4/1980-7/2003	103
--[a]	Kings Creek downstream from USGS gage	--	--	--	--
06905725	Mussel Fork near Mystic, Missouri	11/1997-10/2008	98	11/1997-1/2009	101
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	11/1997-1/2009	99	11/1997-1/2009	101
06900100	Little Medicine Creek near Harris, Missouri	11/1997-1/2009	100	11/1997-1/2009	102
06900900	Locust Creek near Unionville, Missouri	10/1999-1/2009	79	10/1999-1/2009	81
06896187	Middle Fork Grand River near Grant City, Missouri	11/1999-1/2009	47	11/1999-1/2009	48
06921582	South Grand River near Freeman, Missouri	--	--	--	--

[a]Data at this site were collected by the Konza prairie long-term ecological research program (Dodds, 2003).

[b]Kings Creek site downstream from U.S. Geological Survey streamflow-gaging station was sampled for soluble reactive phosphorus, which consists largely of orthophosphate.

Table 2. Prairie and agricultural basin water-quality monitoring stations, sample constituents, and period of record used in water-quality analyses.—Continued

[-- no data or data not used in analyses; USGS, U.S. Geological Survey]

U.S. Geological Survey water quality station identification	Site	Bicarbonate, filtered, in milligrams per liter (parameter code 00450)		Alkalinity, filtered, milligrams per liter as calcium carbonate (parameter code 39086)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	11/1993-1/2009	29	11/1993-1/2009	10
06879650	Kings Creek near Manhattan, Kansas	4/1980-7/2003	32	5/1987-5/1996	35
--[a]	Kings Creek downstream from USGS gage	--	--	--	--
06905725	Mussel Fork near Mystic, Missouri	11/1997-10/2008	69	11/97-11/07	8
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	11/1997-10/2008	70	11/1997-7/2008	8
06900100	Little Medicine Creek near Harris, Missouri	11/1997-10/2008	73	11/1997-7/2008	9
06900900	Locust Creek near Unionville, Missouri	10/1999-10/2008	58	--	--
06896187	Middle Fork Grand River near Grant City, Missouri	3/2000-10/2008	32	--	--
06921582	South Grand River near Freeman, Missouri	--	--	--	--

U.S. Geological Survey water quality station identification	Site	Baseflow fecal coliform bacteria, in colonies per 100 milliliters (parameter code 31625) (laboratory reporting level, 1 col/100 mL)		Baseflow total nitrogen, unfiltered, in milligrams per liter (parameter code 00600) (laboratory reporting level, 0.10 mg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	11/1993-1/2009	27	1/1994-1/1997	5
06879650	Kings Creek near Manhattan, Kansas	6/1980-7/2003	40	6/1981-7/1991	17
--[a]	Kings Creek downstream from USGS gage	--	--	4/1994-5/1996	221
06905725	Mussel Fork near Mystic, Missouri	11/1997-1/2009	101	1/1999-12/2008	56
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	11/1997-1/2009	100	11/1997-12/2008	61
06900100	Little Medicine Creek near Harris, Missouri	11/1997-1/2009	104	1/1999-12/2008	57
06900900	Locust Creek near Unionville, Missouri	10/1999-1/2009	85	12/1999-12/2008	50
06896187	Middle Fork Grand River near Grant City, Missouri	11/1997-1/2009	49	1/2000-1/2009	24
06921582	South Grand River near Freeman, Missouri	--	--	--	--

[a]Data at this site were collected by the Konza prairie long-term ecological research program (Dodds, 2003).

[b]Kings Creek site downstream from U.S. Geological Survey streamflow-gaging station was sampled for soluble reactive phosphorus, which consists largely of orthophosphate.

Table 2. Prairie and agricultural basin water-quality monitoring stations, sample constituents, and period of record used in water-quality analyses.—Continued

[-- no data or data not used in analyses; USGS, U.S. Geological Survey]

U.S. Geological Survey water quality station identification	Site	Runoff total nitrogen, unfiltered, in milligrams per liter (parameter code 00600) (laboratory reporting level, 0.10 mg/L)		Baseflow organic nitrogen, unfiltered, in milligrams per liter (parameter code 00605) (laboratory reporting level, 0.10 mg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	--	--	11/1993-6/1997	16
06879650	Kings Creek near Manhattan, Kansas	9/1989-3/1990	4	6/1981-7/1991	30
--[a]	Kings Creek downstream from USGS gage	4/1994-6/1995	14	--	--
06905725	Mussel Fork near Mystic, Missouri	--	--	1/1999-12/2008	52
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	--	--	3/1999-12/2008	58
06900100	Little Medicine Creek near Harris, Missouri	4/1999-9/2008	18	1/1999-12/2008	55
06900900	Locust Creek near Unionville, Missouri	6/2000-9/2008	27	11/1999-12/2008	43
06896187	Middle Fork Grand River near Grant City, Missouri	--	--	11/1999-1/2009	27
06921582	South Grand River near Freeman, Missouri	--	--	--	--

U.S. Geological Survey water quality station identification	Site	Baseflow ammonia, filtered, in milligrams per liter (parameter code 00608) (laboratory reporting level, 0.02 mg/L)		Baseflow nitrate + nitrite, unfiltered, in milligrams per liter as nitrogen (parameter code 00630) (laboratory reporting level, 0.06 mg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	11/1993-1/2009	10	11/1993-1/2009	22
06879650	Kings Creek near Manhattan, Kansas	6/1981-5/1996	59	6/1980-12/1992	16
--[a]	Kings Creek downstream from USGS gage	--	--	4/1991-12/1997	234
06905725	Mussel Fork near Mystic, Missouri	11/1997-12/2008	103	11/1997-12/2008	99
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	11/1997-12/2008	101	11/1997-12/2008	99
06900100	Little Medicine Creek near Harris, Missouri	11/1997-12/2008	102	11/1997-12/2008	101
06900900	Locust Creek near Unionville, Missouri	10/1999-12/2008	85	10/1999-12/2008	82
06896187	Middle Fork Grand River near Grant City, Missouri	11/1999-1/2009	48	11/1999-1/2009	48
06921582	South Grand River near Freeman, Missouri	--	--	--	--

[a]Data at this site were collected by the Konza prairie long-term ecological research program (Dodds, 2003).

[b]Kings Creek site downstream from U.S. Geological Survey streamflow-gaging station was sampled for soluble reactive phosphorus, which consists largely of orthophosphate.

Table 2. Prairie and agricultural basin water-quality monitoring stations, sample constituents, and period of record used in water-quality analyses.—Continued

[-- no data or data not used in analyses; USGS, U.S. Geological Survey]

U.S. Geological Survey water quality station identification	Site	Runoff, nitrate + nitrite, unfiltered, in milligrams per liter as nitrogen (parameter code 00630) (laboratory reporting level, 0.06 mg/L)		Baseflow phosphorus, unfiltered, in milligrams per liter (parameter code 00665) (laboratory reporting level, 0.04 mg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	--	--	11/1993-1/2009	28
06879650	Kings Creek near Manhattan, Kansas	--	--	4/1980-5/1996	58
--[a]	Kings Creek downstream from USGS gage	4/1994-4/1997	16	4/1994-12/1997	109
06905725	Mussel Fork near Mystic, Missouri	3/1998-2/2008	12	1/1999-12/2008	101
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	3/1998-2/2008	13	11/1997-9/2008	100
06900100	Little Medicine Creek near Harris, Missouri	4/1998-9/2008	20	1/1999-1/2009	101
06900900	Locust Creek near Unionville, Missouri	6/2000-10/2008	27	10/1999-1/2009	94
06896187	Middle Fork Grand River near Grant City, Missouri	3/2001-10/2008	11	11/1999-1/2009	50
06921582	South Grand River near Freeman, Missouri	--	--	--	--

U.S. Geological Survey water quality station identification	Site	Baseflow, orthophosphate, filtered, in milligrams per liter (parameter code 00671) (laboratory reporting level, 0.008 mg/L)		Runoff phosphorus, unfiltered, in milligrams per liter (parameter code 00665) (laboratory reporting level, 0.04 mg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	1/1997-1/2009	10	--	--
06879650	Kings Creek near Manhattan, Kansas	6/1980-5/1996[a]	49[b]	4/1980-3/1990	4
--[a]	Kings Creek downstream from USGS gage	7/1995-12/1997	135	5/1995-5/1995	4
06905725	Mussel Fork near Mystic, Missouri	11/1997-12/2008	100	--	--
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	11/1997-12/2008	99	2/2001-1/2008	7
06900100	Little Medicine Creek near Harris, Missouri	11/1997-12/2008	100	4/1999-11/2008	15
06900900	Locust Creek near Unionville, Missouri	10/1999-12/2008	83	6/2000-11/2008	16
06896187	Middle Fork Grand River near Grant City, Missouri	11/1999-9/2008	48	3/2001-10/2008	10
06921582	South Grand River near Freeman, Missouri	--	--	--	--

[a]Data at this site were collected by the Konza prairie long-term ecological research program (Dodds, 2003).

[b]Kings Creek site downstream from U.S. Geological Survey streamflow-gaging station was sampled for soluble reactive phosphorus, which consists largely of orthophosphate.

Table 2. Prairie and agricultural basin water-quality monitoring stations, sample constituents, and period of record used in water-quality analyses.—Continued

[-- no data or data not used in analyses; USGS, U.S. Geological Survey]

U.S. Geological Survey water quality station identification	Site	Baseflow potassium, filtered, in milligrams per liter (parameter code 0935) (laboratory reporting level, 2 µg/L)		Baseflow chloride, filtered, in milligrams per liter (parameter code 00940) (laboratory reporting level, 0.20 mg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	1/1994-11/2008	13	1/1994-1/2009	14
06879650	Kings Creek near Manhattan, Kansas	4/1980-5/1996	64	4/1980-5/1996	61
--[a]	Kings Creek downstream from USGS gage	--	--	--	--
06905725	Mussel Fork near Mystic, Missouri	1/1998-10/2008	33	1/1998-10/2008	33
06914950	Big Bull Creek near Edgerton, Kansas	--	--	--	--
06899580	No Creek near Dunlap, Missouri	1/1998-10/2008	33	1/1998-10/2008	32
06900100	Little Medicine Creek near Harris, Missouri	1/1998-10/2008	37	1/1998-10/2008	37
06900900	Locust Creek near Unionville, Missouri	11/1999-10/2008	30	11/1999-10/2008	31
06896187	Middle Fork Grand River near Grant City, Missouri	11/1999-11/2007	15	11/1999-11/2007	14
06921582	South Grand River near Freeman, Missouri	--	--	--	--

U.S. Geological Survey water quality station identification	Site	Baseflow sulfate, filtered, in milligrams per liter (parameter code 00945) (laboratory reporting level, 0.18 mg/L)		Baseflow atrazine, filtered, recoverable, in micrograms per liter (parameter code 39632) (laboratory reporting level, 0.007 µg/L)	
		Period of record used	Sample size	Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	1/1994-1/2009	14	4/1994-1/2009	8
06879650	Kings Creek near Manhattan, Kansas	4/1980-5/1996	61	--	--
--[a]	Kings Creek downstream from USGS gage	--	--	--	--
06905725	Mussel Fork near Mystic, Missouri	1/1998-10/2008	33	--	--
06914950	Big Bull Creek near Edgerton, Kansas	--	--	5/1994-3/2007	6
06899580	No Creek near Dunlap, Missouri	1/1998-10/2008	33	--	--
06900100	Little Medicine Creek near Harris, Missouri	1/1998-10/2008	37	--	--
06900900	Locust Creek near Unionville, Missouri	11/1999-10/2008	30	--	--
06896187	Middle Fork Grand River near Grant City, Missouri	11/1999-11/2007	14	--	--
06921582	South Grand River near Freeman, Missouri	--	--	11/1997-7/2002	15

[a]Data at this site were collected by the Konza prairie long-term ecological research program (Dodds, 2003).

[b]Kings Creek site downstream from U.S. Geological Survey streamflow-gaging station was sampled for soluble reactive phosphorus, which consists largely of orthophosphate.

Table 2. Prairie and agricultural basin water-quality monitoring stations, sample constituents, and period of record used in water-quality analyses.—Continued

[-- no data or data not used in analyses; USGS, U.S. Geological Survey]

U.S. Geological Survey water quality station identification	Site	Baseflow alachlor, filtered, recoverable, in micrograms per liter (parameter code 46342) (laboratory reporting level, 0.008 µg/L)	
		Period of record used	Sample size
06917630	East Drywood Creek at Prairie State Park, Missouri	4/1994-1/2009	8
06879650	Kings Creek near Manhattan, Kansas	--	--
--[a]	Kings Creek downstream from USGS gage	--	--
06905725	Mussel Fork near Mystic, Missouri	--	--
06914950	Big Bull Creek near Edgerton, Kansas	5/1994-3/2007	6
06899580	No Creek near Dunlap, Missouri	--	--
06900100	Little Medicine Creek near Harris, Missouri	--	--
06900900	Locust Creek near Unionville, Missouri	--	--
06896187	Middle Fork Grand River near Grant City, Missouri	--	--
06921582	South Grand River near Freeman, Missouri	11/1997-7/2002	15

[a]Data at this site were collected by the Konza prairie long-term ecological research program (Dodds, 2003).

[b]Kings Creek site downstream from U.S. Geological Survey streamflow-gaging station was sampled for soluble reactive phosphorus, which consists largely of orthophosphate.

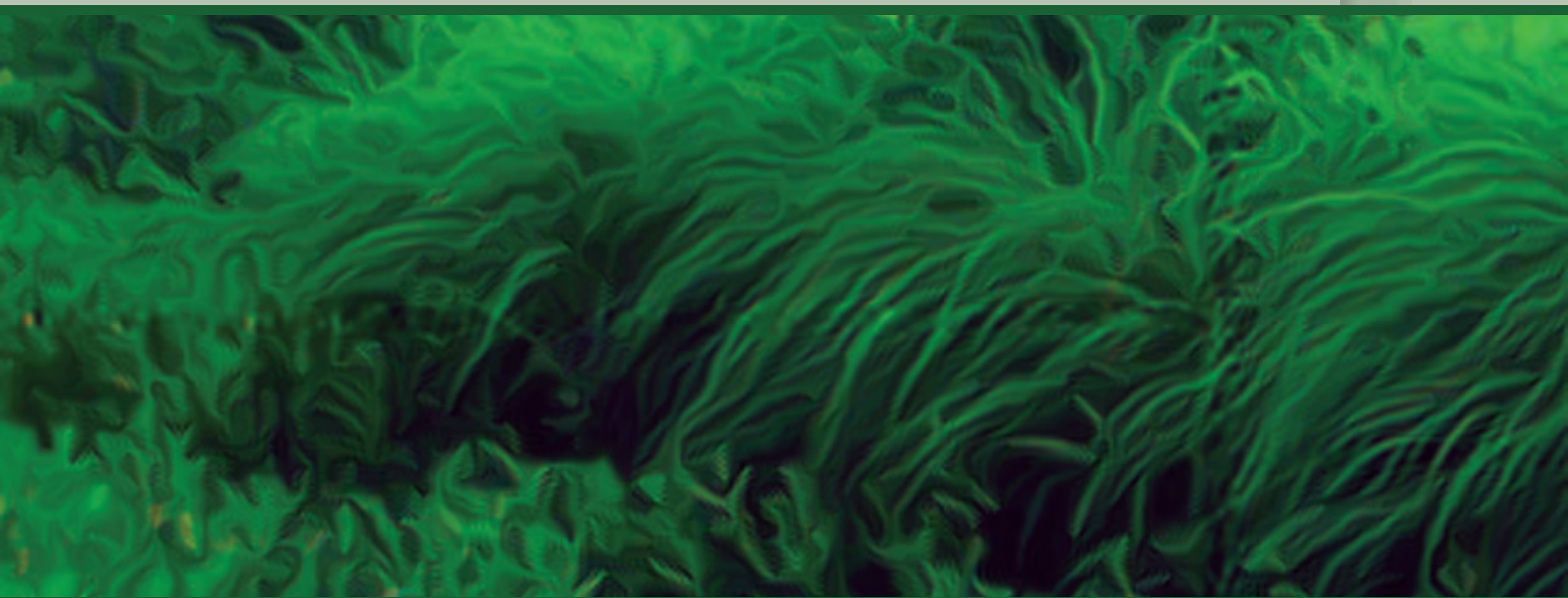


Table 3. Land-cover characteristics of basins included in streamflow and water-quality analyses.

					Percent of basin in land cover category							
						Agriculture						
Station identifier	Site	Prairie or agricultural basin	Streamflow or water quality station	Drainage area, in square miles	Prairie/ grassland	Cropland	Pasture	Forest	Wetland	Open water	Urban	Barren
06921740	Brushy Creek near Blairstown, Missouri	Agricultural	Streamflow	1.15	.7	11.9	71.5	12.1	0	.5	3.4	0
06889100	Soldier Creek near Goff, Kansas	Agricultural	Streamflow	2.06	.6	48.5	43.0	1.9	0	.4	5.6	0
06917630	E Drywood Creek at Prairie State Park, Missouri	Prairie	Streamflow/ Water Quality	3.38	94.3[b]	0	0	4.5	0	1.2	0	0
6927200	Big Hollow near Fulton, Missouri	Agricultural	Streamflow	4.05	2.2	10.2	46.8	23.1	1.7	.8	14.7	.4
06879650	Kings Creek near Manhattan, Kansas	Prairie	Streamflow/ Water Quality	4.09	90.4	0	0	8.8	.5	.1	.2	0
06925200	Starks Creek at Preston, Missouri	Agricultural	Streamflow	4.18	3.7	0	78.8	9.1	1.4	.3	6.7	0
MOGC0296[a]	Goodwater Creek at weir 11 near Centralia, Missouri	Agricultural	Streamflow	4.67	0	60.8	9.1	.9	1.0	.8	27.4	0
06906150	Long Branch Creek near Atlanta, Missouri	Agricultural	Streamflow	23.0	1.7	31.2	41.3	14.1	2.3	.3	9.1	0
06905725	Mussel Fork near Mystic, Missouri	Agricultural	Water Quality	24.0	1.0	5.3	74.7	9.6	3.1	.7	5.6	0
06914950	Big Bull Creek near Edgerton, Kansas	Agricultural	Water Quality	28.7	.8	43.3	35.8	5.7	.4	.7	13.1	.2
06899580	No Creek near Dunlap, Missouri	Agricultural	Water Quality	34.0	.8	10.7	73.7	10	1.3	.3	3.2	0
06900100	Little Medicine Creek near Harris, Missouri	Agricultural	Water Quality	66.5	1.6	12.6	62.7	18.1	.8	.6	3.5	.1
06900900	Locust Creek near Unionville, Missouri	Agricultural	Water Quality	77.5	1.8	20.1	58.7	15.1	.6	.4	3.3	0
06896187	Middle Fork Grand River near Grant City, Missouri	Agricultural	Water Quality	82.4	3.2	18.1	58.0	12.3	.6	.3	7.5	0
06921582	South Grand River near Freeman, Missouri	Agricultural	Water Quality	150	1.7	20.1	46.7	12.7	1.1	.9	16.5	.3

[a]U.S. Department of Agriculture, Agricultural Research Service gaging station.

[b]The prairie/grassland land cover was erroneously categorized as cropland and pasture in raw data values from the 2001 National Land Cover database (U.S. Geological Survey, 2009a) for this basin and, therefore, the presented results differ from the raw values.

C [low infiltration rates and slow rate of water transmission, U.S. Department of Agriculture (2009)], whereas soils in the agricultural basins are classified as hydrologic soil group C or D (very low infiltration rate and very slow rate of water transmission; table 1). The mean saturated hydraulic conductivity values for all measured layers of the prairie soil profiles were 1.52 and 2.13 micrometers per second (µm/s; U.S. Department of Agriculture, 2009) and fell within the range of saturated hydraulic conductivity for the agricultural basins included in the analyses (1.00 to 2.62 µm/s; table 1). The hydraulic conductivities determined in the latest soil surveys were measured possibly decades following conversion of native prairies to agriculture, and the measured hydraulic conductivity values may be affected by this conversion. That is, the soil properties of the agricultural soils may be reflective of post conversion changes in physical soil properties rather than intrinsic conditions of the native (pre-agriculture) soils.

Precipitation varied between hydrologic study basins (fig. 2) as a result of temporal differences in the period of record used in the analyses, and because of distances between sites. Monthly precipitation data for basins used in the hydrologic analyses were obtained from the National Climatic Data Center (2008), the High Plains Regional Climate Center (2008), or, in the case of the Goodwater Creek Basin, from the ARS (John Sadler, ARS, written commun., 2008). The average annual precipitation during the period of analysis for each site varied by more than 15 inches (in.) between sites with East Drywood Creek receiving the greatest amount (49.1 in.) and Kings Creek receiving the least (33.8 in.; fig. 2) average annual precipitation during the period of record used in hydrologic analyses. Average annual precipitation during the period of record used for hydrologic analyses was above the 1971 to 2000 long-term average at five sites, and below the average at three sites with departures from the long-term average of -5.8 to +3.1 in. (fig. 2).

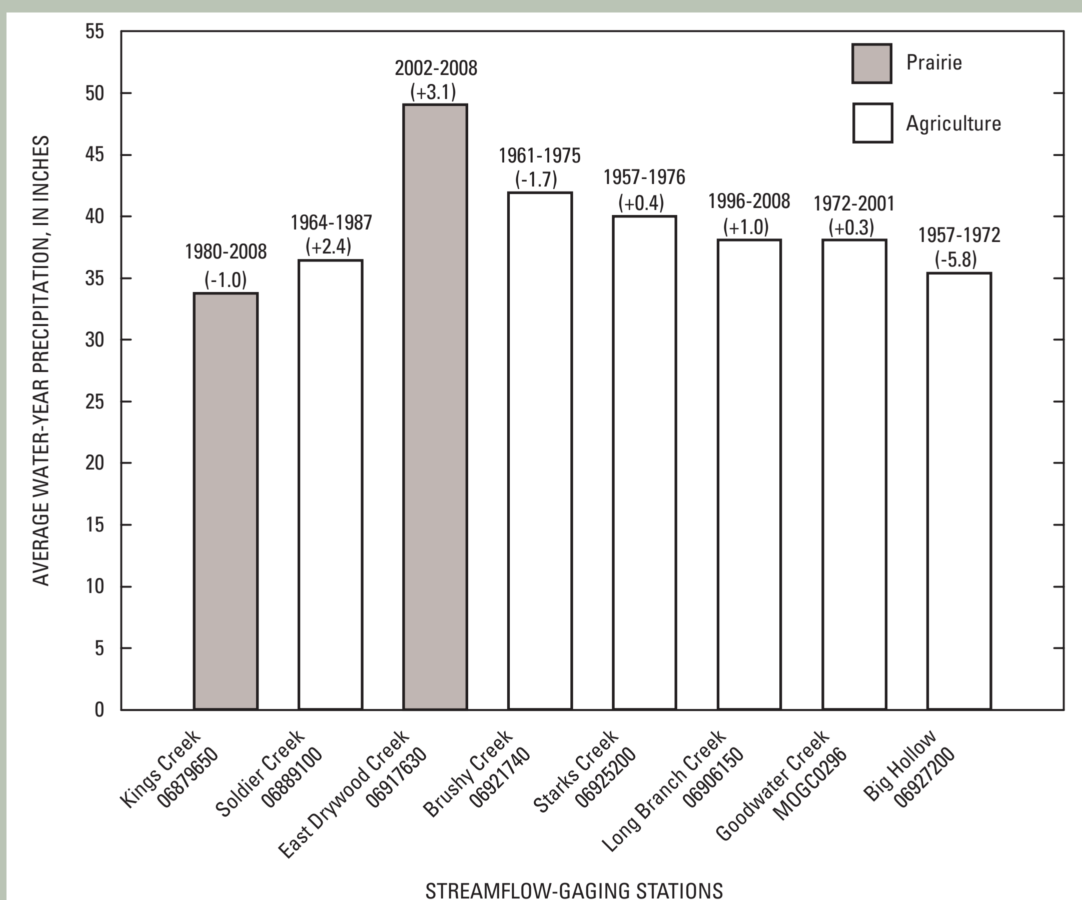


Figure 2. Average water-year precipitation, by site, for period of streamflow record used in hydrologic analyses [values in parenthesis are the average annual departure from the long-term (1971-2000; National Climatic Data Center, 2002a; 2002b) average annual precipitation].

Methods

This study was conducted using hydrologic and water-quality data from USGS, Konza Prairie Biological Station, and ARS monitoring locations (tables 1 and 2). There were insufficient water-quality sample data at the East Drywood Creek site with which to conduct seasonal or runoff sample comparisons; therefore, runoff sample results from the second native tallgrass prairie site, Kings Creek near Manhattan, Kansas (USGS streamflow-gaging station number 06879650), were used for limited comparisons of selected constituents in runoff samples from prairie and agricultural sites. Streamflow data were normalized by drainage area for the flow duration, streamflow-rainfall yield, and ecological flow analyses, and by precipitation in the rainfall-streamflow yield analyses.

Streamflow and Hydrologic Analyses

Daily and monthly streamflow data for USGS streamflow-gaging stations used in the analyses (table 1) were obtained from the USGS National Water-Information System (NWIS) database (U.S. Geological Survey, 2008). Daily streamflow data for Goodwater Creek at weir 11 near Centralia, Missouri, were obtained from the ARS (John Sadler, ARS, written commun., 2008). The period of streamflow record used in an analysis for a given site may vary among analyses to compare concurrent record, when possible. Streamflow data from USGS streamflow-gaging stations were collected following standard USGS techniques (Rantz and others, 1982), whereas the Goodwater Creek data were determined by the ARS from a stage-discharge relation developed for a v-notch weir.

Hydrologic analyses included hydrograph separation to determine the percentage of streamflow as base flow (groundwater component of streamflow) and runoff, flow-duration analyses, rainfall-streamflow yield characteristics, and calculation of ecological flow statistics of the study basins. The annual base-flow and runoff components of the daily mean, streamflow-time series were determined using an USGS hydrograph separation program Hysep 2.2 (Sloto and Crouse, 1996) with modified file input features to accept USGS NWIS file formats (John Walker, U.S. Geological Survey, written commun., 2008). Hydrograph separation results using the sliding-interval technique (Pettyjohn and Henning, 1979) are reported.

Flow-duration curves were constructed using the full record of daily mean streamflow at each streamflow-gaging station divided by the drainage area of the gaged basin. These flow yields were then ranked from highest to lowest for a selected period. Next, the percent exceedance value corresponding to each daily flow yield was determined using the formula

$$(n_i/(n_t+1))*100 \qquad (1)$$

where n_i is the rank of a daily streamflow value and n_t is the total number of values during the period of interest.

Rainfall-streamflow yield characteristics were determined for each site by calculating the mean ratio of monthly streamflow yield (streamflow volume per drainage area, in inches) to monthly precipitation (in inches) for the period of record at each location. This calculation, therefore, determined the mean part of precipitation that resulted in measureable streamflow (base flow plus runoff).

Another means of discerning hydrologic differences between streams was by determining ecological flow characteristics of streamflow time series through the use of the software Indicators of Hydrologic Alteration (IHA; The Nature Conservancy, 2009). This software calculates flow characteristics of ecological significance, including those affecting the frequency, magnitude, duration, rate of change, and timing of low and high flows. To reduce the effects of temporal and drainage area variability between sites, the mean daily flows used in these analyses also were divided by drainage area and concurrent periods of record were used, if possible.

Water Quality

Water-quality data for the nine sites used in the analyses were obtained from the USGS NWIS database (U.S. Geological Survey, 2009b); selected nutrient data from Kings Creek also were collected just downstream from the USGS streamflow-gaging station by Kansas State University (Konza Prairie Biological Station, 2008). The sampling sites and constituents used in the water-quality analyses, and period for which the constituents were sampled, are provided in table 2. Water-quality field measurements (specific conductance, dissolved oxygen, pH, bicarbonate, alkalinity, and fecal coliform bacteria) collected at the USGS streamflow-gaging and water-quality monitoring stations were obtained in accordance with methods described in Wilde (variously dated) and Myers and others (2007). Nutrient (total nitrogen, organic nitrogen, dissolved ammonia, nitrate plus nitrite, total phosphorus, and dissolved orthophosphate), major ion (dissolved potassium, chloride, and sulfate), and pesticide (dissolved atrazine and alachlor) samples were collected and processed in accordance with methods described in U.S. Geological Survey (2006) and Wilde and others (2004). Water samples were analyzed for major ions (dissolved chloride, sulfate, and potassium), nutrients, and pesticides at the U.S. Geological Survey National Water Quality Laboratory using methods described in Fishman and Friedman (1989), Fishman (1993), Fishman and others (1994), Zaugg and others (1995), and Garbarino and Struzeski (1998). Nutrient samples from the Konza Prairie Biological Station were collected and processed according to methods provided in Dodds (2003).

The results of quality control and assurance samples indicate the variability of sample collection and processing procedures (table 4). The relative percent difference in field

Table 4. Quality control and assurance sample results for eight water-quality sample sites used in the study.

[col/100mL, colonies per 100 milliliters; mg/L, milligrams per liter; µg/L, micrograms per liter; RPD, relative percent difference; --, no data; <, less than]

Constituent	Units of measurement	Lab reporting level	Replicates: Number of replicate pairs	Replicates: Median RPD	Blank samples: Number of blank samples	Blank samples: Concentration range in blank samples
Fecal coliform bacteria	col/100mL	1	7	.0	0	--
Nitrogen, total, unfiltered	mg/L	.1	25	2.8	0	--
Nitrogen, organic, unfiltered	mg/L	.1	23	4.3	0	--
Ammonia, filtered	mg/L	.02	31	4.6	20	<.01 - .07
Nitrate+Nitrite, unfiltered	mg/L	.06	2	.0	0	--
Orthophosphate, filtered	mg/L	.008	18	1.6	20	<.008 - .02
Phosphorus, unfiltered	mg/L	.04	31	3.1	19	<.04 - .06
Chloride, filtered	mg/L	.2	7	.1	12	<.2 - .3
Sulfate, filtered	mg/L	.18	7	.4	11	<.18
Zinc, filtered	µg/L	2	7	8.9	13	<2.0 - 2.426
Atrazine, filtered	µg/L	.007	0	--	1	<.007
Alachlor, filtered	µg/L	.008	0	--	1	<.008

replicate samples generally were less than 5 percent and were less than 9 percent, overall. Equipment blank samples were used to assess the sterility of equipment and the potential for cross-contamination and generally were less than or near the lab reporting level.

In the report section “Comparisons of Water-Quality Characteristics” the distributions of the various water-quality field measurements and constituents are presented graphically by site. Selected constituents are then grouped together and categorized as “prairie” or “agriculture” for the presentation of statistical analyses. Statistical comparisons of selected water-quality constituents grouped as prairie or agriculture were conducted using a Mann-Whitney rank sum test (Helsel and Hirsch, 2002) at a significance level of 0.05. Statistical differences were considered significant if the calculated probability values from the statistical tests were less than the 0.05 value. Statistical comparisons of selected water-quality constituents between multiple sites were conducted using a Kruskal-Wallis test (Helsel and Hirsch, 2002) followed by a Dunn Multiple Comparison test (Toothaker, 1993) to discern specific differences between sites. Values of selected water-quality constituents were compared to State and Federal water-quality standards. Such comparisons are made to provide a level of reference, and the standards may not be applicable for the designated use of all the study streams. At a minimum, all streams for which water-quality data are presented are designated for the protection of aquatic life and whole body contact (Missouri Department of Natural Resources, 2008; Kansas Department of Health and Environment, 2008).

Comparison of Hydrologic Characteristics

Daily or monthly mean streamflow from eight streamflow-gaging stations (table 1) were used for analysis of hydrograph characteristics (base-flow and runoff components), flow-duration analyses, rainfall-streamflow yield characteristics, and ecological flow statistics. Streamflow data from prairie basins included 7 years of daily data from East Drywood Creek at Prairie State Park, Missouri (USGS gaging station 06917630) and 29 years of data from Kings Creek near Manhattan, Kansas, in the Konza prairie (USGS gaging station 06879650).

Hydrograph Separation

Streamflow hydrograph separation into base flow (streamflow contributed from groundwater) and runoff was conducted for the two native prairie streamflow-gaging stations—East Drywood Creek and Kings Creek—and at six agricultural streams (table 1) using Hysep 2.2 software. The average percentage of streamflow classified as base flow at East Drywood Creek at Prairie State Park was 27 percent (table 5). This was substantially less than for the concurrent period (2002 through 2008) at the other prairie site, Kings Creek near Manhattan, Kansas, which averaged 63 percent base flow. The greater percentage of base flow at Kings Creek compared to East Drywood Creek may be caused by dry-weather soil cracks, deeper alluvial soils, and fractured limestone rocks that characterize soils in the Konza Prairie (Macpherson, 1996; Lauwo, 2007) and result in increases in infiltration and the streamflow component from groundwater. The percentage of streamflow as base flow at the East Drywood Creek site varied in comparison with concurrent record from the agricultural site, Long Branch Creek. East Drywood Creek had an equal or greater percentage of base flow than Long Branch Creek for 5 of the 7 years of record, including the driest years (2003, 2006; table 5). Some of the differences between the base-flow component at East Drywood Creek and the other two concurrent analysis sites could be attributed to the greater precipitation received at East Drywood Creek than the other two analysis sites (fig. 2). With greater precipitation, there is a greater opportunity for soils to become saturated and, therefore, direct runoff would tend to increase.

Table 5. Hydrograph separation results for prairie and agricultural sites with concurrent periods of record (2002 through 2008).

[Shaded sites are native tallgrass prairie basins and the unshaded site is an agricultural basin; ft ^{3}/s, cubic feet per second]

	East Drywood Creek at Prairie State Park, Missouri (station 06917630)			Kings Creek near Manhattan, Kansas (station 06879650)			Long Branch Creek near Atlanta, Missouri (station 06906150)		
Water year	Cumulative annual flow, (ft^3/s)	Baseflow, (percent)	Runoff, (percent)	Cumulative annual flow, (ft^3/s)	Baseflow, (percent)	Runoff, (percent)	Cumulative annual flow, (ft^3/s)	Baseflow, (percent)	Runoff, (percent)
2002	815	16	84	84	72	28	9,210	19	81
2003	495	40	60	255	65	35	1,900	17	83
2004	1,570	26	74	706	50	50	6,070	21	79
2005	1,100	30	70	833	58	42	6,060	24	76
2006	96	37	63	33	67	33	2,300	26	74
2007	1,860	23	77	1,050	56	44	5,830	23	77
2008	3,040	15	85	1,080	72	28	18,500	19	81
Total/(Average)	8,980	(27)	(73)	4,040	(63)	(37)	49,900	(21)	(79)

Similar differences in the base-flow and runoff contributions of prairie and agricultural streams were detected at stations with long-term (15 years or greater) record. During 22 years of record, the Kings Creek native prairie site had a substantially greater percentage of base flow than five comparable-sized agricultural basins. From 1980 to 2001, the Kings Creek base-flow component averaged 66 percent of total flow, but base flow was only 16 percent of total flows at Goodwater Creek at weir 11 near Centralia, Missouri (ARS streamflow-gaging station MOGC0296) during the concurrent period, and 17 to 26 percent of flows at other agricultural sites of various record periods (fig. 3). The differences in the base-flow and runoff components in prairie and agricultural streams indicate differences in the pathway that precipitation follows in reaching the stream in these basins. The primary controlling factor for this pathway is infiltration. The lower proportion of direct runoff from the prairie site may be attributed to greater infiltration into the non-cultivated native prairie basin soil compared to the basins with agricultural land cover; therefore, an increase in the percentage of land with prairie vegetation has the potential for decreasing direct runoff and the severity of downstream flooding.

Rainfall-Streamflow Yield Characteristics

Monthly streamflow yields (streamflow volume per area) as a percentage of precipitation for prairie and agricultural basins were calculated for the period of record at each station and compared. This hydrologic characteristic can account for some of the differences in precipitation between sites. The average ratio of the monthly streamflow yield to monthly precipitation was 18 percent at Kings Creek and 22 percent at East Drywood Creek. For the agricultural sites, this ratio

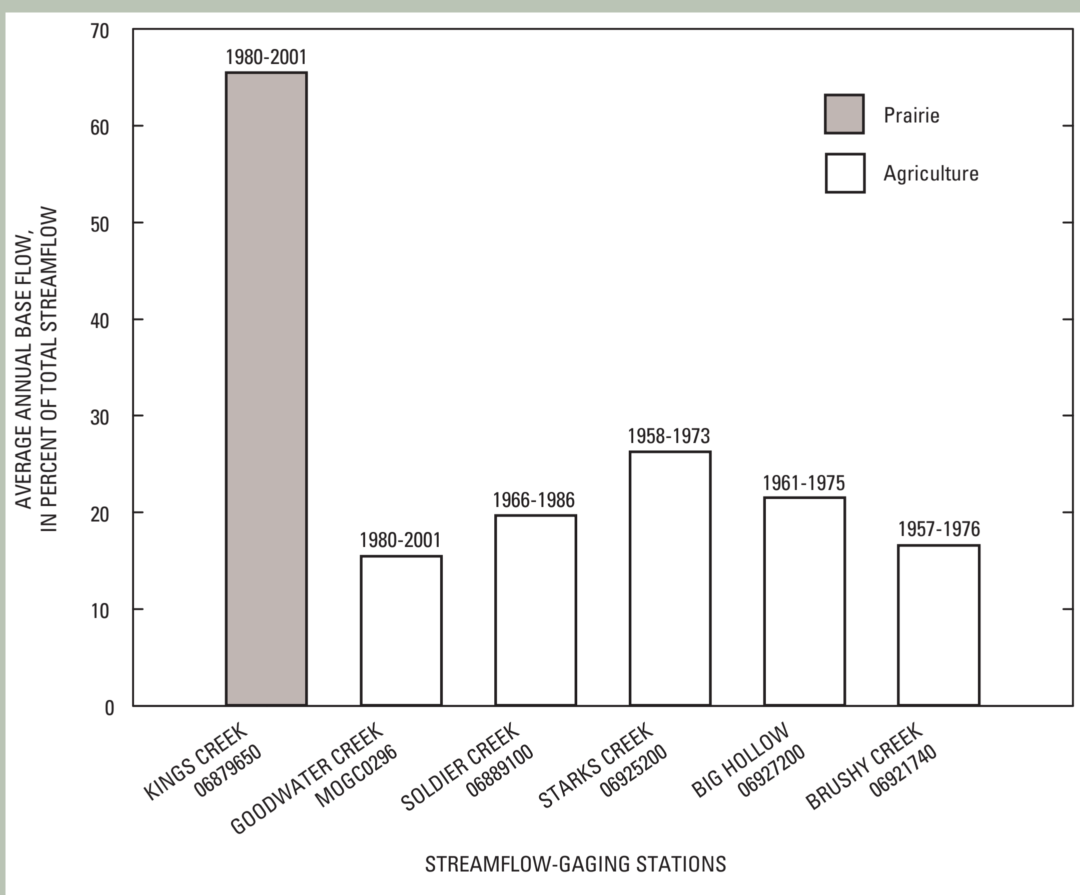


Figure 3. Average annual base flow as a percentage of total streamflow for prairie and agricultural streams with long-term record (values above bars are the periods of record used in analysis; values below the streamflow-gaging station names are the station identification numbers).

was 23 percent at Soldier Creek and Big Hollow near Fulton, Missouri (USGS streamflow-gaging station 06927200), 26 percent at Goodwater Creek, 28 percent at Starks Creek at Preston, Missouri (USGS streamflow-gaging 06925200), 30 percent at Long Branch Creek, and 31 percent at Brushy Creek near Blairstown, Missouri (USGS streamflow-gaging station 06921740). The maximum monthly precipitation during zero flow periods was greater at the prairie sites than agricultural sites indicating that infiltration, interception, and possibly evapotranspiration and groundwater seepage were greater for the prairie basins compared to the agricultural basins. Expansion of prairie vegetation in the region could, therefore, have a large effect on surface water availability. Monthly rainfall totals exceeding 5 in. coincided with months of zero flow on eight occasions at the two prairie sites, and a maximum monthly precipitation of 7.55 in. occurred during one month of zero flow at Kings Creek. Luawo (2007) also reported large precipitation amounts (greater than 4.7 in.) were necessary to produce streamflow following dry periods at Konza Prairie sites, and the large precipitation amount was attributed to increased infiltration rates associated with cracks in shrinking and swelling clays. Monthly precipitation during the months of zero flow at the agricultural sites was a maximum of 4.57 in. at Brushy Creek but generally was not more than 2 in.

Flow Duration

There was a greater occurrence of zero-flow conditions at the two native tallgrass prairie streams (East Drywood Creek and Kings Creek) when compared to normalized daily flows from similar-sized agricultural basins. Despite physical, temporal, and geographic differences in the basins, flow-duration curves of the two prairie sites were similar (fig. 4). The prairie streams were at zero flows about 50 percent of the time, and the agricultural streams were at zero flow 25 to 35 percent of the time. The hydrograph analyses indicated that the prairie streams received a greater contribution

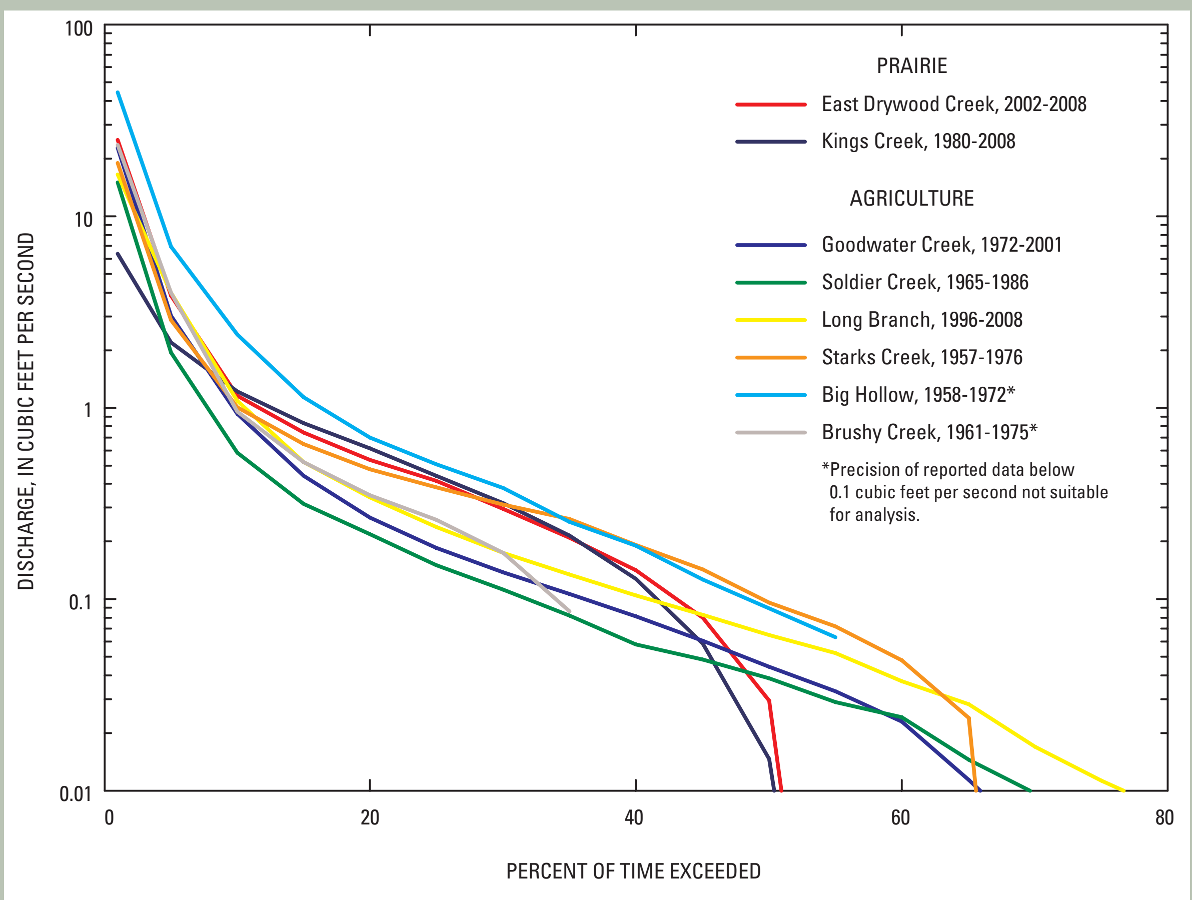


Figure 4. Flow-duration characteristics of prairie and agricultural streams.

from groundwater than the agricultural streams, but the groundwater storage was not sufficient to maintain flows above zero during dry periods. The agricultural streams had less groundwater contributions than the prairie streams, but the zero flow periods were less because it took less rainfall to produce streamflow, and the streamflow yield was greater than at the two prairie sites. The predominance of warm season grasses in prairie basins also may contribute to this difference, as transpiration from warm season grasses peaks during the summer months when streamflow and soil moisture usually are lowest. Other characteristics of the prairie basins that could account for the greater periods of zero flow when compared to agricultural streams include greater infiltration, greater interception and evapotranspiration, shallow soils, and possible greater seepage losses at the prairie sites.

Ecological Flow Characteristics

There were several differences noted in the statistical comparison of the ecological flow characteristics of prairie and agricultural streams as defined and determined by the Indicators of Hydrologic Alteration software (The Nature Conservancy, 2009). Daily streamflow record from East Drywood Creek was compared to Kings Creek and one agricultural basin with concurrent (2002 through 2008 water years) record (table 6). The coefficient of variation (standard deviation of all flows divided by the mean annual flow) of flows was greater at the prairie sites (0.34, 0.63) than at Long Branch Creek (0.17), whereas flow predictability [flow constancy plus periodicity; Colwell (1974)] was greater at East Drywood Creek (0.58) and Kings Creek (0.70) than at Long Branch Creek (0.54). This primarily was the result of the longer duration of zero flow at the two prairie sites. The median number of zero-flow days at East Drywood Creek was 137 and 218 days for Kings Creek, whereas there were 25 zero-flow days at Long Branch Creek (table 6). Differences in low-flow characteristics of the prairie and agricultural streams may be attributed partially to differences in drainage area. Streamflows were adjusted for drainage area, but dividing a positive flow value by drainage area does not change the number of zero-flow days. Although zero-flow periods were greater at the prairie streams than the agricultural stream, the streamflow recession was more sustained at the prairie sites as indicated by the greater extreme low duration (period of time flows were within the lowest 10th percentile) at East Drywood Creek (median of 47 days) and Kings Creek (median of 163 days) than at Long Branch Creek (median of 3 days). This indicates a greater sustained base-flow contribution to streamflow from the prairie sites than at the agricultural site.

The annual median number of flow reversals (number of times flows switch from rising to falling or falling to rising) at East Drywood Creek (61; table 6) and Kings Creek (37) was substantially less than at Long Branch Creek (107) indicating less flow variability and more muted response to precipitation in the prairie streams. There were no low-flow pulses (rises within the lowest 25th percentile of flows) at East Drywood Creek and Kings Creek, but there was a median of six low-flow pulses at Long Branch Creek (table 6). These data indicate that prairie vegetation and soils moderate or eliminate the response of prairie streams to precipitation during dry periods. There were more high-flow pulses (flows exceeding the 75th percentile) at Long Branch Creek (annual median of 14) than at East Drywood Creek (median of 13) and Kings Creek (median of 4), but high-flow pulses lasted 25 percent longer at East Drywood Creek and about 400 percent longer at Kings Creek than at Long Branch Creek. This indicates a more moderate and delayed response to precipitation from the prairie basins than the agricultural basin.

A comparison of the ecological flow characteristics of prairie and agricultural streams with longer record (15 years or more) also indicates substantial differences between prairie and agricultural sites (table 7). The coefficient of variation was substantially greater at Kings Creek (0.72) than at the agricultural sites (0.12 to 0.32) whereas flow predictability was similar at all sites. The 1-, 3-, 7-, and 30-day minimums were zero at all sites. The median 90-day minimum flow was zero at Kings Creek, but was positive at the agricultural sites. Correspondingly, the median number of zero-flow days per year was greater at Kings Creek (185) than at the agricultural sites (70 to 170 days). The increased number of zero-flow days in the prairie basin compared to the agricultural basins indicates that prairie soils and vegetation divert water away from streams during dry periods to storage, evaporation, or seepage. This diversion could come at the expense of surface-water supplies for other uses such as irrigation, drinking water, or recreation during the late summer, when water supplies usually are smallest. One of the largest differences between the prairie and agricultural streams was the duration of extreme low flows (flows within the lowest 10th percentile). The median extreme low-flow duration was 112 days at Kings Creek, but was not greater than 16 days at any of the agricultural sites (table 7). This extended duration of low flow indicates a greater contribution to streamflow from groundwater at the prairie stream compared to the agricultural streams.

The 1-, and 3-day annual maximum (drainage-area weighted) flows were significantly less (Krukal-Wallis test, $p<0.001$, Dunn's Multiple Comparison test, $p <0.05$) at Kings Creek than at the three agricultural streamflow-gaging sites with the lowest percent of urban area (Brushy Creek, Soldier Creek, Starks Creek; table 3) . Differences in the annual 7-day maximum flows were significantly less at Kings Creek than at Brushy Creek and Soldier Creek, but not Starks Creek, whereas differences in the 30- and 90-day maximum flows were not significant between sites. The lower peak flows from the prairie basin in comparison to the agricultural basins supports the hypothesis that infiltration is greater in the native prairie basin and there is less direct runoff than from the agricultural basins. Streamflows from pre-settlement prairies in Missouri and Kansas have been simulated using an increased infiltration parameter from that of current (1995

Table 6. Drainage-area weighted, ecological streamflow summary statistics for sites with concurrent periods of record (water years 2002 through 2008).

[Shaded sites are native tallgrass prairie basins and the unshaded site is an agricultural basin; mi², square miles; ft³/s, cubic feet per second; ft³/s/d, cubic feet per second per day; --, data unavailable]

	Site and period of record used in analysis		
	East Drywood Creek (2002-2008)	**Kings Creek (2002-2008)**	**Long Branch Creek (2002-2008)**
Drainage area, in mi²	3.38	4.09	23.0
Annual coefficient of variation	.34	.63	.17
Flow predictability	.58	.70	.54
Median value for period of record			
1-day minimum, in ft³/s	0	0	0
3-day minimum, in ft³/s	0	0	0
7-day minimum, in ft³/s	0	0	0
30-day minimum, in ft³/s	0	0	0
90-day minimum, in ft³/s	0	0	.01
1-day maximum, in ft³/s	56.8	14.4	34.8
3-day maximum, in ft³/s	27.8	6.76	16.3
7-day maximum, in ft³/s	12.9	4.61	9.48
30-day maximum, in ft³/s	4.20	2.37	2.56
90-day maximum, in ft³/s	2.52	1.38	1.44
Number of zero days	137	218	25
Low flow pulse count	0	0	6
Low flow pulse duration, in days	--	--	4
High flow pulse count	13	4	14
High flow pulse duration, in days	5	19	4
Number of reversals	61	37	107
Extreme low peak flow, in ft³/s	0	0	0

Table 6. Drainage-area weighted, ecological streamflow summary statistics for sites with concurrent periods of record (water years 2002 through 2008).—Continued

[Shaded sites are native tallgrass prairie basins and the unshaded site is an agricultural basin; mi^2, square miles; ft^3/s, cubic feet per second; ft^3/s/d, cubic feet per second per day; --, data unavailable]

	Site and period of record used in analysis		
	East Drywood Creek (2002-2008)	Kings Creek (2002-2008)	Long Branch Creek (2002-2008)
Extreme low flow duration, in days	47	163	3
Extreme low flow timing, day-month	21-June	1-August	13-August
Extreme low flow frequency	2	2	4
High flow peak, in ft^3/s	1.63	.342	.7043
High flow duration, in days	8	6.5	5.5
High flow timing, in day-month	13-March	28-July	9-June
High flow frequency	8	4	14
High flow rise rate, in ft^3/s/d	.65	.34	.29
High flow fall rate, in ft^3/s/d	-.19	-.03	-.13
Small flood peak, in ft^3/s	62.3	48.8	59.0
Small flood duration, in days	25.0	77.5	34.0
Small flood timing, in day-month	24-May	3-June	2-October
Small flood frequency	1	1	1
Small flood rise rate, in ft^3/s/d	11.0	2.41	11.3
Small flood fall rate, in ft^3/s/d	-5.13	-1.12	-4.56
Large flood peak, in ft^3/s	--	--	--
Large flood duration, in days	--	--	--
Large flood timing, in day-month	--	--	--
Large flood frequency	0	0	0
Large flood rise rate, in ft^3/s/d	--	--	--
Large flood fall rate, in ft^3/s/d	--	--	--

Table 7 . Drainage-area weighted, ecological streamflow summary statistics for sites with long-term period of record.

[Shaded site is a prairie stream and unshaded sites are agricultural streams; mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/d$, cubic feet per second per day; --, data unavailable]

	Site and period of record used in analysis					
	Kings Creek 1980-2001 (22 years)	**Goodwater Creek 1980-2001 (22 years)**	**Soldier Creek 1965-1986 (22 years)**	**Starks Creek 1957-1976 (20 years)**	**Big Hollow Creek 1958-1972 (15 years)**	**Brushy Creek 1961-1975 (15 years)**
Drainage area, in mi^2	4.09	4.67	2.06	4.18	4.05	1.15
Annual coefficient of variation	.72	.12	.15	.32	.18	.26
Flow predictability	.43	.4	.38	.41	.38	.5
Median Value for period of record						
1-day minimum, in ft^3/s	0	0	0	0	0	0
3-day minimum, in ft^3/s	0	0	0	0	0	0
7-day minimum, in ft^3/s	0	0	0	0	0	0
30-day minimum, in ft^3/s	0	0	0	0	0	0
90-day minimum, in ft^3/s	0	.023	.014	.005	.009	.011
1-day maximum, in ft^3/s	12.1	57.8	33.7	46.9	30.7	44.4
3-day maximum, in ft^3/s	7.21	30.6	16.1	18.5	13.7	20.2
7-day maximum, in ft^3/s	5.43	15.0	9.87	8.75	8.68	10.1
30-day maximum, in ft^3/s	2.74	5.56	3.79	3.66	3.16	3.76
90-day maximum, in ft^3/s	1.51	2.83	1.82	2.04	1.52	2.12
Number of zero days	185	70	87	110	116	170
High flow pulse count	3	21	14	15	19	15
High flow pulse duration, in days	12	3	2	3	3	3
Number of reversals	45	97	88	73	71	66
Extreme low flow peak, in ft^3/s	0	0	0	0	0	0
Extreme low flow duration, in days	112	16	4	8	5	9

Table 7 . Drainage-area weighted, ecological streamflow summary statistics for sites with long-term period of record.—Continued

[Shaded site is a prairie stream and unshaded sites are agricultural streams; mi^2, square miles; ft^3/s, cubic feet per second; $ft^3/s/d$, cubic feet per second per day; --, data unavailable]

	Site and Period of Record used in Analysis					
	Kings Creek 1980-2001 (22 years)	Goodwater Creek 1980-2001 (22 years)	Soldier Creek 1965-1986 (22 years)	Starks Creek 1957-1976 (20 years)	Big Hollow Creek 1958-1972 (15 years)	Brushy Creek 1961-1975 (15 years)
Extreme low flow timing, day-month	6-August	13-August	22-July	2-August	19-July	12-July
Extreme low flow frequency	1	3	7	7	10	14
High flow peak, in ft^3/s	.538	1.49	.278	1.13	.722	3.48
High flow duration, in days	5	5	4	5	4	4
High flow timing, in day-month	25-May	25-March	7-March	22-March	6-April	22-April
High flow frequency	6	20	19	15	20	12
High flow rise rate, in $ft^3/s/d$	.147	.699	.151	.847	.404	1.89
High flow fall rate, in $ft^3/s/d$	-060	-.285	-098	-.311	-.190	-.924
Small flood peak, in ft^3/s	25.1	97.5	44.2	55.7	34.6	58.9
Small flood duration, in days	54	15	23	20	23	18
Small flood timing, in day-month	24-May	11-July	3-June	8-June	2-July	28-February
Small flood frequency	0	0	1	0	0	1
Small flood rise rate, in $ft^3/s/d$	4.20	13.3	13.7	16.4	6.91	18.0
Small flood fall rate, in $ft^3/s/d$	-.682	-8.79	-3.75	-4.35	-2.71	-8.85
Large flood peak, in ft3/s	106	151	129	71.3	63.21	107
Large flood duration, in days	151	19	15	29	22	8
Large flood timing, in day-month	14-June	6-August	25-May	14-February	20-April	13-September
Large flood frequency	0	0	0	0	0	0
Large flood rise rate, in $ft^3/s/d$	1.19	32.1	54.7	26.8	15.8	53.4
Large flood fall rate, in $ft^3/s/d$	-3.37	-12.1	-10.5	-4.38	-3.32	-15.3

through 2004) agricultural conditions (Heimann and others, 2007). The increase in infiltration resulted in substantially lower peak flows and sustained recessions from the prairie land cover compared with agricultural land cover. The effects of flashier (sharp rises and falls in streamflow) agricultural streams on native aquatic biota are unknown, but may be an important factor in the sustainability of some native aquatic species.

The number of hydrologic reversals was substantially greater at the agricultural sites (66 to 97; table 7) than at Kings Creek (45). The rise and fall rates of “high flows”, “small floods”, and “large floods”, as defined by the default IHA settings (The Nature Conservancy, 2009), generally was greater at agricultural sites than at Kings Creek, whereas the small and large flood durations were substantially greater at the prairie site than agricultural sites. The differences in flow characteristics between the prairie streams and agricultural streams support the previous findings for shorter-period stations that prairie streams are less flashy than agricultural streams.

The results of the hydrologic analyses indicate that there is a larger percentage of precipitation lost to direct runoff in the agricultural basins, whereas the prairie basins likely divert more precipitation to evaporation, base flow, or seepage. Streamflow from prairie basins was less flashy and had a larger number of zero-flow periods than agricultural sites. The hydrologic differences between the prairie and agricultural basins are likely the result of greater infiltration of the prairie soils resulting from undisturbed soil and vegetation conditions. The prairie basins used in this study exist because the soils were shallow and not suitable for agriculture. These basins are the best remaining examples of native tallgrass prairie basins in Missouri and Kansas, but may not be the most representative of the historical hydrology of all tallgrass prairie streams. Rather than being an intrinsic characteristic of prairies, more zero-flow days may simply be a characteristic of prairies overlying shallow soils. Prairie basins with deeper soils and greater water storage may have had fewer zero-flow days than East Drywood Creek and Kings Creek.

Comparison of Water-Quality Characteristics

Water-quality data from the prairie and selected agricultural streams were compared, including field measurements, nutrients, major ions, and pesticides. The water-quality data for East Drywood Creek were sparse; therefore, for some constituents, the East Drywood Creek data were combined with Kings Creek data for analyses, or the Kings Creek data alone were used to represent the water-quality characteristics of prairie streams. The values from agricultural sites also were combined for statistical comparisons between prairie and agricultural streams for some constituents.

Field Measurements

Records of field measurements including specific conductance, dissolved oxygen, pH, bicarbonate, alkalinity, and fecal coliform bacteria during base-flow conditions were compared for the prairie and agricultural streams. Specific conductance values were lowest for the East Drywood Creek samples with median values of 116 microsiemens per centimeter at 25 °C (µS/cm), compared to medians of the other sites, which ranged from 387 to 667 µS/cm (fig. 5). The distribution of dissolved-oxygen concentrations during base-flow conditions was not significantly different in the prairie and agricultural streams (Mann-Whitney test, $p=0.537$). The median dissolved oxygen concentration was 9.4 milligrams per liter (mg/L) at East Drywood Creek and 9.6 mg/L at Kings Creek, and median dissolved-oxygen concentrations at the agricultural sites ranged from 8.5 to 9.5 mg/L (fig. 5). More than 10 percent of the measured dissolved-oxygen concentrations at East Drywood Creek and some concentrations at 3 of 5 agricultural sites were below the standard of 5 mg/L for the protection of aquatic life (Kansas Department of Health and Environment, 2005; Missouri Department of Natural Resources, 2008; fig. 5). These data indicate that low dissolved-oxygen concentrations during summer low-flow periods may be a natural phenomenon for small prairie streams in the Osage Plains; however, no dissolved-oxygen measurements were less than the 5 mg/L standard at Kings Creek or at two of the agricultural sites (Little Medicine Creek near Harris, Missouri, USGS streamflow-gaging station number 06900100; and South Grand River below Freeman, Missouri, USGS streamflow-gaging station number 06921582).

The median pH value at East Drywood Creek during base-flow conditions was significantly less (Kruskal-Wallis test, $p<0.05$; Dunn’s Multiple Comparison test, $p<0.05$) than that of other prairie and agricultural sites with a median value of about 7.0 units (fig. 6), whereas median values at other sites were 7.7 to 8.0 units. The median bicarbonate concentration at East Drywood Creek also was significantly less (Kruskal-Wallis test, $p<0.001$; Dunn’s Multiple Comparison test, $p<0.05$) than at Kings Creek and the agricultural stations. The East Drywood Creek median bicarbonate concentration was 22 mg/L, whereas the median Kings Creek bicarbonate concentration was 344 mg/L, and the medians of bicarbonate concentrations at the agricultural sites ranged from 168 to 242 mg/L. Alkalinity values mirrored that of bicarbonate concentrations, with a median alkalinity value of 19.7 mg/L as calcium carbonate ($CaCO_3$) at East Drywood Creek, a median of 268 mg/L as $CaCO_3$ at Kings Creek, and median alkalinities from 117 to 165 mg/L as $CaCO_3$ at the agricultural sites; fig. 6). Although differences in alkalinity values were substantial, they were not statistically significant because of the small sample size (10) available for East Drywood Creek. Values from the two prairie sites formed the extremes for bicarbonate and alkalinity median values. The median bicarbonate concentration and alkalinity value, for which bicarbonate is

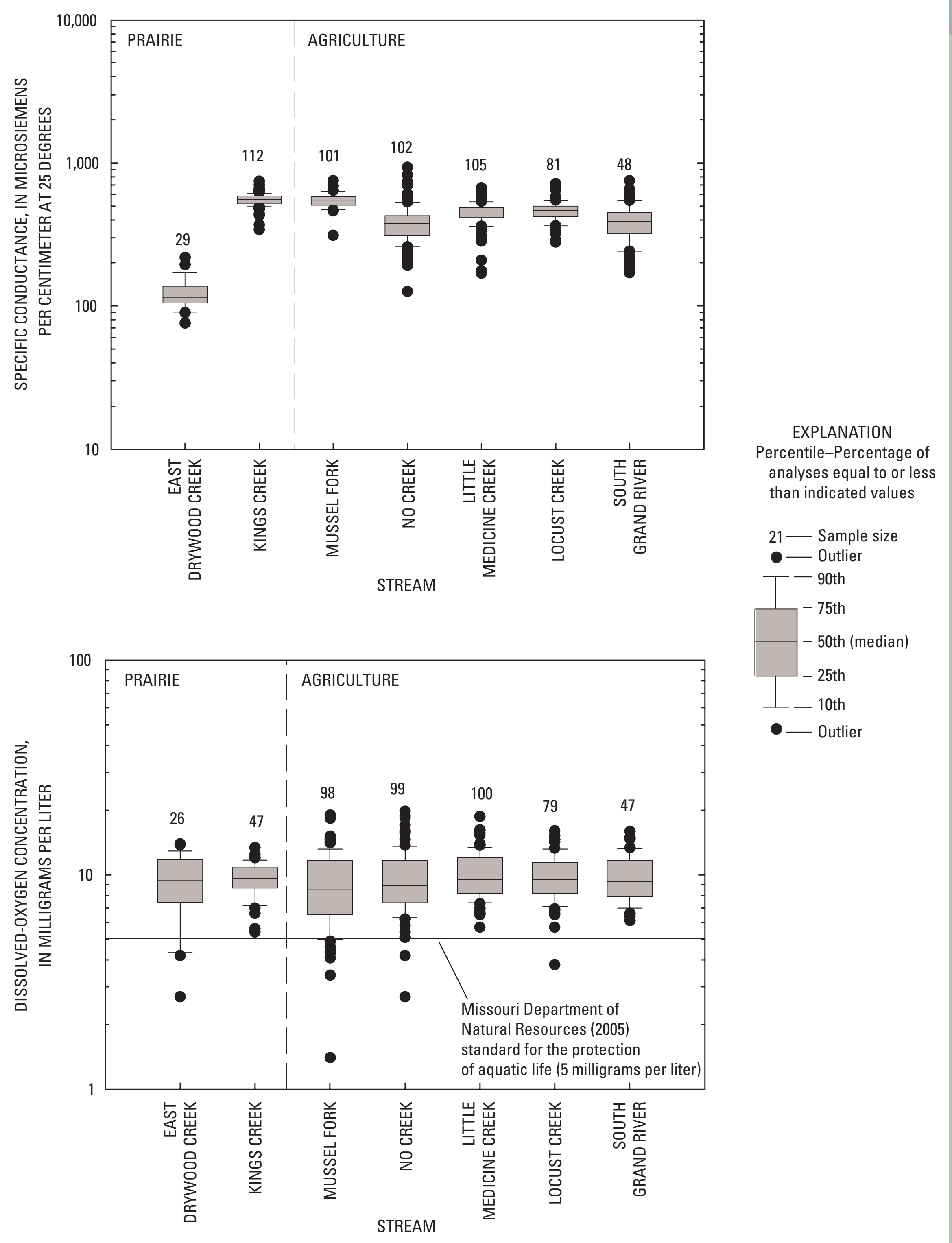


Figure 5. Specific conductance and dissolved-oxygen values measured during base-flow conditions for prairie and agricultural streams.

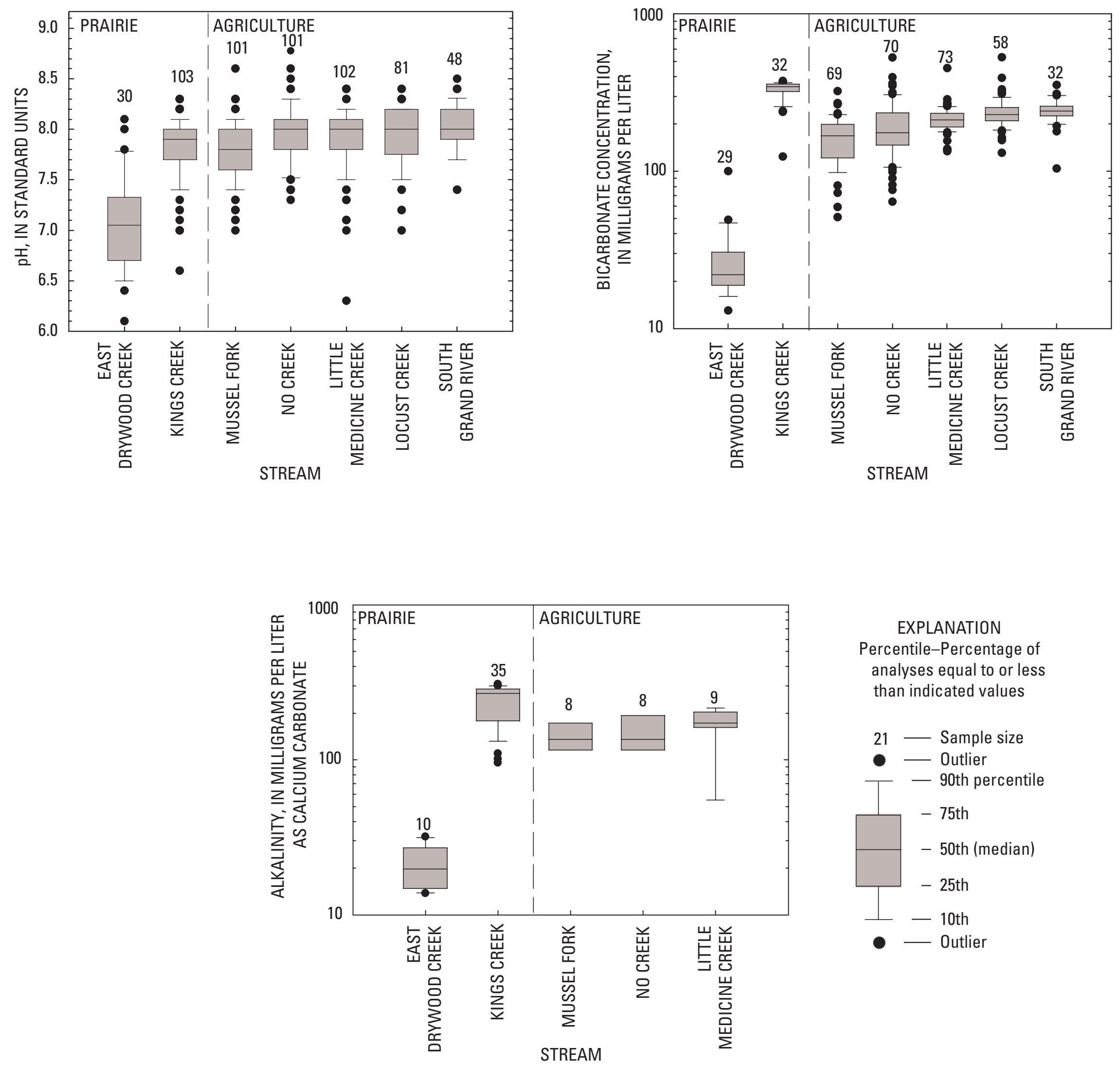


Figure 6. Distribution of pH, bicarbonate, and alkalinity values measured during base-flow conditions for prairie and agricultural streams.

a primary component, were an order of magnitude lower for East Drywood Creek than for any of the other streams in the study, including Kings Creek.

Differences in select field constituents (pH, bicarbonate, and alkalinity) likely can be attributed to differences in geology rather than land cover. The East Drywood Creek Basin is underlain by sandstone bedrock, whereas other basins are underlain primarily by limestone and shale. An average limestone contains more than 70 percent calcium carbonate, whereas silica is the primary (more than 66 percent) component of sandstones (Boggs, 1987). The lower bicarbonate, alkalinity, and resulting lower buffering capacity at East Drywood Creek makes this stream less resistant to natural acidification from precipitation, decomposition of organic matter, and mine drainage.

Fecal coliform bacteria density values were available for the prairie and agricultural streams and provide an indicator of human and animal waste sources in the streams. The median fecal coliform bacteria density of combined values from the prairie streams [33 colonies per 100 milliliters (mL)] collected during base-flow conditions was significantly less (Mann-Whitney test, $p<0.001$) than the median density of combined values from agricultural streams (240 colonies per 100 mL). All but one fecal coliform bacteria value sampled during base-flow conditions at the prairie sites were less than the Missouri standard for secondary contact recreation of 1,800 colonies per 100 mL (fig. 7), and most sample densities were less than the 200 colonies per 100 mL standard for whole body contact (Missouri Department of Natural Resources, 2008). For agricultural sites, most values were greater than the 200 colonies per 100 mL standard at all sites, and some sample values from each site were greater than the 1,800 colonies per 100 mL standard (fig. 7). The order-of-magnitude higher fecal coliform counts in samples from the agricultural sites may be attributed to livestock waste, although bison and elk are grazed in the East Drywood Creek Basin, and bison are grazed in the Kings Creek Basin. While grazing densities may be less in the prairie basins, the lower bacteria densities may also be a result of decreased runoff and associated decreased sediment transport from the prairie basins. Increased infiltration of precipitation into native prairie soils may provide for a greater natural filtering effect than what is found in the agricultural basins.

Nutrients

Nitrogen and phosphorus frequently are limiting nutrients in natural systems, and the concentrations of species of these constituents in streams can be indicators of enrichment from non-natural sources, including fertilizers and wastewater from humans or livestock. Total nitrogen (TN) concentrations were sampled during base-flow conditions from two prairie and five agricultural sites. The median concentration of the five TN base-flow samples from East Drywood Creek (0.92 mg/L) was similar to the medians of the agricultural sites (0.74 to 1.60 mg/L), whereas the median concentration of the 238 TN samples at Kings Creek (0.22 mg/L) was significantly less (Kruskal-Wallis test $p<0.001$; Dunn's multiple comparison test, $p <0.05$) than that of any other sampling site except East Drywood Creek (fig. 8). The median TN concentrations from base-flow samples at all sites other than Kings Creek were above or near the U.S. Environmental Protection Agency (EPA) sub-ecoregion 40 (fig. 1) recommended

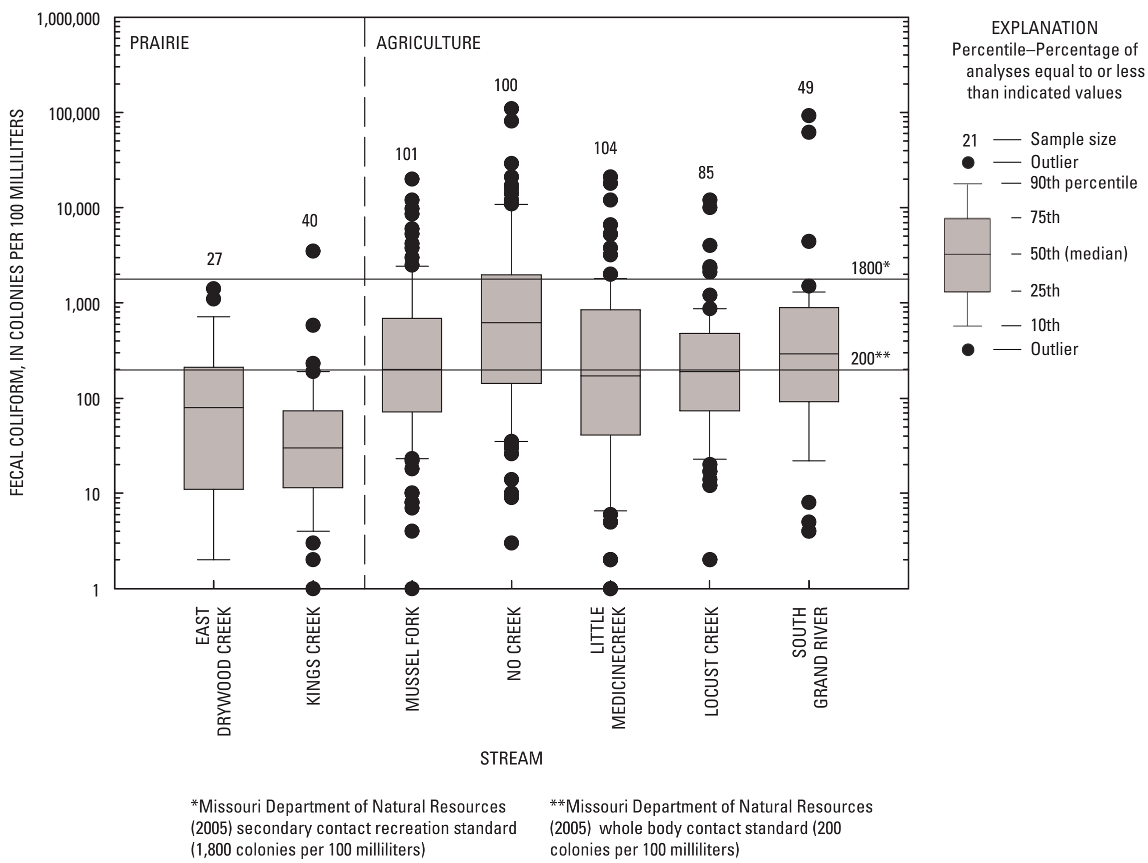


Figure 7. Fecal coliform bacteria densities measured base-flow conditions for prairie and agricultural streams.

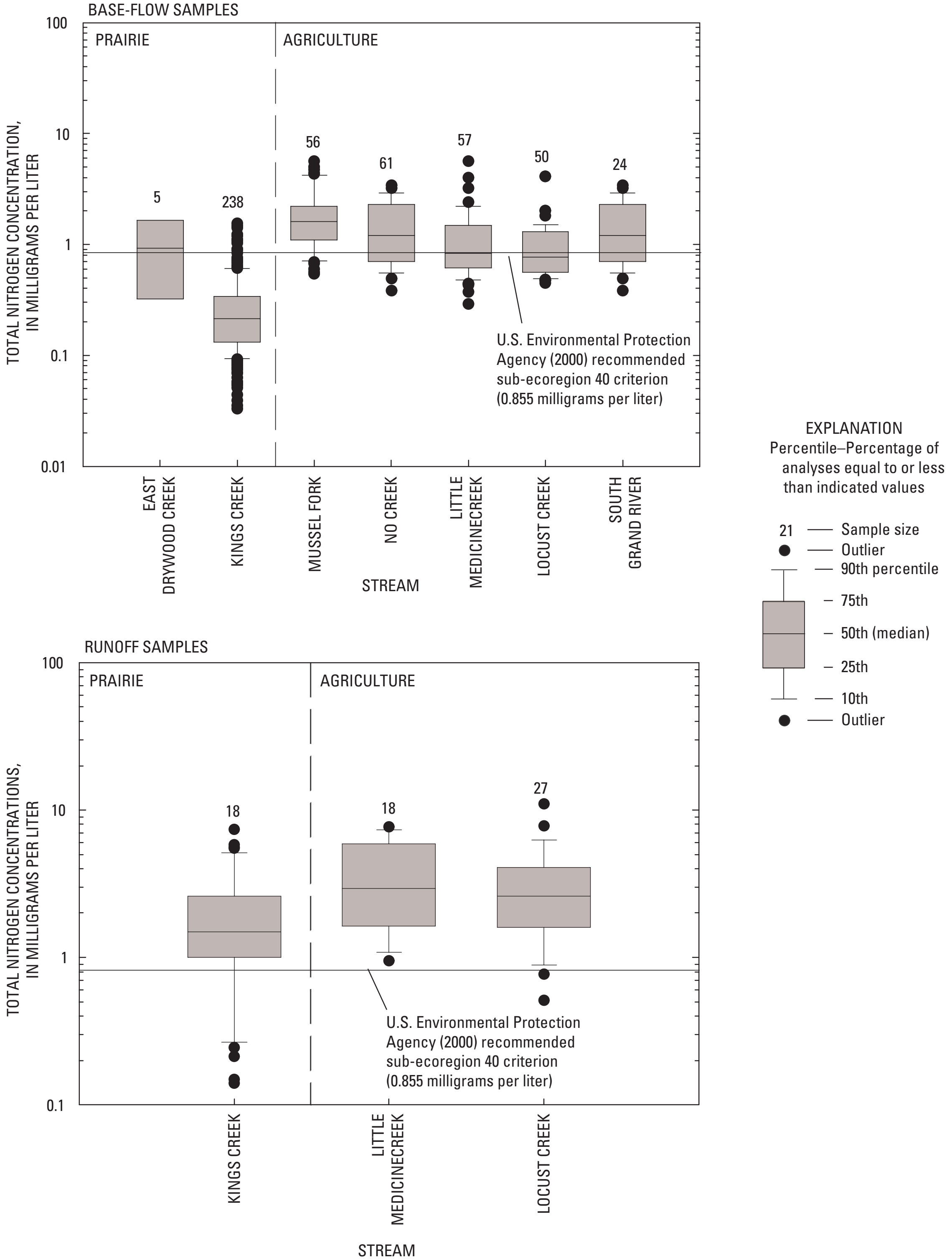


Figure 8. Total nitrogen concentrations measured during base-flow and runoff conditions for prairie and agricultural streams.

nutrient criterion of 0.855 mg/L for the prevention of nutrient enrichment (fig. 8; U.S. Environmental Protection Agency, 2000). Runoff samples also were analyzed for TN at Kings Creek and two agricultural sites, and the median concentration was significantly less (Mann-Whitney test, $p<0.001$) in Kings Creek runoff samples (1.5 mg/L) than the median of combined runoff samples from the agricultural sites (2.7 mg/L); however, most TN concentrations in runoff samples exceeded the 0.855 mg/L recommended criterion at all sites including Kings Creek (fig. 8).

The median of combined total organic nitrogen concentrations in base-flow samples from prairie streams (0.37 mg/L) also was significantly less (Mann-Whitney test, $p<0.001$) than the median of combined values from agricultural stream samples. Most samples from the prairie streams and 3 of the 5 agricultural sites were less than the recommended organic nitrogen criterion of 0.625 mg/L for sub-ecoregion 40 (fig. 9; U.S. Environmental Protection Agency, 2000), whereas most samples from the agricultural streams Mussel Fork near Mystic, Missouri (USGS station number 06905725) and No Creek near Dunlap, Missouri (USGS station number 06899580) exceeded this recommended criterion (fig 9).

The median dissolved-ammonia concentration of combined results from the prairie streams (0.02 mg/L) was significantly less (Mann-Whitney test, $p<0.001$) than the median of combined results from agricultural streams (0.51 mg/L) primarily because of the low concentrations at East Drywood Creek. Maximum ammonia concentrations in base-flow samples from the prairie streams were one to two orders of magnitude less than agricultural sites (fig. 9). Ammonia concentrations in all but a few samples from No Creek near Dunlap, Missouri (USGS streamflow-gaging station number 06899580, fig. 1) were below the chronic ammonia concentration for the protection of warm and cold water fishes of 2.5 mg/L (based on temperature of 20 °C and pH of 7.7; Missouri Department of Natural Resources, 2008; fig. 9). Ammonia concentrations in all samples from all sites were below the acute concentration of 14 mg/L for the protection of fisheries (based on temperature of 20 °C and pH of 7.7; Missouri Department of Natural Resources, 2008).

The median total nitrate plus nitrite-nitrogen concentration was significantly less (Mann-Whitney test, $p<0.001$) in combined base-flow samples from the prairie streams (0.02 mg/L) than the median of combined concentrations from the agricultural streams (0.05 mg/L). The median nitrate-N concentration of runoff samples from Kings Creek also was significantly less (Mann-Whitney test, $p<0.001$) than the median concentration of combined runoff samples from agricultural streams (0.92 mg/L). Nitrate-N concentrations in samples from the prairie streams were, with a few exceptions, below the U.S. Environmental Protection Agency (2000) recommended nitrate-N criterion of 0.23 mg/L for sub-ecoregion 40 in base-flow and runoff samples (fig. 10). Agricultural stream base-flow samples generally were less than the nitrate-N criteria, but runoff samples from agricultural streams generally were above the criteria (fig. 10).

The smaller concentrations of various N species, especially the most soluble and bio-available species (ammonia and nitrate-N), in prairie streams likely is because prairies are not fertilized like agricultural basins, and native prairie basins are able to retain N better than agricultural basins. This retention is enhanced by increased infiltration of precipitation into the prairie soils, less direct runoff, and likely less erosion than in agricultural basins. The greater concentrations of nutrients in agricultural streams can be explained by these source and transport differences.

The median total-phosphorus (TP) concentration was significantly less (Mann-Whitney test, $p<0.001$) in base-flow samples from the combined prairie sites (0.01 mg/L) than the median of the combined agricultural stream samples (0.09 mg/L). TP concentrations also were significantly less (Mann-Whitney test, $p<0.001$) in runoff samples from Kings Creek (median 0.02 mg/L) than combined values in agricultural samples (median 0.42 mg/L). Most TP samples from the prairie sites collected during base-flow conditions were less than the U.S. Environmental Protection Agency (2000) recommended nutrient criterion of 0.092 mg/L (fig. 11), whereas most of the TP concentrations were greater than this standard at two of the five agricultural sites. Similarly, most of the Kings Creek runoff samples were less than the 0.092 mg/L standard, whereas most of the agricultural runoff samples were greater than the 0.092 mg/L standard. Median concentrations of dissolved orthophosphate (or soluble reactive phosphorus in Kings Creek samples) were similar in the combined values for prairie (0.010 mg/L) and combined values for agricultural streams (median of 0.012 mg/L). The lower concentrations of phosphorus from prairie soils is interesting in light of national findings that pasture lands are the primary source of TP to the Mississippi River and the Gulf of Mexico (Alexander and others, 2008). The decreased amount of TP in prairie streams compared with agricultural streams is likely because of a lack of fertilization and increased infiltration of precipitation into prairie soils, resulting in decreased runoff and erosion that allow prairie basins to retain more phosphorus.

Major Ions

Major ions used in comparisons between the prairie and agricultural sites included potassium, chloride, and sulfate concentrations collected during base-flow conditions. These constituents can be used as an indication of anthropomorphic sources of contaminants in the basins. Potassium concentrations generally were less in the prairie streams than in the agricultural streams (fig. 12). The median of combined potassium concentrations in the East Drywood Creek and Kings Creek samples (1.1 mg/L) was significantly less (Mann-Whitney test, $p < 0.001$) compared with combined values from the agricultural sites (5.1 mg/L). Potassium is a primary plant nutrient and common fertilizer component

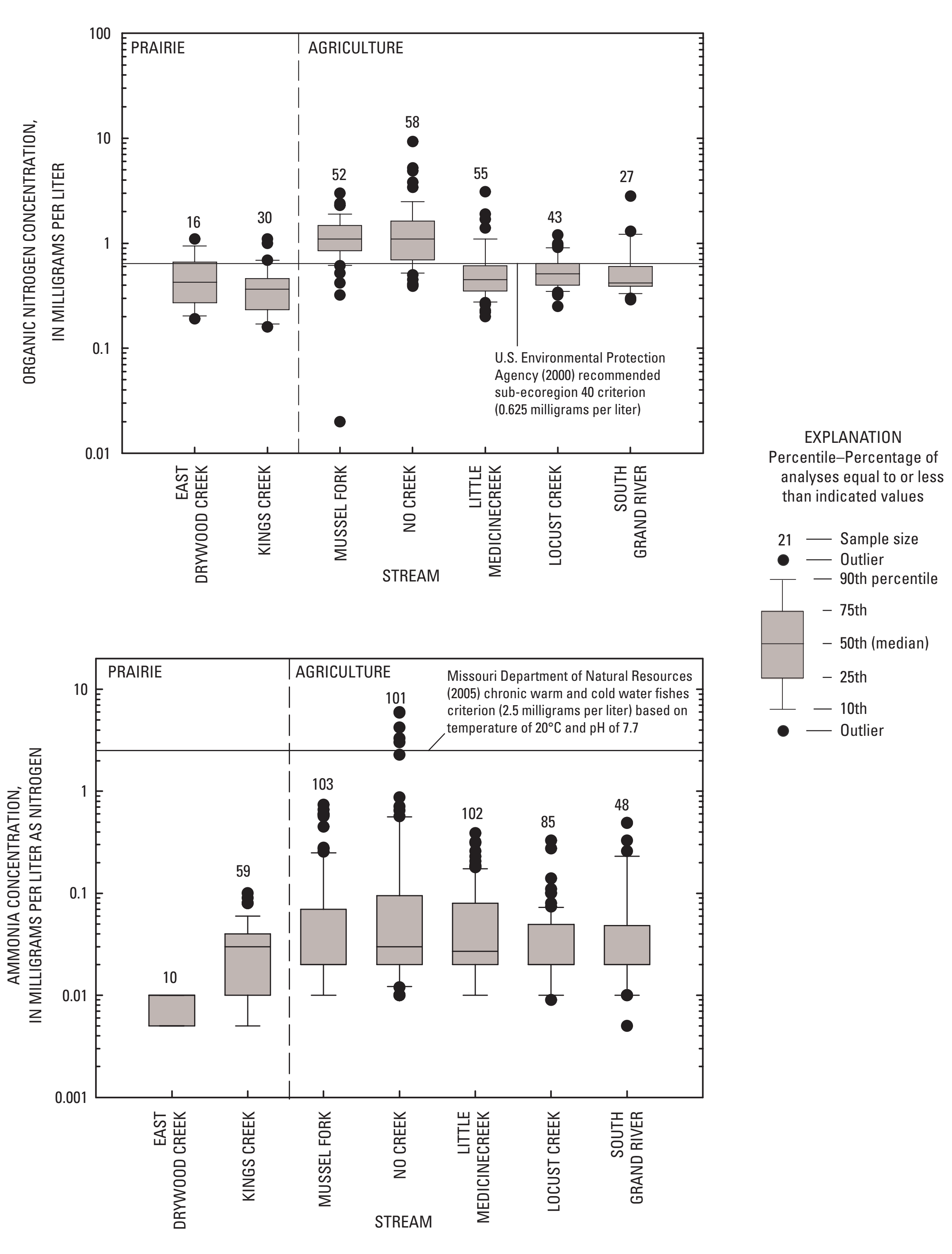


Figure 9. Distribution of organic-nitrogen and ammonia concentrations measured during base-flow conditions for prairie and agricultural streams.

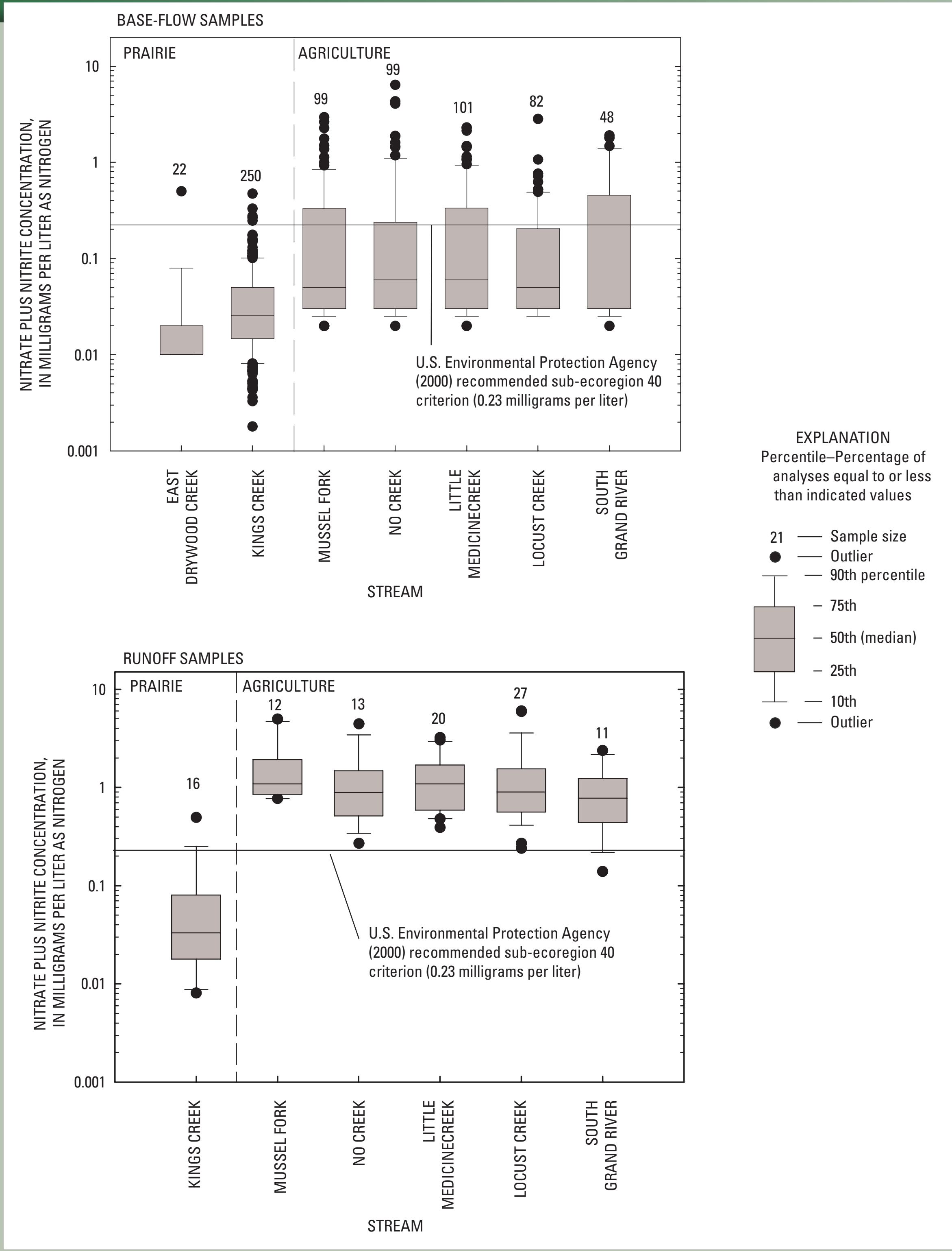


Figure 10. Nitrate plus nitrite concentrations measured during base-flow and runoff conditions for prairie and agricultural streams.

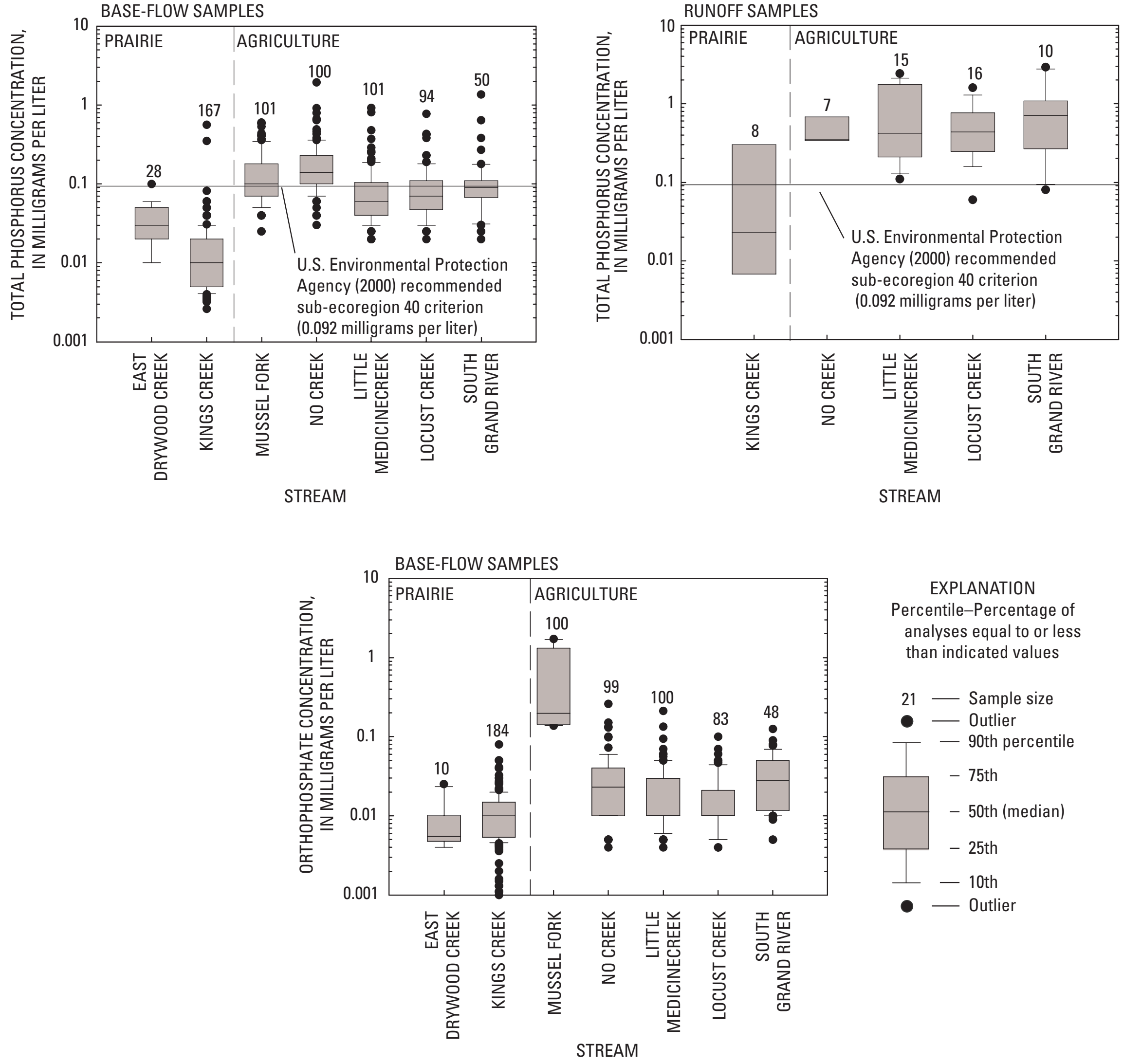


Figure 11. Total phosphorus concentrations measured during base-flow and runoff conditions, and orthophosphate concentrations measured during base-flow conditions for prairie and agricultural streams.

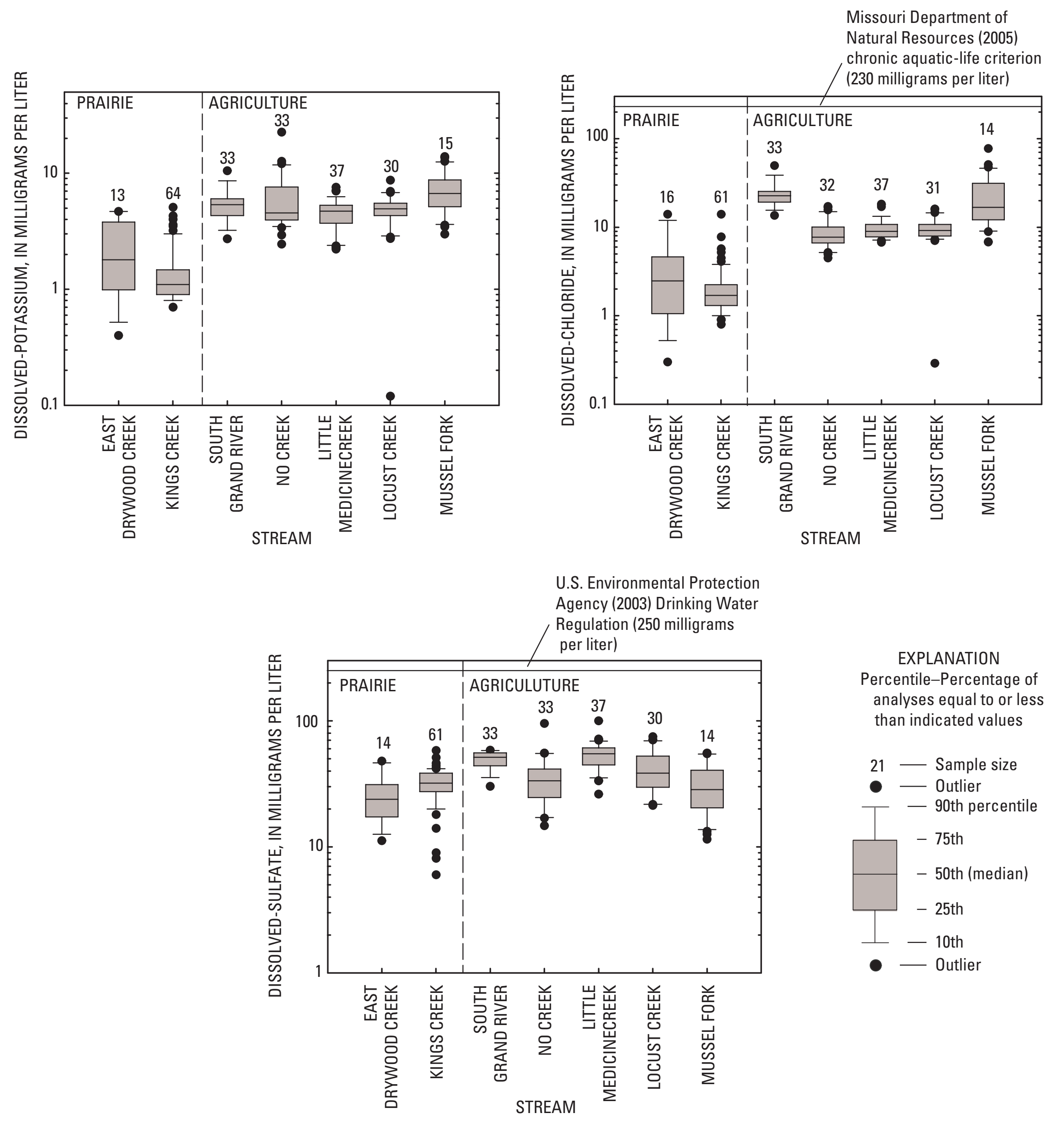


Figure 12. Concentrations of major ions measured during base-flow conditions for prairie and agricultural streams.

and, therefore, would be expected to be present in greater concentrations in agricultural streams. The median chloride concentration also was significantly less (Mann-Whitney test, $p < 0.001$) in the combined prairie stream samples (1.7 mg/L) than the median of combined results from agricultural streams (10.1 mg/L). The chloride concentration did not exceed or approach the Missouri standard of 230 mg/L to protect aquatic life from chronic exposure (Missouri Department of Natural Resources, 2008) or the 250 mg/L standard for drinking water (U.S. Environmental Protection Agency, 2003) in any sample from any study site (fig. 12). Sources of chloride in streamflow include fertilizers, the use of road salt, atmospheric deposition, and treated waste; therefore, the larger concentrations of chloride in agricultural streams can be associated with fertilization of crops, the occurrence of roads, and wastewater treatment facilities in larger drainages. Despite a small amount of reclaimed surface-coal mining in the upper end of the East Drywood Creek Basin, this prairie stream had a lower median concentration of sulfate (23.9) than any of the agricultural sites (medians of 28.5 to 54.7 mg/L; fig. 12), and overall, the combined prairie sample results had a significantly lower (Mann-Whitney test, $p < 0.001$) median concentration of sulfate (31 mg/L) than the combined agricultural stream samples (40.3 mg/L). Maximum sulfate concentrations did not exceed the drinking water standard of 250 mg/L (U.S. Environmental Protection Agency, 2003) at any of the sampling locations (fig. 12).

Pesticides

There were few pesticide sample results for the selected study sites with which to make comparisons of pesticide concentrations, and no runoff samples were analyzed for pesticides at either prairie site. Comparisons of available data did not indicate significant differences in the distributions of atrazine ($p=0.662$) or alachlor ($p=0.606$) concentrations in base-flow samples from East Drywood Creek and agricultural sites. The maximum concentration of atrazine in East Drywood Creek base-flow samples was 0.41 µg/L, which is substantially less than the maximum contaminant level of 3 µg/L for drinking water (U.S. Environmental Protection Agency, 2003). Concentrations of atrazine in two base-flow samples from Big Bull Creek (3.24 and 3.52 µg/L) were greater than this standard, and although concentrations in base-flow samples at the South Grand River site were not greater than the drinking water standard, one runoff sample (5.44 µg/L) was above the standard. Concentrations in base-flow samples from East Drywood Creek or Big Bull Creek did not exceed the maximum contaminant level of 2 µg/L for drinking water (U.S. Environmental Protection Agency, 2003) for alachlor, and concentrations in base-flow or runoff samples from South Grand River did not exceed this standard. Despite the lack of application of atrazine or alachlor in the East Drywood Creek Basin, these agricultural herbicides were still detected in streamflow samples as they can become airborne during, or following, application and can be transmitted across basins (Grover and Cessna, 1988; Thurman and Cromwell, 2000). Concentrations of agricultural chemicals in East Drywood Creek represent background concentrations that cannot be removed without addressing airborne transport.

Implications

Comparisons of hydrologic and water-quality data from native tallgrass prairie and agricultural streams provide an indication of the degree of change that has occurred from historical conditions in the agricultural Midwest and the expected nature of changes that may occur from tallgrass prairie restoration. The results indicate that basins dominated by native tallgrass prairie have a greater base-flow component of streamflow, lower streamflow yields, and lower peak flows compared to similar-sized agricultural basins. Select inorganic, nutrient, pesticide, and microbiological constituents generally were significantly less in the prairie streams compared to agricultural streams as anthropogenic inputs are minimal in the prairie basins. Data needs determined from this study include addressing the lack of a suitable paired agricultural basin to East Drywood Creek in the Osage Plains, and extending the period of streamflow and water-quality record at East Drywood Creek, including runoff samples. Kings Creek near Manhattan, Kansas, is a USGS National Benchmark station, and East Drywood Creek at Prairie State Park, Missouri, could serve a similar role as a reference stream in Missouri providing indications of background levels of contaminants including nutrients, sediment, pesticides, pharmaceuticals and personal care products, and wastewater indicator compounds.

Summary and Conclusions

This report summarizes results from a study conducted by the U.S. Geological Survey, in cooperation with the Missouri Department of Natural Resources, to analyze existing streamflow and water-quality characteristics of remnant tallgrass prairie basins (East Drywood Creek at Prairie State Park, Missouri; Kings Creek near Manhattan, Kansas), and compare these results to those from comparable-sized agricultural basins in Missouri and Kansas. Streamflow data from eight locations (two native prairie and six agricultural basins) were used for hydrologic comparisons, and data from nine locations (two native prairie and seven agricultural basins) were used for water-quality comparisons.

Prairie streams, especially Kings Creek in eastern Kansas, had an increased percentage of base flow and a decreased percentage of direct runoff than similar-sized agricultural streams in the region. During 22 years of record, the Kings Creek base-flow component averaged 66 percent of total flow, but base flow was only 16 to 26 percent of flows at agricultural sites of various record periods. The large base-flow component likely is the result of greater infiltration of precipitation into prairie soils and the resulting greater contribution of groundwater to streamflow; therefore, an increase in the percentage of land with prairie vegetation has the potential for decreasing the severity of flooding downstream.

Both prairie streams had smaller streamflow yields than agricultural streams. The average ratio of the monthly streamflow yield to monthly precipitation was 22 percent at East Drywood Creek and 18 percent at Kings Creek. This ratio was 23 to 31 percent for the agricultural sites. The lower yields from prairie basins likely are because prairies divert more precipitation to infiltration and interception, and subsequently to evapotranspiration and seepage, than do basins with agricultural land covers. If this difference is common to all prairies, expansion of prairie vegetation in the region could have a large effect on surface-water availability.

Streamflow in small native prairie streams had more days of zero flow than similar-sized agricultural streams. The prairie streams were at zero flows about 50 percent of the time, and the agricultural streams were at zero flow 25 to 35 percent of the time. Characteristics of the prairie basins that could account for the greater periods of zero flow when compared to agricultural streams include greater infiltration, lower yields, greater interception and evapotranspiration, shallower soils, and possible greater seepage losses at the prairie sites.

One of the largest differences between the prairie and agricultural streams was the duration of extreme low flows (flows within the lowest 10th percentile). The median extreme low-flow duration was 112 days at Kings Creek, but was not greater than 16 days at any of the agricultural sites. This extended duration of low flow indicates a prolonged period of groundwater contribution to streamflow from the prairie stream compared to the agricultural streams.

A larger contribution of direct runoff from the agricultural streams made them much flashier than the prairie streams. The 1-, and 3-day annual maximum flows were significantly greater at three agricultural sites than at Kings Creek. The number of hydrologic reversals was substantially greater in agricultural streams than in the prairie streams. These differences likely are caused by a greater infiltration capacity of prairie soils. The effects of flashier agricultural streams on native aquatic biota are unknown, but may be an important factor in the sustainability of some native aquatic species.

There were no significant differences in the distribution of dissolved-oxygen concentrations at prairie and agricultural sites, and some samples from most sites fell below the 5 milligrams per liter Missouri and Kansas standard for the protection of aquatic life. More than 10 percent of samples from the East Drywood Creek prairie stream were less than this standard. These data indicate low dissolved-oxygen concentrations during summer low-flow periods may be a natural phenomenon for small prairie streams in the Osage Plains.

All but one fecal coliform bacteria value from samples collected during base-flow conditions at the prairie sites were less than the Missouri standard for secondary contact recreation of 1,800 colonies per 100 milliliters, and most sample values were less than the 200 colonies per 100 milliliters standard for whole body contact. Most agricultural site sample values were greater than the 200 colonies per 100 milliliters standard at all sites, and some sample values from each site were greater than the 1,800 colonies per 100 milliliters standard. Although animal grazing occurred in prairie and agricultural basins, the density of grazing in the agricultural basins likely exceeded that of the prairie basins. The lower bacteria densities also may be a result of decreased runoff and associated decreased sediment transport from the prairie basins.

The median total nitrogen concentrations in base-flow samples at all sites other than Kings Creek were above or near the U.S. Environmental Protection Agency recommended criterion for total nitrogen of 0.855 milligram per liter for the prevention of nutrient enrichment. The median concentration of total nitrogen in base-flow samples from Kings Creek (0.22 milligram per liter) was significantly less than that of any agricultural site (medians of 0.74 to 1.60 milligrams per liter). Total nitrogen concentrations also were significantly less in the Kings Creek runoff samples (1.5 milligrams per liter) than those from two agricultural sites (2.7 milligrams per liter). Most total nitrogen concentrations in runoff samples exceeded the recommended criterion at all sites.

The prairie sites had significantly lower median ammonia and nitrate concentrations than agricultural sites. Ammonia concentrations in all samples except for a single agricultural site were below the chronic ammonia concentration for the protection of warm and cold water fishes. Median nitrate-nitrogen concentrations were significantly less in base-flow and runoff samples from the prairie streams than those from agricultural streams. Nitrate concentrations in samples from the prairie streams were, with a few exceptions, below the U.S. Environmental Protection Agency recommended criterion for subecoregion 40 for nitrate of 0.23 milligram per liter in base-flow and runoff samples. Agricultural site base-flow samples generally were below the 0.23 milligram per liter criteria, but runoff samples from agricultural sites were all above the criteria at most sites. The smaller concentration of various nitrogen species, especially the most soluble and bio-available species (ammonia and nitrate), in prairie streams likely is because prairies are not fertilized like agricultural basins, and prairie basins are able to retain nitrogen better than agricultural basins. This retention is enhanced by increased infiltration of precipitation into the prairie soils and less direct runoff than in agricultural basins.

Total phosphorus concentrations were significantly less in base-flow and runoff samples from the prairie sites than in those from agricultural sites. Most total phosphorus samples from the prairie sites (median 0.01 milligram per liter) collected during base-flow conditions were less than the Environmental Protection Agency recommended criterion of 0.092 milligram per liter, whereas most of the total phosphorus concentrations in samples from the agricultural sites (median

0.09 milligram per liter) were greater than this recommended criterion. The decreased concentration of phosphorus in prairie streams compared with agricultural streams likely is because of a lack of fertilization in prairie basins, as well as decreased surface runoff, less erosion, and more infiltration that allow prairie soils to retain more phosphorus.

Concentrations in base-flow or runoff samples from the prairie sites did not exceed the maximum contaminant level of 3 micrograms per liter for atrazine or the maximum contaminant level of 2 micrograms per liter for alachlor. Because these compounds are not used in the prairie basins, concentrations of these agricultural chemicals in East Drywood Creek represent background concentrations for other streams in the region that cannot be removed without addressing airborne transport.

References Cited

Abel, P., 2005, Soil survey of Nemaha County, Kansas: U.S. Department of Agriculture, Natural Resources Conservation Service, 242 p.

Alexander, R.B., Smith, R., Schwarz, G., Boyer, E., Nolan, J., and Brakebill, J., 2008, Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin: Environmental Science and Technology, v. 42, no. 3, p. 822-830.

Bockhold, A.R., Thompson, A.L., Baffaut, C., and Sadler, E.J., 2006, Evaluating BMPs in a claypan watershed: Presentation at a meeting of the American Society of Agricultural and Biological Engineers, July 9-12, Portland, Oregon, 12 p.

Boggs, S., Jr., 1987, Principals of sedimentology and stratigraphy: Merrill Publishing Company, Columbus, Ohio, 784 p.

Brye, K.R., 2003, Long-term effects of cultivation on particle size and water-retention characteristics determined using wetting curves: Soil Science, v. 168, no. 7, p. 459-468.

Brye, K.R., Norman, J.M., Bundy, L.G., Gower, S.T., 2000, Water-budget evaluation of prairie and maize ecosystems: Soil Science Society of America Journal, v. 64, p. 715-724.

Colwell, R.K., 1974, Predictability, constancy and contingency of periodic phenomena: Ecology v. 55, p. 1148-1153.

Dodds, W.K., 2003, Misuse of inorganic N and soluble reactive P concentrations to indicate nutrient status of surface waters: Journal of the North American Benthological Society, v. 22, p. 171- 181.

Dodds, W.K., Gido, K., Whiles, M.R., Fritz, K.M., and Matthews W.J., 2004, Life on the edge: The ecology of Great Plains streams: Bioscience, v. 54, no. 3, p. 205-216.

Fenneman, N.M., 1938, Physiography of eastern United States: McGraw-Hill Book Company, Inc., New York, New York, 714 p.

Fenneman, N.M., and Johnson, D.W., 1946, Physiographic divisions of the conterminous United States: U.S. Geological Survey special map series, scale 1:7,000,000 accessed April 2009 at *http://water.usgs.gov/GIS/metadata/usgswrd/XML/physio.xml/*.

Fishman, M.J., and Friedman, L.C., 1989, Methods for the determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geologocial Survey National Water-Quality Laboratory-determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93-125, 217 p.

Fishman, M.J., Raese, J.W., Gerlitz, C.N., and Husband, R.A., 1994, U.S. Geological Survey approved inorganic and organic methods for the analysis of water and fluvial sediment, 1954-94: U.S. Geological Survey Open-File Report 94-351, 55 p.

Fuentes, J.P., Flury, M., Bezdicek, D.F., 2004, Hydraulic properties in a silt loam soil under natural prairie, conventional till, and no-till: Soil Science Society of America Journal, v. 68, p.1,679-1,688.

Gann, E.E., Harvey, E.J., and Barks, J.H., 1973, Water resources of northwestern Missouri: U.S. Geological Survey Hydrologic Investigations Atlas HA-444, 4 sheets.

Garbarino, J.R., and Struzeski, T.M., 1998, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory -- Determination of elements in whole-water digests using inductively coupled plasma-optical emission spectrometry and inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 98-165, 101 p.

Gerla, P.J., 2007, Estimating the effect of cropland to prairie conversion on peak storm run-off: Restoration Ecology, v. 15, no. 4, p. 720-730.

Grover, R., and Cessna, A., 1988, Environmental chemistry of herbicides: Adsorption and bioavailability in Soils: CRC Press, 312 p.

Heimann, D.C., Licher, S.S., and Schalk, G.K., 2007, Effects of impoundments and land-cover changes on streamflows and selected fish habitat in the upper Osage River Basin, Missouri and Kansas: U.S. Geological Survey Scientific Investigations Report 2007-5175, 96 p.

Helsel, D.R. and R. M. Hirsch, 2002, Statistical methods in water resources: U.S. Geological Survey Techniques of Water Resources Investigations, Book 4, Chapter A3, 522 p.

High Plains Regional Climate Center, 2008, Historical climate data summaries: accessed November, 2008 at *http://www.hprcc.unl.edu/data/historical/*.

Jastrow, J.D., 1987, Changes in soil aggregation associated with tallgrass prairie restoration: American Journal of Botany, v. 74, no. 11, p. 1,656-1,664.

Jones, H.G., 1983, Plants and microclimate: Cambridge University Press, Cambridge, U.K., 323 p.

Kansas Department of Health and Environment, 2005, Kansas Administrative Regulations (KAR), Title 28, Article 16, Surface water quality standards 2005: Topeka, Kansas, Secretary of State, variously paged.

Kansas Department of Health and Environment, 2008, Kansas integrated water quality assessment 2008: Kansas Department of Health and Environment, Division of Environment, Bureau of Environmental Field Services, Topeka, Kansas, variously paged, accessed June 2009 at *http://www.kdheks.gov/befs/download/2008IR_040108FINAL.pdf/*.

Kemp, M.J., and Dodds, W.K., 2002, Comparisons of nitrification and denitrification in prairie and agriculturally influenced streams: Ecological Applications, v. 12, no. 4, p. 998-1009.

Knox, J.C., 1977, Human impacts on Wisconsin stream channels: Annals of the Association of American Geographers, v. 67, no. 3, p. 323-342.

Knox, J.C., 2001, Agricultural influence on landscape sensitivity in the Upper Mississippi River Valley: Catena, v. 42, p. 193-224.

Konza Prairie Biological Station, 2008, Datasets of Konza aquatic studies: accessed November 2008, at *http://www.konza.ksu.edu/datasets/knzAquat.aspx?currMenu=35&depth=2/*.

Kuchler, A.W., 1964, Potential natural vegetation of the conterminous United States: American Geographical Society, New York, NY, Special publication no. 36, 1 sheet, accessed February 2009 at *http://www.ngdc.noaa.gov/ecosys/cdroms/ged_iib/datasets/b13/ek.htm/*.

Larson, L.W., 1983, Prairie State Park, Interpretation with preservation, *in* Kucera,C.L., ed., Proceeding of the seventh North American Prairie Conference, August 4-6, 1980, Southwest Missouri State University, Springfield, Missouri, p. 247-250.

Lauwo, S.Y., 2007, A modeling investigation of ground and surface water fluxes for Konza Tallgrass Prairie: Master of Science Thesis, Kansas State University, 161 p.

Macpherson, G.L., 1996, Hydrogeology of thin limestones: the Konza prairie long-term ecological research site, northeastern Kansas: Journal of Hydrology, v. 186, p. 191-228.

Mast, M.A., and Turk, J.T., 1999, Environmental characteristics and water quality of hydrologic benchmark network stations in the west-central United States, 1963-95: U.S. Geological Survey Circular 1173-C, 105 p.

Myers, D.N., Stoeckel, D.M., Bushon, R.N., Francy, D.S., and Brady, A.M.G., 2007, Fecal indicator bacteria (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chapter A7, section 7.1, accessed June 2009, at *http://water.usgs.gov/owq/FieldManual/Chapter7/7.1.html/*.

Miller, D.E., 1966, Geology and ground-water resources of Miami, County, Kansas: Kansas Geological Survey Bulletin 181, variously paged, accessed March 2009 at *http://www.kgs.ku.edu/General/Geology/Miami/index.html/*.

Miller, B., 2007, Prairie State Park celebrates 25 years: Missouri Department of Natural Resources, Division of State Parks, Tallgrass Tribune, Fall 2007, accessed Feburary 2009 at *http://www.mostateparks.com/prairie/newsletter.htm/*.

Miller, B., 2008, A new natural area is crafted: Missouri Department of Natural Resources Division of State Parks, Tallgrass Tribune, Fall 2008, accessed February 2009 at *http://www.mostateparks.com/prairie/newsletter.htm/*.

Missouri Department of Natural Resources, 2008, Rules of Department of Natural Resources: Division 20-Clean Water Commission, Chapter 7-Water Quality, Title 10 CSR 20.7.031, accessed March 2009 at URL *http://www.sos.mo.gov/adrules/csr/current/10csr/10c20-7.pdf/.*

National Climatic Data Center, 2002a, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971-2000: National Oceanic and Atmospheric Administration, Climatography of the United States No. 81, Report 23-Missouri, 35 p.

National Climatic Data Center, 2002b, Monthly station normals of temperature, precipitation, and heating and cooling degree days, 1971-2000: National Oceanic and Atmospheric Administration, Climatography of the United States No. 81, Report 14-Kansas, 37 p.

National Climatic Data Center, 2008, Record of Climatological Observations: accessed December 2008 at *http://cdo.ncdc.noaa.gov/dly/DLY/.*

Nigh, T.A., and Schroeder, W.A., 2002, Atlas of Missouri ecoregions: Missouri Department of Conservation, Jefferson City, Missouri, 212 p.

Pearcy, R.W., and Ehleringer, J., 1984, Comparative ecophysiology of C3 and C4 plants: Plant, Cell and Environment, v. 7, p. 1-13.

Pettyjohn, W.A., and Henning, Roger, 1979, Preliminary estimate of ground-water recharge rates, related streamflow and water quality in Ohio: Ohio State University Water Resources Center Project Completion Report Number 552, 323 p.

Rantz and others, 1982, Measurement and computation of streamflow-Volume 1. Measurement of stage and discharge: U.S. Geological Survey Water-Supply Paper 2175, 284 p.

Samson, F., and Knopf, F., 1994, Prairie conservation in North America: BioScience, v. 44, no. 6, p. 418-421.

Sartz, R.S., 1969, Effect of watershed cover on overland flow from a major storm in southwestern Wisconsin: U.S. Forest Service, North Central Forest Experiment Station, Research Note NC-82, 4 p.

Sartz, R.S., 1970, Effect of land use on the hydrology of small watersheds in southwestern Wisconsin: International Association of Scientific Hydrology, v. 96, p. 286-295.

Schroeder, W. A., 1982, Presettlement prairie of Missouri: Missouri Department of Conservation, Jefferson City, Missouri, Natural History Series Number 2, 8 p.

Sloto, R.A., and Crouse, M.Y., 1996, HYSEP: A computer program for streamflow hydrograph separation and analysis: U.S. Geological Survey Water-Resources Investigations Report 96-4040, 46 p.

Sullivan, P., Hellerstein, D., Hansen, L., Johansson, R., Koenig, S., Lubowski, R., McBride, W., McGranahan, D., Roberts, M., Vogel, S., and Bucholtz, S., 2004, The conservation reserve program: Economic implications for rural America: U.S. Department of Agriculture Economic Research Service, Agricultural Economic Report no. AER-834, 112 p.

Thurman, E.M., and Cromwell, A.E., 2000, Atmospheric transport, deposition and fate of triazine herbicides and their metabolites in pristine areas at Isle Royale National Park: Environmental Science and Technology, v. 34, p. 3,079–3,085.

The Nature Conservancy, 2009, Indicators of hydrologic alteration: version 7, User's Manual, accessed March 2009, at *http://www.nature.org/initiatives/freshwater/conservationtools/art17004.html/.*

Thom, R.H., Wilson, J.H., 1980, The natural divisions of Missouri: Transactions of the Missouri Academy of Science, v. 14, p. 9-23.

Toothaker, L.E., 1993, Multiple comparison procedures: Quantitative Applications in the Social Sciences: SAGE Publications Inc., Newbury Park, Calif, 104 p.

Tomko, S.E., and Hall, G.F., 1986, Changes in an Ohio prairie soil as the result of cultivation: Ohio Journal of Science, v. 86, no. 4, p. 171-176.

U.S. Department of Agriculture, 2009, Web Soil Survey: Natural Resources Conservation Service accessed March 2009 at *http://websoilsurvey.nrcs.usda.gov/app/.*

U.S. Environmental Protection Agency, 2000, Ambient water quality criteria recommendations: Rivers and streams in nutrient ecoregion IX: Washington, D.C., Office of Water, EPA 822–B–00–019, variously paged, accessed March 2009 at URL *http://www.epa.gov/waterscience/criteria/nutrient/ecoregions/rivers/rivers_9.pdf/.*

U.S. Environmental Protection Agency, 2003, National drinking water standards, June 2003: Washington D.C., Report EPA-816-F-03-016, accessed March 2009, at *http://www.epa.gov/safewater/contaminants/index.html/*.

U.S. Geological Survey, 2006, Collection of water samples (ver. 2.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, accessed February 2009 at *http://pubs.water.usgs.gov/twri9A4/*.

U.S. Geological Survey, 2008, National Water Information System: Web Interface, U.S. Geological Survey Surface-Water Data for the Nation, accessed December 2008 at *http://waterdata.usgs.gov/nwis/sw/*.

U.S. Geological Survey, 2009a, National Land Cover Database 2001 Land Cover Data, accessed March 2009 at *http://seamless.usgs.gov/website/seamless/viewer.htm/*.

U.S. Geological Survey, 2009b, National Water Information System: Web Interface, U.S. Geological Survey Water-Quality Data for the Nation, accessed February 2009 at *http://waterdata.usgs.gov/nwis/qw/*.

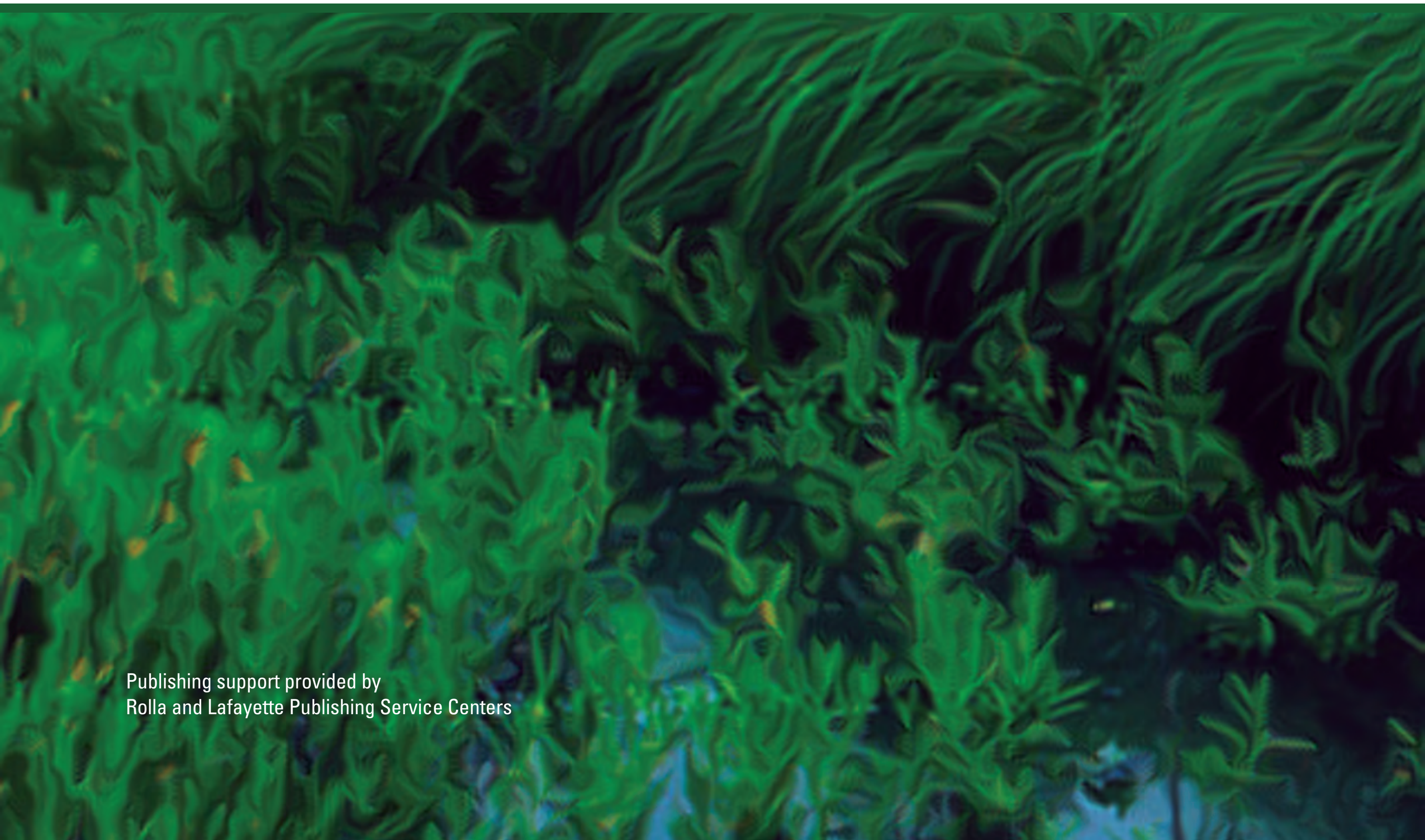
U.S. Geological Survey, 2009c, Aquatic ecoregions of the conterminous United States, accessed June 2009 at *http://water.usgs.gov/GIS/metadata/usgswrd/XML/ecoregion.xml/*.

van der Kamp, G., Hayashi, M., and Gallen, D., 2001, Comparing the hydrology of grassed and cultivated catchments in the semi-arid Canadian prairies: Hydrological Processes, v. 17, p. 559-575.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., eds., 2004, Processing of water samples (version 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A5, accessed February 2009 at *http://pubs.water.usgs.gov/twri9A5/*.

Wilde, F.D., ed., Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, accessed February 2009 at *http://pubs.water.usgs.gov/twri9A6/*.

Zaugg, S.D., Sandstrom, M.W., Smith, S.G., and Fehlberg, K.M., 1995, Methods of analysis by the U.S. Geological Survey National Water-Quality Laboratory-determination of pesticides in water by C-18 solid phase extraction and capillary-column gas chromatography/mass spectrometry with selected ion monitoring: U.S. Geological Survey Open-File Report 95-181, 60 p.



Publishing support provided by
Rolla and Lafayette Publishing Service Centers

David C. Heimann—**Comparison of Hydrologic and Water-Quality Characteristics of Two Native Tallgrass Prairie Streams**—Scientific Investigations Report 2009-5213