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Spatial Variability of Nonpoint Source Yields in Ozark Highlands Watersheds under Historical and Recent Land Use Conditions

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SPATIAL VARIABILITY OF NONPOINT SOURCE YIELDS IN OZARK HIGHLANDS WATERSHEDS UNDER HISTORICAL AND RECENT LAND USE CONDITIONS

A Master's Thesis
Presented to
The Graduate College of
Missouri State University

In Partial Fulfillment
Of the Requirements for the Degree
Master of Science, Geography and Geology

By
Tyler James Pursley
July 2021

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Geography, Geology and Planning

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ABSTRACT

Many of the environmental problems facing communities today stem from historical as well as present land use disturbances related to agriculture, urbanization, and resource extraction. It is important to evaluate a range of land use and soil effects on nonpoint source (NPS) pollution to fully understand land use-water quality relationships. The Ozark Highlands region has undergone significant phases of land use change throughout its settlement history and is actively developing today (2020). This study used nonpoint nitrogen (TN), phosphorus (TP), and sediment (TSS) yields predicted by the US EPA's Spreadsheet Tool for Estimating Pollutant Loads (STEPL) model to evaluate human influences on water quality in different landscapes across the Missouri Ozarks during three time periods: pre-settlement (before 1820), peak agricultural land disturbance (between 1890 and 1950), and present-day (2019). Twelve watersheds of similar size were selected among three land use types: urban, forest, and agriculture, and within three different physiographic regions of the Ozark Plateau including the Springfield Plateau, Salem Plateau and St. Francois Mountains. Historical records and modern databases describing settlement, land use history and landscape characteristics were used to develop and conduct modeling for each sub-watershed. Present-day TN yields averaged 9.3-times and TP and TSS yields averaged 4.4-times higher than pre-settlement yields. However, pre-settlement yields were relatively variable with ranges among all sites of 6.4-times for TN, 5.8-times for TP, and 13-times for TSS. Natural nutrient and sediment loads reflected ecological soil and landscape factors, however, modern yields are most directly tied to land use variables. Anthropogenic contributions to total yields average 81% for TN, 67% for TP, and 56% for TSS.

KEYWORDS: nonpoint source pollution, land use, pre-settlement, anthropogenic, STEPL, Ozark Highlands, Missouri

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I dedicate this thesis to Mom and Dad.

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INTRODUCTION

Human influences on the biosphere, including land, water and climate have increased beyond that of Earth's natural processes (Crutzen 2006). The subtle markers of human existence once left behind have evolved to become so great and obvious that it has potentially pushed humanity beyond the Holocene and into a new geologic epoch: the Anthropocene (Steffen et al. 2011). The Anthropocene is a proposed interval of geologic time that signifies the present period of global-scale human impact on Earth's geology (Lewis and Maslin 2015). Researchers have proposed various starting points to the epoch indicated by human-generated markers such as fossilized megafauna, fossilized pollen or high organic matter soils from the development of farming, ash from the industrial revolution and alterations of the global sediment flux from a range of human-induced geomorphic change (Zalasiewicz et al. 2011; Castree 2015). The escalation of agricultural practices, development of industry, mass deforestation and rapid expansion of urbanized areas are all contributing to the global footprint of the geologic period (Zalasiewicz et al. 2011). Human impacts, while evident at a global scale, begin locally as a land modification to support growing populations. With forests cleared for new farms, urban sprawl, and impounded waterways, many of the driving factors of the Anthropocene can be drawn back to the relationship between humans and the landscape.

The connection concerning land use change and water quality is well documented yet continues to be one of the most pervasive environmental problems today (Omernik 1977; Turner and Rabalais 1991; Tong and Chen 2002; Foucher et al. 2017; Kronvang et al. 2020). Anthropogenic forces have not only altered the geomorphology of streams with channelization and dam construction but, through the supply or limitation of sediment, minerals, metals, nutrients and other chemicals, humans have degraded aquatic health on a global scale (Dadson et al. 2013). Through various hydrologic processes of mobilization, transport and deposition, water serves as a vector by which surface pollutants and disturbances can move throughout the environment. Water quality is one way of evaluating the anthropogenic imprint of land use change and the direct impacts of humans within a watershed.

Watersheds form the collective hydrologic system of an area in which streams sensitive to changes in vegetation, impervious area, soil disturbance, and channel alteration can serve as an indicator of watershed condition (Young et al. 1989; Brabec et al. 2002; Jacobson 2004; Shields Jr. et al. 2010; Aulenbach et al. 2017). A watershed is an area of land in which all water sources drain to one outflow such as a lake, stream, or ocean. In a watershed, small-scale headwater disturbances can cause harmful impacts downstream (Sharpley and Rekolainen 1997; Pringle 2003). Whether through urban runoff, sewage discharge, sediment erosion or the transport of nutrients from agricultural fields, many watersheds throughout the United States are experiencing point and nonpoint source (NPS) pollutant loads above natural levels due to human activities (Alexander et al. 2002; Shields Jr. et al. 2010; Brown and Froemke 2012; Wu and Chen 2013). Excessive nutrient loads and sediment inputs have been associated with negative impacts such as eutrophication, dead zones, and the transport of toxic metals (Meade and Parker 1984). As opposed to point source pollution, which is released from a single and traceable outfall, nonpoint pollution (NPS) is washed off land surfaces by rainfall or snowmelt from diffuse sources such as agricultural lands, or impervious urban areas (Wang et al. 2005; Brown and Froemke 2012). Significant water quality improvements have been made since the passage of the 1972 Clean Water Act (CWA) in the United States, however, many of these gains have been made by reducing point source pollution while NPS pollution continues to impair waterways across the country (Brown and Froemke 2012). NPS pollution is the leading cause of water quality impairment in the United States (Baker 1992). Evaluating potentially harmful and difficult-to-trace NPS loads at the watershed scale allows for a deeper understanding of water quality at a localized level.

Water quality research in the United States began as early as the 1880s to assess urban sewage and wastewater pollution problems (Rauch 1889; Hoskins et al. 1927; Stets et al. 2012). Since the early 20th century, concerns over water quality have broadened to meet the concerns of the time whether it was point sources such as sewage and industrial waste or the modern concern of excess nutrients and other NPS pollutants (Rauch 1889; Murphy 1961; Brown and Froemke 2012). Congress passed the CWA in 1972 “to restore and maintain the chemical, physical, and biological integrity of the Nation’s waters” primarily by addressing point source concerns (Ongley et al. 2010; Stets et al. 2012). In 1984, the Environmental Protection Agency (EPA) published a report that suggested the nation’s primary threat to surface water quality had shifted to nonpoint pollution (Novotny and Chesters 1989). Nonpoint management by the CWA has been driven heavily by section 303(d) which requires states to establish and prioritize lists of waterways that do not meet state-set water quality standards and to impose Total Maximum Daily Loads (TMDL) (USEPA 1991).

Under present conditions, many of the water quality impairments in US streams are from nonpoint sources related to land use conditions such as agriculture, urbanization, and/or resource extraction (Bhaduri et al. 2000; Beman et al. 2005; Brown and Froemke 2012). Presently, 592,688 mi, or 53%, of all assessed stream miles in the United States were listed as threatened or impaired with nearly half of impairments in the United States stemming from agriculture (USEPA 2017). Nutrients, namely nitrogen (N) and phosphorus (P), and sediment (TSS) have been identified as significant NPS pollutants in today’s environment and are associated with over

260,000 stream miles listed as threatened or impaired (Carpenter et al. 1998; USEPA 2017). With population growth expected to continue, and demand for both urban development and agricultural products to match the increase, the study of land use and land use change as a driver of NPS pollutant loads has become integral to evaluating present-day water quality issues (Bhaduri et al. 2000; Bledsoe and Watson 2001; Clancy et al. 2018).

To fully understand NPS threats on a watershed in a modern context it is important to recognize the relationship between historical land use disturbances and modern waterways. Land use change can have both immediate and delayed impacts on NPS loads throughout a hydrologic system in the form of legacy sediment and attached pollutants (Allan 2010; James 2013; Frei et al. 2019; Pavlowsky et al. 2017). Legacy sediment is commonly recognized as sediment deposited in a floodplain following human disturbances including deforestation, agriculture, mining, and other post-settlement land use change (James 2013). NPS pollutants are often transported through a watershed or stored in legacy floodplain deposits (Dikau et al. 2005). Sediment storage can delay NPS transport and extend its release over several decades or centuries (Meade 1982; Storm and Mittelstet 2017). Fox et al. (2015) found that lands with a history of livestock presence and containment featured higher N, and P soil concentrations than surrounding grasslands. Frei et al. (2019) found that even with reductions in nutrient and fertilizer application, some watersheds continue to experience high levels of nutrient output resulting from the storage and delayed release of historical NPS loads.

While much of NPS risk can be linked to land use, the physical environment can influence land use decisions and amplify the effects of anthropogenic land use change on NPS pollution in a watershed. Natural vegetation, soil, and topography factors can influence watershed response to land use change and related NPS generation and transport (Dinnes 2004).

Different vegetation types offer varying levels of protection from soil erosion and can affect soil filtration capacities, uptake and absorption of NPS nutrients (Dinnes 2004). Additionally, soil characteristics, quality and condition can be altered or degraded by human activity in a relatively short period (Huang et al. 2018). Depending on vegetation and land use, a steeper topographic setting is likely to feature soils more susceptible to erosion purely due to slope length and steepness (Dinnes 2004; Wu and Chen 2013). Much of water quality and soil erosion research depends on the widely accredited Universal Soil Loss Equation (USLE) (Olivares et al. 2011; Misir and Misir 2012; Park et al. 2014; Yuan et al. 2020). The USLE relies on a combination of landscape factors including soil erodibility (K), topographical (LS) and cover factors (C) (Bingner and Theurer 2001; Zakeri et al. 2020). Natural and anthropogenic forces combine to influence watershed response to land use change and related NPS water quality impairments.

Water quality degradation is occurring on a global scale, thus monitoring water quality and its relationship to land use and the physical environment is instrumental in understanding and managing potentially disturbed hydrologic systems. Through monitoring stations or sample collection, water quality parameters can be analyzed and evaluated with high accuracy. However, assessing NPS pollution at a regional scale using only sample-based water quality methods is time, resource and cost restrictive. To cut both the time and financial costs of physical water quality monitoring, much of modern land use research and management has focused on the use of digital modeling systems (Donigian Jr. and Imhoff 2006). Water quality models can be developed to address specific research needs like NPS source identification or to evaluate the effectiveness of management practices (Park et al. 2014). Models of varying complexities depend on existing hydrological relationships and previous water quality research to produce simulations or estimations of NPS outputs to assess water quality issues at local, and regional scales (Corwin et al. 1997; Walega et al. 2020). Complex models allow for the simulation of streamflow, sediment, and nutrient transport whereas simpler models such as the US EPA's Spreadsheet Tool for Estimating Pollutant Loads (STEPL) give a more summative look at the total output of a watershed. Models can be used in conjunction with water quality monitoring or as a standalone resource.

This research compares historical NPS loads of N, P and TSS to present loads to evaluate the relationship between land use change and water quality in the Ozark Highlands. Water quality conditions predicted by the STEPL model are used to assess the effects of human-induced land use change on different landscapes across the Missouri Ozarks during three time periods: pre-settlement (before 1820), peak land disturbance (between 1890 and 1950), and present-day (2019). Twelve watersheds of similar size were selected among three present land uses (urban, forest, and agriculture) and locations within three physiographic regions of the Ozark Plateau including the Springfield Plateau, Salem Plateau, and St. Francois Mountains. Historical records and modern databases describing settlement, land use history, and landscape characteristics are used to develop and conduct modeling for each location. The results provide insight into historical water quality relationships of the study area, as well as context to present conservation and management plans.

Background

Nonpoint Source Pollution. Nutrients such as nitrogen (N) and phosphorous (P) exist naturally in most aquatic environments and are essential nutrients for many plants and wildlife (Gruber and Galloway 2008; Kovar and Pierzynski 2009; Brown and Froemke 2012). Additionally, suspended sediments, or collections of soil and rock particles transported within a stream's flow, are present under natural stream conditions (McCarney-Castle et al. 2010).

However, resulting from developed land use, increased runoff, excessive fertilizer application, and erosion, nutrient levels in many streams across the country and the Ozarks exceed the threshold for a healthy aquatic system (Meade and Parker 1984; Petersen et al. 1998; Shock and Pratt 2003). NPS loads in the United States are five times higher than point source counterparts (Carpenter et al. 1998). Streambank erosion has been estimated to have increased 10 to 15 times since early European settlement (Mittelstet et al. 2017). NPS loads transported through surface runoff or sediment erosion have become detrimental to surface and groundwater quality, in large part due to anthropogenic forces (Chesters and Schierow 1985; Sharpley et al. 1994; Sugiharto et al. 1994; Carpenter et al. 1998; Khan et al. 2018). In 2011, approximately 50 percent of all streams in the United States were found to have medium to high levels of both N and P, with N loads doubling between 1950 and 2000 (Alexander et al. 2002; Stoner 2011).

Excessive inputs of N and P to waterways have been strongly linked to increased eutrophication in surface waters (Fluck et al. 1992; Hart et al. 2004). This can lead to oxygen depletion, algal blooms and related losses of plants and wildlife (Smith et al. 1999; Foley et al. 2005). Hypoxia, or "dead zones," occur through the stratification of a water column by which oxygen-rich surface water becomes isolated from that in the lower levels and, through the decomposition of aquatic life and organic matter, oxygen is reduced throughout the bottom waters for an extended period (Diaz 2001). Hypoxia intensity varies; however, low dissolved oxygen can stress aquatic ecosystems and has been linked to fish kills, habitat loss, fish emigration, declines in biodiversity and related declines in commercial fish landings (Diaz 2001; Breitburg 2002). Suspended sediment can add to problems of hypoxia by decreasing dissolved oxygen (Lee and Jones 1999). Suspended sediment can also transport heavy metals, pathogens and other pollutants while increasing turbidity, changing water chemistry, and limiting water clarity/light penetration (Lemly 1982; Kerr 1995; Jacobson and Gran 1999; Haggard 2003; Besser et al. 2009; Brown and Froemke 2012). Furthermore, in-channel sediment deposition can lead to increased flood risks (Meade and Parker 1984). All of these can reduce biological processes such as photosynthesis or fish reproduction, productivity and fish, plant and invertebrate habitat (Kerr 1995).

Land Use Change and Water Quality. Land use or land use change is defined as the process by which human activity alters, or transforms the natural landscape (Bimal and Harun 2017). Land use research has become integral to the assessment of anthropogenic effects on the environment and water quality (Clancy et al. 2018; Kronvang et al. 2020). Nearly all research suggests a link between land use and water quality, and many indicate agricultural and urban watersheds as the largest polluters (Bhaduri et al. 2000; Shirinian-Orlando and Uchrin 2007). Agricultural lands are the leading source of N and P pollution with rates as high as nine times that of forested watersheds, and seven times that of urban development (Omernik 1977; Smart et al. 1985; Tong and Chen 2002; Foucher et al. 2017). Brown and Froemke (2012) found that areas featuring the most significant impairments due to NPS were those supporting agriculture and cultivation where transport of excessive nutrients from fertilizer and livestock manure occurs through runoff. The total application of N-fertilizers has increased in the United States by nearly 20 times since the 1950s (Donner et al. 2004). Estimates suggest that from 10-40% of total applied N fertilizer makes it to waterways (Howarth et al. 1996). Due in part to the scale of NPS contribution from fertilizers and farmland, the primary emphasis of NPS research in recent decades has been on the impacts of agricultural runoff, however, urban environments are also heavy contributors (Wolman 1967; Arnold and Gibbons 1996; Bhaduri et al. 2000).

Residential and urban development have been leading forces in land use change as populations increase and urbanized regions are forced to expand (Wolman 1967; Bledsoe and Watson 2001; Grau and Aide 2008). Since the passage of the CWA in 1972, urban land has continued to increase and only recently has urban stormwater been recognized for its influence on surface water quality (Zivkovich and Mays 2018). In most circumstances, urban expansion comes with a loss of vegetation and more impervious surfaces which increase peak discharge magnitudes, runoff rates and NPS transport (Wolman 1967; Bhaduri et al. 2000; Bledsoe and Watson 2001; Zivkovich and Mays 2018). Bledsoe and Watson (2001) found that 10 to 20 percent impervious surface within a watershed can increase channel instability and aquatic ecosystem impairment. In the EPA's 1992 nationwide assessment, urban runoff was found to be the second-largest contributor to water pollution for lakes and estuaries and the third-largest for rivers (USEPA 1994). As populations migrate from rural communities to more developed cities, the impervious surface is only expected to increase, further amplifying negative water quality effects (Kersten 1958; Wolman 1967; Bledsoe and Watson 2001).

Ozarks Land Use History and Water Quality. The Ozark Plateau has experienced drastic phases of land use change across its history including the conversion of land for agriculture, intensive commercial logging, city development, and mining (Jacobson and Primm 1997). Many early historical accounts of the Ozarks describe a different environment than is seen today with upland areas featuring prairies, and oak savannas with valley slopes and bottoms full of thick, deciduous and pine forests (Jacobson and Primm 1997). One of the most significant changes of the Ozarks native landscape is the net conversion of shrub, brush, prairie and evergreen forest land to deciduous forest (Jacobson and Primm 1997). As populations in the Ozarks increased over the past century, expansion of agricultural and urban areas has led to continued forest clearing, and prairie loss (Jacobson and Primm 1997). Additionally, settlements in the region have often been located on or near rivers, streams, or other water bodies which has intensified the negative effects of land use change in the region (Herring 1978).

The diverse land use histories of the Ozark Plateau have promoted several regional water quality studies since the mid-1990s (Davis et al. 1995; Petersen et al. 1998; Lopez et al. 2008). In general, changes in water chemistry and pollutant loads have been related to land use practices more so than geology or soil (Smart et al. 1985; MDNR 2010a). The USGS National Water-Quality Assessment (NAWQA) found links between agricultural and urban land use and increased nutrient loads in the Ozarks region although very little research has been conducted since the late 1990s (Davis et al. 1995; Petersen et al. 1998). Largely as a result of increased agricultural activity and human population, the Springfield Plateau features higher nutrient loads in its streams than are present in the Salem Plateau, and St. Francois Mountains (Adamski et al. 1995; Petersen et al. 1998; Haggard 2013). Additionally, research has found early historical erosion potential in the Ozark highlands can be attributed to periods of heavy agricultural development (Jacobson and Primm 1997). More recently, Ozark streams and reservoirs have experienced excessive nutrient loads and related algal growth (MDNR 2004a; MDNR 2004b). Furthermore, several reports have found positive links between mining as a source of water pollution and/or stream disturbance (Petersen et al. 1998; Jacobson 2004; Owen et al. 2011; Pavlowsky et al. 2017). Nutrient-based research in this area is limited and any regional assessments have not been updated in over two decades (Smart et al. 1985; Davis et al. 1995; Petersen et al. 1998). Available research in the region has provided a foundation for water quality research, however, the historical effects of development and land use change on NPS such as N, P, and suspended sediment have not been developed fully.

Purpose and Objectives

The purpose of this study is to evaluate anthropogenic effects on Ozark watersheds through land use and water quality relationships using the US EPA Spreadsheet Tool for Estimating Pollutant Loads (STEPL). This study will provide up-to-date land use and NPS research to the region and demonstrate the flexibility and benefit of using a simple modeling approach for regional water quality analysis. The US EPA STEPL model is a spreadsheet-based modeling tool that uses simple algorithms to estimate surface runoff, and associated pollutant loads such as N, P, and sediment according to land use at the watershed and sub-watershed scale (Tetra Tech 2018). STEPL is a highly customizable model in which most default, model-provided, input values can be adjusted or replaced with user inputs according to the conditions of the selected study area. The STEPL model is open-access and provides an accurate and economical means of assessing runoff, total suspended sediment, total nitrogen, and total phosphorous loads for the number of watersheds featured in this study. Additionally, the ability to customize STEPL allows for appropriate adjustments to be made to suit the land characteristics of pre-settlement, peak-disturbance, and present-day conditions to assess a range of water quality impacts during recent (post-1800) Ozarks history.

The watersheds for the study were distributed throughout each of the three regions of the Missouri Ozarks and selected according to present-day land use conditions of agriculture, urban or forest. Furthermore, each region represents a unique geologic and soil setting as well as a history of land use and vegetation change. The Ozarks are subdivided into four primary physiographic regions including the Springfield Plateau, Salem Plateau, St. Francois Mountains of Missouri, and the Boston Mountains of Arkansas. The diverse landscape characteristics and histories behind each region and watershed provide the ability for an expanded comparison of

NPS loads by land use and the assessment of regional variations in geography, geology, and pre-settlement conditions as an influence on water quality. Understanding the geography of these relationships in the Ozarks allows for an opportunity to evaluate the human footprint on regional watersheds (Woolmer et al. 2008).

This study will address the following questions:

1. How do nonpoint pollutant loads of selected watersheds compare across different phases of development (pre-settlement, peak-disturbance, and present-day), and how does this affect the relationship between land use change and various environmental conditions?
2. Under what geological and land use conditions are watersheds most susceptible to the effects of land use change in terms of sediment and nutrient loads?
3. How can the history of Ozarks land use be applied to the present relationship between humans, the landscape, and watershed management in the future?

Benefits of Research

This study will evaluate the influence of natural factors and anthropogenic land use change on NPS pollution across the Ozarks to expand upon limited NPS research and aid in better understanding regional NPS pollution through the lens of the STEPL model. While STEPL has been used to assess watersheds, evaluate best management practices, and develop management plans throughout present-day Missouri, NPS model output as it relates to natural, pre-settlement conditions and land use change over time is not well understood (Adams et al. 2019; Jordan et al. 2019; Reminga et al. 2019; Owen et al. 2020). This research will add to a limited collection of available STEPL literature and explore new applications of the model in a historical context. Finally, the results of this research will provide support and focus to local and regional government management programs for water quality related to nutrients and sediment.

STUDY AREA

Study watersheds were selected across the three major physiographic regions of the Missouri Ozarks and seven ecoregion subsections. The Missouri Ozarks can be divided into three major physiographic regions including the Springfield Plateau, Salem Plateau, and St. Francois Mountains (Figure 1) (Adamski et al. 1995; Jacobson and Primm 1997). The Springfield Plateau’s fertile soils and broad uplands historically supported row-cropping and the largest proportion of farmland in the Ozarks, however, the region’s present land use has become defined by cattle-raising and urban growth (Nigh and Schroeder 2002). The Salem Plateau covers the majority of the Ozarks and is generally defined by rolling hills, dense forest and karst topography. Typically not well suited for agriculture, the Salem Plateau has relied on extractive industries and its rich logging history (Rafferty 1992; Jacobson and Primm 1997; Nigh and Schroeder 2002; Cunningham 2006; Guldin et al. 2008). In stark contrast to the other regions, the St. Francois Mountains’ steep relief, igneous terrane and dense forests have experienced extensive rock quarrying and lead mining (Nigh and Schroeder 2002; Mugel 2016).

To develop a more detailed regional approach, each of the three physiographic regions can be further divided into ecoregion subsections according to the Missouri Department of Conservation (DNC) Atlas of Ecoregions (Nigh and Schroeder 2002). Each region and ecoregion subsection represents a unique physical and human historical setting for the evaluation of human-induced land use change, and disturbance in the Ozarks. This research focuses on twelve watersheds at the Hydrologic Unit Code (HUC) 12 sub-watershed scale throughout the Springfield Plateau, Salem Plateau and St. Francois Mountains. Furthermore, Springfield Plateau sub-watersheds are divided between the Springfield Plain and Elk River Hills ecoregion subsections (Nigh and Schroeder 2002). Salem Plateau sub-watersheds are distributed among the Prairie Ozark Border, Central Plateau, Current River Hills, and White River Hills subsections (Nigh and Schroeder 2002). Finally, the St. Francois Mountains sub-watersheds are classified within the St. Francois Knobs and Basins ecoregion (Nigh and Schroeder 2002).

General watershed information can be found in Tables 1-3. Watersheds were selected to develop an expanded comparison of NPS loads by land use while assessing regional variations in geography, geology, and pre-settlement conditions in watersheds across the Ozarks. Selections were made largely according to present-day land use obtained from the United States Department of Agriculture-National Agricultural Statistics Service (USDA-NASS) as well as physical geography, land use history and pre-settlement vegetation descriptions found in Nigh and Schroeder's Atlas of Ecoregions (Nigh and Schroeder 2002). Watersheds featuring a range of urban, cropland, pasture and forested land use were identified throughout each of the physiographic regions and native vegetation types including prairie, savanna, and pine and hardwood forest. Of the twelve watersheds in this study, there are a total of ten watersheds divided between the Springfield and Salem Plateaus. The remaining two watersheds are in the St. Francois Mountains region. Watersheds in the Springfield and Salem Plateaus include two primarily urban, four agricultural, and four forested land use/land cover split between the regions for a total of five each. Furthermore, to cover a range of land use, agricultural watersheds were subdivided to include a watershed of primarily pasture, and one of cropland. The St. Francois Mountains cover a smaller area of the Ozarks, thus only two watersheds were chosen including one agricultural and one forest.

Springfield Plateau sub-watersheds include Headwaters Wilsons Creek (HUC110100020301), Mikes Creek (HUC110702080106), Kings Valley-Big Sugar Creek (HUC110702080108), Stahl Creek (HUC110702070106) and Headwaters North Fork Spring River (HUC110702070201). Salem Plateau sub-watersheds include Middle Burris Fork (HUC103001021105), Headwaters Lindley Creek (102901070201), Headwaters Howell Creek (HUC110100100201), Big Barren Creek (HUC110100080606) and Zachs Branch-North Fork River (HUC110100060110). Lastly, the St. Francois Mountains region includes the Headwaters East Fork Black River (HUC110100070201) and Headwaters Cedar Creek (HUC071401040103) sub-watersheds. All sub-watersheds are described below according to their ecoregion subsection (Figure 2).

Springfield Plain Subsection. The Headwaters Wilsons Creek, Stahl Creek, and Headwaters North Fork Spring River sub-watersheds are located on the Springfield Plain subsection within the Springfield Plateau. The Springfield Plain is underlain by cherty Mississippian-age limestone, primarily of the Burlington formation, with karst landscape and local relief of less than 30 m (Nigh and Schroeder 2002). Sinkholes, springs and caves are common and are particularly recurrent in and around the Headwaters Wilsons Creek sub-watershed (Nigh and Schroeder 2002). Soils in this subsection are generally deep moderate to well-drained Alfisols or Ultisols (Nigh and Schroeder 2002). This subsection functions as a transitional area between the plains to the west, and the more traditional woodlands of the Ozarks (Nigh and Schroeder 2002; USEPA, 2020). The Springfield Plain was initially settled during the 1820s and 1830s with rural populations peaking in the early 19th century (Nigh and Schroeder 2002). However, the extent to which areas were settled varies widely across the Springfield Plain. The region's agriculture depended largely on livestock, corn and wheat throughout the 19th century (Nigh and Schroeder 2002). The Springfield Plain has continued to be dominated by pasture and cropland with hilly areas holding much of the remaining forest (Nigh and Schroeder 2002). Presently, the Headwaters Wilsons Creek (Wilsons Creek) sub-watershed is 80% urban, 12% agricultural, and 8% forested. This urban area is largely made up of the city of Springfield, Missouri, which is the third-most populous city in the state with roughly 167,000 residents (US Census Bureau 2019). Headwaters Wilsons Creek contains more acres in urban land use than the combined urban area in all other watersheds in this study. The Stahl Creek (Stahl Creek) sub-watershed is 78% agricultural, 16% forested and 6% urban. Miller City is the largest in the sub-watershed with a population of roughly 700 residents (US Census Bureau 2019). The Headwaters North Fork Spring River (Spring River) sub-watershed is 90% agricultural, 7% forested, and only 3% urban. Agricultural land in this sub-watershed is primarily used for cropland while Stahl Creek features a larger proportion of agricultural land in pasture. There are no cities in the Headwaters North Fork Spring River sub-watershed.

NPS concerns in this region are generally associated with excessive nutrients, sediment, and E. coli from a mix of urban and agricultural sources (MDNR 2004a; USEPA 2006; MDNR 2020). Headwaters Wilsons Creek features 17 km of streams classified as "impaired" according to Section 303(d) of the Clean Water Act (MDNR 2020). The primary source of impairment for the three waterways is urban NPS pollution (MDNR 2020). Additionally, Wilsons Creek drains directly into the James River for which a TMDL (Total Maximum Daily Load) targeting excessive nutrients from NPS has been imposed (MDNR 2004a). Headwaters North Fork Spring River contains 9 km of impaired streams resulting from rural NPS (MDNR 2020). Stahl Creek sub-watershed has no impaired streams; however, both Stahl Creek and Headwaters North Fork

Spring River are contributors to the larger Spring River which has been declared impaired due to rural NPS for Escherichia coli (MDNR 2020).

Elk River Hills Subsection. The Mikes Creek and Kings Valley-Big Sugar Creek sub-watersheds are in the southernmost Missouri portion of the Springfield Plateau in the Elk River Hills subsection (Nigh and Schroeder 2002). The Elk River Hills are underlain by cherty Mississippian-age limestone formations (Nigh and Schroeder 2002). While springs are common, sinkholes and losing streams are less common in the Elk River Hills subsection than in the Springfield Plain (Nigh and Schroeder 2002). Topography is characterized by steep-sloped hills with narrow ridges and valleys (Nigh and Schroeder 2002). Local relief is relatively high for the Springfield Plateau at 46-107 m (Nigh and Schroeder 2002). Elk River Hills soils generally include a combination of deep and shallow moderately drained Ultisols (Nigh and Schroeder 2002). Historically, the Elk River Hills featured a blend of oak savanna and oak woodland (Nigh and Schroeder 2002). American settlement of this region began in the early 1830s-1840s with small-scale agriculture in valley bottoms and livestock range in woodland areas (Nigh and Schroeder 2002). Presently, the Mikes Creek (Mikes Creek) sub-watershed is 87% forested, 10% in pastureland and only 3% urban. Kings Valley-Big Sugar Creek (Sugar Creek) is 78% forested, 17% pastureland, and 4% urban. There are no cities in Mikes Creek or Kings Valley-Big Sugar Creek sub-watershed.

NPS pollution in this region is commonly linked to livestock production, primarily confined to large-scale poultry production beginning in the 1980s-90s (MDNR 2004b). There are no 303(d) impaired or TMDL listed streams in the Mikes Creek sub-watershed, however, Mikes Creek drains directly into Big Sugar Creek on the eastern border of the Kings Valley-Big Sugar Creek sub-watershed. Big Sugar Creek, 13.5 km of which flows through the Kings Valley-Big

Sugar Creek sub-watershed, was classified as impaired in 1998 due to excessive nutrients stemming from livestock production (MDNR 2004b). To reduce N and P inputs, Big Sugar Creek has been under TMDL guidelines since 2004 (MDNR 2004b).

Prairie Ozark Border Subsection. Middle Burris Fork is the northernmost sub-watershed in the study located along the northern boundary of the Salem Plateau in the Prairie Ozark Border subsection. The Prairie Ozark Border is underlain by Ordovician dolomite and Mississippian-age limestone (Nigh and Schroeder 2002). Topography is characterized by rolling plains and local relief of less than 30 m (Nigh and Schroeder 2002). Soils in this subsection are generally very deep and poorly drained Alfisols (Nigh and Schroeder 2002). Before Euro-American settlement, this subsection would have been more than 80% tallgrass prairie with scattered oak savanna (Nigh and Schroeder 2002). The Prairie Ozark Border and Springfield Plain are the only ecoregion subsections in the Ozark Highlands that would have featured prairies of this extent (Nigh and Schroeder 2002). Early settlement in the region began in the 1820s with most of the subsection covered by farms by 1850 (Nigh and Schroeder 2002). Prairies were used for stock raising, with croplands of corn, wheat and oats throughout (Nigh and Schroeder 2002). Presently, Middle Burris Fork (Burris Fork) is 70% agricultural, 26% forested, and 4% urban. There are no cities or 303(d) impaired streams in Middle Burris Fork.

Central Plateau Subsection. The Headwaters Lindley Creek and Headwaters Howell Creek are found within the Central Plateau subsection of the Salem Plateau. The Central Plateau is underlain by Ordovician-age dolomites with some sandstones (Nigh and Schroeder 2002). Topography is characterized by gentle slopes with slopes steepening near drainage lines as a result of the solution of largely carbonate bedrock. Local relief is 15-46 m (Nigh and Schroeder 2002). The region features common surface karst characteristics including springs, and sinkholes

(Nigh and Schroeder 2002). Soils in this subsection are generally very deep and well drained Alfisols (Nigh and Schroeder 2002). Historically, the area contained a mixture of tallgrass prairies, oak savanna, and woodlands (Nigh and Schroeder 2002). Settlement of the Central Plateau began in the 1830s and continued slowly through the 1880s (Nigh and Schroeder 2002). The Central Plateau featured some of the last areas settled for agricultural use in the Ozarks (Nigh and Schroeder 2002). The area consisted primarily of small farms and open grazing until the middle twentieth century (Nigh and Schroeder 2002). Presently, the Headwaters Lindley Creek (Lindley Creek) sub-watershed is roughly 71% agricultural with most of that land in pasture, 22% forested, and 7% developed or urban. A portion of southwest Buffalo, Missouri is contained within the sub-watershed. The city of Buffalo has a population of roughly 3,000 residents (US Census Bureau 2019). Headwaters Howell Creek (Howell Creek) is 43% agricultural, 37% forested and 20% urban. The Headwaters Howell Creek sub-watershed features the largest urban area of the five sub-watersheds being evaluated in the Salem Plateau, West Plains, Missouri. West Plains had an estimated 12,300 residents in 2019 (US Census Bureau 2019). There are no 303(d) impaired streams in Headwaters Lindley Creek or Headwaters Howell Creek.

Current River Hills Subsection. Big Barren Creek is the sole sub-watershed selected from within the Current River Hills subsection of the Salem Plateau. The Current River hills are underlain with a variety of sandstones and dolomites of the Ordovician period (Nigh and Schroeder 2002). The region is hilly with narrow ridges, steep slopes and narrow valleys and relatively high local relief ranging 61-183 m (Nigh and Schroeder 2002). Karst topography is common with large numbers of sinkholes, springs, and losing streams throughout the subsection. Soils in this subsection range from shallow to very deep and well to moderately well-drained

Ultisols (Meinert et al. 1997; Nigh and Schroeder 2002). Under historical conditions, the region was overwhelmingly shortleaf pine-oak forest with as much as 50-60 percent pine (Nigh and Schroeder 2002; Guyette et al. 2006; Brice et al. 2012). Early settlers came to the region in the 1820s-1830s with most arable land becoming occupied by the 1860s (Nigh and Schroeder 2002). Toward the end of the 19th century, the region underwent a period of exploitive timber harvest that ended when pine and hardwood supplies were depleted in the early 1920s (Nigh and Schroeder 2002). It is estimated that only 20-50 percent of the Ozarks native pine extent remains (Guyette et al. 2006; Hanberry et al. 2012). Presently, the Big Barren Creek (Big Barren) sub-watershed is 92% forested with only 5% of land in agricultural use and 3% urban. There are no cities or 303(d) impaired streams in Big Barren Creek.

White River Hills Subsection. The Zachs Branch-North Fork River sub-watershed is in the White River Hills subsection of the Salem Plateau. The White River Hills are underlain with Ordovician-age dolomites with karst features found predominantly in eastern portions of the subsection (Nigh and Schroeder 2002). The White River Hills are characterized by steep-sloped hills with narrow valleys and high local relief ranging from 91-244 m (Nigh and Schroeder 2002). Soils in this subsection generally range between shallow and very deep well-drained Alfisols (Nigh and Schroeder 2002). Historically, this area was dominated by open-oak savannas, hardwood forests, and dolomite glades found on ridges, hills or knobs (Nigh and Schroeder 2002). Permanent settlers entered the region in the 1830s and scattered farms throughout valley bottoms (Nigh and Schroeder 2002). Wooded areas were commonly used for raising livestock (Nigh and Schroeder 2002). Rural populations peaked in the early 1920s (Nigh and Schroeder 2002). Presently, the Zachs Branch-North Fork River (North Fork) sub-watershed is 76% forested, 20% pastureland, and 3% urban. There are no cities or 303(d) impaired streams in the Zachs Branch-North Fork River sub-watershed.

St. Francois Knobs and Basins Subsection. The Headwaters East Fork Black River and Headwaters Cedar Creek sub-watersheds are located within the St. Francois Mountains region and St. Francois Knobs and Basins subsection of the Missouri Ozarks. The St. Francois Mountains are within the Salem Plateau contain the oldest geologic formations of granite and basalt in the state with a starkly different volcanic terrain compared to its karst surroundings (Nigh and Schroeder 2002; USEPA 2020). The topography is notably steeper than surrounding areas with local relief as high as 305 m but around 122-213 m on average (Nigh and Schroeder 2002). Missouri's highest peak elevation is located at the summit of Taum Sauk Mountain (540 m) in the St. Francois Mountains (Nigh and Schroeder 2002; USEPA 2020). Soils in this subsection are generally moderately deep and moderately well-drained Ultisols (Nigh and Schroeder 2002). Pre-settlement vegetation would have been almost entirely oak and oak-pine mixed forests with minor tracts of prairie and glades in valley bottoms (Nigh and Schroeder 2002). French settlers began mining for lead in the area as early as 1720 with some iron mining occurring in the region before 1820 (Nigh and Schroeder 2002). American agricultural settlers didn't enter the region until just before 1800 (Nigh and Schroeder 2002). By 1860, all arable land was occupied and by the early 20th century rural populations peaked and began to decline (Nigh and Schroeder 2002). Presently, the Headwaters East Fork Black River (Black River) sub-watershed is 96% forested, with agricultural and urban areas combining for the remaining 4%. In contrast, the Headwaters Cedar Creek (Cedar Creek) sub-watershed is 70% forested, with 28% in cropland or pastureland, and 2% in urban land use. There are no cities in Headwaters East Fork Black River or Headwaters Cedar Creek.

NPS pollution concerns for the St. Francois Mountains region largely result from lead, zinc and other metal mine waste from the Old Lead Belt, Mine La Motte, and Annapolis mining sub-districts (MDNR 2010a; MDNR 2010b ; Mugel 2016). The St. Francois Knobs and Basins subsection has experienced lead mining to varying extents over the last 300 years (Nigh and Schroeder 2002). Beginning with French surficial mines in the early 1720s and propelled by the large-scale mining in the Old Lead Belt in the early 1900s, (Nigh and Schroeder 2002; Pavlowsky et al. 2017). At the closure of the last mine in the Old Lead Belt in 1972, the sub-district had produced 10.8 million Mg of lead and zinc during its operation (Pavlowsky et al. 2017). There are currently no 303(d) impaired waterways in the Headwaters East Fork Black River or Headwaters Cedar Creek sub-watersheds, however, Big River, which flows out of the region to the north, is under TMDL management for lead, zinc, and sediment and listed as impaired for cadmium from mine tailings (MDNR 2010a; MDNR 2020). Additionally, Village creek near Fredericktown, Missouri in the eastern portion of the region is under TMDL management for lead and sediment sourced from abandoned mine land (MDNR 2010b).

Table 1. General watershed geography and characteristics.

ID	Watershed	12-Digit HUC Code	Physiographic Region	Ecoregion Subsection	Primary County	Secondary County
1	Headwaters Wilsons Creek	110100020301	Springfield Plateau	Springfield Plain	Greene	-
2	Mikes Creek	110702080106	Springfield Plateau	Elk River Hills	McDonald	Barry
3	Kings Valley-Big Sugar Creek	110702080108	Springfield Plateau	Elk River Hills	McDonald	-
4	Stahl Creek	110702070106	Springfield Plateau	Springfield Plain	Lawrence	-
5	Headwaters North Fork Spring River	110702070201	Springfield Plateau	Springfield Plain	Dade	Lawrence
6	Middle Burris Fork	103001021105	Salem Plateau	Prairie Ozark Border	Moniteau	Morgan
7	Headwaters Lindley Creek	102901070201	Salem Plateau	Central Plateau	Dallas	Polk
8	Headwaters Howell Creek	110100100201	Salem Plateau	Central Plateau	Howell	-
9	Big Barren Creek	110100080606	Salem Plateau	Current River Hills	Carter	Ripley
10	Zachs Branch-North Fork River	110100060110	Salem Plateau	White River Hills	Douglas	Ozark
11	Headwaters East Fork Black River	110100070201	St. Francois Mountains	St. Francois Knobs and Basins	Iron	Washington
12	Headwaters Cedar Creek	071401040103	St. Francois Mountains	St. Francois Knobs and Basins	Iron	Reynolds

Table 2. General watershed land cover/land use.

ID	Abbreviated Watershed Name	Pre-settlement Land Cover	Present Land Use	Peak-disturbance Year
1	Wilsons Creek	Prairie	Urban	1910
2	Mikes Creek	Hardwood	Forest	1950
3	Sugar Creek	Hardwood	Forest	1950
4	Stahl Creek	Prairie	Agricultural	1945
5	Spring River	Prairie	Agricultural	1910
6	Middle Burris	Savanna	Agricultural	1900
7	Lindley Creek	Hardwood	Agricultural	1920
8	Howell Creek	Hardwood	Urban	1900
9	Big Barren	Mixed-Pine	Forest	1920
10	North Fork	Hardwood	Forest	1950
11	Black River	Mixed-Pine	Forest	1890
12	Cedar Creek	Hardwood	Agricultural	1945

Table 3. Physical watershed characteristics.

ID	Area (km^2)	Relief (m)	Dominant Geology	Dominant Soil Order(s)	Annual Rainfall (cm)
1	130.2	85	Mississippian Limestone	Alfisols/Mollisols	106.7
2	96.4	195	Mississippian Limestone	Alfisols	114.3
3	114.1	148	Mississippian Limestone	Mollisols/Ultisols	114.3
4	82.7	92	Mississippian Limestone	Alfisols	106.7
5	134.0	77	Mississippian Limestone	Alfisols	106.7
6	78.4	68	Ordovician Dolomite	Alfisols	101.6
7	62.9	101	Ordovician Dolomite	Alfisols	104.1
8	134.9	112	Ordovician Dolomite	Alfisols/Ultisols	111.8
9	106.1	189	Ordovician Dolomite	Ultisols	117.4
10	119.0	191	Ordovician Dolomite	Ultisols	106.7
11	134.7	277	Cambrian Dolomite	Ultisols	114.3
12	69.5	225	Cambrian Dolomite	Alfisols	114.3

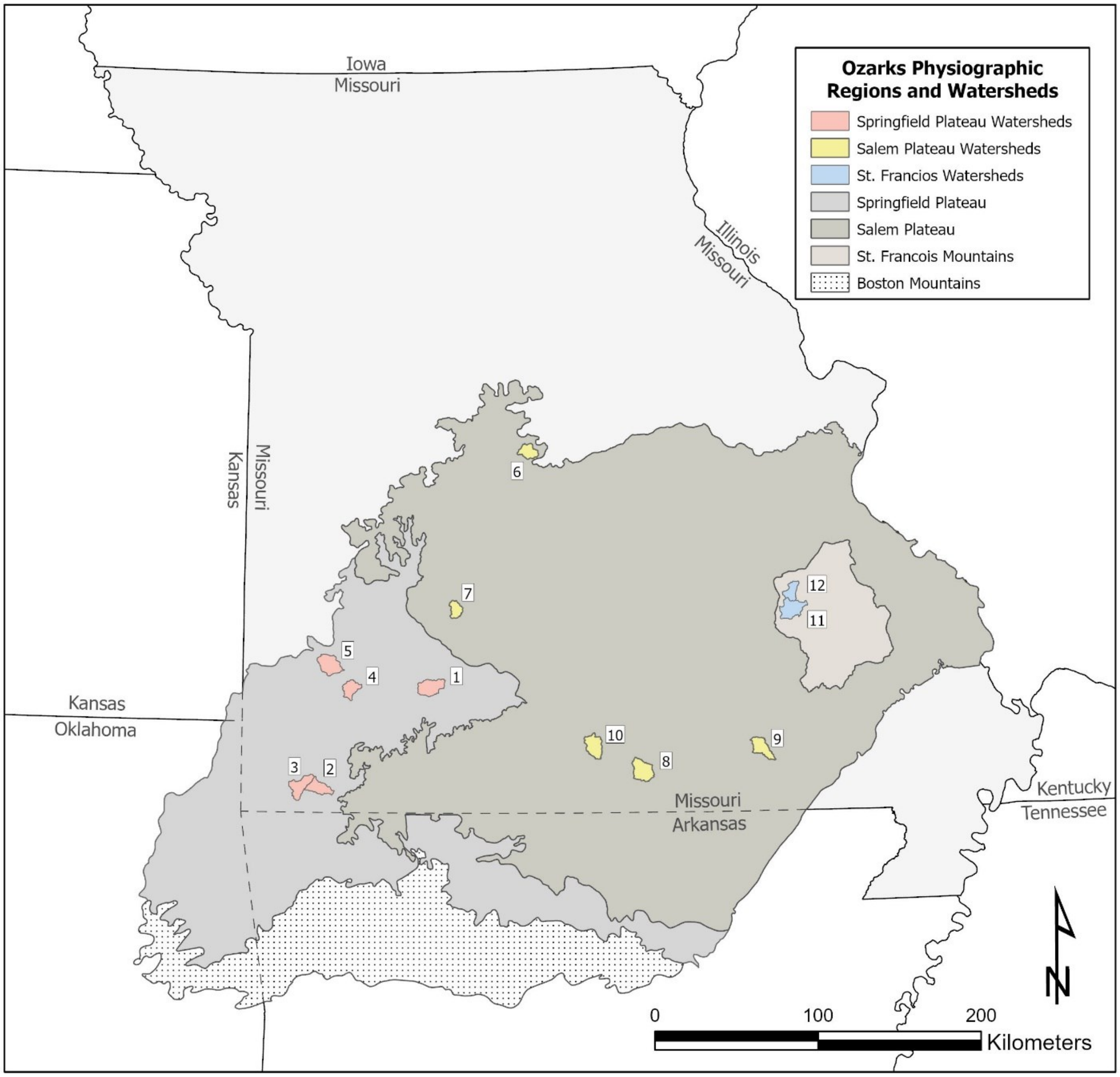

Figure 1. Map of Ozark regions and study watersheds.

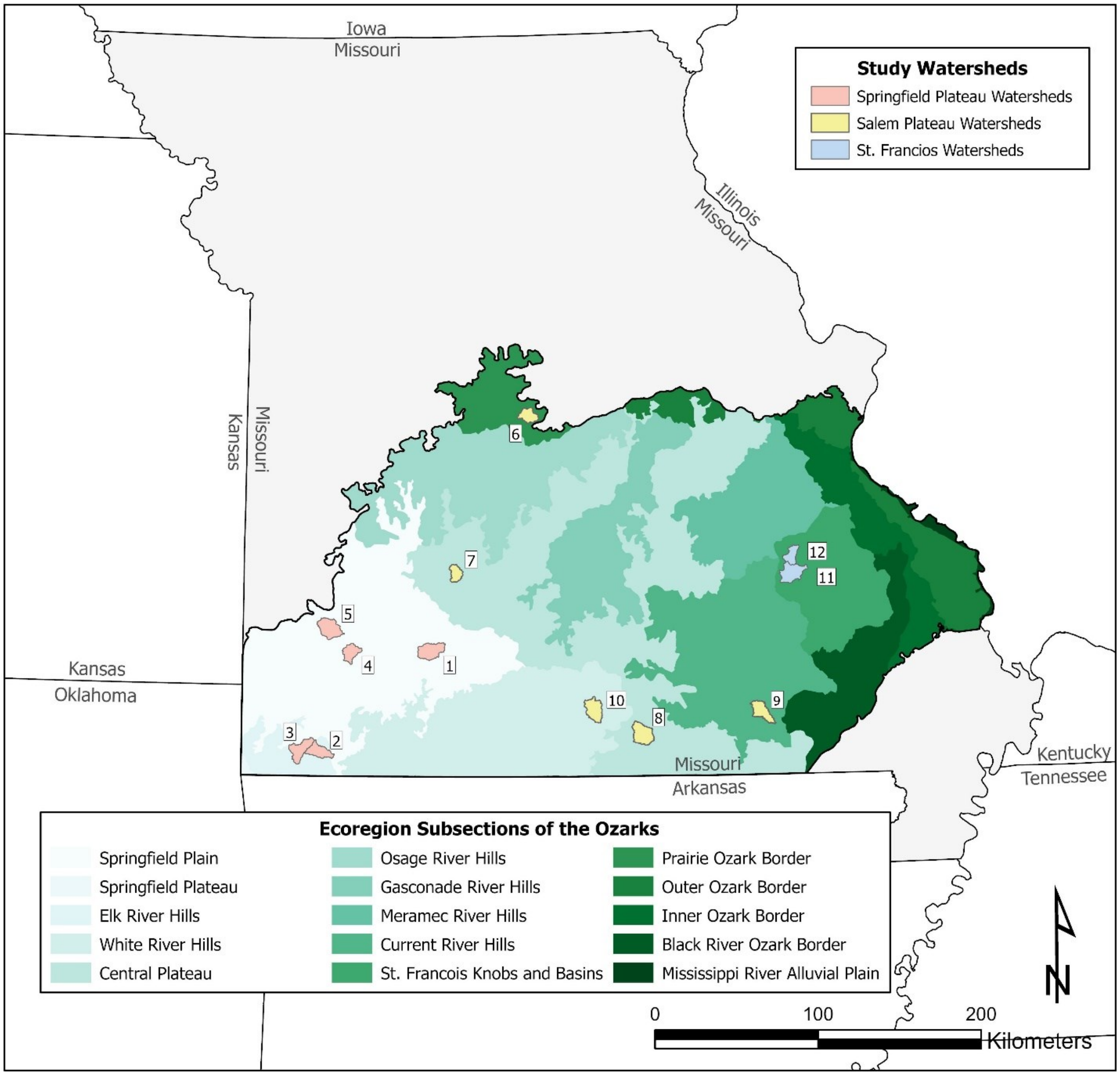

Figure 2. Study area watersheds and Missouri Ecoregions (Nigh and Schroeder 2002).

METHODS

This research used a combination of data collection and geographic information system (GIS) techniques to analyze and represent data. Collected data were used to supply inputs of soil, and land use conditions for model calibration and pollutant load estimation using the EPA's Spreadsheet Tool for Estimating Pollutant Loads (STEPL) modeling platform. STEPL was configured to produce estimates of N, P, and TSS loads for twelve watersheds in simulated pre-settlement, peak-disturbance, and present-day land use/land cover conditions. The methods of this research are described below for data collection, and model calibration for pre-settlement, peak-disturbance, and present-day conditions.

Data Collection

The STEPL model produces NPS load estimations using simple algorithms that rely primarily on soil characteristics and land use area distributions entered by users (Tetra Tech, 2018). Soil data, including series name, order, hydrologic soil group (HSG), k-factor, slope, and slope length, were collected from the Soil Survey Geographic Database (SSURGO) through the USDA Natural Resources Conservation Service Web Soil Survey (WSS) (USDA-NRCS 2020). HSG classification represents the water infiltration rate and runoff potential of a soil on a scale of A-D where "A" has the highest infiltration rate and lowest runoff potential (USDA 2007). K-factor is a soil erodibility factor ranging from 0.02 to 0.64 with higher values indicating increased soil erodibility (USDA 2001). Maps of watershed HSG, K- and LS-factors can be found in Appendix A. In addition to soil characteristics, present-day land use data were obtained from the United States Department of Agriculture's (USDA) National Agricultural Statistics

Service (NASS) in the form of a nationwide Cropland Data Layer (CDL). The 2019 CDL was analyzed using ArcGIS Pro 2.5 to determine and calculate land use areas and distributions for each watershed. Livestock and septic data inputs for present conditions were obtained through the EPA's web-based Input Data Server for STEPL.

Due to the limited availability of high-resolution pre-settlement land cover, pre-settlement distributions were generalized using historical or "native" vegetation descriptions from the NRCS soil database and according to pre-settlement conditions as described in the Missouri Department of Conservation's Ecoregions Atlas (Nigh and Schroeder 2002; USDA-NRCS 2020). Peak-disturbance land use estimations were developed from land use acres described in available historical agricultural censuses over 150+ years from 1840 to the 2000s in conjunction with documented reports of high agricultural or logging activity and soil data (USDA-NASS 2020). Historical census data was collected for any county that contained 10 or more percent of a watershed's area. County data used for peak-disturbance STEPL analysis included total acres in farms, cropland, pasture, and woodland as well as agricultural animal counts for cattle, hogs and sheep (USDA-NASS 2020). Relying on present-day soil descriptions, the presence of a plowed A soil horizon (Ap) was used to estimate and represent land that had been plowed or farmed during peak-disturbance conditions. Lastly, historical developed or "urban" areas were digitized using regional topographical maps available most closely to the determined year of peak disturbance. Period development and modeling methods are detailed below.

STEPL Modeling

STEPL is a simple spreadsheet-based model that relies on empirical relationships and algorithms to estimate total NPS outputs leaving a watershed. The model requires a limited number of inputs when compared to more complex models like SWAT, AGNPS, or SWMM that are also developed and used by the USDA or EPA for estimating NPS loads (Yuan et al. 2020). Soil, land use, and climate characteristics are used to develop runoff and nutrient estimations based on runoff volume, and concentration of runoff pollutants (USEPA 2018). In experience, watershed runoff estimations produced by STEPL have been found to vary 2-30% from estimations developed using localized USGS gage stations (Adams et al. 2019; Jordan et al. 2019; Reminga et al. 2019; Owen et al. 2020). Model runoff can be calibrated using modified rainfall or HSG inputs, however, due to the historical watershed settings and limited gage records this research relied on uncalibrated runoff and climate inputs (Reminga et al. 2019). The sediment delivery ratio is used in conjunction with the Universal Soil Loss Equation (USLE) to calculate annual sediment loads (Park et al. 2014; Tetra Tech 2018). Studied outputs include total nitrogen (TN), total phosphorus (TP), and total suspended sediment (TSS) loads. Each output is estimated as a total for the watershed and by land use category. USLE variables used in this study included area-weighted K- and calculated LS-factors as well as land use specific cover (C) factors. The LS-factor represents erosion risk based on slope steepness and length where steeper and longer slopes would result in higher erosion potential (Stone 2015). All LS-factors were calculated using the following equation where NN ranges from 0.2-0.5 depending on the slope (Stone 2015):

$$LS = [0.065 + 0.0456\ (\text{slope}) + 0.006541\ (\text{slope})^2]\ (\text{slope length} \div 72.5)^{NN}$$

Additionally, STEPL uses Natural Resources Conservation Service curve numbers (NRCS-CN) to simulate average annual runoff from direct rainfall events (Park et al. 2014; Tetra Tech 2018). NRCS-CN is a methodology largely used in simulating direct surface runoff which relies on soil characteristics such as HSG, land cover and land use to develop a curve number for various conditions (Cronshey et al. 1985; Gonzalez et al. 2015). Within STEPL, land use is generalized into five pre-defined categories: (1) Urban, (2) Pastureland, (3) Forest, and (4) Cropland, and (5) User Defined (USEPA 2018). Different parameters were developed to simulate the soil and land use conditions for each period defined in this study (Figure 3).

The STEPL model provides a simple and streamlined approach to evaluating watershed-scale land use-water quality relationships but has related inaccuracies when compared to more technical or detailed models (Nejadhashemi et al. 2011; Liu et al. 2017). Research on the model’s accuracy is extremely limited, however, studies show that STEPL both over and underestimate N, P and TSS loads (Nejadhashemi et al. 2011; Park, Engel and Harbor 2014; Liu et al. 2017). Nejadhashemi et al. (2011) found STEPL produced high predictions of annual N and P while underestimating TSS loads. Liu et al. (2017) found the model accurately represented hydrology – including rates of streamflow, runoff, and baseflow – but overestimated P and TSS. Inaccurate estimations were attributed to the model’s inability to account for crop rotations or affiliated management practices and high total phosphorous soil coefficients related to nutrient and sediment transport (Nejadhashemi et al. 2011; Liu et al. 2017). Generally, the most accurate estimations were a result of modeling runs calibrated with detailed land use, and local USLE soil parameters such as K-, LS- and C-Factors (Liu et al. 2017). To limit potential inaccuracies in this research, STEPL will be calibrated with soil characteristics area-weighted according to land use for each watershed in the study area (Acord 2015; Liu et al, 2017). Furthermore, despite proposed limitations and in support of the regional analysis and watershed comparison featured in this study, Nejadhashemi et al. (2011) suggest the model is sufficient in estimating NPS contributions by land use.

Pre-settlement, peak-disturbance, and present-day were selected as the primary temporal land use settings. With a timeline ranging from the early 19th century to the present (2019), each period has an isolated point of NPS production significant to the development and management of NPS loads over time. Pre-settlement estimations supply natural background nutrient and sediment outputs which serve as a baseline for evaluating the severity of NPS loads under developed peak and present conditions. Additionally, when compared with present conditions, estimations of NPS output during peak agricultural land use can aid in gauging the extent of NPS reductions in the past 70-130 years. Furthermore, present-day land use provides a grounding point tying the history of NPS load production to current conditions and that apply most directly to management today. A complete index of inputs used for period modeling can be found in Appendix B.

Present-day Conditions. Present conditions provided the most straightforward adjustments for this research. Using the 2019 USDA-NASS Cropland Data Layer, land use was classified into each of the models' four general land use categories of urban, pastureland, forest and cropland. Soil K- and LS- factors were then area-weighted by land use to get a spatially representative sample of NPS by land use. The hydrologic soil group was selected by the majority of HSG within each watershed (Tetra Tech 2018). Specific inputs such as septic systems and agricultural animal counts were collected by watershed from the US EPA's Input Data Server. NRCS curve numbers were not adjusted from the county-based values provided by the STEPL model for present-day conditions. Climate Data included is provided by STEPL and uses an annual rainfall, and rain days calculation based on a 30-year climate record for the county.

Pre-settlement Conditions. Land cover for pre-settlement conditions was derived primarily from native vegetation descriptions from the NRCS soil database. Descriptions were interpreted and categorized into historical land conditions of deciduous, hardwood forests (Hardwoods), mixed hardwood and pine forests (Mixed Pine), tall grassland or prairie (Prairie) and mixed grassland with scattered forest (Savanna). Areas with known mixed pine or pine distributions such as the Big Barren Creek watershed were adjusted using ArcGIS to match descriptions found in the MDC's Ecoregions Atlas and other historical sources (Liming 1946; Nigh and Schroeder 2002; Cunningham 2006). The geospatial dataset for present-day soils was then reclassified by watershed to reflect native vegetation groups (USDA-NRCS 2020). Hardwood and Mixed Pine land covers were input in STEPL using the forest land use classification. Prairie and Savanna were input under user-defined. Hydrologic Soil Group was weighted for each land use and considered to be one group higher than present-day HSG (MARC-APWA 2012). NRCS-CN were adjusted to match the deciduous broadleaf forest, mixed forest, grassland and savanna curve numbers from USDA-NRCS TR-55 and Hong and Adler, 2008 (Gonzalez et al. 2015). Soil K- and LS-factors were weighted by land use using the same methods as present-day conditions. USLE C-factors for Hardwoods, Mixed Pine and Savanna were adjusted according to canopy cover descriptions and C-factor values published for undisturbed forests (MDEQ 2009; Misir and Misir 2012).

Peak-disturbance Conditions. Periods of peak disturbance highlighted the historical peak of agricultural land use in each study watershed. Land use distributions were developed for peak-disturbance conditions using a combination of historical agricultural censuses, descriptions of land use histories, historical topographical maps, and soil series descriptions. Historical agricultural census data was compiled for counties in which 10 percent or more of a watershed's area was located. Using total acres of land in farmland, cropland and pastureland from historical census data, the percentage of a county in agricultural use was derived for each census year. The percentage of a county in farmland was then area-weighted according to county area in each watershed. Once area-weighted, the year of peak disturbance for each watershed was assumed to be the year in which agriculture was most prevalent in each county. Urban, cropland, pasture and forest were then determined for each watershed as closely to the year of peak disturbance as possible.

Urban areas were digitized using georeferenced topographic or city maps from the peak year or the next available year. Because STEPL depends on spatially weighted K and LS factors, peak-disturbance relied on the presence of an Ap horizon in soil descriptions of present-day soil series to determine cropland distributions for each watershed. The Ap layer is the soil layer most impacted by land use and agricultural practices (Jabro et al. 2010). Ap soil horizons signify the disruption of natural soil horizons as the result of past cultivation or plowing of the soil's top layers (Jabro et al. 2010). Additionally, soils with a slope of 20% or higher were assumed to be forested as agriculture generally depended on land with lower slopes (Nigh and Schroeder 2002). Pastureland was then assumed to be the remaining land not in urban, crop or forested land use. The percent of land in agricultural use at the county level was applied as a check for accuracy. These methods were used for all watersheds apart from Big Barren Creek which was not representative of county-wide agricultural practices and remained largely forested through time (Hanberry et al. 2012). Big Barren Creek urban and cropland were digitized into ArcGIS from historical topographical maps. Pastureland was assigned to soils with a slope of 2 percent or less to match descriptions of pasture occurring in broad valleys and on ridges (Nigh and Schroeder 2002). Lastly, forest land was attributed to all soils with a slope of 4 percent or higher not already assigned a land use.

Using ArcGIS, present-day soil survey data for all watersheds was attributed according to peak-disturbance land use. Soil data was then used to estimate land use area and calculate spatially weighted K and LS-factors for each. Agricultural animal counts for cattle, hogs and sheep and poultry were weighted by county for each watershed and used as inputs for STEPL (USDA-NASS 2020). NRCS-CN were adjusted to represent cropland and pastureland in poor management conditions for all watersheds and poor management conditions for forested lands for Big Barren Creek. Additionally, for the Big Barren Creek sub-watershed, NRCS-CN and the USLE C-factor for forested land were adjusted for poor management and cover to provide for potential soil compaction or runoff increases as a result of intensive logging or agricultural practices (MDEQ 2009).

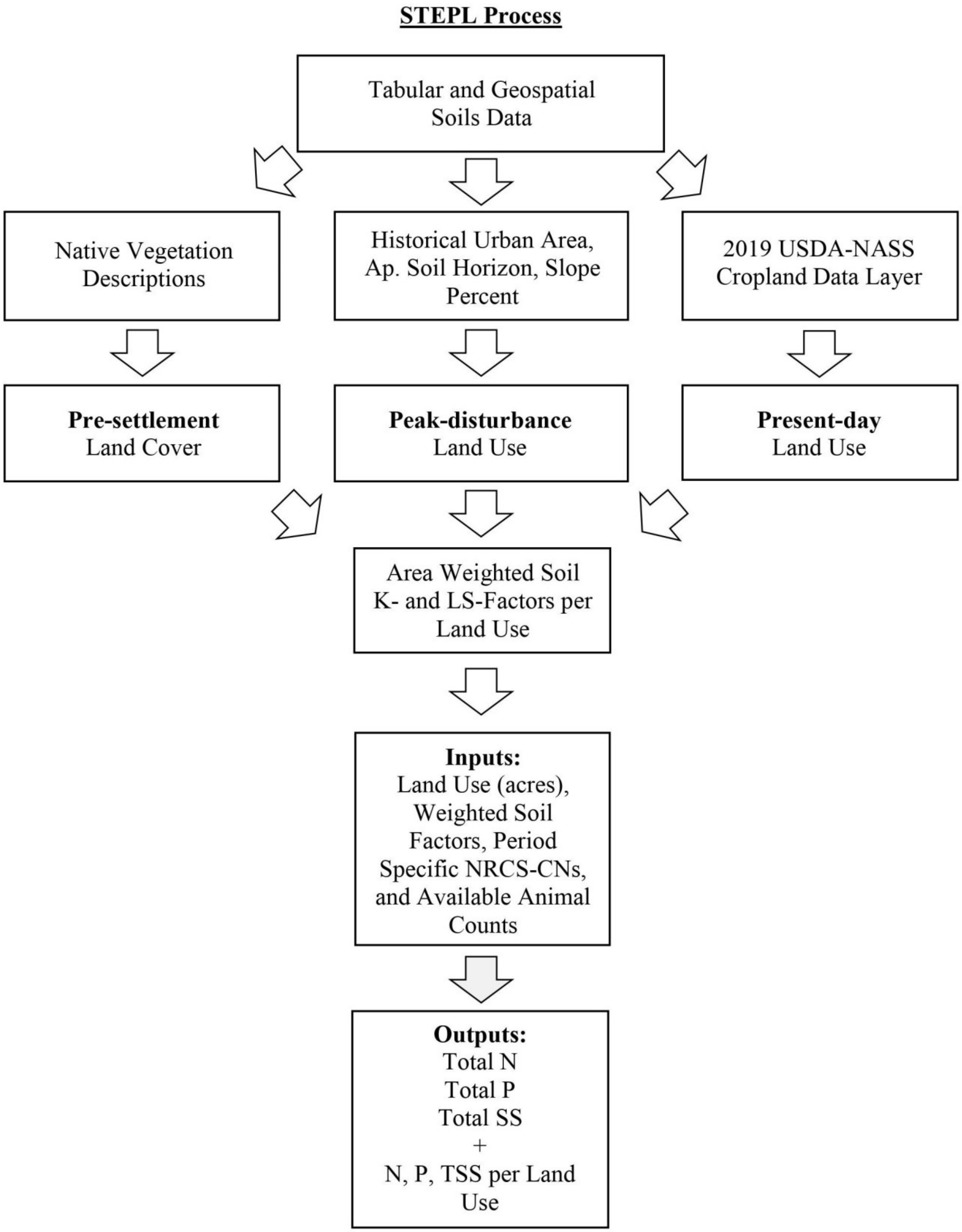

Figure 3. Flow chart of STEPL input development and output estimation.

RESULTS AND DISCUSSION

When evaluating the extent of anthropogenic disturbance on nutrient and sediment loads across the study area, model parameters were developed to fit unique soil and land use characteristics demonstrating local and regional similarities and differences over time. As discussed previously, the native land cover of the Ozark Highlands and the study area included a mix of prairie, oak savanna in the west with a gradual transition toward dense pine and oak forests to the east. Peak agricultural disturbance in the study area occurred throughout the early 20th century and involved the conversion of prairies, savannas and some forest land into crop and pasture. Into present-day, the region has maintained higher agricultural use in the west while experiencing forest recovery and urban development throughout the region. Land use and related NPS production analysis for study area watersheds are presented below. Maps of land use change and a complete index of STEPL outputs can be found in Appendix C and Appendix D.

NPS Modeling Results

Pre-settlement Conditions and Natural NPS Yields. Under pre-settlement conditions, the Springfield Plateau included a wide range of native land cover and the largest extents of prairie throughout the three regions included in this study. The total area of selected watersheds in the Springfield Plateau region was 50% forested and 44% prairie. Spring River had the highest percent of prairie land at 77%, Sugar Creek had the most combined forest at 97% and Stahl Creek has the highest percent of savanna at 18%. The Salem Plateau transitioned the western Ozark prairies to the forested hills of the east. Salem Plateau watersheds were 83% forested, 11% savanna and only 6% prairie. The Big Barren and North Fork watersheds were over 98% forested with Big Barren's forest classified solely as mixed pine (Table 4). Burris Fork featured the largest area of savanna with 44%. Lastly, the St. Francois Mountains were the most heavily forested region under pre-settlement land cover with 92% of land as hardwood or mixed pine forest. Black River, 93% forest, was split between hardwood and mixed pine forest while Cedar Creek, 91% forested, featured predominantly hardwood forest.

Using native vegetation and land cover distributions, pre-settlement conditions were developed to generate estimated background levels of nutrient and sediment exports for each watershed. Across all featured watersheds in the Ozarks, the mean nutrient load was 6,043 kg/year TN and 2,472 kg/year TP with an additional 2,987 t of sediment annually. Under pre-settlement conditions, the St. Francois Mountains generated the highest N, P, and TSS yields and the Salem Plateau the lowest (Table 5). Regionally, Salem Plateau watersheds produced background nutrient and sediment loads 32% and 41% lower than the Ozark mean while the Springfield Plateau and St. Francois Mountains background loads were 16-39% higher than the regional average. The average St. Francois Mountains yield was 1.8 times higher than those of the Salem Plateau in all modeled NPS categories. Additionally, the natural variability of pre-settlement yields among watersheds was 6.4 times TN, 5.8 times for TP and 13 times for TSS (Figure 4). Although the Salem Plateau held the lowest average nutrient and sediment production and yields, the region featured the highest variability between watersheds. Comparing the region's highest and lowest yielding watersheds, Lindley Creek produced 5.5 times more TN, 4.9 times the TP and 11.3 times more TSS than Big Barren. In contrast, the St. Francois Mountains, while producing the highest average yields, had only a 1.5 and 1.4-time difference between TN and TP yields, respectively and a 2-time difference in TSS.

Peak-disturbance Conditions and NPS Yields. Under peak-disturbance, the Springfield Plateau had the highest percentage of land in agriculture at 75% and the highest urban area at 3%. The region featured the lowest percentage of land remaining in forest of the study area with 22%. The Salem Plateau featured the second-highest percent of land in agriculture at 64% while maintaining only 35% of its original 100,000 acres of pre-settlement forest. The St. Francois Mountains region, 53% cropland and pasture at its peak, maintained the highest percentage of forested land of the three regions with 47%. Stahl Creek, Spring River, Burris Fork, and Lindley Creek watersheds were over 98% agricultural at their peak (Table 6). Burris Fork had the largest percentage of land in cropland at 87% and Spring River the largest area in pasture with 68%. Led by the early development of Springfield, Missouri, the Wilsons Creek sub-watershed had the most urban area during peak-disturbance with 14% in 1910. Big Barren was the most heavily forested watershed under peak-disturbance maintaining 85% of land in forest, only a 13% decrease from pre-settlement.

Peak-disturbance land use conditions were used to estimate the extent of NPS pollution generated during the period of highest agricultural disturbance for each watershed. Agricultural peaks for study watersheds occurred between 1890 and 1950 with the Salem Plateau experiencing the earliest peaks and the Springfield Plateau averaging the latest. The average peak-disturbance load for the Ozarks was 91,115 kg/year TN, 18,434 kg/year TP and 19,293 t of sediment annually. Peak Ozark loads represented a 15.1, 7.5 and 6.5-time increase in TN, TP, and TSS over background conditions. The Salem Plateau experienced the largest yield increases of any region from pre-settlement to peak with TN, TP and TSS yields 23.0, 13.2, and 20.9 times higher than background levels (Table 7). In contrast, the St. Francois Mountains saw the lowest TN, TP, and TSS yield increases of only 9.3, 5.5 and 7.3 times. Similar to what was seen under pre-settlement conditions, the Salem Plateau had the highest variability between watershed yields while the St. Francois Mountains the lowest.

Present-day Compared to Peak-disturbance Period. Under present conditions, the Springfield Plateau had the highest percentage of land in agriculture at 41% and the highest urban area at 22%. The region featured the highest area in cropland at 17%. The Salem Plateau featured the second-highest percent of land in agriculture at 38%, and the second-highest urban area at 8%. The Salem Plateau had the most pastureland, 32%, under present conditions and the second-highest forest land, 54%. The St. Francois Mountains region continued to serve as the most forested region with 87% of land in forest, and only 11% of land in agricultural use. The Stahl Creek and Spring River watersheds of the Springfield Plateau held the largest proportions of land in agriculture with 78% and 90% respectively (Table 8). Black River and Big Barren were the most heavily forested watersheds at 96% and 91%.

Driven largely by a decline in agricultural land use across the study area, mean Ozark TN, TP and TSS load decreased by 57, 53, and 45 percent to 51,795 kg/year, 9,847 kg/year, and 8,634 t/year, respectively. This effect was most evident in watersheds that underwent a replacement of cropland with forest as was the case in both Black River and Cedar Creek of the St. Francois Mountains. Watersheds that transitioned from cropland to pasture also saw NPS reductions, however, as these were still primarily agricultural the decreases were not as severe. Areas that saw a loss of agricultural land supplanted by urban development produced higher yields than those replaced with forest. Despite the reduction, present-day yields remained, on average, 9.3 times higher than background levels for TN, and 4.4 times higher for TP and TSS. Regionally, the St. Francois Mountains had the highest NPS yield reductions and the Springfield Plateau experienced the lowest. The Salem Plateau's North Fork sub-watershed and the St.

Francois Mountains' Black River sub-watershed experienced the largest decreases in NPS loads from peak-disturbance to present day with an average drop of over 82,000 kg/year TN, 22,000 kg/year TP and 32,000 t/year TSS. Howell Creek and Big Barren experienced the smallest TN decreases from peak to present, while Sugar Creek and Spring River had the smallest TP decreases. Mikes Creek and Sugar Creek, heavily forested watersheds of the Springfield Plateau, saw the smallest TSS reductions between the two periods. Under present-day conditions, the Springfield Plateau produced the highest N and P yields and the Salem Plateau produced the highest TSS yields. The St. Francois Mountains produced yields significantly lower than other regions in all NPS categories. Present-day land use conditions offered the highest yield variability of any period. The difference between Stahl Creek, the highest TN and TP yielding watershed, and Black River, the lowest, was 10.1 and 4.7 times. For sediment, Mikes Creek yielded at a rate 6.0 times that of Black River.

Importance of NPS Modeling Variables. The relationships between watershed characteristics and period-specific NPS yields were investigated using stepwise regression analysis. Independent input variables included relief, rainfall, drainage area, and percentage of land in period-specific land use/land cover. Pre-settlement yields showed a weak negative relationship to drainage area for TN, TP and TSS while land cover, rainfall and relief showed little to no effect (Table 9). Prairie and savanna were found to produce the highest yields of any native land cover while, in general, there was a negative relationship between percent forest in a watershed and background yields (Figure 5). Soil factors such as high K- and LS-factors, or USLE CNs were found to amplify the effects of higher-yielding prairie and savanna land covers, occasionally resulting in high outputs from a limited land area as occurred in the Cedar Creek watershed of the St. Francois Mountains. General land cover correlations were low and statistically insignificant suggesting that total background yields were most influenced by soil variability.

Peak-disturbance and present-day analysis revealed a stronger relationship between land use and NPS yields than pre-settlement conditions. During peak-disturbance periods, there was a significant positive relationship with cropland and negative relationship with forest. Under peak-disturbance, agricultural land yields were 3.5-8.7 times higher than forest land. The highest yielding watersheds of this period, Burris Fork and Lindley Creek, were almost entirely agricultural with majority cropland while also featuring the highest runoff potential soil group, D, and high USLE CNs. Following the transition from peak-disturbance to present-day, the negative relationship between forest land and NPS yields strengthened and pastureland replaced cropland as the leading agricultural NPS contributor. High CNs and K- or LS-factors generally amplified the negative effects of high-yielding agricultural land use, however, the influence of environmental factors on NPS yields was far lower than land use overall (Figure 6). Across both peak and present day scenarios, TN yields showed the strongest relationship to land use variables and TSS the weakest. This analysis is useful to identify the most influential variables in the STEPL model to determine NPS yields furthering our understanding of what is controlling the spatial variability among the watersheds studied here. Future studies might consider further evaluation of these important variables to verify these observed effects and better understand how they impact NPS yields.

Anthropogenic Influence on Peak-disturbance and Present-day NPS. To most represent the total NPS output associated with human-induced land use change according to STEPL, background estimations from pre-settlement conditions were subtracted from the total output of watersheds under peak-disturbance and present-day conditions to isolate anthropogenic loads. Under peak-disturbance, as much as 98 percent of a watershed's TN, TP or TSS was the result of anthropogenic land use change (Table 10). Maximum present-day influence is slightly lower at 95% of the total load. With current land use, Salem Plateau sub-watersheds feature the highest percent of NPS output resulting from human forces. Additionally, as the result of higher background loads and heavy present-day forest, the St. Francois Mountains watersheds feature the lowest proportion of anthropogenic loads.

Several watersheds displayed minimal anthropogenic influence on NPS generation including Wilsons Creek TSS, and the St. Francois Mountains watersheds. The limited increase in TSS generation above background levels is likely the result of the large proportion of urban land that makes up the Wilsons Creek watershed. The Black River sub-watershed produced the lowest anthropogenic loads of any watershed and as much as a 5% decrease in TP from pre-settlement to present-day. However, it is important to note the difference between TP yield for the Black River sub-watershed of the two periods was incredibly low, -1.4 kg/year, which suggests this watershed should not be viewed as decreasing NPS output over time but rather maintaining similar levels of production throughout its settlement. Furthermore, TSS was the least affected by anthropogenic loads and TN the highest. This suggests that while land use disturbance increases TSS, the pollution generated from increased TN and TP production represents a larger deviation from natural conditions. Anthropogenic loads were accountable for the largest proportion of a watershed's total load in watersheds that experienced a transition to agricultural or urban land use. Overall, most watersheds maintain present-day NPS outputs far above background levels. The anthropogenic increase relates not only to the level of land use change a watershed has experienced but to the NPS susceptibility of the land use of present today.

Present-day Model Validation

Present-day STEPL NPS estimations were compared and checked with reference yields from both modeled and monitored NPS assessments (Table 11) (Sharpley et al. 1987; Hutchison 2010; Adams et al. 2019; Jordan et al. 2019; Reminga et al. 2019, Owen et al. 2020). Watershed-scale yields were, on average, within 35% of reference yields with mean TN, TP, and TSS yields all estimated below the referenced mean. Of present-day land use categories, urban estimations featured the lowest relative percent difference (RPD) from referenced yields while forest, weighted heavily by TSS, had the highest RPD of any land use. Overall, land use-related TP yields were most similar to referenced rates while TSS was overestimated by roughly 68% across crop, pasture and forest land use. TN yields were underestimated in urban, pasture and forest land use but overestimated in cropland. The variability of TN in cropland and other NPS yields across the remaining land use categories can be partially explained by high yields that can occur in a relatively small area of land. Mikes Creek, Sugar Creek, and North Fork feature only 2.0 km^2 of cropland combined, however, TN yields for these watersheds are significantly higher than the study average at 2,570.3, 2,204, and 2228.0 kg/km^2 respectively. Lastly, literature featuring urban or forested NPS at a watershed-scale was limited and thus restricted the validation of urban or forest land use relative to agricultural NPS assessments.

Implications for NPS Management

Human settlement and land use change have played a significant role in the production of NPS loads across the Ozarks. When evaluating Ozark NPS pollution over time through STEPL, the influence of natural runoff factors such as soil characteristics or regional topography was most evident during the pre-settlement period. As the Ozarks developed and landscapes were altered, modified, and disturbed, the effects of land use change and increases in high-yielding agricultural and urban land use became the primary driver of regional NPS yields. Under natural conditions and largely the result of soil and relief, the St. Francois Mountains region generated the highest yields, however, as surrounding regions have developed and the St. Francois Mountains have maintained relative stability, the region has become the lowest NPS producer. Under present-day land use, natural factors appear to have only a minor impact on regional watershed loads relative to non-forest land use, specifically cropland and pasture. While increased relief and erodibility in soils can amplify the negative effects of cropland or pasture on NPS, its influence is not significant enough to outweigh the primary role of land use in NPS production.

While present agricultural land use and overall NPS outputs have decreased from their peak at the beginning and middle of the 20th century, NPS loads remain significantly higher than background levels (Figure 7). Ozark settlement has represented a dramatic increase in NPS pollution of which the lasting effects are not yet known. In addition to NPS generated by modern agricultural practices and land management, sediment stored in soils, streambanks and floodplains during peak-disturbance periods has the potential to further complicate present-day NPS and water quality management, however, this is not accounted for in STEPL (Walter et al. 2007; Fox et al. 2015). Additionally, background loads should be considered in water quality assessment and watershed management to set accurate reduction targets and better understand natural watershed conditions. Pre-settlement outputs will likely not be restored, but landowners and land managers must continue to reduce present NPS pollutant levels and consider the possibility that the legacy of the Ozarks may still require management.

Table 4. Pre-settlement land cover distributions by percent cover.

Physiographic Region	Watershed	Land Cover (%)			
		Hardwood	Mixed Pine	Prairie	Savanna
Springfield Plateau	Wilsons Creek	26%	2%	70%	2%
	Mikes Creek	62%	34%	2%	2%
	Sugar Creek	81%	16%	3%	0%
	Stahl Creek	31%	0%	51%	18%
	Spring River	6%	0%	77%	17%
Salem Plateau	Burris Fork	38%	0%	18%	44%
	Lindley Creek	61%	0%	23%	16%
	Howell Creek	92%	2%	0%	6%
	Big Barren	0%	98%	0%	2%
	North Fork	71%	29%	1%	0%
St. Francois Mountains	Black River	46%	47%	0%	7%
	Cedar Creek	71%	20%	2%	7%

Table 5. Pre-settlement background yields for all study watersheds.

Physiographic Region	Watershed	TN (kg/km^2)	TP (kg/km^2)	TSS (t/km^2)
Springfield Plateau	Wilsons Creek	75.7	29.8	43.7
	Mikes Creek	65.5	26.4	34.6
	Sugar Creek	53.8	21.9	27.1
	Stahl Creek	88.0	34.2	53.4
	Spring River	44.8	17.4	27.0
Salem Plateau	Burris Fork	78.4	31.2	43.5
	Lindley Creek	90.3	36.4	47.6
	Howell Creek	33.2	15.0	8.9
	Big Barren	16.4	7.4	4.2
	North Fork	18.9	8.4	5.9
St. Francois Mountains	Black River	69.2	30.1	24.2
	Cedar Creek	105.2	42.9	52.8

Table 6. Peak-disturbance period land use by percent of the watershed.

Physiographic Region	Watershed	Land Use (%)			
		Urban	Crop	Pasture	Forest
Springfield Plateau	Wilsons Creek	14%	41%	44%	1%
	Mikes Creek	0%	4%	38%	58%
	Sugar Creek	0%	6%	39%	56%
	Stahl Creek	1%	56%	43%	1%
	Spring River	0%	32%	68%	0%
Salem Plateau	Burris Fork	0%	87%	13%	0%
	Lindley Creek	0%	74%	24%	2%
	Howell Creek	3%	37%	37%	22%
	Big Barren	0%	5%	10%	85%
	North Fork	0%	26%	29%	45%
St. Francois Mountains	Black River	0%	23%	22%	55%
	Cedar Creek	0%	37%	31%	32%

Table 7. The ratio of peak-disturbance and present-day yields to pre-settlement conditions.

Physiographic Region	Watershed	TN		TP		TSS	
		Peak	Present	Peak	Present	Peak	Present
Springfield Plateau	Wilsons Creek	14.9	10.7	6.2	4.2	3.3	1.1
	Mikes Creek	9.6	4.9	4.6	3.8	4.0	3.9
	Sugar Creek	11.2	6.4	5.0	4.2	4.2	4.2
	Stahl Creek	12.8	10.1	5.4	3.9	2.6	2.0
	Spring River	26.3	17.1	8.2	7.5	2.7	3.3
Salem Plateau	Burris Fork	15.3	9.8	9.4	4.1	7.3	2.4
	Lindley Creek	14.1	9.0	8.2	3.5	7.0	2.3
	Howell Creek	22.1	18.7	10.1	8.3	18.3	14.9
	Big Barren	14.5	7.2	7.7	4.1	13.0	5.4
	North Fork	49.2	13.5	30.8	7.1	59.1	11.1
St. Francois Mountains	Black River	10.5	1.3	6.3	1.0	10.2	1.0
	Cedar Creek	8.1	2.8	4.6	1.4	4.5	1.1

Table 8. Present-day land use distributions by percent of the watershed.

Physiographic Region	**Watershed**	**Land Use (%)**			
		Urban	**Crop**	**Pasture**	**Forest**
Springfield Plateau	Wilsons Creek	80%	2%	10%	8%
	Mikes Creek	3%	0%	10%	87%
	Sugar Creek	4%	1%	17%	78%
	Stahl Creek	5%	17%	61%	17%
	Spring River	4%	58%	32%	7%
Salem Plateau	Burris Fork	4%	24%	46%	26%
	Lindley Creek	7%	11%	60%	22%
	Howell Creek	20%	2%	41%	37%
	Big Barren	3%	0%	5%	91%
	North Fork	3%	0%	20%	76%
St. Francois Mountains	Black River	2%	0%	2%	96%
	Cedar Creek	2%	4%	24%	70%

Table 9. STEPL input variables with highest predictive valur to study NPS yields where "(-)" indicates a negative relationship. Independent input variables include relief, rainfall, drainage area, and percentage of land in period-specific land use.

		Single Predictor		**Two Predictors**		**Multiple Predictors**	
		Predictor	**R Square**	**Predictor**	**R Square**	**Predictors**	**R Square**
Pre-settlement	TN (kg/km^2)	(-) Drainage Area	0.398				
	TP (kg/km^2)	(-) Drainage Area	0.378				
	TSS (t/km^2)	(-) Drainage Area	0.424	(-) Drainage Area, % Prairie	0.692		
Peak-disturbance	TN (kg/km^2)	(-) % Forest	0.867	(-) % Forest, Rainfall	0.915	(-) % Forest, Rainfall, Relief	0.964
	TP (kg/km^2)	% Cropland	0.671				
	TSS (t/km^2)	% Cropland	0.331	% Cropland, Relief	0.658	% Cropland, Relief, Rainfall	0.828
Present-day	TN (kg/km^2)	(-) % Forest	0.942				
	TP (kg/km^2)	Relief	0.809				
	TSS (t/km^2)	% Pasture	0.349				

Table 10. Percent of total peak-disturbance and present-day NPS load resulting from anthropogenic land use change.

Physiographic Region	Watershed	TN Peak	TN Present	TP Peak	TP Present	TSS Peak	TSS Present
Springfield Plateau	Wilsons Creek	93%	91%	84%	76%	70%	6%
	Mikes Creek	90%	80%	78%	74%	75%	74%
	Sugar Creek	91%	84%	80%	76%	76%	76%
	Stahl Creek	92%	90%	82%	75%	62%	51%
	Spring River	96%	94%	88%	87%	63%	69%
Salem Plateau	Burris Fork	93%	90%	89%	75%	86%	58%
	Lindley Creek	93%	89%	88%	71%	86%	57%
	Howell Creek	95%	95%	90%	88%	95%	93%
	Big Barren	93%	86%	87%	76%	92%	81%
	North Fork	98%	93%	97%	86%	98%	91%
St. Francois Mountains	Black River	90%	21%	84%	-5%	90%	4%
	Cedar Creek	88%	65%	78%	29%	78%	10%
Median		93%	81%	85%	67%	82%	56%
Range		88-98%	21-95%	78-97%	-5-88%	62-98%	4-93%

Table 11. Comparison of NPS yields between this study and other reports by land use. The relative percent difference (RPD) is used to compare mean values.

Study Watersheds			*References: (a,b,c,d,e,f)*			**Mean**
	Range	**Mean**		**Range**	**Mean**	**RPD**
Ad (km^2)	62.9 - 134.9	105.2	**Ad (km^2)**	46.1 - 190.5	113.7	7.8
Watershed	***Yield Range***	***Mean***	**Watershed**	***Yield Range***	***Mean***	
TN (kg/km^2)	88.0 - 887.2	506.8	TN (kg/km^2)	465.0 - 1,470.6	781.7	42.7
TP (kg/km^2)	28.8 - 134.6	95.0	TP (kg/km^2)	62.0 - 178.4	123.9	26.4
TSS (t/km^2)	22.6 - 134.7	84.4	TSS (t/km^2)	87.2 - 186.9	119.2	34.3
Urban			**Urban**			
TN (kg/km^2)	729.2 - 901.1	819.8	TN (kg/km^2)	497.1 - 1,507.7	978.8	17.7
TP (kg/km^2)	112.2 - 139.1	126.3	TP (kg/km^2)	15.8 - 232.8	135.8	7.2
TSS (t/km^2)	33.5 - 41.4	37.7	TSS (t/km^2)	22.9 - 69.3	45.0	17.6
Cropland			**Cropland**			
TN (kg/km^2)	767.8 - 2,570.3	1532.3	TN (kg/km^2)	456.4 - 1,927.9	1,062.4	36.2
TP (kg/km^2)	169.7 - 747.3	379.0	TP (kg/km^2)	115.5 - 544.6	263.9	35.8
TSS (t/km^2)	133.3 - 1,048.5	450.5	TSS (t/km^2)	121.0 - 692.5	260.2	53.5
Pasture			**Pasture**			
TN (kg/km^2)	671.4 - 1,334.4	671.4	TN (kg/km^2)	533.9 - 1823.0	1,192.0	55.9
TP (kg/km^2)	72.4 - 324.5	144.2	TP (kg/km^2)	59.1 - 248.4	138.4	4.1
TSS (t/km^2)	29.3 - 452.4	149.1	TSS (t/km^2)	38.4 - 225.3	98.8	40.6
Forest			**Forest**			
TN (kg/km^2)	35.9 - 178.1	69.9	TN (kg/km^2)	22.6 - 250.0	76.3	8.7
TP (kg/km^2)	17.6 - 71.0	29.8	TP (kg/km^2)	10.8 - 41.3	25.2	17.1
TSS (t/km^2)	1.8 - 97.8	27.6	TSS (t/km^2)	2.3 - 21.6	8.2	108.4

References: (a) Sharpley et al. 1987; (b) Hutchison 2010; (c) Adams et al. 2019; (d) Jordan et al. 2019; (e) Reminga et al. 2019, (f) Owen et al. 2020.

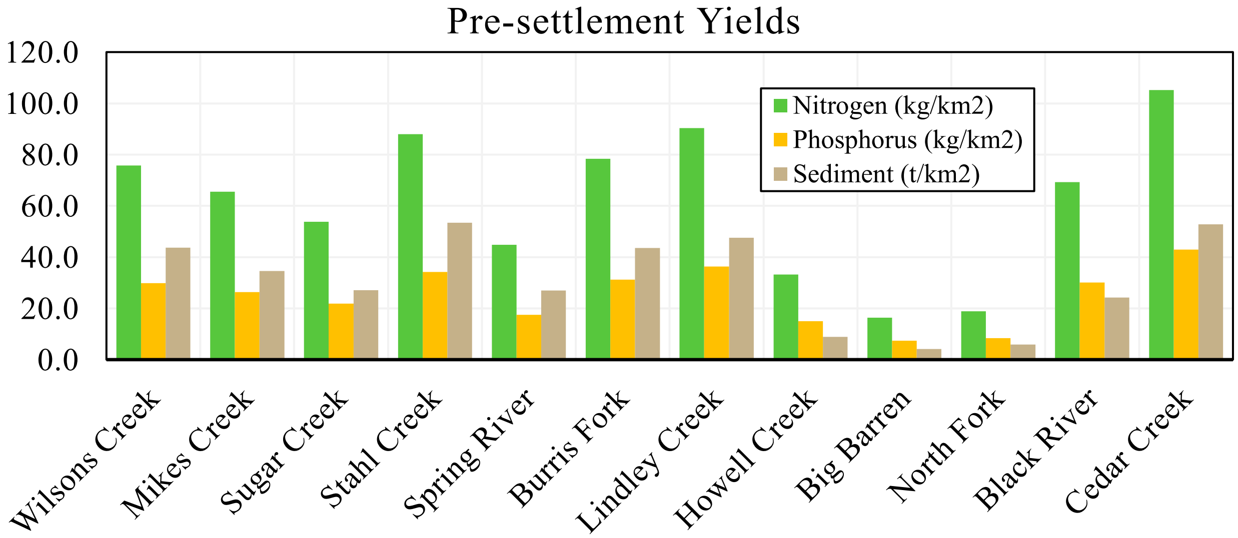

Figure 4. Pre-settlement TN, TP, TSS yields by watershed.

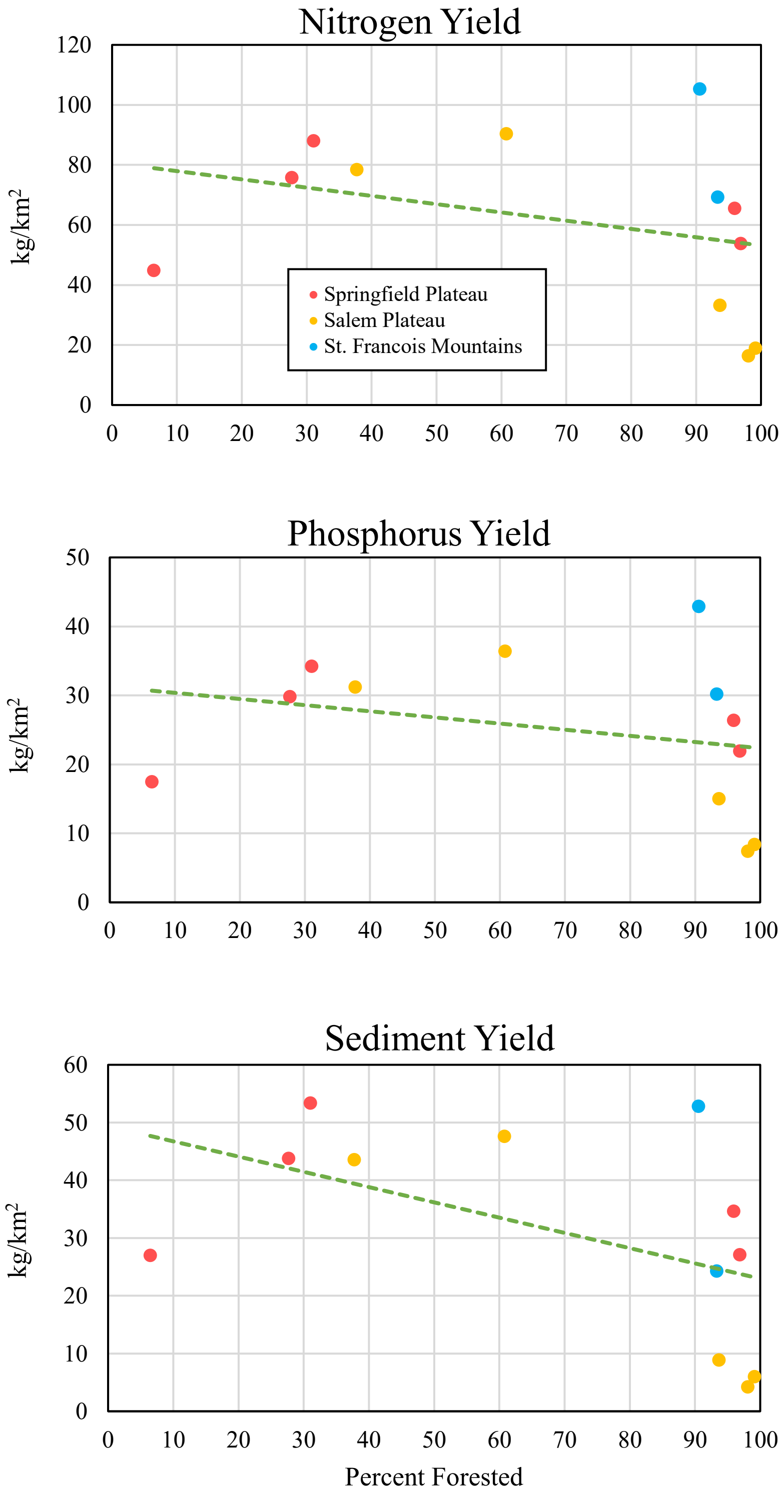

Figure 5. Pre-settlement Total Nitrogen, Total Phosphorus, and Total Suspended Sediment yields by percent of the watershed in forest.

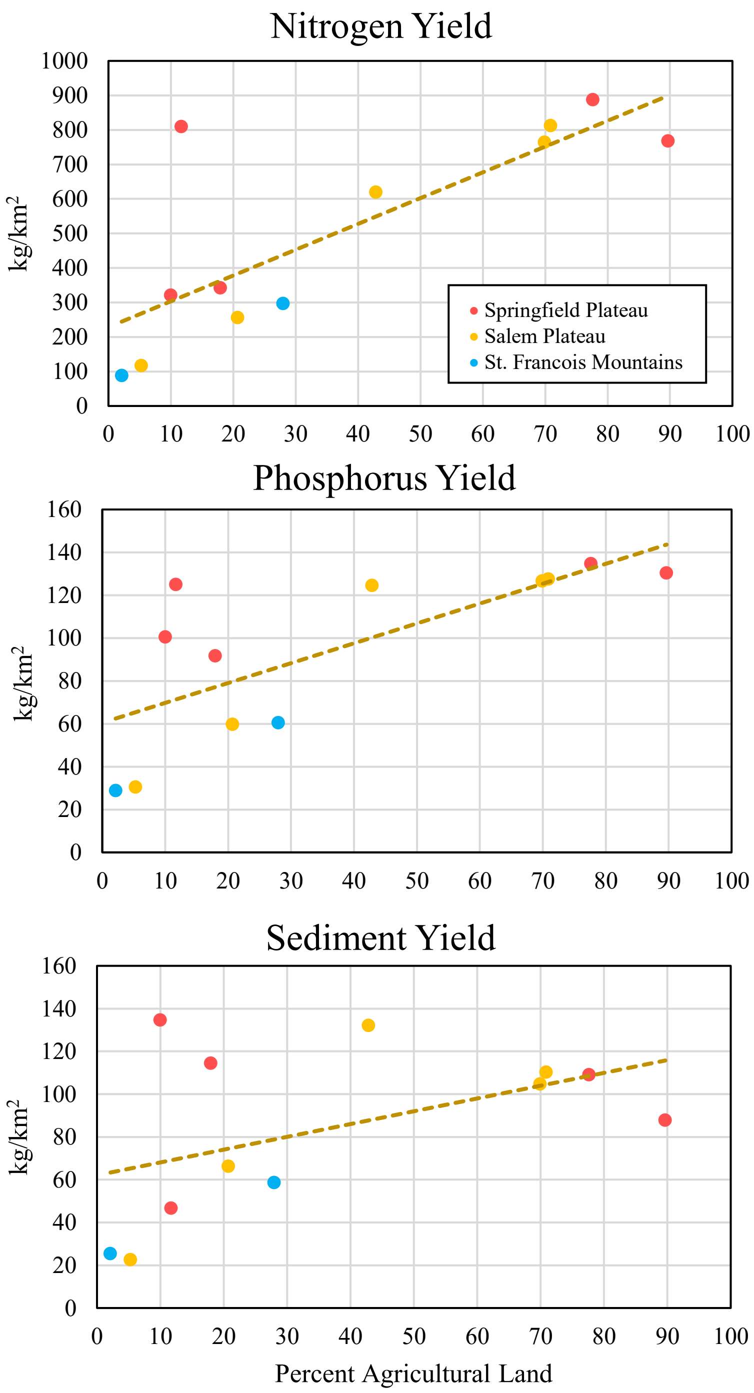

Figure 6. Present-day anthropogenic yields of Total Nitrogen, Total Phosphorus, and Total Suspended Sediment plotted according to the percent of a watershed in agricultural land use.

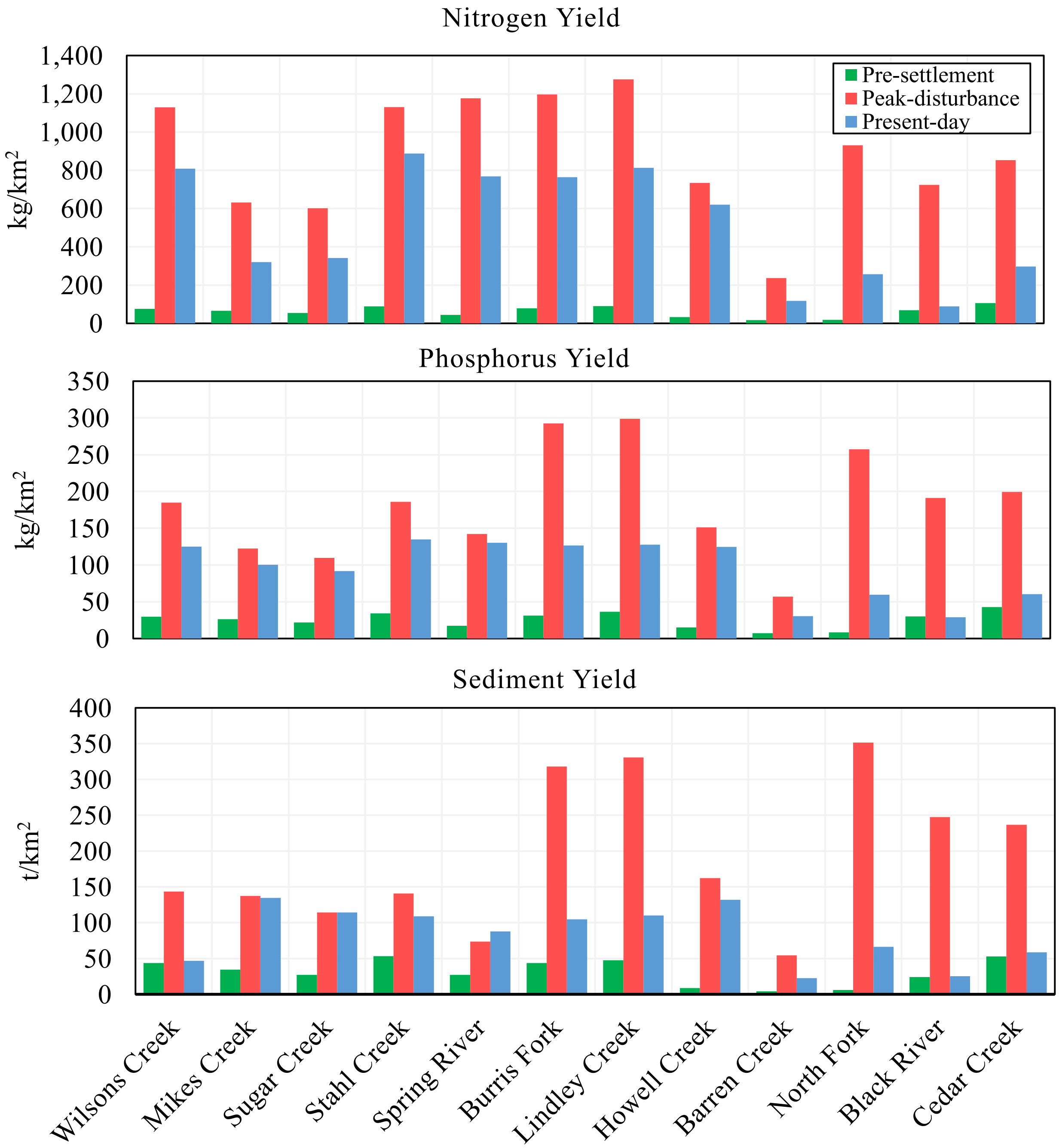

Figure 7. NPS yield estimates during pre-settlement, peak-disturbance, and present-day periods for all watersheds.

CONCLUSIONS

This study modeled nonpoint source pollutant contributions from watersheds in the Missouri Ozarks according to land use, land cover and under varying conditions of land use disturbance including past pre-settlement and peak-disturbance periods. The Ozarks cover a range of physical geographies, settlement histories and land use distributions (Jacobson and Pugh 1992; Jacobson and Primm 1997; Nigh and Schroeder 2002; Cunningham 2006). However, research of how these different regional characteristics interact with NPS pollution is extremely limited (Davis et al. 1995; Haggard 2013; Petersen et al. 1998; Smart et al. 1985). The goal of this research was to fill the gap in regional NPS research and provide insight into the effect of land use change on Ozarks water quality over time. This study relied on the EPA's STEPL model to estimate nitrogen, phosphorus and sediment loads of twelve Ozarks watersheds before Euro-American settlement (before 1820), during peak agricultural use (1890-1950), and under present-day (2019) conditions. Watersheds were selected from the three primary physiographic regions of the Missouri Ozarks, the Springfield Plateau (5), Salem Plateau (5) and the St. Francois Mountains (2).

Before settlement in the early 1800s and under native land cover, study watersheds generated the lowest NPS loads of any modeled period. Despite native prairie and savanna lands offering the highest yields of any native land cover, the St. Francois Mountains produced the highest average watershed yields with over 90% of forest land cover. Prairie and savanna yields were approximately 7.3 times higher in the St. Francois Mountains than in the Springfield Plateau. Higher yields for the St. Francois Mountains were the result of having the greatest relief in the study, and soils more susceptible to erosion. Although the Salem Plateau experienced the lowest average background yields, prairie and savanna land cover produced yields that were 1.7 times greater than the Springfield Plateau. These amplified background yields in high-relief forested regions of the Salem Plateau and St. Francois Mountains suggest that background nutrient and sediment production is largely influenced by natural topography and soil conditions in the STEPL modeling process.

Peak-disturbance period featured the highest NPS loads in the study. Model results for this period demonstrate the transition from yields driven primarily by natural factors to anthropogenic sources of land use change as the leading influence. Peak-disturbance featured average anthropogenic N, P, and TSS loads that were 16, 8, and 10 times higher than background estimations, respectively. As land use became a larger factor, driven by an influx in agricultural land, the Springfield Plateau became the highest yielding region and the St. Francois Mountains became the lowest. This trend continued into the present-day following a drop in NPS loads of approximately 50% in all watersheds. Present-day watersheds showed the highest NPS variability of any modeled period with TN, TP and TSS loads ranging by a factor of 10.0, 4.7, and 6.0, respectively. Like the previous period, this separation is largely the result of land use with, generally, higher-yielding watersheds featuring more urban, crop or pasture lands and the lowest yielding watersheds being predominantly forested. Overall, natural factors had the most significant influence on pre-settlement watershed yields with land use taking over as anthropogenic forces grew in the Ozarks. The main conclusions of this study are:

1. There is high natural variability in background TN, TP and TSS yields. Pre-settlement sub-watershed yields ranged by 6.4 and 5.8 times for TN and TP and by 13 times for TSS. Under pre-settlement conditions, natural variability in soil, slope, topography and hydrologic soil group serve as the best indicators of NPS loads.

2. Under peak-disturbance and present-day conditions, anthropogenic land use change becomes the leading factor in predicting NPS. Across the Ozarks, present-day cropland yielded TN, TP, and TSS 12.2, 6.7, and 5.8 times higher than forest land. Lands with high disturbance and natural soil, or landscape susceptibility are most affected.
3. Modern NPS pollution in the Ozarks has increased nutrient and sediment loads significantly from natural levels as the result of anthropogenic land use change. Based on STEPL generated estimations, present-day NPS yields of TN, and both TP and TSS are an average of 9.3 and 4.4 times above pre-settlement rates, respectively. On average, 81%, 67%, and 56% of present TN, TP and TSS loads are anthropogenic.

As future research explores the relationships between human activities and the landscape it is important to understand the extent of anthropogenic disturbance and the magnitude of the gap to potential recovery. This is one of the first studies to evaluate the impacts of historical land use change on NPS loads such as N, P and TSS in the Ozark Highlands region. This study offers a review of the effects of human-induced land use change on water quality in the region and provides baseline nonpoint information for past land use practices in comparison to present-day. Comparing NPS loads temporally and spatially among watersheds across the Missouri Ozarks provides context to better understand present-day nonpoint yields and can inform watershed management decisions and load reduction targets set by land managers. As described in this thesis, understanding how soil and land use factors can influence the geography of water quality in the Ozark Highlands both with and without human input will help us better understand NPS dynamics and improve the ability to manage our watersheds toward a more sustainable future.

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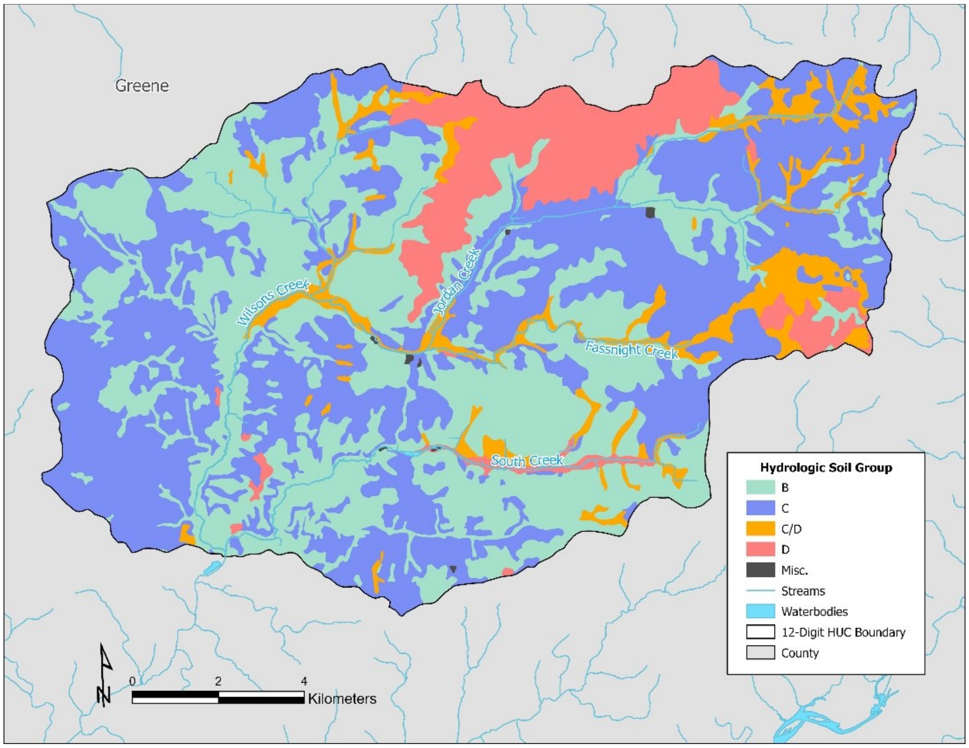
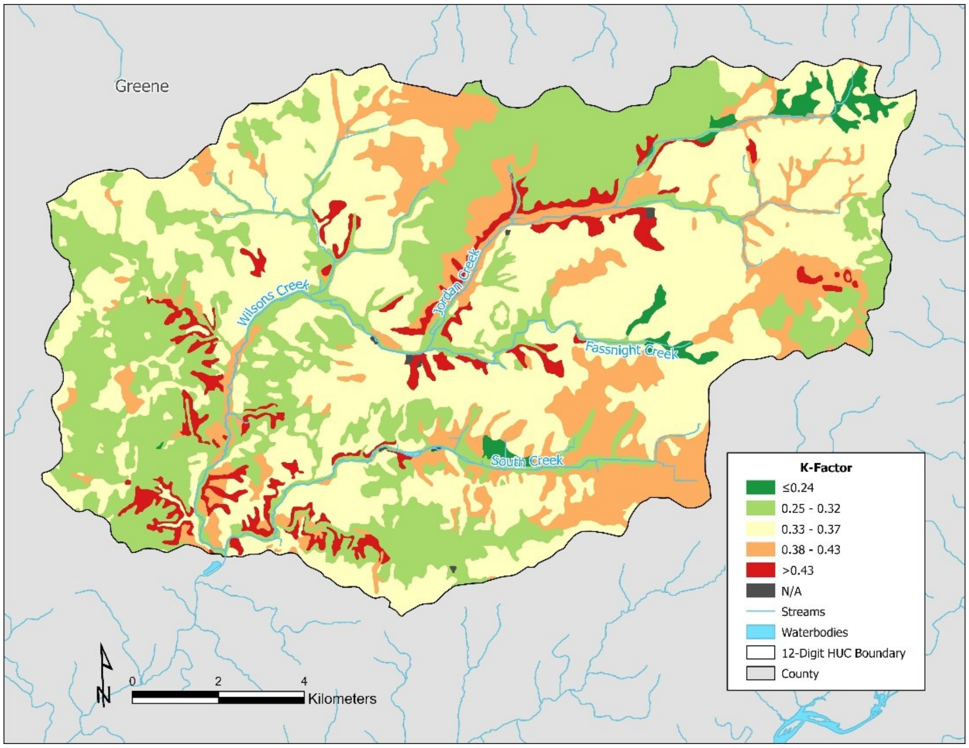
APPENDICES

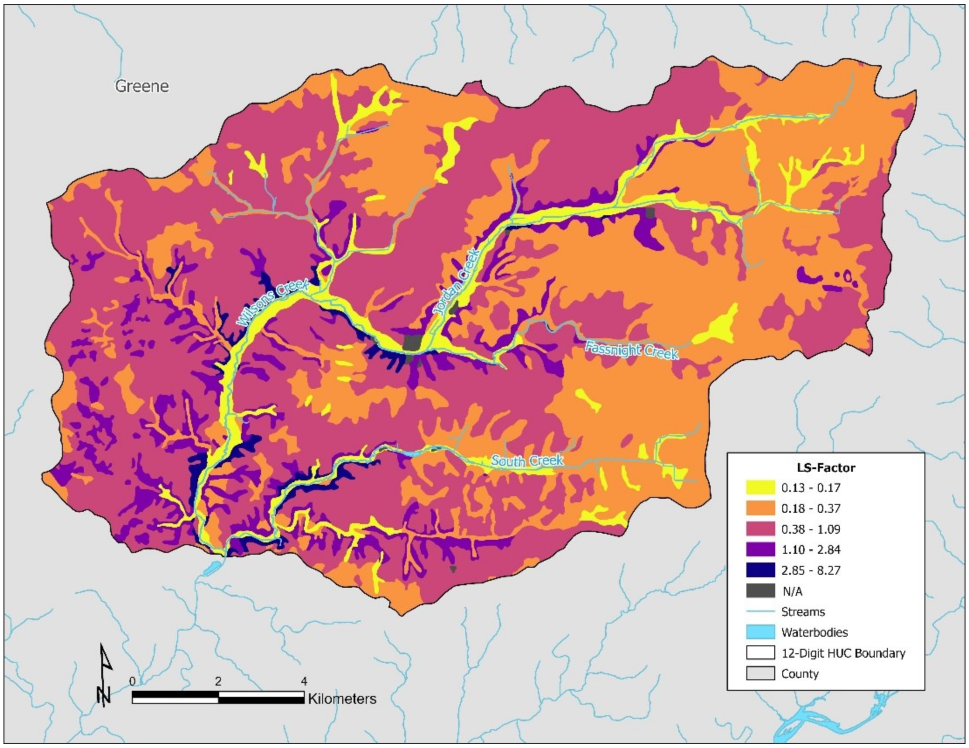
Appendix A. Watershed Soil Maps.



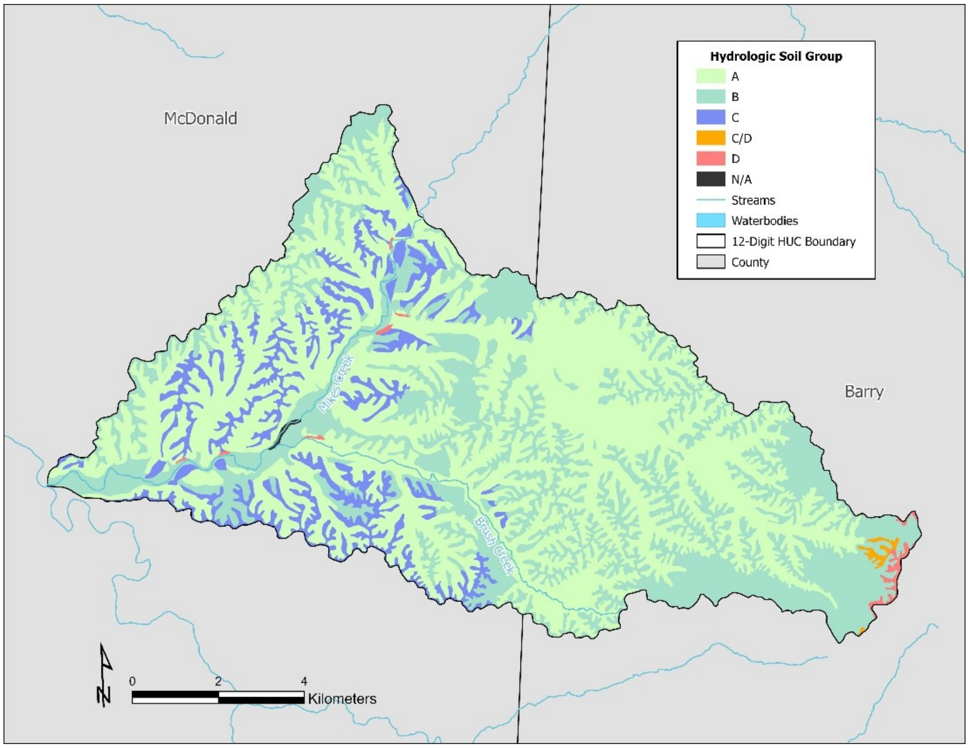
Appendix A-1. Map of hydrologic soil group classifications for soils in the Wilsons Creek watershed.



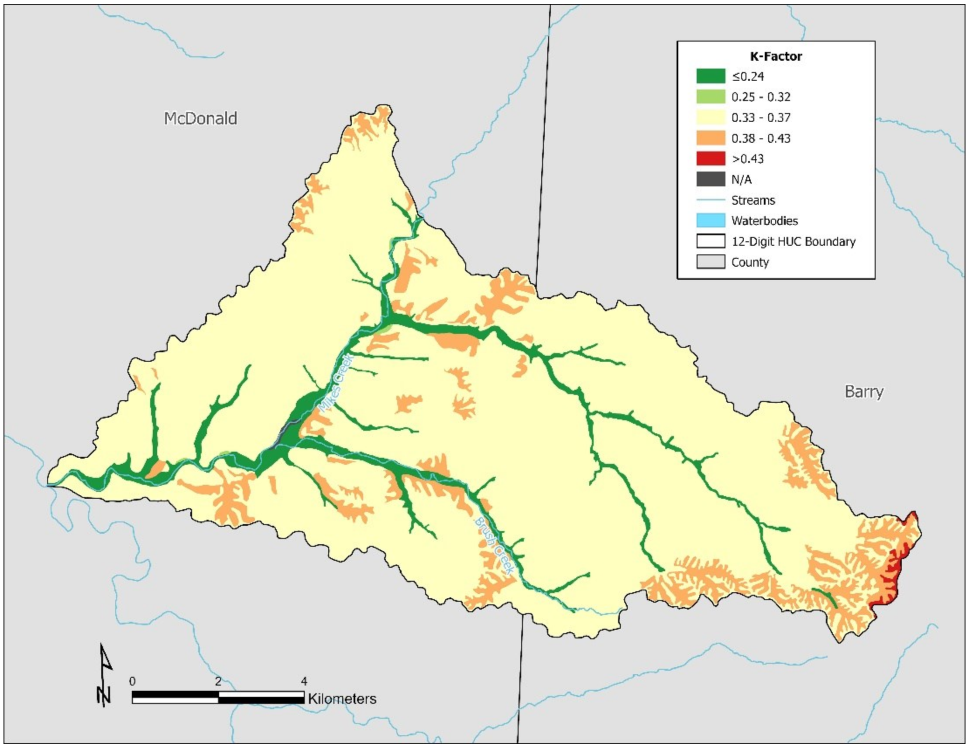
Appendix A-2. Map of soil erosion K-factor ratings for soils in the Wilsons Creek watershed.



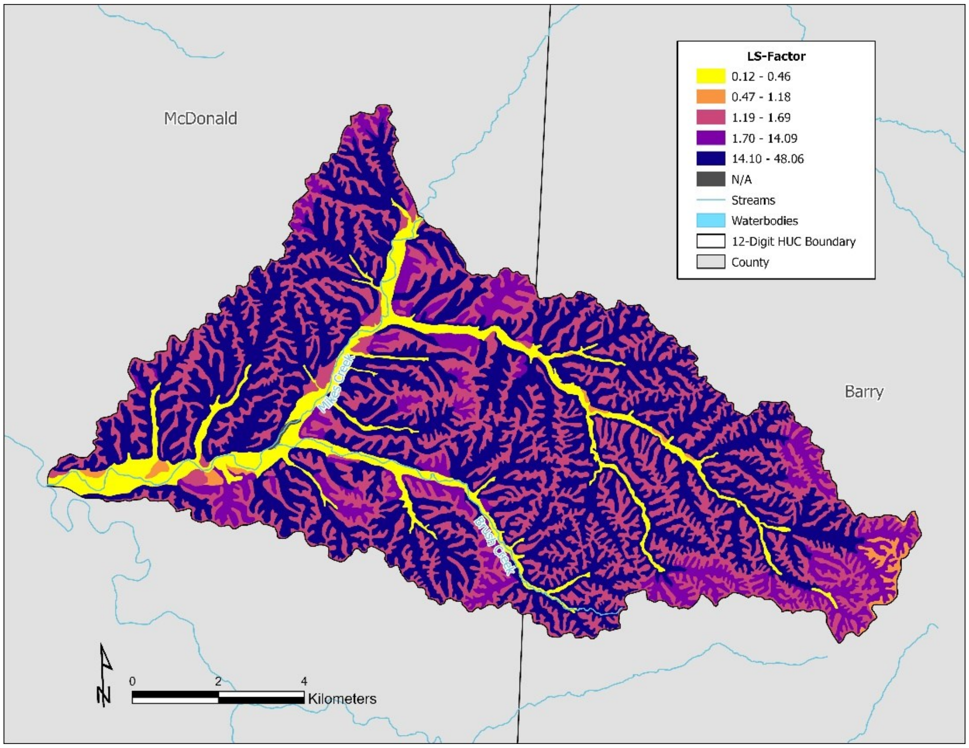
Appendix A-3. Map of LS-factor values for soils in the Wilsons Creek watershed.



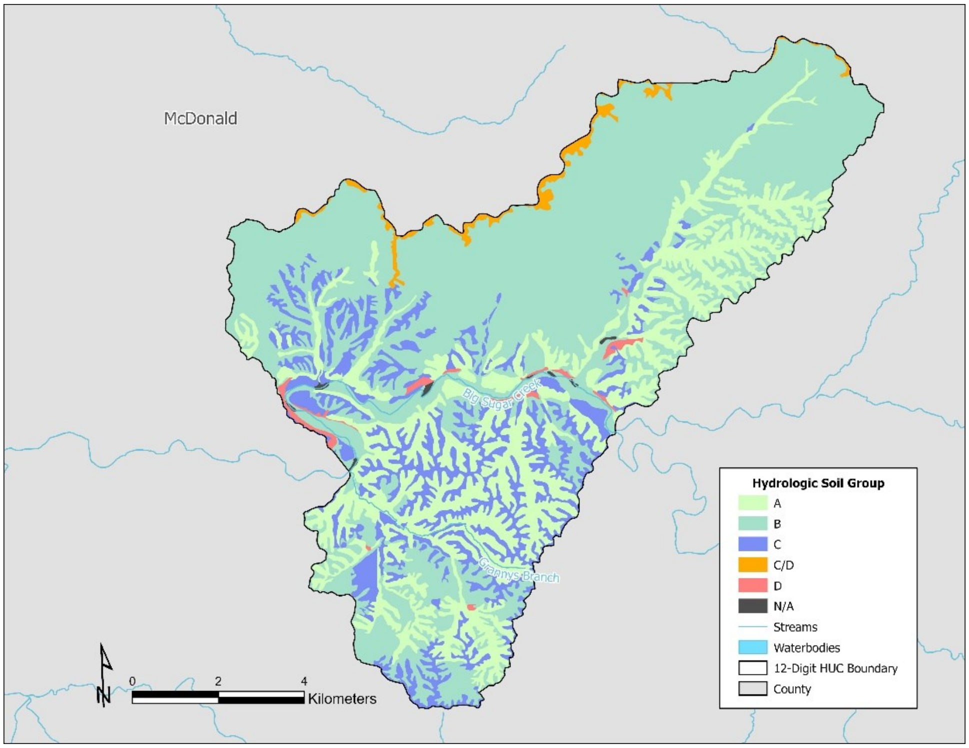
Appendix A-4. Map of hydrologic soil group classifications for soils in the Mikes Creek watershed.



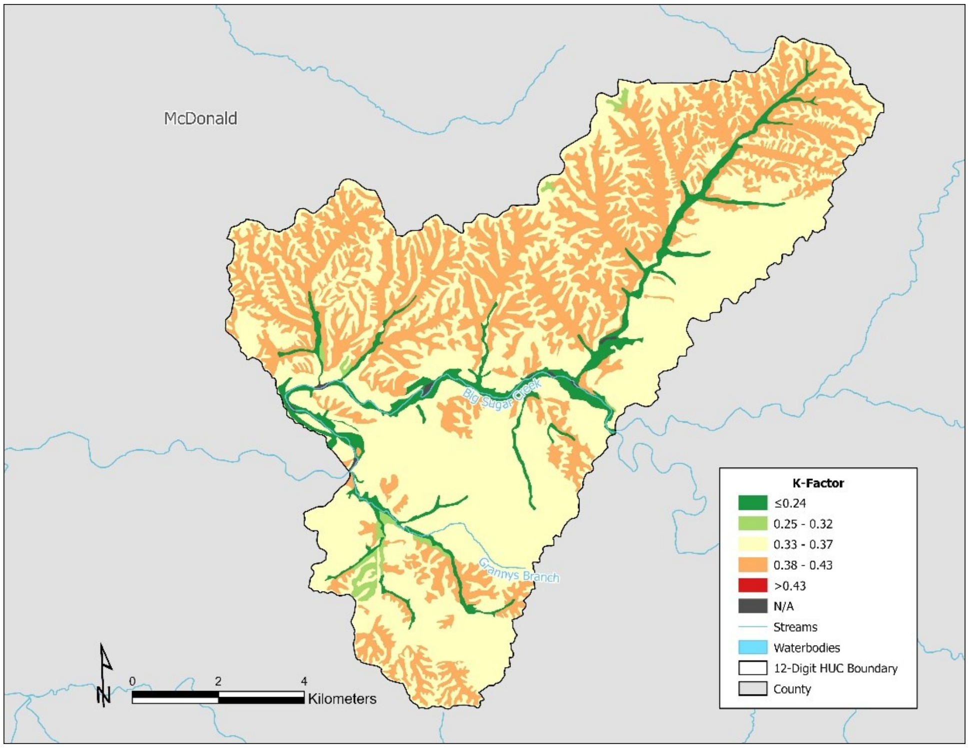
Appendix A-5. Map of soil erosion K-factor ratings for soils in the Mikes Creek watershed.



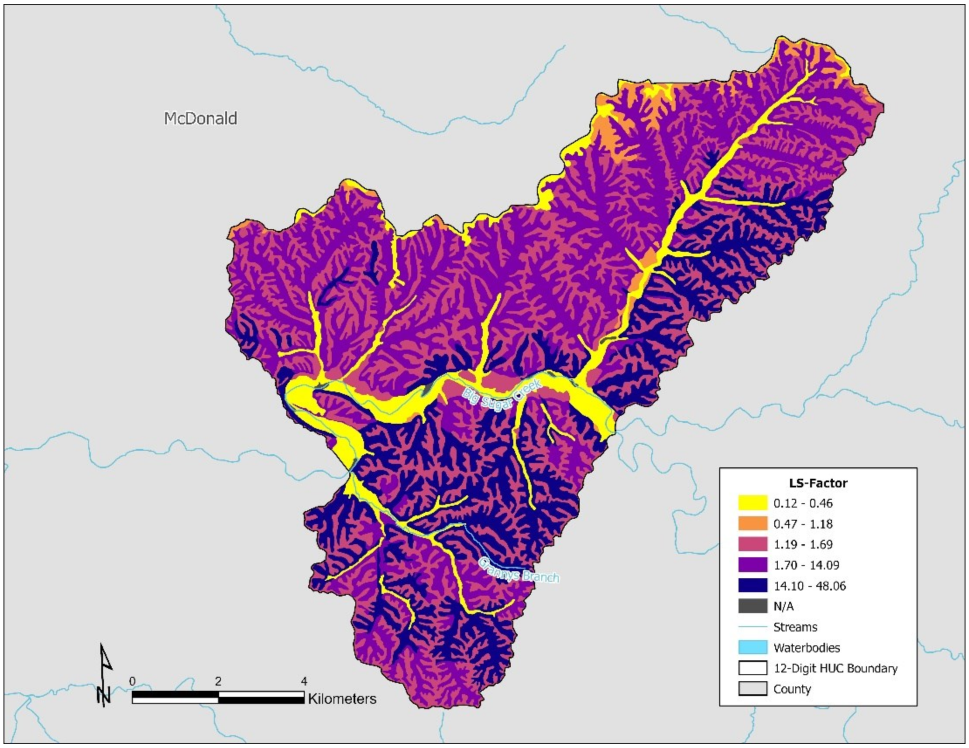
Appendix A-6. Map of LS-factor values for soils in the Mikes Creek watershed.



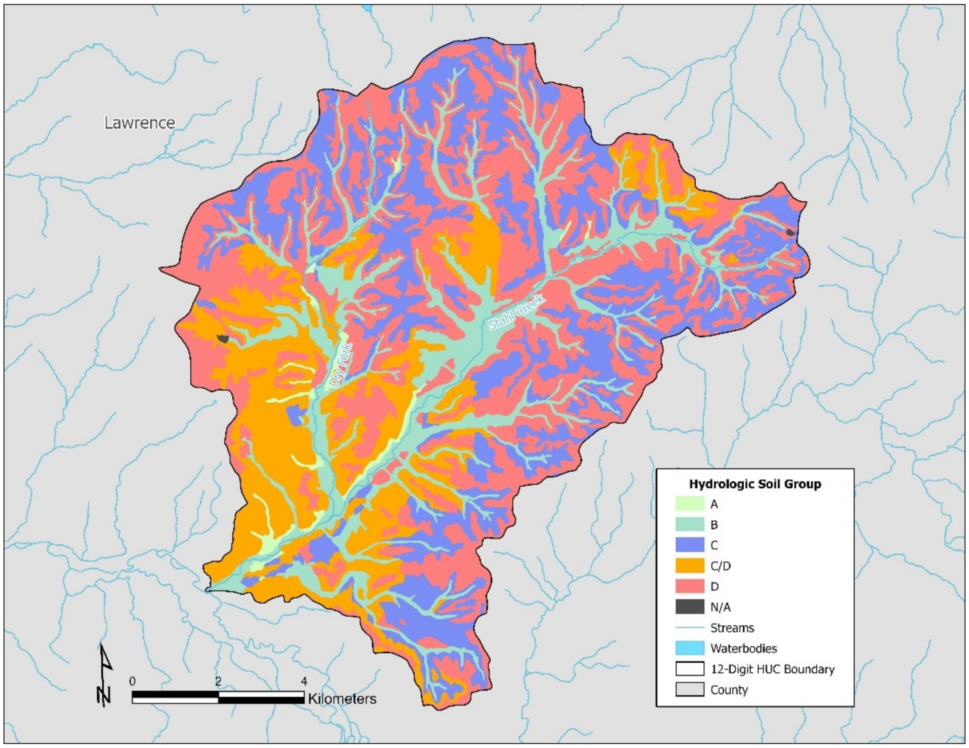
Appendix A-7. Map of hydrologic soil group classifications for soils in the Sugar Creek watershed.



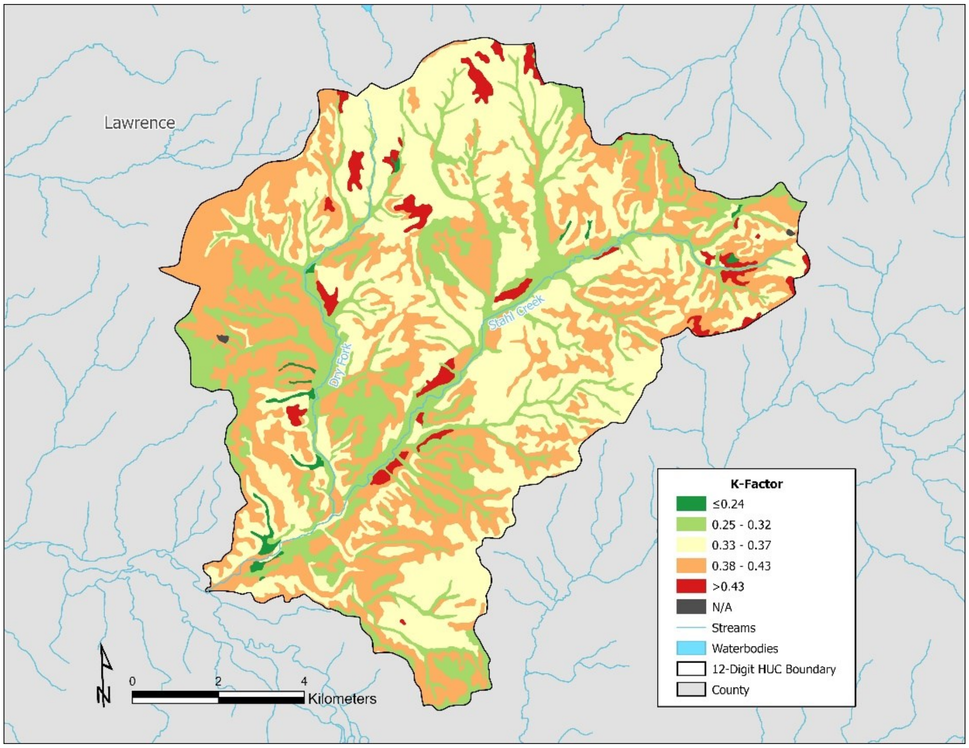
Appendix A-8. Map of soil erosion K-factor ratings for soils in the Sugar Creek watershed.



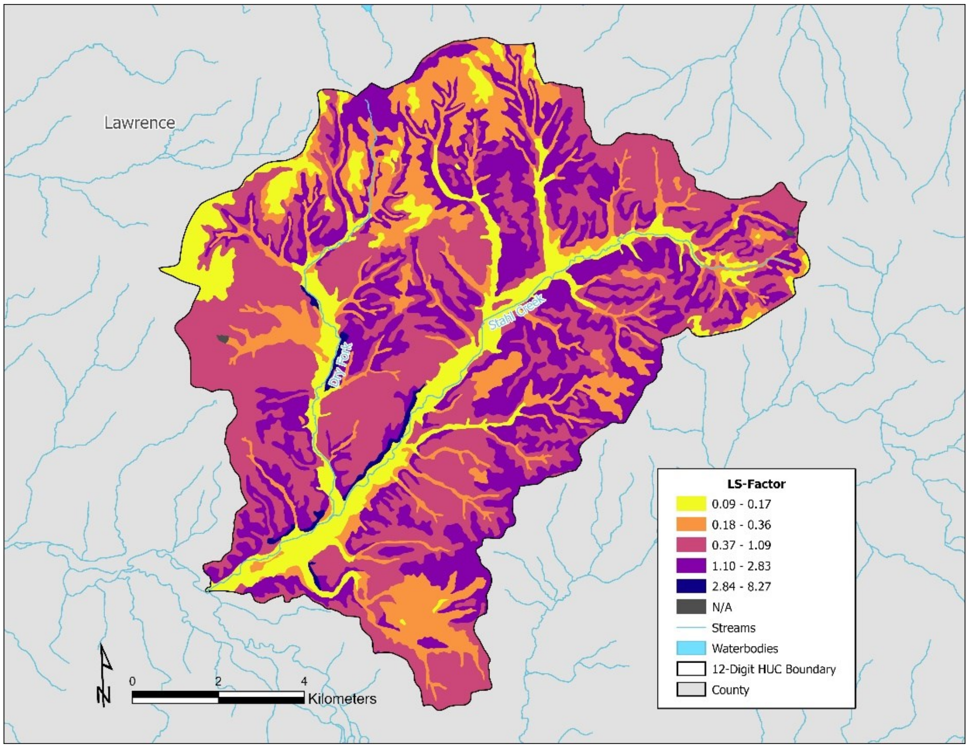
Appendix A-9. Map of LS-factor values for soils in the Sugar Creek watershed.



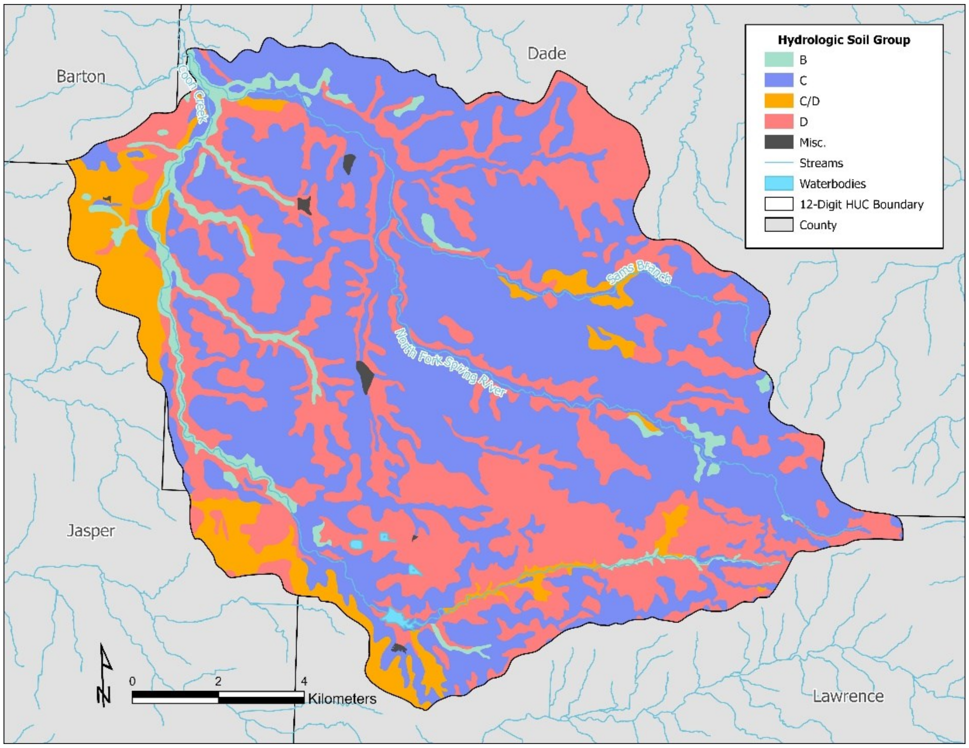
Appendix A-10. Map of hydrologic soil group classifications for soils in the Stahl Creek watershed.



Appendix A-11. Map of soil erosion K-factor ratings for soils in the Stahl Creek watershed.



Appendix A-12. Map of LS-factor values for soils in the Stahl Creek watershed.



Appendix A-13. Map of hydrologic soil group classifications for soils in the Spring River watershed.

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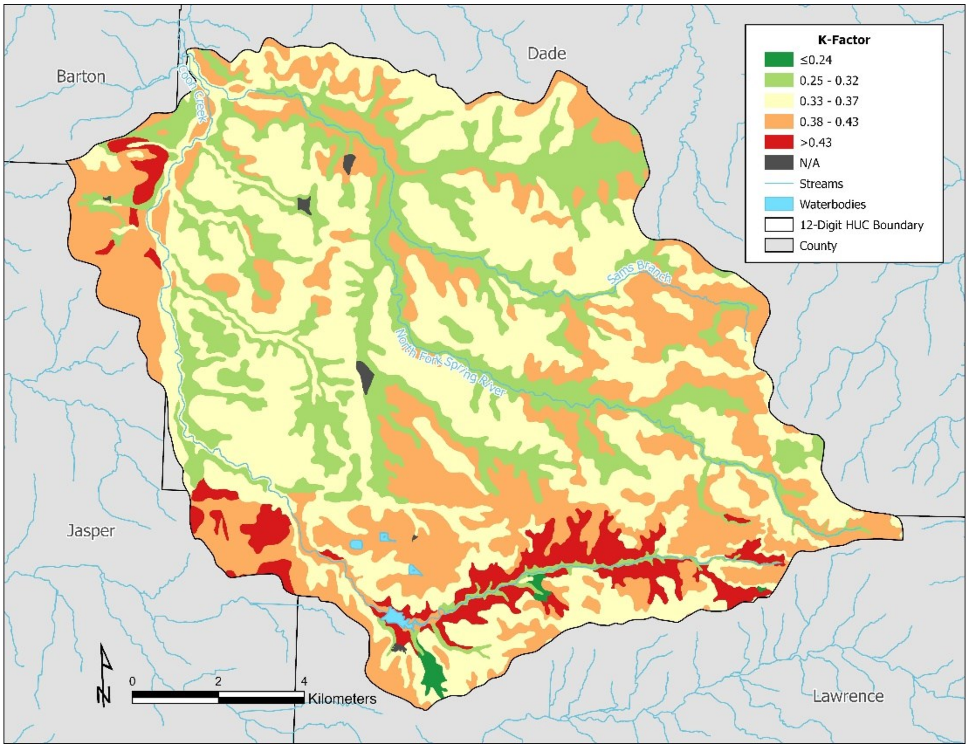
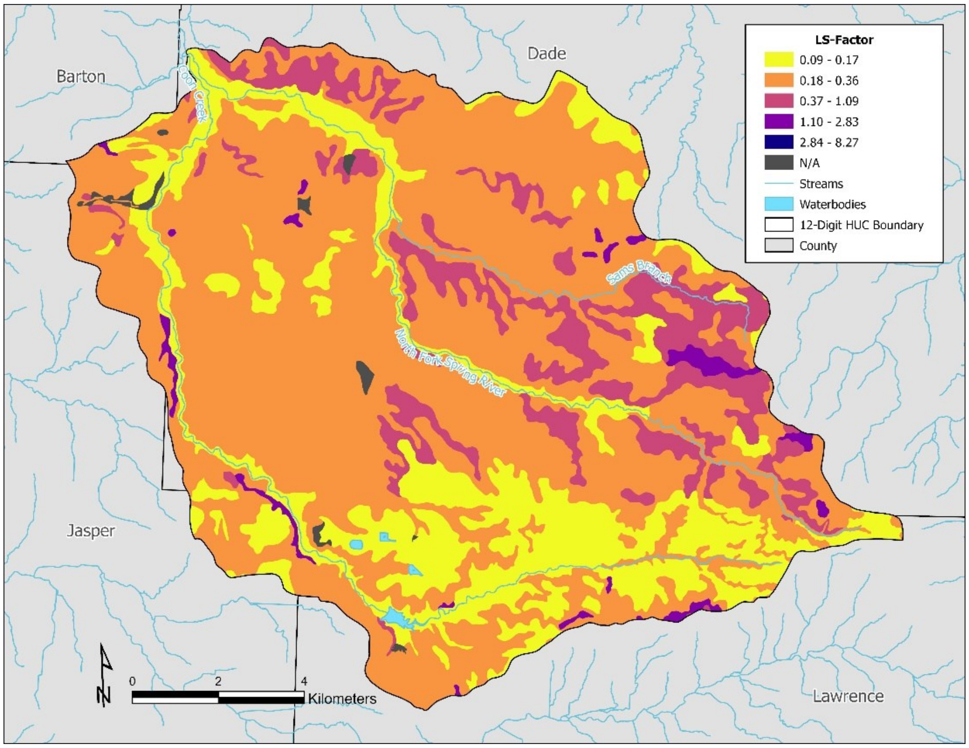
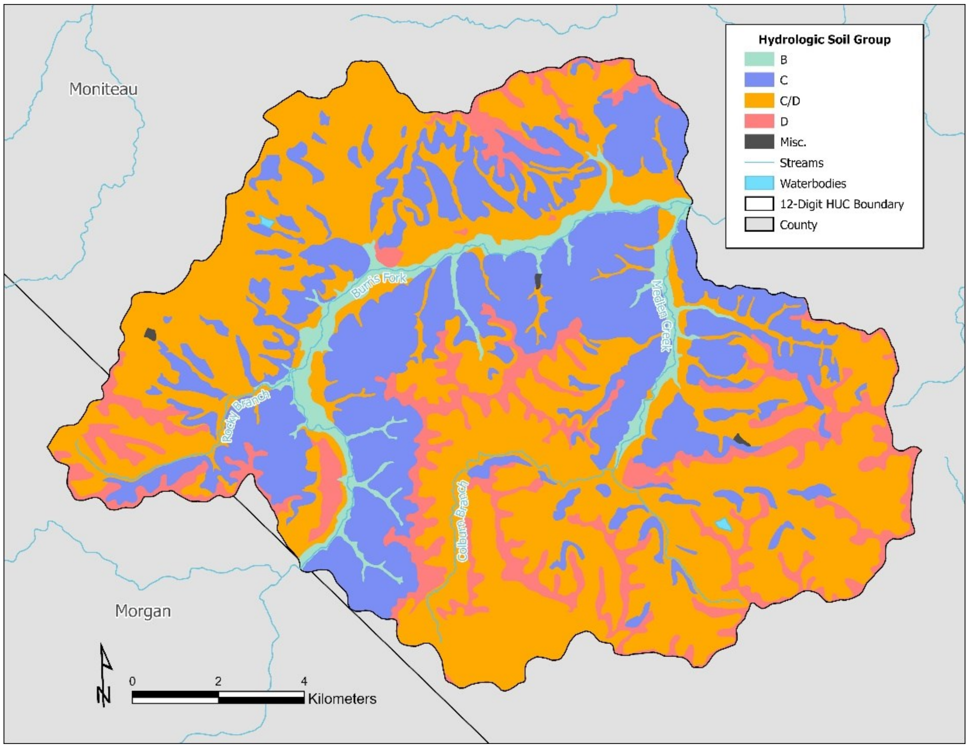


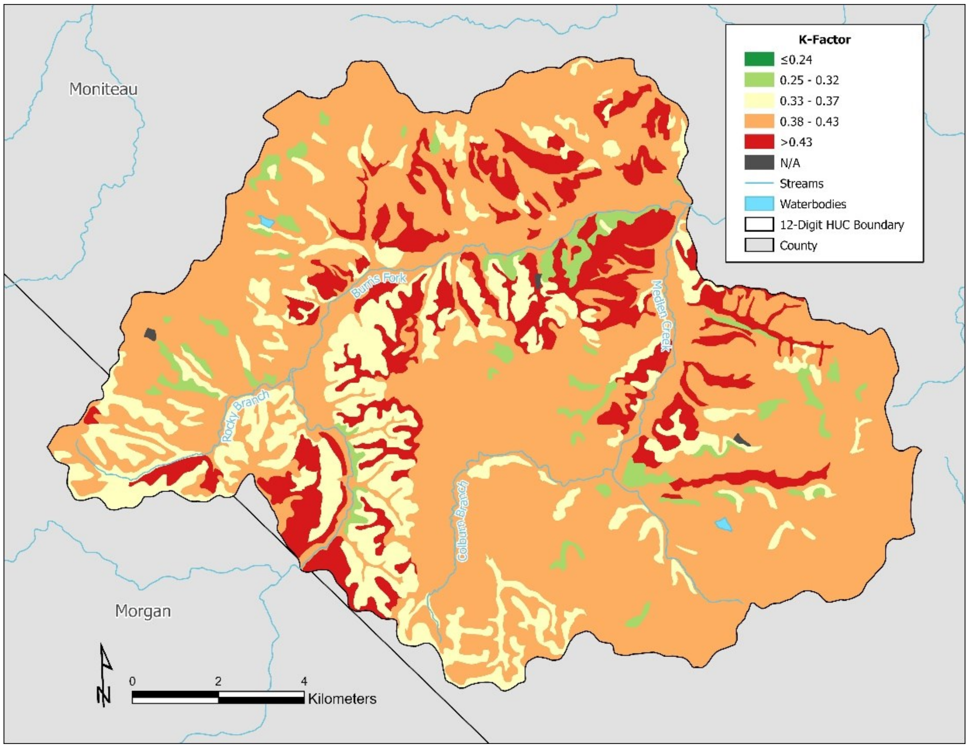
Appendix A-14. Map of soil erosion K-factor ratings for soils in the Spring River watershed.



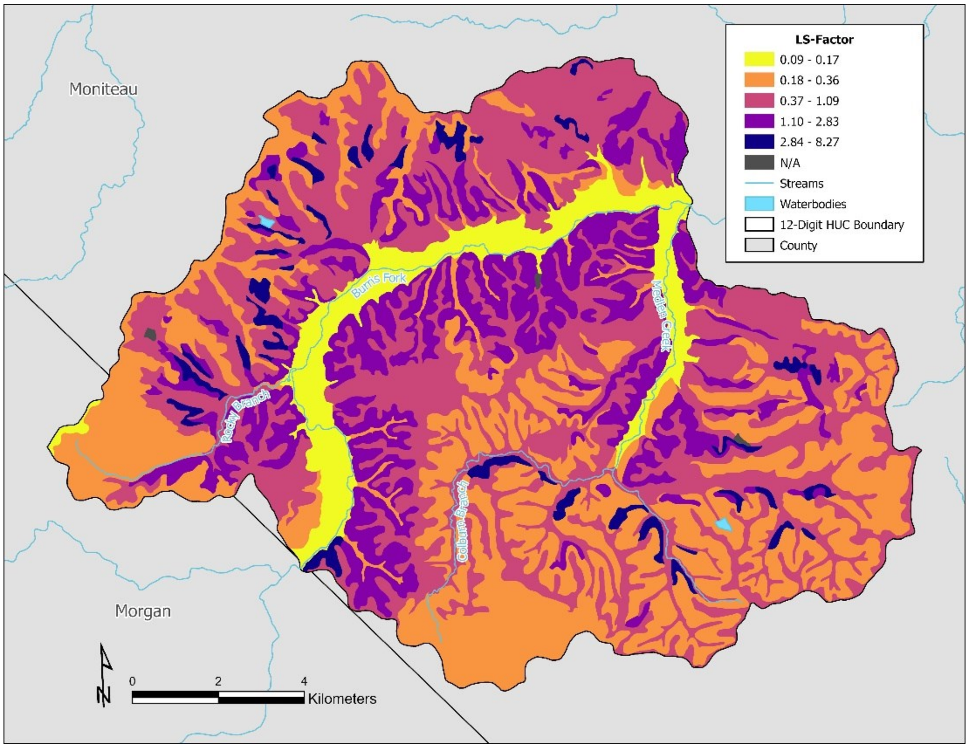
Appendix A-15. Map of LS-factor values for soils in the Spring River watershed.



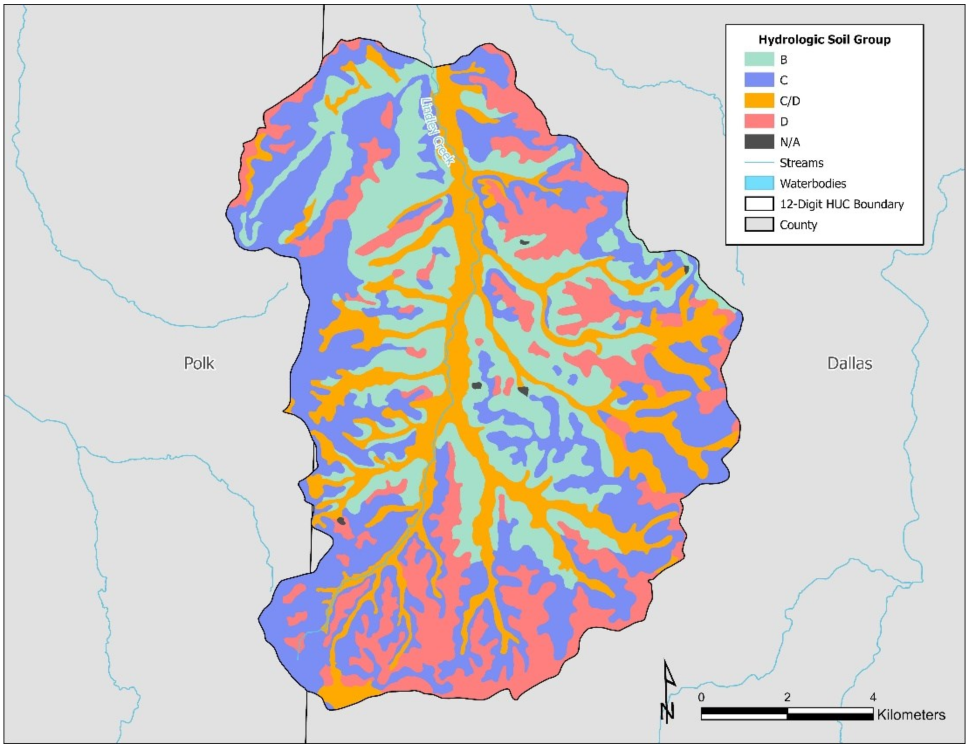
Appendix A-16. Map of hydrologic soil group classifications for soils in the Middle Burris watershed.



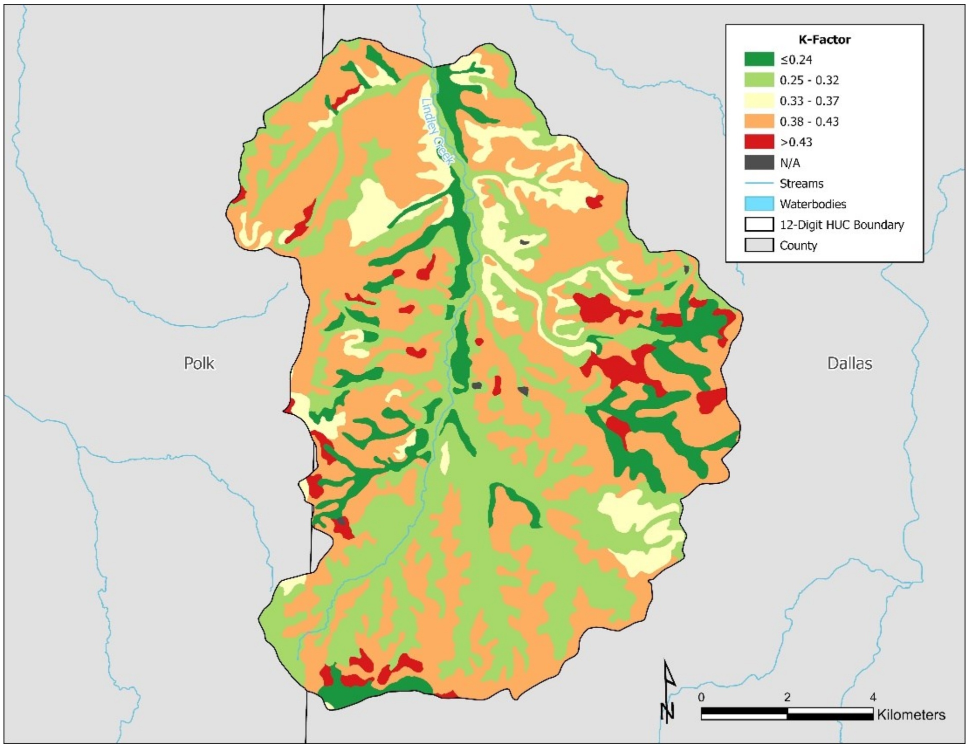
Appendix A-17. Map of soil erosion K-factor ratings for soils in the Middle Burris watershed.



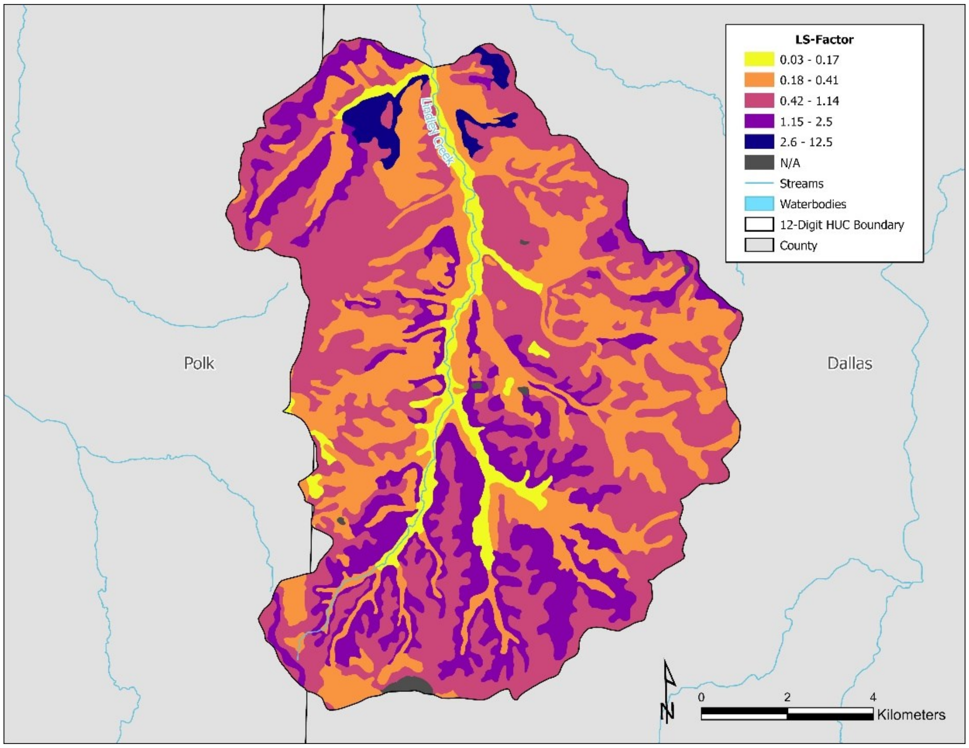
Appendix A-18. Map of LS-factor values for soils in the Middle Burris watershed.



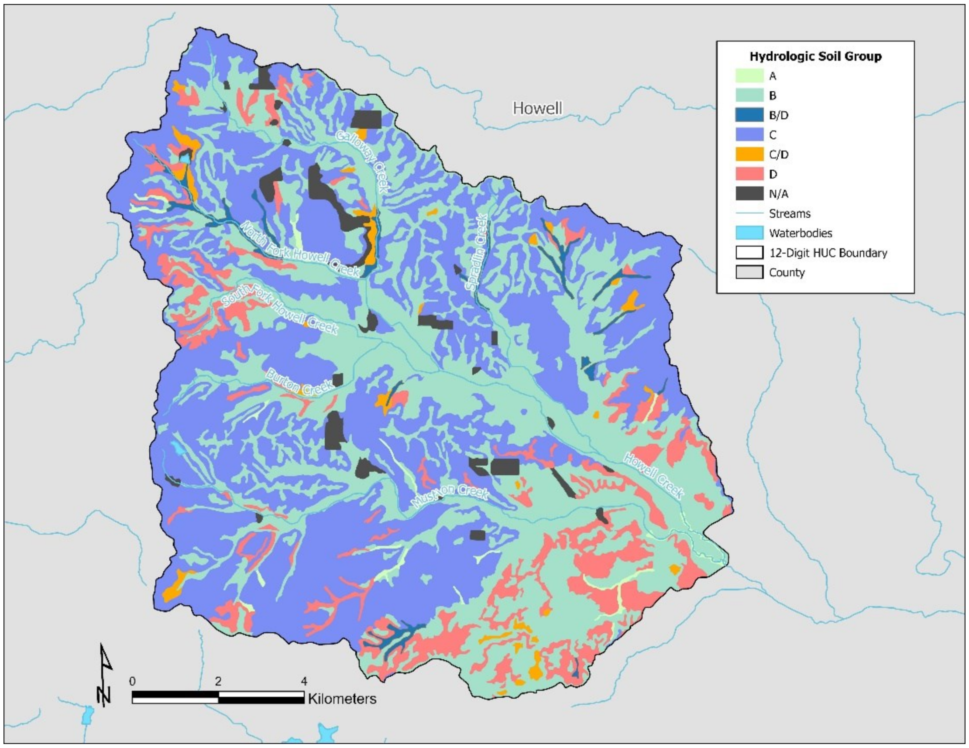
Appendix A-19. Map of hydrologic soil group classifications for soils in the Lindley Creek watershed.



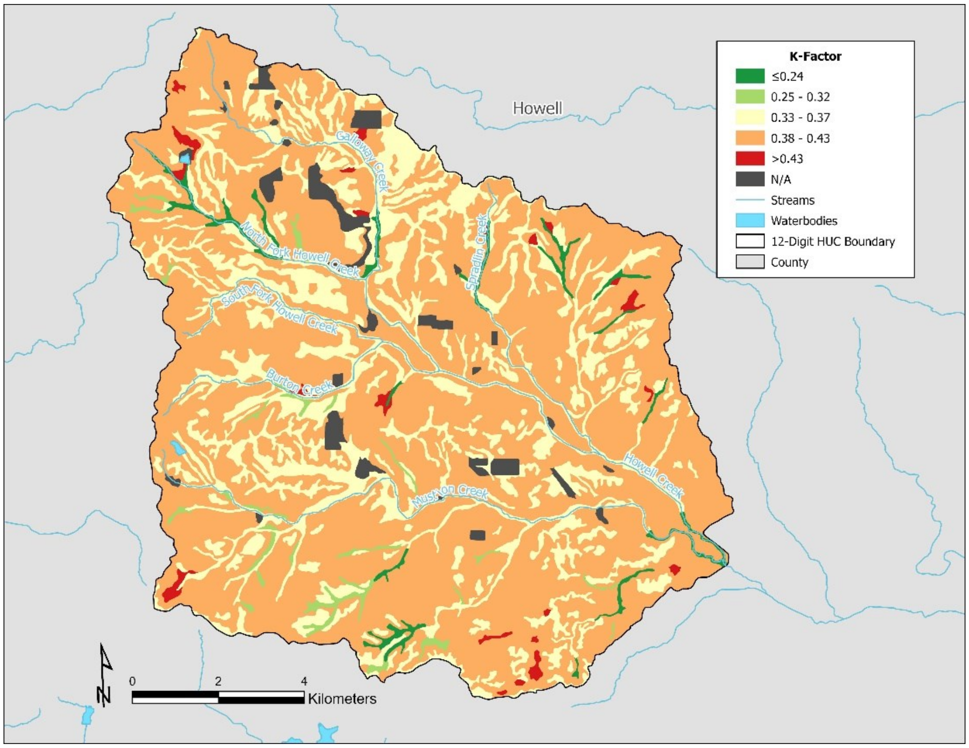
Appendix A-20. Map of soil erosion K-factor ratings for soils in the Lindley Creek watershed.



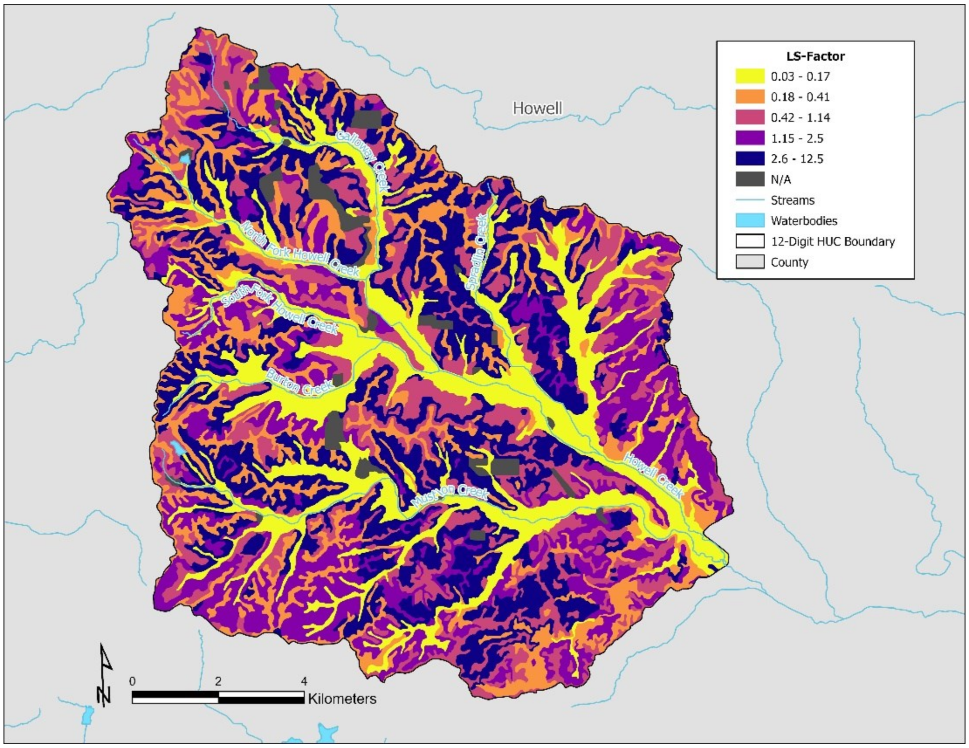
Appendix A-21. Map of LS-factor values for soils in the Lindley Creek watershed.



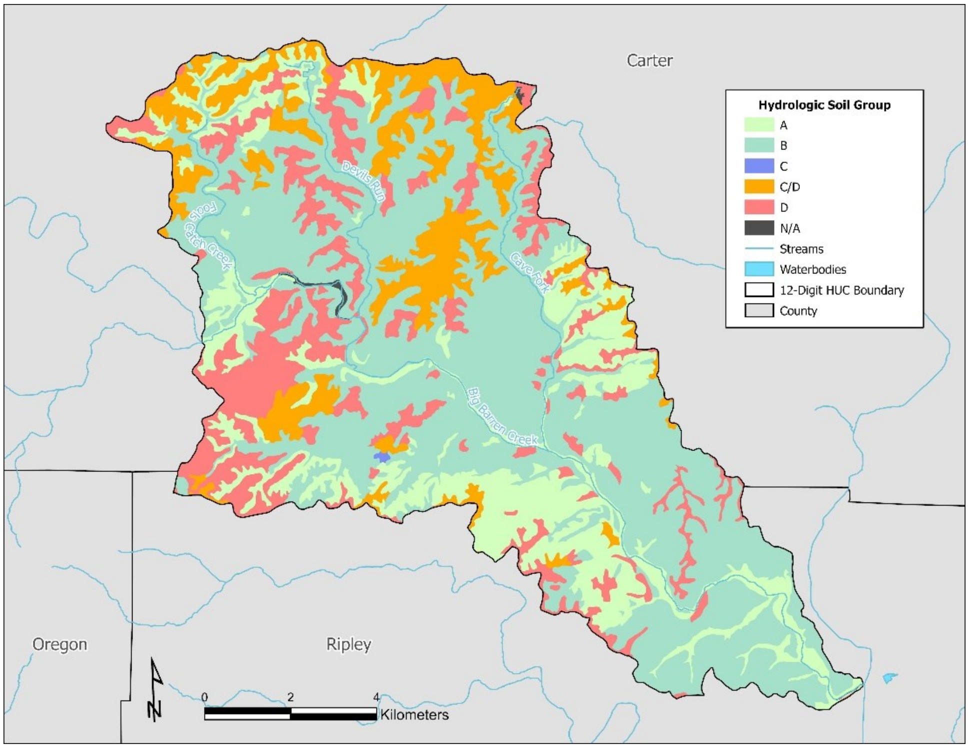
Appendix A-22. Map of hydrologic soil group classifications for soils in the Howell Creek watershed.



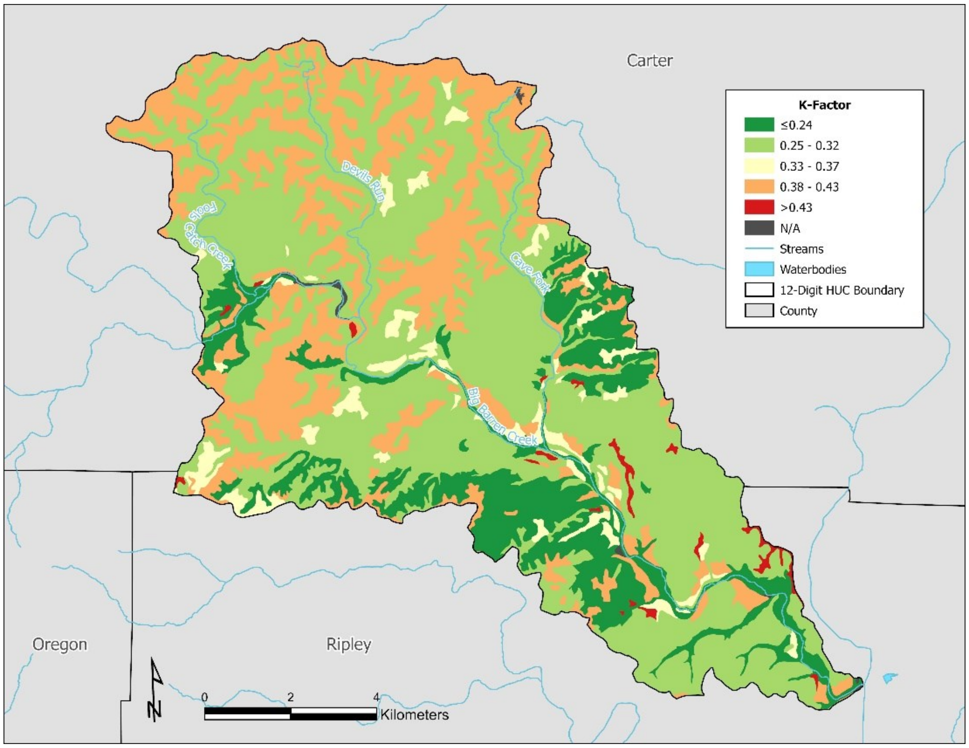
Appendix A-23. Map of soil erosion K-factor ratings for soils in the Howell Creek watershed.



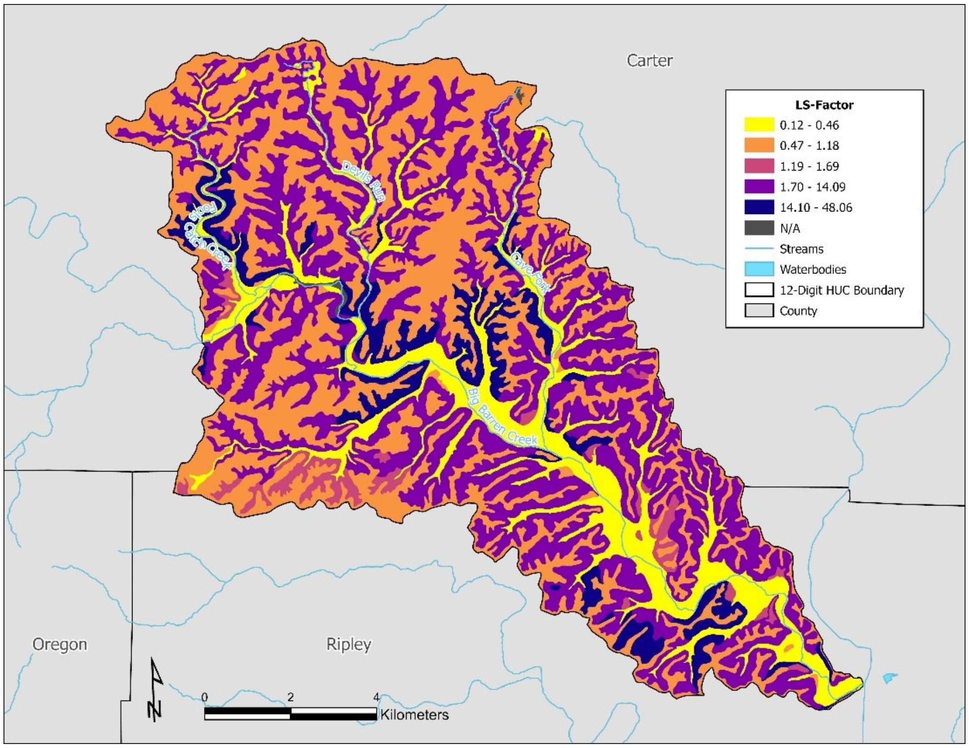
Appendix A-24. Map of LS-factor values for soils in the Howell Creek watershed.



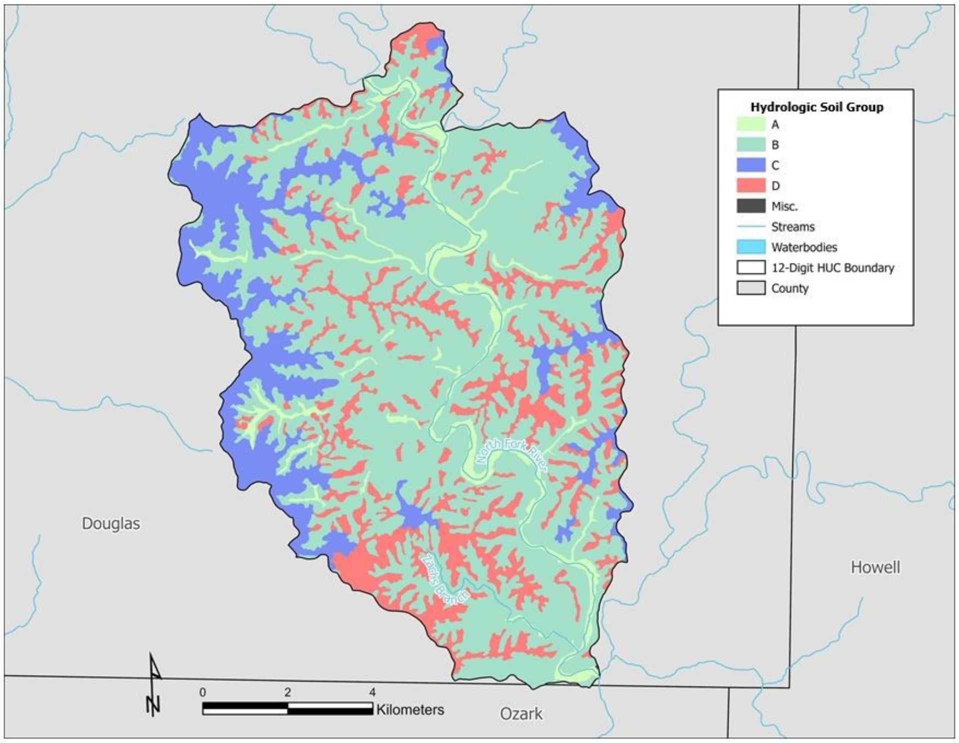
Appendix A-25. Map of hydrologic soil group classifications for soils in the Big Barren watershed.



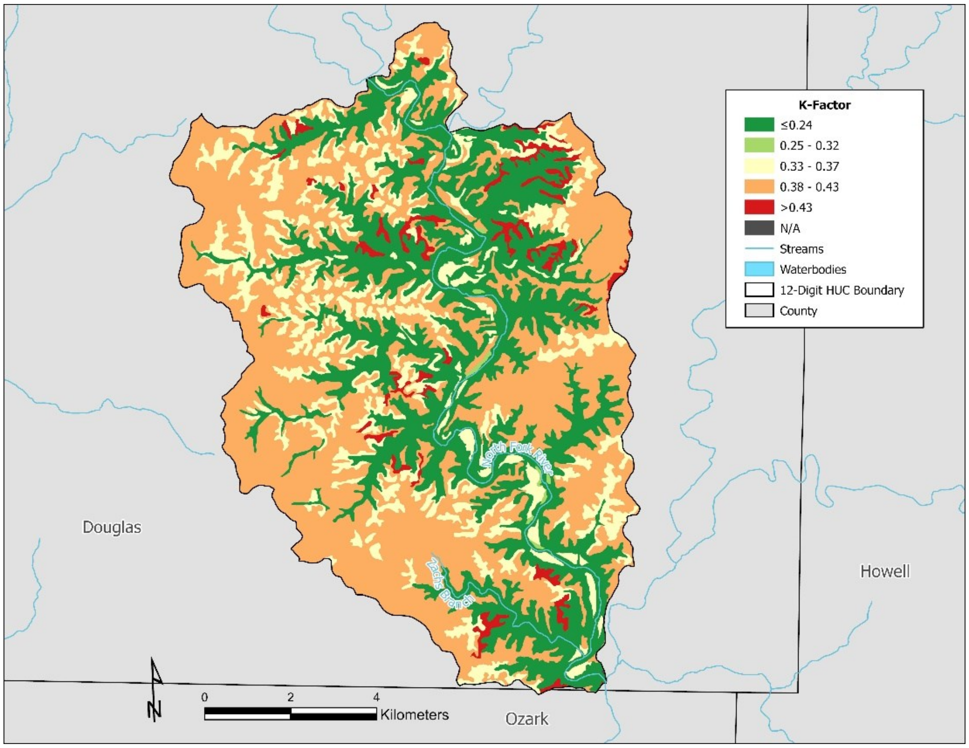
Appendix A-26. Map of soil erosion K-factor ratings for soils in the Big Barren watershed.



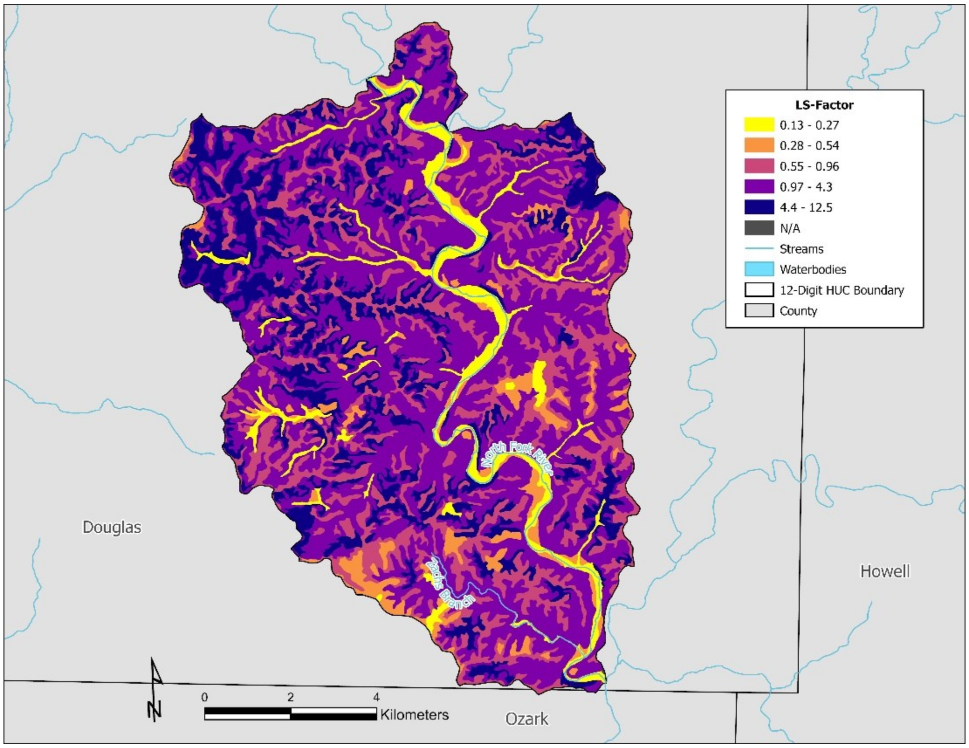
Appendix A-27. Map of LS-factor values for soils in the Big Barren watershed.



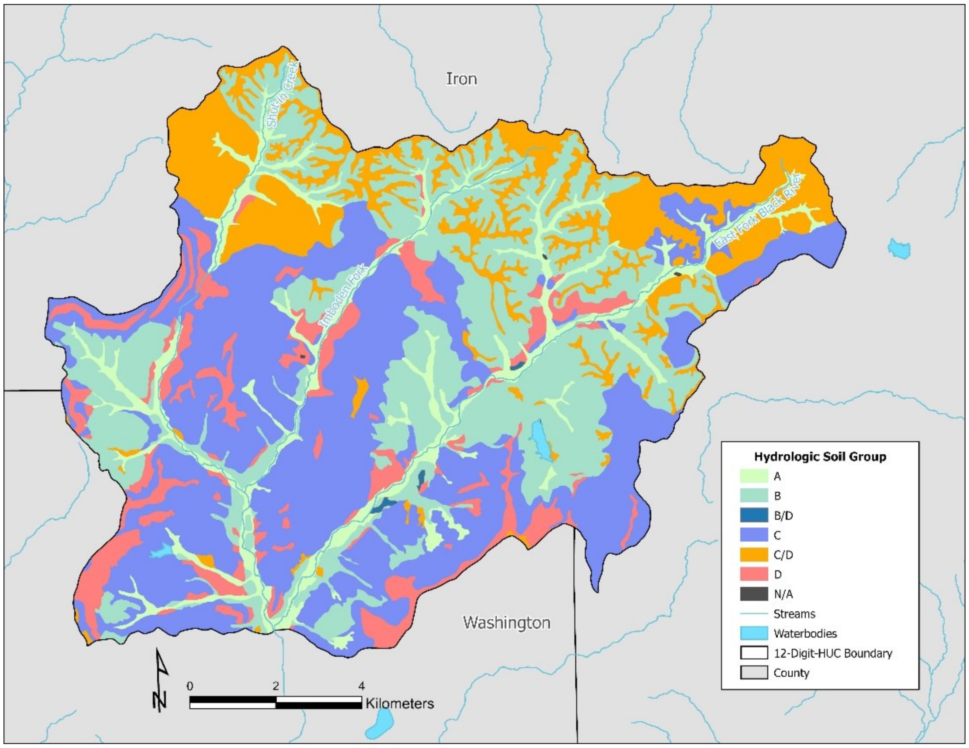
Appendix A-28. Map of hydrologic soil group classifications for soils in the North Fork watershed.



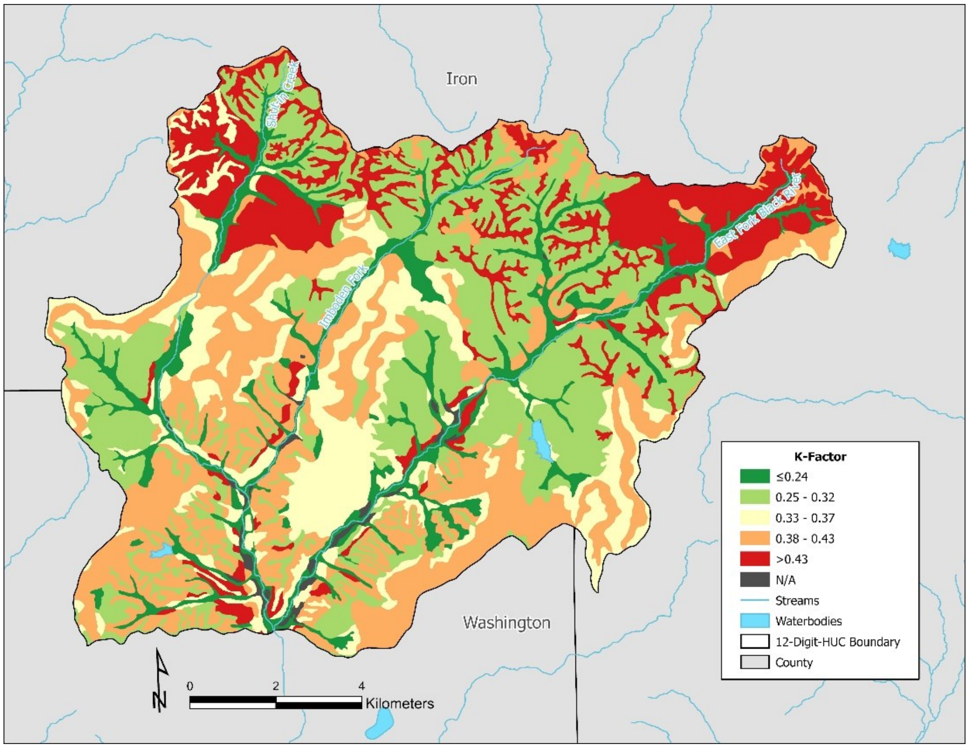
Appendix A-29. Map of soil erosion K-factor ratings for soils in the North Fork watershed.



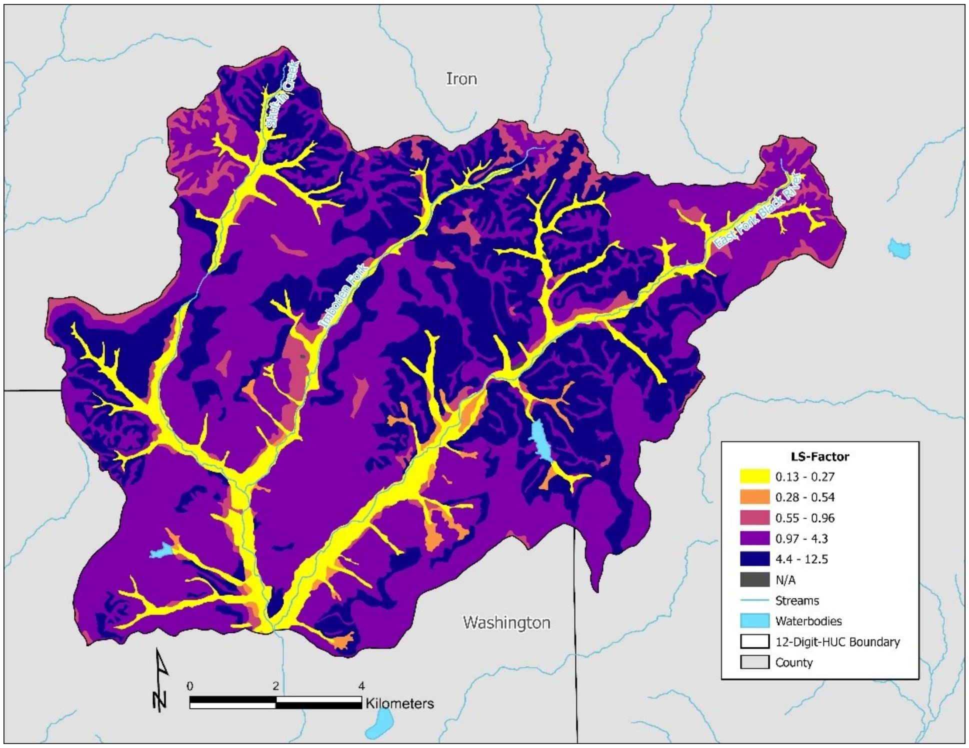
Appendix A-30. Map of LS-factor values for soils in the North Fork watershed.



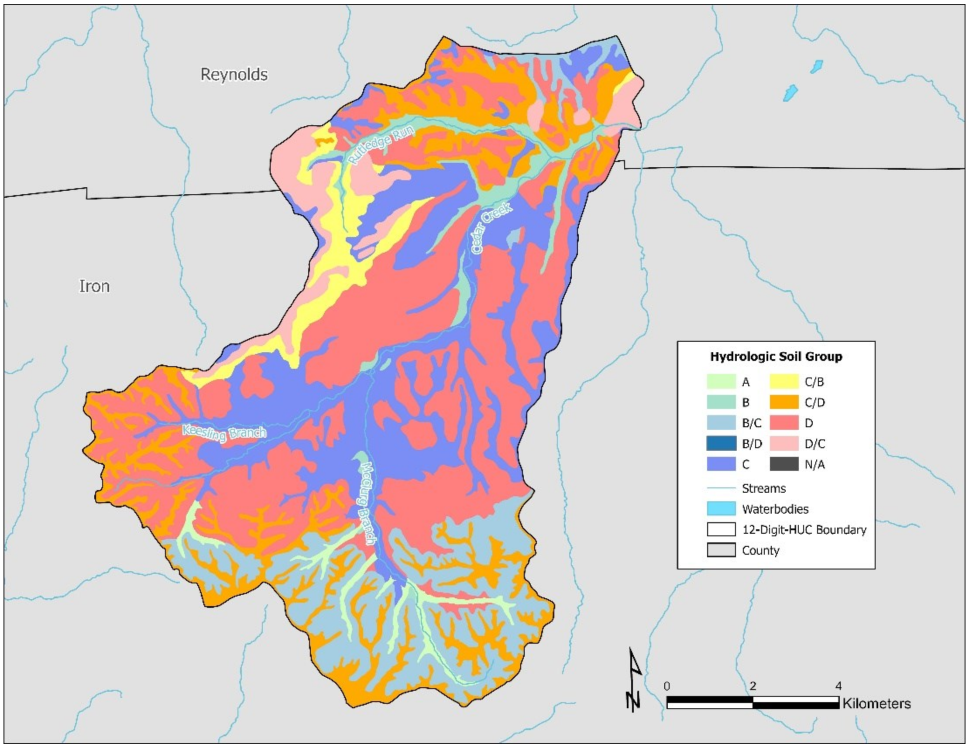
Appendix A-31. Map of hydrologic soil group classifications for soils in the Black River watershed.



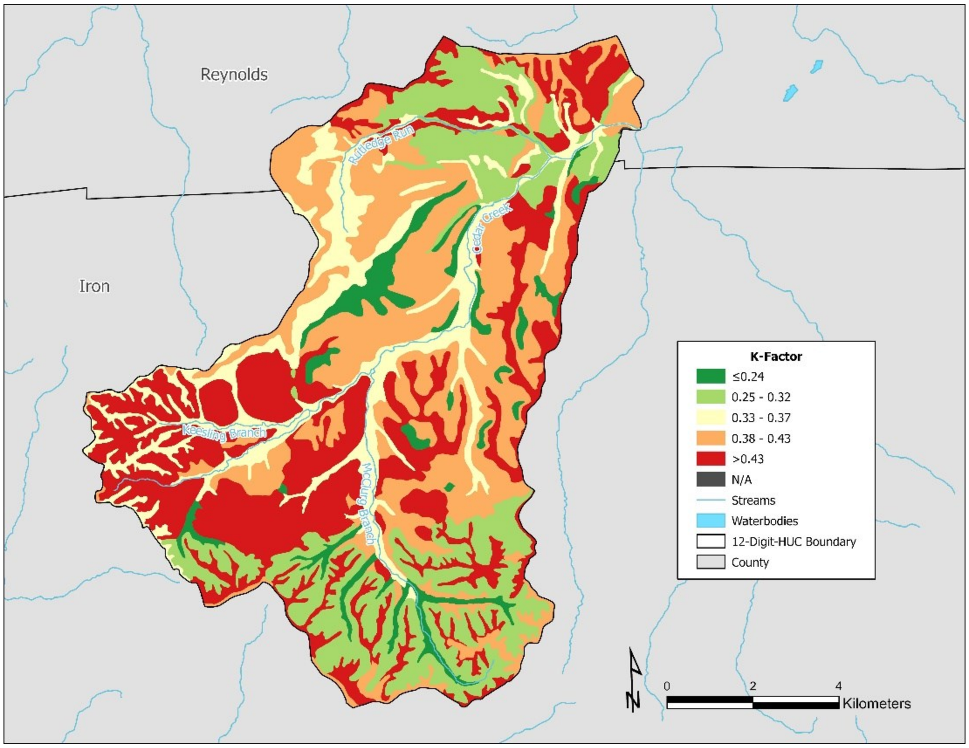
Appendix A-32. Map of soil erosion K-factor ratings for soils in the Black River watershed.



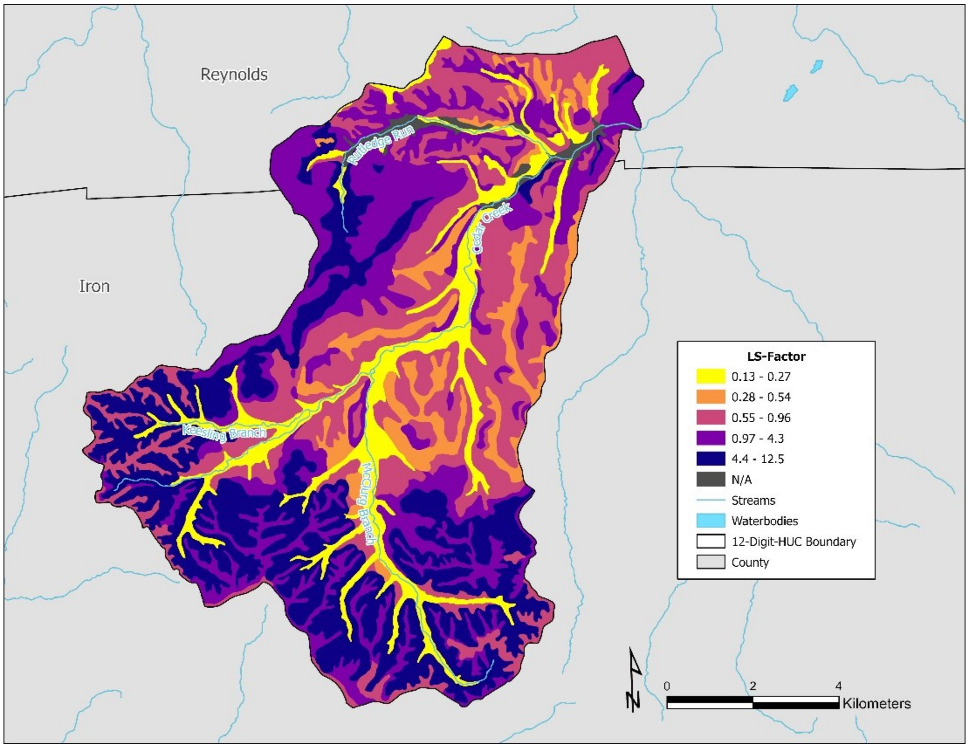
Appendix A-33. Map of LS-factor values for soils in the Black River watershed.



Appendix A-34. Map of hydrologic soil group classifications for soils in the Cedar Creek watershed.



Appendix A-35. Map of soil erosion K-factor ratings for soils in the Cedar Creek watershed.



Appendix A-36. Map of LS-factor values for soils in the Cedar Creek watershed.

Appendix B. STEPL Inputs for All Modeling Scenarios.

Watershed	County	Drainage Area (km^2)	HSG	Land Use (%) Urban	Crop	Pasture	Forest
Wilsons Creek	Greene	130.2	C	80%	2%	10%	8%
Mikes Creek	McDonald	96.4	B	3%	0%	10%	87%
Sugar Creek	McDonald	114.1	B	4%	1%	17%	78%
Stahl Creek	Lawrence	82.7	C	5%	17%	61%	17%
Spring River	Dade	134.0	C	4%	58%	32%	7%
Burris Fork	Moniteau	78.4	C	4%	24%	46%	26%
Lindley Creek	Dallas	62.9	C	7%	11%	60%	22%
Howell Creek	Howell	134.9	B	20%	2%	41%	37%
Big Barren	Carter	106.1	B	3%	0%	5%	91%
North Fork	Douglas	119.0	B	3%	0%	20%	76%
Black River	Iron	134.7	B	2%	0%	2%	96%
Cedar Creek	Iron	69.5	B	2%	4%	24%	70%

Appendix B-1. Present-day STEPL land use inputs.

Watershed	**County**	**Drainage Area (km^2)**	**HSG**	**Land Cover (%)** **Hardwood**	**Mixed Pine**	**Prairie**	**Savanna**
Wilsons Creek	Greene	130.2	A/B/B/B	26%	2%	70%	2%
Mikes Creek	McDonald	96.4	A/A/A/A	62%	34%	2%	2%
Sugar Creek	McDonald	114.1	A/A/B	81%	16%	3%	0%
Stahl Creek	Lawrence	82.7	C/B/B	31%	0%	51%	18%
Spring River	Dade	134.0	B/B/B	6%	0%	77%	17%
Burris Fork	Moniteau	78.4	B/B/B	38%	0%	18%	44%
Lindley Creek	Dallas	62.9	B/B/B	61%	0%	23%	16%
Howell Creek	Howell	134.9	A/A/B/A	92%	2%	0%	6%
Barren Creek	Carter	106.1	A/A	0%	98%	0%	2%
North Fork	Douglas	119.0	A/A/A	71%	29%	1%	0%
Black River	Iron	134.7	A/A/B/C	46%	47%	0%	7%
Cedar Creek	Iron	69.5	A/C/B/A	71%	20%	2%	7%

Appendix B-2. Pre-settlement STEPL land use inputs.

Watershed	**County**	**Drainage Area (km^2)**	**HSG**	**Land Use (%)** **Urban**	**Crop**	**Pasture**	**Forest**
Wilsons Creek	Greene	130.2	D	14%	41%	44%	1%
Mikes Creek	McDonald	96.4	C	0%	4%	38%	58%
Sugar Creek	McDonald	114.1	C	0%	6%	39%	56%
Stahl Creek	Lawrence	82.7	D	1%	56%	43%	1%
Spring River	Dade	134.0	D	0%	32%	68%	0%
Burris Fork	Moniteau	78.4	D	0%	87%	13%	0%
Lindley Creek	Dallas	62.9	D	0%	74%	24%	2%
Howell Creek	Howell	134.9	C	3%	37%	37%	22%
Big Barren	Carter	106.1	C	0%	5%	10%	85%
North Fork	Douglas	119.0	C	0%	26%	29%	45%
Black River	Iron	134.7	C	0%	23%	22%	55%
Cedar Creek	Iron	69.5	C	0%	37%	31%	32%

Appendix B-3. Peak-disturbance STEPL land use inputs.

	# of Animals								Septic Inputs		
Watershed	Beef Cattle	Dairy Cattle	Swine	Sheep	Horse	Chicken	Turkey	Duck	# of Septic	Pop. Per System	% Failure Rate
Wilsons Creek	857	32	8	6	47	82	0	2	6,233	2	0.39
Mikes Creek	1,311	30	6	13	43	242,525	7,135	2	29	2	0.39
Sugar Creek	2,184	35	12	15	81	398,775	6,800	4	57	2	0.39
Stahl Creek	6,367	220	127	98	156	191,528	61,240	2	184	2	0.39
Spring River	5,212	113	198	45	89	55,505	25,226	3	59	2	0.39
Burris Fork	7,213	99	2,460	83	91	82,592	74,026	8	100	2	0.39
Lindley Creek	3,650	196	62	47	152	256	9,104	16	340	2	0.39
Howell Creek	4,834	68	56	160	132	216	0	9	2,806	2	0.39
Barren Creek	461	1	0	3	15	38	1	0	12	2	0.39
North Fork	1,563	85	6	33	70	72	2	6	51	2	0.39
Black River	156	0	1	7	14	27	1	1	70	2	0.39
Cedar Creek	1,339	5	11	40	69	133	3	2	118	2	0.39

Appendix B-4. Present-day STEPL animal and septic inputs.

Watershed	# of Animals Beef Cattle	Dairy Cattle	Swine	Sheep	Horse	Chicken
Wilsons Creek	1,437	1,017	2,879	1,647	1,357	21,003
Mikes Creek	983	843	734	165	239	7,583
Sugar Creek	1,080	933	818	111	274	8,887
Stahl Creek	1,096	1,358	684	1,003	346	13,715
Spring River	1,647	717	3,463	2,080	1,298	22,981
Burris Fork	860	514	2,051	438	658	8,442
Lindley Creek	651	337	673	475	419	6,026
Howell Creek	520	345	1,612	574	463	5,047
Barren Creek	526	197	778	148	199	2,531
North Fork	949	960	621	172	236	7,103
Black River	489	258	738	263	235	5,370
Cedar Creek	400	100	301	63	88	2,309

Appendix B-5. Peak-disturbance STEPL animal input

	Crop		Pasture		Forest		Urban	
Watershed	**K**	**LS**	**K**	**LS**	**K**	**LS**	**K**	**LS**
Wilsons Creek	0.352	0.597	0.352	0.910	0.355	1.385	0.367	0.558
Mikes Creek	0.331	3.039	0.360	5.429	0.369	15.241	0.346	5.654
Sugar Creek	0.369	1.971	0.381	3.665	0.384	10.706	0.361	5.055
Stahl Creek	0.392	0.591	0.380	0.664	0.361	0.876	0.385	0.705
Spring River	0.384	0.263	0.384	0.288	0.378	0.241	0.383	0.283
Burris Fork	0.431	0.477	0.434	0.694	0.414	1.179	0.431	0.685
Lindley Creek	0.387	0.681	0.374	0.786	0.353	1.508	0.367	0.865
Howell Creek	0.418	0.998	0.407	2.392	0.415	3.288	0.410	2.569
Barren Creek	0.340	0.413	0.348	0.505	0.319	2.960	0.329	0.824
North Fork	0.393	1.397	0.411	1.890	0.324	3.469	0.385	1.942
Black River	0.351	0.554	0.354	0.529	0.373	3.676	0.320	1.418
Cedar Creek	0.391	0.687	0.423	0.756	0.402	3.338	0.417	0.912

Appendix B-6. Present-day STEPL soil factor inputs by land use.

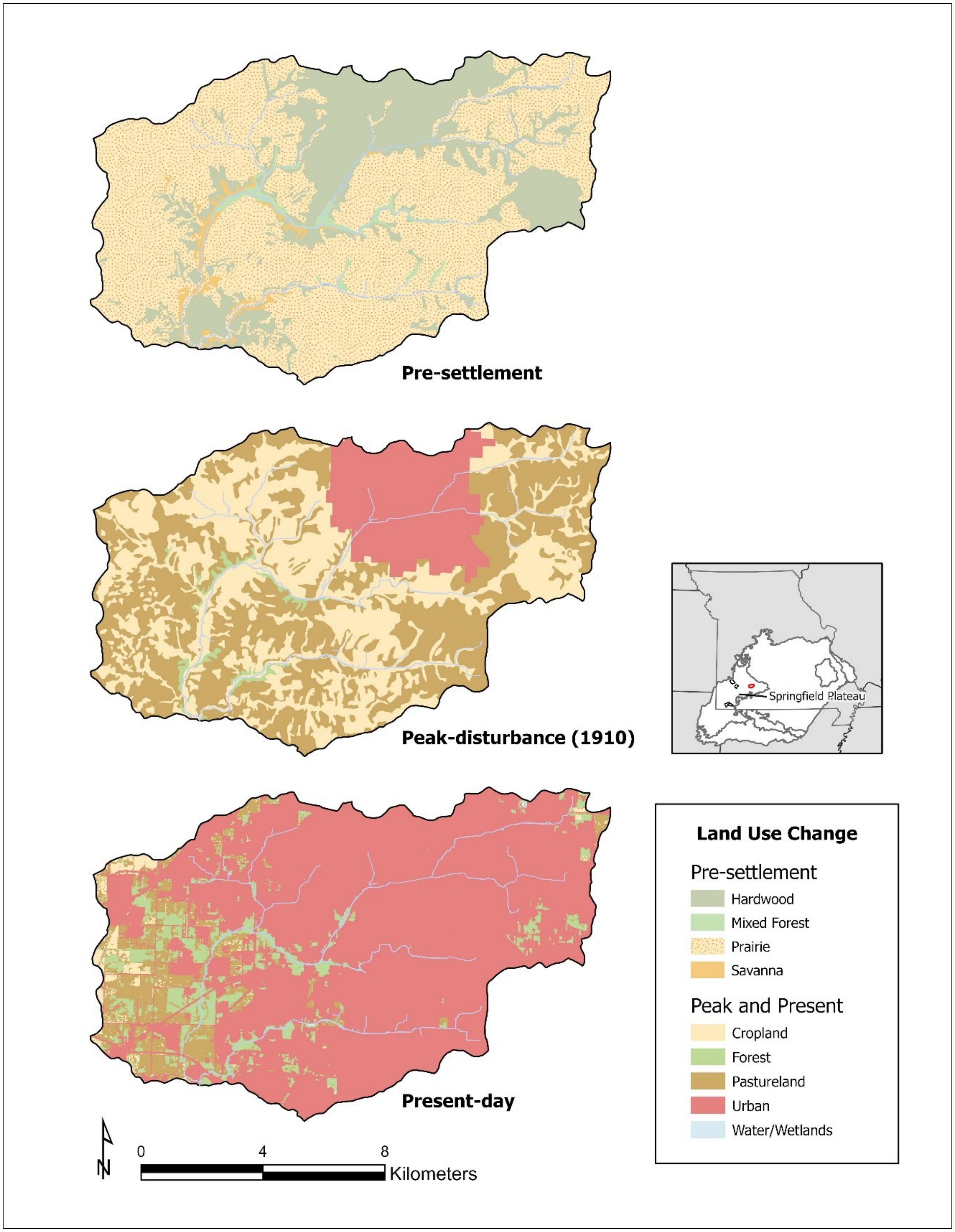
	Prairie				Savanna				Hardwood				Mixed Pine			
Watershed	**K**	**LS**	**C**	**CN**	**K**	**LS**	**C**	**CN**	**K**	**LS**	**C**	**CN**	**K**	**LS**	**C**	**CN**
Wilsons Creek	0.354	0.510	0.035	49	0.379	6.419	0.031	72	0.396	0.710	0.001	66	0.320	0.177	0.001	62
Mikes Creek	0.240	0.120	0.035	49	0.240	0.392	0.031	80	0.370	20.659	0.001	42	0.377	3.290	0.001	38
Sugar Creek	0.246	0.895	0.035	49					0.391	10.762	0.001	66	0.364	2.777	0.001	62
Stahl Creek	0.359	0.648	0.035	79	0.433	0.499	0.031	80	0.381	0.868	0.001	66				
Spring River	0.371	0.252	0.035	69	0.451	0.395	0.031	80	0.351	0.167	0.001	66				
Burris Fork	0.401	0.836	0.035	69	0.428	0.476	0.031	80	0.441	1.076	0.001	62				
Lindley Creek	0.319	0.836	0.035	69	0.427	0.775	0.031	80	0.375	1.036	0.001	62				
Howell Creek	0.240	0.133	0.035	49	0.370	0.131	0.031	72	0.414	2.974	0.001	62	0.385	0.326	0.001	38
Barren Creek					0.351	0.419	0.031	72					0.321	3.080	0.001	38
North Fork	0.209	0.205	0.035	49					0.403	2.607	0.001	42	0.029	0.630	0.001	38
Black River	0.370	0.159	0.035	49	0.399	2.701	0.031	72	0.397	2.364	0.001	62	0.343	4.882	0.001	75
Cedar Creek	0.381	2.080	0.035	49	0.367	3.276	0.031	87	0.435	1.738	0.001	62	0.328	5.362	0.001	38

Appendix B-7. Pre-settlement STEPL soil factor and curve number inputs by land use.

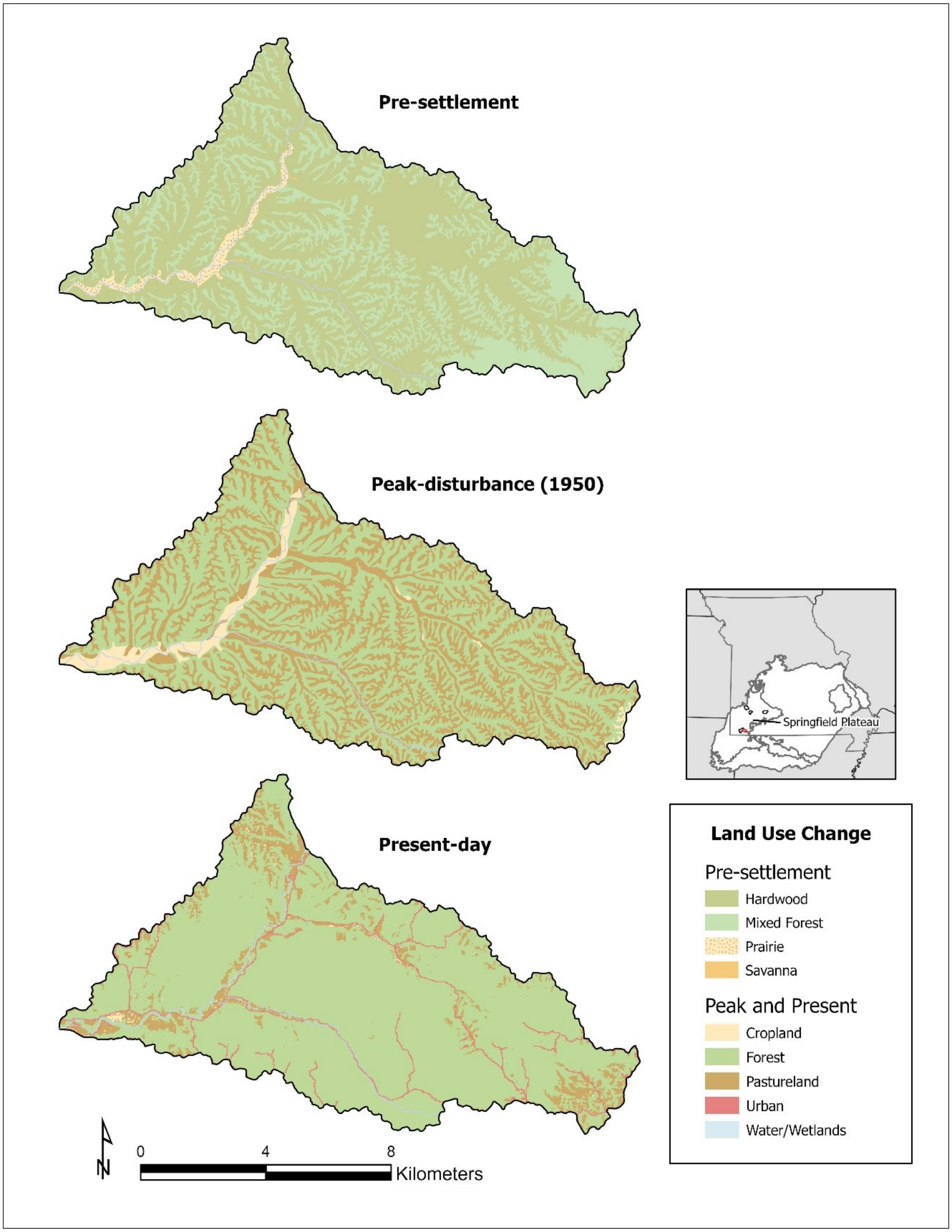
	Crop				Pasture				Forest				Urban		
Watershed	**K**	**LS**	**C**	**CN**	**K**	**LS**	**C**	**CN**	**K**	**LS**	**C**	**CN**	**K**	**LS**	**CN**
Wilsons Creek	0.356	0.581	0.200	91	0.373	0.560	0.040	89	0.370	8.270	0.003	79	0.362	0.538	93
Mikes Creek	0.303	0.272	0.206	88	0.353	1.462	0.040	86	0.380	22.882	0.003	73			
Sugar Creek	0.305	0.630	0.206	88	0.359	1.455	0.040	86	0.404	15.398	0.003	73			
Stahl Creek	0.385	0.501	0.200	91	0.371	0.784	0.040	89	0.324	7.759	0.003	79	0.406	0.721	93
Spring River	0.415	0.328	0.200	91	0.367	0.242	0.040	89	0.490	5.384	0.003	79			
Burris Fork	0.436	0.641	0.200	91	0.434	0.694	0.040	89	0.365	1.549	0.003	79			
Lindley Creek	0.365	0.697	0.200	91	0.383	0.741	0.040	89	0.406	12.622	0.003	79			
Howell Creek	0.404	0.610	0.200	88	0.381	1.083	0.040	86	0.427	8.791	0.003	73	0.417	3.157	92
Barren Creek	0.340	0.470	0.200	88	0.275	0.181	0.040	86	0.325	3.600	0.006	77	0.422	0.839	92
North Fork	0.374	0.677	0.200	88	0.433	1.604	0.040	86	0.270	5.408	0.003	73			
Black River	0.435	1.800	0.200	88	0.296	1.139	0.040	86	0.374	5.244	0.003	73			
Cedar Creek	0.449	0.780	0.200	88	0.367	1.098	0.040	86	0.397	6.035	0.003	73			

Appendix B-8. Peak-disturbance STEPL soil factor and curve number inputs by land use.

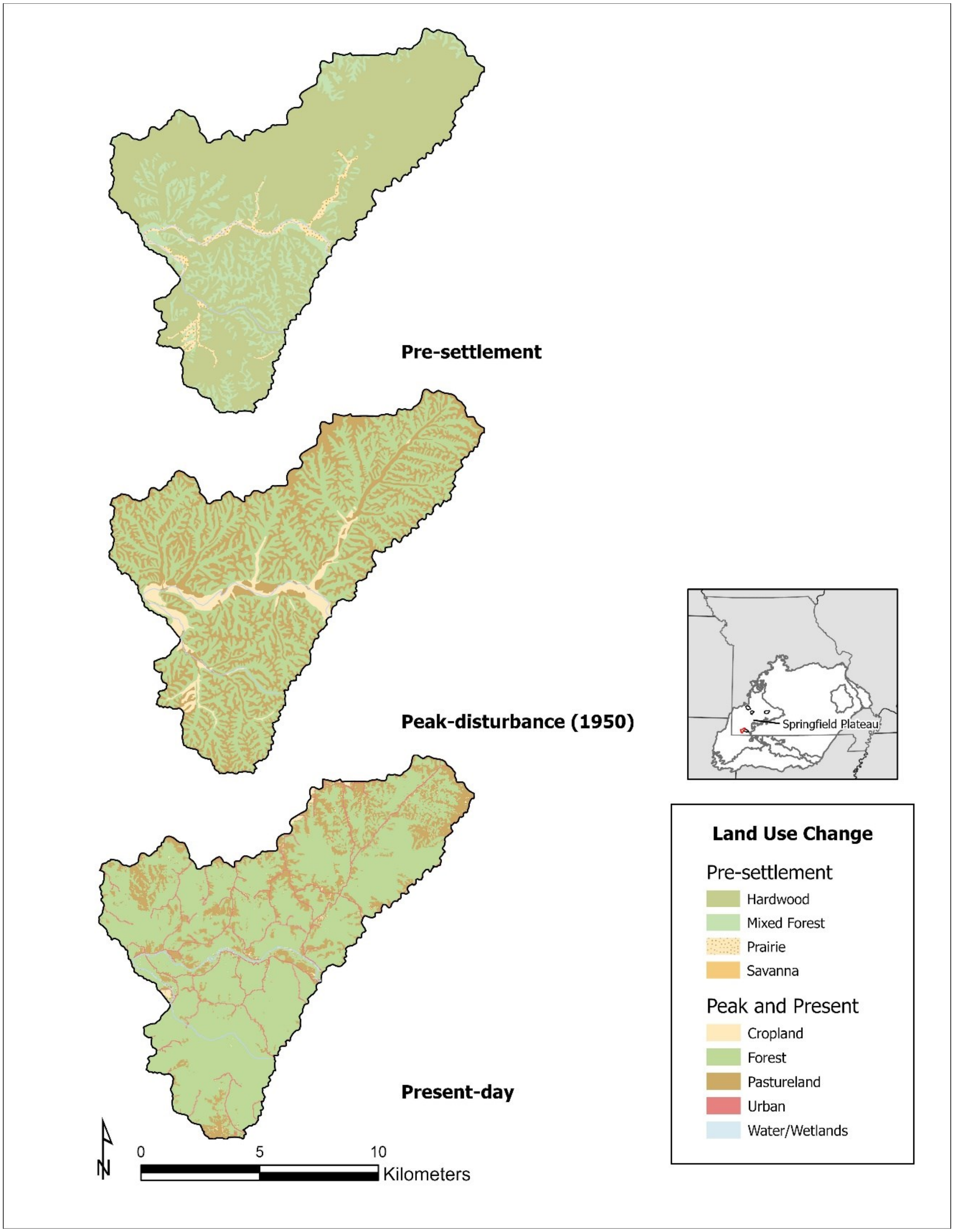
Appendix C. Watershed Land Use Transitions.



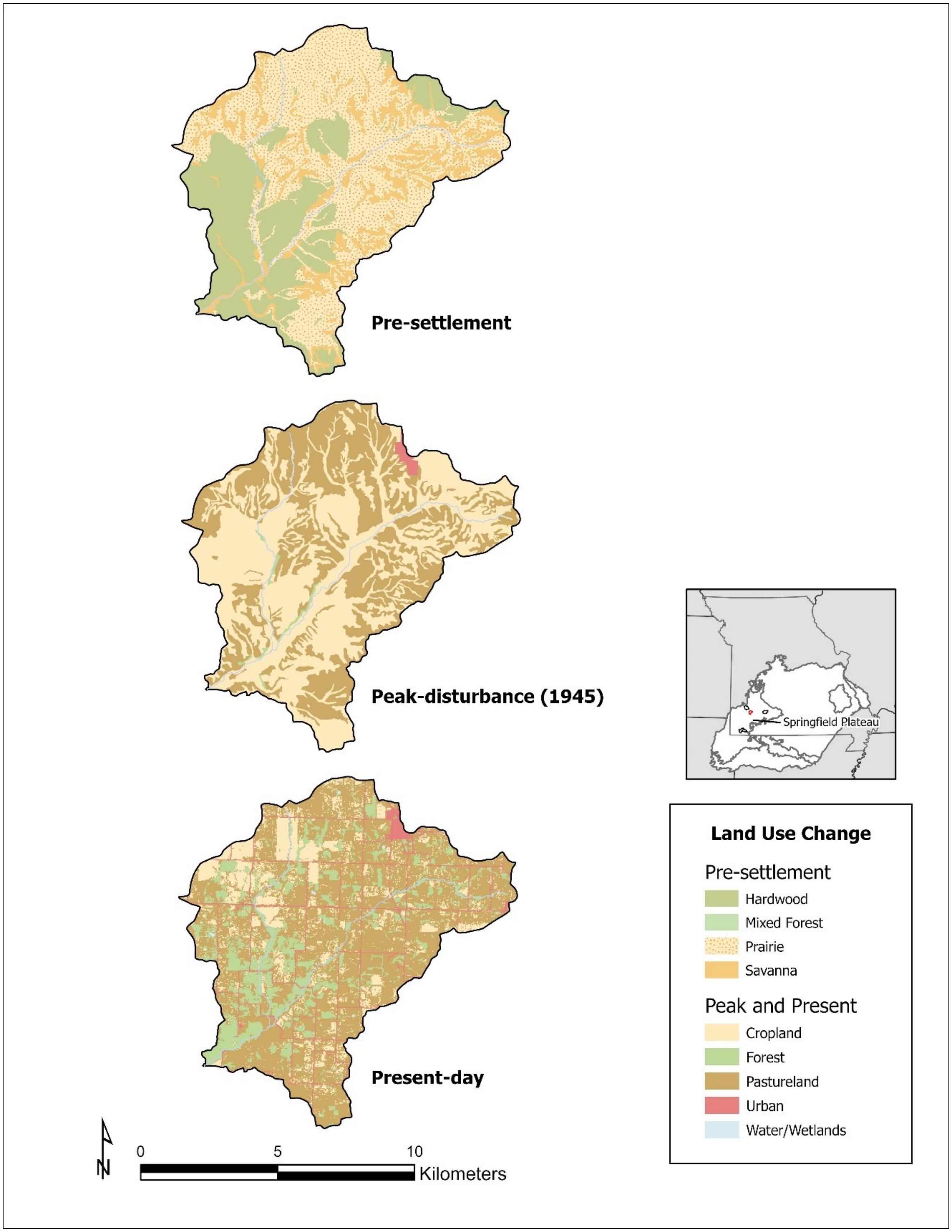
Appendix C-1. Land use development for the Wilsons Creek watershed under pre-settlement, peak-disturbance, and present-day conditions.



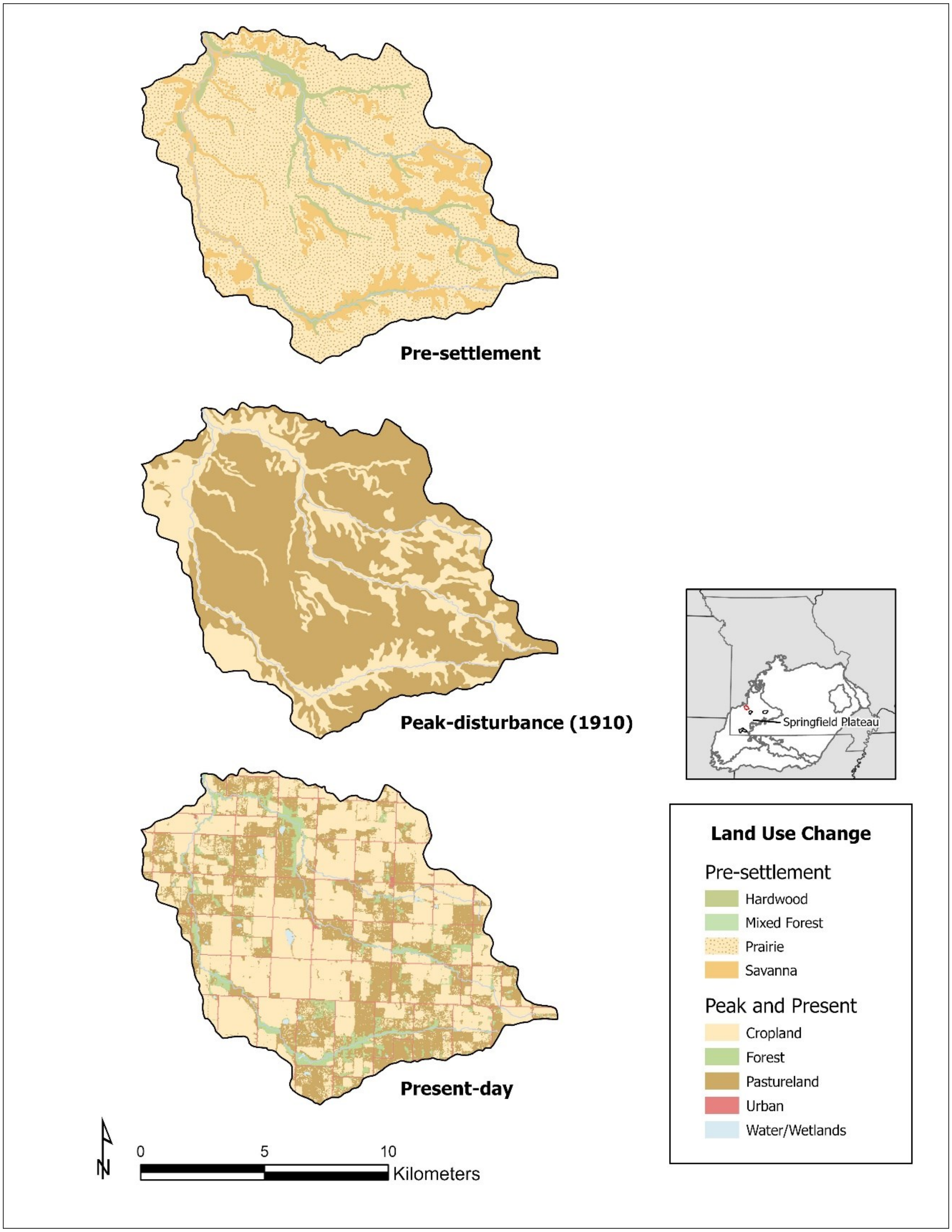
Appendix C-2. Land use development for the Mikes Creek watershed under pre-settlement, peak-disturbance, and present-day conditions.



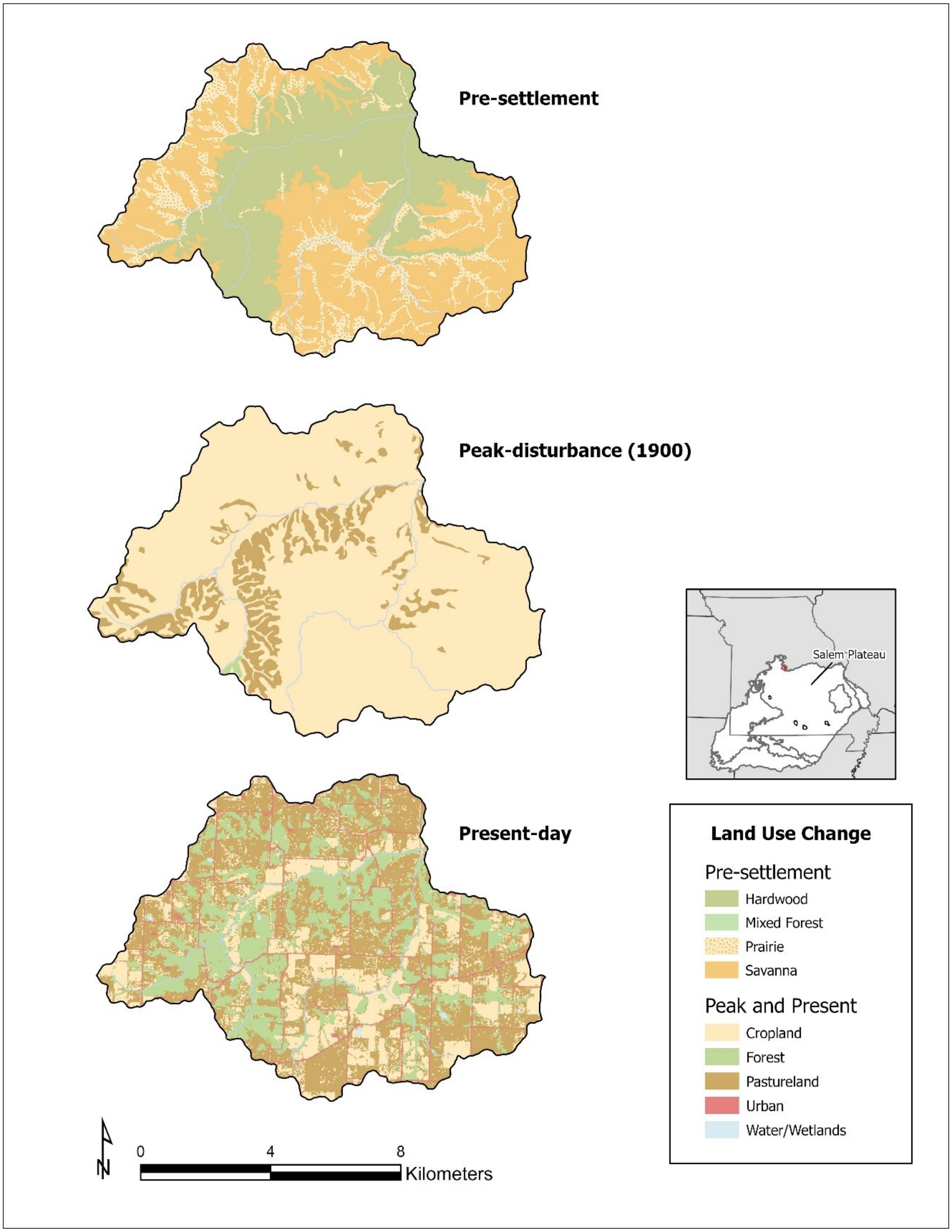
Appendix C-3. Land use development for the Sugar Creek watershed under pre-settlement, peak-disturbance, and present-day conditions.



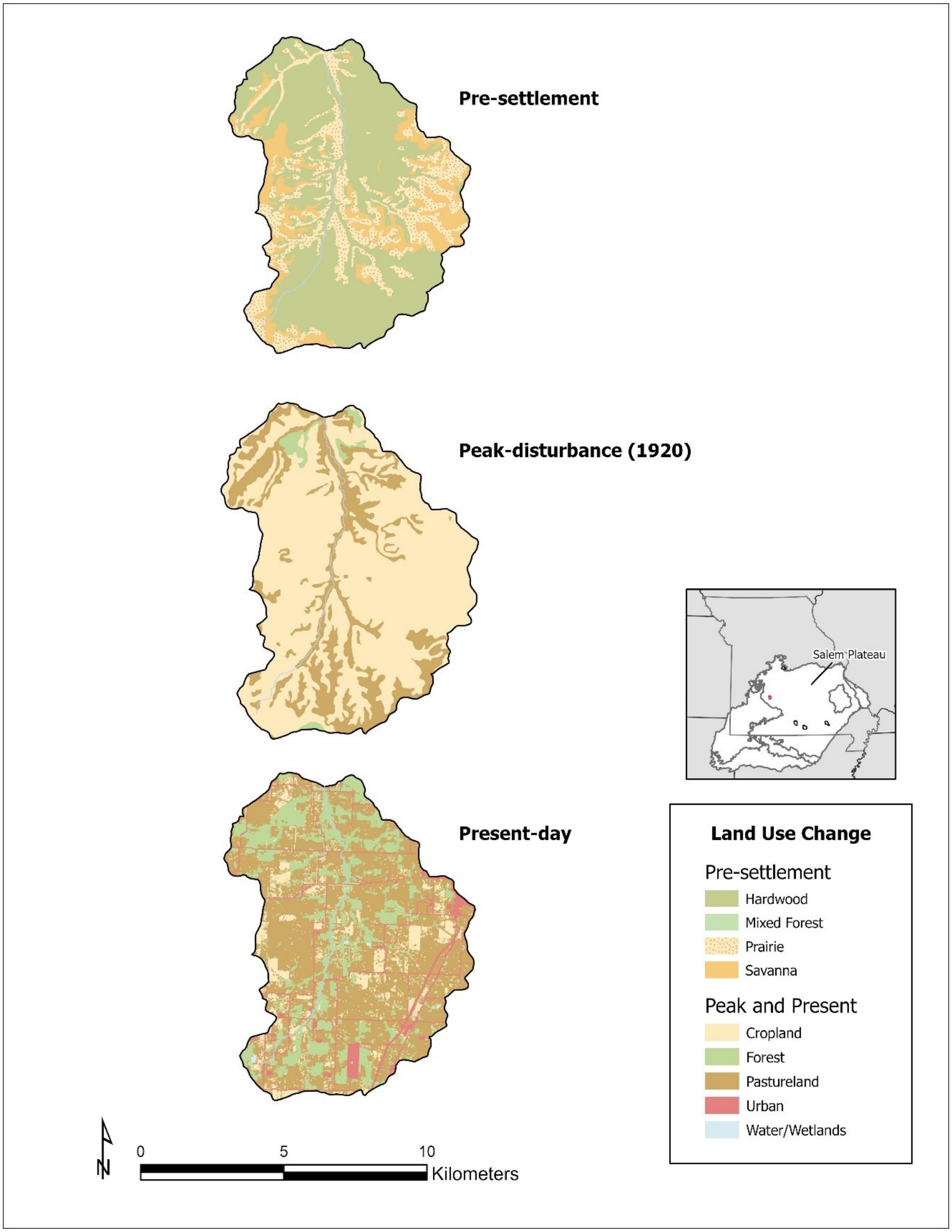
Appendix C-4. Land use development for the Stahl Creek watershed under pre-settlement, peak-disturbance, and present-day conditions.



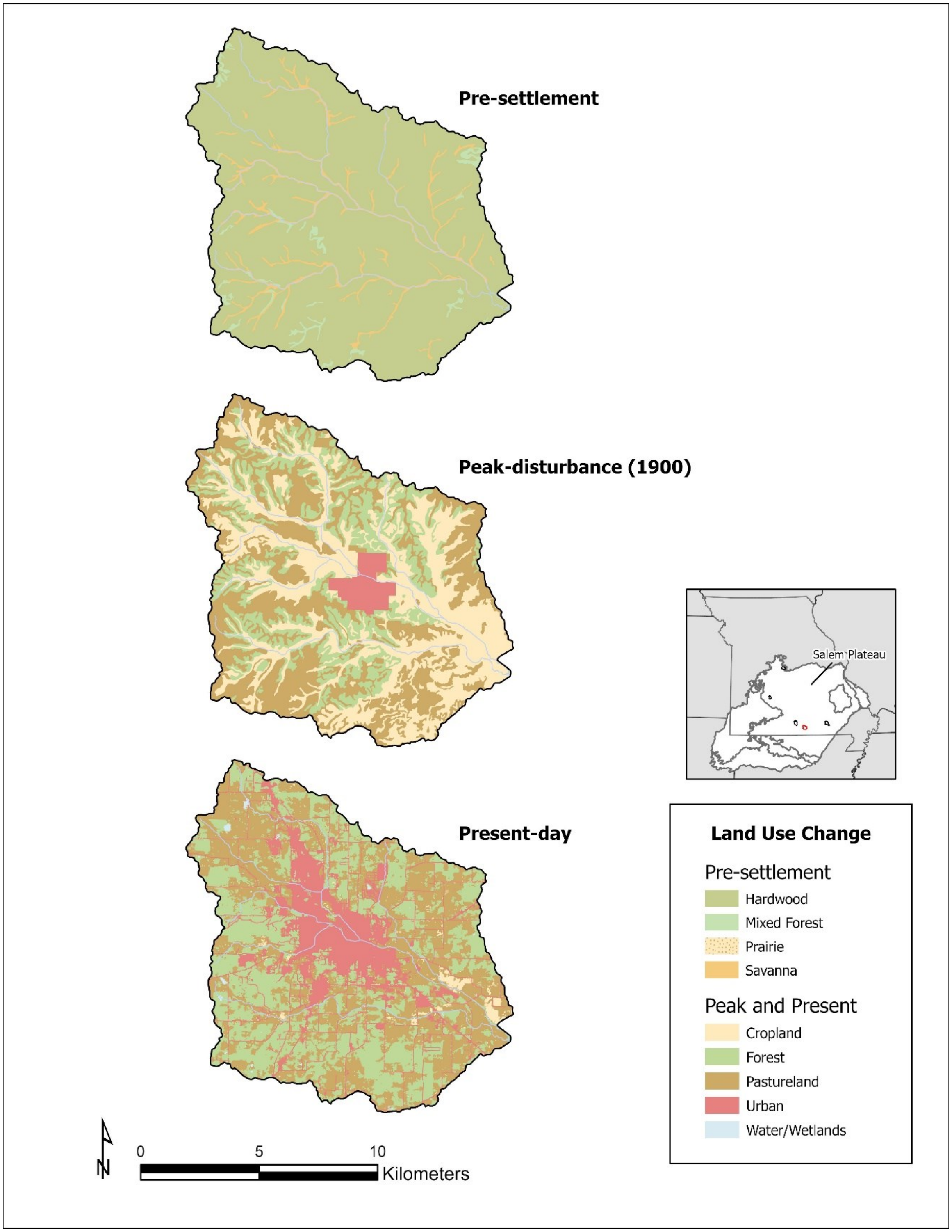
Appendix C-5. Land use development for the Spring River watershed under pre-settlement, peak-disturbance, and present-day conditions.



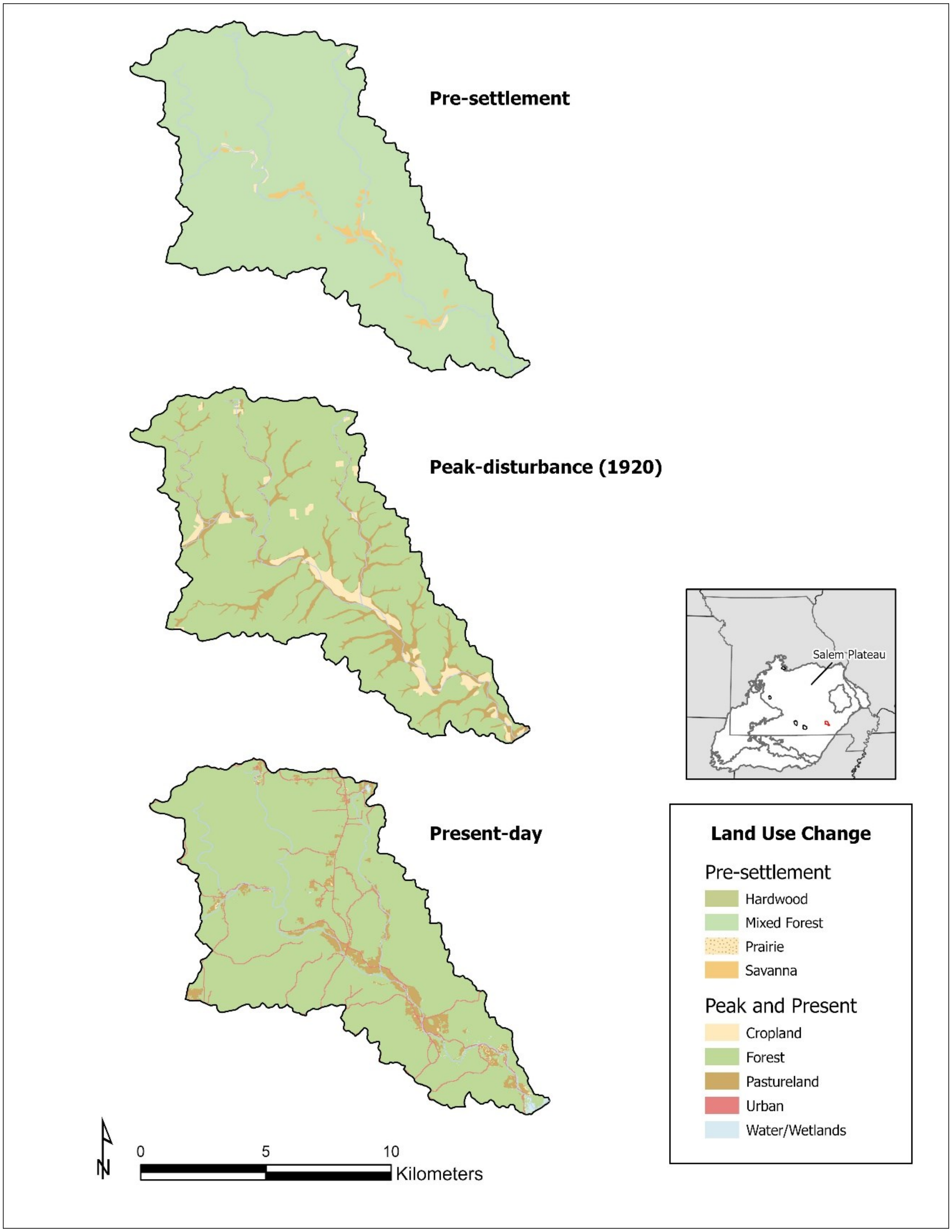
Appendix C-6. Land use development for the Middle Burris watershed under pre-settlement, peak-disturbance, and present-day conditions.



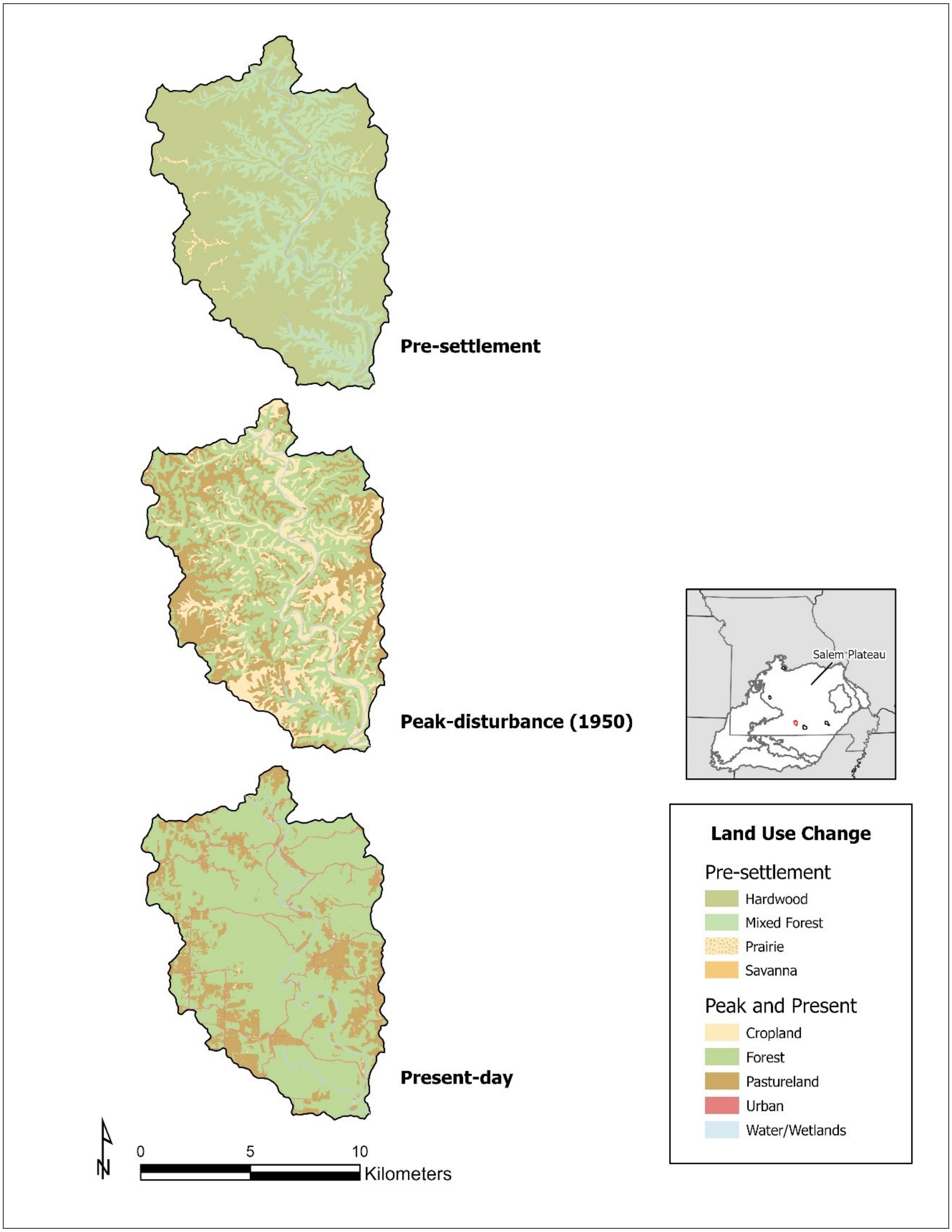
Appendix C-7. Land use development for the Lindley Creek watershed under pre-settlement, peak-disturbance, and present-day conditions.



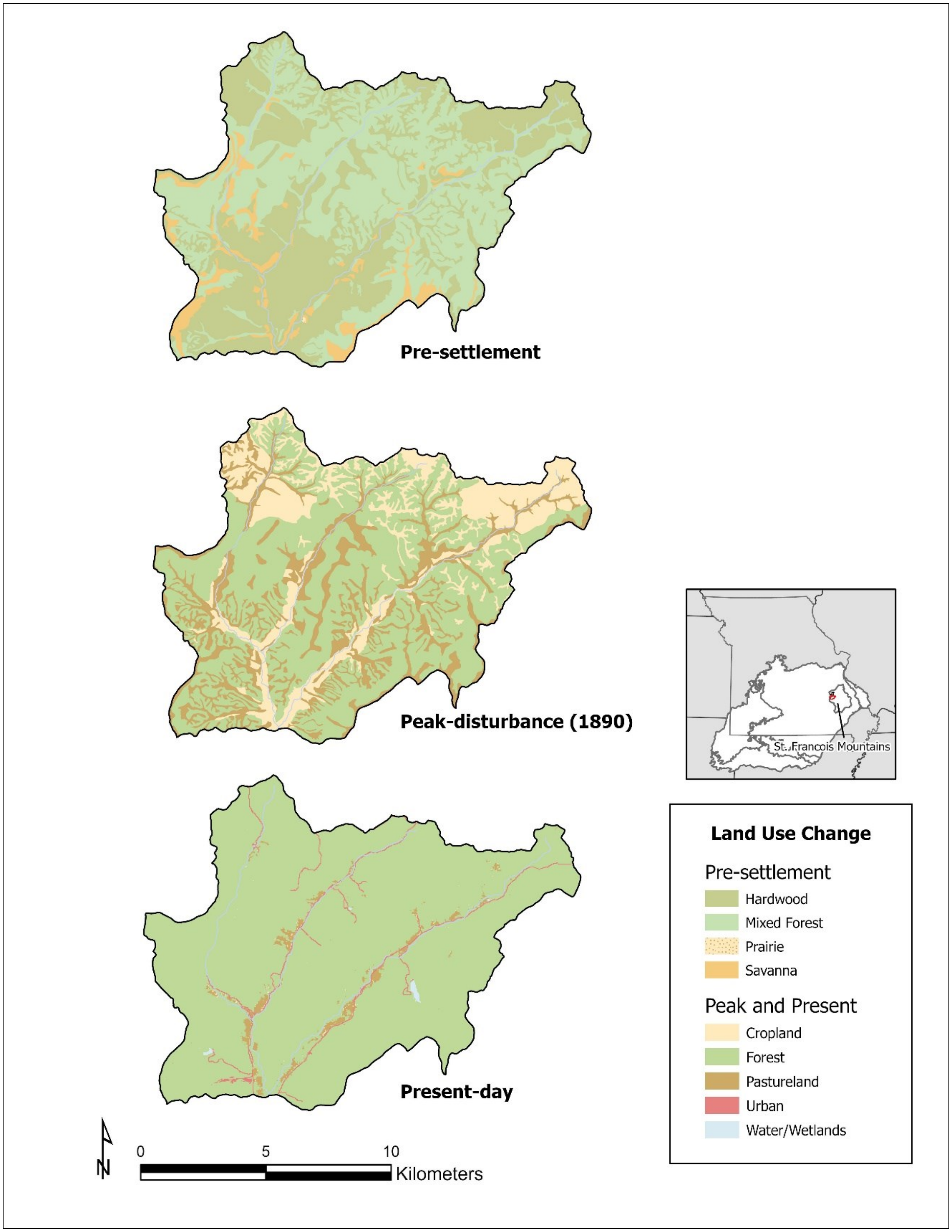
Appendix C-8. Land use development for the Howell watershed under pre-settlement, peak-disturbance, and present-day conditions.



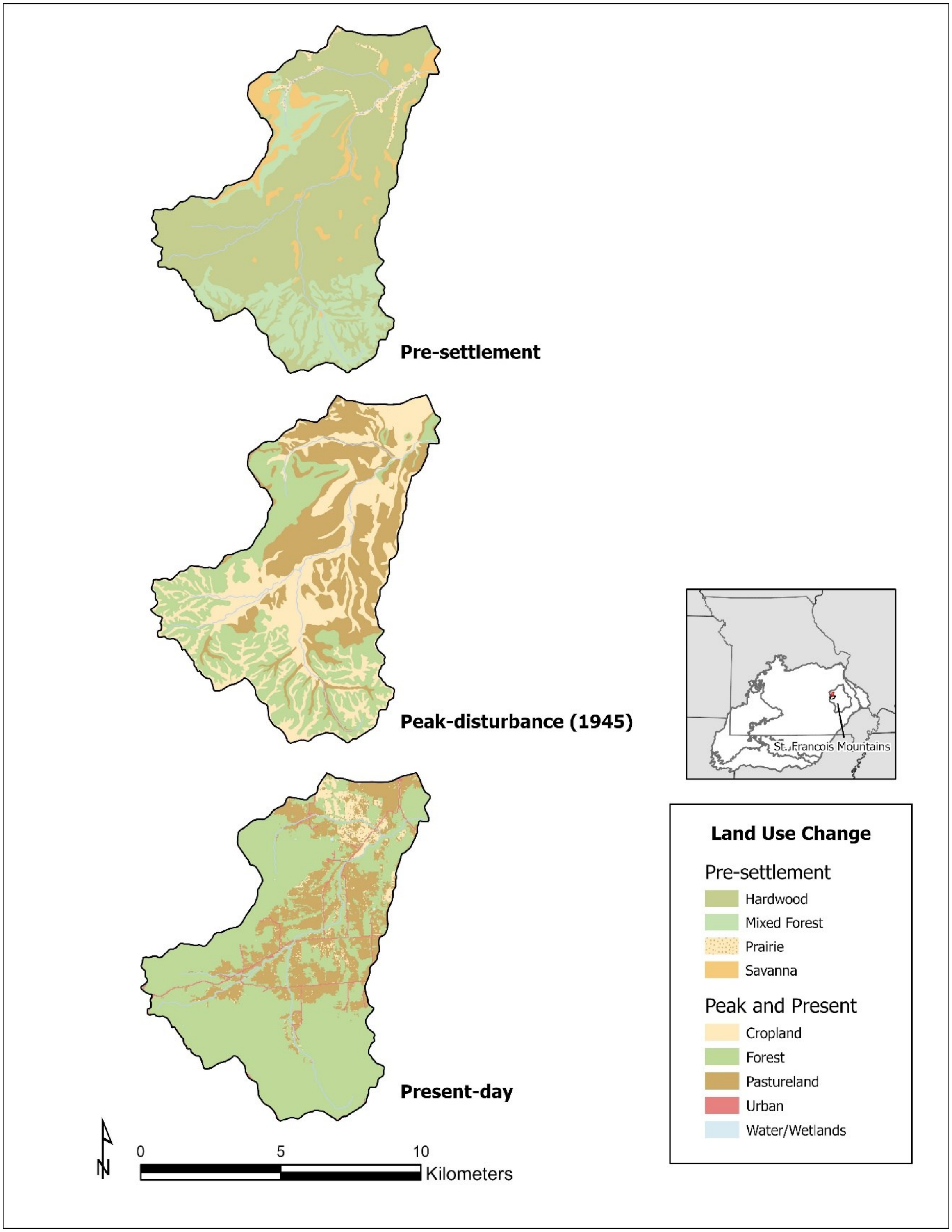
Appendix C-9. Land use development for the Big Barren watershed under pre-settlement, peak-disturbance, and present-day conditions.



Appendix C-10. Land use development for the North Fork watershed under pre-settlement, peak-disturbance, and present-day conditions.



Appendix C-11. Land use development for the Black River watershed under pre-settlement, peak-disturbance, and present-day conditions.



Appendix C-12. Land use development for the Cedar Creek watershed under pre-settlement, peak-disturbance, and present-day conditions.

Appendix D. STEPL Outputs.

		Annual Nutrient and Sediment Loads				**Annual Yields**		
Watershed	**Total Area (km^2)**	**Nitrogen (kg/year)**	**Phosphorus (kg/year)**	**Total Nutrients (kg/year)**	**Sediment (t/year)**	**Nitrogen (kg/km^2)**	**Phosphorus (kg/km^2)**	**Sediment (t/km^2)**
Wilsons Creek	130.2	105,320	16,276	121,595	6,075	809.1	125	46.7
Mikes Creek	96.4	30,889	9,678	40,568	12,982	320.5	100.4	134.7
Sugar Creek	114.1	39,068	10,467	49,535	13,059	342.3	91.7	114.4
Stahl Creek	82.7	73,390	11,135	84,524	9,016	**887.2**	**134.6**	**109**
Spring River	134	102,871	17,467	120,338	11,763	767.9	130.4	87.8
Burris Fork	78.4	59,913	9,919	69,832	8,205	764.4	126.6	104.7
Lindley Creek	62.9	51,099	8,022	59,121	6,934	**812.2**	**127.5**	**110.2**
Howell Creek	134.9	83,621	16,798	100,419	17,815	619.7	124.5	132
Big Barren	106.1	12,419	3,226	15,645	2,394	117	30.4	22.6
North Fork	119	30,490	7,106	37,597	7,878	256.2	59.7	66.2
Black River	134.7	11,862	3,874	15,736	3,417	88	28.8	25.4
Cedar Creek	69.5	20,601	4,198	24,800	4,075	**296.5**	**60.4**	**58.7**

Appendix D-1. Present-day STEPL outputs by watershed.

		Annual Nutrient and Sediment Loads				**Annual Yields**		
Watershed	**Total Area (km^2)**	**Nitrogen (kg/year)**	**Phosphorus (kg/year)**	**Total Nutrients (kg/year)**	**Sediment (t/year)**	**Nitrogen (kg/km^2)**	**Phosphorus (kg/km^2)**	**Sediment (t/km^2)**
Wilsons Creek	130.2	9,855	3,880	13,734	5,695	75.7	29.8	43.7
Mikes Creek	96.4	6,310	2,541	8,851	3,339	65.5	26.4	34.6
Sugar Creek	114.1	6,139	2,500	8,639	3,094	53.8	21.9	27.1
Stahl Creek	82.7	7,280	2,828	10,107	4,415	**88**	**34.2**	**53.4**
Spring River	134	6,004	2,336	8,340	3,617	44.8	17.4	27
Burris Fork	78.4	6,145	2,445	8,589	3,411	78.4	31.2	43.5
Lindley Creek	62.9	5,681	2,289	7,970	2,994	**90.3**	**36.4**	**47.6**
Howell Creek	134.9	4,483	2,022	6,504	1,194	33.2	15	8.9
Big Barren	106.1	1,736	786	2,522	444	16.4	7.4	4.2
North Fork	119	2,251	995	3,246	708	18.9	8.4	5.9
Black River	134.7	9,325	4,062	13,387	3,267	69.2	30.1	24.2
Cedar Creek	69.5	7,310	2,980	10,291	3,666	**105.2**	**42.9**	**52.8**

Appendix D-2. Pre-settlement STEPL outputs by watershed.

		Annual Nutrient and Sediment Loads				Annual Yields		
Watershed	**Total Area (km2)**	**Nitrogen (kg/year)**	**Phosphorus (kg/year)**	**Total Nutrients (kg/year)**	**Sediment (t/year)**	**Nitrogen (kg/km2)**	**Phosphorus (kg/km2)**	**Sediment (t/km2)**
Wilsons Creek	130.2	146,906	24,055	170,961	18,692	1,128.6	184.8	143.6
Mikes Creek	96.4	60,851	11,807	72,659	13,218	631.4	122.5	137.1
Sugar Creek	114.1	68,701	12,521	81,221	13,060	601.9	109.7	114.4
Stahl Creek	82.7	93,527	15,373	108,900	11,640	1,130.7	185.8	**140.7**
Spring River	134	157,628	19,044	176,671	9,837	**1,176.7**	142.2	73.4
Burris Fork	78.4	93,795	22,914	116,709	24,941	**1,196.6**	**292.3**	**318.2**
Lindley Creek	62.9	80,237	18,790	99,027	20,819	**1,275.4**	**298.7**	**330.9**
Howell Creek	134.9	98,970	20,412	119,382	21,915	733.5	151.3	162.4
Big Barren	106.1	25,191	6,064	31,255	5,766	237.3	57.1	54.3
North Fork	119	110,795	30,636	141,431	41,832	930.9	**257.4**	**351.5**
Black River	134.7	97,524	25,753	123,277	33,347	723.9	191.1	247.5
Cedar Creek	69.5	59,250	13,839	73,089	16,444	852.8	**199.2**	236.7

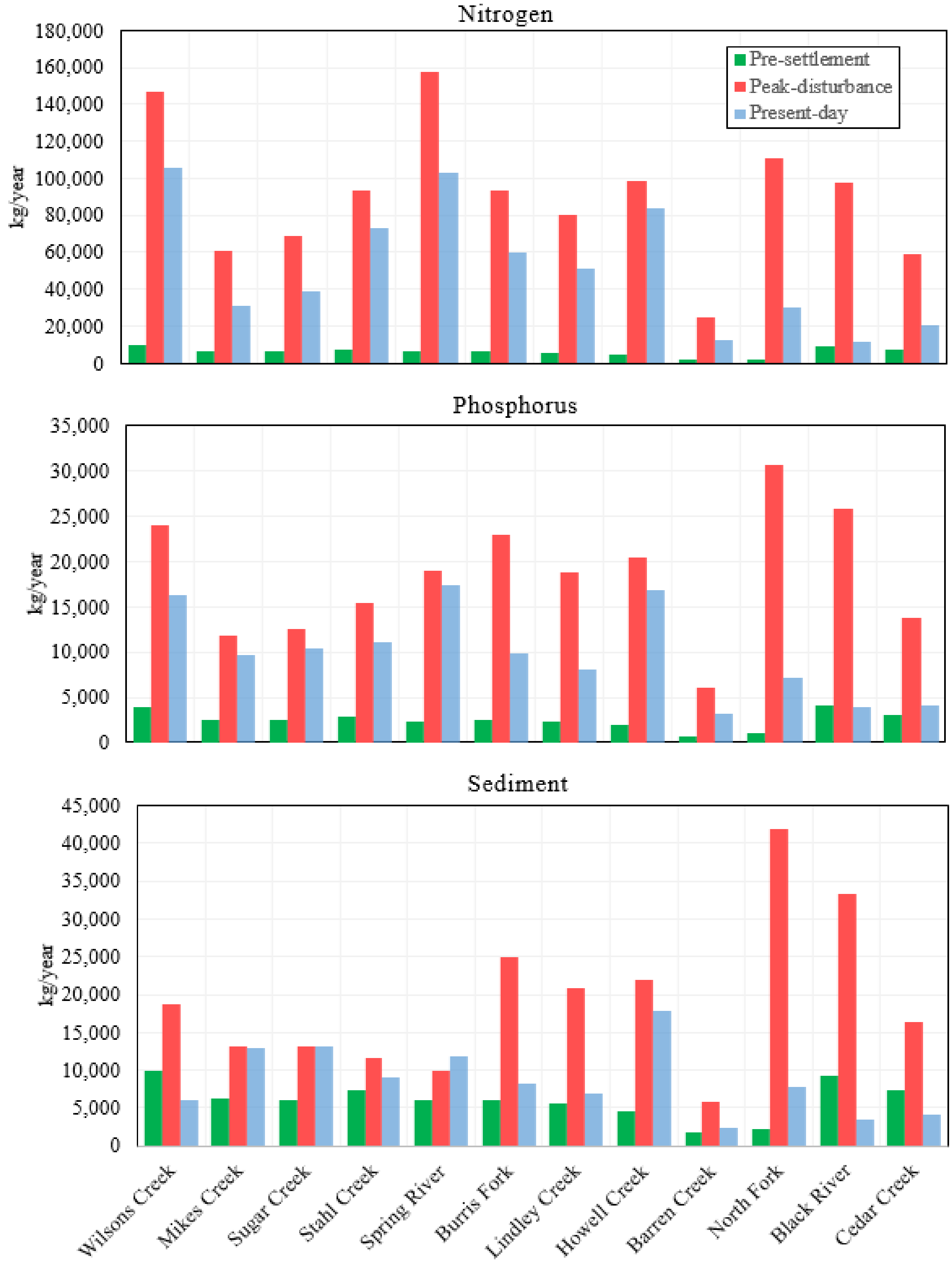
Appendix D-3. Peak-disturbance STEPL outputs by watershed.

			Average Annual Nutrient and Sediment Loads				Annual Yields		
Period	**Physiographic Region**	**Total Area (km^2)**	**Nitrogen (kg/year)**	**Phosphorus (kg/year)**	**Total Nutrients (kg/year)**	**Sediment (t/year)**	**Nitrogen (kg/km^2)**	**Phosphorus (kg/km^2)**	**Sediment (t/km^2)**
Pre-settlement	Springfield Plateau	557.4	7,118	2,817	9,934	**4,032**	65.6	25.9	**37.2**
	Salem Plateau	501.4	4,059	1,707	5,766	1,750	47.4	19.7	22.0
	St. Francois Mountains	204.2	**8,318**	**3,521**	**11,839**	3,467	**87.2**	**36.5**	38.5
	Ozarks	1,263.0	6,043	2,472	8,515	2,987	61.6	25.1	31.1
Peak-disturbance	Springfield Plateau	557.4	**105,522**	16,560	**122,082**	13,289	**933.8**	149.0	121.9
	Salem Plateau	501.4	81,798	19,763	101,561	23,055	874.7	**211.4**	243.5
	St. Francois Mountains	204.2	78,387	**19,796**	98,183	**24,896**	788.3	195.2	**242.1**
	Ozarks	1,263.0	91,115	18,434	109,549	19,293	885.0	182.7	192.6
Present-day	Springfield Plateau	557.4	**70,308**	**13,005**	**83,312**	**10,579**	**625.4**	**116.4**	**98.5**
	Salem Plateau	501.4	47,508	9,014	56,523	8,645	513.9	93.7	87.1
	St. Francois Mountains	204.2	16,232	4,036	20,268	3,746	192.3	44.6	42.0
	Ozarks	1,263.0	51,795	9,847	61,643	8,634	506.8	95.0	84.4

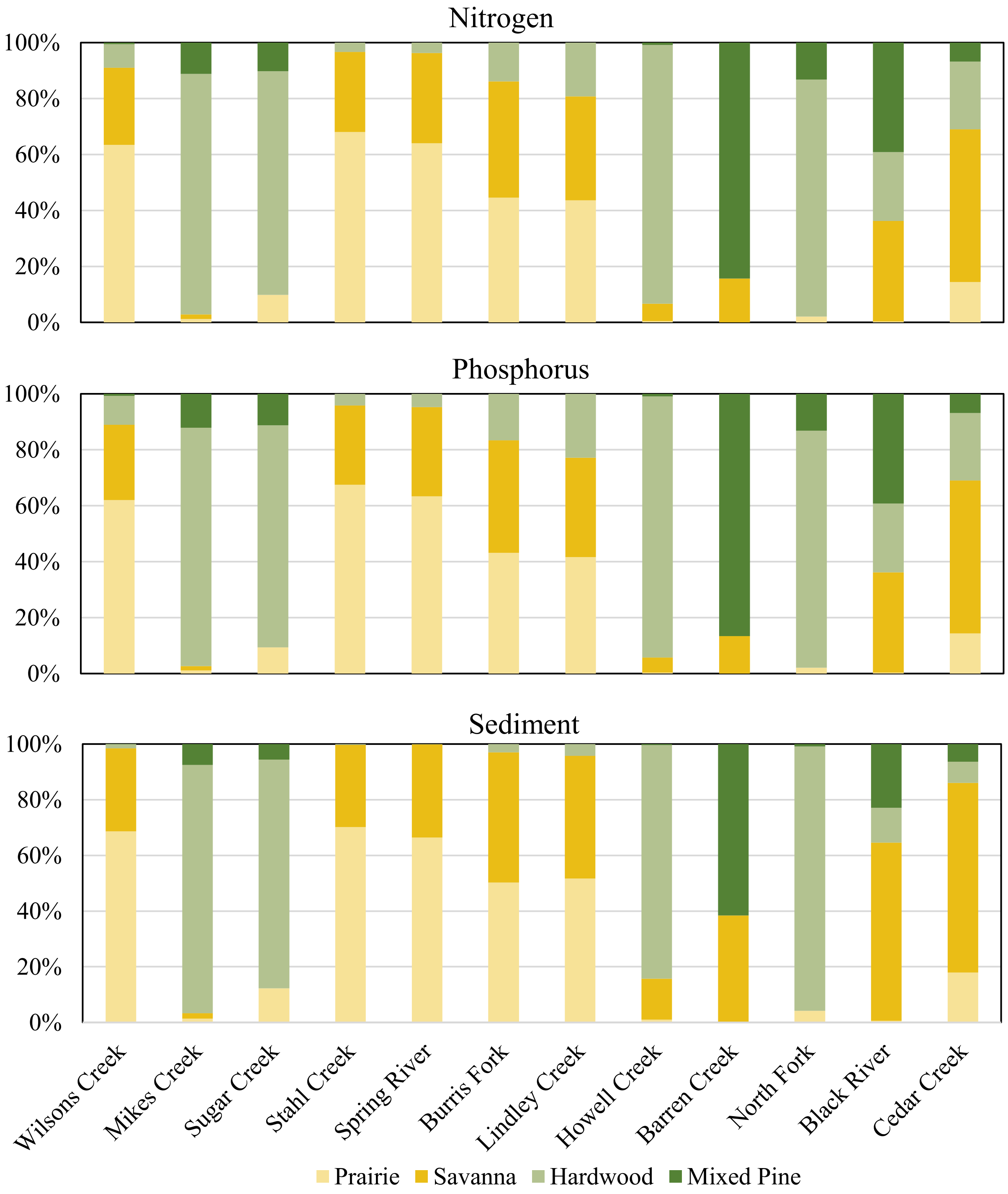
Appendix D-4. Average annual TN, TP, and TSS loads by region for each period.

	Land Use	**Total Area (km^2)**	**Nitrogen (kg/year)**	**%**	**Phosphorus (kg/year)**	**%**	**Sediment (t/year)**	**%**	**TN (kg/km^2)**	**TP (kg/km^2)**	**TSS (t/km^2)**
Pre-settlement	Prairie	180.4	20,227	28.6	8,508	28.7	13,811	38.5	**112.1**	**47.2**	**76.6**
	Savanna	191.8	19,399	27.5	7,468	25.2	12,124	33.8	101.1	38.9	63.2
	Hardwood	543.8	23,680	33.5	10,327	34.8	8,220	22.9	43.5	19.0	15.1
	Mixed Pine	347.0	7,342	10.4	3,360	11.3	1,688	4.7	21.2	9.7	4.9
	Total	1,263.0	70,647	100	29,664	100	35,844	100	69.5	28.7	39.9
Peak-disturbance	Urban	24.2	19,844	1.9	3,062	1.4	912	0.4	820.0	126.5	37.7
	Cropland	410.7	504,942	47.9	139,992	63.3	166,651	72.0	**1,229.3**	**340.8**	**405.7**
	Pastureland	434.5	476,316	45.2	56,930	25.7	36,734	15.9	1,096.3	131.0	84.5
	Forest	393.6	52,463	5.0	21,224	9.6	27,214	11.8	133.3	53.9	69.1
	Total	1,263.0	1,053,565	100	221,207	100	231,511	100	834.2	175.1	183.3
Present-day	Urban	166.2	139,947	22.5	21,588	18.3	6,428	6.2	842.2	129.9	38.7
	Cropland	127.5	127,870	20.6	29,485	25.0	28,001	27.0	**1,003.1**	**231.3**	**219.7**
	Pastureland	312.0	299,244	48.1	44,427	37.6	44,323	42.8	959.1	142.4	142.1
	Forest	657.3	54,483	8.8	22,667	19.2	24,861	24.0	82.9	34.5	37.8
	Total	1,263.0	621,544	100	118,167	100	103,613	100	721.8	134.5	109.6

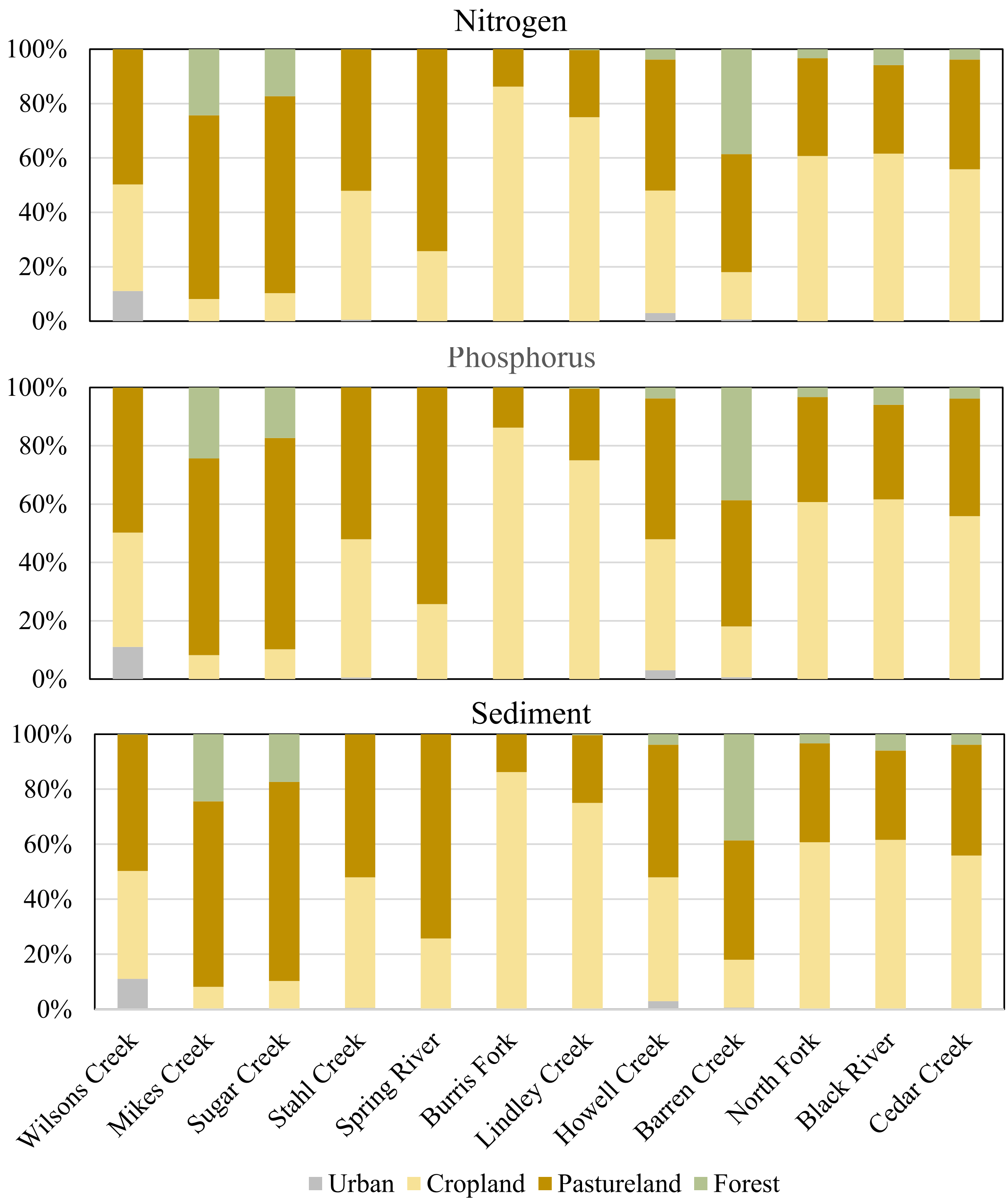
Appendix D-5. STEPL outputs by land use for each period.



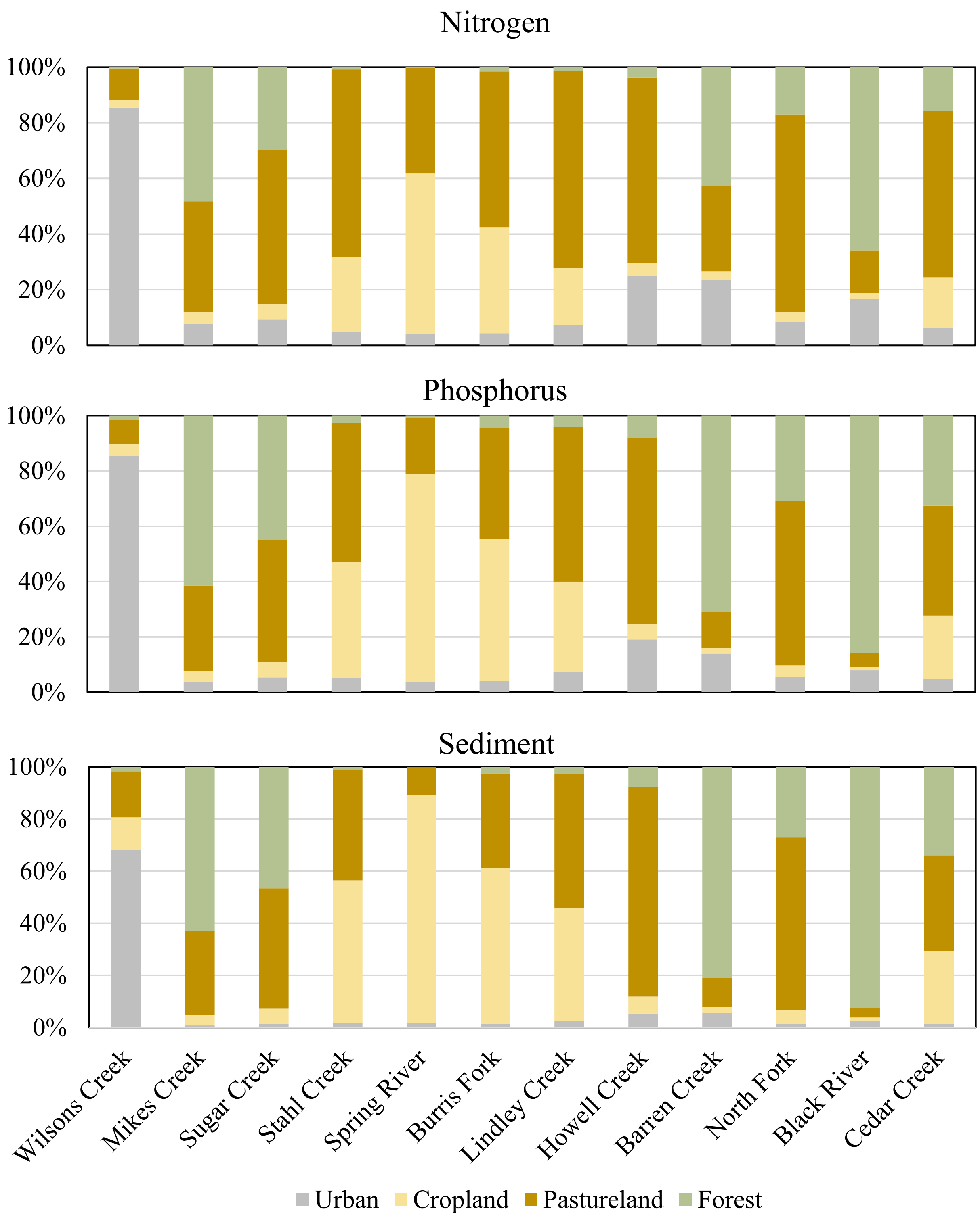
Appendix D-6. Present-day Total Nitrogen, Phosphorus and Suspended Sediment Loads by watershed.



Appendix D-7. Percent of total NPS loads according to pre-settlement land cover for all watersheds.



Appendix D-8. Percent of total NPS loads according to peak-disturbance land use for all watersheds.



Appendix D-9. Percent of total NPS loads according to present-day land use for all watersheds.