STREAM DISCHARGE-DRAINAGE AREA RELATIONSHIPS IN MISSOURI

A Masters Thesis
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In Partial Fulfillment
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Master of Science, Geospatial Sciences

By
Megan Colleen Harrington
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STREAM DISCHARGE-DRAINAGE AREA RELATIONSHIPS IN MISSOURI

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Megan Colleen Harrington

ABSTRACT

Understanding Missouri's streamflow trends is important for conservation efforts by water resource managers and policy makers. Discharge characteristics for two Missouri ecoregions were evaluated using annual streamflow records from the USGS stream gage network. Records from 1981-2010 for a total of 20 gages in the Central Dissected Till Plains and 27 gages in the Ozark Highlands were analyzed. Records from 1925-2010 were compared at 12 sites. All gages used met the following criteria: continuous record, drainage area less than 3,000 square miles, and less than 15% urban. Discharge-drainage area regression equations were analyzed for the 2-year flood, 90th percentile, mean, 50th percentile, and 10th percentile flows. Results show that drainage area explains the majority of variation in discharge in both ecoregions ($r^2 \geq 0.9$) for the 90th percentile, mean, 50th percentile, and 10th percentile flows. Specific discharge is scale independent for in-channel flows, the 90th percentile, mean, 50th percentile, and 10th percentile flows. Including percentage of slope or land use improves the model in some cases. The 10th percentile flow or baseflow increased slightly from 1925 to 2010 in the Central Dissected Till Plains, possibly due to the influence of soil conservation.

KEYWORDS: streamflow, specific discharge, drainage area, runoff, ecoregion

This abstract is approved as to form and content

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INTRODUCTION

Surface water is an important natural resource used for drinking, agriculture, hydroelectric power, recreation, and industry. Surface water resources are also vital for ecological processes, aquatic habitats, and wildlife (Gleick, 1998). As populations, industrialization, and demand for water increases, it becomes ever more essential to increase knowledge of our water supplies for human use and ecological requirements (Gruen, 2008). Analyzing the relationships between streamflow and watershed characteristics are an important step in planning for our future water needs. Streamflow-watershed relationships are used for water supply, planning, and conservation efforts by resource managers and policy makers. Understanding the linkages between streamflow and drainage area, land use, and precipitation are useful for the creation of models used to predict and estimate streamflow where values are unknown. These models can be used for a variety of purposes relating to water supply, water quality, hydropower, agriculture, and recreation (Vogel *et al.*, 1999).

Increases in population can put stress on water supplies. The average population growth rate for Missouri from 2000 to 2009 was 7%, with some counties having growth rates of over 16%. Though this statewide growth was below the national increase of 9.1%, any increase in population will also increase the demand for water (Eathington, 2010). Communities that have a small reserve of surface water supplies in Missouri are particularly vulnerable to possible drought situations (Knapp and Hecht, 2009). As of 1995, in Missouri there were 55 surface water intakes for municipal water supply, from the Missouri, Mississippi, and Meramec Rivers as well as numerous other streams (Vandike, 1996).

Missouri is home to diverse wildlife, including several endangered aquatic species, such as the Ozark Hellbender, the Niangua Darter, and several species of mussels (Missouri Department of Conservation, Endangered Species in the Field Guide, Accessed August, 2012, http://mdc.mo.gov). Aquatic life requires specific ranges of in-channel flows to be prolific. Therefore, understanding our surface water is important for understanding how to preserve our biologic diversity through studies relating to water quality (Murdoch *et al.*, 2000) and aquatic habitats (Covich *et al.*, 1997). For example, modeling in-channel flow is useful for linking ideal sediment loads for aquatic habitat with the hydraulic action needed to achieve those loads (Milhous, 1998). Often the area being studied is ungaged, therefore, a means of estimating streamflow is needed to apply ecohydrologic habitat models.

The last comprehensive report by the Missouri Department of Natural Resources on Missouri's surface water was published in 1996, which looked at surface water characteristics across the state (Vandike, 1996). Though Missouri has been included in national regional regression models (Vogel *et al.*, 1999), none unique to Missouri have been presented before. Detailed studies have been done on watersheds within Missouri, such as a study on long-term trends in the Mississippi River (Zhang and Schilling, 2006) and streamflow modeling on the Jacks Fork River (Hu *et al.*, 2005). However, this study will be the first to use the available stream gage data to examine spatial and temporal variability across the state of Missouri.

Purpose and Objectives

The purpose of this study is to quantify and evaluate the discharge-drainage area relationships for two ecoregions in Missouri, the Central Dissected Till Plains and the Ozark Highlands. The two ecoregions combined cover approximately 85% of the state of Missouri. The Central Dissected Till Plains ecoregion contains 69 United States Geological Survey (USGS) stream gages. Of these, there are 20 stream gages with a continuous record of least 30 years and 3 gages with continuous records going back to the 1920s. The Ozark Highlands ecoregion contains 151 USGS stream gages. Of these, there are 27 stream gages with a continuous record of at least 30 years and 10 gages with continuous records dating back to 1925. Dividing the study into ecoregions will help to hold constant the physiographic and hydrologic factors that influence streamflow.

This study will be the first to use the available stream gage data to examine spatial and temporal variability of in-channel flows across the state of Missouri through a comparative study of its two major ecoregions. The specific objectives of this study include:

1) Quantify the discharge-drainage area and specific discharge-drainage area relationships for a range of flows;
2) Examine land use and terrain influence on discharge trends; and
3) Evaluate temporal variability of discharge relationships and rainfall-runoff relationships since 1925.

Background

Hydrology. The measure of streamflow, or stream discharge, is defined as unit volume of water in a stream per unit of time and can be expressed as Q = v * a, where Q = streamflow, v = velocity, and a = area of cross section (Manning, 1997). This is usually expressed as cubic meters or cubic feet per second (cms or cfs). Government agencies, such as the USGS, monitor discharge continuously in a national flow gaging network. However, the gages need to be calibrated with discharge measurements by technicians. The most common manual method is the current meter method. With this method, each cross section is divided into many vertical subsections. The area and velocity of each subsection is measured, and discharge is calculated. Each subsection's discharge is summed to get total discharge for the cross section (USGS, Water Science for Schools. Accessed November, 2010, http://ga.water.usgs.gov/edu/streamflow2.html.).

Discharge measurements indicate the level of streamflow in the channel at the sampling time. Streamflow can be thought of in terms of baseflow and stormflow. Baseflow, also called low flow, is supplied by the groundwater discharge to a stream and is the main source of flow between rainfall events (Zhang and Schilling, 2006). Low flow measures are useful in determining the reliability of water supplies and overall availability of aquatic habitat (Brooks *et al.*, 2003). Stormflow, or peak flow, is composed of surface runoff following rainfall (Zhang and Schilling, 2006). Peak flow measures are useful for flood preparation and for building structures, such as bridges, and predicting the geomorphic stability of channel systems. Streamflow can be analyzed at watershed scale. A watershed is defined as the total land area which drains to a point on a stream or a basin outlet (Brooks *et al.*, 2003).

The range of stream discharge occurring over a given time period, such as a year or period of record, for a gage can be used to create a flow-duration curve (FDC). An FDC shows the frequency with which flows of different stages or discharges are equaled or exceeded (Brooks *et al.*, 2003). Streamflow values on an FDC can also be reported in percentiles. A 10th percentile flow is a low flow or baseflow that 90% of the flows would exceed. Conversely, a 90th percentile flow is a high flow that only 10% of the flows would exceed. The 50th percentile flow is the same as the median. The mean annual is the average flow for a year. In-channel flows are those that would not overtop a channel's banks, or are below bankfull. Evaluation of flow records indicate in-channel flows typically occur <97% of the time in Missouri streams. Peak flood flows can be used to create flood-frequency curves, which show the average time interval within which an annual maximum of a certain size will occur (Brooks *et al.*, 2003). For example, the 2-year flood is the flood that will on average occur every two years.

Watershed or drainage area (Ad) accounts for the amount of water that can be routed to a stream. Drainage area by itself has been shown to be a good predictor for streamflow. Vogel et al. (1999) showed that using drainage area as the only variable in regional streamflow models accounts for 91% of the observed annual streamflow. Vogel and Kroll (1992) found that drainage area explained 97% of the variability in low flows. Peak flows or flood events have also been found to be strongly correlated with drainage area (Riggs, 1982). Using equations based only on drainage area can be a quick, simple way to predict streamflow. The simplest models, those with few variables, can prove to be the most useful (Wagener, 2004), though in some cases there are higher errors compared to equations using more variables (Koltun and Whitehead, 2001).

The specific discharge (Q/Ad), or unit discharge, to drainage area relationship can be important in explaining the spatial relationship of streamflow. The analysis of specific discharge-drainage area relationships, typically using regression models, can be used to predict streamflow at ungaged locations. It can be a simple way to determine unknown values, if the flow characteristics of the watersheds being compared are similar enough (Emerson *et al.*, 2005). Perry (2008) evaluated specific discharge records from 128 stream gages of drainage basins less than 32 square miles in Kansas. It was found that using specific discharge ratios to predict values at ungaged sites had the least amount of error, compared to other methods.

Hydrologic Controls. Many factors affect streamflow, the primary influences include climate, geology, soils, terrain, and vegetation (Tomer and Schilling, 2009). Climatic conditions, especially precipitation are directly related to variability of the water balance on the earth's surface (Novotny and Stefan, 2007). The amount of precipitation in a watershed directly determines how much water will contribute to streamflow. Other climatic conditions can also impact streamflow. For example, in a regional streamflow model, Vogel *et al.* (1999) used precipitation, temperature, solar radiation, snowfall, and number of heating and cooling days as climatic variables.

Geology will change the way water flows, both on the surface and underground. The bedrock type and permeability will have an effect on groundwater, which in turn affects surface flow (Knighton, 1998). In some areas, studies have shown that groundwater can flow across watershed boundaries affecting streamflow. For example, cross-basin flows are a characteristic of some Ozark Highlands watersheds, though little is known about their patterns. A cross-basin flow can occur in watersheds or basins that are connected underground. When groundwater recharge reaches a certain level, groundwater flow can occur through karst conduits or caves, diverting water to the adjacent watersheds (Hu *et al.*, 2005).

Different soil types will have different saturation rates and soil water potentials affecting infiltration rates. Infiltration is the process by which water enters the soil surface. Thus, differing soil surface conditions and physical properties of the soil itself will affect runoff. Plant litter on the soil surface can limit infiltration, because it can protect the soil surface, slow or detain runoff, and provide water storage capacity. The texture, structure, organic matter content, soil depth, temperature of soil, and the spaces in between particles will all have an effect on infiltration rates (Manning, 1997). Infiltration rates vary from sandy soils with the highest rates, to clayey soils, which have the slowest rates. When rainfall rate exceeds the infiltration capacity, surface runoff can occur (Wagener, 2004).

Watershed relief or physiography will affect how runoff is routed to reach streams (Wagener, 2004). Streams in steeply sloped watersheds respond more rapidly to rainfall than streams in gently sloped watersheds. More runoff can occur in steeply sloped areas, resulting in higher peak flows (Brooks *et al.*, 2003). Slope is a variable used in many streamflow regression models (Perry, 2008; Vogel and Kroll, 1992; Vogel *et al.*, 1999). Average basin slope was one variable used by Vogel *et al.* (1999) in their regional streamflow models. Their study found it to be a significant variable in regions of the Rocky Mountains, where slope is highly varied.

The vegetation type will determine how much precipitation is lost to interception. Interception is the amount of precipitation that is captured and stored on vegetation. It is determined by canopy coverage, total leaf area, number of layers of vegetation, rainfall intensity, branch attitude, shape of tree crowns, and roughness of bark (Manning, 1997). Different types of plants can have different interception rates. Forests have the highest interception losses, but shrublands and prairie vegetation can have substantial interception losses, especially during high growth periods (Brooks *et al.*, 2003). Hu *et al.* (2005) used a leaf area index of different land cover types in their model of streamflow.

Vegetation type can also determine rates of evapotranspiration, the process by which water in the liquid or solid state becomes atmospheric vapor, including evaporation from within plants' leaves (Dingman, 1994). Walnut trees, pasture, or fallow grass have higher annual evapotranspiration rates than corn or soybeans which require water for less of the year (Schilling and Libra, 2003). Changes in vegetation that reduce annual evapotranspiration will increase streamflow and groundwater recharge. For example, converting untilled land or other perennial cover crops to row crops can increase baseflow, because it can limit annual evapotranspiration (Schilling and Libra, 2003).

Anthropogenic Effects. Human influences can also have a considerable impact on streamflow. Forested, agricultural, grassland, or urban streams can have very different streamflow characteristics that range across degree of human management. Land use practices, such as deforestation, intensive grazing, and agriculture, may affect water resources as much as climate change (Stohlgren, 1998) by compacting soils, removing vegetation, and increasing runoff. Human influences through the management of water resources will have an effect on streamflow. For example, the placement of dams will change streamflow conditions upstream and downstream, dependent on their size and purpose (Knighton, 1998). Very large dams decrease annual peak flow downstream (Graf, 2006). Also, over-pumping of surface water and groundwater in highly urbanized areas can decrease the amount of streamflow downstream (Manning, 1997). Inter-basin transfers will also have an effect on streamflow. An inter-basin transfer involves the transfer of water from one watershed to another. For example, in 1996 a pipeline was built to transfer water from Stockton Lake to Springfield, MO for water supply (EPA, 2010). Consideration of inter-basin transfers in a water budget is important for water management (Horn, 2000).

Climate change can also impact streamflow through changes in precipitation, temperature, and evapotranspiration. Observed increases in global temperatures are likely to create a more active and changing hydrologic cycle (Novotny and Stefan, 2007). Several precipitation indicators, such as precipitation, amount of days with precipitation, and intensity of precipitation in the United States all increased during the 20th century (Karl and Knight, 1998). Novotny and Stefan (2007) found variations in precipitation over time to be a primary cause of changes in streamflow in Minnesota, identifying streamflow trends as an important indicator of climate change.

Surface Water Trends. Studies have documented trends of increasing baseflow across the United States (Lins and Slack, 1999; Lins and Slack, 2005) and in the Midwest area (Gebert and Krug, 1996; Juckem *et al.*, 2008; Novotny and Stefan, 2007; Schilling and Libra, 2003; Zhang and Schilling, 2006). Many of these trends are explained by more than just an increase in precipitation, but also by a change in how precipitation is being routed to streams. More precipitation is becoming runoff or infiltrating to groundwater systems and making its way to stream channels. Improved conservation practices and land use changes that reduce evapotranspiration contribute to increases in baseflow.

Lins and Slack (1999, 2005) reported a widespread trend of increasing flows, especially in mid to low flows, across the United States, including major river basins in Missouri. Schilling and Libra (2003) found increasing baseflow across Iowa due in part to land use changes. Gebert and Krug (1996) found a step increase in low flows and a decrease in peak flows in Wisconsin's driftless area, which Juckem *et al.* (2008) explained by climatic changes, which controlled the timing, and land management, which controlled the magnitude. Novotny and Stefan (2007) reported increases in Minnesota's baseflow in the summer and winter seasons. Zhang and Schilling (2006) found an increase of streamflow, including baseflow in the Mississippi River from 1940 to 2003 for four gages in Iowa, Missouri, Tennessee, and Mississippi.

Summary. This study helps to describe the historical and current hydrologic relationships in Missouri. These relationships can be used as a baseline for future comparisons and for the development of models with hydrological applications to water supply, aquatic habitat management, and water quality assessment. Prediction of discharge variables is dependent on drainage area with minor influence seen by other variables at the scale of analysis used here. Some increasing trends over time are seen, attributable in part to land use changes. Though precipitation has significantly increased in parts of Missouri, climate variability does not seem to be the only factor driving changes in streamflow.

METHODS

Study Area

Ecoregions contain watershed areas with similar geological, hydrological, chemical, and biological characteristics (Nigh and Schroeder, 2002). In order to hold the variability of some of these factors constant, streamflow is evaluated for watersheds contained within a single ecoregion. The Central Dissected Till Plains ecoregion covers almost all of northern Missouri, north of the Missouri River (Figures 1 and 2). Much of the land cover is cropland and grassland. Pleistocene loess varies in thickness across northern Missouri, deposited on top of glacial till left behind by ice sheets over four thousand years ago. It includes alluvial plains, deep-loess hills, high, flat prairies, and dissected, steep-sided hills (Nigh and Schroeder, 2002). This ecoregion has a low range of topographic relief.

The Ozark Highlands ecoregion includes most of southern Missouri, south of the Missouri River (Figures 1 and 2). The majority of this ecoregion is covered by forests, both deciduous and some pine. The western part of the ecoregion contains cropland and grassland as well. It is characterized by horizontally-bedded carbonate bedrock, karst features, and cave and spring systems. It includes high, slightly dissected plains, rugged hills, igneous knobs and sedimentary basins, loess-capped bluffs, karst plains, and dissected hills (Nigh and Schroeder, 2002). This ecoregion has a wide range of topographic relief.

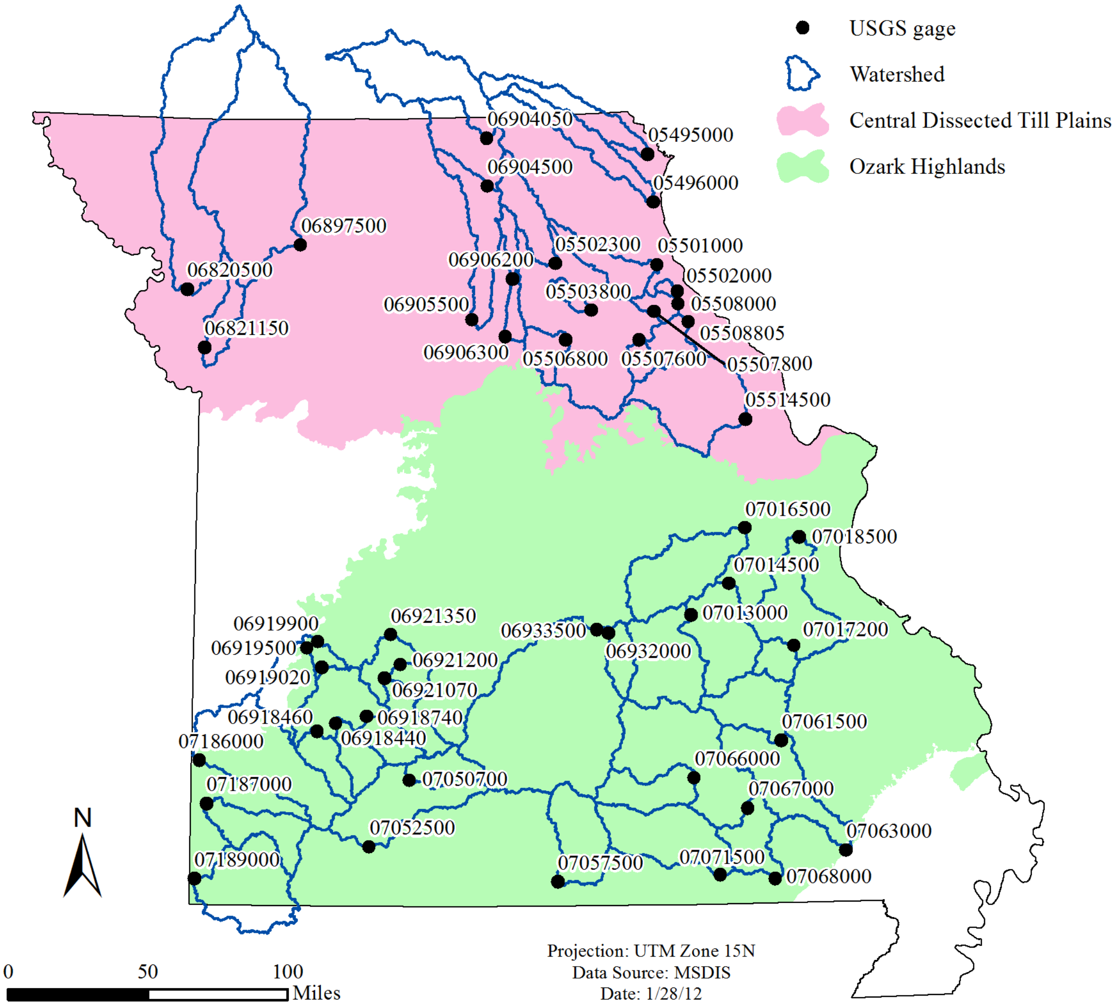
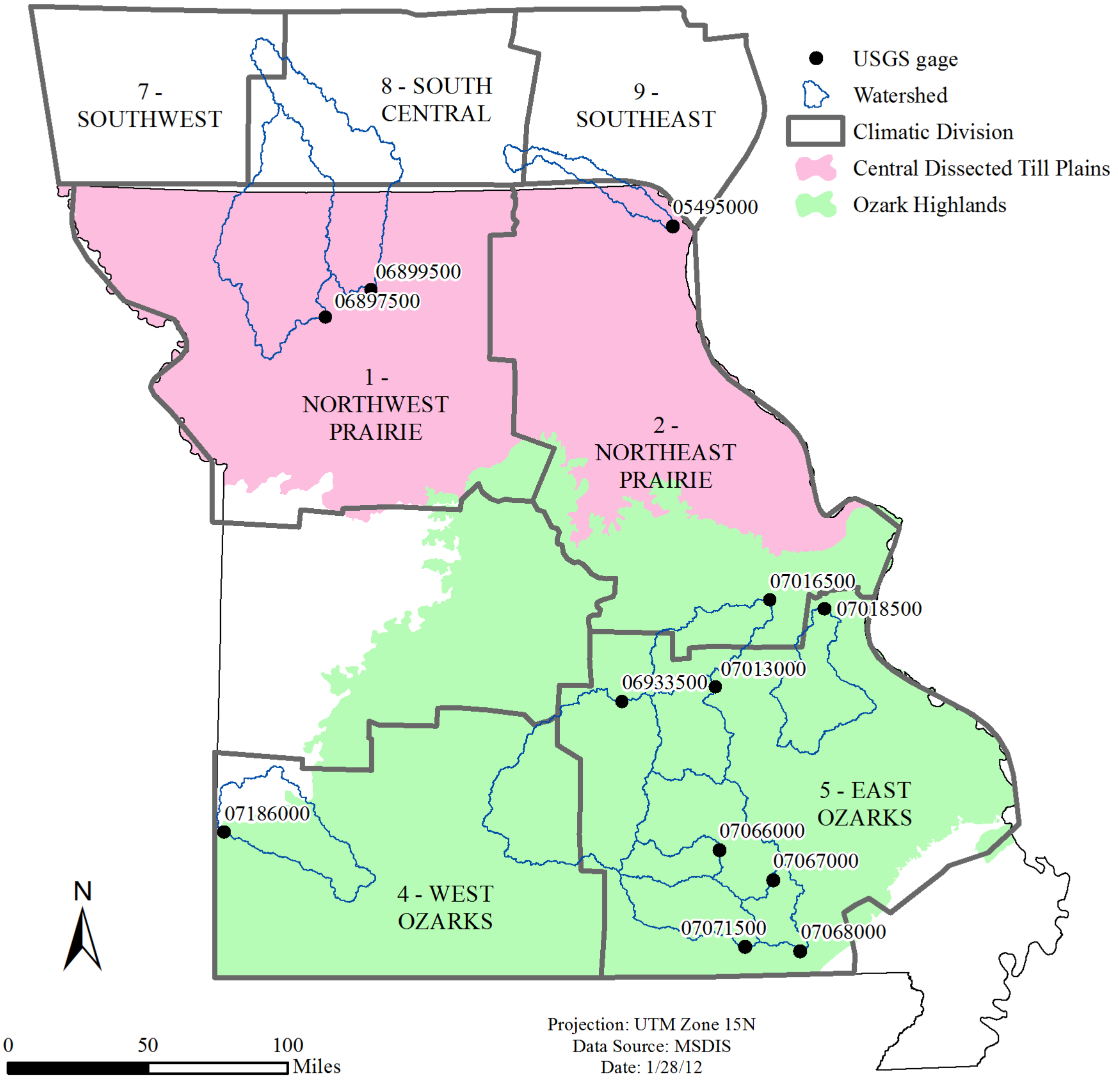


Figure 1. Selected watersheds for 1981-2010



Projection: UTM Zone 15N
Data Source: MSDIS
Date: 1/28/12

Figure 2. Selected watersheds for the 1925-2010 time period

Only one gage used in the Central Dissected Till Plains is located directly below a dam (Table 1). The East Little Fork Chariton River near Macon gage is located just below Long Branch Dam, which is 71 feet high and has a reservoir area of 9.5 square miles. Two gages in the Central Dissected Till Plains, while not located directly below dams, have smaller dams within their watershed, which could contribute to lower floods (Graf, 2006) (Table 1).

In the Ozark Highlands, two gages used are located directly below large dams (Table 2). The Sac River at Hwy J below Stockton gage is located directly below Stockton Dam, which creates Stockton Lake, is 161 feet high, and has a reservoir area of 39 square miles. The Pomme de Terre River near Hermitage gage is located just below Pomme de Terre Dam, which creates Pomme de Terre Lake, is 155 feet high, and has a reservoir area of 12 square miles. Another gage, Black River at Poplar Bluff gage, is not directly below a large dam, but has one in the center of its watershed, as well as several dams in its headwaters (Table 2).

Gage Selection

Discharge records including monthly mean, annual mean, and annual peak records were obtained from the USGS stream gage station network (USGS, National Water Information System. Accessed December, 2010 – November, 2011, http://waterdata.usgs.gov/mo/nwis) (Appendix A). Each gage is identified by an 8-digit number and a descriptive name (Tables 1 and 2). The stream gages selected for analysis in this study have: (1) continuous records to avoid errors associated with estimating missing values, an exception was included in order to increase the number of samples;

Table 1. Drainage area and land use of selected USGS gages in the Central Dissected Till Plains for 1981-2010 [1, 2]

Gage ID	Name	Ad mi^2	For %	Ag %	Urb %
05495000	Fox River at Wayland	400	20	72	5
05496000	Wyaconda R above Canton	393	15	78	4
05501000	North R at Palmyra	354	22	72	5
05502000	Bear Cr at Hannibal	31	13	79	8
05502300	North Fork Salt R at Hagers Grove	365	12	78	6
05503800	Crooked Cr near Paris	80	10	85	5
05506800	Elk Fork Salt R near Madison	200	15	74	6
05507600	Lick Cr at Perry	104	5	98	5
05507800	Salt Cr near Center[2]	2,350	15	76	5
05508000	Salt Cr near New London[2]	2,480	15	75	5
05508805	Spencer Cr below Plum Cr near Frankford	206	22	67	5
05514500	Cuivre R near Troy	903	24	72	5
06820500	Platte R near Agency	1,760	9	82	6
06821150	Little Platte at Smithville	234	10	73	8
06897500	Grand R near Gallatin	2,250	16	77	5
06904050	Chariton R at Livonia[2]	864	15	74	5
06904500	Chariton R at Novinger	1,370	20	70	5
06905500	Chariton R near Prairie Hill	1,870	25	68	5
06906200	E Fork Little Chariton R near Macon[2]	112	22	58	5
06906300	E Fork Little Chariton R near Huntsville	220	28	59	6

[1] Land cover percentages based on 2006 National Land Cover Dataset
[2] Gage record influenced by dam(s)

Table 2. Drainage area and land use of selected USGS gages in the Ozark Highlands for 1981-2010 [1, 2]

Gage ID	Name	Ad mi^2	For %	Ag %	Urb %
06918440	Sac R near Dadeville	257	21	71	8
06918460	Turnback Cr above Greenfield	252	31	66	5
06918740	Little Sac R near Morrisville	237	40	47	11
06919020	Sac R at Hwy J below Stockton[2]	1,292	33	56	7
06919500	Cedar Cr near Pleasant View	420	32	62	4
06919900	Sac R near Caplinger Mills	1,810	34	57	6
06921070	Pomme de Terre R near Polk	276	36	56	5
06921200	Lindley Cr near Polk	112	31	74	7
06921350	Pomme de Terre R near Hermitage[2]	615	39	53	6
06932000	Little Piney Cr at Newburg	200	71	23	5
06933500	Gasconade R at Jerome	2,840	60	34	5
07013000	Meramec R near Steelville	781	65	28	5
07014500	Meramec R near Sullivan	1,475	71	22	5
07016500	Bourbeuse R at Union	808	55	35	6
07017200	Big R at Irondale	175	76	26	3
07018500	Big R at Byrnesville	917	72	20	7
07050700	James R near Springfield	246	41	50	7
07057500	North Fork R near Tecumseh	561	66	29	3
07061500	Black R near Annapolis	484	101	7	3
07063000	Black R at Poplar Bluff[2]	1,245	86	9	4
07066000	Jacks Fork at Eminence	398	82	19	4
07067000	Current R at Van Buren	1,667	82	16	4
07068000	Current R at Doniphan	2,038	84	14	4
07071500	Eleven Point R near Bardley	793	67	27	4
07186000	Spring R near Waco	1,164	12	79	6
07187000	Shoal Cr above Joplin	427	30	62	8
07189000	Elk R near Tiff City	872	49	40	7

[1] Land cover percentages based on 2006 National Land Cover Dataset
[2] Gage record influenced by dam(s)

(2) drainage area less than 3,000 square miles to remove the hydrologic variation of very large rivers that drain several ecoregions and contain main stem dams that can influence hydrologic records; (3) less than 15% urban area in the watersheds to minimize the influence caused by human actions. Dam influence was evaluated by looking at relative proximity of gages to dams (Tables 1 and 2).

Discharge variables, including 2-year flood, 90th percentile, mean, 50th percentile, and 10th percentile, were analyzed for watershed relationships of the 20 gages in the Central Dissected Till Plains and the 27 gages in the Ozark Highlands from 1981-2010 (Tables 1 and 2) (Appendix B). Evaluating a range of discharge variables is useful for analysis of water resources. Studying peak flows is useful for building of structures in or near streams (Riggs, 1982). Accurate and easily available baseflow characteristics are important for water resource and aquatic wildlife managers (Stuckey, 2006).

The same variables were analyzed for longer-term trends of 3 gages in the Central Dissected Till Plains for 1925-2010. An exception was made for the gage at Grand River near Gallatin, or 06899500, for which the record was 1929-2010, in order to include another sample in the analysis. Ten gages in the Ozark Highlands for 1925-2010 were analyzed for longer-term trends. (Tables 3 and 4). The records at these gages were compared with precipitation time series for climatic divisions in the study area. The analysis of long-term gage records is helpful in understanding long-term trends and the natural and human influences on water availability (Hodgkins *et al.*, 2007). It is also useful for evaluating the temporal stability of discharge-drainage area relationships.

For 1981-2010, mean annual records were used to calculate 30-year values for the 90th percentile, mean, 50th percentile, and 10th percentile flows (Appendix B). The 2-year

Table 3. Long-term USGS gages in the Central Dissected Till Plains [1]

Gage ID	Name	Ad mi^2	Years of Record
05495000	Fox River at Wayland	400	1925-2010
06897500	Grand R nr Gallatin	2,250	1925-2010
06899500	Thompson R at Trenton	1,720	1929-2010

[1] Gage 06899500 is missing records for 2003 and 2004

Table 4. Long-term USGS gages in the Ozark Highlands

Gage ID	Name	Ad mi^2	Years of Record
06933500	Gasconade R at Jerome	2,840	1925-2010
07013000	Meramec R nr Steelville	781	1925-2010
07016500	Bourbeuse R at Union	808	1925-2010
07018500	Big R at Byrnesville	917	1925-2010
07066000	Jacks Fork at Eminence	398	1925-2010
07067000	Current R at Van Buren	1,667	1925-2010
07068000	Current R at Doniphan	2,038	1925-2010
07071500	Eleven Point R nr Bardley	793	1925-2010
07186000	Spring R nr Waco	1,164	1925-2010

flood was calculated using annual peak records. The median of the 30-year period is the 2-year recurrence interval flood, the flood that on average occurs every 2 years. The 2-year flood represents the upper-most limit of in-channel flows and the lower limit of overbank floods. The 2-year flood approximates the range of geomorphically effective floods on channel form (Knighton, 1998). For 1925-2010, the 90th percentile, mean, 50th percentile, and 10th percentile flows were calculated for each year using mean monthly records.

Watershed Characteristics

Watershed boundaries were delineated for the area above each gage using ArcHydro toolbar, available to use through ArcGIS 10 (ESRI, 2011). Drainage area and average slope were calculated for each watershed using ArcMap (ESRI, 2011) (Appendix B). Slope is calculated as the rate of maximum change in elevation from each raster cell of the DEM (ESRI, Desktop Help 10.0. Accessed August, 2012, http://help.arcgis.com). Mean slope was then calculated within each watershed boundary. The percentage of forested, agricultural, and urbanized land in each watershed was determined by overlaying the 2006 National Land Cover Dataset (USGS, Multi-Resolution Land Characteristics Consortium. Accessed December, 2011, http://www.mrlc.gov) using ArcMap (ESRI, 2011) (Appendix B). Multiple classes were combined to create the land cover percentages- different types of forest, pasture and agriculture, and different levels of urbanization were combined.

Precipitation data were obtained from the National Climatic Data Center of the National Oceanic and Atmospheric Administration (NOAA) for climatic divisions which overlapped the watersheds, including the Northwest Prairie, Northeast Prairie, West Ozarks, and East Ozarks Divisions in Missouri and the Southwest, South Central, and Southeast Divisions in Iowa (NOAA, National Climate Data Center. Accessed December, 2011, http://www.ncdc.noaa.gov) (Figure 2). Climatic division precipitation data has been found useful for understanding regional trends, as is the goal in this study (Garbrecht *et al.*, 2004). Annual precipitation values for watersheds whose boundaries crossed more than one climatic division were derived by area weighting of division values based on contributing division area in the drainage basin (Schilling and Libra, 2003). Runoff percentage was calculated as the percentage of precipitation that becomes streamflow (mean annual discharge, in cubic feet per year divided by mean annual precipitation in cubic feet) (Appendix B).

Analysis of Streamflow Relationships

Many studies of streamflow relationships use regression to create models to help predict values at ungaged locations (Garbrecht *et al.*, 2004; Gebert and Krug, 1996; Hu *et al.*, 2005; Vogel *et al.*, 1999; Zhang and Schilling, 2006). Linear regression is used in this study to determine if there is a relationship between drainage area, slope, land cover percentages, and discharge variables in each ecoregion for 1981-2010. Multiple regression was used for models with more than one variable to regionalize streamflow characteristics (Riggs, 1982). Collinearity statistics were calculated to ensure that there was no multicollinearity, that the independent variables were not significantly correlated (Rogerson, 2010). Regression was also used to determine if there were any long-term trends over time in discharge variables for gages with records from 1925-2010 (Schilling and Libra, 2003). Logarithmic transformations were performed on discharge variables, precipitation, and drainage area, which are not normally distributed (Gebert and Krug, 1996). A logarithmic transformation allows linear relationships to be evaluated on datasets that are geometric or non-linear in nature by normalizing typically skewed data distributions and which is comprised of ranges in x and y variables that exceed 1-2 orders of magnitude or more (Rogerson, 2010).

The form of the equation used is $\log Q = b_0 + \ldots b_n (\log X_n)$, where Q is discharge, b_0 is the constant, b_n is the coefficient of the independent variable, X is the independent variable, and the significance of the coefficients are shown as α_n. The accepted significance value of the models is alpha (α) less than or equal to 0.05, meaning there is no more than a 5% chance of error in the slope coefficient. The sign, positive or negative, of the coefficient indicates the direction of the relationship (Rogerson, 2010). The coefficient of determination, or r^2 value, shows the amount of variation in the dependent variable that is explained by the independent variable(s) in the regression equation. It is calculated by the regression sum of squares divided by the total sum of squares (Rogerson, 2010). The standard error of the model (se) is the standard deviation of the residuals, calculated by taking the square root of the residual sum of squares divided by its degrees of freedom (n-2). It shows the magnitude of a typical error as it relates to sample size (Rogerson, 2010). The coefficient of variation (cv) shows the dispersion or relative variability within the dataset, and it is equal to ratio of the standard deviation to the mean of the dataset (Rogerson, 2010). The f-ratio, the critical value for significance, indicates the strength of the relationship- the higher the f-ratio, the stronger the relationship. The equation for f-ratio is $F = (r^2(n - 2))/(1 - r^2)$, where n is the number of samples (Rogerson, 2010). If the f-ratio is above a critical value for $\alpha \leq 0.05$, the relationships is significant. All statistical analyses were performed using PASW Statistics 18 Release 18.0.0 (PASW, 2009).

RESULTS AND DISCUSSION

Discharge-Drainage Area Relationships

All five discharge variables in each ecoregion exhibit significant ($\alpha \leq 0.05$) and positive relationships with drainage area. In the Central Dissected Till Plains, the r^2 values, with significance values in parentheses, for the 2-year flood, 90th percentile, mean, 50th percentile, and 10th percentile are as follows: 0.568 (1.24E-4), 0.992 (3.61E-20), 0.996 (1.31E-22), 0.993 (9.03E-21), and 0.916 (4.17E-11) and the cv% values are 12, 19, 21, 22, and 28%, respectively (Table 5a). In the Ozark Highlands, the r^2 values are 0.217 (0.0164), 0.982 (1.96E-23), 0.977 (6.36E-22), 0.975 (1.38E-21), and 0.890 (1.72E-13) and the cv percentages are 6, 13, 14, 14, and 16%, respectively (Table 5b).

The relationships of the in-channel flows to drainage area are very similar (Figures 3 and 4). The coefficients of drainage area (b_1) for the in-channel flows are all very close to 1 (Tables 5a-b). As would be expected, the main difference is in their magnitude, as seen by increasing intercept values (b_0) with flow magnitude. The coefficients for drainage area in other studies are also near 1. In regression models for mean annual streamflow, Vogel *et al.* (1999) found coefficients for drainage area for regions which include Missouri ranging from 0.925 to 1.013. Studies in other areas of the United States also found coefficients for drainage area near 1 (Koltun and Whitehead, 2001; Stuckey, 2006).

The 2-year flood is more weakly related to drainage area than the in-channel flows, as evidenced by its lower r^2 values. This may be a result of the influence of dams, which was not entirely removed in the dataset selection, or other watershed factors not

Table 5a. Central Dissected Till Plains discharge-drainage area relationships [1, 2]

Q	n	cv%	r^2	log se	se %[2]	f-ratio	b_0	Ad b_1	α_1
Log 2 yr.	20	12	0.568	0.309	8	24	2.273	0.623	0.00
Log 2 yr. Upper	16	10	0.788	0.192	5	52	2.246	0.678	0.00
Log 90th	20	19	0.992	0.052	2	2,142	0.222	0.993	0.00
Log Mean	20	21	0.996	0.038	2	4,012	-0.036	0.988	0.00
Log 50th	20	22	0.993	0.048	2	2,501	-0.124	1.000	0.00
Log 10th	20	28	0.916	0.158	8	195	-0.496	0.914	0.00

[1] Equation form: $\text{Log}Q = b_0 + b_1(\text{Log}A_d)$
[2] se% = 100(log se/ log ŷ)

Table 5b. Ozark Highlands discharge-drainage area relationships [1, 2]

Q	n	cv%	r^2	log se	se %[2]	f-ratio	b_0	Ad b_1	α_1
Log 2 yr.	26	6	0.217	0.218	5	7	3.279	0.299	0.02
Log 2 yr. upper	23	5	0.561	0.135	3	27	3.098	0.386	0.00
Log 90th	27	13	0.982	0.051	2	1,390	0.203	0.999	0.00
Log Mean	27	14	0.977	0.059	2	1,046	-0.013	1.016	0.00
Log 50th	27	14	0.975	0.061	2	982	-0.029	1.014	0.00
Log 10th	27	16	0.890	0.140	6	202	-0.403	1.057	0.00

[1] Equation form: $\text{Log}Q = b_0 + b_1(\text{Log}A_d)$
[2] se% = 100(log se/ log ŷ)

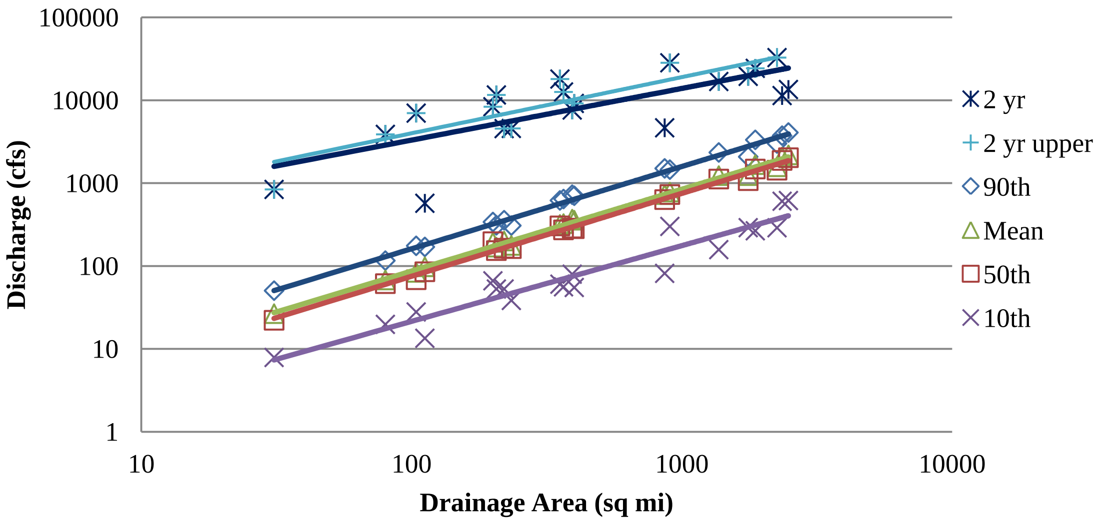


Figure 3. Central Dissected Till Plains discharge-drainage area relationships (1981-2010)

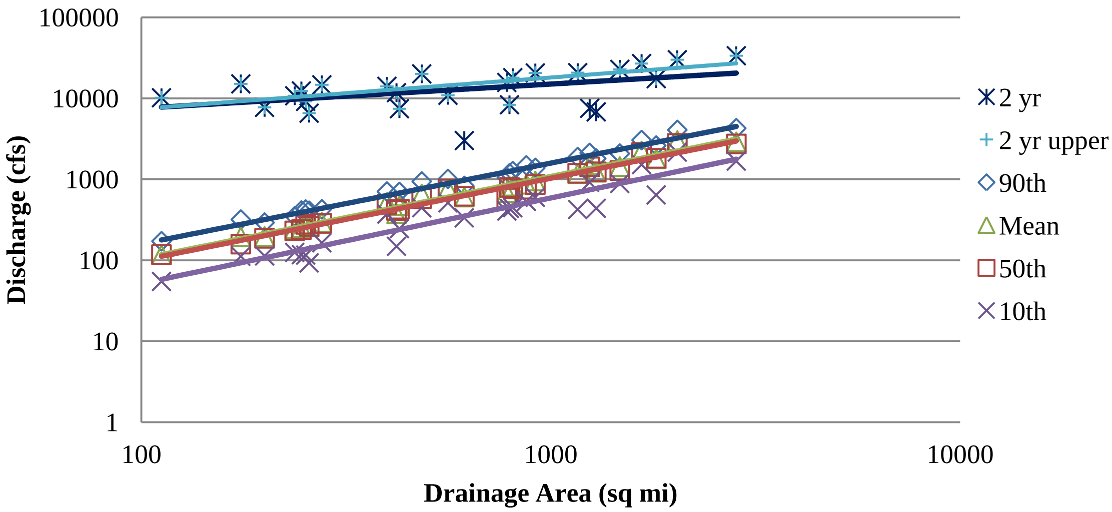


Figure 4. Ozark Highlands discharge-drainage area relationships (1981-2010)

limited to drainage area. Using a dataset from the MoDNR's Water Resource Center, (Missouri Spatial Data Information Service, Assessed March 2011, ftp://msdis.missouri.edu/pub/metadata/utm/st_dams.xml) it is noted that a few of the gages which fall below the 2-year flood trend line (Figures 3 and 4) are located below dams. In an effort to better understand the effect of dams on floods in these watersheds, low outliers were removed from the 2-year flood relationships, referred to as 2-year upper (Tables 5a-b; Figures 3 and 4). Removal of these gages from the model improves the r^2 values, and increases the predicted size of the 2-year flood, because gages directly below large dams have lower annual peak flows (Graf, 2006). For the Central Dissected Till Plains, the r^2 value increases from 0.568 to 0.888, and se% decreases from 7.9% to 4.7%. For the Ozark Highlands the r^2 value increases from 0.217 to 0.749, and se% decreases from 5.3% to 3.2%. Not all gages below dams fall outside the expected values. The size and the purpose of the dam will determine the magnitude of its effect on downstream flow characteristics (Knighton, 1998).

Specific Discharge-Drainage Area Relationships

For in-channel flows, the relationship between specific discharge and drainage area is similar across different sized watersheds (Tables 6a-b; Figures 5a-e). Since the regression slope is very near 0 with significance levels of $\alpha > 0.05$, the discharge per unit of area of the 90th percentile, mean, 50th percentile, and 10th percentile, has no linear relationships for different sized watersheds (Tables 6a-b; Figures 5a-e). Therefore, in-channel flows in Missouri can be considered watershed-scale independent. The non-relationship would allow the in-channel flows of watersheds of varying sizes to be

Table 6a. Central Dissected Till Plains specific discharge-drainage area relationship [1]

Q/Ad	n	r^2	log se	f-ratio	Ad b_0	b_1	α_1
Log 2 yr.	20	0.324	0.309	9	2.273	-0.377	0.01
Log 2 yr. Upper	16	0.457	0.192	12	2.246	-0.322	0.00
Log 90th	20	0.006	0.052	0.101	0.222	-0.007	0.75
Log Mean	20	0.034	0.038	0.634	-0.036	-0.012	0.44
Log 50th	20	0.000	0.048	0.000	-0.124	0.000	0.99
Log 10th	20	0.088	0.158	2	-0.496	-0.086	0.21

[1] Equation form: $\mathrm{Log}Q = b_0 + b_1(\mathrm{Log}A_d)$; α_1 = significance of coefficient

Table 6b. Ozark Highlands specific discharge-drainage area relationship [1]

Q/Ad	n	r^2	log se	f-ratio	Ad b_0	b_1	α_1
Log 2 yr.	26	0.604	0.218	37	3.279	-0.701	0.00
Log 2 yr. Upper	23	0.764	0.135	68	3.098	-0.614	0.00
Log 90th	27	0.000	0.051	0.002	0.203	-0.001	0.97
Log Mean	27	0.010	0.060	0.262	-0.013	0.016	0.61
Log 50th	27	0.007	0.061	0.185	-0.029	0.014	0.67
Log 10th	27	0.023	0.140	0.595	-0.403	0.057	0.45

[1] Equation form: $\mathrm{Log}Q = b_0 + b_1(\mathrm{Log}A_d)$; α_1 = significance of coefficient

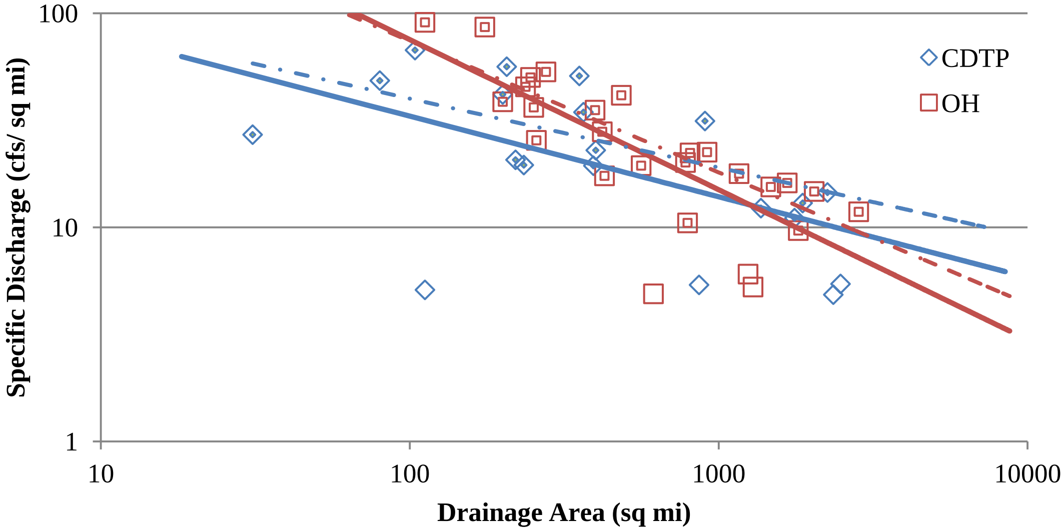


Figure 5a. Differences between ecoregions for 2-year flood and 2-year flood upper limit
CDTP = Central Dissected Till Plains, OH = Ozark Highlands
Dashed lines and filled symbols represent 2-year flood upper relationship

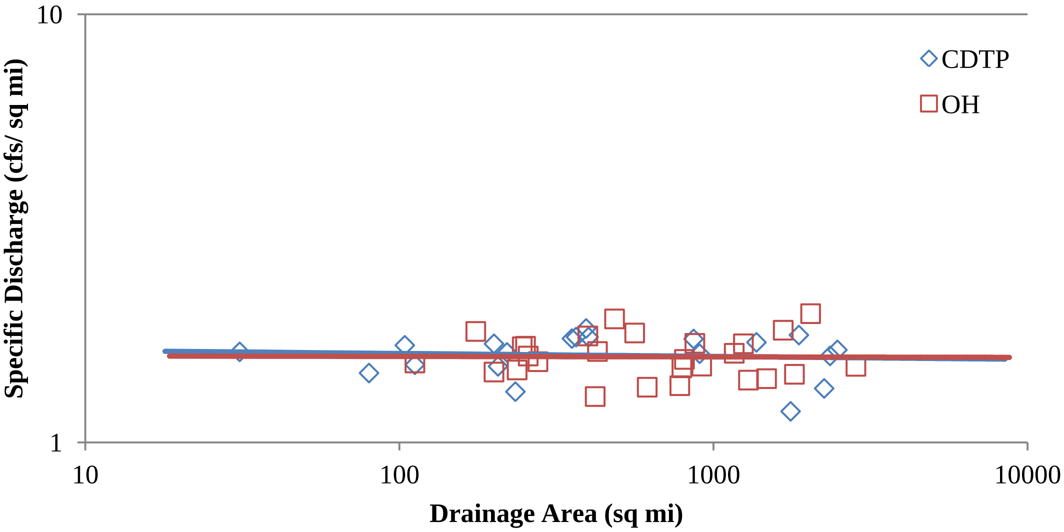


Figure 5b. Differences between ecoregions for 90th percentile flow

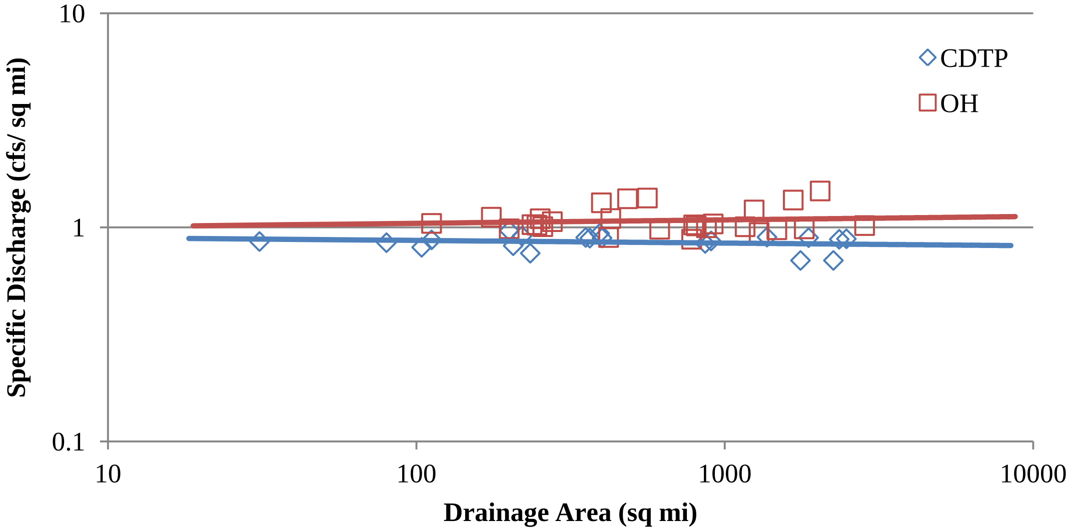


Figure 5c. Differences between ecoregions for mean flow

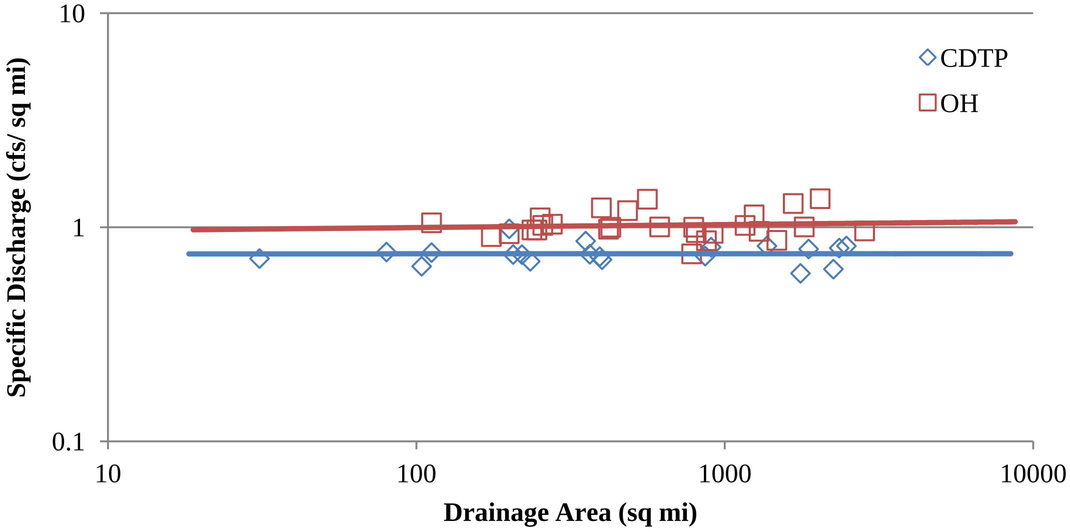


Figure 5d. Differences between ecoregions for 50th percentile flow

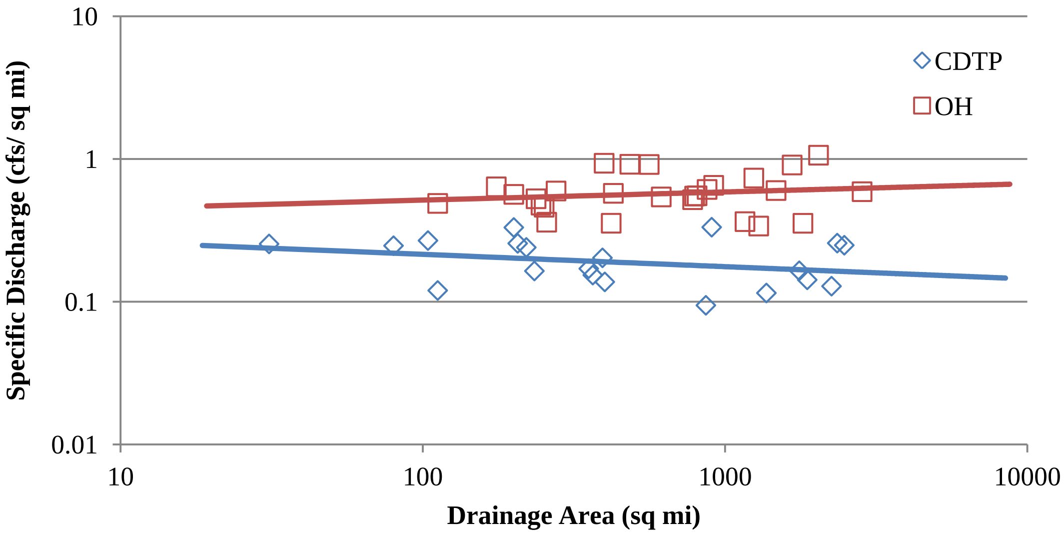


Figure 5e. Differences between ecoregions for 10th percentile flow

compared to one another to estimate specific discharge (Emerson *et al.*, 2005).

In contrast, the size of the watershed does seem to affect specific discharge at the 2-year flood. As drainage area increases, the size of specific 2-year flood decreases. As drainage area increases, the storage capacity of floodplains also increases, which can help to minimize to size of peak flows through attenuation of flood peaks. In lower reaches of streams, the drainage area is larger, and the slopes lower (Knighton, 1998). When the slope is lower, infiltration increases, which also helps to minimize the size of peak flows (Brooks *et al.*, 2003). However, the size of the watershed does not affect the 90th percentile flow, the highest in-channel flow studied here. At some flow level between the 2-year flood and the 90th percentile, increasing drainage area appears to limit streamflow. It could be that flows greater than bankfull, often approximated by the 1.5-year flood (Knighton, 1998), is the point of inflection above which the relationship between discharge and drainage area becomes stronger.

Differences between the Ecoregions

The greatest difference in discharge-drainage area relationships between the Central Dissected Till Plains and the Ozark Highlands is in the 2-year flood and the 10th percentile flow. The 90th percentile, mean, and 50th percentile flows show little difference between the two ecoregions. The differences are seen in the extremes included in this study, peak flows and baseflows. When the 2-year flood low outliers are removed, the Central Dissected Till Plains has larger 2-year floods than the Ozark Highlands, in watersheds of 1,000 square miles. Only in the larger watersheds do the floods surpass the Ozark Highlands. In the Ozark Highlands, the bedrock is more permeable and characterized by sinkholes (Nigh and Schroeder, 2002). So in the large watersheds, there are more opportunities for runoff to be routed into underground storage, before it reaches a stream.

In the Ozark Highlands, there seems to be more water available in a few discharge ranges. The 10th percentile flow in the Ozark Highlands is higher and the mean and 50th percentile flows are slightly higher than the Central Dissected Till Plains, for any-sized watershed. There is slightly more annual rainfall in the Ozark Highlands, an average of 41 inches in the Central Dissected Till Plains and 43 inches in the Ozark Highlands. In the Ozarks Highlands, some runoff is supplied by groundwater outlets to the surface, such as springs (Vandike, 1996).

Differences between the Central Dissected Till Plains and the Ozark Highlands can also be seen in specific discharge-drainage area relationships. Again, the greatest differences are in the 2-year flood and the 10th percentile flow, the extremes of flow (Figures 5a and 5e). The greatest difference in predicted specific discharge values are in the 10th percentile flow (Figure 6). The relationships for the 90th percentile flow are virtually the same (Table 7a-b). The mean and 50th percentile flow relationships show the Ozark Highlands have slightly higher specific discharge over drainage area.

The specific 2-year flood discharge decreases with increasing drainage area. The specific 2-year flood relationship shows that the Central Dissected Till Plains surpasses the Ozark Highlands in large watersheds. When the 2-year flood low outliers are removed, this relationship remains the same, but the point at which the Ozark Highlands is surpassed changes. The large forested watersheds in the Ozark Highlands will have high interception rates (Brooks *et al.*, 2003) and because of the permeable bedrock (Nigh

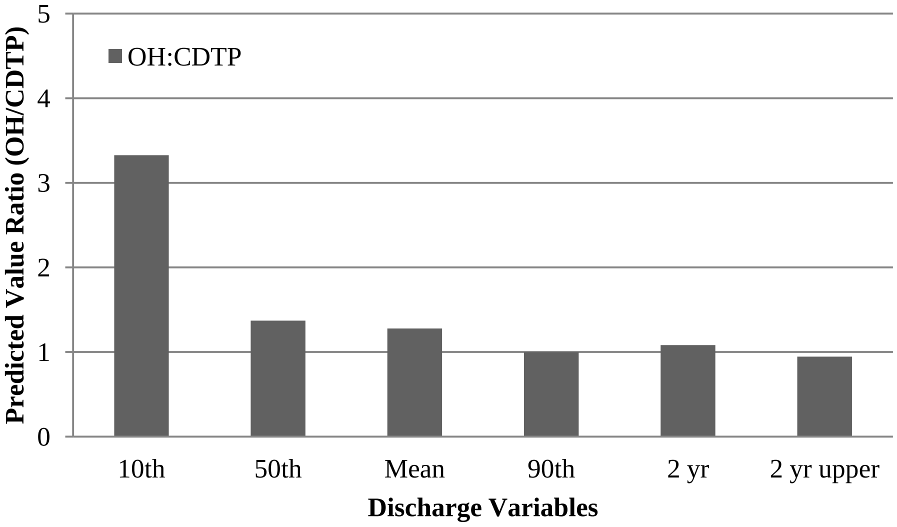


Figure 6. Ratio of predicted specific discharge values (OH/CDTP) for watershed of 1,000 sq mi

Table 7a. Model results of specific discharge (cfs) for the Central Dissected Till Plains

Watershed Size (sq mi)	2-yr	2-yr upper	90th	Mean	50th	10th
100	33.04	39.99	1.61	0.87	0.75	0.21
300	21.83	28.08	1.60	0.86	0.75	0.20
1,000	13.87	19.05	1.59	0.85	0.75	0.18

Table 7b. Model results of specific discharge (cfs) for the Ozark Highlands

Watershed Size (sq mi)	2-yr	2-yr upper	90th	Mean	50th	10th
100	75.34	74.13	1.59	1.04	1.00	0.51
300	34.88	37.76	1.59	1.06	1.01	0.55
1,000	15.00	18.03	1.58	1.08	1.03	0.59

and Schroeder, 2002), the highest potential for infiltration, reducing the size of peak flows when drainage area increases.

Slope and Land Use Influence

Terrain relief and land use can contribute to streamflow variability among watersheds. Slope was found to be a significant variable in some regional streamflow models in the United States (Vogel *et al.*, 1999). In this study, mean slope is a significant variable in the discharge-drainage area model and improves the r^2 values for some discharge variables, especially in the Ozark Highlands where slope is more variable. Watersheds of different land uses can have different surface runoff rates and groundwater storage (Lenz *et al.*, 2003). There are some significant relationships ($\alpha \leq 0.05$) with land use variables, though the coefficients are often very small, so the effects on the models are minimal.

Mean Slope. Watershed slope correlates significantly with percentages of forested and agricultural land for both ecoregions combined (Figures 7 and 8). As slope increases, the amount of forested land increases and agricultural land decreases. The steeper the land, the less it can be used for farming and the more likely it is to remain forested. Correspondingly, the steeper the land, the lower relative infiltration, the faster precipitation can be routed to the stream channel, resulting in higher discharges (Brooks *et al.*, 2003).

In the Central Dissected Till Plain, when mean slope is added to the discharge-drainage area model, there is little effect (Table 8a). The only significant relationship ($\alpha \leq 0.05$) is in the 10th percentile. The mean slope variable addition increases the r^2 value by

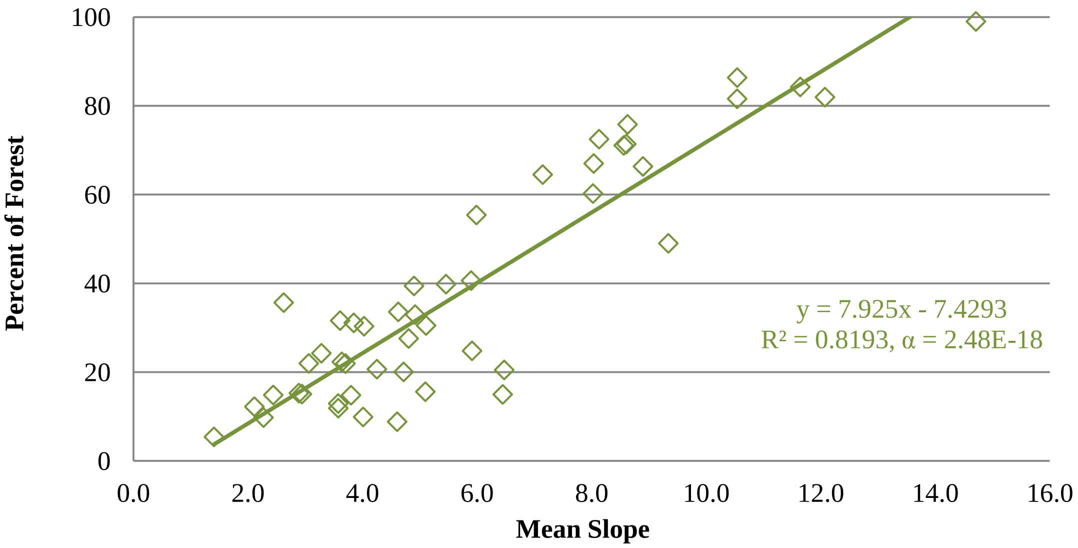


Figure 7. Percent of forest and mean slope relationship for both ecoregions

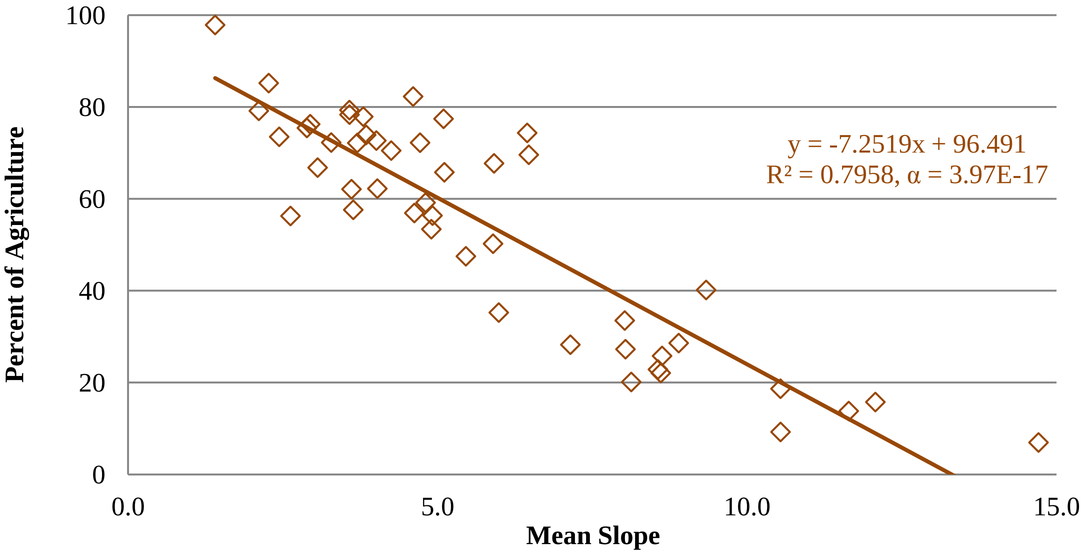


Figure 8. Percent of agriculture and mean slope relationship for both ecoregions

Table 8a. Central Dissected Till Plains discharge-drainage area and slope relationship[1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad b_1	α_1	Slope b_2	α_2
Log 2 yr.	20	0.602	+3.4%	0.305	13	2.336	0.704	0.00	-0.070	0.25
Log 90th	20	0.992	0%	0.053	1022	0.218	0.988	0.00	0.004	0.68
Log Mean	20	0.996	0%	0.039	1895	-0.036	0.988	0.00	0.000	0.98
Log 50th	20	0.993	0%	0.049	1221	-0.118	1.008	0.00	-0.007	0.46
Log 10th	20	0.964	+4.8%	0.105	230	-0.409	1.026	0.00	-0.097	0.00

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

4.8%. It is a negative relationship, suggesting that as slope decreases, baseflow increases, but the coefficient is near zero, so the effect is minimal. In lower reaches of a stream, where the slope is lower, there is more infiltration and baseflow. In contrast, in headwater reaches of a stream, where the slope is steepest, there is less infiltration (Knighton, 1998). The range of mean slope values in this ecoregion is low, from 1.4 to 6.5 percent increase. This may help to explain the lack of significant relationships, since little dispersion within a variable means it is not likely to be a significant in a regression model (Riggs, 1982).

In the Ozark Highlands, when mean slope is added to the discharge-drainage area model, there is significant effect on the in-channel flows (Table 8b). Slope is a significant variable ($\alpha \leq 0.05$) for the 90th percentile, mean, 50th percentile, and 10th percentile flow models. It improves the r^2 values of all, especially the 10th percentile which increases by 7.5%. However, in the Ozark Highlands, the relationships are all positive. This suggests that as slope increases, discharge increases. The coefficients are all close to zero, so the effect is minimal. It may be explained by the fact that steeply sloped watersheds respond quickly to rainfall, producing more runoff (Brooks *et al.*, 2003). Generally, in the Central Dissected Till Plains there are watersheds with low slopes and less discharge, and in the Ozark Highlands there are watersheds with steep slopes and more discharge. Therefore, two different relationships are produced.

Forest Percentage. In the Central Dissected Till Plains, significant relationships are seen between discharge and drainage area and percent of forested land in the mean flow (Table 9a). However, the r^2 value increases by only 0.1%. In the Ozark Highlands, there are significant relationships between discharge and drainage area and percent of

Table 8b. Ozark Highlands discharge-drainage area and slope relationship[1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad b_1	α_1	Slope b_2	α_2
Log 2 yr.	26	0.281	+6.4%	0.213	4	3.274	0.250	0.05	0.020	0.17
Log 90th	27	0.990	+0.8%	0.039	1148	0.202	0.972	0.00	0.011	0.00
Log Mean	27	0.987	+1.0%	0.044	941	-0.014	0.983	0.00	0.013	0.00
Log 50th	27	0.979	+0.4%	0.057	559	-0.030	0.994	0.00	0.008	0.05
Log 10th	27	0.965	+7.5%	0.081	328	-0.406	0.961	0.00	0.038	0.00

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

Table 9a. Central Dissected Till Plains discharge-drainage area and forest relationship [1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad b_1	α_1	For % b_2	α_2
Log 2 yr.	20	0.568	0%	0.318	11	2.286	0.626	0.00	-0.001	0.93
Log 90th	20	0.993	+0.1%	0.05	1156	0.187	0.987	0.00	0.003	0.14
Log Mean	20	0.997	+0.1%	0.034	2486	-0.07	0.982	0.00	0.003	0.03
Log 50th	20	0.994	+0.1%	0.045	1433	-0.162	0.994	0.00	0.003	0.08
Log 10th	20	0.916	0%	0.162	92	-0.482	0.916	0.00	-0.001	0.85

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

Table 9b. Ozark Highlands discharge-drainage area and forest relationship [1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad b_1	α_1	For % b_2	α_2
Log 2 yr.	26	0.288	+7.1%	0.212	5	3.258	0.252	0.04	0.003	0.14
Log 90th	27	0.987	+0.5%	0.045	890	0.194	0.981	0.00	0.001	0.01
Log Mean	27	0.985	+0.8%	0.049	782	-0.026	0.991	0.00	0.002	0.00
Log 50th	27	0.977	+0.2%	0.06	515	-0.035	1.001	0.00	0.001	0.15
Log 10th	27	0.966	+7.6%	0.08	342	-0.445	0.974	0.00	0.005	0.00

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

forested land in the 90th percentile, mean, and 10th percentile flows (Table 9b). The r^2 value is increased by over 7% when percentage of forest is added to the equation of the 10th percentile. All significant relationships are positive, indicating that as forested land increases, discharge increases. As forested land increases, agricultural and urbanized land decreases, which would decrease human demands for water (Brooks *et al.*, 2003).

In the Central Dissected Till Plains, the average percentage of forest is 17%, and in the Ozark Highlands, the average percentage is 54%. In the Central Dissected Till Plains, all forest percentages are less than 30%. However, in the Ozark Highlands the percentages range from 12% to 99%. The cv% is also slightly higher in the Ozark Highlands, 36% versus 43%. These differences may account for the fact that there are fewer significant relationships between streamflow and forested land in the Central Dissected Till Plains. When there is little dispersion within a variable, it is not likely to be a significant variable in a regression model (Riggs, 1982).

Agriculture Percentage. In the Central Dissected Till Plains, no significant relationships exist between discharge and drainage area and agricultural land ($\alpha \leq 0.05$) (Table 10a). This may be a result of the small variability within percentage of agriculture in this ecoregion. Its coefficient of variation is only 12%, while in the Ozark Highlands it is a much higher 53%. In the Ozark Highlands, significant relationships ($\alpha \leq 0.05$) are seen between discharge and drainage area and percent of agricultural land for the 90th percentile, mean, and 10th percentile flows (Table 10b). These relationships are negative, indicating that as percent of agricultural land increases, discharge decreases. In agricultural watersheds, discharge can be decreased by farming activities, such as irrigation, and baseflow can be decreased by drainage tiling, which diverts water from

Table 10a. Central Dissected Till Plains discharge-drainage area and agriculture relationship [1, 2]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad	α_1	Ag %	α_2
							b_1		b_2	
Log 2 yr.	20	0.621	+5.3%	0.298	14	1.324	0.642	0.00	0.012	0.14
Log 90th	20	0.992	0%	0.053	1022	0.268	0.992	0.00	-0.001	0.68
Log Mean	20	0.996	0%	0.036	2176	0.082	0.985	0.00	-0.002	0.13
Log 50th	20	0.994	+0.1%	0.046	1361	0.029	0.997	0.00	-0.002	0.13
Log 10th	20	0.921	+0.5%	0.157	99	-0.834	0.921	0.00	0.004	0.31

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

Table 10b. Ozark Highlands discharge-drainage area and agriculture relationship [1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad	α_1	Ag %	α_2
							b_1		b_2	
Log 2 yr.	26	0.269	+5.2%	0.215	4	3.534	0.246	0.06	-0.003	0.21
Log 90th	27	0.986	+0.4%	0.046	827	0.305	0.978	0.00	-0.001	0.03
Log Mean	27	0.983	+0.6%	0.051	698	0.13	0.986	0.00	-0.002	0.01
Log 50th	27	0.976	+0.1%	0.061	494	0.03	1.002	0.00	-0.001	0.30
Log 10th	27	0.961	+7.1%	0.085	298	0.117	0.949	0.00	-0.005	0.00

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

saturated zones and decreases groundwater recharge (Lenz *et al.*, 2003).

Urban Percentage. In the Central Dissected Till Plains, when percentage of urbanized area is added to the model there is no significant effect (Table 11a). However, in the Ozark Highlands, when percentage of urbanized area is added to the model, the variable is significant for most of the in-channel flows (Table 11b). For the mean, 50th percentile, and 10th percentile the urban land use variable is significant. The relationships show that as urbanized area increases, in-channel flows decrease (Hodgkins *et al.*, 2007). The significances found in the Ozark Highlands and in the Central Dissected Till Plains may be a result of the variability of the urbanized percentages. In the Central Dissected Till Plains, the range of values is 5 to 8% urbanized, with a coefficient of variation of 19%. In the Ozark Highlands, the range of values is from 3 to 11% urbanized, with a coefficient of variation of 34%. Since only watersheds with urbanized percentages of less than 15% were used, the urban effect is not strong.

Historical Variations in Discharge-Drainage Area Relationships

Studying the relationships of discharge at long-term gages can give insight into overall trends. It can also help in understanding the natural and human influences on water availability (Hodgkins *et al.*, 2007). The gages that exhibit the most change from 1925-2010 are those in the Central Dissected Till Plains. All three gages used show an increase in the 10th percentile flow (Figures 9a-c). Using the trend line as a basis, the 10th percentile flow at Fox River at Wayland, Grand River near Gallatin, and Thompson River at Trenton has significantly increased by 207, 142, and 186%, or by 12, 90, and 100 cfs, with significance values of $\alpha = 0.05$, 0.05, and 0.04, respectively (Table 12). The 50th

Table 11a. Central Dissected Till Plains discharge-drainage area and urban relationship[1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad b_1	α_1	Urb % b_2	α_2
Log 2 yr.	20	0.597	+2.9%	0.307	13	2.843	0.573	0.00	-0.079	0.29
Log 90th	20	0.993	+0.1%	0.048	1243	0.381	0.979	0.00	-0.022	0.07
Log Mean	20	0.996	0%	0.037	2114	0.051	0.980	0.00	-0.012	0.18
Log 50th	20	0.993	0%	0.049	1203	-0.077	0.996	0.00	-0.006	0.58
Log 10th	20	0.916	0%	0.162	92	-0.497	0.914	0.00	0.000	1.00

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

Table 11b. Ozark Highlands discharge-drainage area and urban relationship[1]

Q	n	r^2	1p - 2p	se	f-ratio	b_0	Ad b_1	α_1	Urb % b_2	α_2
Log 2 yr.	26	0.257	+4.0%	0.217	4	3.519	0.264	0.04	-0.026	0.28
Log 90th	27	0.984	+0.2%	0.048	759	0.286	0.987	0.00	-0.009	0.08
Log Mean	27	0.982	+0.5%	0.054	638	0.116	0.998	0.00	-0.014	0.02
Log 50th	27	0.979	+0.4%	0.057	560	0.085	0.998	0.00	-0.013	0.05
Log 10th	27	0.915	+2.5%	0.126	130	-0.084	1.013	0.00	-0.036	0.01

[1] 1p - 2p shows the change in r^2 from using 1 parameter to 2 parameters

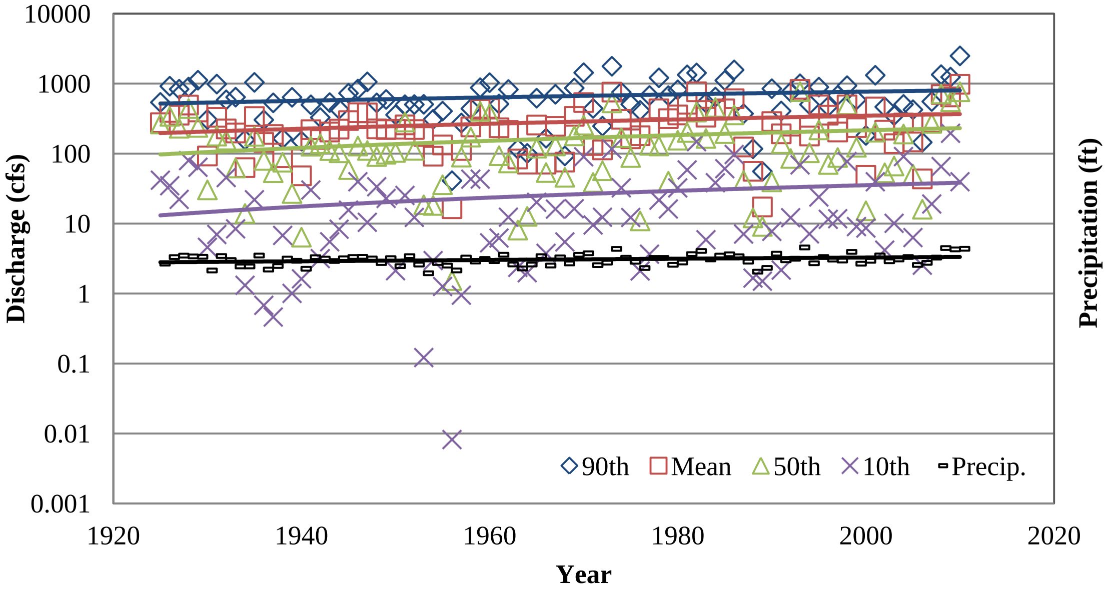


Figure 9a. In-channel flows and precipitation for Fox River at Wayland, 05495000 (1925-2010) in Central Dissected Till Plains. Relationships are as follows: y = 3.3205x - 5872.6 R² = 0.0377, α = 0.07, y = 2.0167x - 3685.6 R² = 0.0682, α = 0.02, y = 1.5742x - 2933 R² = 0.0532, α = 0.03, y = 0.2969x - 558.35 R² = 0.0461, α = 0.05, y = 0.0063x - 9.3427 R² = 0.0781, α = 0.01

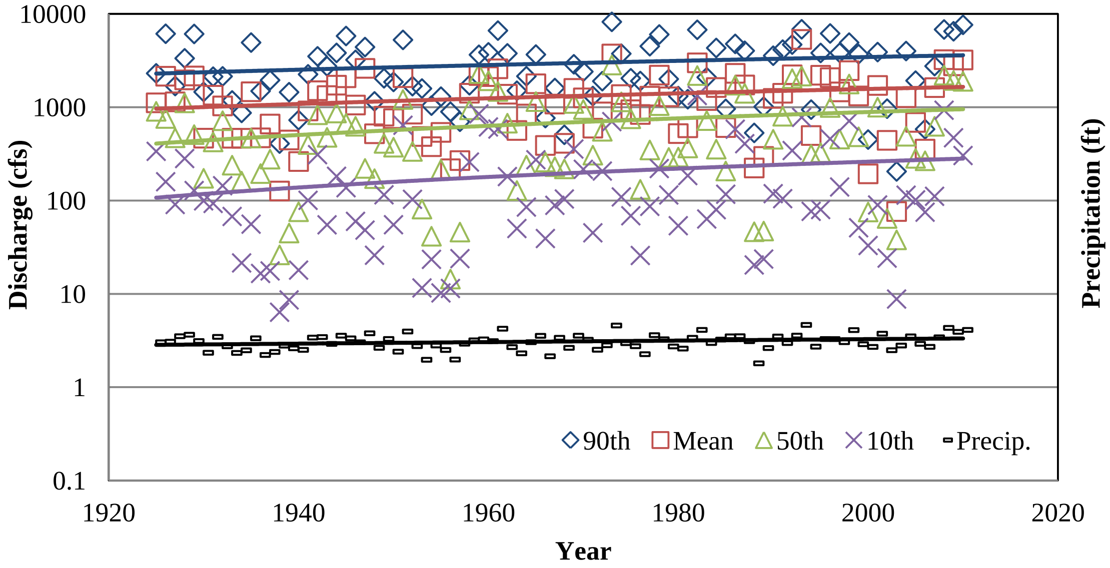


Figure 9b. In-channel flows and precipitation for Grand River near Gallatin, 06897500 (1925-2010) in Central Dissected Till Plains. Relationships are as follows: y = 15.447x – 27444 R² = 0.0381, α = 0.07, y = 8.0873x – 14605 R² = 0.0469, α = 0.05, y = 6.3981x – 11908 R² = 0.0605, α = 0.02, y = 2.0491x - 3837.3 R² = 0.0432, α = 0.05, y = 0.0057x - 8.1974 R² = 0.0584, α = 0.03

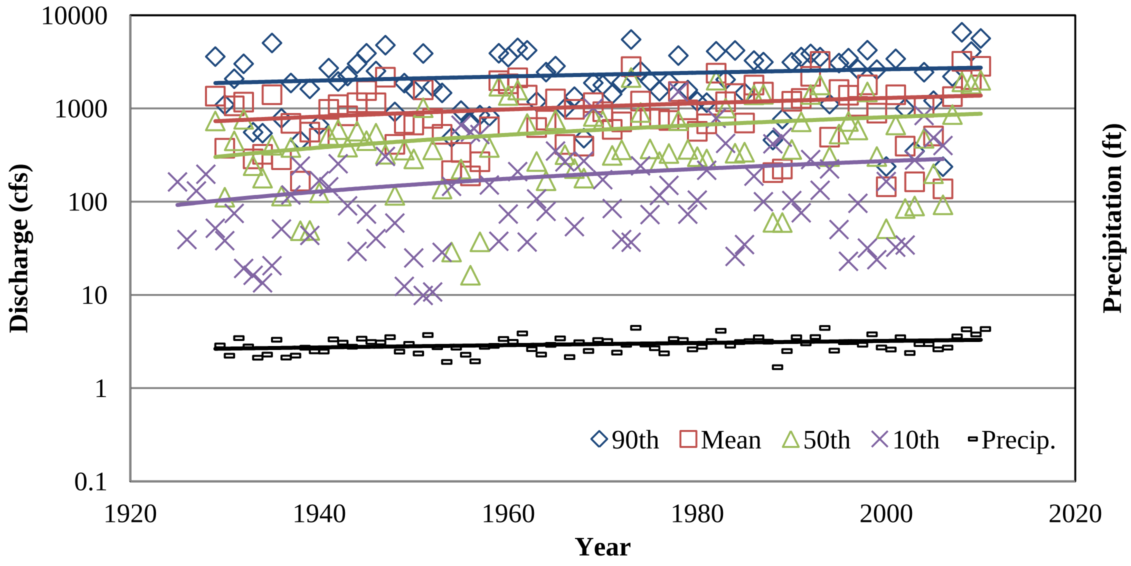


Figure 9c. In-channel flows and precipitation for Thompson River at Trenton, 06899500 (1929-2010) in Central Dissected Till Plains. Relationships are as follows: y = 10.663x – 18694 R² = 0.031, α = 0.11, y = 7.9625x – 14630 R² = 0.0703, α = 0.02, y = 7.0996x – 13393 R² = 0.0941, α = 0.01, y = 2.4057x - 4538.6 R² = 0.0533, α = 0.04, y = 0.008x - 12.72 R² = 0.1057, α = 0.00

Table 12. Percent increase in streamflow in the Central Dissected Till Plains (1925-2010)[1]

Gage Name	90th	Mean	50th	10th	Precip.
Fox River at Wayland	31	43	56	207*s*	18*s*
Grand River near Gallatin	27	38	86	142*s*	16*s*
Thompson River at Trenton	29	54	130*s*	186*s*	19*s*

[1] *s* = significant (α ≤ 0.05)

percentile flow significantly increased at Thompson River at Trenton by 130% or 314 cfs. However, the mean precipitation in these watersheds has only increased by 18, 16, and 19%, respectively, which is approximately 0.5 feet each.

The suggested increase in baseflow trends in the Central Dissected Till Plains agrees with the findings of Schilling and Libra (2003) on Iowa discharge trends. They report that the percentage of streamflow that is baseflow has increased by 20 to 30% from 1940 to 2000. Zhang and Schilling (2006) found increases in baseflow in the Upper Mississippi River of 28, 47, 59, and 134% at four different gages. The Central Dissected Till Plains in Missouri shares the same land types and land uses as much of Iowa and the upper Mississippi River valley; it makes sense that similar hydrologic trends are seen.

Like the study in Iowa, increases in precipitation do not seem to be great enough to account for the increase in discharge. It is likely there is a change in how precipitation is being routed to streams. The causes of increased baseflow proposed by Schilling and Libra (2003) and Zhang and Schilling (2006) may help to explain increased baseflow in the Central Dissected Till Plains. Some agricultural areas of the Midwest were poorly managed early in the 20th century, but over time better land management practices have been implemented. These include practices that decrease field erosion and increase infiltration. Increased infiltration results in greater groundwater recharge and more water available for low flows (Schilling and Libra, 2003). Changes in land use, such as converting untilled land to row crops, have decreased evapotranspiration and increased groundwater recharge and baseflow (Zhang and Schilling, 2006). Intensive row crop production, stream channelization, and removal of riparian vegetation have caused streams in this ecoregion to incise over time, making them more likely to intersect groundwater, increasing baseflow levels (Schilling and Libra, 2003).

The gages in the Ozark Highlands have not increased as much as in the Central Dissected Till Plains, and only a few relationships were significant ($\alpha \leq 0.05$) (Figures 10a-c). The gages at Bourbeuse River at Union, Jacks Fork at Eminence, and Spring River at Waco have the greatest increases, which range from 29 to 49% (Table 13). The precipitation increases at these gages were not significant. The Ozark Highlands does not have nearly as much agriculture as the Central Dissected Till Plains, an average of 40% compared to 74% in the watersheds of this study. Therefore, changes in land use and farming practices will have less of an effect on baseflow in this ecoregion. Additionally, streamflow is augmented in the Ozark Highlands by groundwater flows to the surface (Vandike, 1996), so baseflow levels are higher, leaving less room for observable increases. Tomer and Schilling (2009) found that in the Midwest land use changes were the dominate drivers behind streamflow increases until the 1970s, when land use change declined and changes in climate became more dominate.

While increases in discharge over time are shown, much variability is due to annual precipitation variations and drought periods. In most of the long-term gages, low discharge values are seen in decades that experienced low precipitation and drought conditions. During the 1930s, 1950s, 1980s, and 2000s, areas of the U.S., including Missouri, experienced severe drought conditions (Hu *et al.*, 2005; Mehta *et al.*, 2010). Evidence of this is seen in the Central Dissected Till Plains and in the western gage of the Ozark Highlands (7186000), where more agriculture is seen. Agricultural practices create a demand for water that intensifies drought conditions (Ritschard and Tsao, 1978).

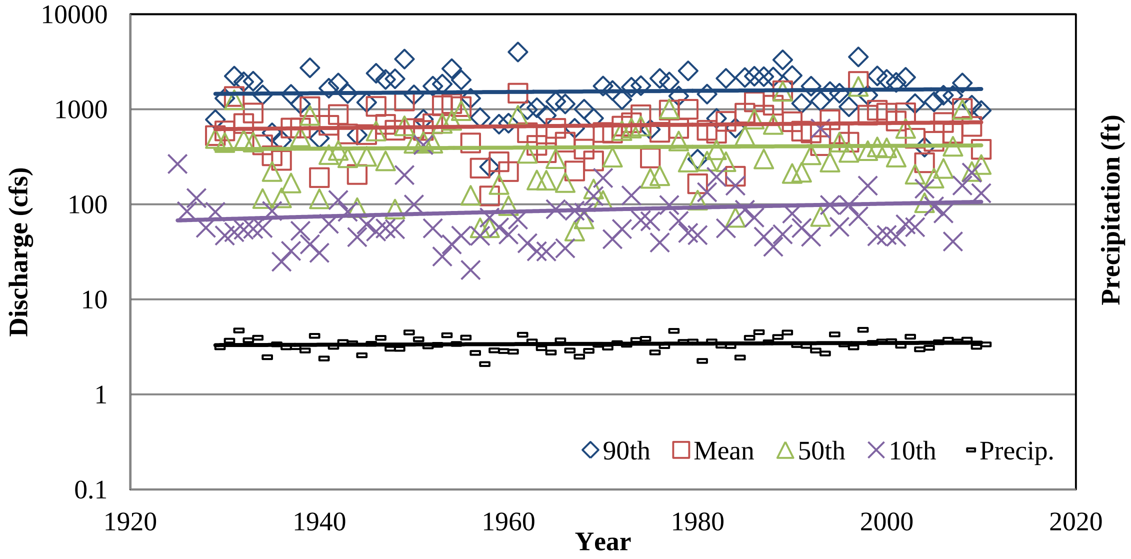


Figure 10a. In-channel flows and precipitation for Bourbeuse R at Union, 7016500 (1925-2010) in Ozark Highlands. Relationships are as follows: y = 2.2082x - 2808.1 R² = 0.0048, α = 0.24, y = 1.3815x - 2047.4 R² = 0.0091, α = 0.15, y = 0.4492x - 486.16 R² = 0.0011, α = 0.31, y = 0.4524x - 803.09 R² = 0.0181, α = 0.22, y = 0.0025x - 1.5097 R² = 0.0105, α = 0.10

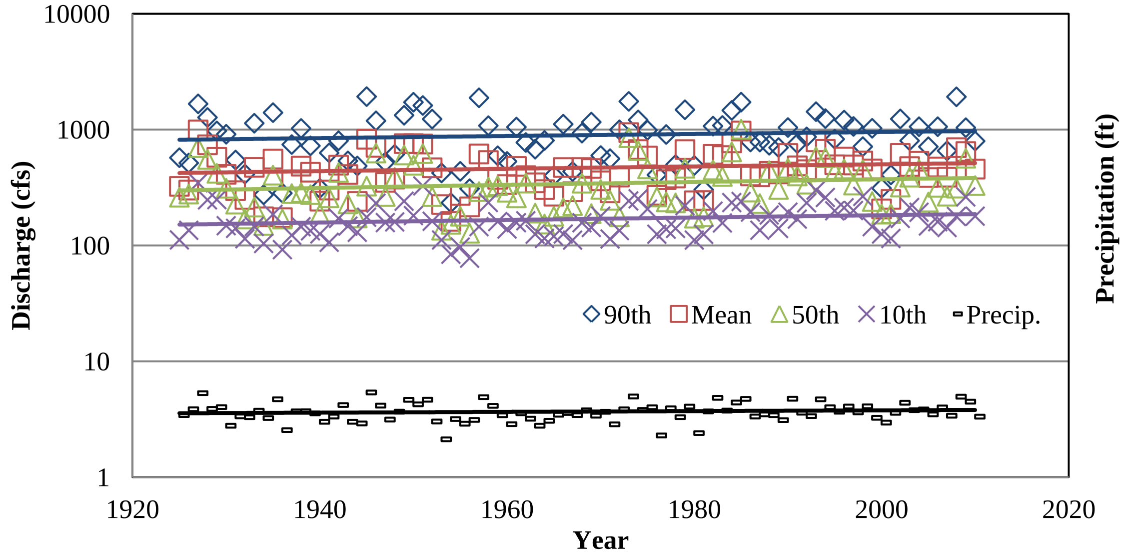


Figure 10b. In-channel flows and precipitation for Jacks Fork at Eminence, 07066000 (1925-2010) in Ozark Highlands. Relationships are as follows: y = 1.8229x - 2692.7 R² = 0.0116, α = 0.32, y = 1.064x - 1626.3 R² = 0.0197, α = 0.20, y = 0.9876x - 1602.5 R² = 0.0218, α = 0.17, y = 0.413x - 643.67 R² = 0.0352, α = 0.08, y = 0.0028x - 1.9114 R² = 0.0111, α = 0.34

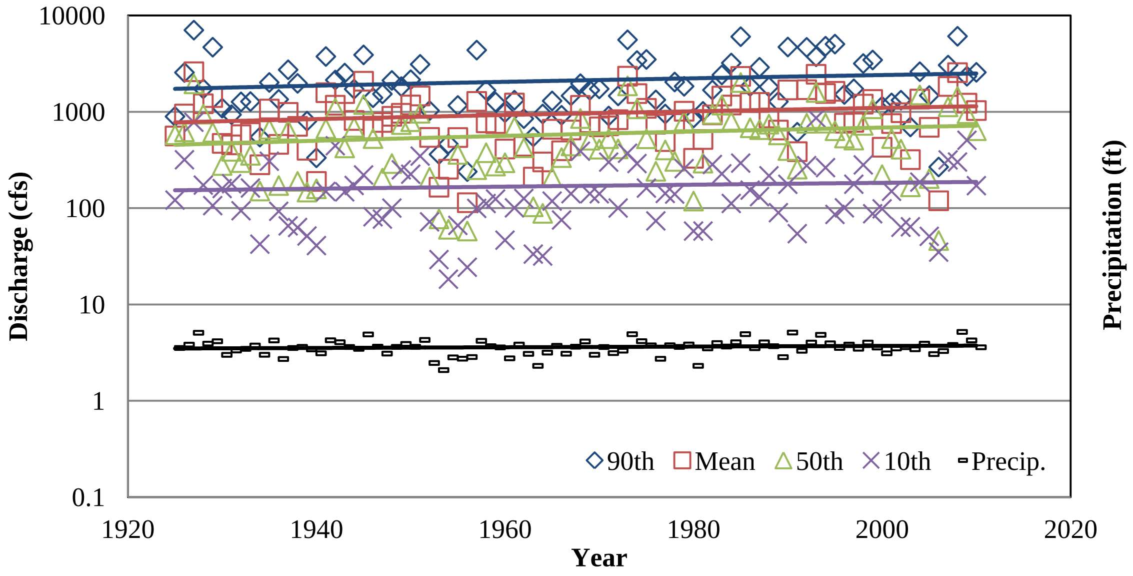


Figure 10c.In-channel flows and precipitation for Spring River near Waco, 07186000 (1925-2010) in Ozark Highlands. Relationships are as follows: $y = 8.9913x - 15577$ $R^2 = 0.0234$, $\alpha = 0.16$, $y = 4.2879x - 7478.4$ $R^2 = 0.0346$, $\alpha = 0.09$, $y = 3.0845x - 5483.7$ $R^2 = 0.032$, 0.10, $y = 0.3999x - 616.8$ $R^2 = 0.0048$, 0.53, $y = 0.0029x - 2.1088$ $R^2 = 0.0133$, $\alpha = 0.29$

Table 13. Percent increases in streamflow in the Ozark Highlands (1925 to 2010) [1]

Gage Name	90th	Mean	50th	10th	Precip.
Bourbeuse River at Union	31	35	35	49	12
Jacks Fork at Eminence	32	32	33	28*s*	8
Spring River at Waco	46	46	43	29	7

[1] *s* = significant ($\alpha \le 0.05$)

Rainfall-Runoff Relationships

The amount of rainfall that becomes runoff is an important indicator for streamflow relationships. It aids in understanding how much rainfall is lost to evapotranspiration or to groundwater recharge. The average percentage of precipitation that becomes runoff for the state of Missouri is about 26% (Vandike, 1996). The amount of precipitation is very similar in the two ecoregions, an average of 41 inches per year for watersheds in the Central Dissected Till Plains and 43 inches in the Ozark Highlands. However, the percentage of precipitation that becomes discharge is different. In the Central Dissected Till Plains, the average amount of precipitation each year that becomes discharge is 28%. In the Ozark Highlands, the average amount of precipitation each year that becomes discharge is 35%. Therefore, 72% of precipitation in the Central Dissected Till Plains is lost to evapotranspiration and groundwater storage and 65% of precipitation in the Ozark Highlands is lost.

This difference in how much precipitation is directly routed to streams reflects the variation in geology and terrain between the two ecoregions and accounts for some of the differences seen in the discharge-drainage area relationships. In the Ozark Highlands, some of what appears to be surface water runoff is coming from groundwater sources. Losing streams and sinkholes capture water, and route it underground, until eventually it may be returned to streams via springs (Vandike, 1996). The average slope is much lower in the Central Dissected Till Plains than in the Ozark Highlands, causing more precipitation to be able to infiltrate through soil to groundwater storage (Brook *et al.*, 2003). Conversely, the average slope is higher in the Ozark Highlands, causing more precipitation to runoff the surface.

The relationship of runoff percentage to slope is fairly constant for the Central Dissected Till Plains. Neither the percentage of runoff, nor mean slope varies much in the Central Dissected Till Plains. However, in the Ozark Highlands, the percentage of rainfall becoming runoff is more variable. As expected, the trend line indicates a positive relationship with slope (Figure 11). The steep slopes will increase runoff and low slopes will have more infiltration and less runoff (Brooks *et al.*, 2003). In both ecoregions, it seems that the lower slopes have less of an effect on percentage of runoff. It appears that there may be a breaking point somewhere around 6% slope increase, above which slope and runoff have a stronger relationship.

The long-term gages exhibit significant relationships between mean annual discharge and mean annual precipitation ($\alpha \leq 0.00$) (Figures 12a-f). As expected, all relationships are positive, more rainfall results in more discharge. However, precipitation is not a significant variable in the 30-year discharge-drainage area models. When using 30-year average values (1981-2010), much of the variation in precipitation is removed. The coefficient of variation for 30-year mean precipitation for the Central Dissected Till Plains is only 3% and for the Ozark Highlands is only 7%.

For some long-term gages the percentage of rainfall which becomes runoff is increasing (Figures 13a-f). Only two gages exhibit a significant increase, Thompson River at Trenton and Spring River near Waco (Figures 13c and 13f) and one gage a nearly significant increase, Fox River at Wayland (Figure 13a). Fox River at Wayland and Thompson River at Trenton are in the Central Dissected Till Plains and have

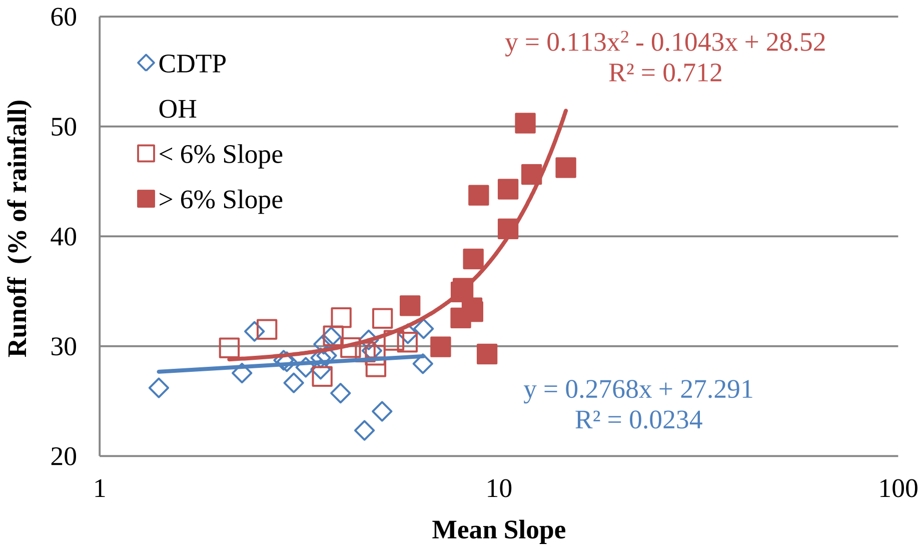


Figure 11. Runoff percentage and mean slope relationship (1981-2010) for both ecoregions

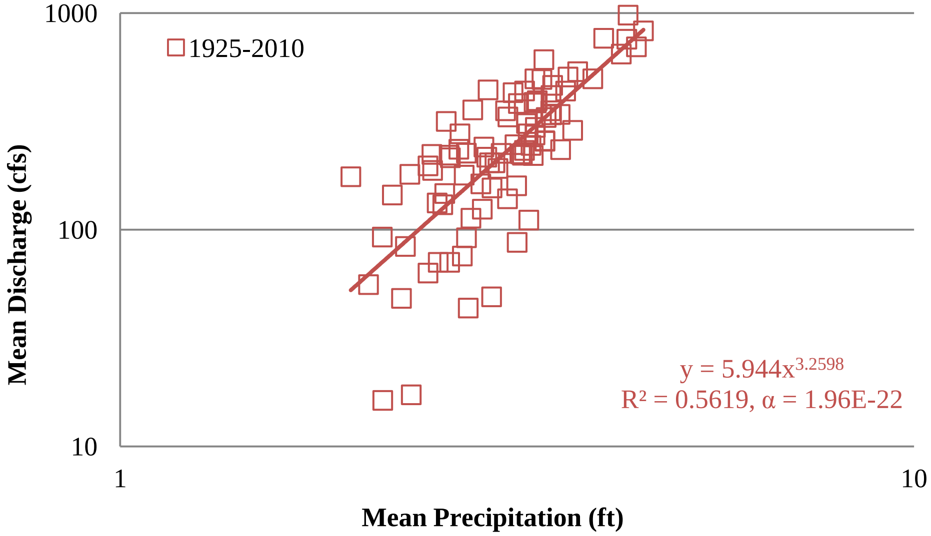


Figure 12a. Discharge and precipitation relationship for Fox River at Wayland (1925-2010) in Central Dissected Till Plains

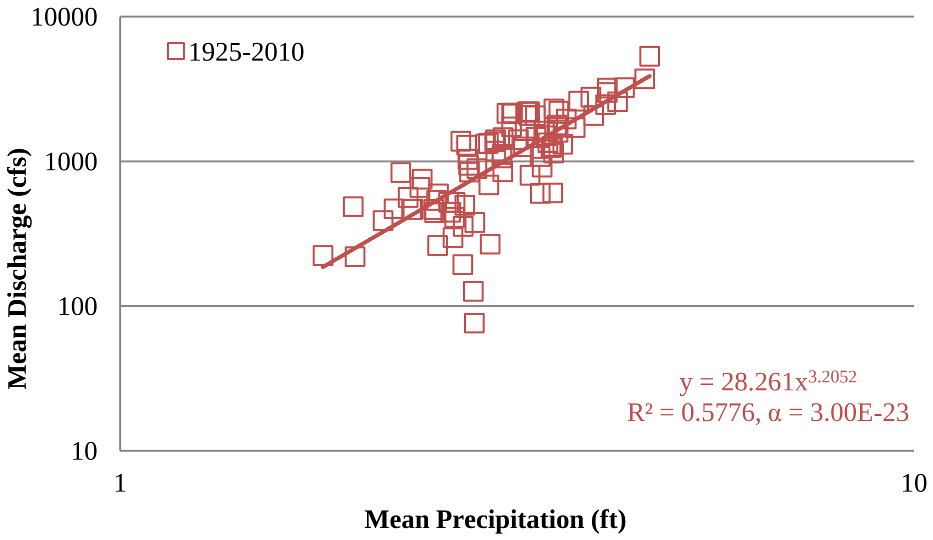


Figure 12b. Discharge and precipitation relationship for Grand River near Gallatin (1925-2010) in Central Dissected Till Plains

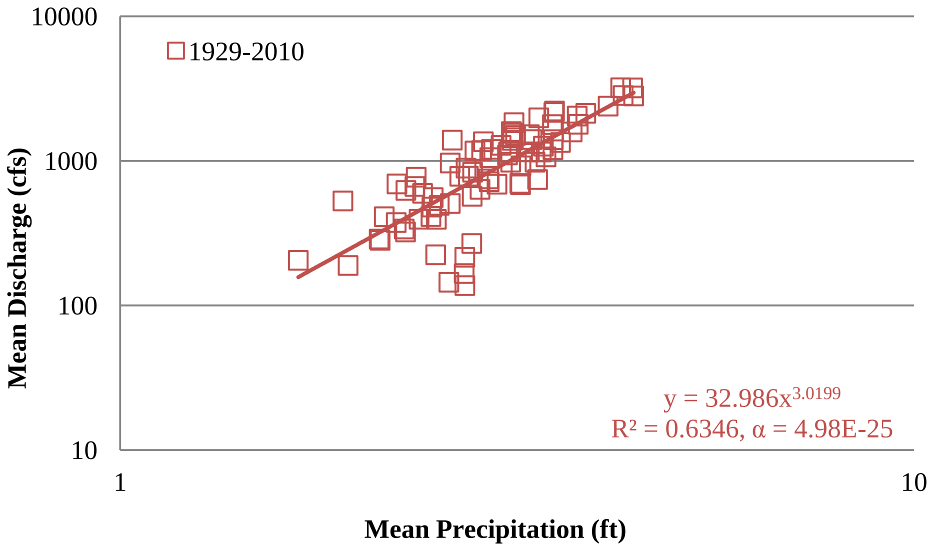


Figure 12c. Discharge and precipitation relationship for Thompson River at Trenton (1929-2010) in Central Dissected Till Plains

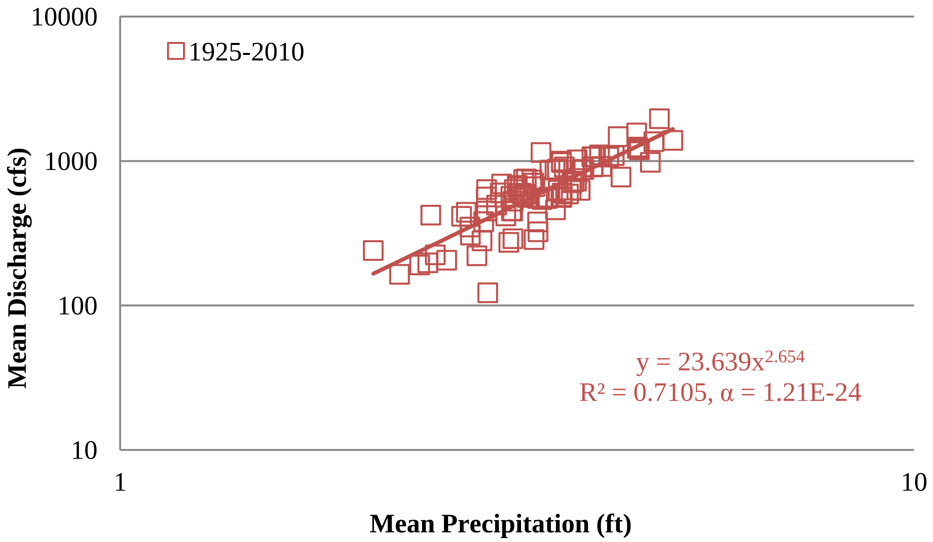


Figure 12d. Discharge and precipitation relationship for Bourbeuse River at Union (1925-2010) in Ozark Highlands

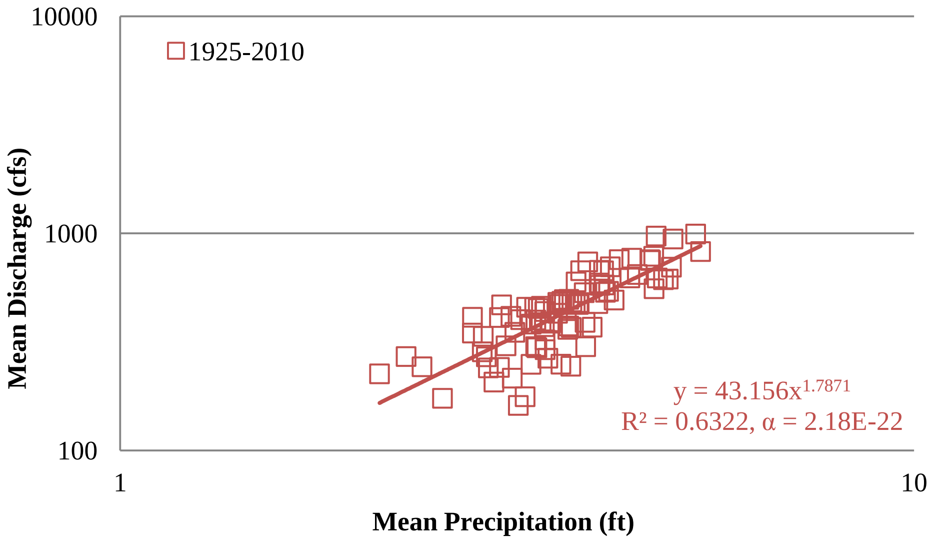


Figure 12e. Discharge and precipitation relationship for Jacks Fort at Eminence (1925-2010) in Ozark Highlands

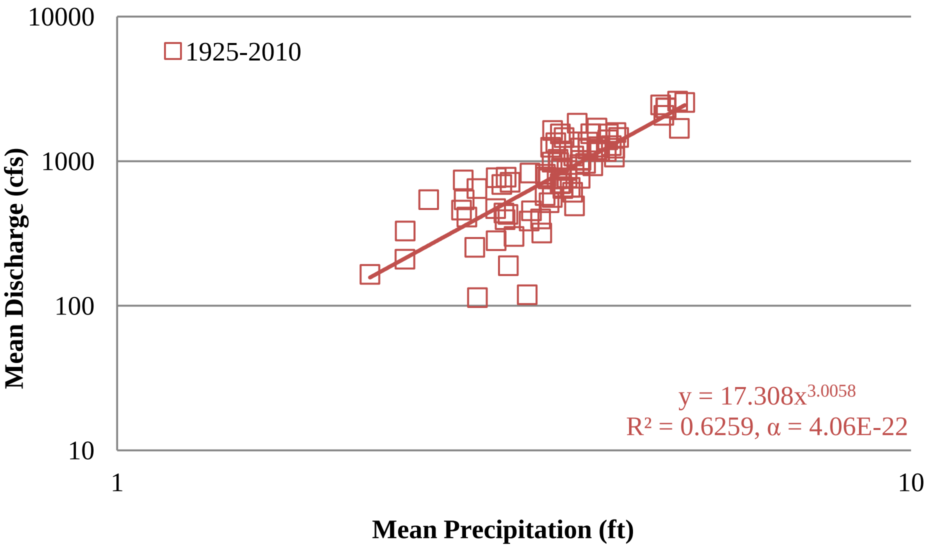


Figure 12f. Discharge and precipitation relationship for Spring River near Waco (1925-2010) in Ozark Highlands

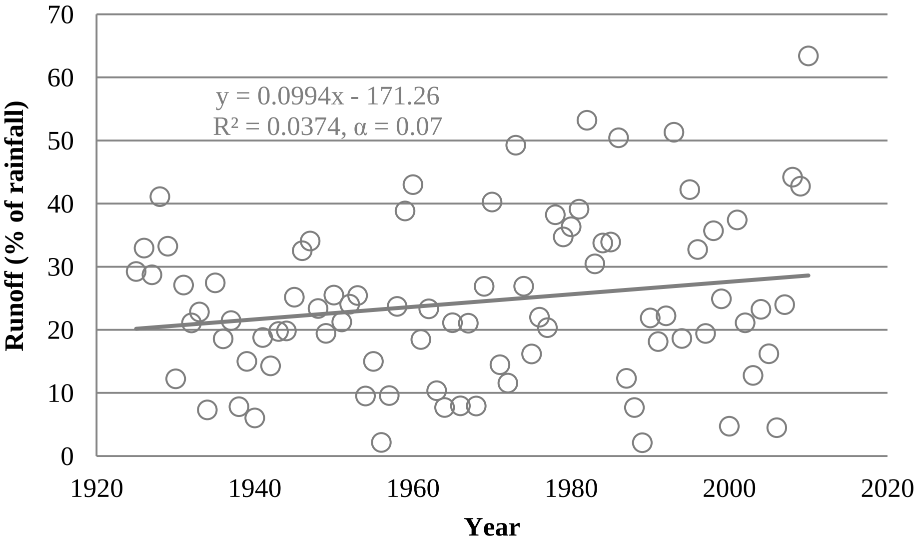


Figure 13a. Runoff percentage for Fox River at Wayland (1925-2010) in Central Dissected Till Plains

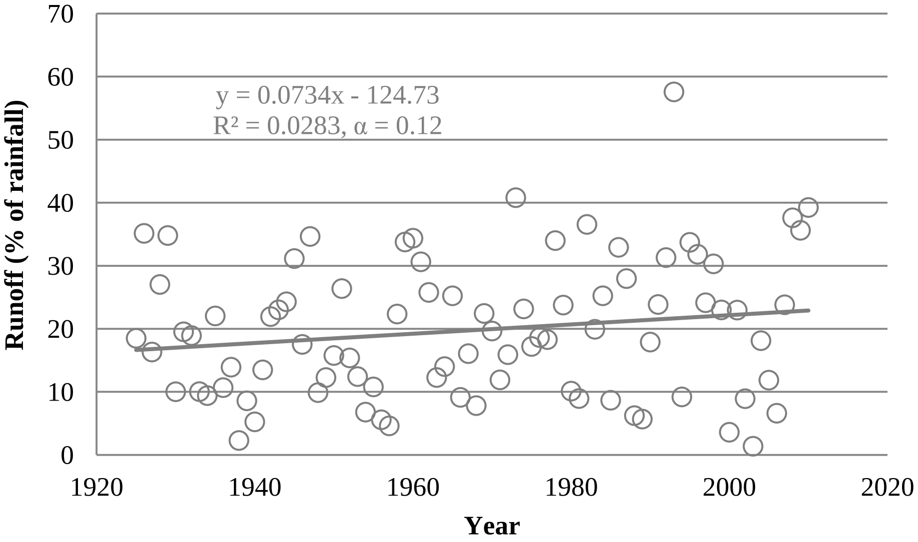


Figure 13b. Runoff percentage for Grand River near Gallatin (1925-2010) in Central Dissected Till Plains

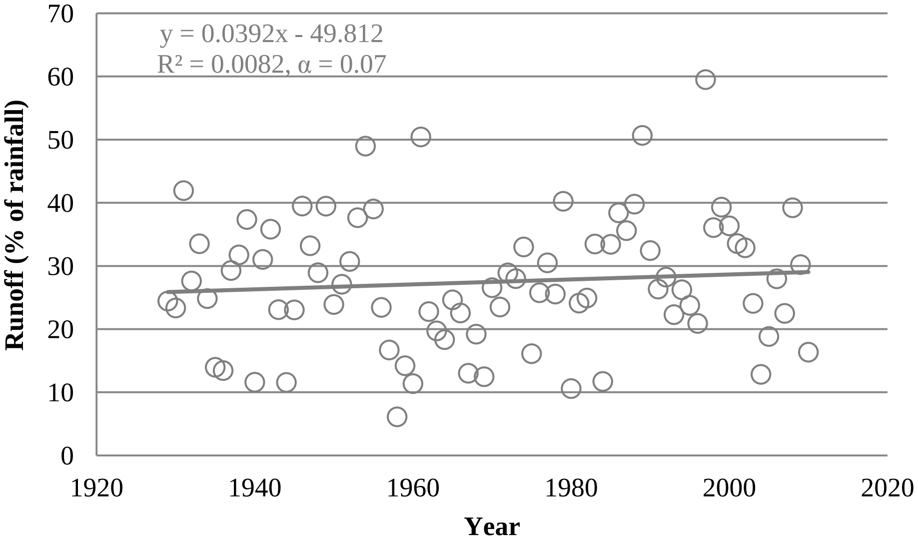


Figure 13c. Runoff percentage for Thompson River at Trenton (1929-2010) in Central Dissected Till Plains

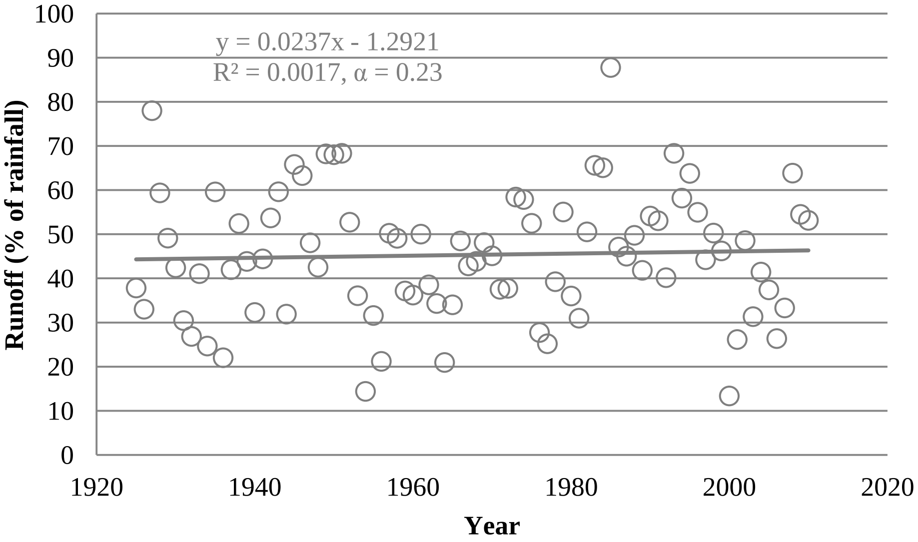


Figure 13d. Runoff percentage for Bourbeuse River at Union (1925-2010) in Ozark Highlands

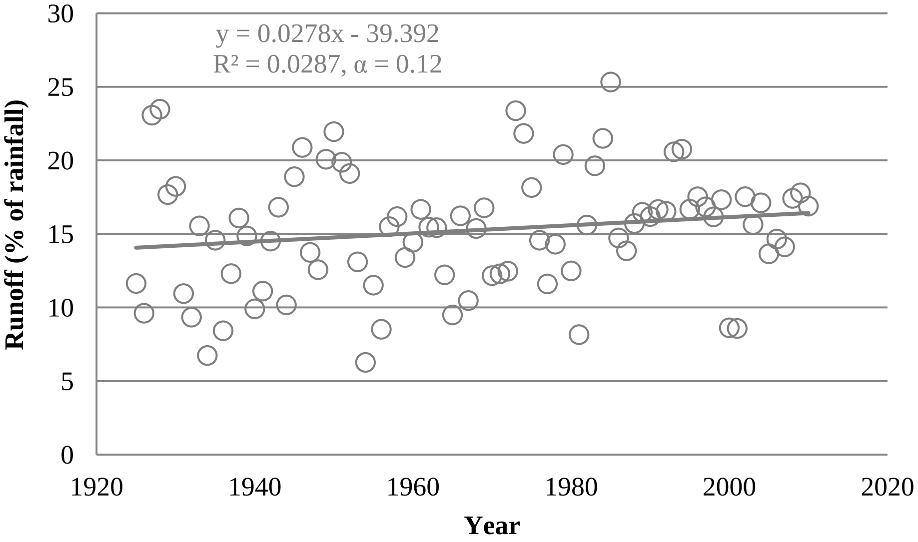


Figure 13e. Runoff percentage for Jacks Fork at Eminence (1925-2010) in Ozark Highlands

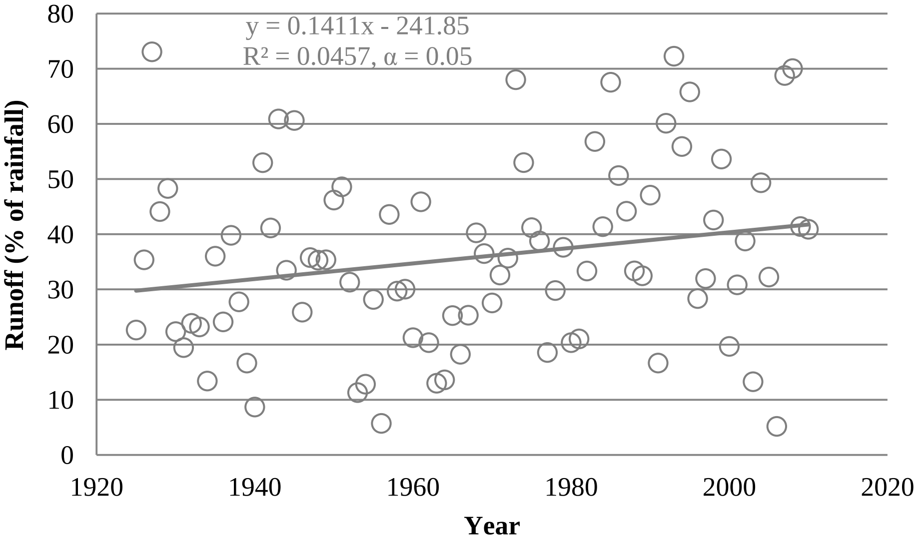


Figure 13f. Runoff percentage for Spring River near Waco (1925-2010) in Ozark Highlands

percentages of agriculture greater than 70%. Spring River near Waco is in the Ozark Highlands, but has a high percentage of agriculture, 79%. Historical changes in agricultural practices have resulted in increased discharge (Schilling and Libra, 2003), reflected by the increase in runoff percentage. Fox River at Wayland and Thompson River at Trenton both have significant increasing trends in precipitation as well, which may partially account for this increase.

Implications

The results of this study can be useful for tools in estimating streamflow at ungaged locations. These estimations are applicable to water supply analysis, aquatic habitat management, and water quality assessment. Discharge-drainage area equations are an easy way to estimate in-channel flows (Riggs, 1982), especially useful for estimating the 90th percentile, mean and 50th percentile flows in this study. Specific discharge ratios can be used to quickly estimate discharge for watersheds of different drainage areas (Emerson *et al.*, 2005).

The differences in discharge between the Central Dissected Till Plains and the Ozark Highlands prove that it is important to consider regional characteristics. The variations in geology, terrain, and land use help to explain the differences in streamflow between the two ecoregions. The Central Dissected Till Plains contain relatively low-sloped and highly agricultural watersheds (Nigh and Schroeder, 2002). Demand for water is increased by intensive farming. The result is less baseflow and larger peak flows in large watersheds. Conversely, the Ozark Highlands contains high-sloped watersheds with mostly forested land and only some agriculture (Nigh and Schroeder, 2002). The karst geology allows groundwater to easily flow into surface water (Vandike, 1996). The result is more baseflow and lower peak flows in large watersheds.

Variations in climate as well as land use are important in predicting streamflow changes. It is not likely that changes in discharge can be attributed to land use or climate variation alone (Tomer and Schilling, 2009). The separate effects of climate and land use changes on streamflow can be difficult to pinpoint (Garbrecht *et al*, 2004). Some studies in the Midwest have shown that climate and land use changes have a synergistic effect on each other, that the effects of climate and land use combined are greater than their individual effects (Hu *et al.*, 2005). If precipitation amounts change, it will depend on land use changes to determine the magnitude of its influence on discharge in Missouri.

The results of this study indicates a slight increase (1.7-2.4% per year) in baseflow in the Central Dissected Till Plains. However, a more detailed time series analysis should be done before concluding that there have been significant changes in streamflow and to understand their causes. Streamflow seems to have remained stable for most flow percentiles in both ecoregions. This temporal stability creates more confidence in using the 30-year discharge-drainage area models to predict streamflow at ungaged locations as indicated by drainage area explaining greater than 90% of in-channel flow variability.

The discharge relationships presented here can be further analyzed for temporal trends over shorter than one year periods. Often climatic variables, including streamflow, are examined for seasonal trends (Novotny and Stefan, 2007). The seasonal effect of Missouri’s climate on streamflow should also be examined. Many studies look for decadal variations (Garbrecht *et al.*, 2004). Some studies on streamflow have used atmospheric oscillations to analyze seasonal, decadal, and multi-decadal relationships (Fu *et al.*, 2010; Regonda *et al.*, 2004). Though climate and land use have had an effect on Missouri's streamflow trends, more analysis could be done to assess the magnitude of effect.

CONCLUSION

Drainage area explains the majority ($r^2 \geq 0.9$) of discharge variation in the 90th percentile, mean, 50th percentile, and 10th percentile flows in both the Central Dissected Till Plains and the Ozark Highlands ecoregions of Missouri ($\alpha \leq 0.05$). With such a high degree of explained variance, it is statistically difficult to find additional variables to correlate with flow trends in a significant manner in multivariate regression models. Adding percent of mean slope and urbanized land variables improves the models for most in-channel flows in the Ozark Highlands. This effect was not found in the Central Dissected Till Plains, since these variables do not range in value for the sample watersheds to drive the models. Adding percent of forested or agricultural land to the model has little additional effect on both ecoregions. Indeed, in the Ozark Highlands, slope was autocorrelated with both forest and agricultural area due to land use-relief relationships.

Specific discharge is scale independent for all in-channel flows evaluated in this study. However, the specific 2-year flood discharge decreased with increasing drainage areas. Peak flows are minimized in large drainage areas by increased floodplain storage and infiltration. For the mean, 50th, and 10th percentile flows, there is more discharge per square mile for the Ozark Highlands, due to groundwater additions to streamflow as controlled by karst drainage, forest hydrology, and topography.

The greatest differences between the two ecoregions are in the 2-year flood and the 10th percentile flow, the two extremes of discharge in this study. The Ozark Highlands has the largest predicted 2-year flood discharges for smaller watersheds

(Figure 7a). The Central Dissected Till Plains has the largest 2-year flood discharges for large drainage areas, by 3,000 cfs for a watershed of 2,000 square miles. The Ozark Highlands has greater stream discharge in the mean, 50th percentile, and 10th percentile flows than the Central Dissected Till Plains, with almost twice as much predicted for the 10th percentile flow. Mean annual precipitation for the Central Dissected Till Plains and the Ozark Highlands ecoregions are very similar, 41 and 43 inches per year, respectively. However, the percentage of precipitation which becomes runoff is greater in the Ozark Highlands.

Differences in geology, relief, and land use account for the differences in streamflow between the two ecoregions contrasting karst and glacial terrains. The bedrock is more permeable in the Ozark Highlands allowing groundwater inflows to augment baseflow. This groundwater inflow may also contribute to the fact that there is more runoff in this ecoregion (Vandike, 1996). The average watershed slope is different between the two ecoregions. The Central Dissected Till Plains is more gently sloped than the Ozark Highlands, which affects the amount of surface runoff produced. The gentler slopes allow more time for rainfall to infiltrate through soils, decreasing runoff. The difference in terrain leads to differences in land use. The Central Dissected Till Plains is heavily agricultural, and the Ozark Highlands is more forested with some agriculture and grassland.

This study suggests that baseflow in the Central Dissected Till Plains has increased from 1925 to 2010, by an average of about 180% for the 3 long-term gages, approximately 2% per year. This increase is greater than the observed increase in precipitation, an average of 18%. As Schilling and Libra (2003) found in Iowa and Zhang and Schilling (2006) found on the Mississippi River, the increase in baseflow is likely a result of: (1) improved conservation practices, which decrease runoff and increase infiltration, (2) increased row crop production in agricultural areas, which decreases evapotranspiration, and (3) increased channel incision by fluvial or human forces, increasing channel depth below the groundwater table, resulting in high baseflow contribution.

Climate changes as well as land use changes account for increases in streamflow throughout the Midwest in the 20th century (Tomer and Schilling, 2009). Since 1925, annual precipitation rates have increased in the Central Dissected Till Plains and in the Ozark Highlands. The effects of climate and land use changes on streamflow can be difficult to separate (Tomer and Schilling, 2009). Some studies in the Midwest have shown that climate and land use changes have a synergistic effect on each other, that the effects of climate and land use combined are greater than their individual effects (Hu *et al.*, 2005). If precipitation amounts change, it will depend on land use changes to determine the magnitude of its influence on discharge in Missouri.

The relationships presented in this study can be useful for future studies. They can be used as a baseline for future hydrological analyses to investigate Missouri flow trends. The models can be used to predict flow frequency relationships at ungaged streams to evaluate habitat and pollutant loads. The relationships can also be used to relate watershed resources to land use and climate change effects. Further, this study could be extended to look for trends at different time scales, such as seasonal or decadal, and linked to atmospheric oscillations. The applicability of the models can be tested at ungaged locations. While the 2-year flood peak was included in this study, a more specific study of different flood frequencies and maximum flood occurrence could yield important information for hazard mitigation, climate change, and geomorphology.

Water is one of the most important resources we have. We use our water for drinking, agriculture, hydroelectric power, recreation, and industry. It has been predicted that, especially as populations and industrialization increase, water will be to the 21st century what oil was to the 20th century, a precious commodity that will determine the wealth of nations (Gruen, 2008). Whether or not this proves to be true, water supply will always be a vital concern.

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APPENDICES

Appendix A. USGS Gage Records

Appendix A-1. Gage records for the Central Dissected Till Plains for 1981-2010 (mean annual discharge, cfs)

	USGS Gage ID						
Year	5495000	5496000	5501000	5502000	5502300	5503800	5506800
1981	507	545.2	366.2	34.5	424.4	87.5	234.2
1982	764.9	725.4	663	45.1	642.5	94	280.4
1983	331.5	330.6	380.3	26.6	309.8	58.8	208.1
1984	416.5	526.5	402.2	27.4	441.6	75.9	241.3
1985	436.5	511.4	616.6	49.7	481.3	118.9	338.7
1986	609.5	727.4	402.2	20.2	416.9	74.8	222.8
1987	124.4	144.4	178.9	15.7	136.5	32.5	67.6
1988	55.8	81.6	61.7	7.97	37.6	7.28	27.5
1989	17.3	13.8	21.9	5.4	35.6	7.39	47
1990	287.5	247	355.5	24.8	199.7	81.4	192.3
1991	191.8	214.6	318.8	27	271.3	67.1	99.2
1992	246.9	254.3	175.1	18.2	291	34.6	80.8
1993	827.7	742.8	640.4	57.3	648.9	176.2	376.2
1994	178.6	204	214.7	19.9	133.2	49.3	155.8
1995	497.1	522.3	367	30.2	472.1	87.5	232.5
1996	353.9	370.5	197.8	14.2	264.5	72.6	81.5
1997	203.6	224.8	233.4	18	274.8	48.2	138.9
1998	497.2	568.2	479.2	37.1	607.1	115.9	312.4
1999	235.2	248.8	267.9	20.1	258.2	57.7	227.1
2000	49	63.7	26.5	7.09	32.9	12.2	54.8
2001	463.8	468.1	214.6	21.5	260.7	63.8	201.2
2002	216.2	286.6	299.2	25.9	294.7	55.2	138.9
2003	138.9	168	110.3	12.6	124.4	26.7	148
2004	273.8	286.5	311.1	22.8	209.6	52.5	203.3

	USGS Gage ID						
Year	5495000	5496000	5501000	5502000	5502300	5503800	5506800
2005	146.9	171.5	144.6	14.1	175	29.1	113.5
2006	43.5	40.6	49.1	5.23	58.2	20.6	104
2007	277	210.3	182.5	16.6	181.4	45.4	159.5
2008	698.5	585.4	699.2	67.5	791.9	169.5	463.3
2009	646.8	690.3	568.3	48.4	613.2	107.7	288.9
2010	978.3	874.7	583.5	57.8	667.9	106.1	351.9

	USGS Gage ID						
Year	5507600	5507800	5508000	5508805	5514500	6820500	6821150
1981	70.1	2428	2587	255.8	737.9	453.4	215.2
1982	138.7	3321	3560	256.7	1478	2734	154
1983	84.4	1615	1726	221.9	825.3	1058	194
1984	103.3	2458	2579	219.6	788.9	1647	208.5
1985	127.4	3606	3836	299.9	1274	663.3	327.6
1986	43.2	2412	2509	118.5	487.5	1988	189.5
1987	33.5	835.3	901.9	113.3	385.5	1246	133.8
1988	28.5	616.8	631.7	68.7	389.4	166.8	29.9
1989	25.3	357.9	387.5	36	201.8	332.7	39.3
1990	57.1	1965	2072	145.7	813.4	840.3	183.8
1991	82.2	1571	1734	193.5	503	721.4	83.5
1992	46.1	1175	1225	126.2	460.4	1547	286
1993	186.9	4457	4596	355.2	2171	3800	501.8
1994	64.7	1548	1646	115.3	775.6	475	116.5
1995	82.2	2696	2833	166.1	1137	1589	126.7
1996	60.1	1441	1535	142.8	610.1	1502	143.6
1997	61.1	1529	1637	105.6	393.2	1024	110
1998	120.1	3122	3292	186.4	1010	1786	294.7
1999	66.6	2099	2223	163.8	624.8	1087	181.7

	USGS Gage ID						
Year	5507600	5507800	5508000	5508805	5514500	6820500	6821150
2000	22.3	396.9	416.2	33.7	307.2	292.4	30.7
2001	98.5	1949	2028	133	720.5	1454	299.2
2002	85.8	1812	2029	169.4	860.5	271.5	74.4
2003	54.9	886	938.8	109.4	698.1	143.3	10.9
2004	97.1	2028	2107	161.6	857.8	1015	128
2005	55.1	1305	1352	98.1	543.7	788.9	170.5
2006	14	501	489.9	20.8	193.6	500.9	45.1
2007	28.2	1275	1291	54.7	242	1678	111.3
2008	216.2	4949	5296	361.3	1453	2050	278.2
2009	174.1	3716	4058	307.6	1495	1787	345
2010	190.3	3988	4282	333.5	986	2355	305.3

	USGS Gage ID					
Year	6897500	6904050	6904500	6905500	6906200	6906300
1981	601.4	751.1	1319	2172	133	285.9
1982	2987	1487	2274	3243	150.2	315.5
1983	1178	886.1	1323	1863	113.2	215.6
1984	1625	701.5	1228	1777	169.8	267.9
1985	604.6	570.2	1154	1938	159.1	322.4
1986	2304	1076	1756	2311	139.2	267.7
1987	1731	589	910.2	1173	40.1	96.3
1988	223.1	129.7	220.6	269.1	18.4	32
1989	296.8	68	111.3	165.8	7.24	17.9
1990	1242	608.2	1049	1204	61.7	147.9
1991	1410	653.1	1078	1355	78.6	125.4
1992	2222	894.5	1368	1656	83.9	138.9
1993	5320	1836	3183	4129	234	450.5
1994	497.1	281.7	441.2	684	53.4	131.6

	USGS Gage ID					
Year	6897500	6904050	6904500	6905500	6906200	6906300
1995	2199	703	1178	1822	151.8	271.2
1996	2073	613.8	1087	1468	86.7	145.4
1997	1458	534.4	911.6	1249	80.4	132.6
1998	2464	1054	1901	2505	172.6	294
1999	1320	607.2	972.9	1241	95.6	180
2000	193.1	75.2	104.4	161.2	9.28	28.8
2001	1710	796.2	1495	1747	61.9	144.7
2002	441.4	271.5	581.3	941.7	88.5	181.7
2003	76.2	82.3	162.4	283.5	8.56	60.2
2004	1263	467.8	947.9	1153	75.6	205.2
2005	686.9	279.6	533	800.6	60	129
2006	355.5	47.6	116.4	241.1	13.9	55.2
2007	1621	759.6	1253	1493	63.9	119.9
2008	3230	1691	3005	4264	201.9	517
2009	2775	1117	1830	2631	158.9	354.6
2010	3207	2187	3526	4291	167.6	379.3

Appendix A-2. Gage records for the Ozark Highlands for 1981-2010 (mean annual discharge, cfs)

	USGS Gage ID						
Year	6918440	6918460	6918740	6919020	6919500	6919900	6921070
1981	92.9	115.2	126.5	381.2	268.3	648.2	170.2
1982	236.3	284.2	206.6	1184	332.9	1529	271.2
1983	275.1	318.1	254.4	1417	449.9	1978	322.6
1984	315	352.9	338.7	1564	457.5	2133	402.7
1985	463.1	521.8	474.9	2228	785.2	3401	607.5
1986	209.7	264.2	174.1	1240	530.2	2524	300.7
1987	284.2	310.6	306.2	1272	432.4	1852	303.5
1988	251.7	251.2	242.4	1398	284.8	1815	260.6

	USGS Gage ID						
Year	6918440	6918460	6918740	6919020	6919500	6919900	6921070
1989	187.7	203.5	179	971	294.1	1378	181.6
1990	403.1	418.7	339.9	1760	450.1	2346	414.4
1991	167.7	161.8	202.1	620.5	71.6	766.5	248.4
1992	285.2	336	244.1	1102	501	1819	228.4
1993	505.4	546.5	441.1	2567	605.2	3520	510.7
1994	399.3	385.2	336.3	1704	457.4	2498	416.7
1995	310.7	331.4	297.4	1583	515.8	2387	388.3
1996	237.4	224	222.5	936.2	259.9	1362	339.7
1997	163	166.3	162.2	834.4	300.1	1315	185.4
1998	228.8	271.6	233.5	1069	481.5	1692	297.7
1999	304.9	306.3	265.9	1331	485.4	1955	315.9
2000	56.4	101.3	63.8	444.7	92.6	563.6	71.9
2001	144.1	166.5	151	604.6	242.2	995.1	197.1
2002	281.4	269.4	207.1	1089	272.2	1568	257.9
2003	91.9	115.9	109.8	377	155.4	585.5	116.3
2004	250.4	283.1	226.2	1010	451.7	1581	273
2005	167.2	177.9	167.8	1234	193.9	1568	203
2006	57.6	56.6	61.3	80	7.41	92.2	62
2007	304.3	334.1	308.4	1360	391	1953	315.9
2008	523.8	460.4	500.7	2398	652.6	3421	557.1
2009	300.5	288.7	253.6	1445	494.9	2133	327.2
2010	272.9	275.1	227.2	1453	386.4	2078	261.6

	USGS Gage ID						
Year	6921200	6921350	6932000	6933500	7013000	7014500	7016500
1981	66.3	348.5	145.7	1700	478.6	1111	909
1982	112.9	535.3	281.1	3424	1056	2134	1196
1983	137.1	689.5	246.6	3701	822.7	1719	867.2

	USGS Gage ID						
Year	6921200	6921350	6932000	6933500	7013000	7014500	7016500
1984	170.6	799.7	243.1	4207	820	1844	1103
1985	236.3	1263	422.2	6425	1534	3104	1565
1986	159.2	704.2	171.2	2447	473.2	1116	739.1
1987	101.8	493.5	146.3	2553	526.8	1131	588.3
1988	97	625.8	153	2679	523.9	1104	563.5
1989	56	370.3	113.7	1900	398.8	901.2	414.3
1990	166.2	773	224.6	4038	859.5	1703	774.2
1991	82	418.8	188.1	2800	602.4	1166	550.4
1992	97.2	430.2	132.3	2230	441.3	1026	450.3
1993	224.1	1081	289.4	4946	1172	2583	1963
1994	164.7	775	239.2	3527	962.9	1975	866.2
1995	141.4	707.5	228.3	3504	808.2	1700	976.2
1996	122.9	604.3	200.5	3314	750.8	1521	910
1997	74.6	398.8	195.6	2392	571.4	1500	752
1998	131.4	629.3	243.3	3101	929.3	1689	917.4
1999	125.8	619.2	154	2383	565.1	1221	495
2000	17	134.1	63	613.9	167.3	360.1	273.5
2001	85.1	424.2	116.5	1410	329.3	691.7	459.6
2002	123.3	615.6	239.3	2982	754.7	1504	725.2
2003	43.3	200.9	130.3	1728	465.3	1026	558.7
2004	122.2	590.8	167.2	2441	512.2	1079	1019
2005	88.1	489.8	143.6	1873	445.2	998.5	659.9
2006	25.7	92.9	103	1476	406.2	890.7	378.7
2007	110.2	632.4	107.8	1807	417.8	858.3	453
2008	181.8	1127	320.9	4906	1095	2073	1389
2009	140.3	781.7	316.5	3624	1019	2073	1249
2010	103.7	739.7	185.3	2783	725.9	1343	872.2

	USGS Gage ID						
Year	7017200	7018500	7050700	7057500	7061500	7063000	7066000
1981	103.5	623.2	79.5	369	455.9	883.5	244.3
1982	307.8	1460	287.7	770.6	1038	1864	611.6
1983	251.4	1266	280.6	834.7	815.8	2021	597.2
1984	268.3	1223	343.6	1005	846.8	1649	768.5
1985	422.5	1959	442	1527	1400	2702	971.8
1986	125.4	670.3	148.8	648	447.9	1322	398.6
1987	115	643.3	261.4	582.6	514	919.8	391.4
1988	157.9	736.2	281.1	721.2	519.4	1226	436.4
1989	133.3	674.8	180.6	756.8	494	1299	414.7
1990	265.7	1290	408.3	935.1	905.9	1726	622.8
1991	143.9	705.4	293.1	853.1	569.7	1602	486.4
1992	115.4	609.2	194.4	713.4	492.6	1152	450.7
1993	367.2	2122	486.1	1298	1005	1761	784.2
1994	207.9	1227	309.8	987.7	743	1834	675.7
1995	183.1	960.2	339.2	822.5	588.6	1286	496.7
1996	259.9	990.9	228.7	779.4	773.1	1658	578.4
1997	198.9	1008	152.4	761	663	1449	495
1998	207.3	1012	215.9	762.5	810.4	1700	535.3
1999	158.8	749.3	207.4	664.2	629.3	1436	456.6
2000	30.5	284.7	50.2	349.9	224.2	737.5	206.5
2001	81.6	406.1	144.3	415.8	363.5	865.1	249.6
2002	288.9	970.3	237.9	909.1	880.9	2116	623.3
2003	148.3	820.4	121.2	524.7	493.3	1281	479.8
2004	152.8	898.5	240	728.3	531.3	1277	532.9
2005	138.4	760	155.1	604.3	455.3	1063	385.6
2006	155.7	639.4	79.4	634.2	475.6	1339	474.7
2007	121.1	518.1	200.9	579.9	486.4	1411	388
2008	317.9	1374	570.3	1063	782.9	2216	698.7
2009	318.2	1337	326.1	799.2	933.5	2123	646.4

	USGS Gage ID						
Year	7017200	7018500	7050700	7057500	7061500	7063000	7066000
2010	112.7	618.7	296.2	688.1	416.6	1138	455.6

	USGS Gage ID					
Year	7067000	7068000	7071500	7186000	7187000	7189000
1981	1081	1717	305.3	515.9	150	257
1982	2818	4271	944.8	928.5	400.5	638.4
1983	2548	3577	869.8	1456	412.7	681.8
1984	3243	4028	1177	1175	504.9	1059
1985	4376	5304	1432	2328	1013	1711
1986	2123	2652	765.9	1248	453.7	1091
1987	1735	2296	446.7	1251	429.3	989.1
1988	2034	2568	714.8	862	360.3	691.8
1989	1798	2478	820.4	646.3	249.3	681.4
1990	2738	3336	904	1686	597.3	1468
1991	2410	3192	1078	385.6	303.3	670.5
1992	2140	2680	723.4	1695	518.9	1013
1993	3252	4096	1169	2451	1101	1709
1994	2840	3798	1254	1548	664.4	1094
1995	2313	3088	847.1	1631	659.4	1213
1996	2422	3088	853.2	761	309.4	583.9
1997	2166	2865	858.7	777.4	362.3	688.5
1998	2374	3321	685.4	1200	483	796.4
1999	2066	2679	557.6	1342	514.2	976.8
2000	882.4	1488	343.5	428.3	266.8	554.2
2001	1070	1612	317.7	754.5	256.7	618.9
2002	2696	3736	1041	978.1	414.8	772.9
2003	1563	2368	556.2	318.6	211.8	351.9
2004	1934	2679	720.4	1355	511.4	905.1

	USGS Gage ID					
Year	7067000	7068000	7071500	7186000	7187000	7189000
2005	1569	2218	604.5	689.8	360.8	678.7
2006	1810	2549	707.1	119.1	156.4	264
2007	1738	2592	767.8	1831	425	577.6
2008	3027	4072	1326	2547	984.8	1646
2009	2583	3498	891.8	1229	564.9	953.6
2010	1783	2626	766.2	1030	451.8	737.1

Appendix B. Calculated Watershed and Streamflow Characteristics

Appendix B-1. Watershed and streamflow characteristics for the Central Dissected Till Plains (1981-2010)

Gage ID	Name	Ad (mi^2)	Mean Slope	Precip. (ft)	Run-off %	CV %	2-year flood	90th	Mean	50th	10th	For %	Ag %	Urb %
05495000	Fox River at Wayland	400	4.7	3.3	69	70	9,170	705	357	282	55	20	72	5
05496000	Wyaconda R above Canton	393	3.8	3.4	69	65	7,630	726	368	287	80	15	78	4
05501000	North R at Palmyra	354	3.7	3.5	71	62	18,050	619	318	305	60	22	72	5
05502000	Bear Cr at Hannibal	31	3.6	3.5	72	62	841	50	27	22	8	13	79	8
05502300	North Fork Salt R at Hagers Grove	365	3.6	3.5	71	65	12,600	643	325	273	56	12	78	6
05503800	Crooked Cr near Paris	80	2.3	3.5	72	62	3,880	116	68	61	20	10	85	5
05506800	Elk Fork Salt R near Madison	200	2.4	3.5	69	56	8,355	340	193	197	66	15	74	6
05507600	Lick Cr at Perry	104	1.4	3.5	74	64	7,000	175	84	68	28	5	98	5
05507800	Salt Cr near Center	2,350	2.9	3.5	71	59	11,400	3743	2069	1881	605	15	76	5
05508000	Salt Cr near New London	2,480	2.9	3.5	71	59	13,500	4080	2193	2029	618	15	75	5
05508805	Spencer Cr below Plum Cr near Frankford	206	3.1	3.5	73	56	11,600	310	169	154	53	22	67	5
05514500	Cuivre R near Troy	903	3.3	3.5	72	58	28,350	1456	781	729	301	24	72	5
06820500	Platte R near Agency	1,760	4.6	3.5	78	68	19,450	2081	1233	1073	290	9	82	6

Gage ID	Name	Ad (mi^2)	Mean Slope	Precip. (ft)	Run-off %	CV %	2-year flood	90th	Mean	50th	10th	For %	Ag %	Urb %
05495000	Fox River at Wayland	400	4.7	3.3	69	70	9,170	705	357	282	55	20	72	5
06821150	Little Platte at Smithville	234	4.0	3.3	74	64	4,575	308	177	162	38	10	73	8
06897500	Grand R near Gallatin	2,250	5.1	3.3	76	74	32,750	3009	1577	1434	289	16	77	5
06904050	Chariton R at Livonia	864	6.4	3.5	72	63	572	170	98	85	13	15	74	5
06904500	Chariton R at Novinger	1,370	6.5	3.2	68	71	16,850	2347	1234	1121	158	20	70	5
06905500	Chariton R near Prairie Hill	1,870	5.9	3.3	69	69	24,300	3332	1674	1481	266	25	68	5
06906200	E Fork Little Chariton R near Macon	112	3.6	3.2	70	73	4,655	1507	727	633	82	22	58	5
06906300	E Fork Little Chariton R near Huntsville	220	4.8	3.5	69	63	4,550	357	200	164	53	28	59	6

Appendix B-2. Watershed and gage characteristics for the Ozark Highlands (1981-2010)

Gage ID	Name	Ad (mi^2)	Mean Slope	Precip. (ft)	Run-off %	CV %	2-year flood	90th	Mean	50th	10th	For %	Ag %	Urb %
06918440	Sac R near Dadeville	257	4.3	3.8	70	46	6,555	409	259	262	93	21	71	8
06918460	Turnback Cr above Greenfield	252	5.1	3.8	70	43	9,160	423	277	279	116	31	66	5
06918740	Little Sac R near	237	5.5	3.8	67	44	10,750	350	244	230	125	40	47	11

Gage ID	Name	Ad (mi^2)	Mean Slope	Precip. (ft)	Run-off %	CV %	2-year flood	90th	Mean	50th	10th	For %	Ag %	Urb %
	Morrisville													
06919020	Sac R at Hwy J below Stockton	1,292	4.9	3.8	69	47	6,805	1,807	1,222	1,237	438	33	56	7
06919500	Cedar Cr near Pleasant View	420	3.6	3.7	72	47	11,750	538	377	412	149	32	62	4
06919900	Sac R near Caplinger Mills	1,810	4.6	3.8	73	47	17,500	2,612	1,782	1,817	642	34	57	6
06921070	Pomme de Terre R near Polk	276	2.6	3.8	71	43	14,700	426	294	285	165	36	56	5
06921200	Lindley Cr near Polk	112	3.8	3.8	68	44	10,165	172	117	118	55	31	74	7
06921350	Pomme de Terre R near Hermitage	615	4.9	3.8	69	44	3,010	828	603	617	334	39	53	6
06932000	Little Piney Cr at Newburg	200	8.6	3.3	71	40	7,725	292	197	187	113	71	23	5
06933500	Gasconade R at Jerome	2,840	8.0	3.5	67	42	33,600	4,277	2,897	2,731	1,678	60	34	5
07013000	Meramec R near Steelville	781	7.1	3.3	67	44	15,700	1,060	688	587	405	65	28	5
07014500	Meramec R near	1,475	8.6	3.3	70	41	22,800	2,079	1,438	1,282	887	71	22	5

Gage ID	Name	Ad (mi^2)	Mean Slope	Precip. (ft)	Run-off %	CV %	2-year flood	90th	Mean	50th	10th	For %	Ag %	Urb %
	Sullivan													
07016500	Bourbeuse R at Union	808	6.0	3.4	67	46	18,000	1,263	821	763	447	55	35	6
07017200	Big R at Irondale	175	8.6	3.3	66	47	15,100	318	195	158	112	76	26	3
07018500	Big R at Byrnesville	917	8.1	3.3	62	44	20,600	1,383	952	859	600	72	20	7
07050700	James R near Springfield	246	5.9	3.8	65	48	12,350	412	252	239	117	41	50	7
07057500	North Fork R near Tecumseh	561	8.9	3.5	70	32	10,900	1,011	770	759	514	66	29	3
07061500	Black R near Annapolis	484	14.7	3.3	56	38	20,050	941	659	579	445	99	7	3
07063000	Black R at Poplar Bluff	1,245	10.5	3.4	54	30	7,535	2,117	1,502	1,424	916	86	9	4
07066000	Jacks Fork at Eminence	398	10.5	3.3	59	32	14,050	706	519	491	372	82	19	4
07067000	Current R at Van Buren	1,667	12.1	3.3	56	33	26,900	3,049	2,238	2,153	1,515	82	16	4
07068000	Current R at Doniphan	2,038	11.6	3.3	54	28	30,000	4,074	3,016	2,773	2,168	84	14	4
07071500	Eleven Point R near Bardley	793	8.0	3.3	50	35	8,325	1,185	815	794	436	67	27	4
07186000	Spring R near Waco	1,164	2.1	3.8	65	53	20,750	1,881	1,172	1,188	424	12	79	6
07187000	Shoal Cr above Joplin	427	4.0	3.8	70	50	7,435	696	470	427	246	30	62	8
07189000	Elk R near Tiff City	872	9.3	3.8	67	44	N/A	1,486	869	755	534	49	40	7