HISTORIC CHANGES OF ECOLOGICALLY RELEVANT HYDROLOGIC INDICES OF UNREGULATED KANSAS STREAMS

by

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B.S., University of the Philippines Los Baños 1996
M.S., University of the Philippines Los Baños 2005

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submitted in partial fulfillment of the requirements for the degree

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Department of Biological and Agricultural Engineering
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Abstract

Over the past decades, it has been observed that the streamflow characteristics in the Great Plains rivers have substantially changed. These changes have affected and will continue to affect the management decisions within the watershed. This study was undertaken to document the changes for some unregulated streams in Kansas, characterize the streams in terms of some hydrologic indices, and identify the probable factors influencing the changes. Fourteen unregulated streams with 60 or more years of daily discharge data geographically distributed across the state were used. The analysis focused on hydrologic indices judged to be relevant to the lotic ecosystem. The state was divided into four regions, representing roughly the northwest, southwest, northeast and southeast sections of the state. Log Pearson III method was used for computing flow probabilities, Mann-Kendall test in conjunction with Sen's slope estimator was used for trend analysis, whereas the indicators of hydrologic alterations software was used to generate most hydrologic indices. Several factors believed to affect the streamflow were identified, and their influence was modeled over time. A multi-variate statistical model was run. Results show that there is substantial difference in the streamflow characteristics between the western and eastern regions. Many streamflow aspects have changed over time, and a number of them show significant and important change. Most streams in western Kansas have longer and more frequent dry periods. Potential recharge rate, land use, water use, soil and water conservation practices, and soil type were significant factors influencing the median to very low flow, but the effect varied among the regions. Results of this study could be useful to decision makers, water users, watershed stakeholders, and environmental conservation advocates in addressing problems and concerns related to stream and river management.

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Dedication

Karen, Abby and Nikkos

Papa† *and Mama*

CHAPTER 1 - Overview

There is an ongoing competition for the use of water in the world. Conflicts exist between neighboring administrative boundaries regarding quantity and quality of water coming in and out of their jurisdictions. There is also competition between users of water within watersheds and stream segments. Agriculture, domestic, industrial and aquatic resources are competing to get their share of water from relatively limited water sources. Kansas is a classic example of a region that has ongoing disputes over water with neighboring states and also internal competition between users of its highly regarded resource: water. Landlocked and predominantly under a continental climate, Kansas relies on precipitation, which accounts for 98% of the total water budget (Koelliker, 1987; Koelliker, 1998; Sophocleous, 1998) for much of its needed water. This makes the competition between users tougher since streams are mostly fed by the surface runoff from the adjacent fields. Over the past 150 years or so, precipitation amount has changed little (Koelliker, 1997 as cited in (Sophocleous, 1998)), but water use has changed considerably (Sophocleous, 1998), making a remarkable impact on the landscape, society and the ecosystem as a whole. Documenting the changes in unregulated streams, its probable impacts on the aquatic ecosystem and the factors involved are the major foci of this dissertation.

Introduction

"Many rivers around the world, large and small, are drying up before they reach their natural destinations" (Postel and Richter, 2003). Postel, an internationally renowned author and conservationist, recounts that healthy rivers perform a myriad of functions – such as purifying water, moderating floods and droughts, and maintaining habitat for fisheries, birds, and wildlife; bringing sediment to deltas, delivering nutrients to coastal fisheries, and maintaining salinity balances that sustain productive estuaries. Flowing water also attracts people who not only directly utilize the benefits of the stream but also indirectly treasure the sight and feeling of the ecosystem it nourishes. In other words, the flow of water in the streams is the master variable that controls the river's physical, biological, and chemical processes (Poff et al., 1997).

Subsequently, people build houses, communities, cities, and other structures in and around the streams, thus modifying the stream functions and negatively altering the streams' natural processes (Annear et al., 2004).

On another aspect, agriculture is also drawn to the use of water in order to cultivate and grow crops for food, feed and fuel. In order to sustain an irrigated agriculture, it has to draw water from either the aquifer below the surface or at surface from streams, ponds, and reservoirs. Much has been said about agriculture taking the major share of water used, roughly two thirds of the total use on the global scale. This large demand for water has helped dewater our streams and lowered groundwater levels. This condition has increased to the extent that the groundwater is ceasing to supply the dependable baseflow of some perennial streams, thus making them intermittent. In addition, it has also altered the connectivity and natural flow regime of the streams to the detriment of the riverine ecosystem.

The Great Plains rivers and streams are not immune from this condition. Several researchers have pointed out the changes happening in the streams that may impact the water quality (Angelo, 1994), water resource (Sophocleous, 2002), freshwater ecosystem (Dodds et al., 2004), and fish species distribution (Hoeinghaus, in press). It has been acknowledged to be highly endangered conditions that can serve as a model system for studying disturbance ecology especially for temperate freshwater (Dodds et al., 2004).

Analyses in this study focused on the unregulated streams across Kansas which will represent the "unaltered flow regime" of the streams. This eliminates direct modification of streamflow patterns caused by the regulated release from large dams and reservoirs. The general approach is to characterize the streamflow across the state, identify hydrologic indices and document the historic changes that have occurred, and then identify possible factors that brought such changes to help understand the mechanics underlying these changes. It is important to note though that the general approach focused only on some relevant hydrologic indices that have high ecological relevance.

This dissertation is formatted to contain stand-alone articles for submission to peer-reviewed journals, thus, some introductory statements will be repetitive. The overall goal of this dissertation is to document, characterize and understand the historic changes happening in the unregulated streams of Kansas focusing on a number of ecologically-relevant hydrologic indices. An overview chapter puts the study into its proper context. The first part is to characterize the streamflow patterns in terms of differences and similarities across the different regional settings of the state. This includes the general flow characteristics, extreme events, and some trend analyses. The second part documents the historic changes of hydrologic indices relevant to the freshwater or riverine ecosystem. The focus of the analysis will be from mean to low flows including some seasonal analyses with high significance to the ecological processes in the ecosystem. The third part identifies the factors contributing to the changes in streamflow pattern and adds understanding for the mechanics and their involvement. General conclusions and recommendations are found in the last part of the dissertation.

Review of Literature

Hydrologic Index

Relating the hydrologic aspects to fish and other aquatic studies is sometimes the weakest link in this type of research. Often, the hydrologist will analyze the stream mechanics and dynamics as well as streamflow characteristics with minor or little regard to the aquatic resources in the streams, and vise versa to an aquatic biologist. This situation is exemplified by the construction and development of river and stream structures such as reservoirs, bridges and culverts, to the transformation of land into subdivisions, farms and forests, with very simplistic estimates on flow prescription for fishery resources (Annear et al., 2004). A good number of research studies though have made a remarkable stride in reinforcing this gap in research. It became apparent that hydrologic indices have to be established in order to provide aquatic and ecological factors to form a sound basis for quantifying streamflow characteristics. Probably one of the most referenced articles is that of Poff and Ward (1989) when they made a regional analysis of streamflow patterns of 78 streams across the continental United States (US) linking the streamflow variability and predictability to lotic community structure. This paved the way for researchers to focus on some applicable hydrologic indices to certain stream segments. There are different ways by which hydrologic indices could be categorized. There are indices that consider the magnitude (i.e., high, median, and low flows), flow variability, duration, timing, frequency and the rate of change of hydrologic events (Lytle and Poff, 2004; Olden and Poff, 2003; Poff and Ward, 1989; Poff et al., 1997). With the increased application of hydrologic indices for describing various aspects of the streamflow in relation to riverine research, Olden and Poff (2003) conducted a comprehensive review of 171 hydrologic indices to narrow down and remove redundancy in the choice of appropriate hydrologic indices for hydroecological studies. Depending on the stream type, as well as the overriding climatic and geologic environments, certain hydrologic indices can adequately characterize flow regimes in a non-redundant manner (Poff et al., 1997). For example, Kansas streams were characterized as mostly intermittent flashy and perennial flashy types. With such classifications some of the appropriate hydrologic indices include: mean monthly flow, median of annual minimum flows, mean minimum monthly flows, high-flow volume, frequency of low-flow spells, low-flow pulse duration, constancy (Colwell, 1974), seasonal predictability of flooding, change of flow and variability in reversals, among others (Olden and Poff, 2003). These hydrologic indices have relevance to the aquatic ecosystem in terms of community richness, stability and persistence, structure and succession, and population size, recruitment, specialization and emergence (Poff et al., 1997).

Low-flow hydrology

Low flow is the dominant flow condition in most rivers. As such, the low-flow level imposes a fundamental constraint on a river's aquatic communities: it determines the amount of habitat available for most of the year (Postel and Richter, 2003). Most of the low flows are from groundwater discharge, through springs or generally where the phreatic surface in a draining aquifer intersects with the stream channel, or from surface discharge from lakes, marshes, or melting glaciers (Smakhtin, 2001). These sources sustain the supply of water in the streams during periods of no precipitation, which is normally seasonal. Nearly all streams need to have some groundwater contribution in order to provide reliable habitat for aquatic organisms (Winter, 2007).

Natural and anthropogenic factors affect the gains and losses in the low flow of a stream. Natural factors include distribution and infiltration characteristics of soils, the hydraulic characteristics of aquifers, the rate, frequency and amount of recharge, the evapotranspiration rates from the basin, distribution of vegetation types, topography and climate (Smakhtin, 2001). Streams lose water to groundwater when and where their hydraulic head is higher than the contiguous water table. This is particularly common to semi-arid and arid regions (Winter, 2007). Losses due to evapotranspiration, especially from riparian vegetation, could be substantial. Afforestation for example, has been found to have a significant decreasing effect on the low flows of the streams. Smith and Scott (1992) reported a reduction in low flows of up to 100% with the establishment of forest in some of their experimental catchments in South Africa.

There are different ways of describing and characterizing low flows. The magnitude of annual low flows, variability of flows, rate of stream depletion, duration of continuous, low-flow events, and relative contribution of low flow to the total streamflow are just some of the measures used in low-flow hydrology (Smakhtin, 2001). A number of researchers studied several measures and indices of low flow from streamflow time series. Smakhtin (2001) did a comprehensive review of the latest developments on this field. In defining the low-flow domain, mean annual runoff (MAR), mean daily flow (MDF), median flow (MF), and absolute minimum flow (AMF) are the indices usually used depending on the application. MF is considered to be a conservative value over MAR because streamflow time series data are usually positively skewed. In displaying the whole range of stream discharge, a frequency duration curve (FDC) is the most common choice. Handling zero flows is a common challenge in dealing with the lower bounds of the streamflow data, but using FDC could better handle this type of data set. Within the FDC, there are still a number of indices that can be computed, with most of the focus on 70-99% time exceedance flow range. Another method of analysis, which is more descriptive of the low flow rather the whole set of flow ranges, is the low-flow frequency curve (LLFC). Smakhtin (2001) describes this as the average interval in years that the river falls below a given discharge, taken from a series of annual flow minima of the original continuous flow series. Theoretical distribution functions are usually used to extract frequency quantification of extreme low-flow events. The most frequently referred to distribution functions include Gumbell, Weibul, Pearson Type III and log-normal distributions. A recent study on the probability distribution of low streamflow series in the US showed that the Log Pearson III and the 3-parameter lognormal distributions are the recommended distributions for intermittent and nonintermittent (perennial) streams, respectively (Kroll and Vogel, 2002). In consideration of continuous low-flow events, there are three main low-flow characteristics that can be considered using the theory of runs, the run duration, the severity (cumulative water deficit or the negative run sums) and the magnitude (intensity) which is calculated as severity divided by duration (Smakhtin, 2001). The types of information derived from this analysis are required for different purposes.

Another important aspect in low-flow analysis is the baseflow. There are a number of measures to quantify and characterize baseflow. Baseflow separation is an initial stage in baseflow analysis, which is the basis for computing relevant indices such as average baseflow volume, average daily baseflow discharge and baseflow index (BFI). Baseflow index usually describes the main source of water. Streams with a BFI close to one have high groundwater contribution, and BFI is close to zero for ephemeral streams. Baseflow analysis is closely related to another low-flow characteristic based on the analysis of streamflow recession characteristics (Smakhtin, 2001).

Riverine ecosystem

Riverine ecosystem in this context refers to the aquatic community, its physical environment and the complex interactions within and in the immediate (riparian and flood plain) corridor of the river/stream. Riverine values can only be maintained by preserving the processes and functions of the river ecosystem. The Instream Flow Council (IFC) recognizes five riverine components: hydrology, geomorphology, biology, water quality and connectivity. River hydrology deals with four dimensions: lateral (channel to floodplain), vertical (channel bed with groundwater), longitudinal (headwater to mouth) and chronological. The hydrologic record is needed to assess the habitat changes, hydraulic functions, water quality factors, channel maintenance, and riparian and valley forming processes, which are all important and affect the river community in different ways. Geomorphology encompasses a number of stream characteristics including, but not limited to, channel form and profile, sediment delivery, pool and riffle balance, ice formation and breakup processes and floodplain management. One of the essential roles of geomorphology is the dynamic interaction of the river in supplying the needs for the habitat of the aquatic community. Biology is also referred to here as the aquatic and terrestrial communities comprised of plants and animals from the vertebrates to macroinvertebrates to the macrophytes that thrive in the river and its periphery. Implied, but not necessarily an integral part of the aquatic community, are the predators and other organisms within the ecotone of the river ecosystem which somehow affect the healthy interactions of the riverine ecosystem. Some of the important information for biology is the life history and hydraulic habitat of different aquatic species addressing the questions such as spawning and feeding habits, habitat use, migration patterns, and predatory and evasive tactics (Annear et al., 2004). Water quality of the river is an important factor that generally dictates the survival and productivity of the natural inhabitants of the river. Depending on the organism and function, slight alteration in the chemical and physical characteristics of water could lead imbalance in the ecosystem that could somehow change the adaptive, reproductive, behavioral and physical attributes of organisms. In a broader sense, connectivity is defined as the ease with which organisms, matter or energy traverse the ecotones between adjacent ecological units (Ward et al., 1999). In simpler terms, connectivity refers to the extent of spatial mobility of the living organisms, energy, nutrients, organic matter and other physical and chemical components of the ecosystem. Complexity and interdependence is the hallmark of connectivity (Annear et al., 2004) owing in part to its role played in structuring succession in biodiversity patterns (Ward et al., 1999). For example, delivery of nutrients and other essential products from upstream sources could hamper the survival of the organisms downstream. On the other hand, some aquatic organisms, like certain fish species, migrate upstream to feed or spawn and rely on the connectivity of the stream segments to undertake it. Connectivity also refers to the seasonal flooding that connects the floodplain to the main stream, and this is important to some organisms rely on this for feeding and spawning purposes.

The plants and animals living in a river ecosystem depend upon habitat conditions that are determined largely by the river’s flow. Each river-dependent animal or plant has different habitat needs or preferences, which typically vary during their life cycles, as well as different tolerances for unfavorable conditions. A river’s native species have been tested by nature’s variability over thousand of years. Factors such as communism, predation and competition, are affected by river flow to varying degrees, making the flow regime a powerful influence on river health (Poff et al., 1997; Postel and Richter, 2003).

Rationale

The riverine ecosystem responds to different stressors in the river system. Alteration of any of the natural components could affect the balance of the riverine ecosystem and could disrupt, modify or totally eliminate some essential functions and processes of the ecosystem. It is evident that water flow is the master variable that dictates the other processes and functions in the stream. Ecologically relevant hydrologic indices are therefore important to monitor and characterize to determine the changes that might have happened or what could happen.

There is convincing evidence that the riverine ecosystem has been affected by the changes in the streamflow patterns in Kansas. How much and what aspects have changed and spatial extent of these changes are still undocumented.

Purpose

The major goal of this dissertation is to document the historic changes of ecologically relevant hydrologic indices of Kansas streams. The focus of this work is on unregulated streams with a long, continuous, daily-discharge record. The research questions this dissertation aims to answer are the following:

1. What set of hydrologic indices are relevant in studying the ecology of streams in Kansas?
2. Are there substantial changes occurring in the streams across the state?
3. What aspects of the streamflow have changed or are changing?
4. What factors are affecting these changes?
5. Is there a model that could adequately characterize the changes that are occurring?

Consequently, the dissertation will add knowledge, understanding and awareness on Kansas streams and rivers with respect to the changes that are occurring.

"From a strictly human perspective, healthy rivers perform numerous 'ecosystem services' – the processes carried out by natural ecosystems to benefit human societies and economies." (Postel and Richter, 2003)

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CHAPTER 2 - Differences in streamflow pattern across Kansas

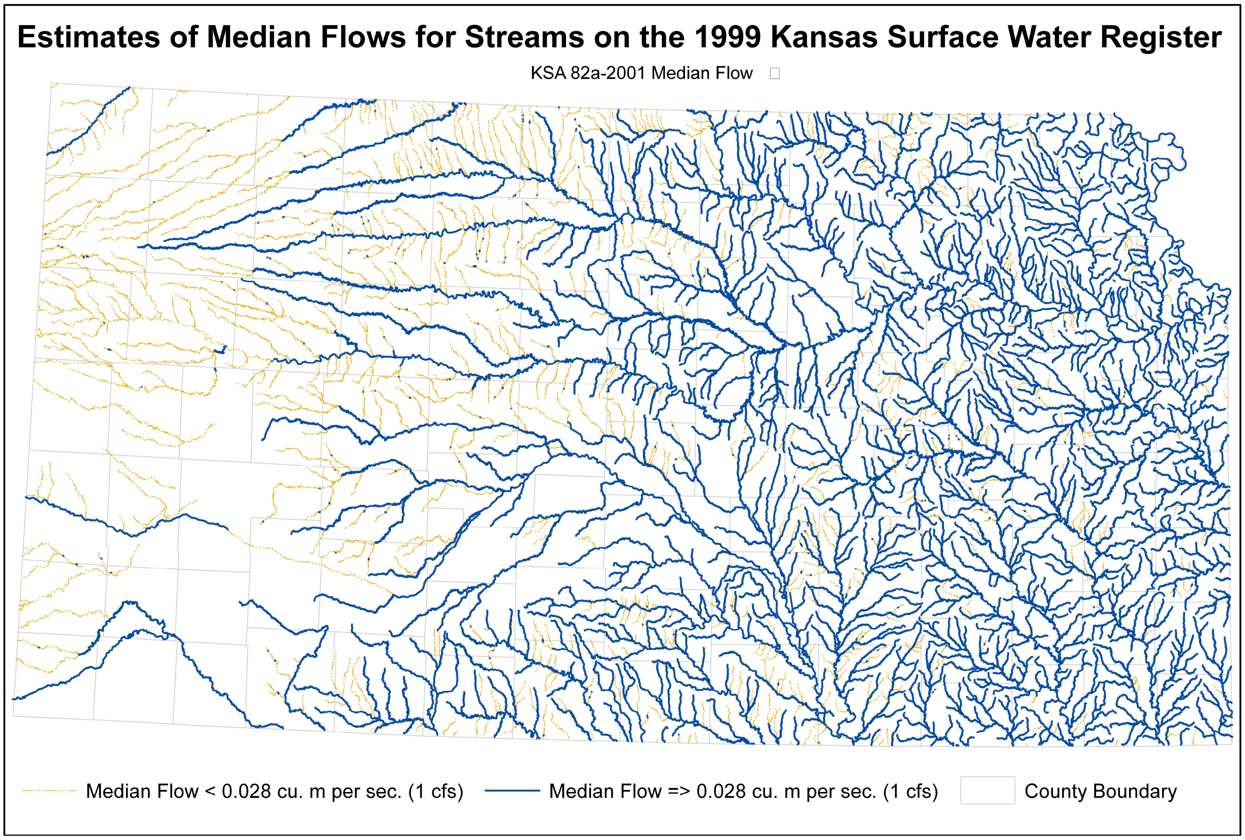
Introduction

Since the dawn of agriculture in Kansas, there have been many changes that have resulted in the physical surroundings of the state. Roughly 90 percent of the land area has been converted for agriculture (Patrick, 1998; Sophocleous, 1998), and also 90 percent of the total water pumped from the High Plains aquifer is used for irrigation (Koelliker, 1987; Koelliker, 1998; Sophocleous, 1998). Many streams once considered perennial in the area have now become intermittent as the water table fell below the stream bed and caused the stream to dry up during periods of no rain. This condition is more prevalent in the western regions of the state rather than in the east. A similar observation was reported by Perry et al. (2004) to the US Geological Survey (USGS) in the Scientific Investigations Report, which made the estimates of the median flows for stream segments (Figure 2-1). All the stream segments were considered perennial in the 1960s. It is apparent from this figure that many of those stream segments are now intermittent. Another interesting observation is that the eastern and western stream segments seem to exhibit a different scenario. This observed difference as well as the behavior of streamflow pattern over time will be the object of scrutiny in this paper.

Climate and water resources

Located in the center of the contiguous United States, the state of Kansas is land-locked, and the major input of water is through precipitation (rainfall and snow). A general water budget of the state shows precipitation accounts for 98 percent to the total input (Koelliker, 1987; Koelliker, 1998; Sophocleous, 1998). Sophocleous (1998; 2000), describes the water resources of Kansas knowledgeably in his papers, and he estimates that the remaining portion of the water budget inputs are from the boundary flow at the Missouri River and streamflows from adjoining states of Colorado and Nebraska. Precipitation in Kansas decreases toward the north and west, with the northwest region getting only about half of that in the southeastern region of the state. This results in the western portion being characterized as semiarid and the eastern portion, subhumid (Patrick, 1998). During the period of predominantly southerly winds, from April to September, on average about 70 percent of the total precipitation for the year occurs. Although seasonal, as well as annual, patterns of precipitation are highly variable (Koelliker, 1987; Patrick, 1998), May and June are usually the two wettest months of the year. These spring and summer rainstorms tend to be mostly intense and of short duration and they typically cover areas that are typical of convective-type rainfall.

Figure 2-1. Estimates of median flows for streams on the 1999 Kansas surface water register showing stream reaches below and above a threshold flow of one cubic feet per second. Adapted from Perry et al. (2004).

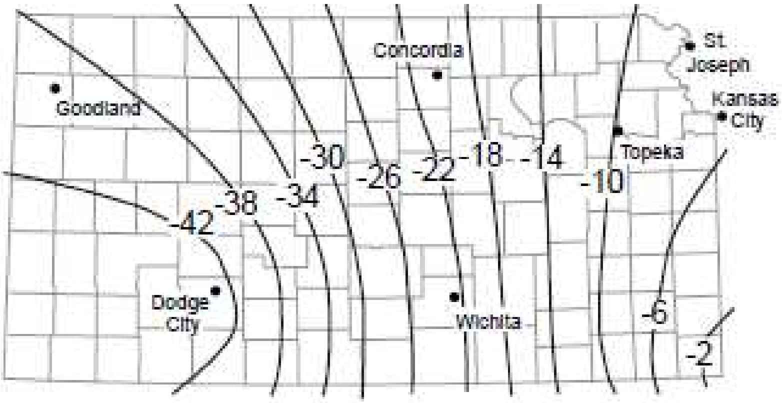


The mid-latitude location of Kansas, far removed from the marine influence and without transverse mountain barriers, produces a wide range of temperature (Kincer, 1923; Sophocleous, 1998). Annually, the temperature ranges from highs around 100˚F (38˚C) and lows below 0˚F (-18˚C). Within the state, the average temperature, which varies primarily due to differences in latitude and elevation, increases steadily from northwest to southeast. The average annual temperature is about 58˚F (14.4˚C) along the south-central and southeastern border to 52˚F

(11.1˚C) in the extreme northwest corner of the state (Sophocleous, 1998). The long, warm season, is usually from mid-April to mid-October.

The prevailing wind in Kansas is southerly, although northerly winds are also common. Winds are mostly in the moderate to strong category. They average about 24 km/hr (15 mph) in the west and 16 km/hr (10 mph) in the east. The combination of the wind and temperature, among other climatic factors makes the state to have a high evapotranspiration rates. Roughly 90 percent of the rainfall that occurs is lost back to the atmosphere through evapotranspiration. In western Kansas where there is relatively low precipitation, a moisture deficit exists in consideration to the potential evapotranspiration of the region. Here moisture deficit refers to the difference between free-water surface evaporation and average annual precipitation (Figure 2-2).

Figure 2-2. Moisture deficit computed using annual precipitation minus free water surface evaporation (inches). Adapted from Sophocleous (1998).



Hydrogeologic characteristics

The general topography of Kansas is characterized as an eastward-sloping plain that gradually rises from east to west at a rate of approximately 1.9 m per kilometer (10 ft per mile). The western half has slightly steeper slope than the eastern half (Sophocleous, 1998).

The surface and subsurface geology of Kansas differs from one area to another because of the seas, glaciers, and rivers that in some point in time influenced the topography of the region. Essentially, most of Kansas is underlain with sedimentary rocks. The total thickness of the sedimentary rocks ranges from about 300 m (1,000 ft) in eastern Kansas to more than 2,700 m (9,000 ft) in southwestern Kansas (Sophocleous, 1998). In western Kansas, especially, sedimentary rocks, of the unconsolidated or loosely packed type, are the major source of ground water, which is essentially part of the High Plains aquifer. The High Plains aquifer, which underlies eight neighboring states, refers to three hydraulically-connected but areally distinct aquifers within Kansas, namely, the Ogallala, the Great Bend Prairie and the Equus Beds (Sophocleous, 1998; Sophocleous, 2000; Sophocleous, 2005). In the southwestern part of the state, a considerable region is covered with sand dunes, especially along the Arkansas River. Most of the eastern portion of the state surface is of Permian and Pennsylvanian rocks which are generally remnants of the rising and falling seas that happened eras ago (Sophocleous, 1998). They consist of layers of shale, limestone, sandstones and chert, which is said to have formed the Flint Hills. Practically, the Kansas water resources are affected by the geology of the state, influencing both the quantity and quality of water that flows in its streams or that can be obtained from wells (Sophocleous, 1998).

Streamflow generation

Most of Kansas' streams were categorized by some authors as intermittent flashy (Olden and Poff, 2003; Poff, 1996). This is partly due to the fact that most of the streamflow originates as precipitation (Patrick, 1998), and the precipitation in Kansas is of short duration and high intensity from storms that cover relatively small areas. Another controlling factor is the land cover, which was historically perennial grass. Much of this land cover has been converted to cropland. In addition, these lands are underlain with mostly slowly permeable soil (Sophocleous, 1998), except in the alluvial floodplains and the southwest and south-central regions. Unlike forest trees, grasses and cropland tend to hold the surface runoff only for minimal periods of time and thus contribute to the flashy characteristic of streamflow (Annear et al., 2004). With precipitation increasing from only 46 centimeters (18 inches) in the west and a little more than 102 cm (40 inches) in the east, overall Kansas is considered a semiarid region (Committee on Integrated Observations for Hydrologic and Related Sciences, National Resource Council, 2008).

Many perennial streams in Kansas have permanent streamflow or baseflow as a result of groundwater discharge. On the other hand, streamflow may be the major source of recharge to some alluvial aquifers (Sophocleous, 1998a). The interdependence of surface and ground water is essential in the management and utilization of these resources.

Historical background

The earliest European settlers of Kansas found a lot of difficulty farming in the treeless plain, flat topography, dryland condition and adequate yet inaccessible water sources (i.e., streams and aquifer) (Koelliker, 1987). After the Dust Bowl of the 1930s, soil conservation practices were started and a renewed interest for farmers to till Kansas land began. Farm mechanization, irrigation and improved crop management systems that started from about 1940 to 1980 boosted agricultural production in the state. In terms of water use, the introduction of the turbine pump and the discovery of natural gas in southwest Kansas helped spur the interest in irrigation in the region. By the 1970s, water was being withdrawn from the aquifers several times faster that was being replenished (Froth, 1988; Koelliker, 1987). Koelliker (1987) recounts that the number of center-pivot irrigation increased rapidly during the 1970s because of its many advantages, including better efficiency and lower labor requirements. Around this time, over 600 dams and reservoirs were built across the state as part of watershed projects to reduce local flooding, reduce soil erosion, increase water-based recreation and, in some cases, provide public water supplies. The combination of surface impoundment and groundwater extraction has created more water availability, as well as water quality problems for the state as a whole (Sophocleous, 1998a).

Relevant aspects of streamflow

Streams can be characterized in many different ways. In most irrigation and flood projects, median to high flows are the major concerns. For the purpose of this study, focus was given to median to low flows as these aspects of the flow have big impact on the habitat of the aquatic ecosystem.

Methods

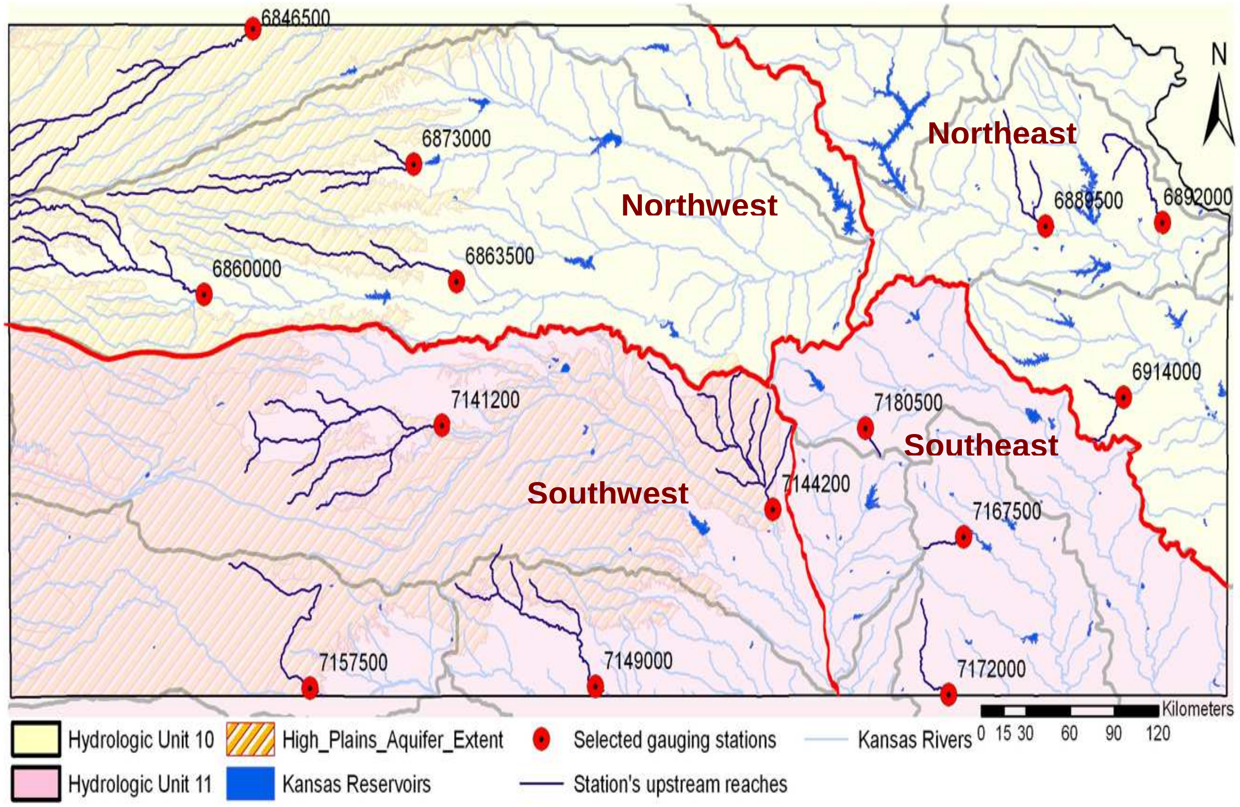
Selection of gauges

Selection of gauging station was based primarily on the availability and length of daily discharge data and whether the stream is unregulated as indicated in the remarks of the USGS Water-Data Reports (Putnam and Schneider, 2003). According to the USGS Reports, an unregulated stream denotes the absence of major reservoirs and diversion dams upstream of the gauging stations that would otherwise substantially influence the streamflow. However, there may be substantial groundwater abstraction and irrigation activities within the watershed that may somehow affect the streamflow at the gauging station. For the purpose of the study, unregulated streams represent streams whose flow regime has not been artificially altered, especially by flow regulation. Nevertheless, the stream is still expected to exhibit changes in streamflow pattern due to other factors within the watershed.

Another consideration is the spatial distribution of the gauging stations (Figure 2-3). Two considerations were taken into account: the north-south and east-west orientation, and the ecoregional representation. It should be noted that Kansas climate varies more greatly from east to west than from the north to south. However, the water resources regions by USGS, which are based on the major watershed divide between the Kansas and Arkansas Rivers, is on a north-south orientation (Figure 2-3).

This study looked at these orientations as possible reasons for the variations of the streamflow pattern. Incorporating the ecological relevance, gauging stations selected were also located to represent relevant ecoregions. There are several ecoregions that exist in the state of Kansas (Figure 2-4): ecoregions by Omernik (1987) and Bailey (1983), National Ecological Observatory Network (NEON) regions (Hargrove et al., 2006; Keller et al., 2008) and fish ecoregions (Hawkes et al., 1986). The ecoregions by Omernick and Bailey are based more on the environmental factors creating variations in the ecosystem (Bailey, 1983), and causal and integrative factors for the potential natural vegetation (Hargrove et al., 2006; Omernik, 1987). Both of Omernik’s and Bailey’s ecoregions, though aquatic ecosystem was considered (Bailey, 1983), do not entirely represent the differences in aquatic ecosystem of Kansas and combine different water resources regions in which the hydrologic regimes are very different. NEON ecoregions empirically partitioned the US into 20 ecoclimatic domains using a comprehensive statistical analysis of ecoclimatic state variables and dynamic air mass seasonality data, among others (Hargrove et al., 2006). Applicability of the NEON ecoregion for this study is relatively inappropriate. Fish ecoregions were the closest applicable regional delineation found. The delineation of the fish ecoregions was done by Hawkes and others (1986) based on ecologically meaningful fish assemblage and canonical discriminant analysis of environmental variables (i.e., mean annual runoff, mean annual growing season, and stream discharge). One good characteristic of the fish ecoregion is that it conforms with the hydrologic unit and watershed divides as well as the east-west orientation of Kansas that dictates the regional variation on climate. With minor modification, this ecoregion was adopted to group the gauging stations.

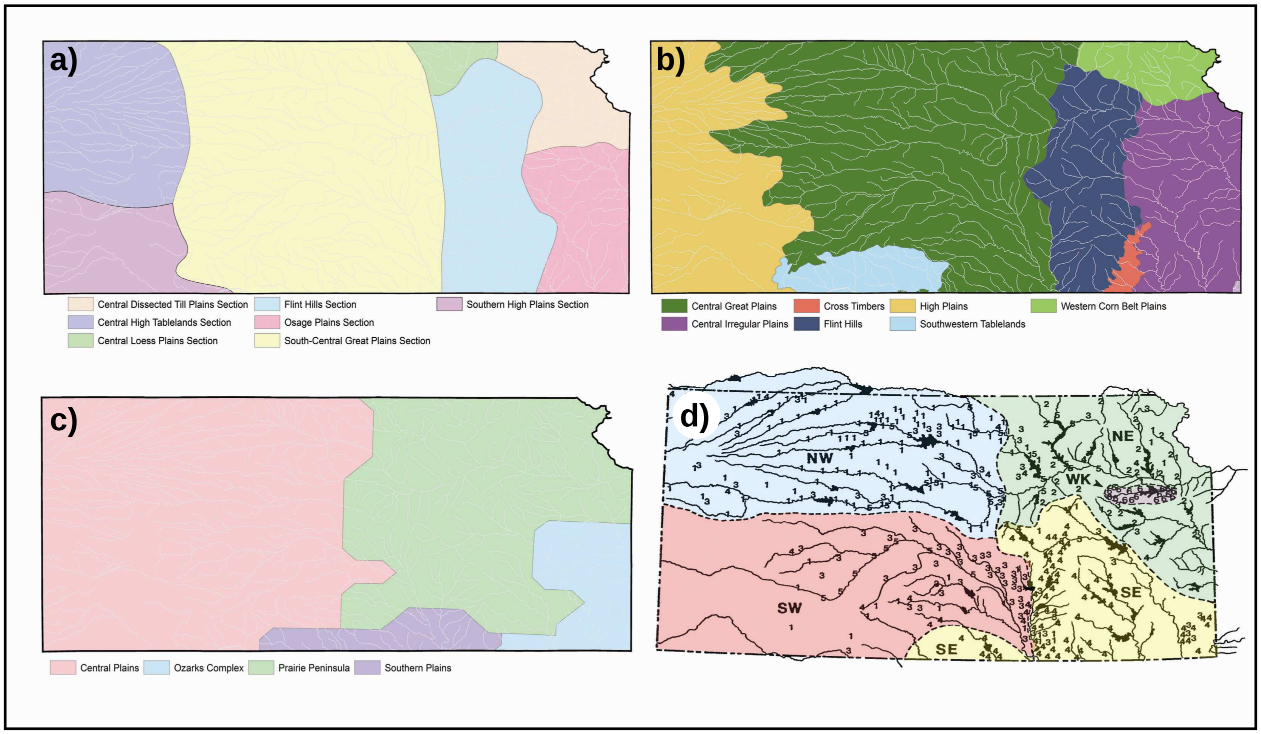
Figure 2-3. Location of the selected gauging stations and the regional grouping.



Comparison of streamflow aspects

Several aspects of the streamflow were computed for the selected streams in Kansas. The "approved" USGS daily streamflow data were downloaded from the USGS website (http://waterdata.usgs.gov/ks/nwis) for the years starting 1931 though 2006. A summary of the data and some characteristic information of the gauging stations are presented in Table 2-1.

Figure 2-4. Different ecoregions of Kansas: a) ecoregion by Bailey (1983); b) ecoregion by Omernik (1987); c) NEON ecoregion (Hargrove et al. 2006); and d) fish ecoregions of Kansas by Hawkes et al. (1986).



Comparison of streamflow characteristics for this study was limited to aspects of the flow relevant to the habitat and some functions of the aquatic community (USGS has numerous analyses on other hydrologic characteristics of the flow in their website and other publications). In order to compare between different watersheds on a consistent basis, the unit flow was used by dividing actual discharge by the effective drainage area. In many cases, the unit used was liters per hour per square kilometer ($l/hr/km^2$). This prevented having to work with and report values in decimal places. However, for this study, values of 0.01 $l/hr/km^2$ or less are essentially zero. Another method to compare the values between streams is to convert discharge rates into depth of water per time period (year) by dividing the discharge value by the effective drainage area.

Table 2-1. Summary of data and other important characteristics of the USGS gauging stations

Station No	Name	Start date	Effective Drainage Area (km^2)	Remarks	Regional grouping
6846500	BEAVER C AT CEDAR BLUFFS	5/13/1946	3,429		Northwest
6860000	SMOKY HILL R AT ELKADER	10/1/1939	9,207		Northwest
6863500	BIG C NR HAYS	4/1/1946	1,421		Northwest
6873000	SF SOLOMON R AB WEBSTER RE	1/8/1945	2,694		Northwest
6889500	SOLDIER C NR TOPEKA	5/23/1929	751		Northeast
6892000	STRANGER C NR TONGANOXIE	4/21/1929	1,052		Northeast
6914000	POTTAWATOMIE C NR GARNETT	10/1/1939	865	Discontinued after 2000	Northeast
6914100	POTTAWATOMIE C NR SCIPIO	10/1/2000	888	Replaced 6914000	Northeast
7141200	PAWNEE R AT ROZEL	10/1/1924	5,206		Southwest
7144200	L ARKANSAS R AT VALLEY CENTER	6/10/1922	3,237		Southwest
7149000	MEDICINE LODGE R NR KIOWA	2/11/1938	2,339		Southwest
7157500	CROOKED C NR ENGLEWOOD	10/1/1942	2,106		Southwest
7167500	OTTER C AT CLIMAX	10/1/1946	334		Southeast
7172000	CANEY R NR ELGIN	10/1/1939	1,153		Southeast
7180500	CEDAR C NR CEDAR POINT	10/1/1938	285		Southeast

Low flow was one of the major foci in this study. Low-flow parameters, such as zero days, days below threshold, 1- and 7-day annual minimum, and a number of seasonal and annual low-flows measures, were also examined. An arbitrary flow threshold of 0.028 m^3/s (1 cfs) was used for the purpose of establishing a method of analysis using threshold levels (e.g., threshold for fish survival or passage). Some high-flow parameters were also explored, not only as a factor in maintaining aquatic diversity but also to get a glimpse of what is happening on the watershed. In most cases, the Log Pearson III distribution was used in the analysis due to numerous zero values in the streamflow data and as recommended by Kroll and Vogel (2002) in their study of the low-streamflow data series of numerous streams in the US. Log Pearson Type III method uses Poisson process to describe the probability of occurrence and is particularly applicable to skewed dataset. The HydroToolbox, an Excel add-in, which has a built-in Log Pearson III computational function, was used (http://www.dartmouth.edu/~renshaw/hydrotoolbox - accessed 20 February 2009).

Periods of analysis

In synchronization with the Kansas fish collection data (K. Gido, 2007, personal communication), periods of analysis were established with length of each period at around 15 years. The periods identified are: 1931-47, 1948-62, 1963-77, 1978-92 and 1993-2006. Other than being coincident with the fish collection data, these periods also coincide with some events in agriculture, climate and irrigation. The first period (1931-47) could be associated with the time before soil and water conservation and irrigation were widespread in Kansas. The next period, 1948-62, corresponds to the time when the large federal reservoirs were constructed and soil and water conservation and irrigation was steadily developing, leading to the fragmentation of major streams. The 1963-77 interval represents the period of rapid increase in groundwater extraction from irrigation development. Adoption to irrigation tapered off and crop residue management was being practiced around 1978-92 (Rogers and Alam, 2008). The period of 1993-2006 represents the sustained soil and water conservation efforts in agriculture as well as high water use efficiency of irrigation systems. Finally, for studies on dryland watersheds, a minimum of 15 years is needed to establish reasonable average to minimize variations due to climatic effects (Hauser, 1968).

Trend analysis was also performed in some parameters. The Mann-Kendall trend analysis was employed to determine if there is a significant upward or downward trend over time in the dataset. Mann-Kendall analysis is a non-parametric method of detecting trend suitable for non-normally distributed data such as most hydro-climatic datasets (Yue et al., 2002) and it establishes if the dataset has a significant positive or negative trend. However, the magnitude of trend and the slope is not computed by this method.

Results and Discussions

General flow characteristics

A quick look at Table 2-2 would intuitively show the differences and similarities of the streams being analyzed. Median unit flow shows that gauging stations 6846500, 6860000 and 7141200 have similarities in their long-term (i.e. using all data from the station) values and considering the values by periods, all are exhibiting a downward trend in flow over time. As early as the 1963-77 period, the median flow, which is the flow at 50% probability of exceedance taken using the Log Pearson III distribution, was practically zero in these streams. One common factor of these streams is that they are adjacent to the High Plains aquifer. The same downward trend could also be observed on stations 6863500, 6873000 and 7157500, except that stations 6863500 and 6873000 rebounded in the 1993-2006 period. All but one of the other stations in the eastern regions show a steady and upward trend in their median flows by as much as two to three times that of their 1930s flows. This can also be observed in the total annual streamflow.

Figure 2-5 is a graph that compares the 5-year trailing average of total annual streamflow and 5-year trailing average precipitation of Kansas in terms of depth. The 5-year trailing average value for a year is the average of the current year plus previous four years. It is useful in ecological studies since the existence of aquatic organisms is determined by the current flow and the flow from the previous period than by the future flow of the stream. The National Oceanic and Atmospheric Administration (NOAA) estimates that for the 1931-2006 record for the whole state of Kansas, the increasing trend in precipitation is at a rate of approximately 1.35 cm/decade (http://climvis.ncdc.noaa.gov/cgi-bin/cag3/hr-display3.pl - accessed 23 March 2009). Though there is still variability, stream gauges in the east (dashed lines) also depicts a steady increasing trend in flow.

Results from the Mann-Kendall trend analysis (Table 2-3) confirm the significantly increasing trends in four of the six stations in the east at the 90 percent confidence interval. Streamflow in the western region (solid lines) are very erratic and it is difficult to see any generalization or trend at this scale. Looking instead at the result of the trend analysis shows that some streams have significantly decreasing trend in its annual streamflow. It is fitting to point out that even on the annual scale streamflow generation is very much controlled by precipitation such that the dips and ups in the precipitation are clearly reflected in the streamflow.

Table 2-2. Median unit flow discharges of the stream at the gauging station over the periods of analysis (l/hr/km^2).

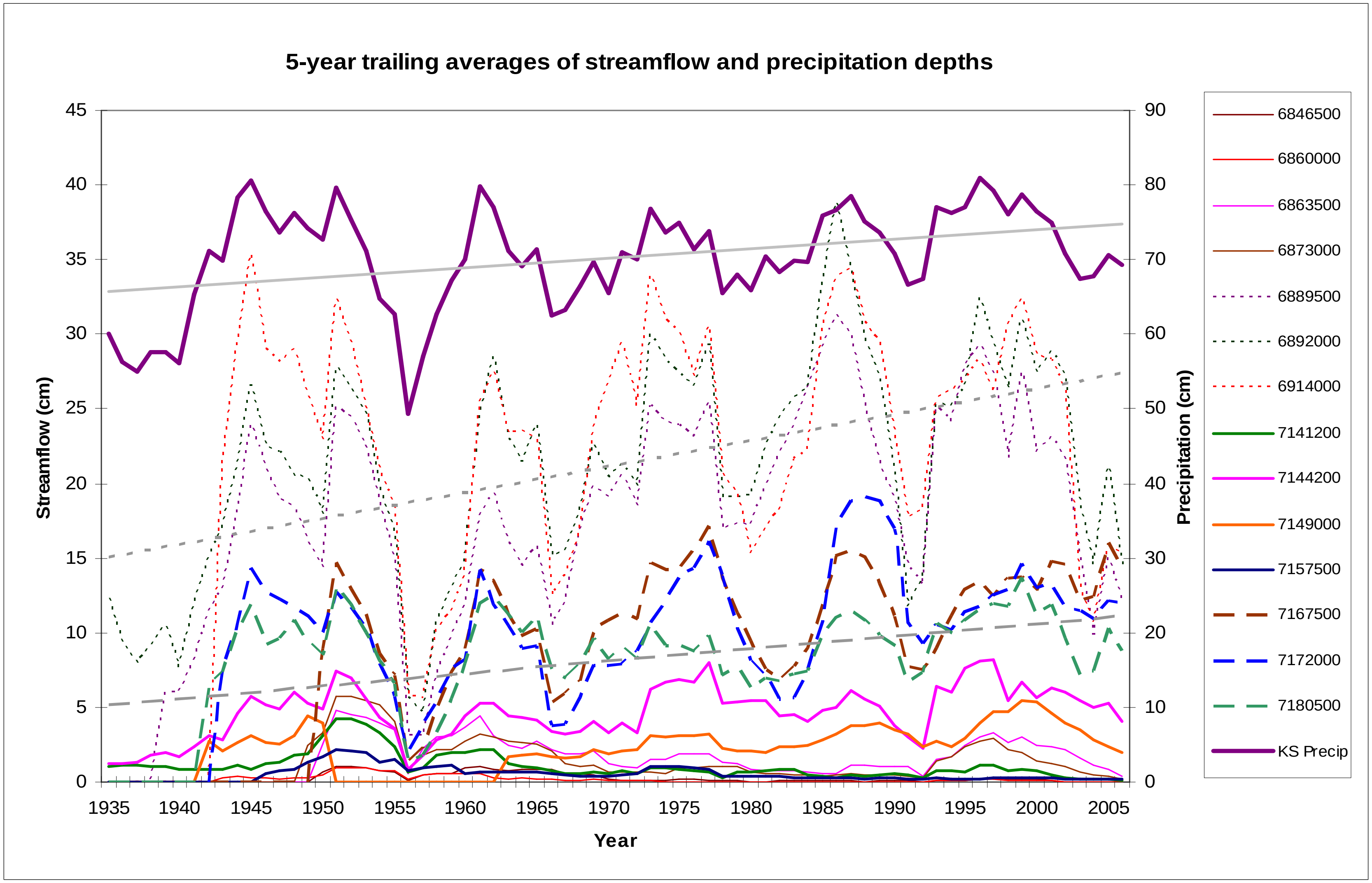
Station No	1931-47	1948-62	1963-77	1978-92	1993-2006	Long-term*	Region
6846500	207	31	0	0	0	1	Northwest
6860000	31	51	15	0	2	6	
6863500	715	801	491	405	1,116	919	
6873000	173	926	264	46	276	231	
6889500	2,781	3,361	4,297	5,299	4,562	7,011	Northeast
6892000	3,725	4,192	4,707	5,564	4,277	5,876	
6914000	4,435	1,022	2,756	1,931	2,024	2,223	
7141200	115	159	1	0	0	7	Southwest
7144200	1,511	1,885	2,233	1,837	2,430	1,928	
7149000	1,855	5,163	4,530	5,404	7,024	5,678	
7157500	959	784	933	483	417	829	
7167500	1,453	415	3,597	2,977	3,158	2,769	Southeast
7172000	2,274	921	4,479	3,776	6,899	3,283	
7180500	9,796	2,102	5,504	10,406	11,080	9,915	

* using all data from the station

Table 2-3. Result of the Mann-Kendall trend analysis for annual streamflow at the gauging stations at alpha = 0.1.

Region	Station	Test Z	Significant Trend
Northwest	6846500	-3.30	Downward
	6860000	-3.42	Downward
	6863500	-2.58	Downward
	6873000	-3.54	Downward
Northeast	6889500	1.99	Upward
	6892000	1.85	Upward
	6914000	0.98	None
Southwest	7141200	-3.74	Downward
	7144200	2.59	Upward
	7149000	1.01	None
	7157500	-3.10	Downward
Southeast	7167500	0.71	None
	7172000	1.71	Upward
	7180500	1.32	Upward

Figure 2-5. The 5-year trailing averages of the total annual streamflow and annual precipitations in Kansas. Precipitation data were taken from NOAA. Linear trend lines (grey) were drawn for the precipitation (solid line), southeast stations (short dashed-line), and the southwest stations (long dashed-line)



Looking into the seasonal variation (Figure 2-6) by dividing the year into seasons (March to May is spring, June to August is summer, September to November is fall, and December to February is winter), spring and summer generate a lot of precipitation, and the eastern streams are responding accordingly. However the western streams rarely exceed more than 2 cm of streamflow. Two things are evident in this figure: the drought and flood responses. If a substantial decrease in the summer precipitation is experienced, there is drastic reduction also in the streamflow and it takes some time before the streams recover as evidenced by the 1950s drought. On a similar manner, the wet years of the early 1950s (ranked 112 and 114 by NOAA against all its record) was almost replicated in the early 1990s (ranked 110 and 113) (http://climvis.ncdc.noaa.gov - accessed 3/17/2009), but the response of the streams during the summer in the 1990s was substantially below the discharge at the same stream during the 1950s. This was similar to the observation of Koelliker (1998).

Low flows

The low-flow unit discharges, which were obtained here using the value at 90% probability of exceedance from Log Pearson III distribution, of the streams are presented in Table 2-4. Also included in the table is the threshold flow in unit discharge of the individual streams if the actual flows were not less than 0.028 m^3/s (1 cfs). It appears from the condition of the flow that the low flows are prevalent in the western region even before the 1930s. This somehow supports the intermittency of the streams in Kansas. Only three of the 14 streams have a dependable low flow above the threshold. Interestingly, at the end of the 2006, there are now seven streams that have low flows above the threshold levels, and most of these streams are in the eastern region.

Low-flow conditions, in terms of zero flow and below-threshold flow days, depict the intermittent condition of the streams on the western regions of the state. Figure 2-7a shows that at the high ends, 20 to more than 50 percent of the time, the flow is zero at these gauging stations (i.e., 6846500, 6860000, and 7141200) with a relatively increasing trend over the decades. Comparing the zero flows of during 1978-92 with those of 1993-2006; it seems that the streams are gaining flow somewhat between these two periods, a trend shared by most other streams. At the other stream gauging stations, zero flows seldom occur more than 10 percent on the average. The majority of the eastern streams appear to be improving in terms of zero flows.

Figure 2-6. Seasonal 5-year trailing averages of the streamflow and precipitation depths by regional clustering.

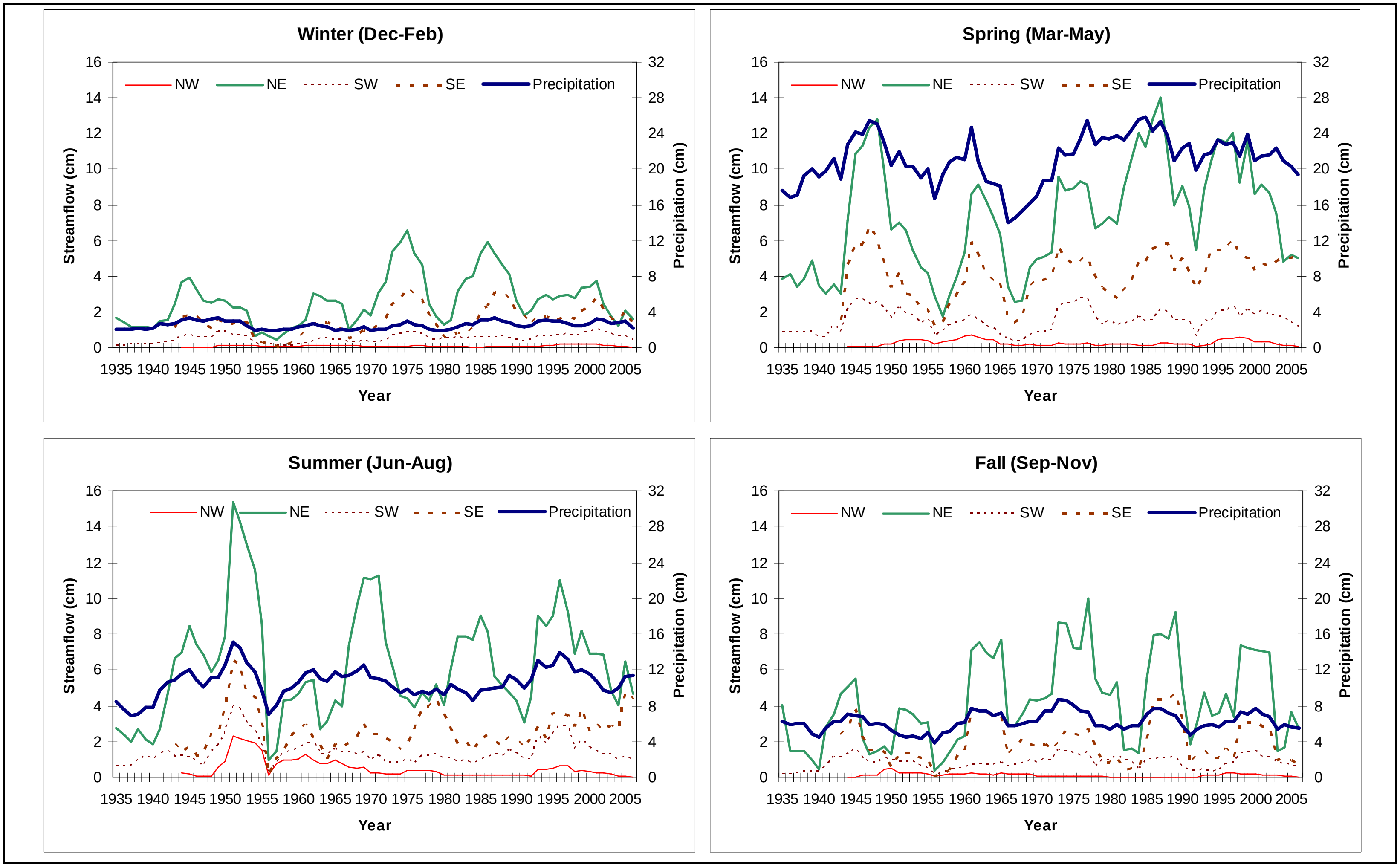


Table 2-4. Low flow discharges (90% probability of exceedance) of the stream at the gauging station over the periods of analysis (l/hr/km^2).

Station No	1931-47	1948-62	1963-77	1978-92	1993-2006	Long-term*	Threshold flow**	Region
6846500	2	0	0	0	0	0	30	Northwest
6860000	0	0	0	0	0	0	11	
6863500	13	64	172	73	8	41	72	
6873000	0	4	2	0	0	1	38	
6889500	6	6	690	836	828	70	136	Northeast
6892000	22	32	433	249	409	94	97	
6914000	11	1	25	6	16	7	118	
7141200	1	0	0	0	0	0	20	Southwest
7144200	574	455	789	441	646	549	44	
7149000	2	83	229	752	934	123	48	
7157500	9	2	9	108	103	16	305	
7167500	98	0	4	5	253	3	88	Southeast
7172000	2	0	11	7	41	4	358	
7180500	109	1	1,348	460	651	87	20	

* using all data from the station ** actual streamflow less than 0.028 m^3/s (1 cfs)

Days with flows below threshold (Figure 2-7b) follow almost the same scenario as zero-flow days, but are of larger magnitude. For the same three gauging stations as above, the yearly average has increased from 40 to around 65 percent of the time. The period, 1978-92, at station 6846500 reached to as high as 91 percent. Interestingly at this threshold level, station 6914000 exhibited an increasing trend, when the rest of its eastern counterparts were on a decreasing trend. Again, it could be noted that most of the streams seem to be improving between the periods of 1978-92 and 1993-2006. Unique among the others is station 7144200 which did not have any day with streamflow reading of zero or below threshold flow. In general, this information shows the intermittency of the Kansas streams as well as the differences in the behavior between the western and eastern streams of the state.

Exploring the 3-day minimum flows, which is defined as the least sum of flow of any three consecutive days in a year, of the streams shows a different aspect of the stream condition. If the threshold level will be the minimum value considered (0.028 m^3/s), most of the streams are able to support some aquatic life form during non-drought years (Figure 2-8). Only 4or 5 stations (i.e., 6846500, 6860000, 6914000, and 7141200, and 7167500 to some extent) could not adequately support the flow at the threshold level (note the change in the scale of the SW graph).

Figure 2-7. Number of days with a) zero flow and b) below threshold flow per station and over the periods expressed as percent of the year. Threshold flow value was set at 0.028 m^3/s (1 cfs).

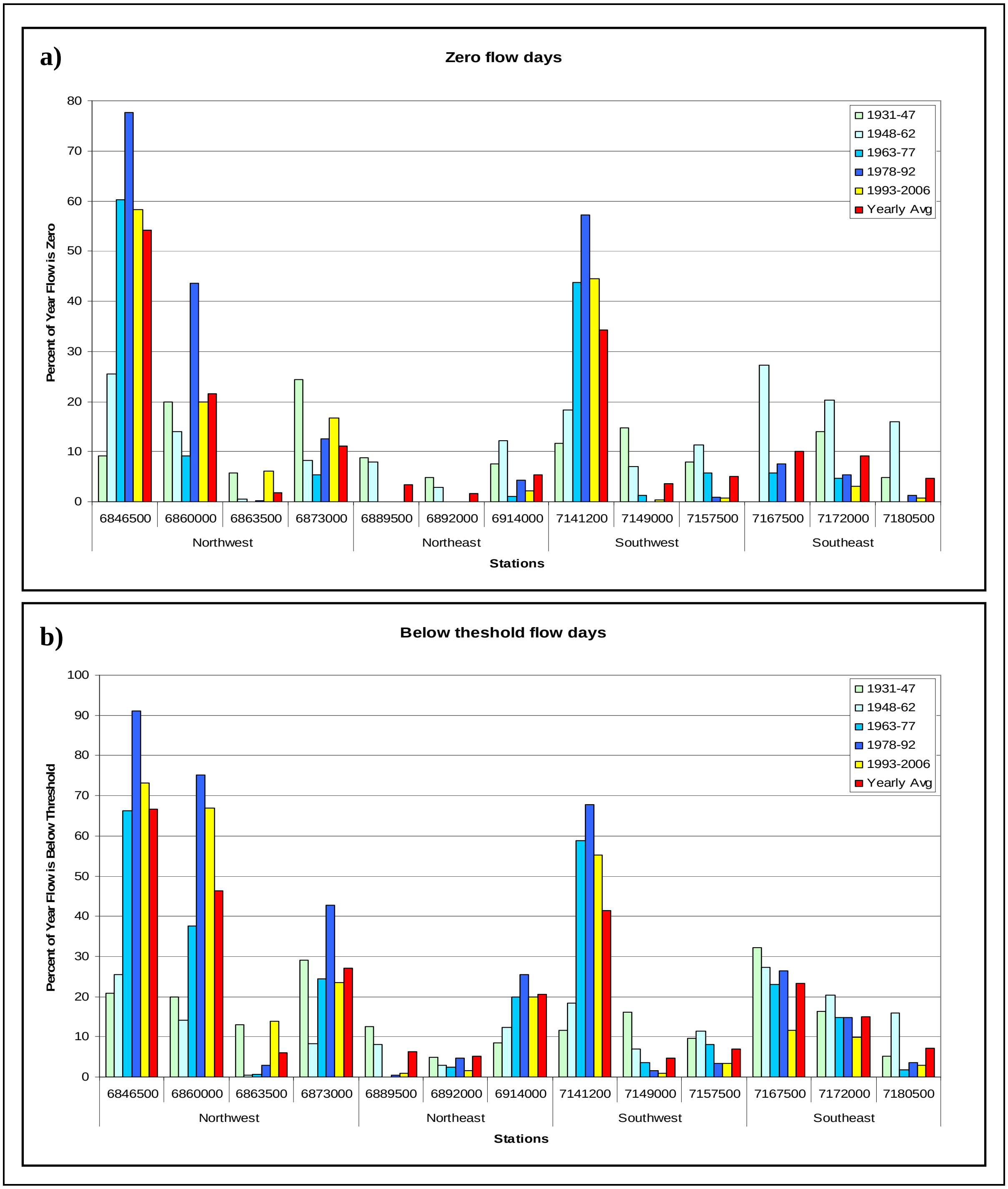
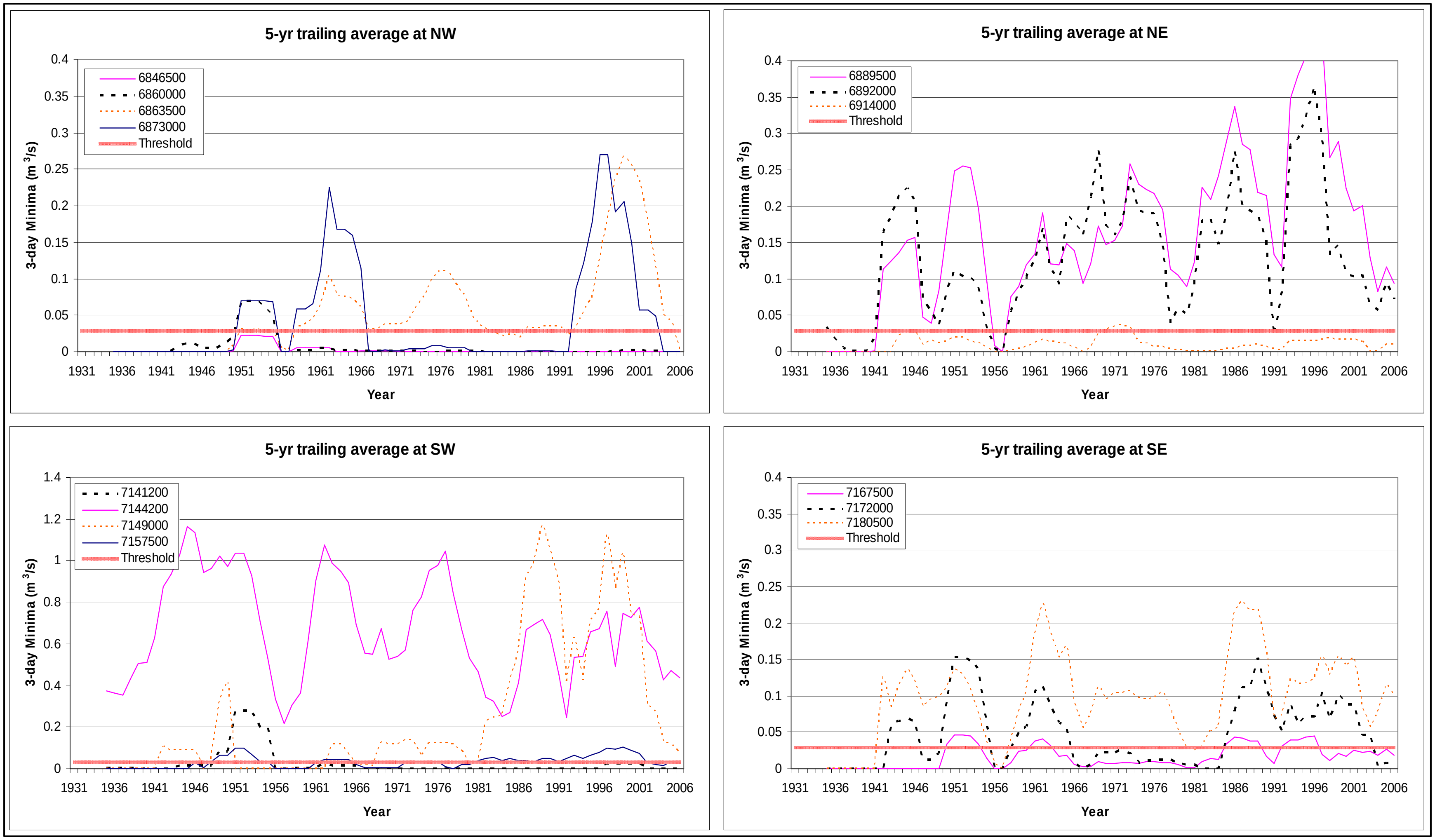


Figure 2-8. The 5-year trailing averages of 3-day minima of each station grouped by region.

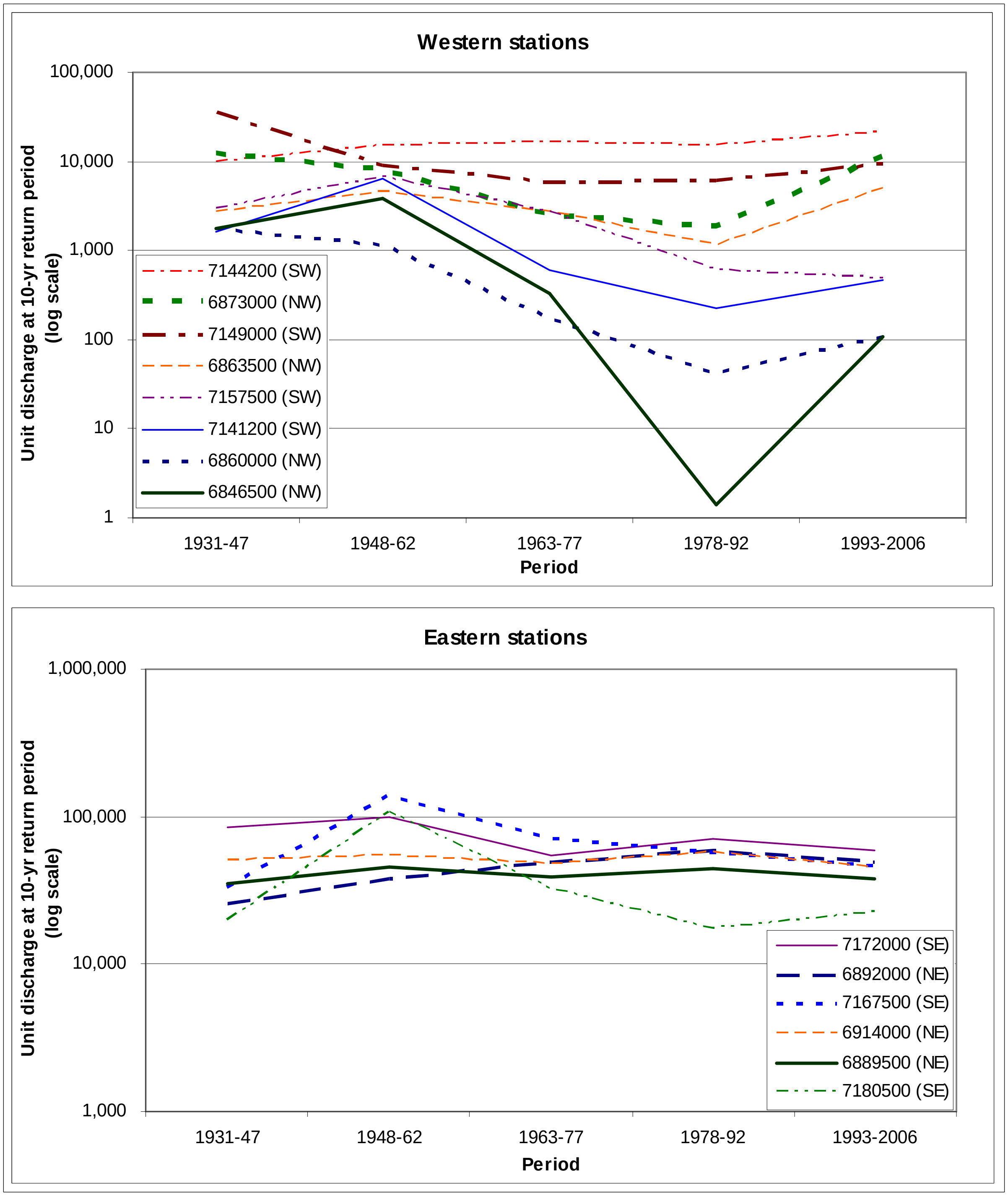


But it also shows that, in fact, flows below the threshold level do occur in most of the streams. This below-threshold condition could actually mean a disruption in the function and continuity of the aquatic community. This intermittent condition is the actual condition of Kansas streams, and the native aquatic species have already adapted to this condition. The only gauging station that never fell below the threshold was of 7144200. On another note, it seems that many of the streams, especially on the east, are showing a positive trend. But Mann-Kendall trend analysis identified only two streams (i.e. 6889500 and 6892000) to be showing significantly upward trend at an alpha of 0.10. Moreover, it could also be observed that northeast gauging stations have higher values of 3-day minima compared to their southeast counterpart.

High flows

The high flows, represented here by the flow at 10-year return period (Figure 2-9), show that western streams have a lot more differences and variability than the eastern streams. The streams on the east have a general increasing pattern with time except for two stations. While in the west, almost all of the streams show a downward trend. But, one interesting observation is the rebound of the trends during the recent period (1993-2006). Other than the east-west grouping of the stream gauges, one other factor common to them is the magnitude of flow. It is evident that that eastern streams have relatively large unit discharges essentially because of the difference in precipitation received; about twice of the western precipitation. Watershed modifications, such as soil and water conservation structures and practices, probably have minimal impact on the high flows of the streams on the east. However, the same watershed modifications could be one of the driving factors that reduce the high flows in the west. These high flows are relevant in the aquatic ecosystems since they command the changes in the morphology of the streams, rearrange the streambed materials, deliver essential nutrients to the floodplain, and maintain ecosystem diversity in the stream, among other functions.

Figure 2-9. Unit discharge at 10-year return period at the gauging stations of streams in the west and east. The y-axes are in log scale and the unit is l/hr/km^2.



Summary and Conclusions

Streams are one of the valuable resources of the state being shared by numerous users. Agriculture, being the biggest water user, has made a big impact on the water sources. One of its impacts is on the water flowing on the streams and rivers. But Kansas streams are not the same. Most of them are intermittent, but not all of them respond equally from changes in the watershed and climatic conditions. Since the 1930s, Kansas precipitation has been increasing at a slow but steady trend. Most of the eastern streams seem to also have an increasing trend in their high, median and low flows. Western streams do not share the same trend. As evidenced by this study, western streams do not exhibit increasing trend in their median flows. Conversely, the low and high flows are generally decreasing over the decades with an increasing number of days with no (zero) flow. Applying an arbitrary flow threshold, in this case 0.028 m^3/s (1 cfs), the numbers of days below this threshold in western streams are all increasing. Such application of a flow threshold could be the defining factor for the survival or extirpation of certain aquatic organisms.

Changes and activities in the watershed are probably creating the different responses of the streamflow. It should be noted that extensive agricultural development and groundwater abstraction happened in the 1960s through the early 1980s, and these might be the reason for the sudden changes in the low and high flows of the west. The rebound observed in the low flows might be because of the sustained soil and water conservation efforts in agriculture and the relatively high water use efficiency of irrigation systems.

There is now reason to conclude that streamflow aspects of most Kansas streams are changing, and the pattern of changes varies regionally. The major contributing factor for the different response or pattern of change is the precipitation, in terms of the regional difference in precipitation amount, but activities and changes in the watershed are probably more influential. It is therefore important that before making future decisions that will or may have effect on streamflow conditions, it is imperative to consider the local conditions, such as land use, water use, and conservation practices, as well as the watershed's regional or climatic condition, such as precipitation.

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CHAPTER 3 - Historic changes in ecologically relevant hydrologic indices of unregulated Kansas streams

Introduction

Historical background

Historically, Kansas was part of the great expanse of grassland of the Great Plains. Early settlers discovered that tilling this grassland where a thick nutrient-rich topsoil had existed through hundred of years of natural development would be an ideal place to grow agricultural crops. Though the settlers found a lot of difficulty farming in the treeless plain, flat topography and dryland condition, adequate water sources (i.e. streams and aquifer), yet still inaccessible at that time, are available (Koelliker, 1987). Much of the grassland has been tilled without regard for soil conservation and proper residue management. Then, the Dust Bowl of the 1930s came sweeping the unprotected soil destroying crops and livestock as well as taking a toll on human lives. After the Dust Bowl, soil conservation practices were started and farmers found a renewed interest to till Kansas land. Developments in farm mechanization made farming easier and irrigation technologies were already becoming available. Coupled with improved crop management systems, agricultural production in the state was boosted from about 1940 to 1980. The introduction of the turbine pump and the discovery of natural gas in southwest Kansas helped spur the interest in irrigation in the region. By the 1970s, farmers realized that the groundwater was being depleted faster than was being replenished by nature (Froth, 1988; Koelliker, 1987). Koelliker (1987) further states that the number of center-pivot irrigation systems increased rapidly during the 1970s because of their many advantages including better efficiency and lower labor requirements. Over 600 small flood-control and multi-purpose dams and more than 20 large federal reservoirs have been built since the 1950s across the state as part of the watershed projects to reduce local flooding, reduce soil erosion, increase water-based recreation and in some cases provide public water supplies. The combination of surface impoundments and groundwater extractions has created water-availability, as well as water quality problems for the state as a whole (Sophocleous, 1998).

Hydrologic indices

Hydrologic and aquatic studies are highly interlinked, but in many cases, seldom studied together. Often, the hydrologist analyzes the stream mechanics and dynamics as well as streamflow characteristics with minor or little regard to the aquatic resources in the streams, and vise versa to an aquatic biologist. Construction and development of river and stream structures, such as reservoirs, bridges and culverts, to the transformation of land into subdivisions, farms and forests, often have very simplistic estimates on flow prescription for fishery resources (Annear et al., 2004). It is apparent that hydrologic indices have to be established in order to provide aquatic management and ecological studies a sound basis for quantifying streamflow characteristics. Probably one of the most referenced articles on this matter is that of Poff and Ward (1989) when they made a regional analysis of streamflow patterns of 78 streams across the continental United States (US), linking the streamflow variability and predictability to lotic community structure.

There are different ways by which hydrologic indices could be categorized. There are indices that consider the magnitude (i.e., high, median, and low flows), flow variability, duration, timing, frequency and the rate of change of hydrologic events (Lytle and Poff, 2004; Olden and Poff, 2003; Poff and Ward, 1989; Poff et al., 1997). Olden and Poff (1997) conducted a comprehensive review of 171 hydrologic indices to narrow down and remove redundancy in the choice of appropriate hydrologic indices for hydroecological studies. Depending on the stream type, as well as the overriding climatic and geologic environments, certain hydrologic indices can adequately characterize flow regimes in a non-redundant manner (Poff et al., 1997). For example, Kansas streams were characterized as mostly intermittent flashy and perennial flashy types. With such classifications some of the appropriate hydrologic indices include: mean monthly flow, median of annual minimum flows, mean minimum monthly flows, high-flow volume, frequency of low-flow spells, low-flow pulse duration, constancy (Colwell, 1974), seasonal predictability of flooding, change of flow and variability in reversals, among others (Olden and Poff, 2003). These hydrologic indices have relevance to the aquatic ecosystem in terms of community richness, stability and persistence, structure and succession, and population size, recruitment, specialization and emergence (Poff et al., 1997).

Changes on aquatic community and diversity

There are several ways by which the riverine ecosystem could be affected by the changes in streamflow patterns. Flood patterns and frequency, drought, decreased flows or low flows, and average sustained flows are some of the important flow patterns in a river ecosystem. But as far as habitat degradation, vulnerability to extirpation, and critical threshold of existence are concerned, the lower stages of flow are the most important aspect of streamflow patterns for the fish and river inhabitants. In the 2008 annual report of the American Fisheries Society on the conservation status of the North American freshwater and diadromous fishes, it listed habitat degradation and nonindigenous species as the main threats to at-risk fishes and could be associated with the 92% increase in imperilment of inland fishes from its 1989 listing (Jelks et al., 2008).

There is convincing evidence that riverine ecosystems have been affected by the changes in the streamflow patterns. The responses of instream habitat and macroinvertebrates have been studied extensively in a number of streams around the world. Dewson et al. (2007) have a good review on almost all the published research linking decreased flow to instream habitat and macroinvertebrates. Thirty-four (34) documented studies agree fairly well that changes in the physical habitat such as velocity, depth, wetted width, water temperature and sedimentation as a consequence of decreased flow influence on the biotic as well as other abiotic properties of streams. Invertebrate density, richness, and community composition are the most common reported measure of biotic changes in the literature.

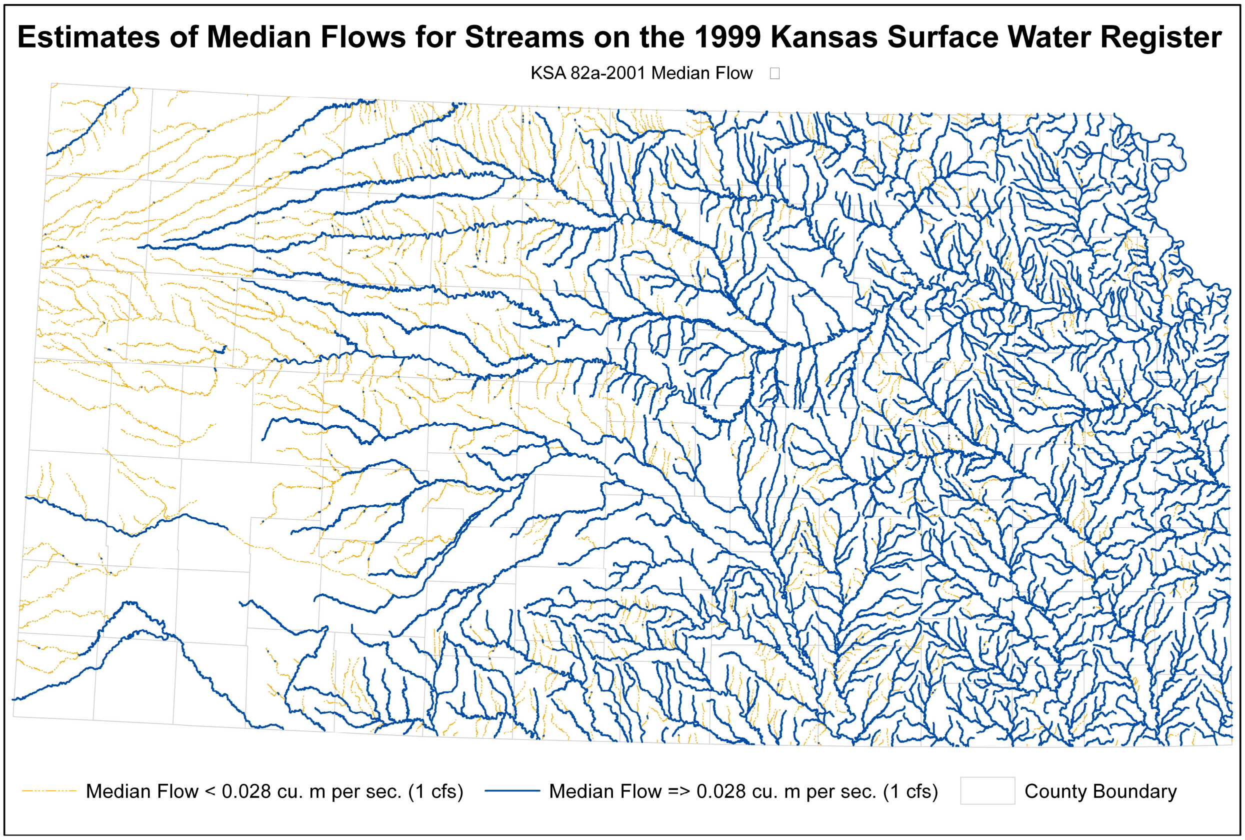
An analysis of fish communities in the Little Arkansas River Basin by Strong et al. (1998) showed that during the last 100 years, fluctuation in the fish community composition was evident. But for the past 25 years of their data, which was composed of observations from 1884 to 1996, two species could no longer be identified. Furthermore, two other species, namely *Notropis topeka* and *Moxostoma macrolepidotum*, were not collected again after it was found in 1884 in Harvey County. *Notropis topeka* is considered sensitive to habitat degradation (Strong et al., 1998).

Relevant research

There is now increasing evidence that the streamflow characteristics of the Great Plains rivers and streams have changed over the past century (Eberle et al., 2002; Perry et al., 2004; Szilagyi, 2006). These streams exist in a precarious balance between flood and drying (Dodds et al., 2004), supporting a very diverse and unique aquatic ecosystem. Although prairie fish living in smaller streams and headwaters are able to muster the typical drought condition, the intensity and the increasingly harsh conditions (Walks et al., 2007) they are experiencing recently are probably taking a toll on them. It is thought that these small fishes and other invertebrates take refuge in perennial pools as the streambed dries, but the changes in these perennial pools over the years is not known (Walks et al., 2007). Many macroinvertebrates have a rapid recovery rate after drought due to their mobility and strategies to survive drying, but the impacts may be disproportionately severe when certain critical thresholds are exceeded (Boulton, 2003).

Attempts to link the streamflow to the aquatic ecosystem are available. Decreases in discharge, in most cases, result in decreases in water velocity, water depth, and wetted perimeter. At the same time increased sedimentation and changes thermal regime and water chemistry result (Angelo, 1994; Clausen and Biggs, 1997; Dewson et al., 2007; Lake, 2003; Olden and Poff, 2003; Poff and Ward, 1989; Poff et al., 1997). In a local study reported by the USGS, Perry (2004) made estimates of the median flows of the streams across Kansas using the 1999 surface water register. The study used a median discharge of one cubic foot per second (0.028 m^3/s) as the threshold delineating the sections of the streams with flow (Figure 3-1). Several studies exist that relate the fish assemblages in the Great Plains streams with reservoirs (Falke and Gido, 2006), hydrologic disturbance (Walks et al., 2007), habitat alterations and non-native species introductions (Eberle et al., 2002). A similar study exists for the Northern Great Plains relating fish assemblages to some streamflow regimes and biotic interactions (Kelly, 2008). Other than these, there has not been a single study that has focused on the hydrologic changes happening on Kansas' streams and that relates those changes to the aquatic ecosystem.

Figure 3-1. Estimates of median flows for streams on the 1999 Kansas surface water register showing stream reaches below and above a threshold flow of one cubic foot per second. Adapted from Perry et al. (2004).



Critical flow conditions for aquatic community

Identifying and specifying critical flow conditions for a stream to support a robust and diverse aquatic community is quite elusive. The Instream Flow Council expended most of its efforts in addressing this concern regarding the optimal flow regime for the aquatic ecosystem (Annear et al., 2004). However, no single and universal flow regime exists because every stream is unique as well as the ecosystem that it supports. Moreover, there is also likely to be a different threshold flow for every individual species in a community. Thus, satisfying the flow requirement of one does not necessarily satisfy another. One of the approaches then is to restore the “original” natural flow regime of the stream (Annear et al., 2004; Poff et al., 1997). This approach is widely accepted, but defining and establishing the natural flow regime in most cases is also difficult. Most of the streams in Kansas, for example, have undergone a major shift during the late 1800s, through the transformation of the rangelands into agriculture (Walks et al., 2007). Those changes occurred before measurements of daily discharges in the streams were started. For the purpose of this study, the critical flow conditions include the low-flow measures, intensity of low-flow, below threshold flow which is 0.028 m^3/s (1 cfs), intensity of below-threshold flow, and several other relevant hydrologic indices suggested by Poff and Ward (1989) and Olden and Poff (2003). Table 3-1 summarizes the important hydrologic indices and the potential biological attributes in lotic habitats mostly adapted from Poff and Ward (1989) and Indicators of Hydrologic Alteration (IHA) Version 7 documentation (The Nature Conservancy, 2007, unpublished data).

Table 3-1. Summary of hydrologic indices and its associated potential ecosystem influences.

Flow factor	**Hydrologic index**	**Ecosystem influence and biological attributes**
Intermittency	• Magnitude and frequency of low- and zero flows • Timing of zero flows • Flows below threshold	• Enable recruitment of certain floodplain plant species • Purge invasive, introduced species from aquatic and riparian communities • Concentrate prey into limited areas to benefit predators • Upstream migrations following resumption of flow • Increased physiological eurytopy or environmental adaptation • Possible extirpation of some species
Flow predictability	• Colwell's predictability • Constancy / predictability • Annual coefficient of Variance • Mean annual flow	• Habitat availability for aquatic organisms • Access by predators to nesting sites • Availability of water for terrestrial animals • Influences water temperature, oxygen levels, water chemistry and photosynthesis in water column • Soil moisture availability for plants • Reliability of water supplies for terrestrial animals

Flow factor	**Hydrologic index**	**Ecosystem influence and biological attributes**
Flow predictability (continued)		- Enabling fish and amphibian eggs suspended - Enable fish to move to feeding and spawning areas - Maintains trophic complexity
Flood predictability / frequency	- Flood frequency, magnitude, timing, duration - % of floods in 60-day period - Flood-free season	- Behavioral and/or life history avoidance of floods - Maintain balance of species in aquatic and riparian communities - Provide migration and spawning cues for fish - Trigger new phase in life cycle (i.e. insects) - Deposit cobbles and gravel in spawning areas - Flush organic materials and woody debris into channel - Control distribution and abundance of plants on floodplain - Purge invasive, introduced species from aquatic and riparian communities - Shape physical character of river channel including pools and riffles - Restore normal water quality conditions after prolonged low flows

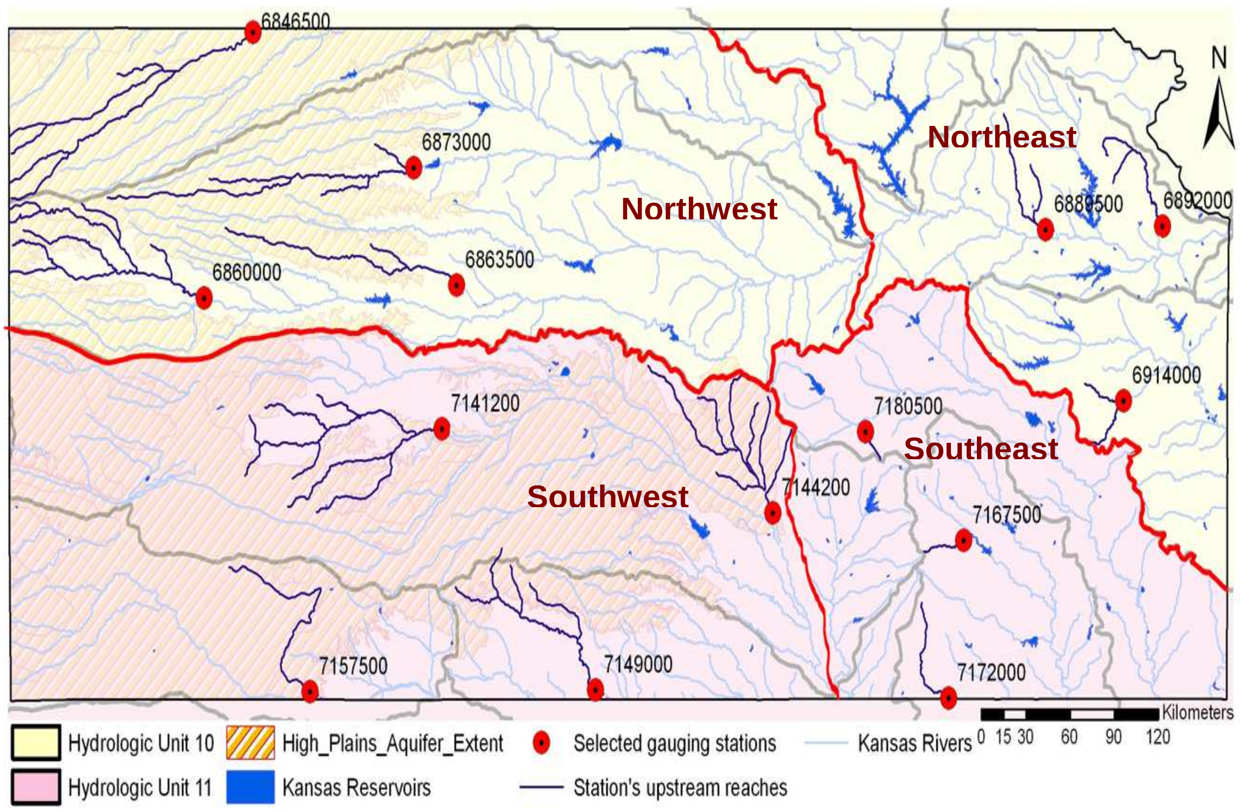
Methods

Data and gauging stations

The availability and length of daily discharge data and whether the stream is unregulated as indicated in the remarks of the USGS Water-Data Reports (Putnam and Schneider, 2003) were the main criteria in selecting the gauging stations for this study. An unregulated stream denotes the absence of major reservoirs and diversion dams upstream of the gauging stations that would otherwise substantially influence the streamflow. However, there may be substantial groundwater abstraction and irrigation activities within the watershed that may somehow affect the streamflow at the gauging station. Unlike regulated streams, which have a relatively abrupt change in its streamflow pattern, the unregulated streams were expected to have a gradual shift on some of their hydrologic indices over the period of record.

Another consideration is the spatial distribution of the gauging stations (Figure 3-2). Two considerations were taken into account: the north-south and east-west orientation, and the ecoregional representation. It should be noted that Kansas climate varies more greatly from east to west than from the north to south. However, the water resources regions by the USGS, which are based on the major watershed divide between the Kansas and Arkansas Rivers, is on a north-south orientation (Figure 3-2). This study looked at these orientations as possible reasons for the variations of the streamflow pattern. The regional grouping coincides, with minor modification, with the fish ecoregions identified by Hawkes and others (1986) based on ecologically meaningful fish assemblage and canonical discriminant analysis of environmental variables (i.e., mean annual runoff, mean annual growing season, and stream discharge).

Figure 3-2. Location of the gauging stations used for this study and the regional grouping.



Comparison of hydrologic indices

The “approved” USGS daily streamflow data were downloaded from the USGS website (http://waterdata.usgs.gov/ks/nwis) for the calendar years starting 1931 through 2006. A summary of the gauging stations is presented in Table 3.2. A regional grouping was also adopted to capture the similarities between streams in terms of fish assemblage (Hawkes et al., 1986), watershed divides, and climatic characteristics (Sophocleous, 1998). Most of the hydrologic indices were computed using the Indicators of Hydrologic Alterations (IHA) software which is a well-documented (Colwell, 1974; Poff and Ward, 1989; Richter et al., 1996; Richter et al., 1997; Richter et al., 1998) and popular software package used for many environmental studies. The following parameters or indices were computed as described by Poff and Ward (1989), Colwell (1974) and the IHA V.7 documentation:

Table 3-2. Summary of data and other important characteristics of the USGS gauging stations

Station No	**Name**	**Start date**	**Effective Drainage Area (km^2)**	**Remarks**	**Region**
6846500	BEAVER C AT CEDAR BLUFFS	5/13/1946	3,429		Northwest
6860000	SMOKY HILL R AT ELKADER	10/1/1939	9,207		
6863500	BIG C NR HAYS	4/1/1946	1,421		
6873000	SF SOLOMON R AB WEBSTER RE	1/8/1945	2,694		
6889500	SOLDIER C NR TOPEKA	5/23/1929	751		Northeast
6892000	STRANGER C NR TONGANOXIE	4/21/1929	1,052		
6914000	POTTAWATOMIE C NR GARNETT	10/1/1939	865	Discontinued after 2000	
6914100	POTTAWATOMIE C NR SCIPIO	10/1/2000	888	Replaced 6914000	
7141200	PAWNEE R AT ROZEL	10/1/1924	5,206		Southwest
7144200	L ARKANSAS R AT VALLEY CENTER	6/10/1922	3,237		
7149000	MEDICINE LODGE R NR KIOWA	2/11/1938	2,339		
7157500	CROOKED C NR ENGLEWOOD	10/1/1942	2,106		
7167500	OTTER C AT CLIMAX	10/1/1946	334		Southeast
7172000	CANEY R NR ELGIN	10/1/1939	1,153		
7180500	CEDAR C NR CEDAR POINT	10/1/1938	285		

1. Mean flow – magnitude of water flowing over a certain time (e.g. annual and monthly) using assuming a normally-distributed data set.
2. Mean unit discharge – mean flow divided by the drainage area expressed for this purpose in liters per second per square kilometer ($l/s/km^2$).
3. Annual coefficient of variation (C.V.) – standard deviation of all daily flow values divided by the mean annual flow.
4. Flow predictability (P)– Colwell's (1974) predictability index for all flows over the period of record. The value of predictability ranges from 0 to 1 and is composed of two additive components: constancy (C), a measure of temporal invariance, and contingency (M), a measure of periodicity (readers are directed to Collwell 1974 for the detailed computation and description of these two components). Predictability of a stream with a very constant flow is mainly due to constancy while that of a highly variable flow, with a fixed periodicity, will be mostly due to contingency.
5. C/P – flow constancy over flow predictability computed as C / (C+M).
6. Percent of floods in 60-day period (Flood 60D)– maximum proportion of floods that occur during any common 60-day period in all years during the period of analysis. Floods are defined here as any flows above the high-pulse threshold (flow exceeding 75% of flows for the period of analysis).
7. Length of flood-free season – length in days of the longest period where flows are at or below the high pulse threshold (as defined in #6) in every year.
8. Low-flow frequency, timing and duration – low flows are defined as any flows below 25% of flows for the period of analysis.
9. Flood frequency, timing and duration - floods are defined as any flows exceeding 75% of flows for the period of analysis.
10. Magnitude and frequency of annual-extreme flow conditions.
11. Baseflow fraction – used Baseflow Filter Program, an automated baseflow separation technique utilizing the automated recursive digital filter technique (Arnold, 1995) downloaded online at www.brc.tamus.edu/swat/soft_baseflow.html.

Several other hydrologic indices were computed using the zero-flow days and flow below threshold level. These include:

12. Duration of consecutive days with zero flow and below threshold flow.

13. Seasonal (related to spawning period) occurrence with zero flow and below threshold flow.
14. 5-year trailing average – some of the parameter values were computed by averaging the value of the present year together with the values for the four preceding years.

Timeline of analysis

In synchronization with the Kansas fish collection data (K. Gido, 2007, personal communication), periods of analysis were established with length of each period at around 15 years. The periods identified are: 1931-47, 1948-62, 1963-77, 1978-92 and 1993-2006. Other than being coincident with the fish collection data, these periods also coincide with some events in agriculture, climate and irrigation. The first period could be associated with the time before soil and water conservation and irrigation were widespread in Kansas. The next period, 1948-62, corresponds to the time when the large federal reservoirs were constructed causing and fragmentation of major streams, and at the same time agriculture was steadily developing conservation techniques. The 1963-77 interval represents the period of rapid increase in groundwater extraction from irrigation development. Adoption of more irrigation tapered off and crop residue management was being practices increased around 1978-92 (Rogers and Alam, 2008). The period of 1993-2006 represents the sustained soil and water conservation efforts in agriculture as well as higher water-use efficiency of irrigation systems. Finally, for studies on dryland watersheds, a minimum of 15 years is needed to establish reasonable average to minimize variations due to climatic effects (Hauser, 1968). In some of the analyses, the computation and comparison of periodic values were only from 1948 through 2006 because not all gauging stations have data starting as early as 1931 (Table 3-2).

Trend analysis

Trend analysis was performed for a number of parameters. The Mann-Kendall trend analysis was employed to determine if there is a statistically-significant upward or downward trend over time in the dataset. Mann-Kendall analysis is a non-parametric method suitable for detecting trends for non-normally distributed data such as most hydro-climatic datasets (Yue et al., 2002), and it establishes if the dataset has a significant positive or negative trend. The standardized normal test statistic, z, is the basis for evaluating the trend. A positive z value indicates an upward trend, while a negative one indicates a downward trend. However, the magnitude and the true slope of the trend are not computed by this method. Thus, the Sens' slope estimator was utilized for this purpose. The Sen's slope nonparametric method is used in cases where the trend can be assumed to be linear by calculating the slopes of all data value pairs before consolidating it into one slope value representing the trend line (Salmi et al., 2002).

The Makesens program, a MS Excel template provided by the Finnish Meteorological Institute (http://www.fmi.fi/organization/contacts_25.html - accessed 29 April 2009), was used in performing the trend analysis.

Results and Discussions

General characteristics

The major hydrologic indices are presented in Table 3-3 to get a glimpse of the general characteristics of the selected unregulated streams and these were computed based on all the available records since 1931. The mean unit discharge clearly depicts the differences in the climatic condition which differentiates the eastern and western regions of the state. The unit discharges of the streams in the east are usually more than twice the amount on the west.

Poff and Ward (1989) have computed some values for the hydrologic indices that were part of the suite of parameters used for characterizing the streams (Table 3-4). The values they computed in 1989 for two other streams in Kansas give us some indication of what happened recently with some of our streams. The percent of floods occurring in any 60-day period has markedly decreased. This corroborates with the information on the proportion of total predictability comprised by constancy or C/P which has actually increased in values ranging from 0.69-0.89. These values of C/P are close to being in the perennial flashy class. But keep in mind that the intermittency, which deals with zero and low flows, has not yet been considered here.

Flow predictability

Comparing the percent difference between the long-term (using all data for the station) and periodic annual C.V., predictability and C/P, it is evident that flow predictability (red bars) is

Table 3-3. General characteristics of the unregulated stream based on the major hydrologic indices

Station No.	Mean annual flow	Mean Unit Discharge	Annual C. V.	Predict-ability (P)	C/P	Flood 60D	Region
	m^3/s	$l/s/km^2$					
6846500	0.34	357	6.67	0.45	0.89	0.36	NW
6860000	0.61	239	9.53	0.33	0.79	0.28	
6863500	0.87	2,204	6.25	0.24	0.77	0.29	
6873000	1.41	1,884	7.83	0.29	0.71	0.27	
6889500	4.33	20,756	4.16	0.20	0.72	0.26	NE
6892000	8.67	29,669	4.12	0.22	0.71	0.29	
6914000	6.44	26,802	4.19	0.28	0.75	0.26	
7141200	1.64	1,134	6.37	0.30	0.86	0.34	SW
7144200	8.80	9,787	3.57	0.28	0.81	0.27	
7149000	4.20	6,464	2.38	0.34	0.71	0.25	
7157500	0.79	1,350	6.35	0.38	0.73	0.22	
7167500	2.35	25,329	5.72	0.26	0.72	0.28	SE
7172000	7.65	23,886	4.19	0.24	0.69	0.27	
7180500	1.61	20,337	4.82	0.23	0.73	0.25	

Table 3-4. Some of the hydrologic indices used in the stream classification by Poff and Ward (1989)

Hydrologic index	Kansas stream representative		Stream classes			
	Smoky Hill river	Rattlesnake creek	Intermittent flashy	Perennial flashy	Harsh intermittent	Intermittent runoff
Predictability	0.16	0.33	0.29	0.49	0.29	0.25
C/P	0.31	0.79	0.30	0.80	0.54	0.32
Flood 60D	0.57	0.50	0.61	0.48	0.59	0.55
Mean Annual Flow	0.90	1.00				

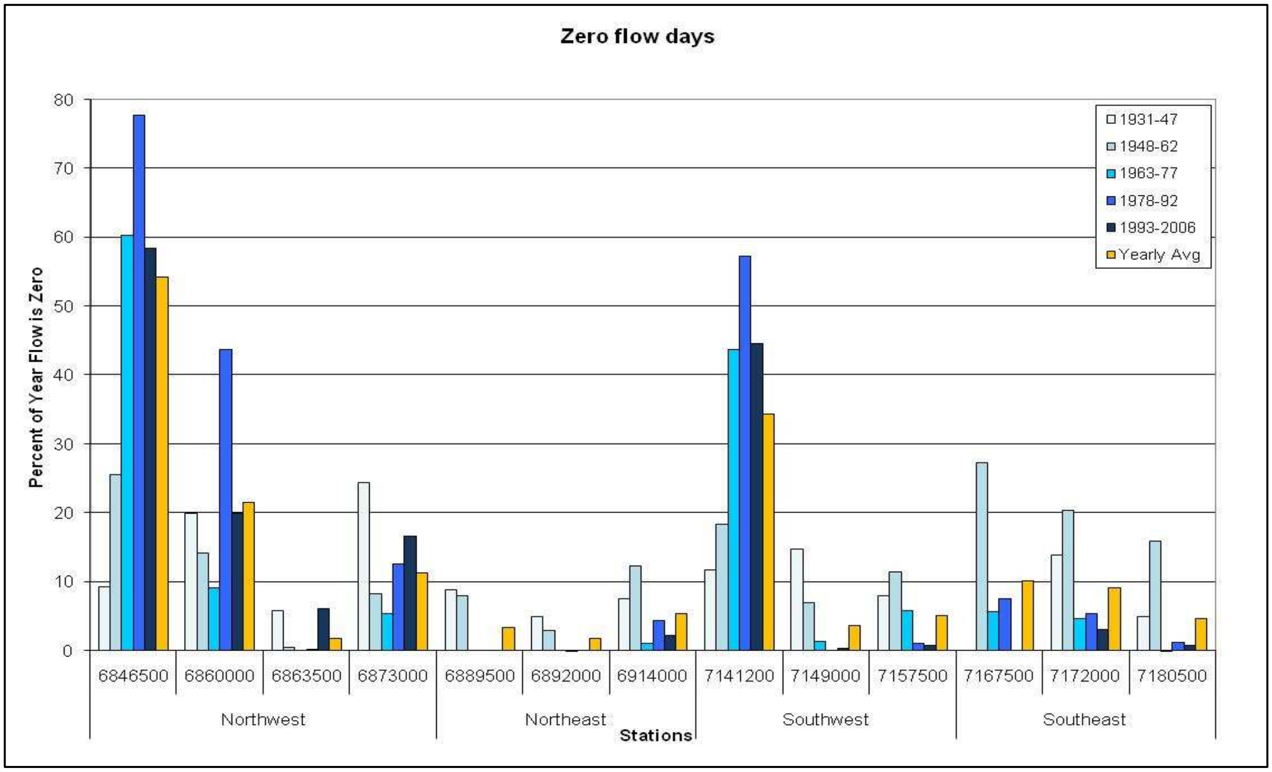
always above the long-term values (Figure 3-3). Conversely, the constancy-predictability ratio (green bars) is almost always below the long-term value. It is difficult to draw any conclusive statement here since the long-term indices consider all values of the record but do not necessarily represent the natural or original flow conditions for the stream. Somehow, during the small periods of analyses, the variations in flow could have been attenuated as observed for the lower (negative percent difference) annual coefficient of variance of almost all gauging stations. But useful information that can be deduced here is that there is a relative increase in predictability and C/P between periods in many of the western streams compared to the eastern streams. Poff and Ward (1989) describe C/P as the proportion of total predictability comprised by constancy. It goes to say that as the predictability increases in the west, constancy is probably the main driving factor causing it. This does not necessarily mean a stable and dependable flow, but whatever the flow, it is somehow becoming more constant (and is taking over on the influence of contingency (M), which is associated with periodicity).

Intermittency and low-flows

The first measure of intermittency is the number and frequency of days when the flow in the stream is essentially zero. A zero in the discharge data does not necessarily mean that no water is flowing, but that it is below the lowest measurable flow, which is 0.01 cfs (0.00006 m^3/s), at the USGS gauging station. Actual condition of the stream could have the presence of pools deep enough to accommodate some fishes and invertebrates and support other aquatic organisms. But it could also be that at zero flow the stream is totally dry and could even be in a water deficit condition that would require water to be added just to wet the stream. The percent of time the flow is zero per period was computed and presented in Figure 3-4. Over the period of time, four western stations (i.e., 6846500, 6860000, 6873000 and 7141200) exhibited an increasing percentage of zero flow days per year. All other stations, however, seem to be improving over the period. The range of the yearly average is between 22-54 percent. Bringing this into the context of the aquatic organisms, the streams in which they are living are not flowing at most half of the time.

Figure 3-3. Percent difference of the periodic values of annual coefficient of variance, predictability and ratio of constancy and predictability with its long-term values

Figure 3-4. Annual percent of days flow is zero.



Looking at the 5-year trailing-average number of days per year flow is zero (Figure 3-5) is not at all favorable for the aquatic organisms for at the same four western stations. These stations show a steady increase in the number of zero days. Two of the stations (i.e., 6846500 and 7141200) are already in the 300-days per year level, which is more than 80 percent of the time. Other than the four stations previously identified, the other stations seem to be improving compared to their historic values in terms of this index. The periodic increase in the zero flow days could be associated with the decrease in precipitation totals or climatic droughts.

Applying a threshold level of flow of 0.028 m^3/s (1 cfs), the 5-year trailing averages of the days below this threshold are presented in Figure 3-6. Five stations in the west are now somewhere in their highest recorded values, and most of them are exhibiting an upward trend in the number of days per year below the threshold level. One station in the east (i.e., 6914000) is also exhibiting an upward trend in the recent years. Although the behavior of the graphs is similar to the zero days (Figure 3-5), the magnitude is around 50 percent higher for several of the peaks.

Trend analysis of the flow intermittency (Table 3-5) would support some of the observed trends in the Figures 3-5 and 3-6. Three of the stations in the west show important and significant increasing trend. Although a decreasing trend was also detected at four stations in the south, the magnitude of change, in terms slope (Sen's slope in days per year), is relatively small.

Table 3-5. Mann-Kendall and Sens slope analyses result for the flow intermittency.

Region	Stations	Days of zero flow			Days of below 1cfs flow		
		Test Z	*Signific.*	*Sen's slope*	*Test Z*	*Signific.*	*Sen's slope*
NW	6846500	5.30	***	4.507	5.19	***	3.577
	6860000	1.95	+	0.684	6.96	***	4.226
	6863500	0.16		0.000	0.72		0.000
	6873000	0.81		0.000	1.47		0.737
NE	6889500	0.09		0.000	-1.14		0.000
	6892000	0.09		0.000	-1.17		0.000
	6914000	-1.52		0.000	0.68		0.346
SW	7141200	5.27	***	3.045	5.48	***	3.580
	7144200						
	7149000	-2.07	*	0.000	-2.73	**	-0.001
	7157500	-2.28	*	-0.004	-2.33	*	-0.182
SE	7167500	-1.73	+	0.000	-0.96		-0.260
	7172000	-2.96	**	0.000	-0.46		0.000
	7180500	-1.57		0.000	-1.52		0.000

*** 99.9% significance ** 99% significance * 95% significance
+ 90% significance (blank) below 90% significance

These conditions of zero and below-threshold flow add evidence to the idea that some of the flashy intermittent streams have become harsher for aquatic organisms that now have to contend with dry streams more than 50% of the time in some streams found in the western region. The survival techniques of the native fishes and invertebrates are now being challenged. But on the other side, the streams on the east are now experiencing fewer days of zero flows. This may be advantageous for the native fishes since their stress levels may be reduced. However, this may have some other repercussions on the natural selective capacity of the streams. With shorter periods of zero flow, this could encourage more invasive fishes and aquatic organisms that were once held aback and unable to tolerate long periods of zero flow or intermittency.

Figure 3-5. Five-year trailing average of days per year flow is zero at each station

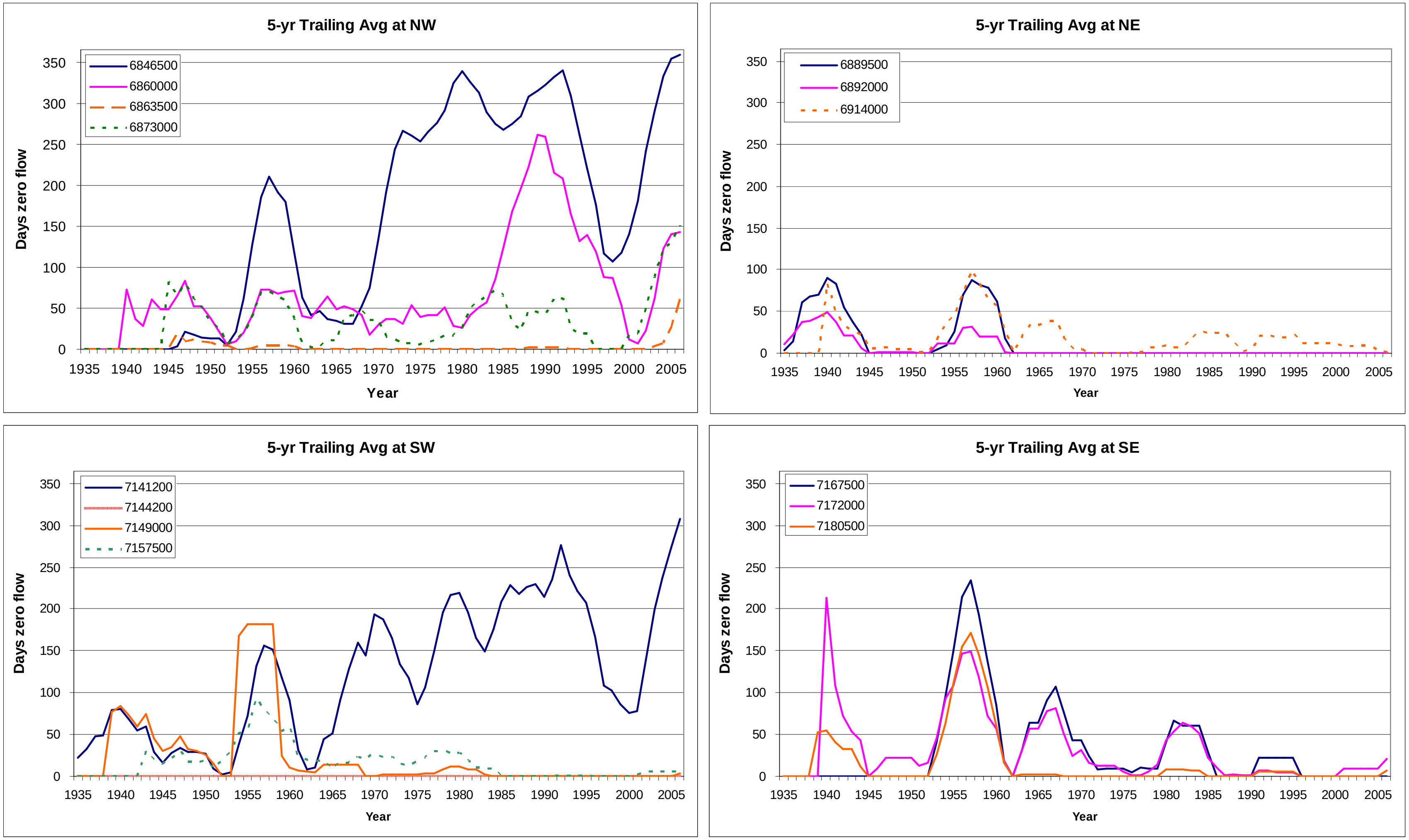
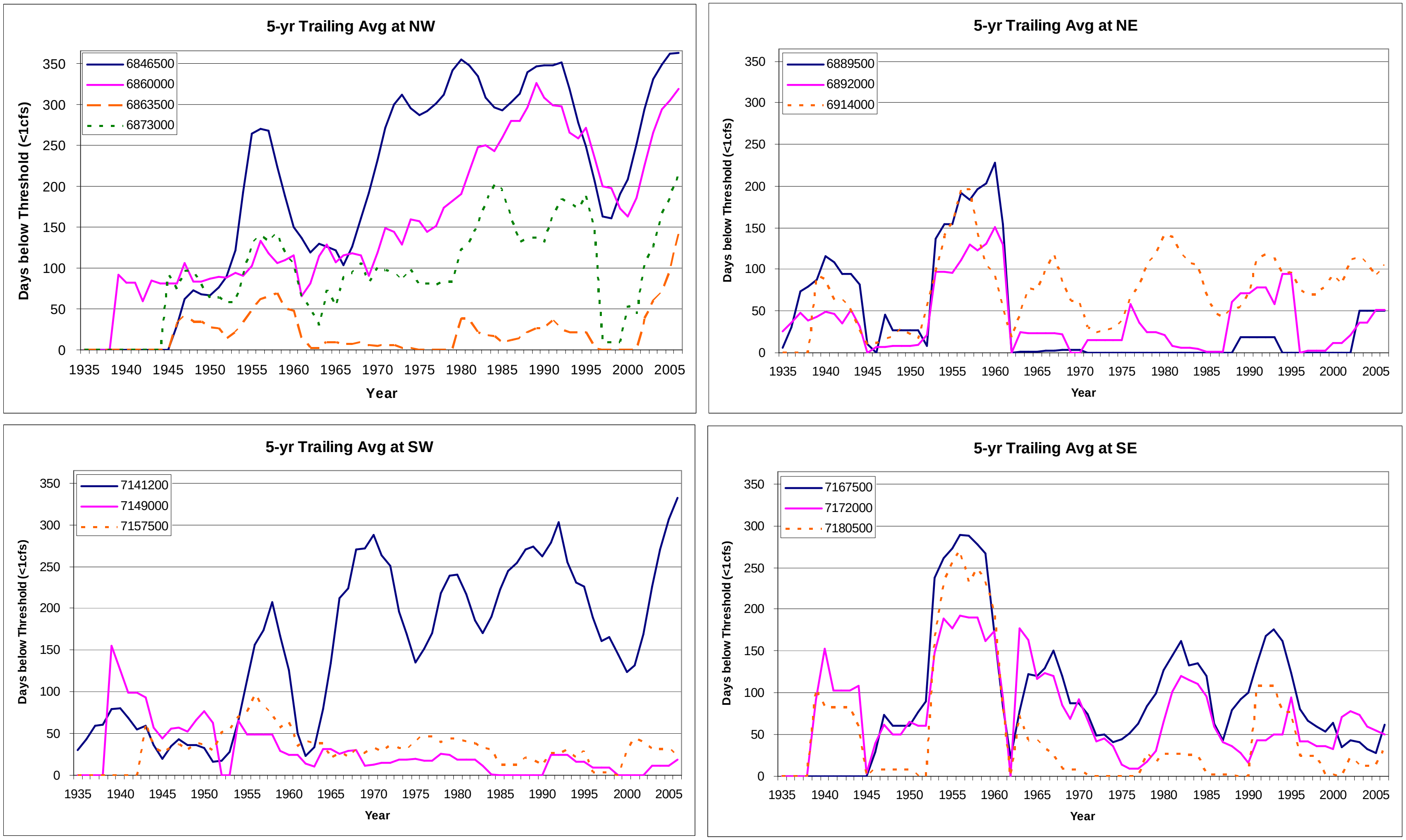


Figure 3-6. Five-year trailing averages of days per year flow are below threshold level of 0.028 m^3/s (1 cfs) at each station



The duration of the dry spell, which is for example flow below the threshold level (Figure 3-7), was also analyzed. It appears that almost half of the stations have increased and the other half decreased their duration of dry spells. Most of the stations that increased are in the northwest region, and those that decreased are in the southeast. Comparing the magnitude of change, the increase was very drastic in most cases. Two stations showed increased duration of the dry spell by around three to four times. Such an increase in duration may be drastic changes for the aquatic organisms to cope with. Another notable observation on the majority of the stations is an improvement for the streams by having shorter duration of dry spells in the recent (1993-2006) compared to its prior period (1977-1992).

The 3-, 7- and 30-day minimum flows were explored and the graph of the 7-day minimum is presented in Figure 3-8 (which was also similar the 3-day and 30-day graphs) (see Appendix A). It is observed that there are many stations in the west that show no discernable trend over the years, but there is a noticeable rebound in improved flow during the recent wet years (1993-2006). However, even the occurrence of wet years now is not a guarantee that the low flows will increase following wet periods. This was a general observation for the western as well as some eastern stations. Even the trend analysis has detected some very minimal, though some are statistically significant, changes (Table 3-6).

A quick check on the baseflow at station 6860000 shows that the proportion of baseflow and surface runoff did not change much over time (Figure 3-9). However, both the baseflow and the surface runoff amounts are decreasing over the decades. The apparent increase in streamflow during the 1990s is caused by the relatively wet years of 1992 and 1993. Otherwise, the general trend in the streamflow is decreasing despite relatively constant amount precipitation in the area (Aguilar et al., 2008; Walks et al., 2007).

Figure 3-7. Average duration of yearly dry (below threshold) spell at each station and region.

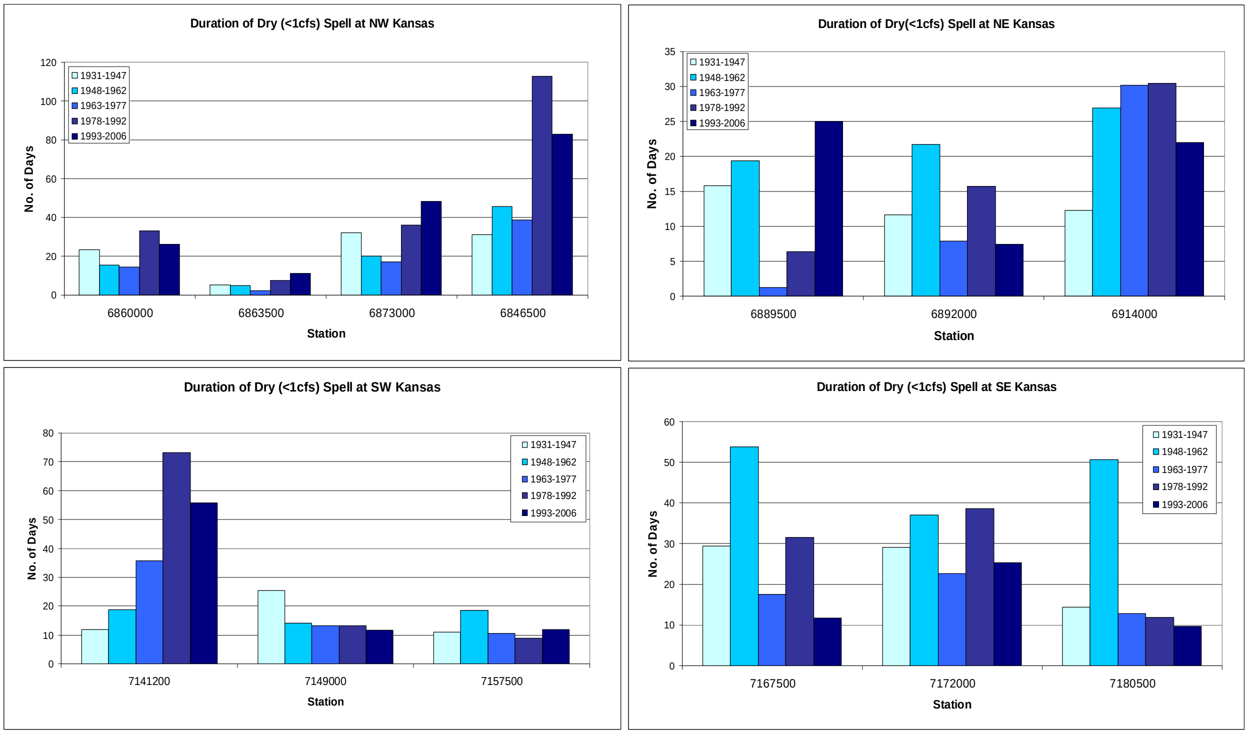
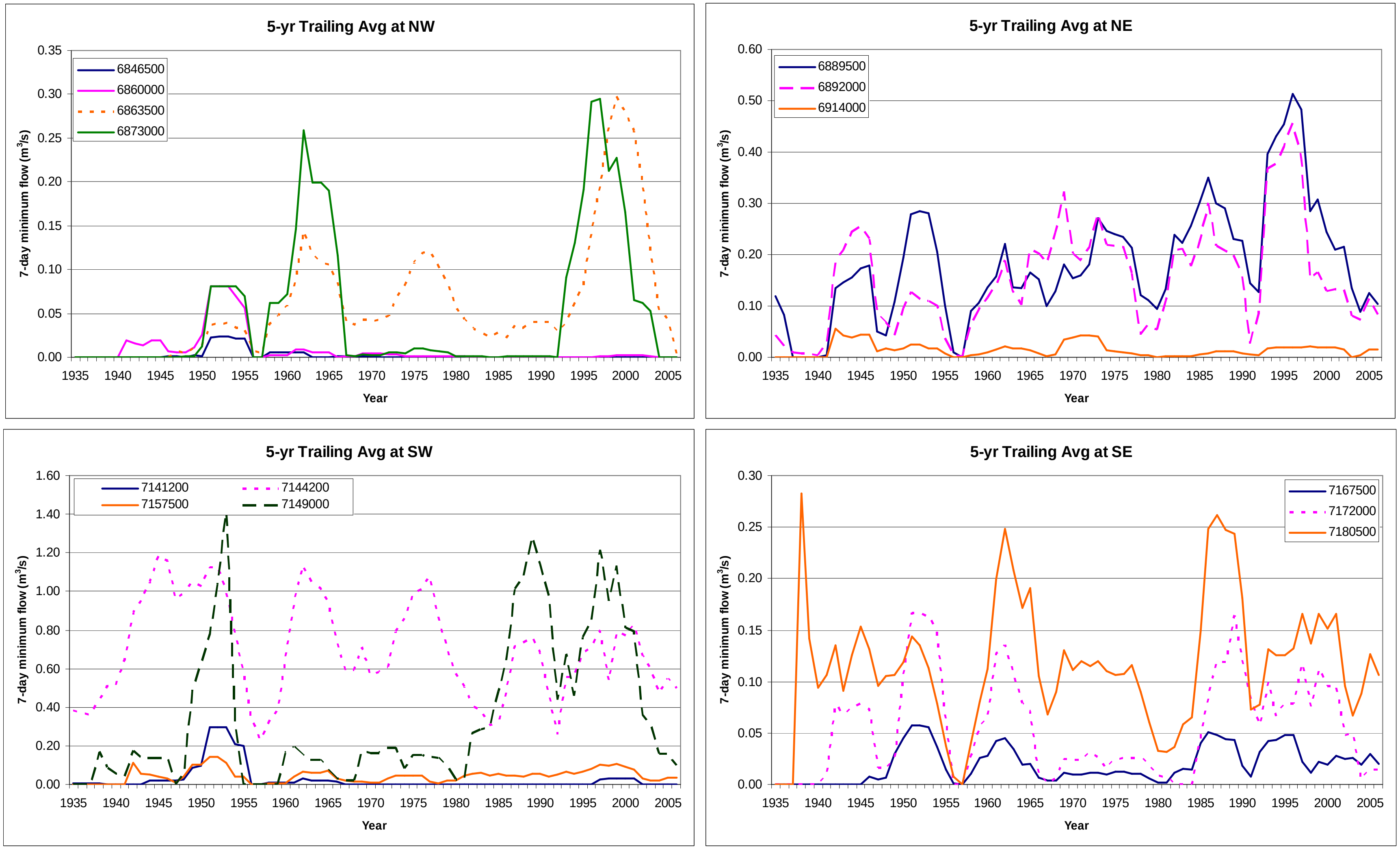


Table 3-6. Mann-Kendall and Sen's slope analyses result for the low flow and occurrence of low flow.

Region	Stations	7-day minimum			Day of year minimum flow occurs		
		Test Z	*Signific.*	*Sen's Slope*	*Test Z*	*Signific.*	*Sen's Slope*
NW	6846500	-2.94	**	0.000	-2.92	**	-0.001
	6860000	-1.13		0.000	-0.69		-0.099
	6863500	0.15		0.000	0.46		0.242
	6873000	-0.88		0.000	1.11		0.500
NE	6889500	2.24	*	0.002	1.06		0.256
	6892000	1.89	+	0.001	1.53		0.407
	6914000	-0.65		0.000	1.26		0.407
SW	7141200	-2.53	*	0.000	-3.04	**	-0.937
	7144200	-0.35		-0.001	1.56		0.500
	7149000	2.61	**	0.005	2.76	**	0.550
	7157500	0.63		0.000	3.95	***	1.033
SE	7167500	1.06		0.000	3.32	***	1.396
	7172000	1.13		0.000	3.40	***	0.941
	7180500	0.28		0.000	3.17	**	1.121

*** 99.9% significance ** 99% significance * 95% significance
+ 90% significance (blank) below 90% significance

Figure 3-8. The 5-year trailing average of 7-day minimum flows at each stations grouped by region.



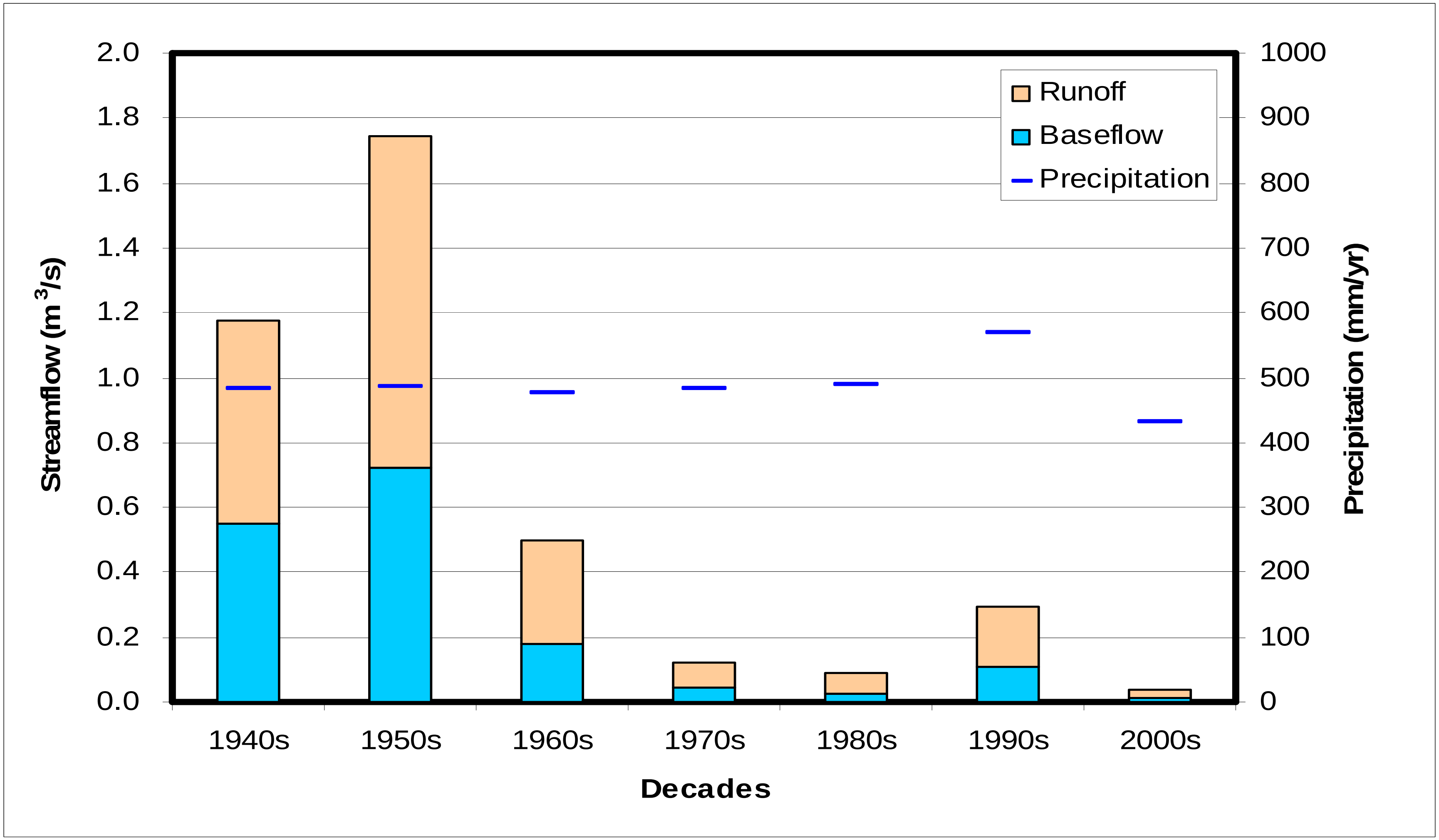


Figure 3-9. Separated total streamflow and precipitation by decades at station 6860000

There is a big variability in terms of timing of low-flow occurrence (Figure 3-10), especially in the west. Running simple linear regression shows that most of them are now occurring latter in the year. This general trend is also observable in the results of the Mann-Kendall and Sen's slope analyses, whereby five stations in the south are even showing a high significance level for the increasing trend. Three stations, 6846500, 6860000 and 7141200, show a downward trend or an earlier occurrence of the low-flow. But, except for 6860000, only two are statistically significant (Table 3-6). Just to clarify this trend, the method in identifying the low-flow timing is reset every year to the start of the year and will only consider one instance for the year. In some cases for these stations, the actual low-flow (in many instances zero flow) commenced the previous year, but will register on the first day of the following year. Nonetheless, if there is a shift in the low-flow timing, this would definitely affect the migration pattern or timing, availability of some nutrients or prey (as well as being preyed-upon), and other ecological functions.

Flood events

Flood events, in terms of the 7-day maximum, seem to be decreasing in magnitude in many of the western stations (Figure 3-11). It is evident in the northwest region where all the stations have this decreasing trend. The reduction is more than half of the flood magnitude in the 1940s compared to the recent years. Conversely, the eastern stations seem to show a steadily increasing trend in all of its stations. The Mann-Kendall and Sen's slope analyses (Table 3-7) show statistically significant trend on this index, especially on the downward trends of the stations in the northwest and some on the southwest regions.

The timing of occurrence of these floods is relatively concentrated during the summer in the western regions, and during the late spring for the eastern regions (Figure 3-12). In terms of variability, eastern regions have a greater variability in the timing of these flood events as compared to the western regions. Except for two stations (6873000 and 7141200), no significant trend were detected on this index.

Figure 3-10. Annual timing of low-flow at each stations grouped by regions. Trend lines were supplied and are represented by the same color of the dataset.

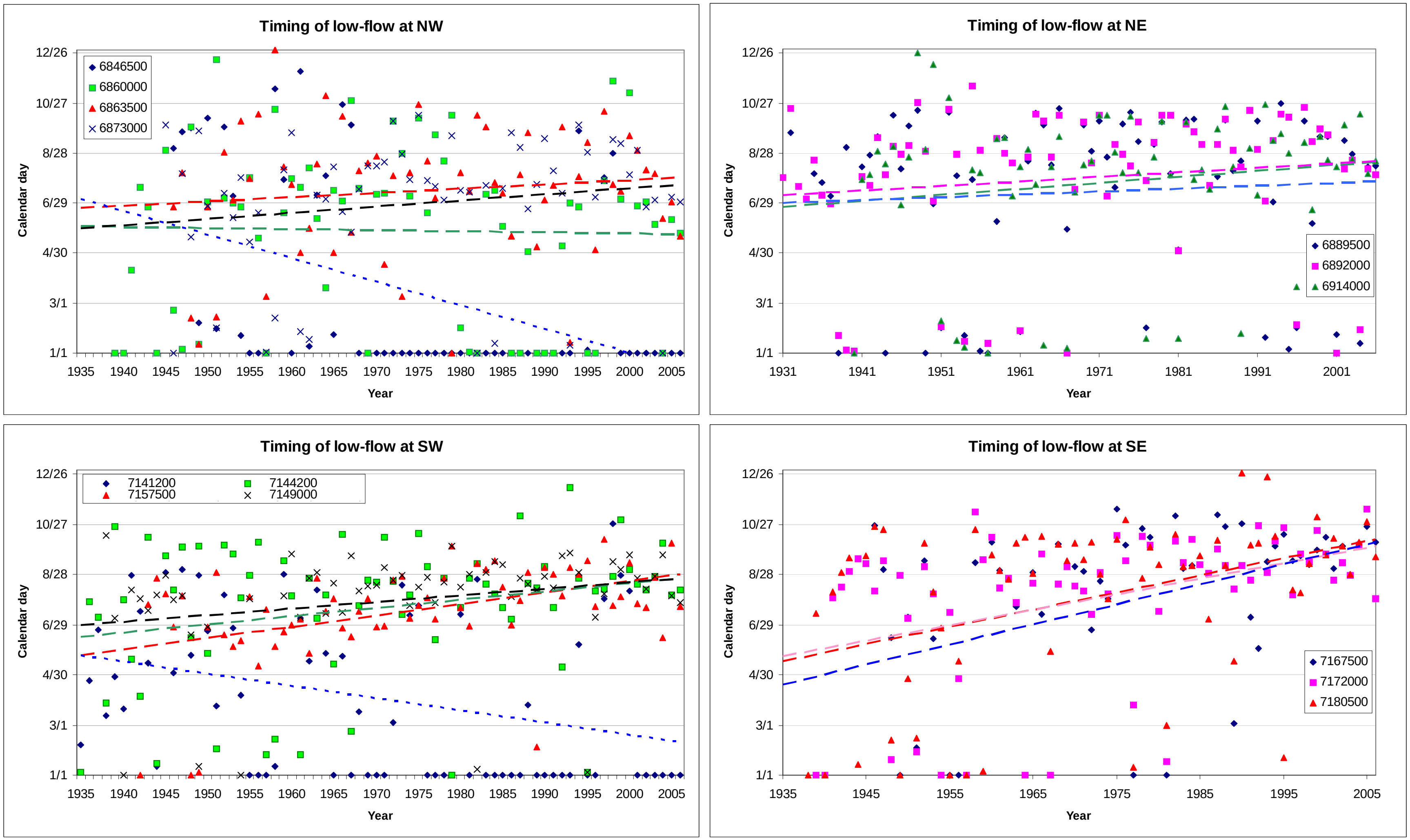


Figure 3-11. Graph of 5-year trailing averages of 7-day maximum grouped by regions.

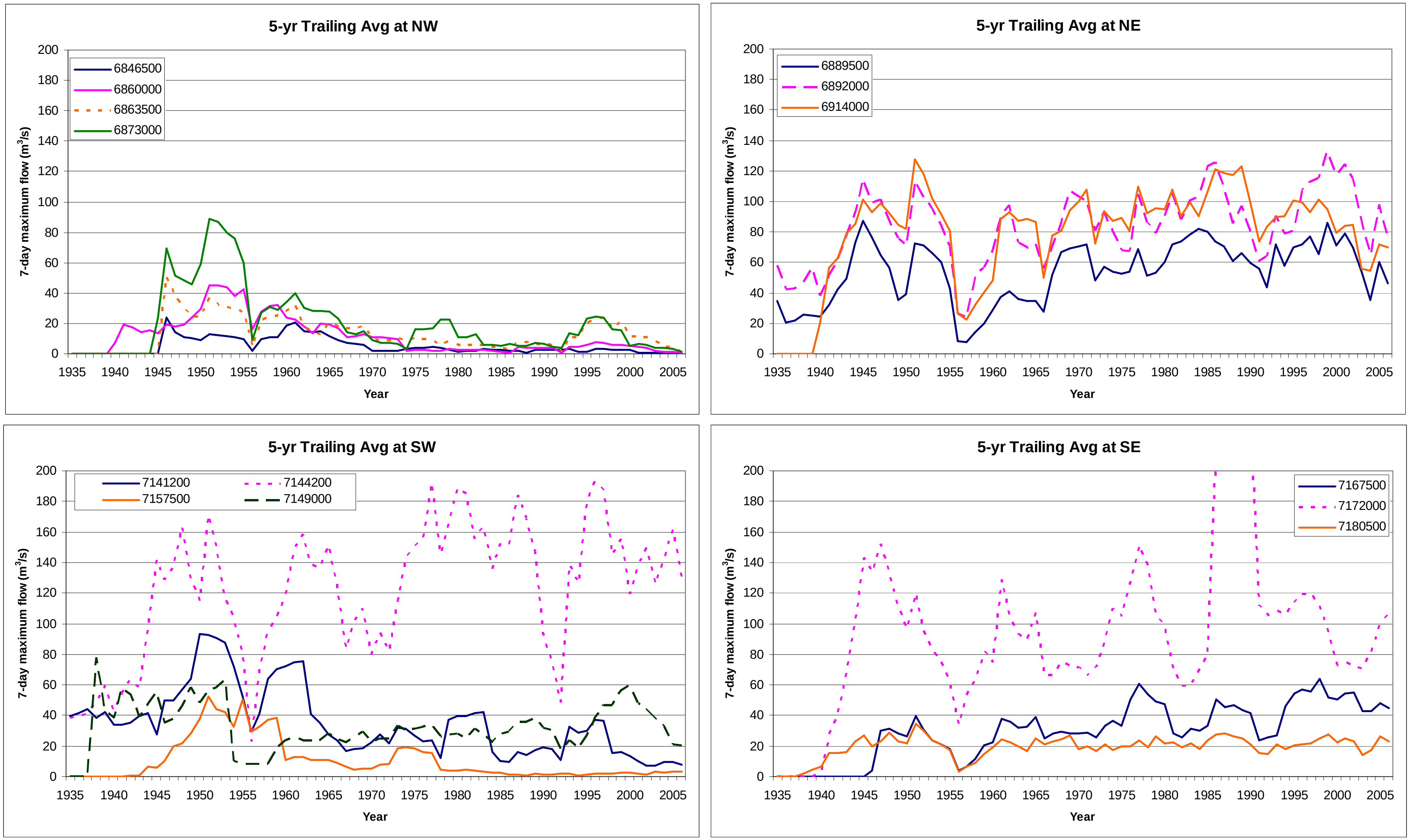


Figure 3-12. Timing of occurrence of flood events (>75% recurrence interval for a station) in each gauging station grouped by region. Trend lines were supplied and are represented by the same color of the dataset.


Timing of high-flow at NW

Timing of high-flow at NE

Timing of high-flow at SW

Timing of high-flow at SE

Table 3-7. Mann-Kendall and Sen's slope analyses result for the high flows and occurrence of high flow.

Region	Stations	Day of year max. flow occurs			7-day Maximum Flow		
		Test Z	***Signific.***	***Sen's Slope***	***Test Z***	***Signific.***	***Sen's Slope***
NW	6846500	1.21		0.375	-5.00	***	-0.080
	6860000	1.16		0.386	-3.31	***	-0.114
	6863500	1.28		0.664	-3.49	***	-0.184
	6873000	-1.96	+	-0.895	-4.79	***	-0.287
NE	6889500	0.28		0.103	2.18	*	0.387
	6892000	-0.02		0.000	1.97	*	0.548
	6914000	-0.95		-0.467	0.57		0.192
SW	7141200	1.67	+	0.500	-3.52	***	-0.348
	7144200	-1.00		-0.396	2.49	*	1.040
	7149000	-0.46		-0.229	1.12		0.199
	7157500	-0.80		-0.414	-4.46	***	-0.133
SE	7167500	-0.07		-0.045	2.82	**	0.514
	7172000	0.43		0.219	0.75		0.301
	7180500	-0.50		-0.219	1.03		0.078

*** 99.9% significance　　** 99% significance　　* 95% significance
+ 90% significance　　(blank) below 90% significance

Flood events provide a "reset" function in the streams. The reduction in these flood events in terms of magnitude and frequency pose a different condition in the streams that the aquatic organisms must deal with. Perhaps, the deterioration of water quality and the delivery of the essential nutrients are just some the negative implications. The eastern streams seem to be in a better position to deal with these problems since many of the streams in that region are gaining flood magnitude (to the disadvantage of the human communities near the streams). One issue in the eastern region is the highly-variable timing of flood events which may underscore some spawning cues of some species.

Hydrologic index for spawning

A special scenario was taken into consideration wherein the spawning period of fish species was taken into account. According to Gido (2009 – personal communication), many of the fish species in Kansas usually spawn between March to August. They could further be classified or grouped into early spawners (March – May) and the late spawners (July – September). The number of days during the spawning season where the flow is dry (below threshold level) was analyzed. Results of the trend analysis are presented in Table 3-8. There are 4 or 5 stations in the west showing a significant and increasing trend on the number of dry days during the spawning season. This increasing trend is tantamount to losing opportunity to spawn during this season. Comparing the relative dryness for the early and late spawning season, early-spawning fishes have greater opportunity to spawn than late-spawners.

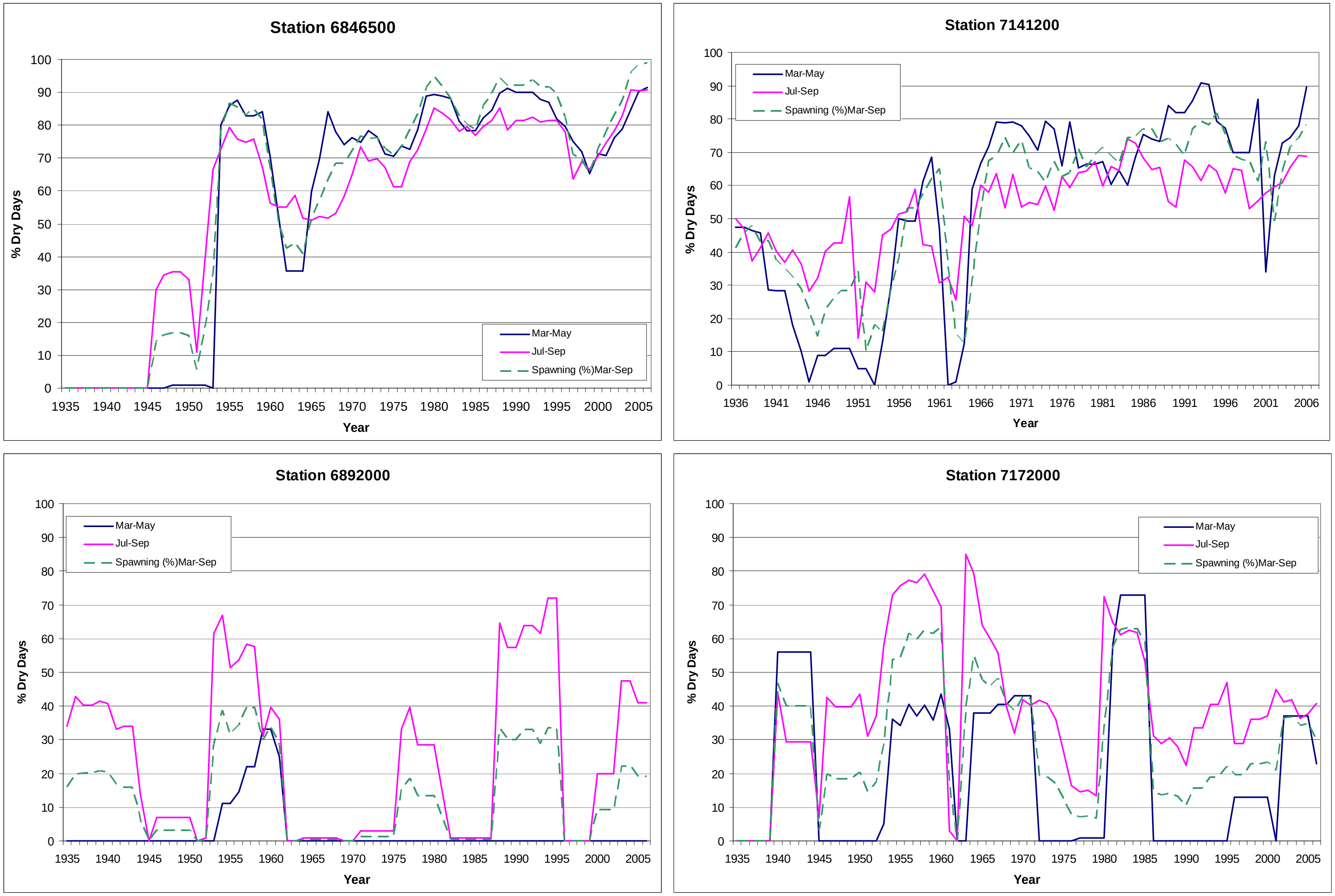
Representative stations showing the percent of time the stream is dry (below threshold level) during the spawning period is also presented in Figure 3-13. The values were computed using 5-year trailing averages. From the information on stations 6846500 and 7141200, the fishes for those streams will be having difficulty in spawning as they only have a very small time of opportunity to spawn. Over the years, the dry days increased such that 70-99% of the time it is dry in recent years. Station 6892000 is different, there are likely more early- than late-spawning fishes in this stream since the record shows that there is always water from March to May for the fishes to spawn compared to the months of July to September. At station 7172000, here is no clear indication that the dry days are increasing nor decreasing.

Table 3-8. Mann-Kendall and Sen's slope analyses result for the number of days per spawning season the flow is below threshold level.

Region	**Stations**	**March-May (Early spawning)**				**July-September (Late spawning)**			
		Test Z	***Signific.***	***Sen's Slope***	***B***	***Test Z***	***Signific.***	***Sen's Slope***	***B***
NW	6846500	2.42	*	0.198	75	4.86	***	0.806	32
	6860000	3.71	***	1.000	-20	3.70	***	0.612	42
	6863500			1.061	-13	1.92	+	0.318	14
	6873000	3.07	**	1.194	-15	2.24	*	0.519	36
NE	6889500			0.714	7	0.94		0.474	33
	6892000			4.667	-96	-0.42		-0.042	23
	6914000	0.80		0.607	2	0.52		0.095	24
SW	7141200	4.10	***	0.860	20	3.15	**	0.529	25
	7144200								
	7149000					-2.48	*	-0.641	49
	7157500			0.000	1	-1.03		-0.169	41
SE	7167500	-0.60		-0.320	73	-1.59		-0.490	66
	7172000	-0.79		-0.278	47	-0.67		-0.126	37
	7180500			-5.462	191	-1.18		-0.390	48

*** 99.9% significance ** 99% significance * 95% significance
+ 90% significance (blank) below 90% significance

Figure 3-13. Percent of days stream is dry during spawning periods computed using 5-year trailing average.



Summary and Conclusions

In general, most of the streams in the west are deteriorating or becoming harsh in terms of their capacity to support aquatic life. Drying of streams has become prevalent accounting for the condition almost 80% of the time recorded in some stations in the recent period. Duration of dry spells in the west has also become longer such that the adaptive capabilities of aquatic organisms are probably being tested to the limits. Flood events have diminished and that probably has incapacitated the intended function of floods in these streams. The timing, frequency and duration of low-flow are not so optimistic. Most of the streams in the east, however, do have a better prognosis. The low-flow, high-flow and most other hydrologic indices are improving. This creates a less stressful environment condition for the aquatic organisms in those streams.

The positive improvement of the hydrologic indices, especially in the east, could also pave way for an increase of invasive and introduced fishes and organisms that might otherwise have been thwarted by the relatively harsh condition of the streams. This is one area in which further study could be initiated. On the other hand, the deteriorating condition of the streams in the west could also encourage specialists that would create a special niche in that kind of environmental condition.

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CHAPTER 4 - Factors contributing to changes in the streamflow pattern

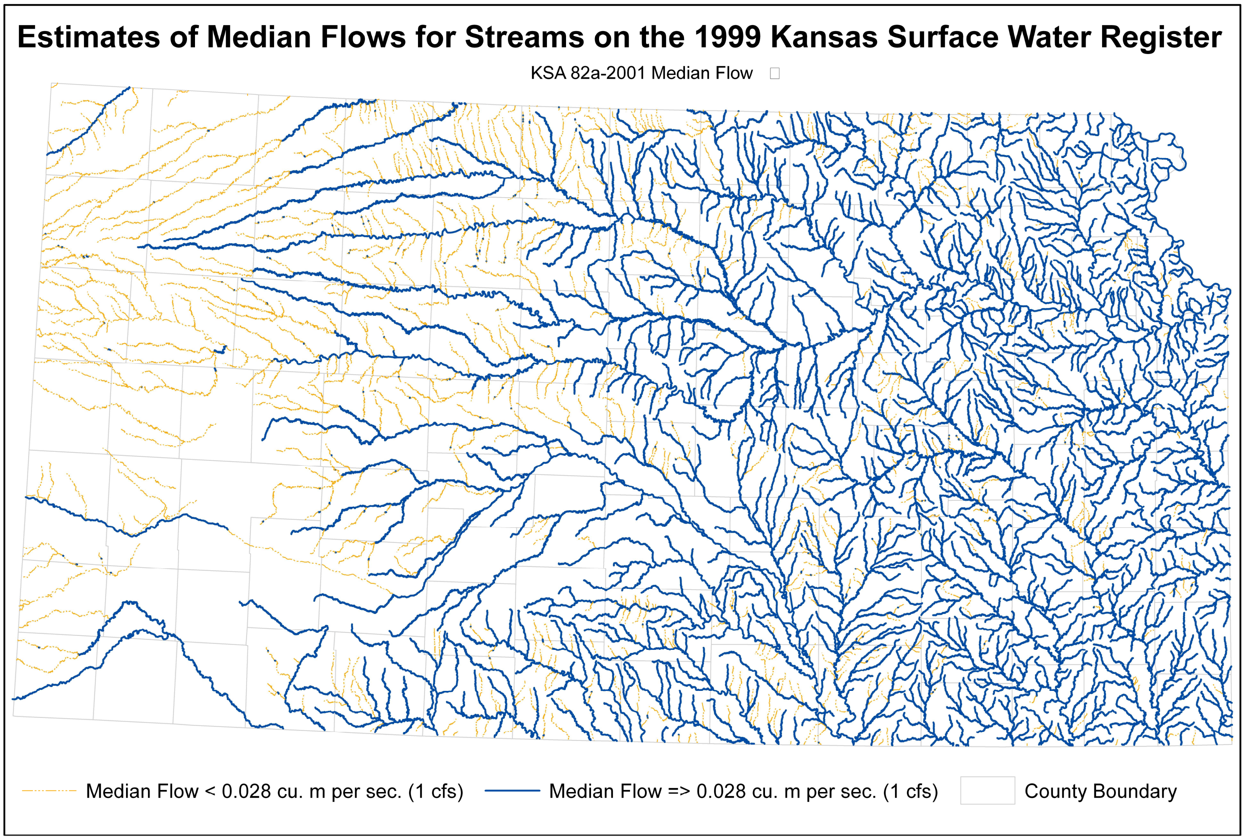
Introduction

Evidence of streamflow changes

Most of Kansas' streams were categorized by some authors as intermittent flashy (Olden and Poff, 2003; Poff, 1996). This is partly due to the fact that most of the streamflow originates as precipitation (Patrick, 1998) and the precipitation in Kansas is of short duration and high intensity from storms that cover relatively small areas. Today, tributary streams in Kansas might already be categorized as harsh intermittent. Most probably this is not because of changes in the amount of precipitation totals but because of one or combination of factors such as land conversion, agriculture, groundwater extraction, surface water diversion and impoundment, soil and water conservation, and urbanization, among others. In western Kansas, for example, groundwater extraction from aquifers became the most evident human impact in that region. The streams in the area, once considered perennial, became intermittent as the water table fell below the stream bed and caused the stream to dry up during periods of no rain. This condition was documented in a US Geological Survey (USGS) report (Perry et al., 2004) that found many of the western Kansas streams have median flow below one cubic feet per second (0.028 m^3/s) (Figure 4-1). The condition is greatly exacerbated in the area considering that the western region receives minimal rainfall, in addition to being theoretically water deficit (i.e. more potential evapotranspiration than precipitation). On the other hand, agriculture, as well as, communities built retention dams along the streams and applied land conservation practices such as terraces and residue management on agricultural fields to conserve water and reduce evaporation and soil erosion. This has a positive effect in terms of water use efficiency and conservation in agriculture, but rather a negative effect on the streams as this reduces runoff from the field. This also has similar effects on the numerous water-harvesting techniques, such as farm ponds and reservoirs that are in operation within the farm lands. It might be argued that these practices also encourage recharge of the aquifers. However, the rate of recharge in western

Kansas is so low (~0.6 cm per year) thus, negligible compared to the current rate of groundwater abstraction (Hansen, 1991; Sophocleous, 2005). On the downstream side, the presence of large dams and reservoirs cut the continuity of aquatic habitat along the streams and generally control the stream flow discharge further downstream of the structure.

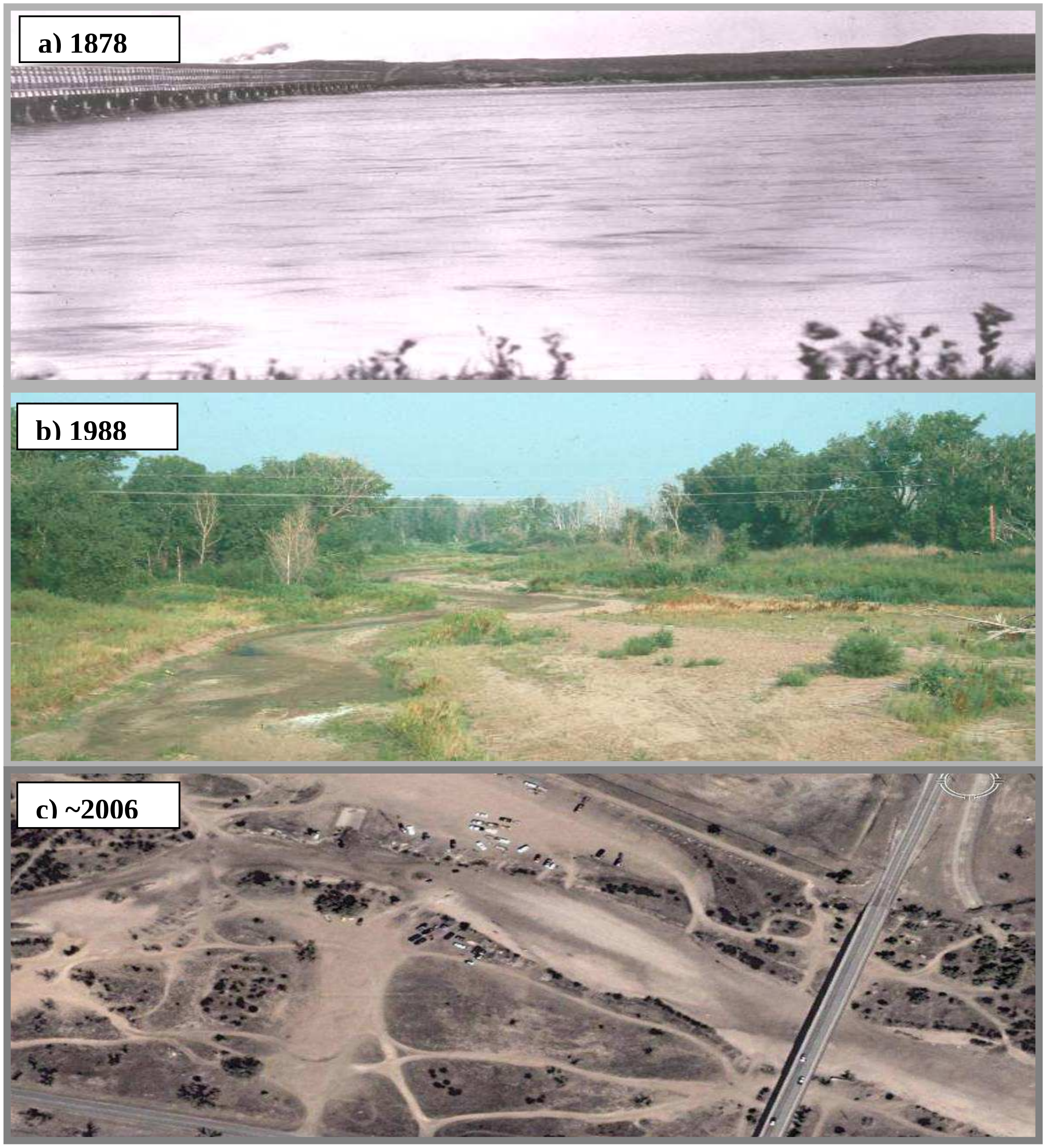
Figure 4-1. Estimates of median flows for streams on the 1999 Kansas surface water register showing stream reaches below and above a threshold flow of one cubic feet per second. Adapted from Perry et al. (2004).



Physical evidence of changes has been documented by photographs at certain stretches of streams across Kansas. Figure 4-2 is one of the two of the most vivid examples that portrays the magnitude of change. The Arkansas River in Finney County, a), was flowing almost at full bank in 1878, but 110 years later, b), the river has receded into a stream meandering through its original riverbed. The presence of some perennial plants within the river bed is evidence enough to suggest that this condition of the river is now the prevalent flow pattern for some time already.

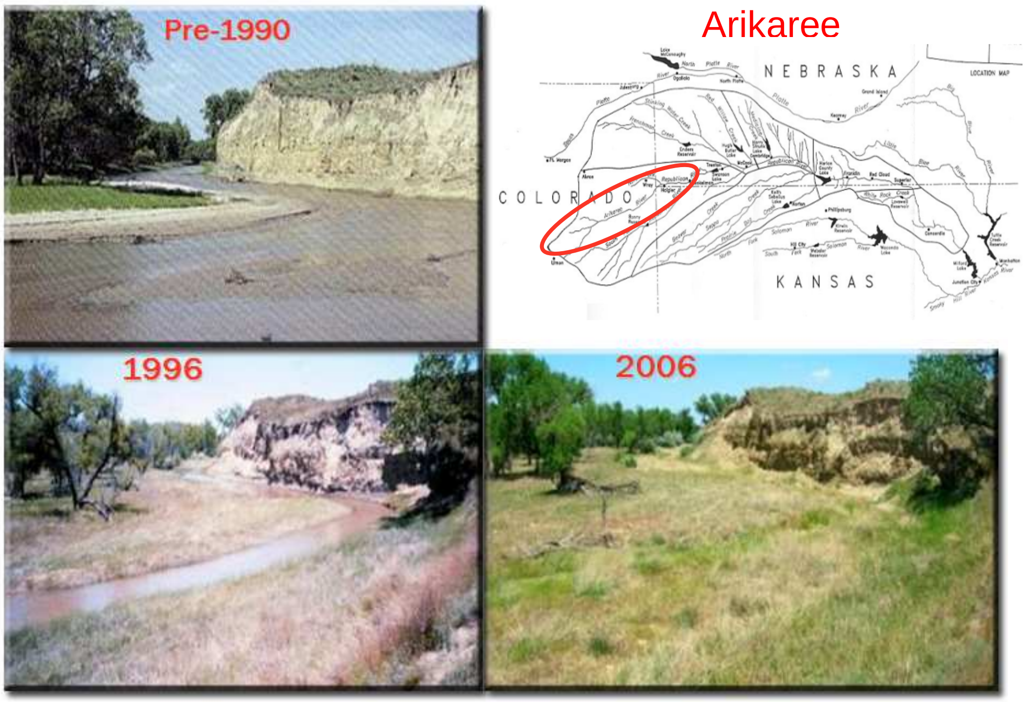
Checking on the aerial photograph, c) available in Google Earth, which is conservatively around the year of 2006, reveals a more altered hydrologic state. The stream has totally dried up, opening the area to some other use such as a parking space.

Figure 4-2. Physical evidence of streamflow changes in Arkansas River, Finney County, Kansas as captured by these different photographs on a) 1878 by the Kansas State Historical Society; b) 1988 by Guy Ernsting; and c) roughly 2006 from the Google Earth.



In yet another dramatic change in streamflow had happened in a matter of little more than a decade (Figure 4-3) at a section of Arikaree in extreme northwest Kansas. The baseflow of the river is fed by groundwater flow, but because of the agricultural activity in the area, the groundwater level has dropped and is no longer able to sustain the flow in that stretch. In 2006 pioneer species (e.g. wild grasses) had taken over much of the river bed. This is a typical observation of the streamflows in western Kansas where the once effluent streams, where groundwater supply the baseflow, have now become influent streams (Jordan, 1982; Ratzlaff, 1994; Sophocleous, 2000; Szilagyi, 2006).

Figure 4-3. Physical evidence of the condition is depicted by these pictures taken from the Arikaree River in extreme northwest Kansas. Photo source: Kansas Department of Wildlife and Parks.



Changes in the runoff have also been documented in several watersheds of Kansas. Ratzlaff (1994) noted these changes in hydrology at least for the period of 50 years since 1940 in 27 watersheds across Kansas. According to the study, in western Kansas watersheds runoff has declined by as much as 93 percent. These changes were a cumulative effect of changes that was happening in the watershed starting around the 1950s (Ratzlaff, 1994).

Factors associated with streamflow

Many factors affect the magnitude, timing and the general characteristics of streamflow. They include, but are not limited to, land use and land cover, precipitation and climatic conditions, soil characteristics, hydrogeologic characteristics, evapotranspiration, watershed characteristics, soil and water conservation practices, water usage, vegetation, topography and stream geomorphology. The effect of one or combination of two or more factors creates a different response for the streamflow. In this study, the factors identified to be associated with the changes in the Kansas streams are recharge rate, soil type, land use, soil and water conservation practices, water use and climatic condition.

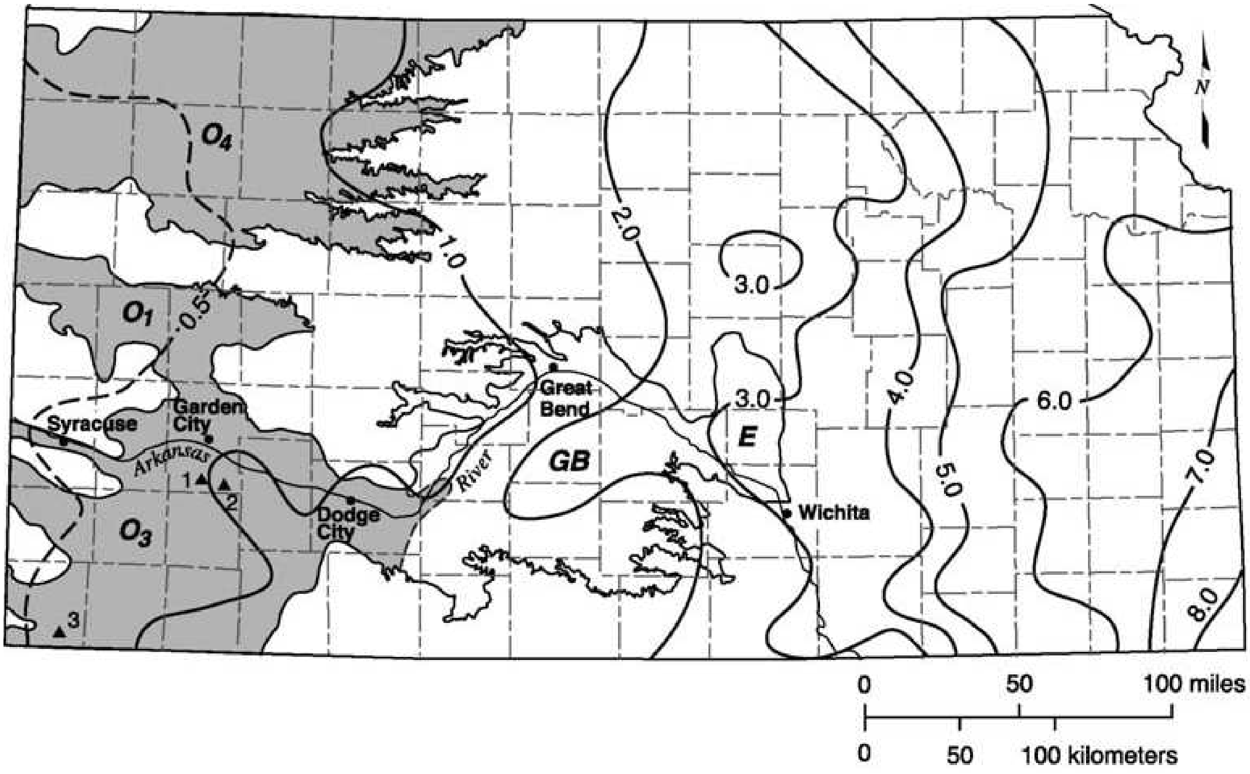
Recharge rate

Recharge is the infiltration of water into the saturated zone or groundwater. The rate at which the water infiltrates after saturating the initial profile is the recharge rate. There are many factors that affect groundwater recharge rates such as the general soil texture within the soil profile, amount and intensity of precipitation, and land cover and vegetation among others. Hansen (1991) estimated the “potential natural recharge” for the entire Kansas (Figure 4-4). Potential natural recharge refers to the deep percolation rate of soil water (made available by precipitation) below the root zone, where the water is presumed to be below the zone of influence of evapotranspiration processes, and thus potentially available to move downwards towards the water table and thereby eventually recharge the aquifer (Sophocleous, 2004). The major contribution of recharge rate to streamflow is indirectly achieved by maintaining the water table thus sustaining the baseflow of streams. Like many of the western headwaters, the aquifer is capable of contributing substantial and stable discharge in the streams. However, due to extensive groundwater withdrawals the water table dropped and was either unable sustain the baseflow or the stream ceased to flow altogether (Sophocleous, 2000; Winter, 2007).

Soil type

Soil type influence several processes in the soil-water relationship, one of which is surface runoff. Surface runoff refers to the water that drains out of an area by flowing over the land surface. Conversely, soil type also influences the amount of water that infiltrates into the soil surface that either percolates further into the groundwater or emerges somewhere along the flow line to constitute the interflow. Although individual soil parameters are important, they may not be predictive of the effective hydraulic conductivity (Ward and Trimble, 2004). The Natural Resources Conservation Service (NRCS) through a detailed soil survey for each county in the US has divided the soils into four hydrologic soil groups, namely: Group A, high rate of water transmission, thus low runoff potential; Group B, moderate rate if water transmission; Group C, slow rate of water transmission; and Group D, very slow rate of water transmission, thus high runoff potential. This hydrologic grouping is one of the main inputs for computing volume of runoff using the NRCS curve number procedure (Ward and Trimble, 2004). Relating it directly with surface runoff generation, the US Soil Survey devised surface runoff classes which also considered slope, climate, and vegetative cover. The concept indicates relative runoff for very specific conditions. The classes are labeled as negligible, very low, low, medium, high, and very high (Soil Survey Division Staff, 1993).

Figure 4-4. Mean annual potential recharge (in inches per year) in Kansas (adapted from Hansen (1991) as cited by Sophocleous (2005 and 2004)).



Water use

Water use directly and indirectly affects the discharge of water in a stream. Diversion and pumping-out of water from the stream channel constitutes a direct modification on the streamflow. Groundwater extraction, on the other hand, indirectly affects the streamflow since the direct impact of extraction is the lowering of the water level, thus possibly reducing the baseflow of the stream. In the context of this study, water use refers to the extraction of water from major bodies of water including streams, rivers and aquifers for domestic, agricultural and industrial use. In Kansas, these water uses are being regulated by the state governed by the *a priori* or appropriation doctrine. Somehow, this doctrine spurred the development of water resources in the state (Koelliker, 1987), but it now is being viewed as one of the major factors for the worsening condition of the streams because of “over-appropriation” (Sophocleous, 2000).

Land use

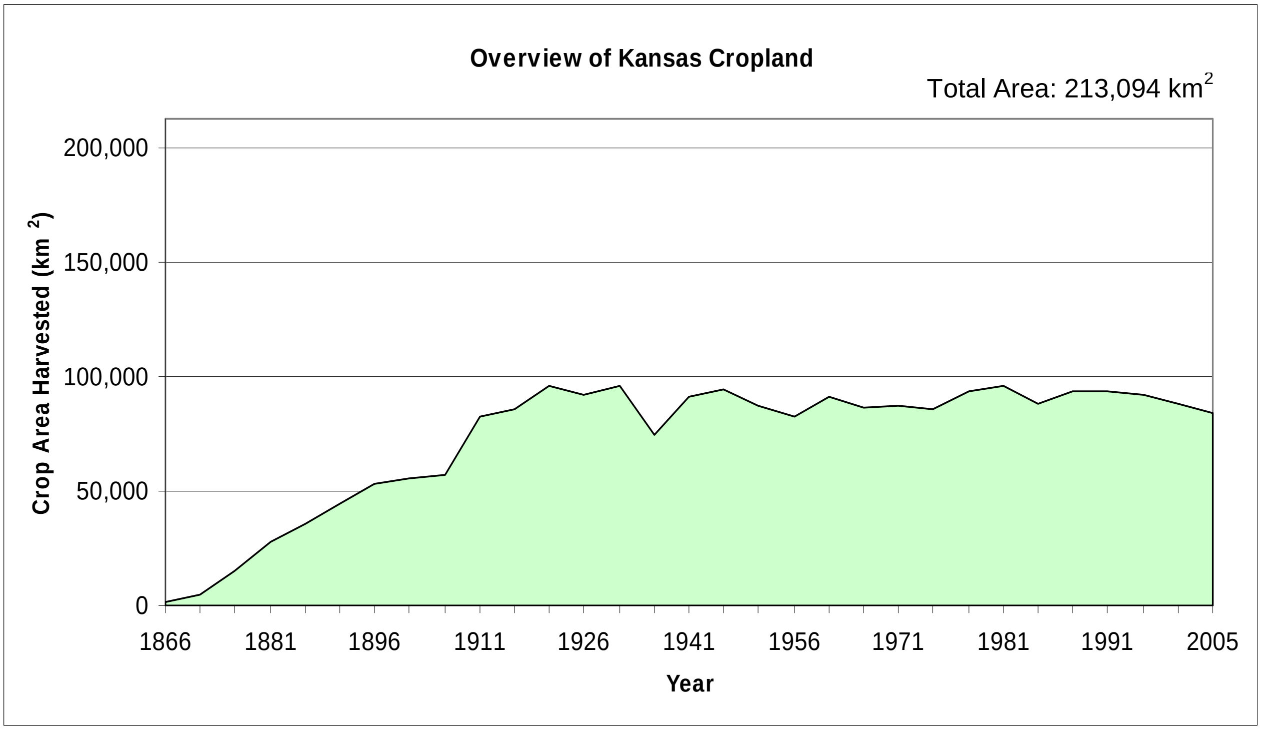
Land use and land cover, though technically different, are usually associated with each other. Land use refers to the primary activity conducted on the land. Some empirical methods for computing hydrologic events, such as the Soil Conservation Service Curve Number (SCS-CN) (Agricultural Research Service (ARS) Curve Number Work Group and Moody, 2004) and Soil and Water Assessment Tool (SWAT), consider land use a major factor that dictates water yield of a watershed or streamflow. A number of basic parameters are influenced by the land use, which includes soil cover, slope, infiltration capacity, evapotranspiration, and soil and water conservation/retention. Since the late 1800s, land in Kansas has been converted from native prairies grassland into arable land (Figure 4-5) which now comprises almost half of the total land area. One notable water conservation practice for agricultural land in Kansas is fallowing. Fallowing is a farming practice of keeping the land free of all vegetation throughout one season to store and conserve the water in order to achieve a more dependable crop (e.g. wheat) production the following year (Throckmorton and Meyers, 1941). Fallowing was originally practiced in a 2-year cycle with one crop grown per cycle, but recently the prevailing practice is to have a 3-year cycle with two crops, one wheat and the second a row crop, grown per cycle. This generally shortens the fallow period while making the land more productive. It is said that for an inch (2.5 centimeter) of water stored during fallow, can be translated into a certain number of bushels (tons) of grain.

Soil and water conservation practices

Soil and water conservation practices on a watershed are an important factor that can significantly influence the streamflow. These practices include terracing, mulching, conservation tillage, and contouring, among others. They alter the slope, runoff and infiltration capacity and soil cover, thus enhancing infiltration and recharge and minimizing direct runoff.

In Kansas, the adoption of soil and water conservation practices varies over time and extent of area. When early settlers of the state came, much of the grassland was tilled without regards to soil conservation and proper residue management. After the Dust Bowl, soil conservation practices were started and farmers found a renewed interest to till Kansas land. In the recent years, Kansans have built more miles of terraces than any state in the U.S. (USDA SCS as cited by Koelliker (1987)).

Figure 4-5. Agricultural activity in Kansas represented by the area harvested to major crops. Data taken from Kansas Agricultural Statistics and National Agricultural Statistics Service.

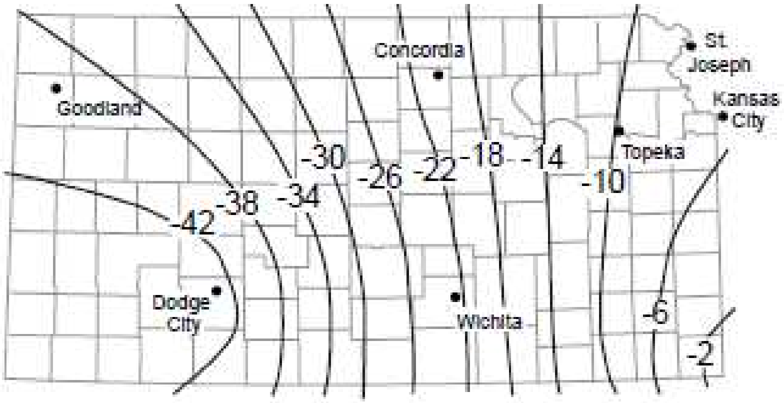


Climate

Precipitation and potential evapotranspiration are two of the most important climatic factors that influence the streamflow in a watershed. Kansas is generally considered a semi-arid region (Sophocleous, 2005)and thereby these two factors are critical.

A general water budget of the state shows precipitation accounts for 98 percent to the total input (Koelliker, 1987; Koelliker, 1998; Sophocleous, 1998). Precipitation decreases toward the north and west, with the northwest region getting only about half of that in the southeastern region of the state. Annually, the temperature ranges from highs around 100˚F (38˚C) and lows below 0˚F (-18˚C). The prevailing wind in Kansas is southerly, although northerly winds are also common. Winds are mostly in the moderate to strong category. The combination of the wind and temperature, among others makes the state to have a high evapotranspiration rates. Roughly 90 percent of the rainfall that occurs is lost back to the atmosphere through evapotranspiration. In western Kansas where there is relatively low precipitation, a moisture deficit exists in consideration to the potential evapotranspiration of the region. Here moisture deficit refers to the annual precipitation minus free-water surface evaporation (Figure 4-6).

Figure 4-6. Moisture deficit computed using annual precipitation minus free water surface evaporation (inches). Adapted from Sophocleous (1998)



Relevant research

Physical evidence and studies have increasingly shown that the streamflow characteristics of the Great Plains rivers and stream have changed over the past century (Eberle et al., 2002; Perry et al., 2004; Szilagyi, 2006). Attempts to link the streamflow to the aquatic ecosystem are available. Decreases in discharge, in most cases, result in decreases in water velocity, water depth, and wetted perimeter. At the same time increased sedimentation and changes thermal regime and water chemistry result (Angelo, 1994; Clausen and Biggs, 1997; Dewson et al., 2007; Lake, 2003; Olden and Poff, 2003; Poff and Ward, 1989; Poff et al., 1997). In a local study that have been reported by the USGS by Perry (2004), made estimates of the median flows of the streams across Kansas using the 1999 surface water register. The study used a median discharge of one cubic foot per second (0.028 m^3/s) as the threshold delineating the sections of the streams with flow (Figure 3-1). It should be noted that all the stream segments shown in the figure were considered perennial by the USGS in the 1950s. Another attempt to understand the streamflow patterns was conducted in the Republican River which identified human-induced changes in the basin as the major cause of the declining flow (Szilagyi, 2006). However, there is still no research study that focused on Kansas streams relating the changes in the ecologically relevant streamflow characteristics to the factors that influence them.

Methods

Streamflow data

The major emphasis of this study is on streamflow data. USGS gauging station throughout Kansas were considered, but analysis was conducted only on those gauging stations considered unregulated as indicated in the remarks of the USGS Water-Data Reports (Putnam and Schneider, 2003). Another consideration in the selection of gauging stations was on the length of the daily data record. At least 60 years of continuous available data were included in the analysis in order to establish a good historical representation of the period. The records were divided into four periods, comprising roughly of 15 years each and matches with the fish data collection for Kansas (K. Gido, 2007, personal communication). This also satisfies the minimum

15 years of data needed to establish reasonable average and to minimize variations due to climatic effects for studies on dryland watersheds (Hauser, 1968). Only streamflow data labeled "approved" by the USGS were included. Several flow parameters were computed but for this specific study, much of the focus was on the median to low flows only. The Log Pearson III distribution was used in the analysis due to numerous zero values in the streamflow data and as recommended by Kroll and Vogel (2002) in their study of the low-streamflow data series of numerous streams in the US. The HydroToolbox, an Excel add-in, which has a built-in Log Pearson III computational function (http://www.dartmouth.edu/~renshaw/hydrotoolbox - accessed 20 February 2009), was used.

Spatial distribution and grouping

Spatial distribution of the gauging stations was also taken into account. Two aspects were considered, the north-south and east-west orientation, and the ecoregional representation. It should be noted that Kansas climate greatly varies from east to west rather than from the north to south orientation (Sophocleous, 1998). However, the water resources regions by USGS which is based on the major watershed divide between the Kansas and Arkansas Rivers is on a north-south orientation (Figure 4-7). Incorporating the ecological relevance, gauging stations selected were also located to represent relevant ecoregions. There are several ecoregions that exist in the state of Kansas (Figure 4-8), namely; ecoregions by Omernick (1987) and Bailey (1983), National Ecological Observatory Network (NEON) regions(Hargrove et al., 2006; Keller et al., 2008) and fish ecoregions (Hawkes et al., 1986). The ecoregions by Omernik and Bailey are based more on the environmental factors creating variations in the ecosystem (Bailey, 1983), and causal and integrative factors for the potential natural vegetation (Hargrove et al., 2006; Omernik, 1987). Both of Omernik's and Bailey's ecoregions, though aquatic ecosystem was considered (Bailey, 1983), does not entirely represent the differences in aquatic ecosystem of Kansas and combines different water resources regions in which the hydrologic regimes are very different. NEON ecoregions empirically partitioned the US into 20 ecoclimatic domains using a comprehensive statistical analysis of ecoclimatic state variables and dynamic air mass seasonality data, among others (Hargrove et al., 2006). Applicability of the NEON ecoregion for this study is relatively inappropriate. Fish ecoregions were the closest applicable regional delineation found. The delineation of the fish ecoregions was done by Hawkes and others (1986) based on ecologically meaningful fish assemblage and canonical discriminant analysis of environmental variables (i.e. mean annual runoff, mean annual growing season, and stream discharge). One good characteristic of the fish ecoregion is that it conforms with the hydrologic unit and watershed divides as well as the east-west orientation of Kansas that dictates the regional variation on climate. With minor generalization, this ecoregion was adopted to group the gauging stations.

Figure 4-7. Location of the selected gauging stations, representative counties and the regional grouping.

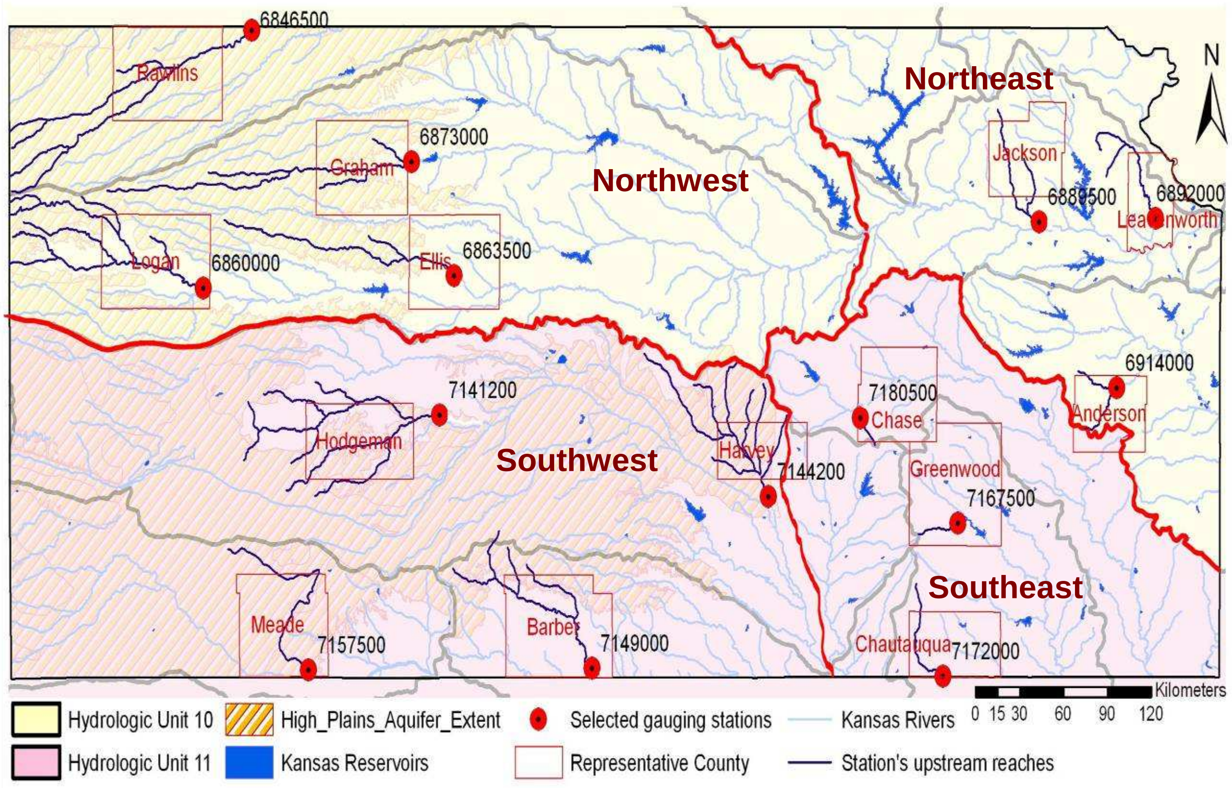
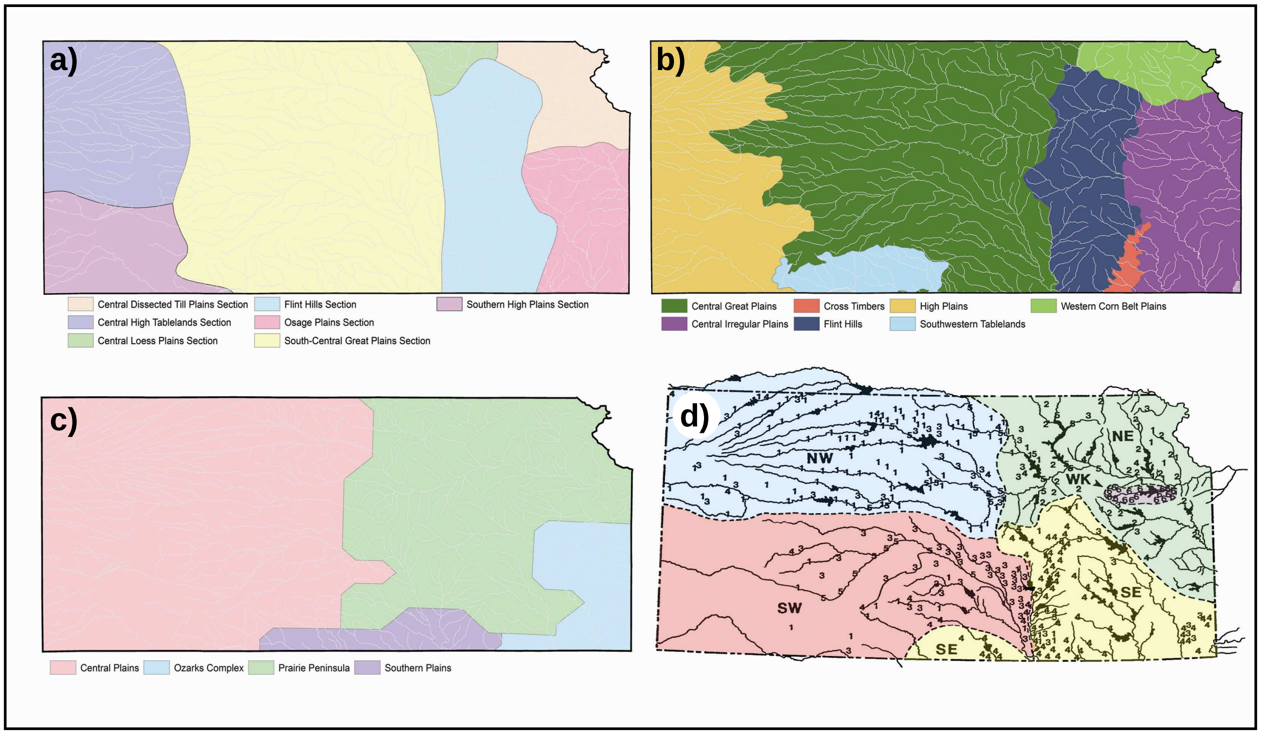


Figure 4-8. Different ecoregions of Kansas: a) ecoregion by Bailey; b) ecoregion by Omernik; c) NEON ecoregion; and d) fish ecoregions of Kansas by Hawkes, et al.



Statistical Model

One of the approaches in determining factors contributing to a certain phenomenon is by running a multi-variate statistical model. In determining the presence of correlation between variables, Pearson correlation was employed. Acceptable remedial measures were implemented where correlation was detected. Step-wise, backward elimination regression method was conducted using the Minitab 5.0 software program. One of the good characteristics of the backward elimination procedure is that the mean standard error values tend to be more nearly unbiased because important predictors are retained at each step (Kutner et al., 2005). Assessment of the model was based on alpha = 0.10. The Mallows' Cp (prediction sums of squares) criterion, which is concerned with the total mean squared error, was also computed as an added tool in assessing the performance of the model. The closer the value of Mallows' Cp to the total number of *p* (number of predictors plus the constant), the lesser is the bias, and the smaller is its value, the smaller is the total mean squared error. The coefficient of determination (r^2) was computed to assess the ability of the regression line in explaining variations of the independent variables in the model. Another measure that was generated was the predicted r^2, which is useful in assessing the performance of the model for future scenarios. A state-wide analysis was first conducted followed by a regional approach.

Sources of data

One of the major challenges for this study was the availability of historical data for each stream and its watershed. The general approach was to select the most representative county for each watershed since much published information is available on a county basis. The county selected occupies, if not the majority of the watershed area, at least the highest percentage of watershed area compared with other counties in the watershed. The list of stations and the corresponding representative counties are presented in Table 4-1 and the location of the counties are in Figure 4.7.

The groundwater recharge rates were estimated from the maps generated by Hansen (1991) and Sophocleous (2005). The values of the recharge rates, in centimeter per year, are the estimated potential natural recharge rates for the representative county.

Soil type data for the representative counties were downloaded from the US Soil Survey Geographic (SSURGO) database (http://soils.usda.gov/survey/geography/ssurgo). The surface runoff, which refers to the loss of water from an area by flow over the land surface, is based on slope, climate, and vegetative cover. The concept indicates relative runoff for very specific conditions. Classes were generated on the assumption that the surface of the soil is bare and that the retention of surface water resulting from irregularities in the ground surface is minimal (Soil Survey Division Staff, 1993). The classes are labeled as negligible, very low, low, medium, high, and very high. The numerical values are on a scale of 1-10, with 10 as having very high surface runoff (Table 4-2). A single value was derived for each county using the weighted-area method.

The water use data was taken from the Kansas Geological Survey's (KGS) Water Information Management and Analysis System (WIMAS) database (http://hercules.kgs.ku.edu/geohydro/wizard/index.html). The database contains the information of all the water rights issued in Kansas. The data extends back to the 1950s when the first water rights were issued. Water rights are the maximum permitted amount of water that can be extracted from water sources such as a river and groundwater. Average volume of water use for the representative county in cubic meters (acre-feet) was used in the analysis.

Table 4-1. List of gauging stations, representative counties and regional grouping used for the study.

Gauging Station No.	Representative County	County Area (km^2)	Region
6860000	Logan	1,619,950	Northwest
6863500	Ellis	1,358,736	
6873000	Graham	1,356,193	
8646500	Rawlins	1,614,859	
7141200	Hodgeman	1,298,275	Southwest
7144200	Harvey	814,261	
7149000	Barber	1,712,208	
7151500	Meade	1,477,170	
6889500	Jackson	987,428	Northeast
6892000	Leavenworth	699,428	
6914000	Anderson	880,066	
7167500	Greenwood	1,720,620	Southeast
7172000	Chautauqua	968,792	
7180500	Chase	1,171,401	

Table 4-2. Assignment of numerical values to SSURGO soil runoff classes.

Soil class label	Numerical assignment
Negligible	1
Very low	2
Low	4
Medium	6
High	8
Very high	10

The values used for land use were the average percent cropland in the representative counties. The Kansas State Board of Agriculture, which publishes the Kansas Agriculture Annual Report, was the source of data for land use. Part of the publication was the area of land per county that is harvested to crops and this was the area used in computing the percent cropland. It is important to note that especially in the western region of Kansas including some counties in the central region, fallowing is being practiced and it was included in the cropped area total.

Conservation practices refer to the adoption of different soil and water conservation practices on the farm. The adoption varies over time and extent of area. There is no database available on this aspect for Kansas. Estimation of this factor was based on expert judgment. Dr. Koelliker is one of the leading hydrologist and watershed modeler in Kansas. He was also involved in several water conservation projects across the state and thus is knowledgeable enough to give some figures on the estimated adoption of the practices. A scale of 1-100 was used. Emphasis placed on how much in percent these practices were estimated to reduce surface runoff. A value of 50 would represent a 50 percent estimate of reduction of surface runoff.

Moisture deficit, which is the difference between free-water surface evaporation and average annual precipitation, was used as the climate factor. The moisture deficit values used were the estimated value for the representative county from the map (Figure 4-6) taken from Sophocleous (1998).

The complete list of parameters, including the values, is in Appendix C.

Results and Discussions

The Log-Pearson III method was used to calculate the median to low-flow. The flow values for each station and are presented in Table 4-3. It shows that most of the streams in the west, all flow aspects (i.e. median, low and very low flows) are decreasing over the periods but the last period (1993-2006) shows some rebound on the flow. In the east, however, the values are increasing over time. There could be a number of reasons for this trend in streamflow, but to single out one factor would be difficult at this point.

Before running the multi-variate regression, correlation between paired parameters was determined using the Pearson correlation method. At the state-wide level, correlation was detected between some variables, such as between climate and recharge rate and soil type, and between soil type and recharge rate. Omitting one or two variables is one of the remedial measures that can be used where collinearity between variables occurs. This is especially applicable if the information on the variable to be dropped is integrated into the remaining

Table 4-3. Flow values derived using Log Pearson III distribution at the stations. The P50 is the median flow, P80 is low flow and P90 is very low flow.

Region	Station	Period	Flow (l/sec/km^2)		
			P50	P80	P90
Northwest	8646500	1948-62	31	1	0
		1963-77	0	0	0
		1978-92	0	0	0
		1993-2006	0	0	0
	6860000	1948-62	51	2	0
		1963-77	15	1	0
		1978-92	0	0	0
		1993-2006	2	0	0
	6873000	1948-62	926	42	4
		1963-77	264	16	2
		1978-92	46	1	0
		1993-2006	276	5	0
	6863500	1948-62	801	170	64
		1963-77	491	232	172
		1978-92	405	144	73
		1993-2006	1,116	74	8
Southwest	7151500	1948-62	784	29	2
		1963-77	933	80	9
		1978-92	483	266	108
		1993-2006	417	235	103
	7141200	1948-62	159	4	0
		1963-77	1	0	0
		1978-92	0	0	0
		1993-2006	0	0	0
	7149000	1948-62	5,163	657	83
		1963-77	4,530	1,106	229
		1978-92	5,404	2,269	752
		1993-2006	7,024	2,544	934
	7144200	1948-62	1,885	696	455
		1963-77	2,233	1,034	789
		1978-92	1,837	673	441
		1993-2006	2,430	940	646
Northeast	6889500	1948-62	3,361	92	6
		1963-77	4,297	1,248	690
		1978-92	5,299	1,535	836
		1993-2006	4,562	1,431	828
	6892000	1948-62	4,192	248	32
		1963-77	4,707	992	433
		1978-92	5,564	798	249
		1993-2006	4,277	910	409
	6914000	1948-62	1,022	16	1
		1963-77	2,756	162	25
		1978-92	1,931	59	6
		1993-2006	2,024	105	16
Southeast	7180500	1948-62	2,102	21	1
		1963-77	5,504	2,107	1,348
		1978-92	10,406	2,117	460
		1993-2006	11,080	2,428	651
	7167500	1948-62	415	2	0
		1963-77	3,597	74	4
		1978-92	2,977	76	5
		1993-2006	3,158	593	253
	7172000	1948-62	921	8	0
		1963-77	4,479	143	11
		1978-92	3,776	99	7
		1993-2006	6,899	366	41

variables (Kutner et al. 2005). In this case, climate and soil type were integral in the computation and assessment of the potential recharge rate (Hansen, 1991; Sophocleous, 2004). Running a simple linear regression on climate, recharge rate and soil showed a very good agreement in the variables with a coefficient of determination or $r^2 = 0.97$ and predicted $r^2 = 0.96$. Climate can then be expressed as:

$$\text{Climate} = -61.6 + 5.66\ (\text{Recharge rate}) + 1.00\ (\text{Soil})$$

Pearson correlation was also applied for regional analysis, and in all cases, climate continued to be correlated with recharge rate and sometimes soil type or land use. Omission of climate in the independent variables was employed to maintain non-collinearity between variables. This is a basic assumption in multiple linear regressions (Kutner et al., 2005). Soil type was also omitted in the analysis for the southwest and northeast regions, and water use was likewise omitted for the southeast region.

Running a multi-variate, backward-elimination linear regression for each of the flow aspects using the identified factors reveals interesting information. Table 4-4 presents the simplified summary of results of the model run for the whole state and at the regional level (see Appendix B for detailed results). The significant factors, at alpha of 0.10, are the ones listed in the table with its corresponding effect, either increase (+) or decrease (-), on the streamflow. The measure of errors and bias, Mallows' Cp, and the predicted r^2 for each flow regime model are also shown on the lower portion for each region.

The state-wide models could not adequately identify the factors through the linear regression. One measure of this inadequacy is the low r^2 values, with the median flow reaching only at 0.40. The predicted r^2 was even lower rendering the low to very low flows inappropriate for predicting future values. The measure of errors and bias, Mallows' Cp, were also poor. The very low flow has no significant factor at all. The major factors that are relevant for the median to low flow regimes are potential recharge rate and land use, with land use reducing the flow with the increase in the conversion of land into cropland. Intuitively, potential recharge rate tends to increase the very low flows since discharge from the groundwater, should sustain the baseflow or low flow, because it is a product of the recharge process.

Regional analysis produces better models than on a state-wide level, with r^2 rising to as high as 0.90 in the southwest region. In the northwest region, soil type is the significant factor influencing the very low to low flows. Soil type tends to increase the magnitude of flow. There is little intervention that can be done on soil type help sustain the very low and low flows in the region. At the median flow, potential recharge rate is the only significant factor. The r^2 values are less than 0.50 and the predicted r^2 values are even lower. Bias is relatively high.

In the southwest region, potential recharge rate and land use are the two significant factors for the three flow regimes. All of them have good r^2 values, and even predicted r^2, with the highest at 0.90, indicating good correlation between the flows and the variables. The measure of biasness is relatively low, too.

Table 4-4. Summary of results of multivariate linear regression on the median, low-flow and very low flow on each region and its effect.

REGION	Very Low Flow (P90)			Low Flow (P80)			Median Flow (P50)		
	R^2	Factor	Effect	R^2	Factor	Effect	R^2	Factor	Effect
All Regions		*-none-*		0.09	Land Use	–	0.40	Land Use	–
								SWCPractice	–
				(0)	$MC_p = 0.6$		*(0.33)*	$MC_p = 1.7$	
NW	0.30	Soil type	+	0.42	Soil type	+	0.43	Recharge	+
	(0.04)	$MC_p = 0.1$		*(0.23)*	$MC_p = 3.2$		*(0.25)*	$MC_p = 2.5$	
SW	0.66	Recharge	+	0.74	Recharge	+	0.90	Recharge	+
		Land Use	–		Land Use	–		Land Use	–
	(0.41)	$MC_p = 5.0$		*(0.54)*	$MC_p = 4.8$		*(0.82)*	$MC_p = 3.0$	
NE	0.81	Land Use	–	0.75	Land Use	–	0.69	Recharge	–
		SWCPractice	+		SWCPractice	+		Water Use	+
		Water Use	–						
	(0.58)	$MC_p = 3.3$		*(0.58)*	$MC_p = 2.9$		*(0.44)*	$MC_p = 1.8$	
SE	0.43	Recharge	–	0.73	Recharge	–	0.74	SWCPractice	+
					SWCPractice	+		Recharge	–
	(0.04)	$MC_p = -0.1$		*(0.42)*	$MC_p = 5.0$		*(0.48)*	$MC_p = 1.4$	

( ) – predicted r^2 MC_p – Mallows' Cp value Recharge – potential recharge rate
SWCPractice – adoption of soil and water conservation practice

There is no single factor that dominates in the northeast region, but the r^2 values are relatively high. For very low flow, land use, soil and water conservation practice, and water use are the significant factors, while land use and soil and water conservation practice are significant factors for low flow. On both flow regimes, soil and water conservation practice contribute to the increase of flow. Bias is also low for both flow regimes. For the median flow, recharge rate and water use are the significant factors, with good correlation but with the presence of biasness. It is at this flow regime where potential recharge rate tends to decrease the flow, while the water use increases flow. This is a major shift in the influence on the flow. This is also a similar observation on the effects of the significant factors in the southeast, even for the land-use factor.

In the southeast region, the only significant factor for the very low flow is potential recharge rate. This has the lowest r^2 value for all the regional models. The low flow has a relatively high r^2 value as well as the least bias model base on its Mallows' Cp value. Recharge rate, and soil and water conservation practices are the significant factors, similar to median flow. The median flow has high model r^2 and predicted r^2 values.

Implications

In all flow regimes and regional setting, land use effect was always negative and tends to decrease the flow with increase in percent of area harvested for crops. Though not directly implied, the conversion of rangeland to cropland increases infiltration and effective use of water, inhibits surface runoff to leave the farm area, and irrigates the farm, in some area, by either extracting groundwater or by other means. Collectively, these activities generally decreases the sustained low flow in nearby streams, thus is reflected in the model. Increasing the percent cropland will subsequently reduce the median to very low flow in the streams.

Potential recharge rate is another significant factor in many flow aspects and regions. Potential recharge rate has increasing effect on the flow in the western regions, but a decreasing effect on the east. Western sections of the state are more water deficit than the east which makes potential recharge rate a significant factor on increasing the median to low flow west. Probably in the east, instead of the percolated water recharging the stream, the water is rather lost or goes deeper into the soil profile. But, it should be noted that potential recharge rate is based on at least three components: precipitation, soil type and hydraulic potential of the soil column. To isolate one or two of these components is beyond the objective of this study.

Adoption of soil and water conservation practices decreases the median flow in the west, but increases the flow in the eastern regions. With the little available water to actually conserve in the west, it just makes sense that little to no water will end up to the streams. But in the east, the different practices will actually help in sustaining the median to very low flow of the streams.

Water use tends to decrease the flow of the streams. However, in the east, water use could actually increase the flow, to some respect, since water use also includes extraction for domestic and industrial use. Somehow, the drainage water and other excess water in urban areas on the east help maintain the median flow.

In the interest of the climate factor, though it was omitted in the variables for establishing the relations, its contribution in determining the fate of the streamflow is vital. In fact, the factors with which it was highly correlated, potential recharge rate, land use and soil type are significant factors in many of the regions and flow regimes. Other than the climate being integrated in the values of these factors, it could also be argued that climate can also be expressed as a function of these factors (as shown earlier).

These explanations attempt to explain and link the statistical result to the actual mechanisms and processes occurring in the state. However, it should also be recognized that there is more complexity in nature than what is observed. The complex climatic and hydrogeologic characteristic of Kansas, as well as agricultural activity throughout the region, add more to this condition.

Summary and Conclusion

This study has shown that changes in streamflow pattern have been experienced in unregulated streams in Kansas. These changes differ depending on the regional location within the state. Western Kansas streams are losing flow over the decades, while eastern streams are gaining. Statistical models were used to identify the causes of these changes in streamflow. Of the factors identifies, multi-collinearity was found on the climate, thus, was omitted in the succeeding statistical runs. A good relationship between what is happening in the watershed and the streamflow resulted with r^2 of up to 0.90 in two cases. The dominating factor as well as the behavior of individual factors is different between regions. Interestingly, the potential recharge rate, soil and water conservation practices, and water use factors were found to have different effects on the streamflow depending on the region. One thing is definite, anthropogenic factors (i.e. land use, water use and soil and water conservation practices) are substantial players in changing the stream flow pattern across the state. This corroborates with the observation of Sophocleous et al. (1998; 2002) and the result of the studies of Szilagyi (2000; 2006) that indeed human activities in the watershed play a vital role in determining the fate of the streams in the Great Plains.

Changes in the climate condition, though not directly included in the regression models, are also essential factor that is important. In fact, the factors where it was highly correlated, potential recharge rate, land use and soil type, were some of the dominant factors in the regional analysis.

The regional grouping of the streams was constrained by the available long, continuous streamflow data from unregulated streams. However, it should be recognized that the grouping adopted here does not necessarily be the best geospatial clustering. Adding stations and undergoing cluster testing might improve the reliability of the statistical model.

The results of this study are useful for decision makers and stakeholders in being aware that the factors causing streamflow changes may differ from one region to another. Thus, decisions made in response to the different activities within the watershed may result in different streamflow changes. Another potential use for this study is for forecasting the effect on streamflow should there be changes in the identified factors within the watershed. Except for a few cases, the predicted r^2 are high enough for changes in the significant factors to help forecast changes in the conditions in the streams.

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CHAPTER 5 - Conclusion and Recommendations

This dissertation has methodically documented the changes occurring in several unregulated streams of Kansas. The chapters have been sequentially arranged to characterize the streams across the state, to connect the hydrologic indices to the riverine ecosystem, and eventually identify the relevant factors involved in the changes.

Conclusion

The first study characterized the unregulated streams of Kansas. This is an important task since Kansas has a lot of variability in precipitation amounts, temperature, geologic formations and agricultural conditions. Variations come also in the regional setting from north to south for hydrologic units and east to west for climatic conditions and geologic formations. The different ecoregions (Bailey, 1983; Hargrove et al., 2006; Hawkes et al., 1986; Omernik, 1987) are another indication of the regional variations in the state. The differences in streamflow characteristic were substantiated by computing and comparing different hydrologic indices over time. In the east, the flow in the streams is increasing over the decades, while in the west, the flow is relatively decreasing, despite the steady increase in precipitation during the study period. Worse, the days with no (zero) flow and flow below threshold level, in this case 0.028 m^3/s (1 cfs), are also increasing in many of the western streams. This is particularly disturbing for the survival of aquatic organisms. At the conclusion of the study, there is reason to believe that streamflow aspects of most Kansas streams are changing, and the pattern of changes varied regionally. The major contributing factor for the regional differences in streamflow response, or pattern of change, is probably precipitation, but activities and changes in the watershed are probably also influential.

The second part of the dissertation looked at what is occurring with the streamflow aspects relevant to the aquatic ecosystem, or what are called hydrologic indices. It was evident from Chapter 3 that somehow the variability of the streams was suppressed as shown by the predictability index and the flood events. Research findings from hundreds of rivers around the world clearly demonstrate that when one or more aspects of hydrologic variability are removed or suppressed in a river ecosystem, many river species suffer (Postel and Richter, 2003). This condition of the unregulated streams in Kansas has probably precluded the investigations of Strong (1998), Eberle (2002), Walks (2007), Dodds (2004), and Jelks et al. (2008), among others, that saw some impact and changes on the fishes and other riverine organisms in the region. The magnitude, frequency and intensity of low flows were also analyzed and were found to be changing over the decades. The condition of the western streams on this aspect is getting worse, such as longer periods of dry days that occur more often. Spawning season is one of the critical periods for the fishes that could be greatly affected and there is evidence to believe that changes have been detected in some streams. This brings out the fact that plants and animals of a riverine ecosystem depend upon habitat conditions that are determined largely by the streamflow. Each organism has different habitat needs or preferences, which typically vary during their life cycles, as well as different tolerances for unfavorable conditions. Many of Kansas' native species have been tested by nature's variability over thousands of years. Factors such as communism, predation and competition, are affected by streamflow to varying degrees, making the flow regime a powerful influence on stream or river health (Postel and Richter, 2003). Thus, changes that have been observed on the streamflow will pose some degree of stress on the organisms and could eventually initiate ecological changes.

Human activities are not without effect to the riverine ecosystem, through streamflow changes. This is clearly evident in the results of Chapter 4. There are many ways in which humans could alter the flow either to improve or degrade the condition of the stream. This was shown in this chapter where a significant factor (e.g. land use) in the west contributed to the decline of flow, but that same factor influenced an increase in flow in the east. The statistical model was able to establish good, if not the best, correlation between the identified factors that could influence streamflow and the median to very low flows. Forecasting certain conditions could also be implemented since the predictive r^2 values are at acceptable levels.

Kansas would not want to lose a stream. There is no amount of words that could put the whole scenario of losing a stream into its relevance to human communities as well as the various ecosystems. Postel and Richter (2003) eloquently stated that the economic benefits of ecosystem conservation have largely been ignored because most of nature's life-sustaining services, like the benefit of the stream, are not valued in the market place or by any other conventional mechanisms. We are prone to squandering the wealth of nature without ever tallying the losses. It is difficult to quantify the cultural and aesthetic values of river fishes other than the commercial catches, as well as the value people place on just knowing that native fish populations continue to exist. In monetary terms, ecosystem services contribute as much to human welfare as all goods and services valued in the marketplace do. But the question now is what should be done.

This study documented the changes that are occurring in the unregulated streams of Kansas with focus on some of the ecologically-relevant hydrologic indices. The factors influencing these changes were identified and the streams were characterized. The next step is to make the necessary resource management plan taking into consideration the differences, and similarities, that make Kansas stream and aquatic ecosystem highly diversified. On another aspect, it is important that before making future decisions that will or may have an effect on streamflow conditions, it is imperative to consider the local conditions, such as land use, water use, and conservation practices, as well as the watershed's regional or climatic condition, such as precipitation.

In many parts of the world, the harnessing of streams and rivers for economic gain is now causing more pain than good. Will Kansas streams follow suit?

Recommendations and Limitations

There are several objectives set for this study. It was envisioned to link the biological aspect of the stream to hydrology. There have been a lot of discussions and contentions set forth in this study to narrow that gap. But it has to be recognized that in as much as hydrology wants to supply all the answers for the aquatic ecosystem, the interaction, complexity and diversity of the ecosystem itself poses greater uncertainty as well as resiliency in its response to the changes. Detecting and quantifying the changes may be effectively delivered, but giving definitive answers on the ecological response of the aquatic ecosystems, individually or a whole, is a major limitation.

The studies conducted in this dissertation only used data from 14 gauging stations of streams regarded to be unregulated having 60 or more years of continuous discharge data. One assumption is that these types of data will represent the numerous unregulated and ungauged streams around the state. However, changes in flow regimes and characteristics are not only occurring on unregulated streams but more especially to regulated streams. It is also important to assess the changes in these streams and relate them to the realm of aquatic ecosystem.

The majority of the data used here are all secondary data taken by different government agencies. The measure of data uncertainty and reliability of data were not considered. This is one aspect that could be worth investigating.

In identifying the factors that influence the changes in the stream, the statistical method used was step-wise regression using backward elimination. This method does not assure that the best model will be derived. There are still a number of regression analyses that could be examined that may produce a more accurate and robust model. But for the purpose of the study, the result of the back-ward elimination is sufficient to identify the predictive or influential factors on the streamflow. Furthermore, statistical analyses could also be expanded to include other hydrologic indices as well as identify more factors. It should also be noted that the approach in generating the values for the different factors was on a county-wide basis. One area of improvement for this, should the data become available, is to use basin-wide data. This might improve the reliability and accuracy of the model since the county-wide data may not be the best depiction of the conditions in the watershed.

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Appendix A - The 3- and 30-day minimum flows

Figure A-1. The 5-year trailing average of 3-day minimum flows at each stations grouped by region.

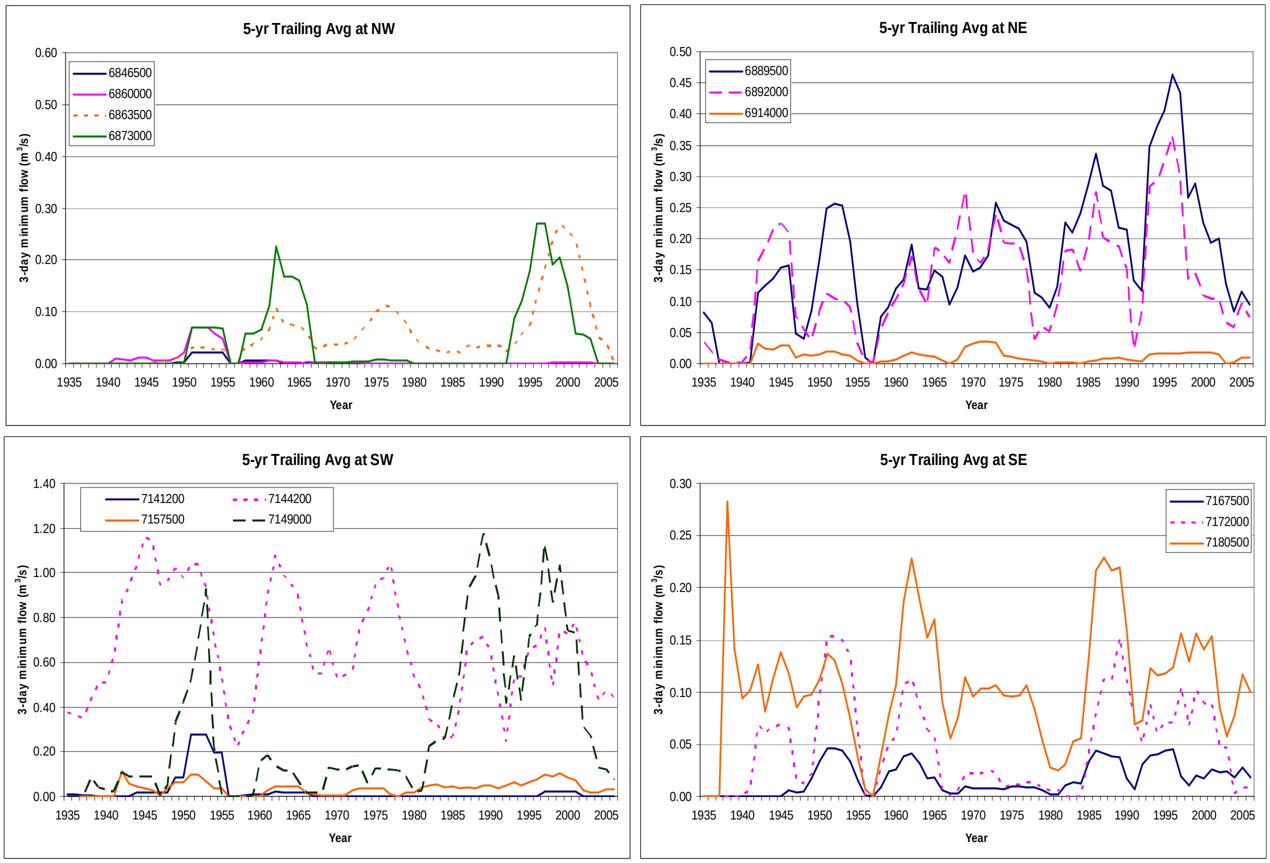
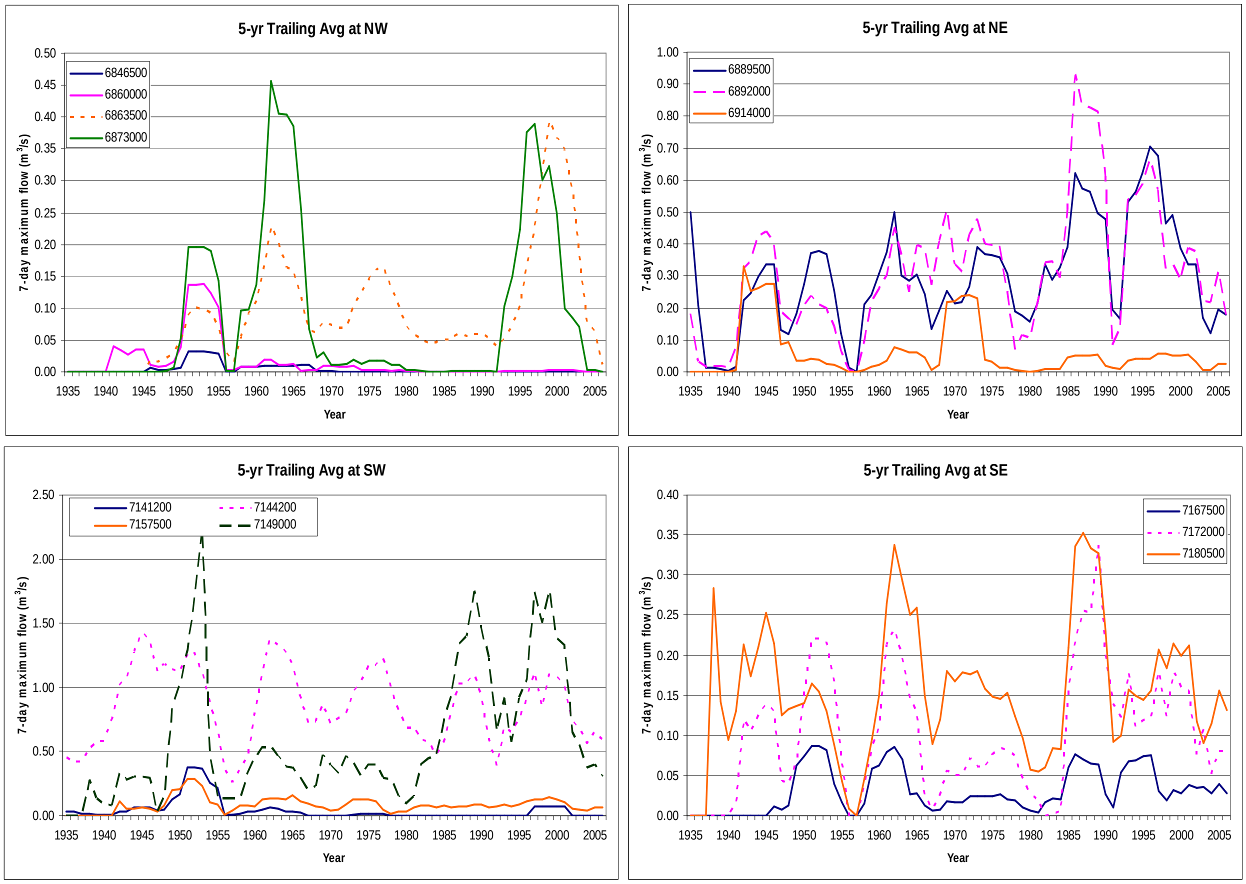


Figure A-2. The 5-year trailing average of 30-day minimum flows at each stations grouped by region.



Appendix B - Detailed model results

Table B-1. Model results of backward elimination regression using alpha=0.10.

REGION	Variable	Measures	Flow Aspect		
			P90	P80	P50
All Regions	**Land Use**	Coefficient			-72
		p-value			*0.00*
	SWCPractice	Coefficient		-12.2	-47
		p-value		*0.03*	*0.01*
	Constant			945	6067
		R^2		0.09	0.40
		Mallows Cp		6.85	1.7
		Predicted R^2		0	0.33
NW	**Soil Type**	Coefficient	79	146	
		p-value	*0.03*	*0.01*	
	Recharge Rate	Coefficient			572
		p-value			*0.01*
	Constant		-254.5	-468.8	-295.4
		R^2	0.30	0.42	0.43
		Mallows Cp	0.4	3.2	2.5
		Predicted R^2	0.04	0.23	0.25
SW	**Recharge Rate**	Coefficient	260	590	1718
		p-value	*0.00*	*0.00*	*0.00*
	Land Use	Coefficient	-9.2	-41.9	-141
		p-value	*0.03*	*0.00*	*0.00*
	Constant		116.37	1297.7	4857
		R^2	0.66	0.74	0.90
		Mallows Cp	5.0	4.8	3
		Predicted R^2	0.41	0.54	0.82
NE	**Land Use**	Coefficient	-45.6	-68	
		p-value	*0.00*	*0.00*	
	SWCPractice	Coefficient	51	59	
		p-value	*0.01*	*0.036*	
	Recharge Rate	Coefficient			-1393
		p-value			*0.01*
	Water Use	Coefficient	-0.00004		0.00025
		p-value	*0.05*		*0.01*
	Constant		1880	2944	13524
		R^2	0.81	0.75	0.69
		Mallows Cp	3.3	2.9	1.8
		Predicted R^2	0.58	0.58	0.44
SE	**Recharge Rate**	Coefficient	-357	-946	-2725
		p-value	*0.02*	*0.00*	*0.01*
	SWCPractice	Coefficient		100	532
		p-value		*0.05*	*0.01*
	Constant		2518.86	6082	18636
		R^2	0.43	0.73	0.74
		Mallows Cp	-0.1	4.0	1.4
		Predicted R^2	0.04	0.42	0.48

Appendix C - List of parameters used in the model

Histo

County	Period	SW Practices	Land use	Soil Type	Recharge	Climate	Water use
		Scale (1-100)	*%*	*Scale (1-10)*	*cm/yr*	*cm*	m^3
Rawlins	1948-62	10	48	3.7	0.7	-49.8	3,082
	1963-77	25	50	3.7	0.7	-49.8	8,001,420
	1978-92	45	49	3.7	0.7	-49.8	20,432,103
	1993-2006	60	52	3.7	0.7	-49.8	23,081,542
Logan	1948-62	10	39	3.1	0.5	-55.2	179
	1963-77	25	45	3.1	0.5	-55.2	1,249,762
	1978-92	45	48	3.1	0.5	-55.2	11,896,503
	1993-2006	60	44	3.1	0.5	-55.2	10,813,391
Graham	1948-62	10	49	3.3	1.5	-48.5	0
	1963-77	25	47	3.3	1.5	-48.5	223,450
	1978-92	40	49	3.3	1.5	-48.5	12,242,782
	1993-2006	50	40	3.3	1.5	-48.5	15,446,870
Ellis	1948-62	10	48	3.9	1.3	-47.1	86
	1963-77	20	47	3.9	1.3	-47.1	324,323
	1978-92	30	42	3.9	1.3	-47.1	6,494,026
	1993-2006	40	42	3.9	1.3	-47.1	5,456,651
Meade	1948-62	10	49	3.4	1.5	-56.5	1,714
	1963-77	25	50	3.4	1.5	-56.5	2,680,105
	1978-92	40	46	3.4	1.5	-56.5	177,684,192
	1993-2006	50	43	3.4	1.5	-56.5	205,425,081
Hodgeman	1948-62	10	50	3.2	1.2	-56.5	688
	1963-77	25	50	3.2	1.2	-56.5	1,964,194
	1978-92	40	48	3.2	1.2	-56.5	35,450,544
	1993-2006	50	47	3.2	1.2	-56.5	37,040,435
Barber	1948-62	5	28	3.5	2.4	-45.8	259
	1963-77	10	27	3.5	2.4	-45.8	93,416
	1978-92	20	24	3.5	2.4	-45.8	4,300,487
	1993-2006	30	25	3.5	2.4	-45.8	6,250,660
Harvey	1948-62	5	67	2.5	4.3	-31	582
	1963-77	10	68	2.5	4.3	-31	3,319,788
	1978-92	15	71	2.5	4.3	-31	51,827,623
	1993-2006	25	80	2.5	4.3	-31	60,026,864
Jackson	1948-62	2	39	7	6.6	-14.8	10
	1963-77	4	35	7	6.6	-14.8	21,159
	1978-92	8	35	7	6.6	-14.8	972,775
	1993-2006	12	33	7	6.6	-14.8	1,548,017

County	Period	SW Practices	Land use	Soil Type	Recharge	Climate	Water use
		Scale (1-100)	*%*	*Scale (1-10)*	*cm/yr*	*cm*	*m³*
Leavenworth	1948-62	2	38	6.9	7.8	-10.8	3,406
	1963-77	4	33	6.9	7.8	-10.8	6,629,379
	1978-92	8	39	6.9	7.8	-10.8	8,610,430
	1993-2006	12	33	6.9	7.8	-10.8	9,560,968
Anderson	1948-62	2	43	7.1	8.2	-9.4	0
	1963-77	4	46	7.1	8.2	-9.4	16,529
	1978-92	8	50	7.1	8.2	-9.4	958,085
	1993-2006	12	52	7.1	8.2	-9.4	1,682,731
Chase	1948-62	2	13	6.7	5.4	-21.5	26
	1963-77	4	13	6.7	5.4	-21.5	90,661
	1978-92	8	13	6.7	5.4	-21.5	310,672
	1993-2006	12	12	6.7	5.4	-21.5	362,203
Greenwood	1948-62	2	15	7	7.1	-17.5	1
	1963-77	4	14	7	7.1	-17.5	17,974
	1978-92	9	12	7	7.1	-17.5	905,045
	1993-2006	12	12	7	7.1	-17.5	1,342,379
Chautauqua	1948-62	2	14	6.5	6.7	-17.5	0
	1963-77	4	11	6.5	6.7	-17.5	109,305
	1978-92	8	11	6.5	6.7	-17.5	566,825
	1993-2006	10	9	6.5	6.7	-17.5	714,802

Appendix D - Working database

Description

The MS Access database, JPA_KSHydro.mdb, was developed to facilitate data management and queries for the dissertation. It contains daily streamflow discharge, water use and land use data for Kansas. It also contains the analysis generated by the IHA for the unregulated gauging stations.

Queries

Operational queries and cross-tabulations were developed to extract the information from the tables of the database. These are usually in the formats that are ready for export and computation in MS Excel.

For more information and questions on the specifics of the database, email: jaguilar@ksu.edu or jpa911@gmail.com.