RIVER BASIN FRAGMENTATION, CLIMATE CHANGE AND PERCEPTION OF SURFACE WATER SUSTAINABILITY IN THE CENTRAL GREAT PLAINS OF THE UNITED STATES

by

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A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Geography

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ABSTRACT

Recent historical records for Kansas show dramatic declines in native fish population distribution in the last 60 years, in spite of having various morphological and behavioral adaptations to natural cyclical droughts. This is likely due to widespread dam construction during this same period, which disrupts the linear nature of the stream ecological habitat, that is particularly sensitive to habitat alteration that severs connectivity and isolate population. Dam fragmentation effects on fish biodiversity are magnified in semi-arid basins where drought is common, as fragmented network segments dry completely, eliminating fish populations upstream of fragmentation points, creating flow homogenization, excess carbon deposition and sedimentation. When re-wetted, these segments remain biodiversity dead zone as fish cannot negotiate barriers to recolonize. The cumulative effect is dramatic reduction of available habitat and isolation of sub populations leading to first localized and then basin-wide extirpation. Threats from environmental degradation as a result of the combined risks related to anthropogenic climate change, agriculture and cattle grazing are going to make this region more vulnerable, both ecologically and economically.

This project will examine the extent of small dams in semi-arid streams, which underplays a major role as a mode of silent or hidden fragmentation on the fragile landscape of the central Great Plains of Kansas and will link fragmentation to climate model outputs to compare stream discharge for future projections. A perception analysis of individual understanding of damming is further integrated to know more about surface water sustainability in the basin.

Chapter 1

INTRODUCTION

Freshwater is central to agriculture, industry, residential development and other aspects of the United States economy, provides essential ecosystem goods and services for society, and is the foundation of aquatic ecosystems (Gleick 1998, Postel 2000, Baron and Poff 2004). The relative abundance and quality of freshwaters dictate the fate of ecosystem biodiversity as well as human enterprises on the landscape. Existing freshwater resources are presently challenged by increasingly unsustainable land use and water use practices (Vorosmarty 2000, Malmquist et al. 2002, Tilman et al. 2002).

The distribution, abundance and quality of freshwater supplies will undoubtedly be affected by projected climate change. Unless landscapes are managed proactively in the future, sustaining even the present level of ecosystem goods and services that aquatic systems provide will be impossible. Among the most pressing environmental challenges related to freshwater is how to formulate and implement sustainable, science-based, strategies to adapt to climate variation, land use land cover (LULC) change, damming and other consequences of human development. While recent studies have significantly increased our understanding of the relationships between river basin fragmentation, flow and aquatic biodiversity (Cross et al. 1985, Winston et al. 1991, Luttrell et al. 1999, Gido et al. 2010, Perkin and Gido 2012), there are still many unknowns regarding how climate change will interact with these forces to alter aquatic ecosystems.

To achieve sustainable landscape management, integrative models are needed that account explicitly for human-landscape interactions and incorporate detailed, well developed, coupled models of hydrosystem, aquatic ecosystem, and human-system response to changing climate and water use. This dissertation uses a research approach that interactively couples the natural and the human dimension of the factors controlling the water supply and water quality in the central Great Plains. It is a naturally occurring water-scarce region that has become more vulnerable due to intensification of drought cycles and with a greater demand of water from agriculture, industry, residential development and ecosystem maintenance (Caldas et al. 2015) over the last few decades. The incomplete understanding of environmental risks to climate change and hydrosystems is concerning here and at many other places experiencing similar conditions, across the world. The population in the central Great Plains is ill-equipped to adapt to the changing climate and is restricted through various technological and socio-economic structures. Risks to the ecology of the region are compounded by the combined pressures from climate change, intensive land-use (cropping, cultivation and livestock), and fragmentation of the rive networks. A more complete investigation of the coupled natural and human system study in this area would hence help to establish a stronger foundation for understanding water usage and better ways of river basin management.

The specific objective of this research is to contribute to an integrative coupled human-landscape model that incorporates the linkages and feedbacks among atmospheric, terrestrial, aquatic and social processes that can be used to predict the potential impact of climate variability and change, land use and human activity on water resources on decadal to centennial scales. To understand future sustainability of freshwater resources, it is important to recognize how anthropogenic forces can damage the environment, and how it changes with the change in climate. Hence to achieve sustainability, it is important to get inputs from local stakeholders and to involve their understanding into the analysis of water sustainability and water security. Towards these goals, the dissertation addresses the three following questions:

1. How will river basin fragmentation from small-scale damming affect aquatic biodiversity and river basin connectivity?

2. How will hydrological flow regimes change with projected climate change?

3. How do landowners and other local stake-holders perceive risks to water and aquatic ecosystem sustainability?

Each of these questions is addressed in separate chapters of this dissertation. Chapter 2 is focused on the analyses of small dams in the watershed and how these affect stream network connectivity, calculated using the Dendritic Connectivity Index (Cote et al. 2009). It also looks at stream restoration modeling for various dam removal scenarios. Chapter 3 assesses future climate change impacts on flow regime by comparing changes in hydrological parameters between historical flow (1981-2010) and, 50-year (2045-2055) and 100-year (2090-2100) bias corrected projected flow data. Chapter 4 presents a study of local environmental perception within the watershed focused on understanding of surface water sustainability and the impacts of stream fragmentation. Finally, in chapter 5, the conclusions from all three chapters are woven together to address the broader research question that is proposed for this dissertation research.

Chapter 2

SMALL DAM FRAGMENTATION OF STREAM NETWORK CONNECTIVITY IN THE CENTRAL GREAT PLAINS OF SEMI ARID KANSAS-IMPLICATIONS FOR AQUATIC BIODIVERSITY WITHIN THE CONTEXT OF RECURRING DROUGHTS

2.1 Introduction

Water is widely regarded as the most essential of natural resources, integral to all ecological and societal activities, yet freshwater systems are directly threatened by many human activities (Gleick et al. 1993, Vorosmarty et al. 2010). Damming of streams and rivers for the purposes of water supply, irrigation, hydro-electric power or flood control has now become a major contributing factor driving stream dewatering and ecological degradation. As Leopold (1956) predicted more than half a century ago, American rivers are now partly natural and partly artificial, with dams so pervasive that they now function as a primary control on river ecosystems, fundamentally altering system hydrology, geomorphology and ecology (e.g. Poff et al. 1997, Graf 1999, Wohl 2004, Magilligan and Nislow 2005, Barnett et al. 2008, Arrigoni et al. 2010, Costigan and, Daniels 2012) and contributing to the declines of more threatened and endangered species than any other resource-related activity (Losos et al. 1995).

These large dams are often responsible for sediment trapping (Poff et al. 2002), channel erosion and bed-coarsening (Kondolf 1997), erosion, downcutting and rejuvenation of tributaries (Petts 1984, Chien 1985) and disruption in flow (Poff 1997). Coarsening of streambed and change in flow alters both gross and fine scale geomorphic features that constitute habitat for aquatic and riparian species (Poff 1997), deteriorating habitat quality and fragmenting streams. Studies (Winston et al. 1991, Luttrell et al. 1999, Gido et al. 2010, Perkin et al. 2013, Perkin et al. 2015) that looked into ecology and patch dynamics of stream fragmentation are showing that dams are the major causes of decline in native fish populations in stream networks along with spatial variability in species occurrences. Studies also suggest that various riverine pelagic-spawning (distribution of aquatic eggs or embryo near the surface of the river via water current) and pelagic-substrate-spawning (spawning in sand-mud or gravel substrate) fishes requires up to hundreds of kilometers of unfragmented river mileage to support their reproductive approach (Perkin and Gido 2012). Due to increased fragmentation in the network, created both from large and small impoundments, native fishes are perishing and the percentage is higher in case of the existence of the smaller barriers because they are privately owned and far outnumber the larger ones. Majority of these small impoundments or artificial dams are used for a variety of purposes that can range from livestock feeding, ranching, small scale farming to domestic and recreational uses. These dams, although small, holding only a few acre feet of water, can act as active sinks for sediment (Bushaw-Newton et al. 2002), carbon (Renwick et al. 2006) and contaminants (Roberts et al. 2007), similar to larger dams. Since, small dams typically occupy sites with smaller drainage, they are close to source areas for sedimentation and other materials from storm water runoff and have proportionately higher sedimentation rates than larger reservoirs (Renwick et al. 2006), making them detrimental to intermittent or smaller tributary streams. They keep accumulating sediment and associated materials even after they are abandoned or are not in use. While small dam construction has virtually stopped and small dam removal has accelerated in certain regions of the country, Midwest United States have experienced continued growth in the number of small dams, particularly in headwater stream networks. In the Great Plains, where water stress is an annual risk to agricultural operations, large numbers of small dams were built in the 1940-50s with technical and/or financial assistance from the Soil Conservation Services (ASCS 1981, Helms 1992, Renwick et al. 2005, 2006) to encourage farm management plans. Following a construction lull in the 1970s, the pace of small dam installation has continued to the present day without receiving much attention in the scientific literature (Renwick et al. 2006). Though individually small, when all of the small dams present in a watershed are considered collectively, they represent a profound human alteration of the fluvial and the ecological landscape.

The Kansas Department of Wildlife and Parks and the Kansas Museum of Natural History have accumulated extensive datasets of aquatic species distribution throughout the Kansas River basin, and these data suggest that a major fish extinction event has been in progress since the 1960s. The probable reason for this can be attributed to the life history traits of the Great Plains fishes, which make them particularly susceptible to negative impacts from stream fragmentation apart from the cyclic droughts in the region. For example, during spawning, pelagic fishes of the Great Plains release eggs that drift downstream and may be transported up to 140 kilometers in suspension during development (Platania and Altenbach 1998). During adult life stages these fishes makes upstream migrations as a mechanism for recolonizing upstream areas and allowing for suitable drifting distance following spawning (Cross et al. 1985). Because of the long range movements of the pelagic-spawning fishes, stream fragmentation contributes to imperilment by disrupting upstream migration (Luttrell et al. 1999) as well as downstream drifting (Dudley and Platania 2007), where the drifting eggs often get trapped in the small dams and soon die due to lower dissolved oxygen content and high level of sedimentation. Apart from this, extensive fragmentation by numerous small dams has likely enhanced threats associated with climate change and increased temperature.

For example, in an unfragmented network, fish may retreat downstream to wetted refugia as the extreme situations of dry tributary networks during drought years. Pelagic spawners may suffer reproductive failures in such years, but in all likelihood can recover when flow returns in non-drought years as they move back upstream. However, in a network fragmented by numerous small dams, escape to refugia is blocked, as is recolonization following drought. The drought since 2012 and 2014 in Kansas have potentially exacerbated stream network fragmentation and conservation managers within the Kansas State Government are now actively exploring dam removal as a conservation strategy for native fishes, but there is a lack of understanding as to the nature of network fragmentation in Kansas. Removal of numerous small dams located at crucial tributary habitat space is henceforth beneficial to restore a natural flow regime to the river and have the potential to increase biodiversity, restore fish passage, eliminate hazardous conditions and re-establish riffle-pool sequences (Bednarek 2001, Roberts et al. 2007).

In this context, the current research examines how small dams and stream network connectivity are related and develops a dam removal strategy to maximize connectivity within the network, improve tributary habitat space. To understand stream network fragmentation and improve ecological-biological-hydrological connectivity and aquatic biodiversity habitat, three objectives developed for the study area:

(i). the first objective of this research is to understand the extent and distribution of small damming across the central Great Plains of Kansas and how it affects connectivity.

(ii). the second objective looks at scenarios of increased small dams, and

(iii). the third objective looks at scenarios of removed dams to analyze change in connectivity within a given basin respectively.

2.2 Context and study area

The Great Plains prairie streams have become an interesting area of focus of biodiversity conservation due to their unstable flow regimes and fluctuations in environmental conditions (Matthews 1988). It is an area with natural precipitation gradient stretching from the west to east, crossing the 100th meridian, allowing a very heterogeneous landscape depending on the availability of surface water system. These streams are highly endangered and can serve as model streams for studying disturbances in ecology, resistance and resilience in temperature of freshwater ecosystem (Dodds et al. 2015). Apart from this, impoundments, diversion dams and stream dewatering have created a mosaic of large river fragments in the last few decades throughout the region (Perkin and Gido 2011). The process of stream dewatering removes water from streams via excessive groundwater extraction, surface water retention and diversion, and, in addition to damming, is the major driver of native Great Plain fishes decline (Hoagstrom et al. 2011, Perkin et al. 2015). Hence, the central Great Plains of Kansas is selected as the study area for the investigation of this research. It has the presence of significant anthropogenic pressure, as well as a history of cyclic droughts in the last hundred years. As studied by Gido et al. (2010), the Smoky Hill River in western Kansas received a dramatic reduction in flow associated with increased groundwater withdrawals and increased fragmentation by impoundments. The major change in stream conditions occurred in the Smoky-Hill due to land-use change and increase in the number of small dams and farm-ponds since the 1950s. Prior to 1870, most of western Kansas was bison grazing ground, which later transformed into row-crop agriculture and lead to establishment of reservoirs. Much of the loss of fish species richness is less attributed to groundwater reduction and more to fragmentation, as evident from historical fish data from 1966-2003 (Gido et al. 2010).

Through this research, we analyze the geographical pattern of the distribution of small dams, and its consequences on a severe drought-prone region of the Great Plains. The study area is primarily focused on the Smoky-Hill River basin of Kansas, as a representative basin with stream fragmentation that also experiences the cyclic droughts of the Great Plains. The Smoky-Hill originates in the high plains of eastern Colorado at the rise of the North and the South Fork rivers and flows eastward to the confluence with the Kansas River, near Junction City, covering around 15 counties and 25,454 square kilometer of drainage basin. Geologically, the basin consists of shale, limestone and Niobrara chalk whose permeable and fractured nature allows shallow surface storage and influence the rate of soil-water movement downslope. However, due to extreme flatness of the plains and low topographic relief, the base flow is hardly determined by the topography of the area. The basin further lacks topographical surface storage due to the absence of extensive floodplains as a result of low precipitation in the area (Kansas Water Office, 2009). The Ogallala-High Plains aquifer is the major groundwater supply for the region, but only underlies portions of the far western half of the state, and several major tributaries to the Kansas River, including the Smoky Hill, are devoid of large groundwater resources. Rather, hydrosystem, agriculture and ecosystems are entirely reliant on water supplied via direct precipitation, runoff, and shallow alluvial surface storage zones strongly connected to surface water systems that fluctuate dramatically and unexpectedly with weather and climate patterns. Since drought is a naturally recurring feature of western Kansas, human population is sparse and concentrated only in sub urban centers, drawing large amount of the water supply from selected portions of the drainage basin. To handle situation of water stress, irrigation and flash flooding in the area, two major federal impoundments are located in the Smoky Hill basin— the Cedar

Bluff reservoir and the Kannapolis Lake, apart from numerous privately-owned small dams on the smaller order streams.

We evaluate the extent and distribution of small dams on the Smoky-Hill that flows from northwest to central Kansas and on the Neosho River, flowing from east central towards southeast Kansas, joining Arkansas River near Oklahoma, to identify longitudinal pattern of the distribution of small dams across the state. Both basins constitute a sixth ordered stream system with different drainage density pattern and basin characteristics, and together they highlight the gradient of biophysical characteristics, climatic and longitudinal variation, along with the change in water-use behavior across the state. However, the analysis of connectivity is assessed only on the Smoky-Hill River, and the change in connectivity with change in the number of small dams is evaluated only on one creek (Indian Creek), located within the Smoky-Hill River basin.

2.3 Methods

2.3.1 Data

Dams are barrier structures built artificially within the basin that disrupt the connectivity of flow in the stream network. This includes artificial large flood control structures, low-head dams as well as publicly and privately owned small dams. In this project, we focus only on privately owned artificially built small dams and henceforth referred to as both, dams and small dams. Usually, they retain 15-20 acre-feet of surface water and the construction is comparatively simple and cost-effective. To construct a small dam within the state of Kansas, a dam construction permit is required from the Kansas Department of Agriculture (KDA) Division of Water Resources and can be built at a minimum cost of $200, more details of which can be viewed at—

http://agriculture.ks.gov/divisions-programs/dwr/dam-safety/permit-requirements (last accessed 30 September 2016). However, dams that hold above 15 acre-feet or more surface water requires a permit and hence majority of these dams are below the specified limit. These are structures that are used for water supplies to small-scale cultivation, cattle ranching, small industrial purposes, domestic and/or recreational uses (Renwick et al. 2006), and contributes to a 'silent fragmentation' of the river basin, as the majority of these dams remains unregistered and unaccounted. We evaluated the distribution of these small dams and documented the location of each in the study area using a Geographical Information System (GIS) developed by Environmental Systems Research Institute (Esri) ArcGIS version 10.x. The data for the small dams were manually digitized using a GIS stream layer and aerial photograph, obtained from U.S. Geological Survey (USGS) and the Kansas Data Access & Support Center (DASC) website respectively. To identify the location of the small dams, we overlaid the National Flood Interoperability Experiment (NFIE) stream layer, obtained from USGS National Hydrographic Dataset (NHD) Plus Version-2, with 1-meter resolution aerial photographs obtained from USGS Digital Orthophoto Quarter Quads (DOQQs) 2002, and marked small dams as a separate GIS point layer. The NFIE data was used as it is a fully connected network, which is later used for the connectivity calculation, with additional information such as stream order, creek name, and length of the stream. Any small dam from the headwater of the river systems are excluded from the study, as it did not concern the connectivity of the basin. The precipitation data used in the research is the annual average precipitation for the period of 1981-2010, downloaded from the PRISM website maintained by Oregon State University, available at http://www.prism.oregonstate.edu/normals/ (last accessed 30 September 2016). The city administrative boundary layer that is used to identify urban locations within the study area is obtained from Census TIGER/Line data, available from the Kansas Data Access and Support Center (DASC) website- http://www.kansasgis.org/catalog/index.cfm (last accessed 30 September 2016) and lastly, the land-use data is obtained from National Land Cover Database (NLCD) for 2011, available at http://www.mrlc.gov/nlcd06_data.php (last accessed 30 September 2016).

2.3.2 Analysis of Stream Network Connectivity

Stream network connectivity is the most crucial element sustaining the aquatic biodiversity and water availability in any river basin. Streams in the United States, especially in the Great Plains, are highly disconnected and fragmented with small dams. Since, majority of this area depends largely on precipitation for water supply; it is probable that it is a major contributing factor towards damming. To examine distribution of dams geographically along the longitude and with change in precipitation across the state, we measure, the density (D) of small dams in the Smoky-Hill and the Neosho River by,

$$D = \frac{n}{A} \qquad \text{........ (1)}$$

where n= number of small dams within one-degree longitudinal extent or 15 cms range of precipitation, and A= area of drainage basin in square km, within the given longitudinal extent or precipitation range.

For further analysis, to understand connectivity and to look at various damming scenarios, we focus only on the Smoky-Hill River downstream to the Kanopolis Lake. We concentrate our study on this region, as it is more fragile to change in fragmentation and climate change because of its location, receiving lower precipitation and due to excessive water withdrawals from two federal dams. We aim to calculate connectivity from the positioning of the small dams on individual river network systems and to come up with a numeric value so that connectivity across the basin can be compared at a creek level that can be analyzed longitudinally. The connectivity analysis is conducted on 30 federally identified Geographic Names Information System (GNIS) sampled creeks across the longitudinal gradient of the Smoky-Hill River basin. We choose the GNIS creeks as sample creeks to conform with the US Geological Survey and US Board of Geographic names, where these creeks are federally recognized and have defined location by state, county, topographical map and geographic coordinates. The criteria for selecting the 30 sampled creeks include the following factors: they are independent sub-basins, located outside administrative urban and suburban boundaries, connectivity with the main stem of the river and are not part of other upstream contribution.

To quantify connectivity within the network system and to evaluate the effects of the number, passability and spatial location of small dams, we will use the Dendritic Connectivity Index [see Cote et al. (2009) for detailed calculation and method] with potadromous component (riverine fishes) or DCIp (Equation 2), as we are investigating dendritic structures within riverine systems.

$$\mathrm{DCI_P} = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}\frac{l_i}{L}\frac{l_j}{L} * 100 \qquad \text{…….. (2)}$$

where l_i and l_j, are the upstream and downstream length and form part of the total length of the drainage network, L. The coefficient c_{ij} is a discrete random variable denoting connectivity and depends on the number of barriers and their passabilities (Cote et al. 2009).

Each of the small dams is assigned a permeability value of 0.95, which can be regarded as a 95% probable chance for a given fish to pass the barrier. In this study, we assume that each barrier is independent of each other and that any particular fish can pass each barrier with the same probability percentage. The permeability value of 0.95 is chosen as DCI for 0.95 yields informative structural connectivity measures even in the absence of specific permeability values for each of the barriers, where 0 is impassable and 1 is completely passable (Cote et al. 2009, Perkin and Gido 2012). A DCI value of 100 indicates a completely connected basin and 0 represents an absolutely disconnected one. While analyzing connectivity, it is important to note that connectivity is mostly impacted by the first barrier added to the network, and a curvilinear relationship exists between barrier passability and structural connectivity (Cote et al. 2009). Also, a single dam in any part of the basin may fragment the network to such an extent that it might be able to drop the DCI value to as low as 25, with a 0.95 permeability value. Therefore, it is assumed from Cote et al. (2009) that connectivity of the sampled river network with independent small dams, acting as barriers, will decline as the number of small dams increases, but the biggest loss to connectivity will occur at the addition of the first barrier and every subsequent dam will have increasingly smaller impact on the DCI metric (Figure 2.2). The calculation for the DCI metrics is conducted on 30 sampled GNIS creeks and then compared longitudinally. Other physical factors like precipitation, stream order and total number of dams in the network are also examined to see the correlation among each of the factors with the DCI metric.

The analysis of DCI uses geometric network in ArcGIS to set the flow and an external add-in, Fish Passage Extension (FIPEX), available as an open source external addin from github at https://github.com/goldford/FIPEX_v10_23_ArcGIS10.x_2 (last accessed 30 September 2016), to obtain the distances between two consecutive small dams in the DCI analysis. The automation of the DCI calculation for each of the 30 sampled creeks is done using model builder and python scripting in ArcGIS. After obtaining the DCI from the sampled creeks, a principal component analysis (PCA) is used to capture variation among the sampled creeks in terms of connectivity and other parameters across the basin. A correlation coefficient, with a statistical test of significance of $p \leq 0.1$, among the variables is also conducted to understand the relationship between the variables. The aim is to analyze the factors that drive connectivity of these stream networks, among the total number of small dams in the system, highest stream order for the respective creek and average precipitation received by the creek system. The annual average precipitation received by individual creek system (over 1980-2010) is computed from the precipitation received by the watershed formed by the respective creek and is obtained from the precipitation layer using GIS.

All statistics and plots use R: The R Project for Statistical Computing, more specifically, the plot, boxplot, biplot function and the psych, PerformanceAnalytics and corrplot package. The models and scripts developed for the analysis using ArcGIS and Python are added in Appendix B.

2.3.3 Changes in Stream Network Connectivity with Additional Dams

As already stated, small dams are major problem of the Midwest and it has only outgrown itself in number, changing its purpose from water supply to recreational uses, over the last few decades. Since, this is not yet scientifically recognized as a major contributor to aquatic and hydrological and biological loss because it is unrestricted under current policies. Hence, it is safe to assume that over time, the number of small dams is going to increase. The second objective of this research focuses on this aspect and is examined only on the Indian Creek, from the Smoky-Hill River basin. The objective is to analyze connectivity in the Indian Creek and how it changes with the addition of dams to the already existing dam layer. The Indian Creek is chosen from the 30 sampled creeks as it is one of the complex creeks, with higher ordered systems with a large number of existing small dams. However, this analysis can be replicated to other creeks within the study area and beyond. Since majority of these small dams are privately owned and are located within relatively flat topography with similar physiography and precipitation pattern, we hypothesize that small dam building in the study area is dominated mostly by the land use of the region. Within the entire Smoky-Hill River basin, most of the dams are dictated by land use within a kilometer buffer from the dam. This does not change significantly if we increase the buffer distance. So, for the analysis, we buffered the existing 51 dams on the Indian Creek by a kilometer and extracted the dominating land use.

Five scenarios of additional dams on the creek are then evaluated and compared to the base level, which is the currently existing dam layer of 51 small dams. For each scenario, which include: add cluster (AC) 1, AC 2, AC 3, AC 4, AC 5; 10, 20, 30, 40 and 50 dams are added to the existing 51 small dams, based on a spatial probability using GIS (Figure 2.3). Each of these five scenarios are independent on each other, which means a particular area may or may not receive a dam when 10 dams are added versus the scenario when 50 dams are added. ArcGIS Spatial Analyst and Geostatistical Analyst extensions are used to determine the dominating land use for damming and to create the probability surface raster that can generate additional dams as spatially balanced points. The probability of getting the new dams is based on two distance factors: (i). how far the stream is from the dominating land use that drives dam building for the Indian Creek and, (ii). how far is the closest located dam from one given stretch of the stream, so that it can avoid overlap. Hence, the probability of getting a new dam is higher where the dominating land use, herbaceous land in this case, is overlapping the Indian Creek or is in close proximity, and away from an existing dam. A minimum 150-meter distance is considered to allow for a new dam. For each of these five scenarios, DCI is then calculated based on the location of the new dams in addition to the existing ones in the network. Since DCI decreases with the increase in the number of dams, we hypothesize that the connectivity would decrease with each additional dam in the network.

2.3.4 Changes in Stream Network Connectivity with Dam Removal Scenarios

The third objective of this research is to analyze how to maximize connectivity in any given basin by looking at various dam removal scenarios. This objective also considers the Indian Creek and five scenarios for dam removal, later referred to as remove cluster (RC) 1, RC 2, RC 3, RC 4 and RC 5. RC 1 removes all small dams located on the 1st order stream, and RC 2 eliminates all dams located in the 1st and 2nd order streams. In RC 3 and RC 4, we maximize the upstream and downstream distances from each small dam, by removing dams from clusters. The distances from the existing dams are extracted from the automated DCI calculation (Appendix A- Table A.2). The final scenario or RC 5 analyzes connectivity allowing only 1 dam in the network. For this objective, we hypothesize that connectivity would increase with decrease in the number of dams and increase with the increase in the upstream and downstream length between two consecutive small dams. Both these criteria are considered to have equal weightage in determining or predicting connectivity in a dendritic network. For each of these 5 scenarios, DCI is then recalculated and compared to see how connectivity changes with number and location of small dams within the basin.

2.4 Results

2.4.1 Distribution and Extent of Small Dams

To analyze the location and extent of small dams along the longitudinal extent and precipitation gradient of the state, all small dams from the two basins are analyzed and plotted to identify areas of dam concentration. The number of dams increases longitudinally eastward, following the precipitation pattern of the region (Figure 2.4), which ranges between 40-115 cms annually at a 30-year annual average (1980-2010). We identified a total of 2424 small dams in the Smoky Hill basin and approximately 2246 small dams in the Neosho River basin. With a total of 4670 dams in both the basins, around 70% or about 3000 dams are located east of the 98ºW longitude that receives an annual average rainfall greater than 75 cms. Analyzing the location of the dams with various stream orders as shown in Figure 2.5, we see that majority of the small dams are situated in the lower order streams. About 85% or a total of 4005 small dams are located in headwater or 1st order streams and around 480 are in 2nd order streams. Only a low percentage of 0.04% of small dam is located in stream orders higher than 2nd order. From the sampled creeks analyses, the distribution of small dams within each creek (Figure 2.6) varies for every stream order, with overall decrease as stream order increases. The number of small dams varies from 1 to 40 in the 1st order streams, 1-10 in a 2nd order stream and a maximum number of 7 and 2 small dams are located on the 3rd and 4th order streams respectively, within the 30 sampled creeks.

2.4.2 Analyzing Connectivity

In the PCA, DCI is compared with precipitation, stream length, stream order and number of dams for the 30 sampled creeks to see how connectivity changes longitudinally and with each of these factors in the biplot (Figure 2.7). To determine the number of principal components to retain for the PCA analysis, we used eigen values to test through Cattell's (1966) scree-plots and Kaiser-Guttman criterion (Guttman 1954, Kaiser 1960, 1970). We have 3 significant components, explaining about 81.3% of the total variation in the data-set. From the coefficient of the components in the correlation matrix, we see that all variables are negatively correlated to the principal component 1, apart from DCI. Besides, total dams and length of creek significantly contribute towards the first component. To explain for around 30% of the variation in the dataset, we see that precipitation and DCI have an influence on the second principal component. The correlation matrix plot (Figure 2.8) illustrates that DCI is negatively related to all the factors (precipitation, length of the creek and total number of dams) and is mostly affected by the number of dams in the network (r= -0.32). Number of dams is also the only significant factor with DCI, at $p \leq 0.1$. Connectivity falls with both precipitation and length of the stream network and have r= -0.25 and r= -0.21 respectively, where r is the correlation coefficient. Highest stream order however, does not have any influence on connectivity measurement, with the lowest r value of -0.01.

2.4.3 Change in Connectivity with Change in the Number of Dams

Small dams are added to the existing ones based on the probability surface generated from the GIS analysis in Figure 2.9. The dominating land use within a kilometer buffer from the small dams is cultivated land, followed by herbaceous or grassland. From prior knowledge, we know that these dams are not large enough to supply water for irrigation and remain dry for most of the year due to the intermittent nature of the Smoky-Hill River in general, and the Indian Creek in particular. Therefore, we base our analysis on the next dominating land use to determine the distribution of small dams. Herbaceous land represents 35% of the total land use within a kilometer buffer from the Indian Creek. For each of the added scenarios (AC 1, AC 2, AC 3, AC 4 and AC 5), the DCI values with the increase in the number of small dams behaves inconsistently (Figure 2.11). DCI value for the existing 51 small dams is 4.72, increases with the addition of the 10 dams but then decreases for the addition of 20 dams. The DCI values fluctuate and instead of decreasing with the increase in the number of small dams, it increases to 7.06, 5.02, 6.46, 5.41 and 5.82 for additional 10, 20, 30, 40 and 50 dams in the network respectively.

A similar trend is also observed with the dam removal scenarios (Figure 2.10) based on the location of the dams on the Indian Creek (Figure 2.11). With RC 1 and RC 2, the DCI does not increase significantly and rather drops from 4.72 to 2.98 and 2.68 respectively. The value of DCI however, increases to 13.71 and 16.29 when selective dams are removed from dam clusters in scenarios RC 3 and RC 4, which maximizes the upstream and downstream distances of one dam from the other. The DCI value reaches a maximum value of 21.63 when all dams, apart from one dam, located on the main stem, are removed from the network in the analysis for RC 5.

2.5 Discussion

The density of small dams increases from west to east Kansas, following the longitudinal distribution of the precipitation pattern of the central Great Plains, which indicates that existence of small dams are directly proportional to availability of water from precipitation in the region. The distribution of the dam also justifies that density of small dams are related to the drainage density of the basin. Rivers flowing east, following the precipitation pattern of the state have a higher dendritic drainage density which gives these rivers the potential to sustain a larger number of smaller dams, thereby providing a potential condition to become a higher fragmented network system. Within the two basins that are considered for the distribution of small dams, the Smoky-Hill River flows eastward and has a parallel drainage pattern, with fewer but larger drainage systems connecting to the main stem. The stream segments of this basin have to traverse a greater length before it can form a higher order stream, whereas the Neosho River in the southeastern part of Kansas is mostly dendritic with a denser but comparatively shorter drainage system. Here the dam density of individual stream segments are less as the individual stream segments are comparatively shorter in length, obstructed by gravel bed features and other geological structure of the basin. The drainage basin of the Neosho River is narrower in extent, denser in structure and located mostly above 90 cms of precipitation. Hence, although the Neosho basin can support larger number of small dams within the basin as a whole, individual stream segments that join the main stem are shorter in length are capable of a larger range of small dams. This results in clustering of the dams throughout the Neosho basin in comparison to the Smoky-Hill. Majority of these small dams are concentrated in the headwater streams for both the basin and greatly affects connectivity.

2.5.1 Assessment of Hydrological Connectivity

The 30 sampled creeks analysis indicates that connectivity decreases with the increase in the number of dams in the network. Regions that receive higher precipitation or have greater stream length are also associated with lower connectivity because of the greater number of small dams in the area. Since majority of the sampled creeks are either 3rd or 4th order creek systems, stream order does not have any particular influence on connectivity or the DCI values. There are two major clusters of creeks from the PCA, the first shows that, connectivity is higher or lower depending on the number of small dams in the creeks for 3 (Cheyenne Creek), 8 (East Spring Creek), 10 (Hell Creek), 15 (North Fork Big Creek), 17 (Rose Creek), 19 (Sandy Creek), 20 (Shelter Creek), 27 (West Salt) and 29 (Willow Creek). The second cluster consist of creeks like, 5 (Downer Creek), 14 (North Branch Hackberry Creek), 18 (Sand Creek), 22 (Snake Creek), 23 (Spring Creek) and 28 (Wild Horse Creek), that have longer stream length and receives higher precipitation, but fails to determine connectivity directly. Some of the creeks that are located outside the cluster are anomalies, that includes 21 (Sixmile Creek) with no dams and 11 (Indian Creek) with the maximum number of dams. Some other creeks that have a different pattern from the rest of the creeks are 13 (Middle Fork Lake Creek), and 25 (Turtle Creek), both of which are lower ordered streams. The results therefore demonstrate that connectivity is not determined longitudinally based on precipitation pattern or stream length or higher ordered stream system, but on the number of dams located in the network.

Therefore, we look at the final scenario to understand how connectivity would change with additional and removal of dams in the network. From the added dam scenarios (AC 1, AC 2, AC 3, AC 4 and AC 5) in the Indian Creek, we see DCI does not change as expected. The fluctuation of the DCI values with increases in small dams in the network indicates that once a river network is pushed beyond a certain threshold, DCI is no longer a useful measure of connectivity within a basin. We find that the positioning and density of the dam distribution in the network mostly affects the DCI, in contrast to

Cote et al. (2009), where he suggested that the connectivity of the river basin depends on the number of dams and its positioning. This gets verified when we look at the dam removal scenarios. For scenarios RC 2 and RC 4, the number of small dams is same, but the DCI values are widely different. This is due to the differential clustering of the dams in the 2 scenarios. In RC 2 all the 6 dams are located very close to each other, whereas in RC 4, each of the 6 dams has significant upstream and downstream lengths resulting in a significantly higher DCI value. The DCI for the Indian Creek however, reaches its maximum with only one dam in the main stem of the network.

It is however understandable that removing all small dams at a given time is not possible due to cost, timing and purpose. To maximize connectivity, cluster of dams should be targeted for removal or areas that already have dams should be restricted from further damming. Analyzing the clusters can be done from the individual DCI values, and upstream and downstream length of that particular dam. The small dams that have a lower upstream and downstream length would consequently have lower DCI and should be prioritized for removal to maximize connectivity.

2.5.2 Assessment of Ecological Connectivity

Density of dams reduces the overall flow in the basin. To address ecological flow and protect aquatic biodiversity, an effective dam removal strategy should be generated, as it is not feasible to remove all the small dams from the study area or any given basin. During droughts, the small tributaries that have dams dry out totally. With the revival of the monsoon and the flow of water in the stream, water and ecology gets their access back to the upstream region. This gives the ecological system a higher stream length movement and tributary habitat space. However, if the creek system is dammed at a higher order (like the 3rd or the 4th order stem of the river), the creek gets fragmented completely. This often eliminates the upstream sections from the main channel even during high flow seasons. This reduces the habitat space and shrinks the ecological biodiversity of the area. In the Indian Creek, the DCI changes nearly exponentially with every addition of dams. However, the index flattens out in this system after a given threshold is reached. It is vital to understand that the DCI is not only a function of the total number of dams in the system, but also depends on the positioning of these dams on the network (the upstream and downstream distances). Therefore, once a given threshold for dis-connectivity is reached for a particular river basin or creek, the DCI analysis will no longer be effective to analyze the river basin connectivity. Thus, dam removal scenarios for small dams should be considered based on dam location within the network and how clustered or dispersed they are with respect to the surrounding dams. Prioritizing ecological connectivity would therefore be based on restoration species priority and their biological adaptive strategies (like growth, reproduction and so on), to determine what parts of the basin should be managed more efficiently than the rest.

2.6 Conclusion

Understanding of stream network connectivity is the key to maintain ecological biodiversity and sustainable flow within a basin. Since the majority of the rivers in the Midwest and other parts of the United States are in a fragmented state, it is important to remove dams, at least selectively, to maximize ecological connectivity and hydrological flow as well as to fulfill the purpose of the existing dams. This study contributes to the understanding of stream restoration by removal of small dams like stock-ponds and farm-ponds. We suggest that relying just on the DCI value is not the best possible decision making effort, as the major factor determining river basin connectivity is not the number of existing dams on the network, but the positioning of the dams within the network. This approach will help users (stakeholders, planners and landowners) understand how individual dam locations within the basin can change the connectivity of the whole watershed. This will generate awareness as well as provide them with a useful tool to communicate for planning and supervision and help with river basin restoration.

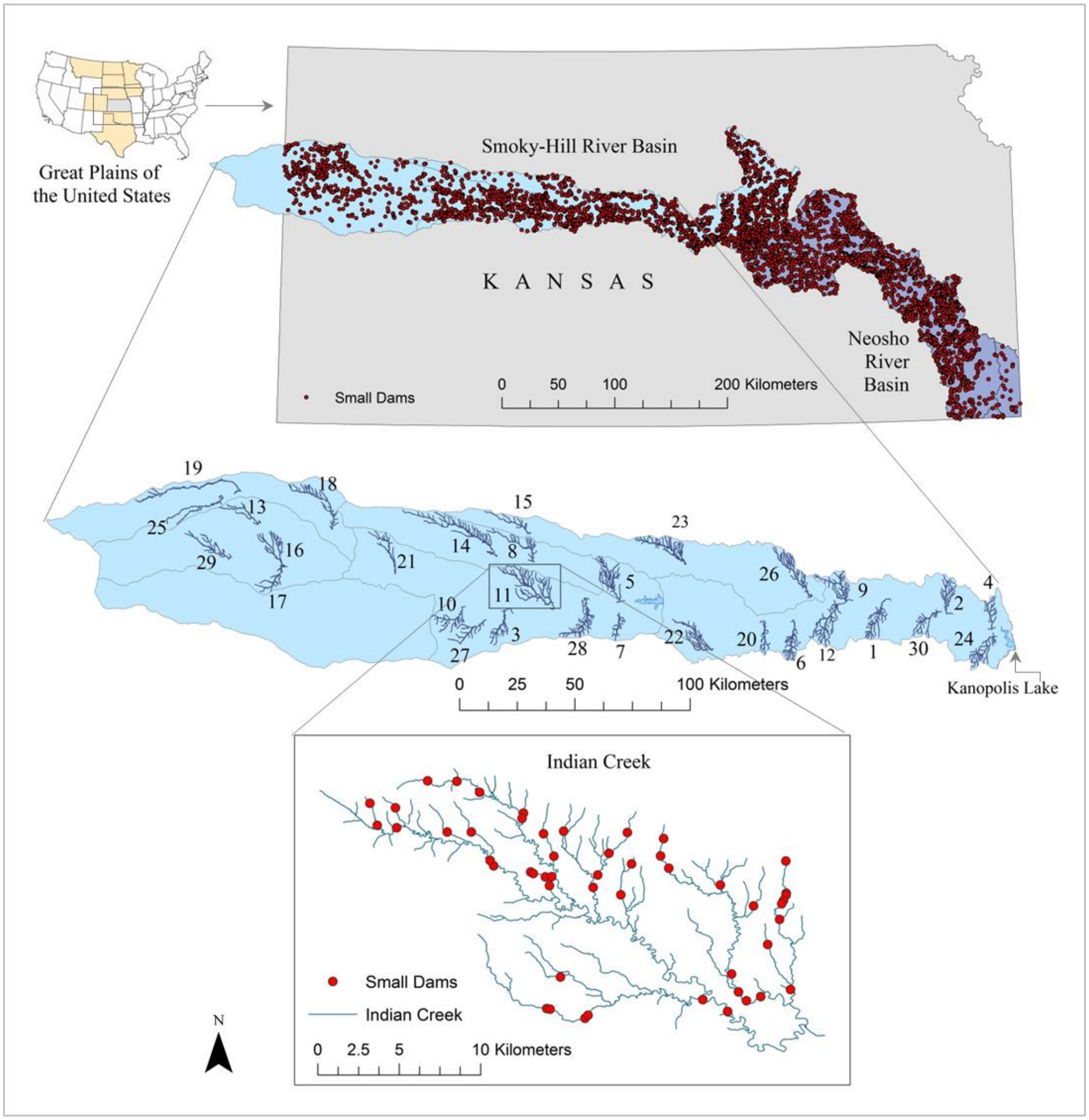

Figure 2.1: The study area is located in the central Great Plains of Kansas. Small dams across the state within the Smoky-Hill and the Neosho River are analyzed (top panel). Connectivity is compared within 30 sampled creeks (Appendix A- Table A.1) in the Smoky-Hill River until the upstream of the Kanopolis Lake (middle panel). The Indian Creek is the focus to model connectivity with additional and removed dams (bottom panel).

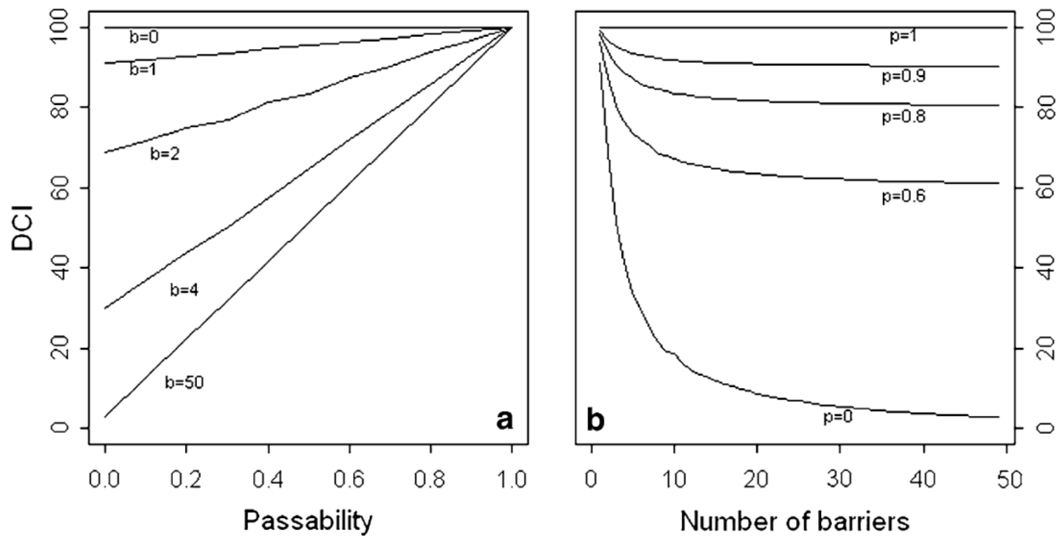

Figure 2.2: The effect of (a) passability and (b) number of barriers on the potadromous DCI when passability of barriers is dependent (i.e., an individual that passes through the worst barrier is assumed to be able to pass through all barriers with higher passability values) in a simulated dendritic river system. Lines represent different numbers of barriers (b = 0, 1, 2, 4, and 50) (panel a). Panel b lines represent different passability values for the barriers (p = 1, 0.9, 0.8, 0.6, and 0) (Cote et al. 2009).

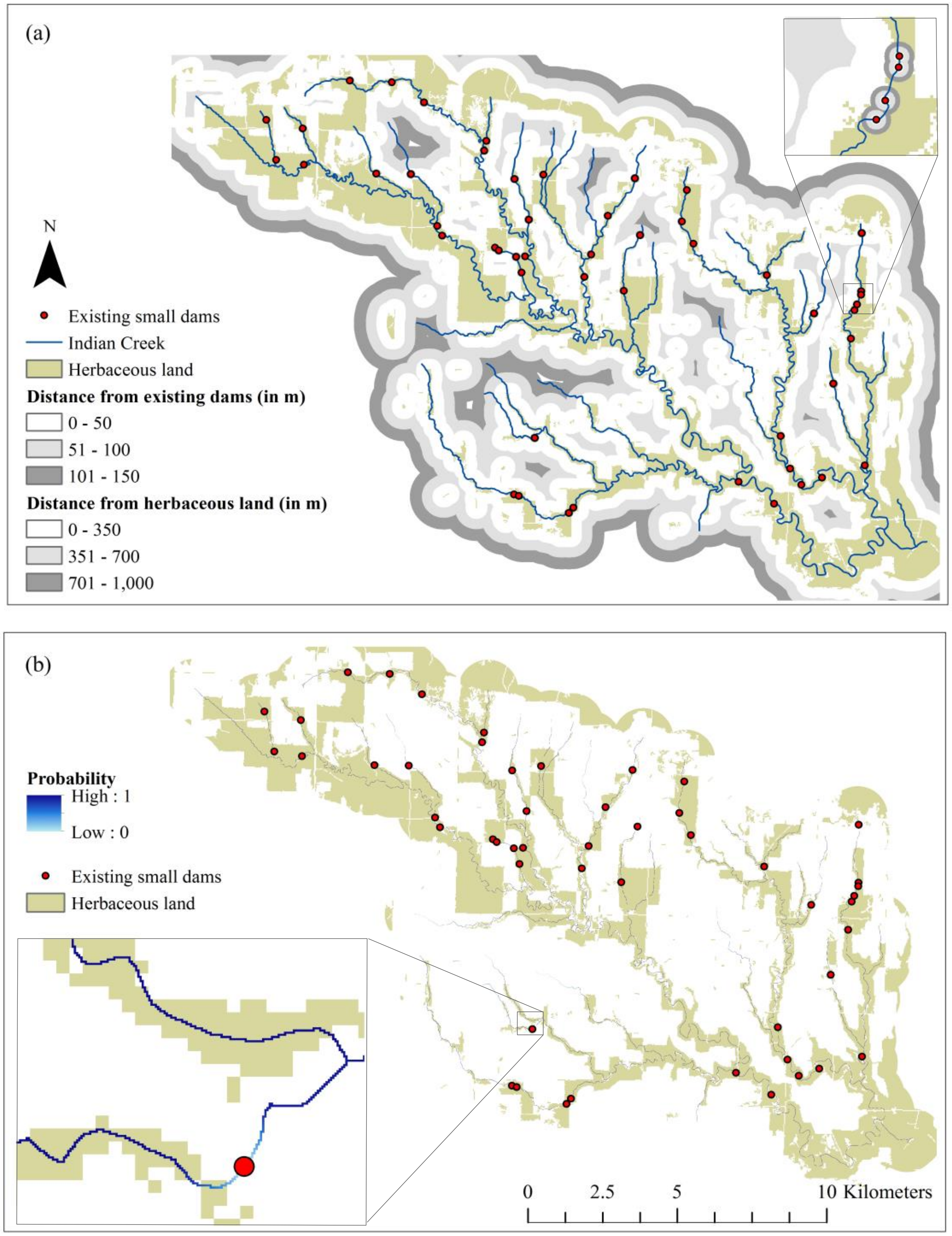

Figure 2.3: Generating the probability surface from two criteria, (a) distance from dominating land use and from existing dams, to create (b) a probability surface from the combined distance to determine the location of the new dams on the stream.

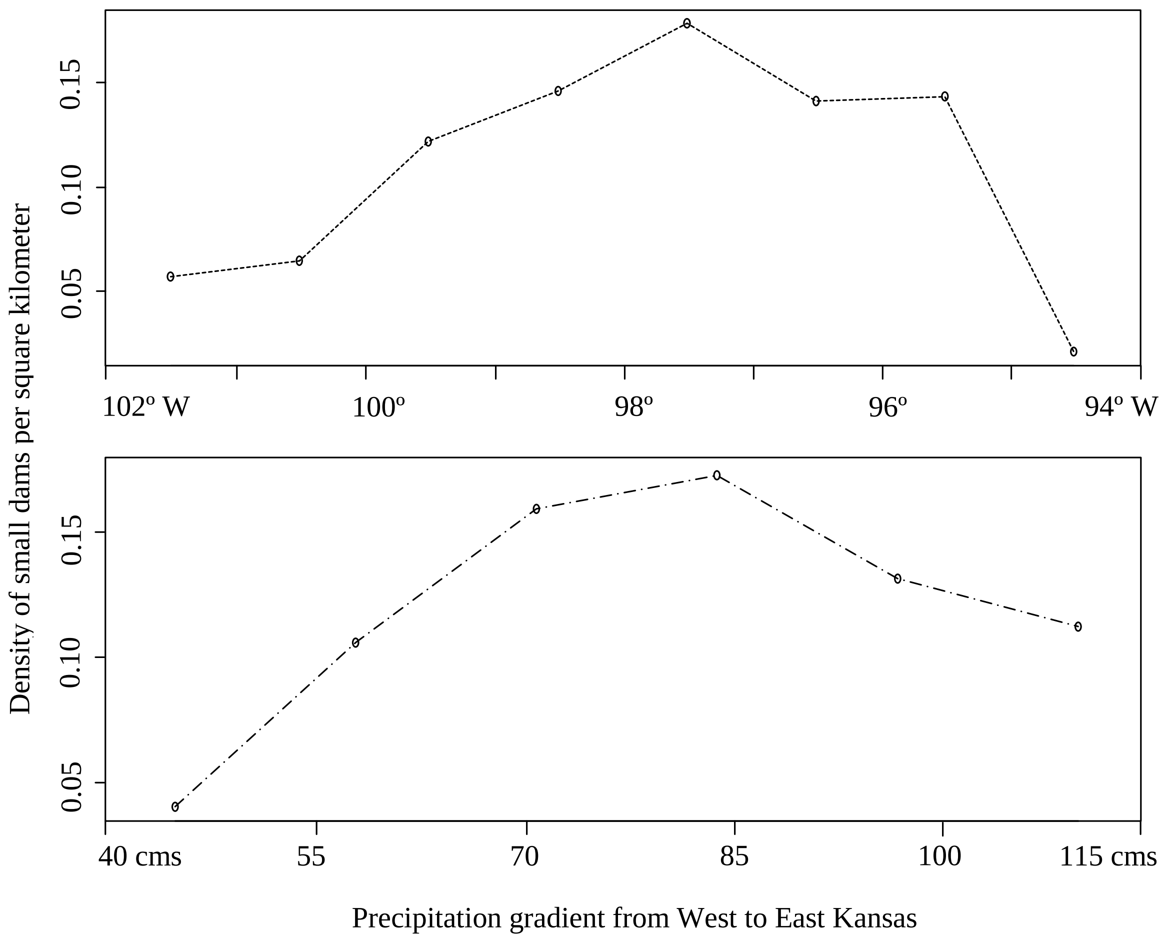

Figure 2.4: Geographical distribution of the small dams from west to east Kansas that follows the precipitation gradient of the region. Density of small dams was calculated for about 4670 small dams within approximately 40,000 square kilometer area from the Smoky-Hill and the Neosho river basin.

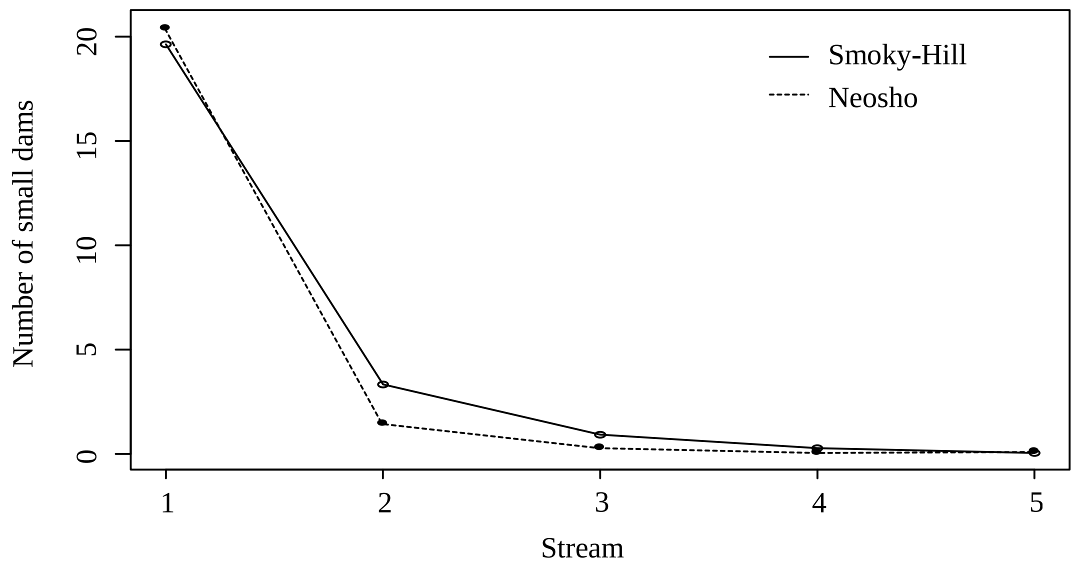

Figure 2.5: The distribution of all small dams in the Smoky-Hill and the Neosho River basin by its designated stream order, based on Strahler's classification.

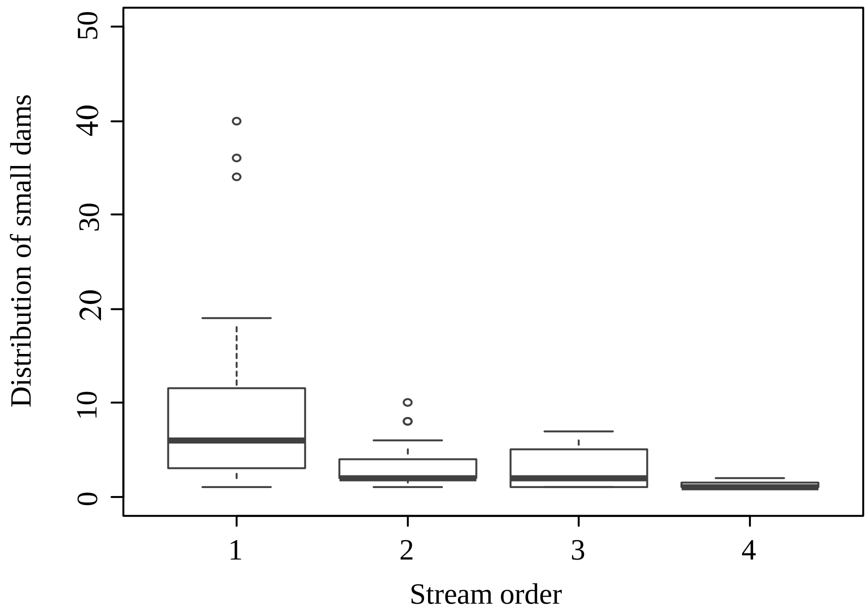

Figure 2.6: Distribution of mean and range of small dams within different stream order, based on Strahler's classification for the 30 sampled creeks in the Smoky-Hill River.

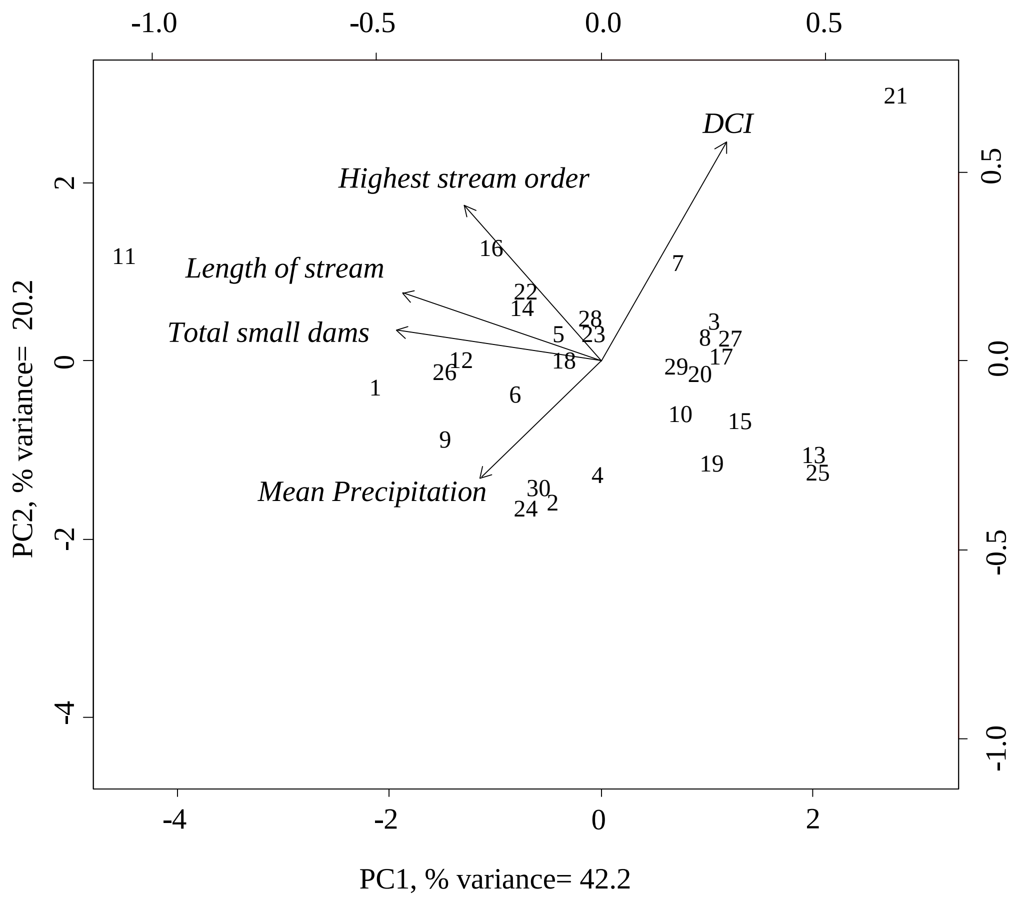

Figure 2.7: Principal component analysis of the 30 sampled creeks (Appendix A, Table A.1) within the Smoky-Hill River basin to analyze connectivity (DCI) with other relevant factors, where each number represents a given sampled creek.

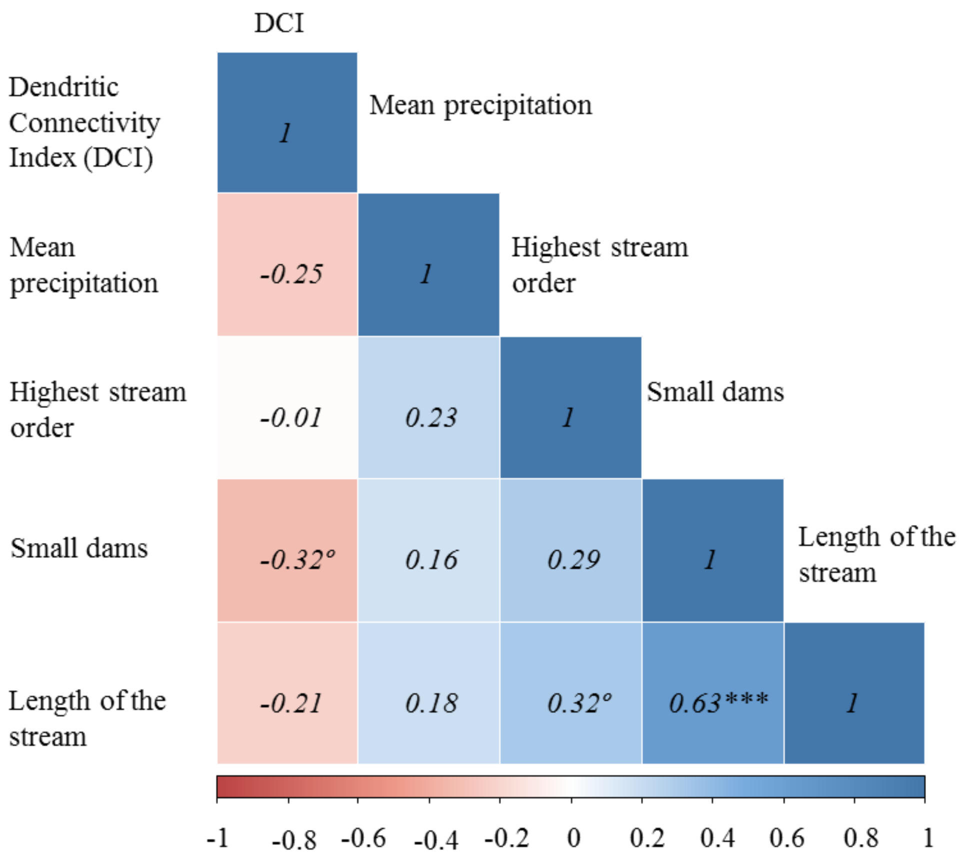

Figure 2.8: Correlation matrix derived from the sampled creeks, where significant correlation among the variables exists at '***' $p \leq 0.001$ and '°' $p \leq 0.1$ level.

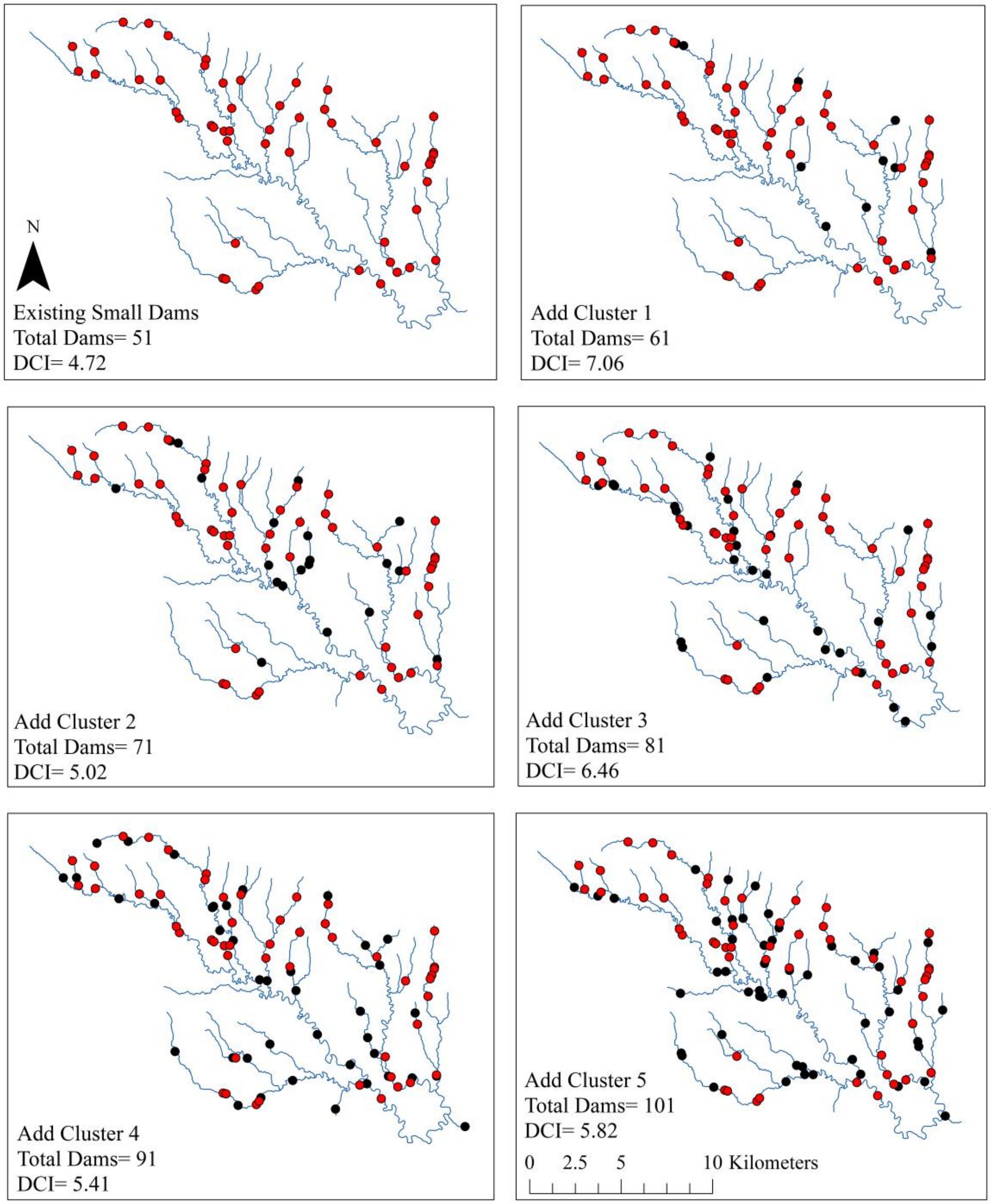

Figure 2.9: Analysis of five dam addition scenarios for the Indian Creek, where additional dams (in black) are added to the existing ones (in red) using a probability surface in GIS. The newly built dams are located within a kilometer from herbaceous land and at least 150 meters away from an existing dam.

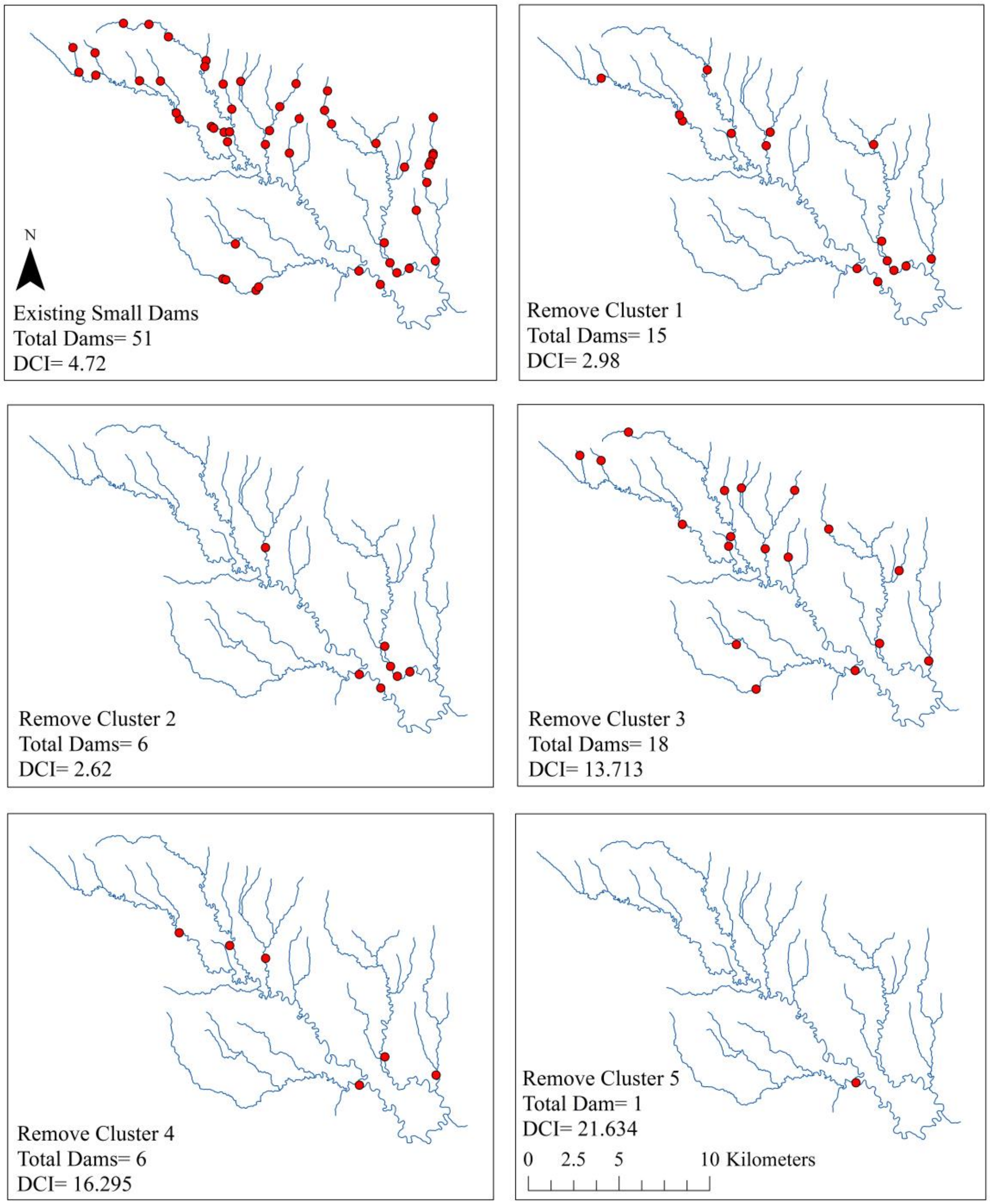

Figure 2.10: Analysis of five dam removal scenarios for the Indian Creek.

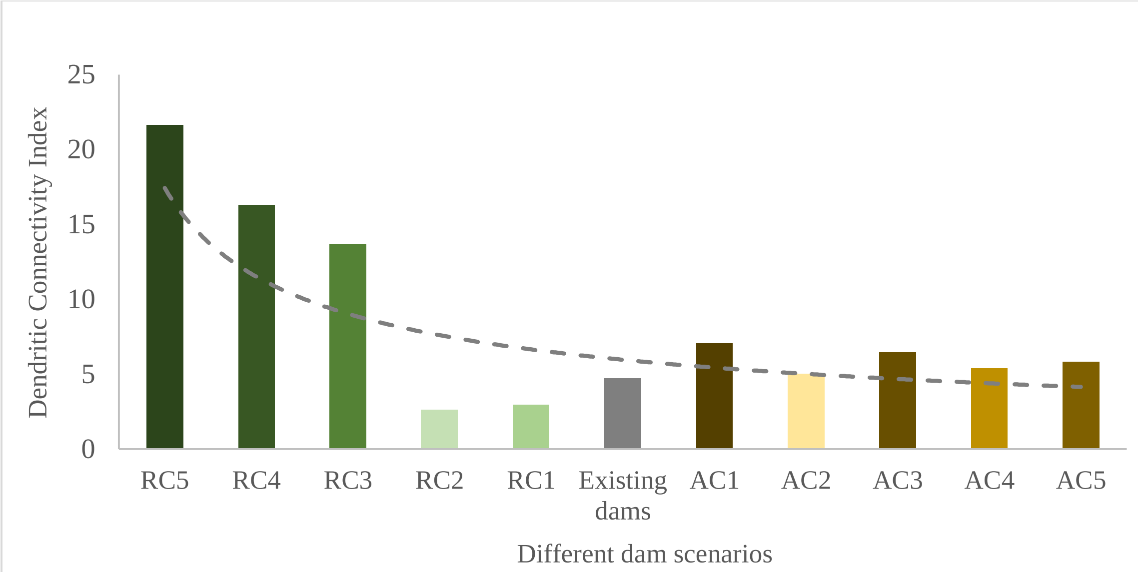

Figure 2.11: Change in DCI with total number of small dams in the Indian Creek with different removal (RC) and additional clusters (AC).

Chapter 3

PROJECTED CLIMATE CHANGE IMPACTS ON HYDROLOGIC FLOW REGIMES IN THE CENTRAL GREAT PLAINS OF KANSAS

3.1 Introduction

The flow regime is regarded by many aquatic ecologists as a key driver of river ecosystem function (Poff et al. 1997; Bunn and Arthington, 2002). The timing, magnitude, frequency, and duration of low and high flows regulate ecosystem processes of sediment and nutrient transport, along with biological rejuvenation. Its characteristics also feature prominently in the life history adaptations of aquatic organisms, with many reproduction, migration and other behaviors many coinciding with flow regime elements such as large flood pulses (Poff et al. 1997). Several theories central to stream ecosystem ecology feature the flow regime, including the Flood Pulse Concept (Junk et al. 1989), the Natural Flow Regime (Poff et al. 1997), and the Network Dynamic Hypothesis (Benda et al. 2004). The combination of flow regime and spatial structure of the river network determine the spatio-temporal patterns of habitat heterogeneity within the river ecosystem (Wu and Locks, 1995; Benda et al. 2004), and therefore is also recognized as a critical driver of river geomorphology, dictating the sediment transport regime and channel geomorphology as well as ecology of the river system (Vannote et al. 1980; Karr 1991, Poff et al. 1997).

Several studies (Poff et al. 1997, Arrigoni et al. 2010, Costigan and Daniels 2012, McClunney et al. 2014 and many others) have documented that direct anthropogenic alterations of river networks and watersheds through damming, water diversions, and land use changes have altered natural flow regimes disrupting the dynamic equilibrium between the movement of water and the movement of sediment that exists in free flowing rivers (Dunne and Leopold, 1978). Water abstraction, storage in reservoirs, and effluent returns affect different aspects of river flow regimes, such as magnitude, variability and timing (Junk et al. 1989, Richter et al. 1996, Poff et al. 1997, Biggs et al. 2005, Arthington et al. 2006, Kennen et al, 2007, Monk et al, 2008, Laize et al. 2014). Often these modifications result in conditions that make it difficult for native species to continue thriving (Poff et al. 1997). Homogenization of the flow regime leads to a decrease in inter-annual hydrograph heterogeneity and increases intra-annual heterogeneity (Costigan and Daniels, 2012, Arrigoni et al. 2010, Propst et al. 2008). This disrupts life history adaptations like the reproductive timing of aquatic species in response to natural flash floods (Lytle and Poff, 2003), nutrient exchange between in-channel stream and floodplain ecology, and creates a favorable condition for non-native species in the basin (Gido et al 2010, Propst et al. 2008).

Anthropogenic climate change has the potential to further alter river flow regimes, worsening the situation for native aquatic and riparian communities. According to the IPCC 2007 report, average global temperature is expected to rise by 1.8 – 4.0ºC, with precipitation expected to rise along with temperature and potential evapotranspiration (Budyko 1982, Jha et al. 2006, Bernstein et al. 2008). Future climate scenarios can cause dramatic shifts in flow regimes, influencing ecological processes, shifts in flood timings, changes in seasonal flow and magnitude of base flows, causing a reduction of biodiversity and available ecological habitat in the region (Gibson et al. 2005). Numerous studies (Hauer at al. 1997, Melack et al. 1997, Moore et al. 1997, Mulholland et al. 1997, Meyer et al. 1999, Stone et al, 2001, Bunn and Arthington 2002, Lytle and Poff 2003, Bragg et al. 2005, Palmer et al. 2009, Poff and Zimmerman 2010, Okruszko et al. 2011, Piniewski et al. 2012) that examined potential impacts of climate change on aquatic ecosystem at a regional scale predicted reduced habitat, loss of ecosystem function and factors favoring the growth of invasive species. Increases in surface air temperature associated with climate change would vary seasonally and would be greater in some regions than others (Rosenzweig et al. 2008, Palmer et al. 2009). The projected temperature change is expected to cause winter warming, changing the timing and form of precipitation, for example by shifts from winter snowfall to rainfall (Barnett et al. 2008). The conversion of the form of precipitation would decrease the amount of infiltration, due to lack of snow and increase direct runoff to the streams. These changes in the timing and form of precipitation can affect the timing of minimum and maximum flow. Many ecosystems have a high capacity to absorb disturbances without significant alteration; consequently, some ecosystem functions and services may be restored by re-introducing certain flow regime elements, whereas for other functions, the ecosystem may be pushed beyond its resilience limits and may change to a new irreversible state (Laize et al. 2014). Resilience of ecosystems (Holling 1973, Robson and Mitchell 2010, McClunney et al. 2014), behavioral adaptations (Poff 1996, Fausch and Bestgen, 1997) and morphological adaptations (Barrat-Segretain 2001, Karrenberg 2002) helps the system restore back to its equilibrium stage. However, river discharge is anticipated to change in the future, and it is estimated currently that habitats associated with 65% of ‘continental discharge’ are at risk worldwide (Vörösmarty et al., 2010), especially in semi-arid systems.

River systems draining the semi-arid regions of the central Great Plains, USA, are characterized by extremes of high and low flows and are fragmented severely through unaccounted small dams. Climate projections for this region suggest high temperature and precipitation changes. Precipitation is projected to increase in the winter and decrease or remain constant in summer. Other hydrological variables, including precipitation, evaporation, runoff and soil moisture, are expected to increase throughout the region in winter and spring, but decrease in summer (Wuebbles and Hayhoe 2003). Unsystematic and uncontrolled small damming in the Great Plains (Renwick et al. 2006, see Chapter 2, this dissertation), accompanied by change in climate have the severe potential to fragment the river system and can create a permanent change in the system that it is unable to adapt. This study seeks to translate downscaled climate projections into projected stream flow scenarios via watershed modeling to understand how river flow regimes will respond to anthropogenic climate change. Furthermore, these changes are evaluated within the context of dam fragmentation to evaluate combined likely anthropogenic effects on flow regime and stream network habitat connectivity.

3.2 Study area

The Great Plains of the United States is characterized by a semi-arid highly variable climate regime. The region experienced the most severe drought in recorded history in the continental United States during the 1930s and in general has more pronounced drought and wet intervals in comparison with the rest of the USA. Studies (Covich et al. 1997) of past climatic changes in the Great Plains indicate that the spatial and temporal distributions of rainfall and temperature have changed relatively rapidly several times in the last 10,000 years. These climatic changes not only influenced the distribution of terrestrial plant communities, but also altered the distribution of aquatic plants and animals, water levels and salinities (Covich et al. 1997). Historical flow records of streamflow pattern in western Kansas, in the central Great Plains show a substantial change in flow, especially since the mid-1960s, where mean daily discharge generally declined over time. It is likely that impoundments have altered the timing and possibly intra-annual variability of flows in the streams, and these trends were probably not related to climate. However, the mean annual temperature near Hays, in western Kansas in the Smoky Hill basin has increased by ~1^{0}C in the past century (Heinrichs, 2006, Gido et al. 2010). More significantly, the extremely low precipitation associated with the Dust Bowl (1930s) and the strong drought in the 1950s did not lead to stream drying as extensive as is occurring now under normal precipitation (Gido et al. 2010).

The study area for this research is based on the stretch of the Smoky-Hill River basin (Figure 3.1) between two large flood control dams - Cedar-Bluff and Kanopolis, in the central Great Plains region of Kansas. The river originates in the high plains of eastern Colorado at the rise of the North and the South Fork River, and flows eastward to the confluence with the Kansas River, near Junction City, Kansas (Kansas Water Office, 2009). The Ogallala-High Plains aquifer is the major groundwater supply for the region, but only underlies small portions of the far western half of the Smoky Hill watershed. Most of the basin is largely devoid of large deep groundwater resources (Kansas Water Office, 2009) and is extensively fragmented by numerous small dams (see Chapter 2, this dissertation). Approximately 750 dams are located within 6300 sq. km area of the study area, and are mostly undocumented and unidentified by state authority, as majority of them are privately owned, holding lower than the state specified limit of requiring any permit. The outflow from a reach (Figure 3.2) increases with decrease in zero flow days (r = -0.26 at $p \leq 0.1$) for any particular reach within the study area, for drought year 2012. Around 35 out of the 54 reaches in the study area, covering approximately 4300 sq. km area, experienced 30 or more zero flow days, and around 14 of these reaches experienced around 70-90 zero flow days in that particular year. This scenario is hypothesized to intensify with the change in climate and the same is analyzed in the later sections.

3.3 Methodology

3.3.1 Data Analysis

To evaluate potential climate change alterations to flow regimes, a Soil Water Assessment Tool (SWAT) model is developed and calibrated for the study area by Gao et al. (2015a, 2015b, 2016 in review). The SWAT model delineates the watershed and generates the flows at sub-watershed outlets, using the downscaled climate scenario parameters form General Circulation Models. The outlets are set to correspond to USGS gage stations where SWAT generated flows are compared with USGS observed records for calibration. For the flow analysis, historical USGS flow records are then compared to projected flow records using a series of ecologically relevant flow metrics derived from the Indicators of Hydrologic Alteration (IHA) program (Richter 1996).

Historical flow data is obtained from three United States Geological Survey (USGS) gage stations— 6864500 (Ellsworth), 6863500 (Hays) and 6862850 (Schoenchen), each having more than 30 years of historic flow data. Observed historical discharge data is obtained from the USGS website (https://ks.water.usgs.gov/) for the period of time period 1 (1981-2010), and is then compared with two sets of flow projected data for time period 2 (2045- 2055) and time period 3 (2090- 2100).

Projected future climate data for the two periods (2045- 2055) and (2090- 2100) are obtained from Representative Concentration Pathways (RCP) 8.5 emission of six Global Circulation Models (GCMs): 1) Community Climate System Model (CCSM4), 2) Centro Euro-Mediterraneo sui Cambiamenti Climatici Climate Model (CMCC-CM), 3) Centre National de Recherches Me´te´orologiques (CNRM-CM5), 4) EC-EARTH, 5) Model for Interdisciplinary Research on Climate (MIROC), and 6) Coupled Global Climate Model 3 developed at the Meteorological Research Institute (MRI-CGCM3). The RCP 8.5 emissions scenario combines the assumptions of high population and relatively slow income growth with modest rates of technological change and energy intensity improvements, leading in the long term to high energy demand and greenhouse gas (GHG) emissions in absence of climate change policies. Compared to the total set of RCPs, RCP 8.5 corresponds to the pathway with the highest GHG emission contributing highly towards the development of spatially explicit air pollution projections and enhancements in the land-use and land-cover change projections (Riahi et al. 2011).

The data is then bias corrected (Gao et al. 2015b) based on Parameter–elevation Regressions on Independent Slopes Model also known as PRISM (1994-2005), available from the Climate Group at Oregon State University. The procedure is done through a distribution mapping technique, where observed and GCM historical daily rainfalls at the different rainfall ranks/percentiles are taken and then the GCM future daily historical rainfall series are translated to obtain an observed future daily rainfall series. The precipitation data is then used to compute projected discharge at the individual outlets. This approach preserves the observed daily rainfall sequence in the GCM future daily rainfall sequences, but with GCM-scale values translated to finer grid cell/station scale values.

For comparison of the means between the historical dataset with the climate flow projection, Welch's unequal variances t-test has been used at significance level, $p \leq 0.001$. It is a two-sample location test used to test the hypothesis that two populations have equal means, when the sample sizes are unequal and have unequal variances. All the statistical analysis and plots for the research has been done using statistical software R: The R Project for Statistical Computing, more specifically, using the plot function.

3.3.2 Indicators of Hydrologic Alteration

The hydrologic records for the three gages for the three periods are analyzed using IHA, also known as the Indicators of Hydrologic Alteration (Richter et al. 1996), developed by The Nature Conservancy. IHA's assessment defines a series of biologically relevant hydrological attributes that characterizes intra- and inter-annual variations in flow, obtained from daily hydrological data. The IHA constitutes of 67 parameters, which are sub divided into 2 groups: 33 IHA parameters and 34 Environmental Flow Components (EFC). The IHA parameters compute measures of central tendency and dispersion for each of them and were developed based on their ecological relevance and their ability to reflect human-induced changes in flow regimes (Richter et al. 1996, Mathews and Richter 2007). These indicators are grouped into five major categories: 1) magnitude of monthly water conditions (mean discharge for each calendar month), 2) magnitude and duration of annual extreme water conditions (1, 3, 7, 30 and 90-day mean annual minimum and maximum discharge), 3) timing of annual extreme water conditions (Julian date of each annual 1 day minimum and maximum), 4) frequency and duration of high and low pulses (number and mean duration of high and low pulses each year), and 5) rate and frequency of water condition changes (number of rises and falls and reversals in the daily hydrographs).

To date, 170 hydrologic metrics have been published to summarize various aspects of the flow regime, but the majority of these have inherent statistical redundancy (Olden and Poff 2003). IHA, as a suite of metrics, also contains various parameters that are inter-correlated (Olden and Poff 2003) and provide numerical redundancy, complicating environmental flow assessment (Arthington et al. 2006, Gao et al. 2009). However, there should be a balance between statistical simplicity and natural system complexity to enable the design of logical and environmental sustainable river regulation guidelines (Gao et al. 2009).

Based on finding from previous studies (Olden and Poff 2003, Yang et al. 2008, Gao et al. 2009, Costigan and Daniels 2012), we selected 27 hydrological parameters (Table 3.1) from the five groups and the 25th and 75th percentiles of flow for our research. The common elements for each of these studies included at least one monthly flow statistic, two extreme events representing both high and low extremes, and one associated with the frequency of low and high pulses (Gao et al. 2009). Following Richter et al. (1996), we calculate the percentage change of the mean values of the IHA parameters between the historical and the two projected flow periods. The median values for monthly flows are used to analyze more about the extremities in flow.

3.4 Results

The historical USGS discharge data is regarded as the base line flow regime, and the two future projections are evaluated for departures from the base line for each of the given indicators. All the indicators show significant yet varying degrees of departure from the base line period.

3.4.1 Magnitude of Monthly Stream Discharge

Projections for changes in the magnitude of mean annual discharge in the study area vary by gage site and model (Table 3.2). For period 2, models project decreased mean annual discharge for the Ellsworth (-17% to -47%) and Hays (gages with the exception of the EC-EARTH model projections which suggest strong increases in annual discharge. All models project increased annual discharge at the Shoenchen gage. For period 3, most models at all gages project increased annual discharge, with the largest increases at the Schoenchen gage.

Projections of mean monthly flow for Ellsworth for all the model projections in both the projected periods predicts an increase in flow in late fall-early spring and a decrease in flow from April to September (Table 3.3). The peak for both the projections is expected to move to early April, with high flows extending through May (the historical peak flow period). Although the annual peak flow for Hays for projected period 2 is May, which is similar to the historic period, it is predicted to move earlier, to April for period 3 (Figure 3.4). The fall of July monthly mean is consistent across all models, for both the projected periods for Hays and Ellsworth. The mean monthly flow is expected to rise in Schoenchen (Figure 3.5) for both the projected periods, with a possibility of dual peaks in April and June. Monthly discharge at Schoenchen for late fall in October and November shows a statistically significant increase in flow for all the model projections (Table 3.3), for both the future scenarios. The discharge, although in lower magnitude, continues to increase in the spring months of February and March. Late spring discharge (April and May) from snow-melt, increases in Schoenchen for both the projected periods (Table 3.3, Figure 3.3). Overall discharge is predicted to increase in early spring throughout the watershed, but no particular pattern is observed for the month of March through June. In general, the model projections from CCSM4, CMCC-CM and MRI-CGCM3, for period 2 (2045-55), for Ellsworth (Figure 3.3) and Hays (Figure 3.4), shows an overall fall from historical discharge. Projections from CNRM- CM5, EC-EARTH and MIROC models however, predicts an overall increase discharge for all the three gages for mean monthly October flows for both the projected periods.

The annual stream discharge is further investigated using quartile monthly average flows from the 25th (Figure 3.6, 3.7 and 3.8) and the 75th percentiles (Figure 3.9, 3.10 and 3.11) of flow to analyze the flow extremes. The 25th and 75th percentile flow suggested an increased late fall- early spring flow and a decrease in flow for the months of May through September for Ellsworth (Figure 3.6 and (Figure 3.9) for both the projected time periods, with an increased flow for period 3 over period 2. A similar trend is observed at Hays for the 25th percentile (Figure 3.7). The 75th percentile flow is expected to drop for the future projections in an average (Figure 3.10). In Schoenchen (Figure 3.8), the flows for both the projected periods are expected to rise, with multiple peaks between February and July. Similar to the mean monthly flow predictions, the 75th percentile flow is expected to rise at Schoenchen (Figure 3.11) with an increase in flow during April and May. Among the three gages, Schoenchen is affected most from changes in flow compared to Hays or Ellsworth, occurring mostly in the form of late fall and early spring discharge, as observed from mean annual discharge, mean monthly and median flow.

3.4.2 Magnitude and Duration of Annual Extreme Stream Discharge Conditions

Apart from one model (EC-EARTH), projected flow regimes show a decrease in magnitude between period 1 and 2 for the annual 7- and 30-day minimum flows when compared with the baseline historical flow regime (Table 3.4). This is also the scenario for 90-day minimum flow for Ellsworth and Hays. The 90-day minimum for Schoenchen is predicted to increase for both the projected periods. There was no zero flow days recorded for Ellsworth during the baseline historical period and is therefore excluded from the projection analysis. The number of zero flow days in the study area may increase about ten times for Hays, from 11 to 108-173 days and, about 30% for Schoenchen, from 117 to 126-179 days (Table 3.4). The magnitude of the maximum discharges (Table 3.5) also shifts significantly for the projected flow regimes. The 7-, 30- and 90-day mean annual maximum discharges are expected to increase in the study area, apart from Ellsworth for projected period 2.

3.4.3 Timing of Annual Extreme Stream Discharge Conditions

Projected stream flows indicate a substantial shift in timing of extreme high and low flows across all the models (Table 3.6). The difference of date of maximum discharge between the baseline and projection period 2 ranged from 1 to 42 days and 3 to 58 days for period 3 (Table 3.6). However, for difference of date of minimum discharge, the range widens up for both projected periods, ranging from 1 to 60 days. The direction of shifts is consistent across the models for the date of minimum for both the projections in all the three USGS gages but is mostly inconsistent while predicting the date of maximum flow, across the six models. The date of minimum is expected 42-64 days earlier at Ellsworth for projected period 2 and 8-58 days earlier for projected period 3. However, it is expected to get delayed by 54-62 days for projected period 2 and 46-56 days for projected period 3 for Hays; and by 5-34 days for projected period 2 and 11-25 days for projected period 3 for Schoenchen, when compared to the baseline period as seen from five of the six models.

3.4.4 Frequency and Duration of High and Low Pulses

The IHA reported zero for low pulse count and no value for low pulse duration for both Hays and Schoenchen for the projected period and hence were not been included in the analysis. The low pulse count (or the number of times flow drops below the 25^{th} flow percentile) is expected to rise for Ellsworth (Table 3.7), but the duration of low flows (low pulse length) is predicted to decrease for both projected periods and across all the models. On the other hand, the high pulse count (number of times flow rises above the 75th flow percentile) is expected to rise on an average for both the projected periods across the watershed. Among all the three gages, Schoenchen is expected to have the highest pulse count, with an increase of more than 100% over the base line for both the projected periods.

3.4.5 Rate and Frequency of Stream Discharge Conditions Change

Rise rate is a sequence of continuously rising mean daily discharge, and fall rate is a sequence of continuously decreasing mean daily discharge. In Table 3.8, on an average, rise and fall rate are going to increase for Hays and Schoenchen by a magnitude of 10-200%. The overall rate of discharge condition is however going to decrease or increase by a very low margin (>30%) for Ellsworth, in comparison to the other two gages, for both the projected period, across the six GCMs. The frequency of discharge condition or hydrological reversals from a fall to a rise or vice-versa is significantly going to increase for Ellsworth and Schoenchen, both located at the main stem of Smoky-Hill. Numbers of reversals are expected to decrease marginally by 1-20% for Hays (Table 3.8).

3.5 Discussion and Conclusions

Simulations of stream flow under current and future climate conditions often exhibit high modeling error and uncertainty. Several projections and estimations of regional streamflow can be made, but none can be considered without large uncertainty. It is therefore necessary to investigate how different estimates of stream flow can alter the simulated response of the water resource system (Nazemi and Wheater 2014). To avoid and reduce uncertainty and modeling error, six bias corrected GCM projections are used to generate hydrological parameters for the two future flow projections. Nazemi and Wheater (2014) also concluded that in-basin water allocation complicates the propagation of the in-flow bias and uncertainty in the outflow of the system, especially in case of system that faces scarcity due to drought or increased water demand conditions, both of which exist in the central Great Plains study region.

The results from this research indicates significant alteration of flow regimes due to projected changes in climate, and the analyses and results supported the hypothesis that climate change will alter ecologically important indicators of river flow regime. These findings are consistent with previous studies of climate change and flow alteration in other regions projecting shifts in flood timing and magnitudes with climate change (Gibson et al. 2005, Laize et al. 2014). Future climate scenarios can cause dramatic shifts in flow regimes, influencing ecological processes, reduction of species and their habitat in an aquatic ecosystem (Gibson et al. 2005, Palmer et al. 2009, Laize et al. 2014, Piniewski et al. 2014). The relationship between zero flow days and outflow from a reach is not significantly strong in the study area at the reach scale, but are negatively related to one another. With the change in climate, the flow is going to change drastically, increasing the number of zero flow days in the basin significantly. Besides that, due to the location of the dams in crucial tributary locations, the river is severely fragmented, restricting the movement of aquatic species (Cote et al. 2009, Perkin and Gido 2012) and disconnecting tributary connections hydrologically (see Chapter 2, this dissertation). High dam density can also lead to other basin wide hydro-geomorphic and ecological changes, like strong basin flow homogenization, decreased network connectivity, ecological patches and variation (Mc.Clunney et al. 2014). Therefore, a basin like the

Smoky-Hill River, which is highly fragmented, becomes more susceptible to changes in flow, with change in climate.

As analyzed from our study, the hydrological indicators of flow regime changes are reasonably consistent with the various model runs, except the EC-EARTH model for period 2. The EC-EARTH model seems to pre-empt the other five climate models for period 2 but is consistent with the other model projections for period 3. This might be attributed to the factor that EC-EARTH is developed based on a seamless earth-system prediction approach, where variability in a fully coupled setting degrades the prediction skill on shorter time scales (Hazeleger et al. 2010).

The key findings of this study, in terms of the five main components of flow regime are:

- The mean monthly, and the first quartile flow increases in late fall to early spring, and decreases between May and September, with an earlier shift in timing of the annual peak discharge. The changes in flow during projected time periods are expected to be faster compared with the historical baseline period. These changes can be attributed to projected increases in atmospheric carbon-dioxide and the resulting changes in temperature and precipitation (Lettenmaier et al. 1994, Vorosmarty et al. 2000, Alcamo et al. 2003, Palmer et al. 2009). The increased carbon-dioxide in the atmosphere results in the increase in temperature, evapo-transpiration and changes in precipitation pattern and form. The majority of the winter precipitation is expected to be in the form of rain or rain plus snow, instead of snow (Barnett et al. 2008). Due to increased winter rain and increase in the length of summer low flow, the peak is expected earlier in the year. This would lead to decreasing maximum and minimum flows in the basin (Gibson et al.

2005), but would change the shape of the hydrograph. The hydrograph would therefore have an earlier shift with flashier flow than before.

- The 7-, 30- and 90-day minima are expected to decline, and the 7-, 30- and 90-day maxima are expected to rise, increasing the variability and extremities of flow. Both Hays and Schoenchen, which are located downstream from the Cedar-Bluff Reservoir and upstream in the study area, are projected to experience a significant growth in the number of zero flow days. The increase in the number of zero flow days in upstream Smoky-Hill, indicates that major tributary, like the Big Creek may completely get separated from the main stem if it experiences zero flow days for more than one-third of the year.
- Climate change effect on Julian calendar timing varied between 1-60 days or a shift in peak flow by two months for both 1-day minimum and 1-day maximum discharge. Prediction of warmer and wetter winter and warmer and drier summer than historic and current conditions, from the Hadley Center Model (Gibson et al. 2005) can be a major cause for this shift in flow.
- The rise in low pulse count indicates drier summers in the basin, but the reduced length of the low pulse in Ellsworth points to the changing flashy nature of the flow, with change in climate. Increased high pulse count and length further indicates to an increased flow in the basin that might also result in prolonged floods.
- Both rise and fall rate are expected to increase on an average for the upstream reaches in comparison to downstream Smoky, which receives more rainfall. The reversals from one pattern of flow to another is expected to rise mostly in the main stem of the Smoky-Hill, over the tributary also indicates higher frequency of flash flood in the main stem. Shorter and frequent duration of precipitation and

increase in rainfall over snow would decrease infiltration time and increase direct runoff to the basin. Apart from that, higher intensity of flow at the beginning and end of the flow period will generate flashier flood not giving enough lag time for hydrological transition.

An important implication from these results indicate that change in climate can cause significant changes to discharge and therefore groundwater recharge, which is a major source of water for irrigation and livelihood in the study area. Increased precipitation in the form of winter rainfall, instead of snow, would reduce the available time period for infiltration, thereby diverting precipitation from infiltration to runoff flowpaths and increasing the magnitude and flashiness of flow.

In summary, our findings strongly suggest that the inter-annual and the intra-annual changes in flow regime of the Smoky Hill will result in increased drying of parts of the network as well as increased flash flood frequencies and magnitudes with changes in climate. These changes, when combined with shifts in timing of flows are likely to fundamentally alter the ecology of the system (Poff et al. 1997, Palmer et al. 2009, Laize et al. 2014 and others) by reducing native species in the basin, disconnecting tributaries that dessicate above dams, and altering sediment fluxes channel geomorphic complexity (Pizzuto 2002, Graf 2006, Schmidt and Wilcock 2008, Arrigoni et al. 2010 and others). Resource managers, policy makers, and scientist would have to participate together and need to consider the effect of both climate change and anthropogenic activities that can modify river basins, when analyzing future impacts of river flow regimes (Poff et al. 2003, Palmer et al. 2009, Arrigoni et al. 2010), for better river basin management.

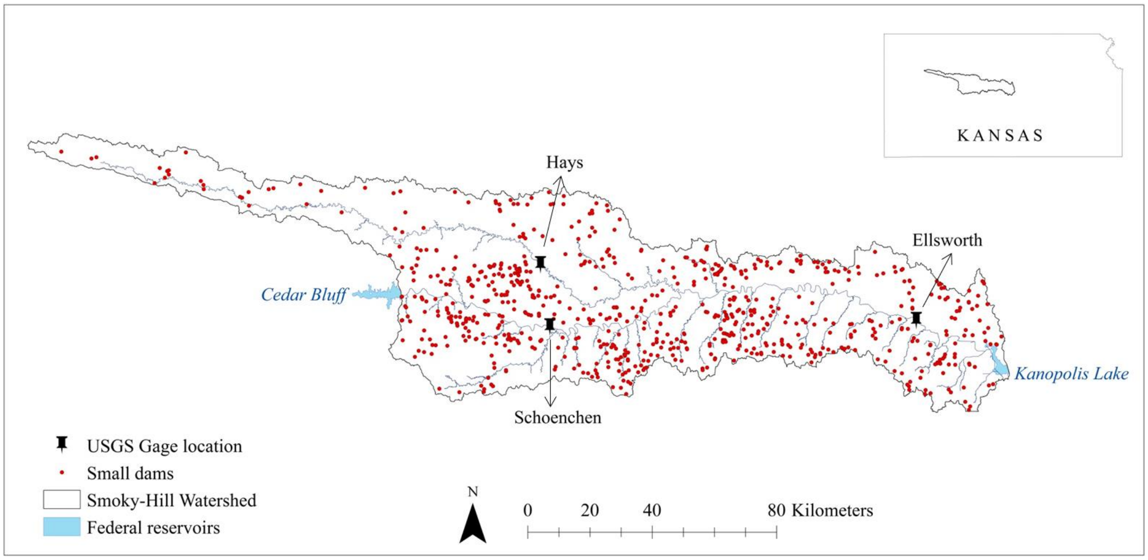

Figure 3.1: Study area showing the location of the three USGS gages where discharge data for historical and climate projected data are compared in the Smoky-Hill River basin.

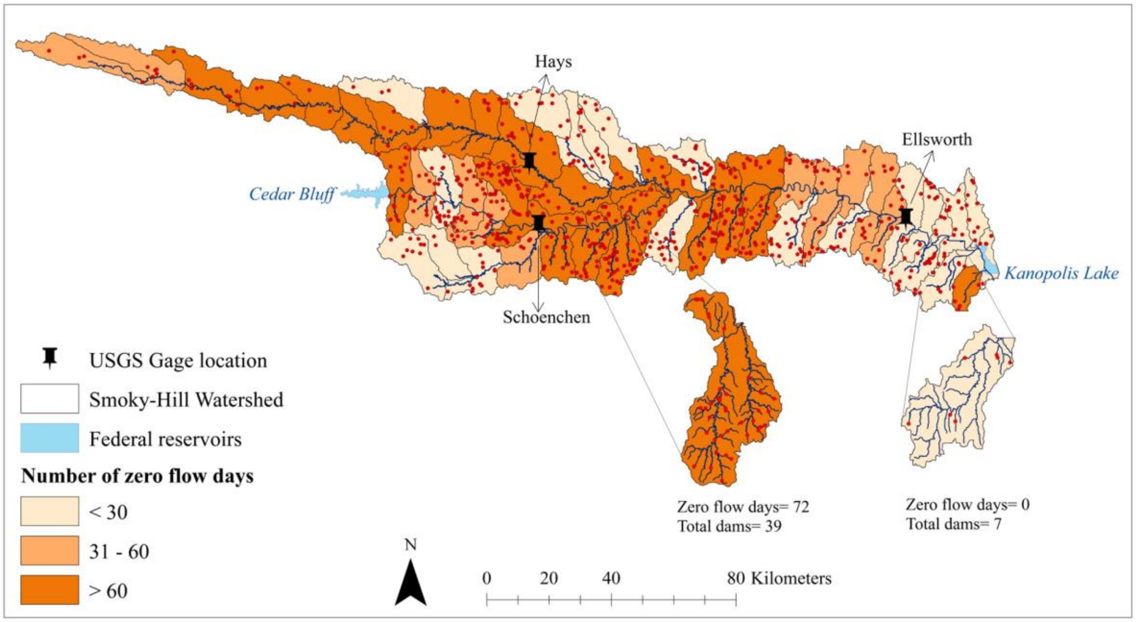

Figure 3.2: Distribution of small dams in the study area and analysis of number of zero flow days for the drought year 2012 at a reach scale for the Smoky-Hill River basin.

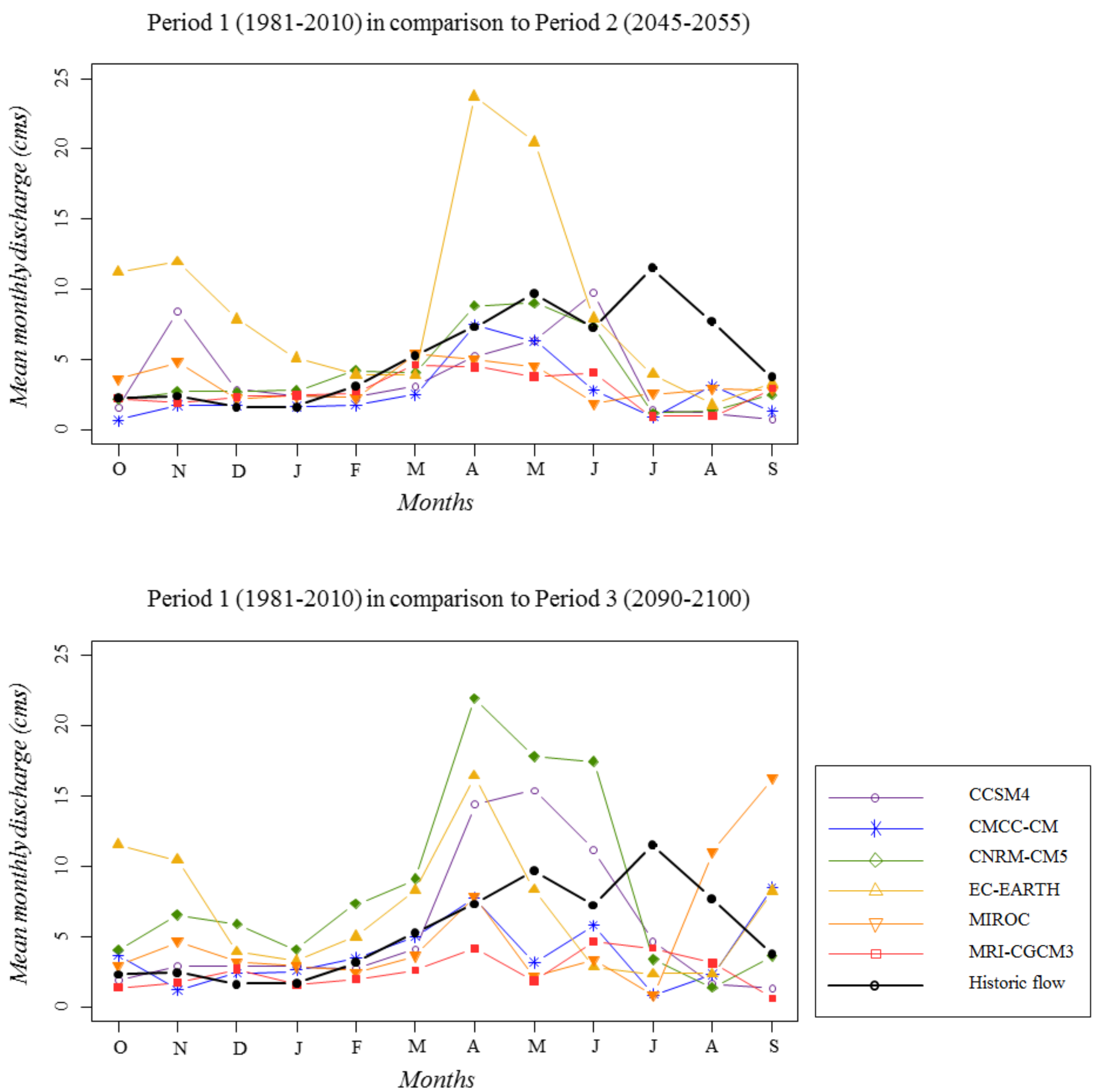

Figure 3.3: Comparison of mean monthly stream discharge at Ellsworth between historical flow (period 1) and projected flow (period 2 and period 3).

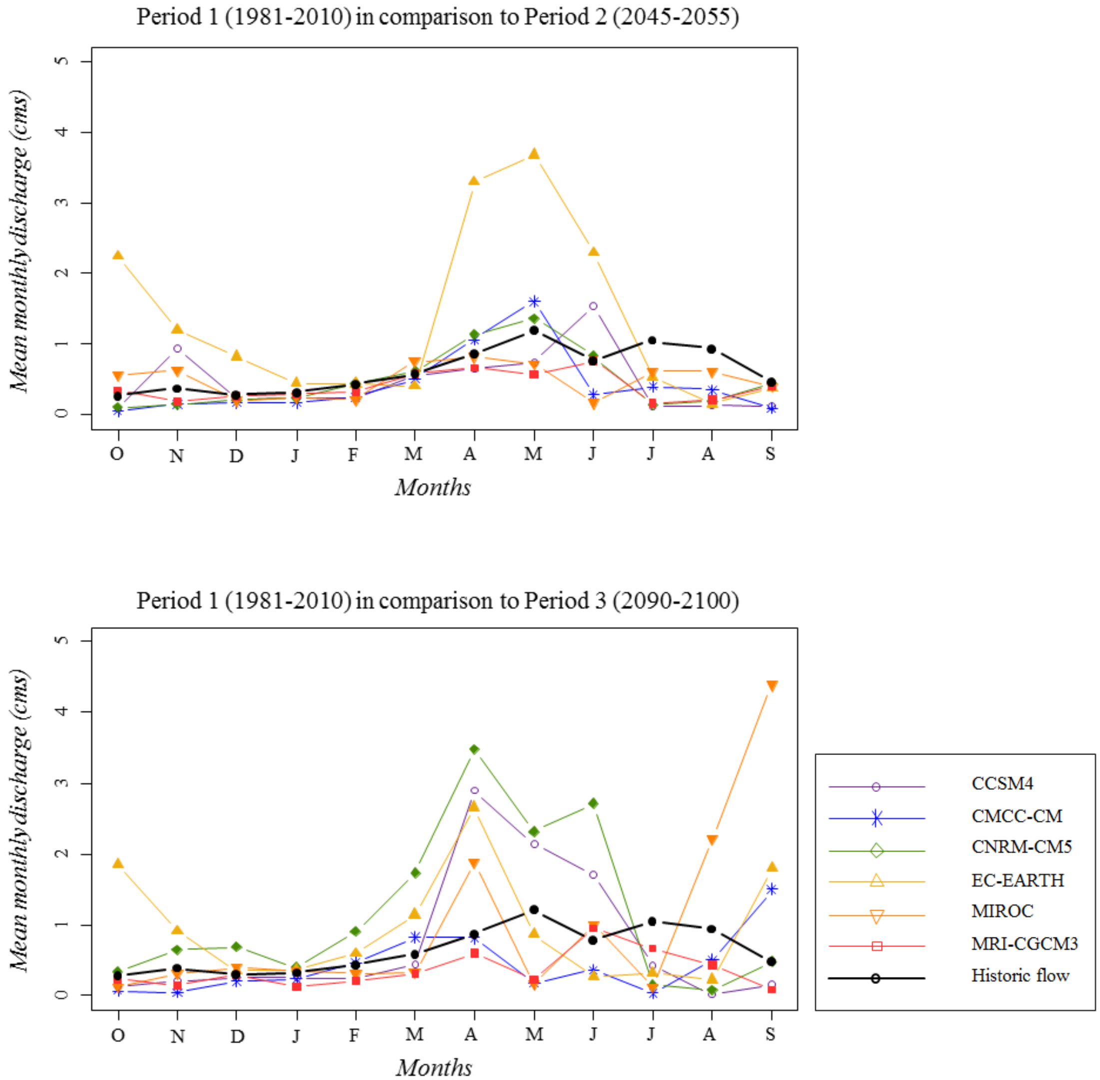

Figure 3.4: Comparison of mean monthly stream discharge at Hays between historical flow (period 1) and projected flow (period 2 and period 3).

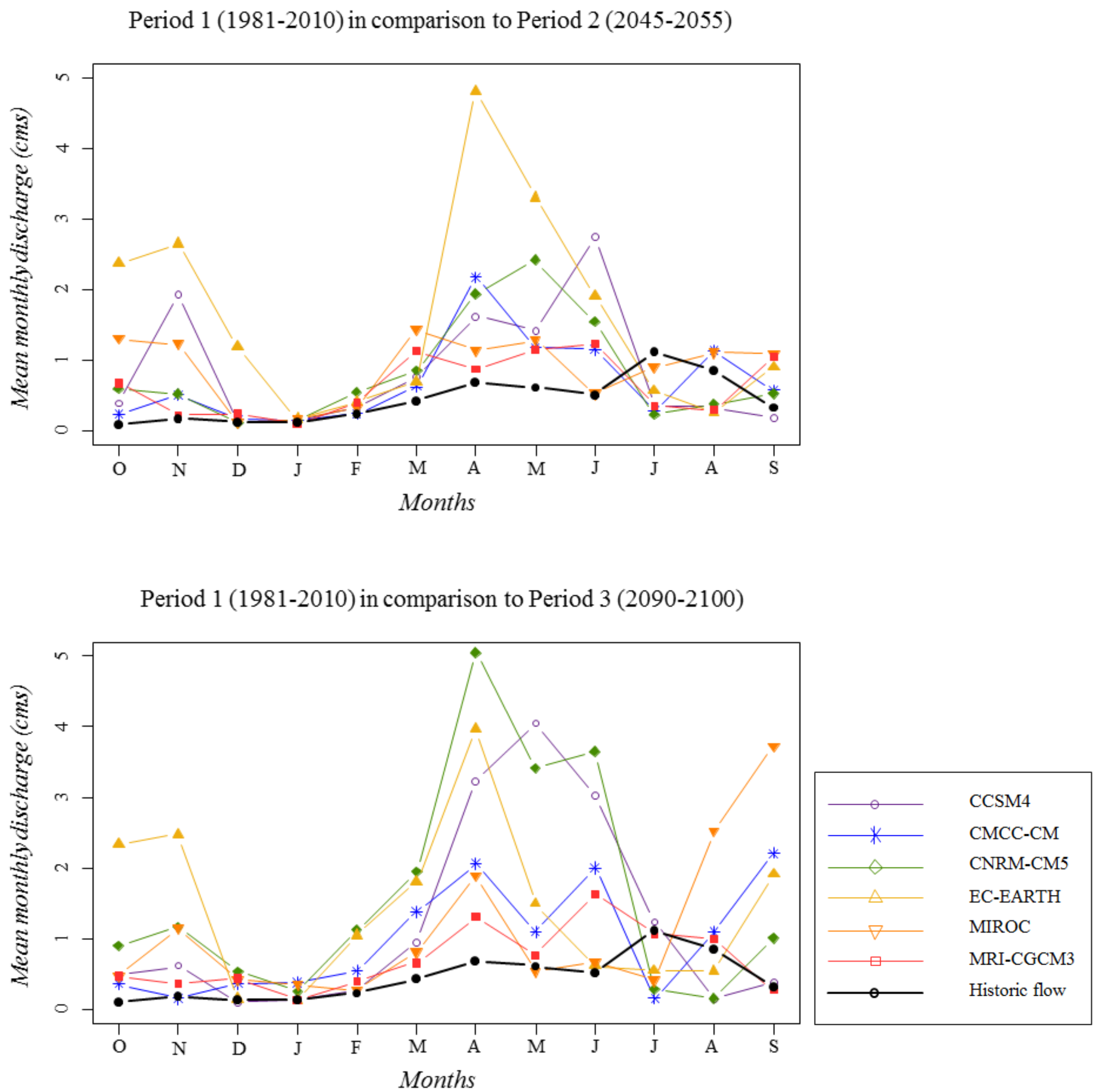

Figure 3.5: Comparison of mean monthly stream discharge at Schoenchen between historical flow (period 1) and projected flow (period 2 and period 3).

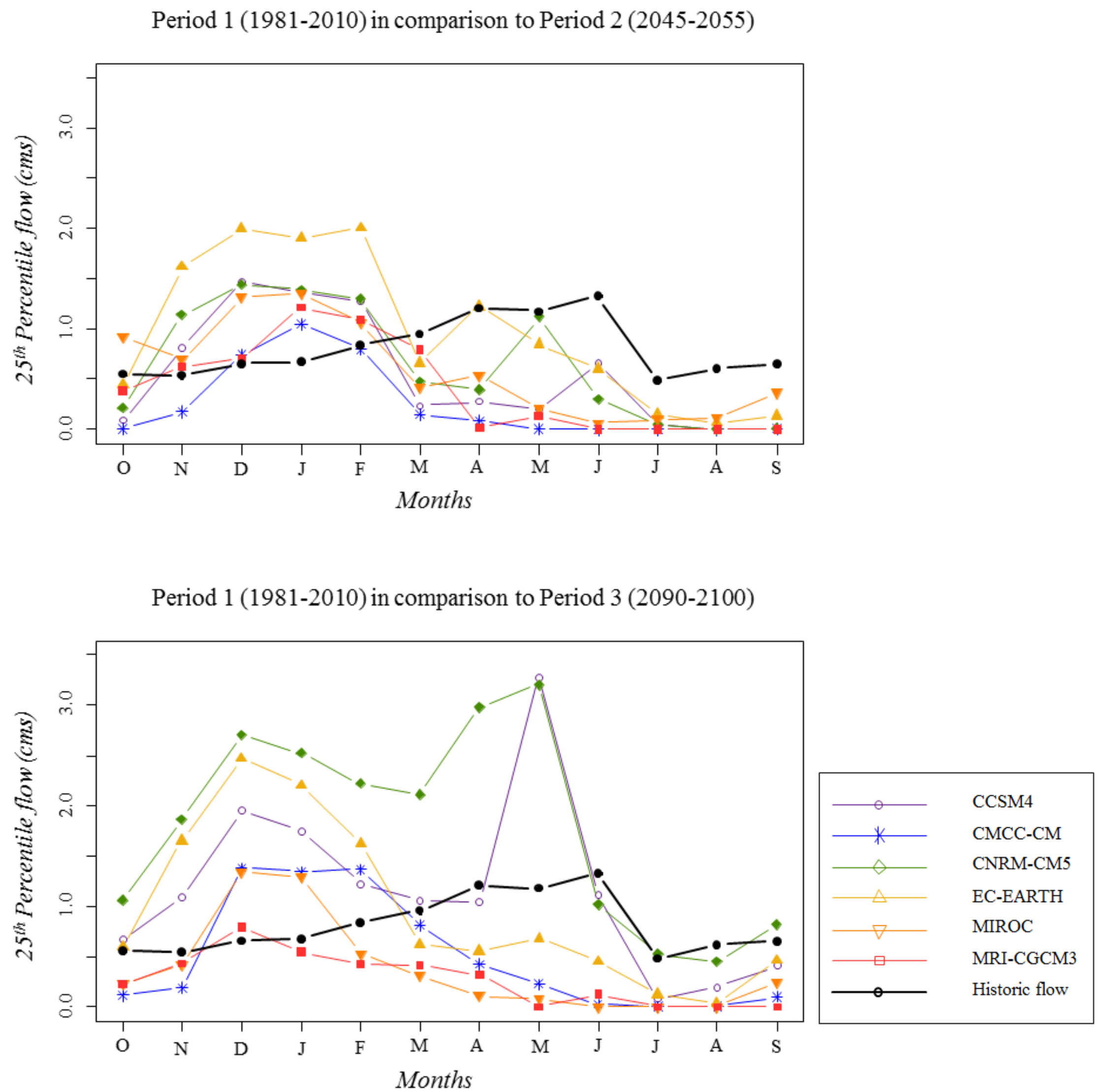

Figure 3.6: Comparison of extreme flow at Ellsworth between historical flow (period 1) and projected flow (period 2 and period 3).

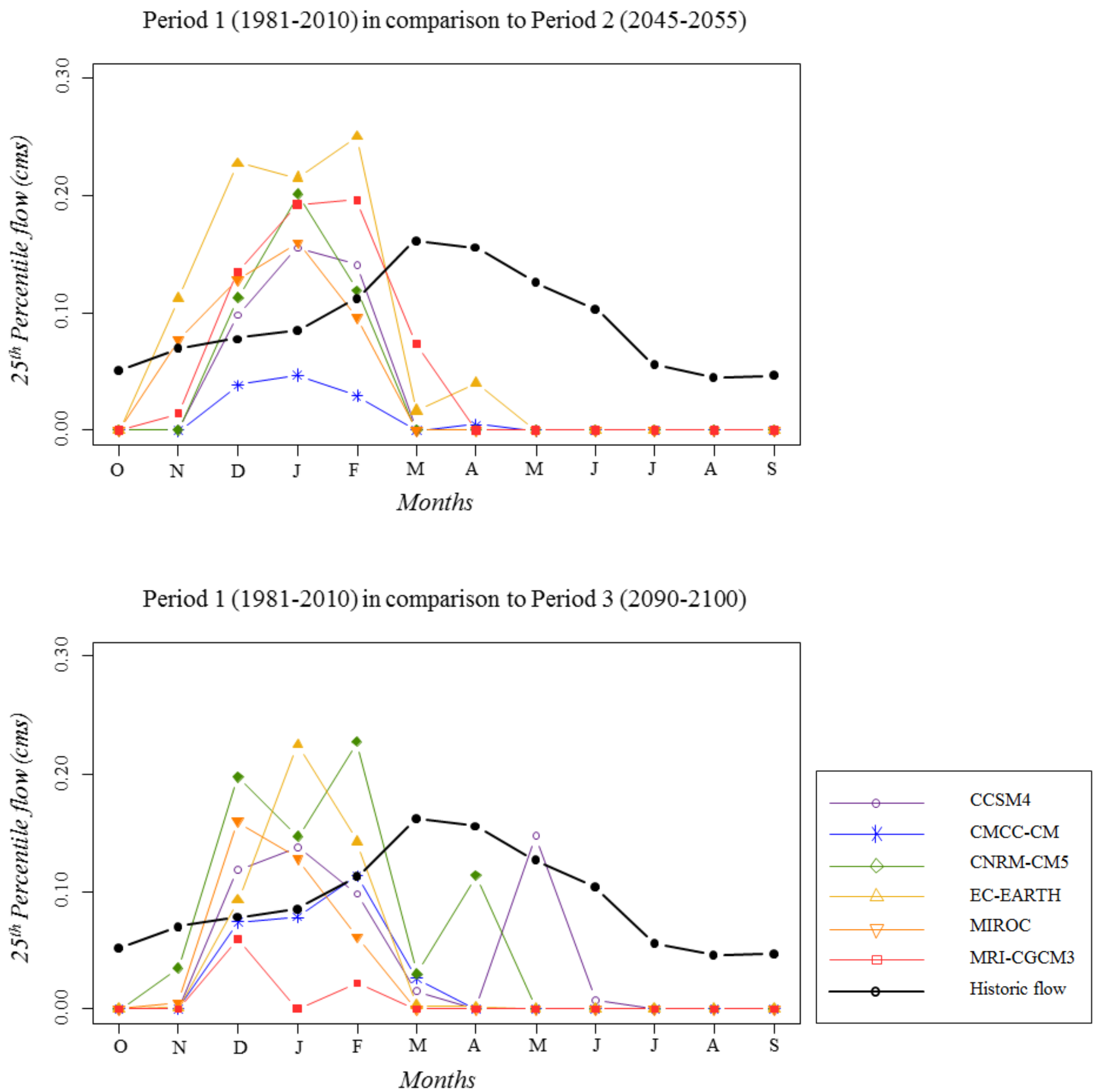

Figure 3.7: Comparison of extreme flow at Hays between historical flow (period 1) and projected flow (period 2 and period 3).

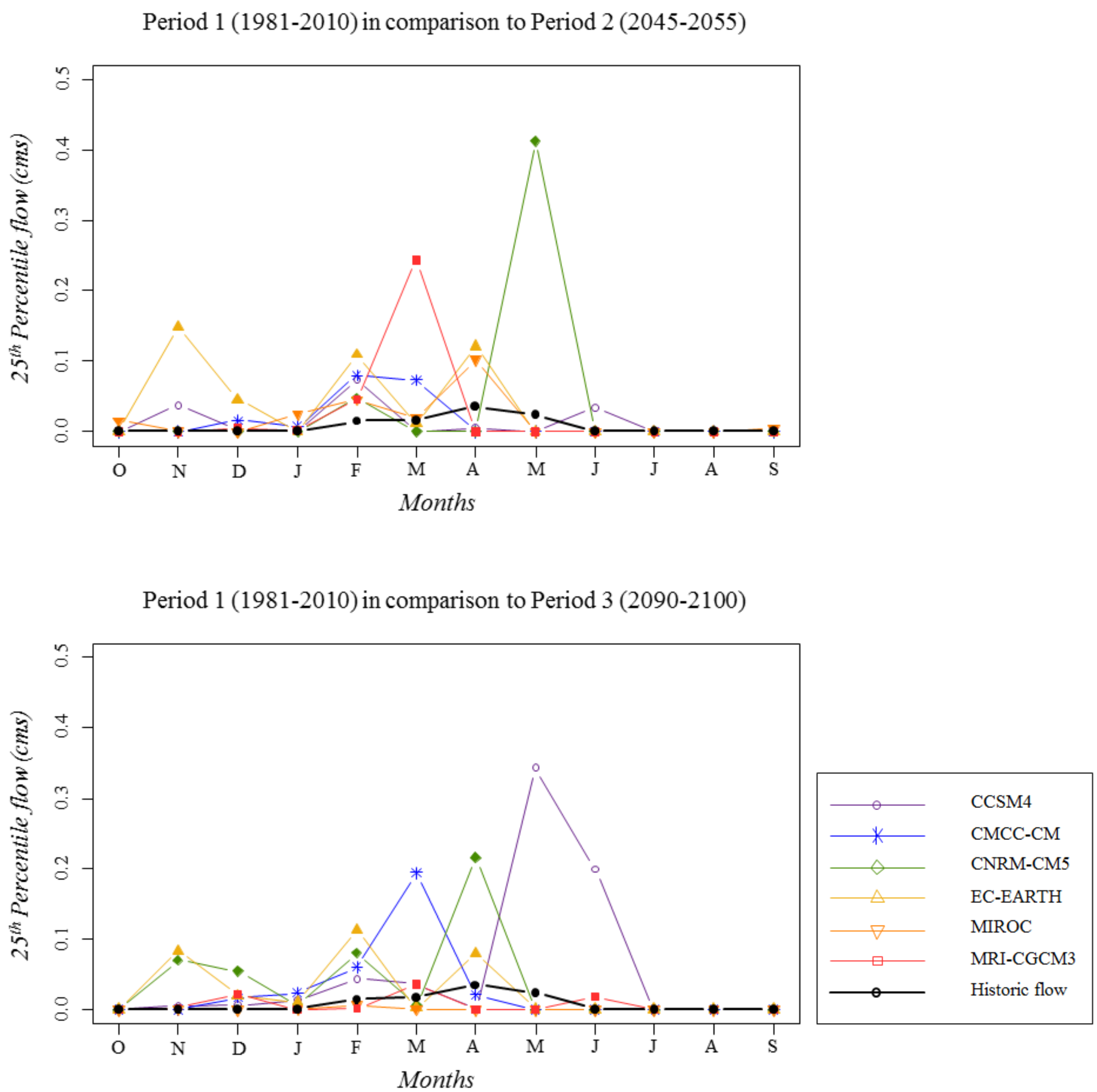

Figure 3.8: Comparison of extreme flow at Schoenchen between historical flow (period 1) and projected flow (period 2 and period 3).

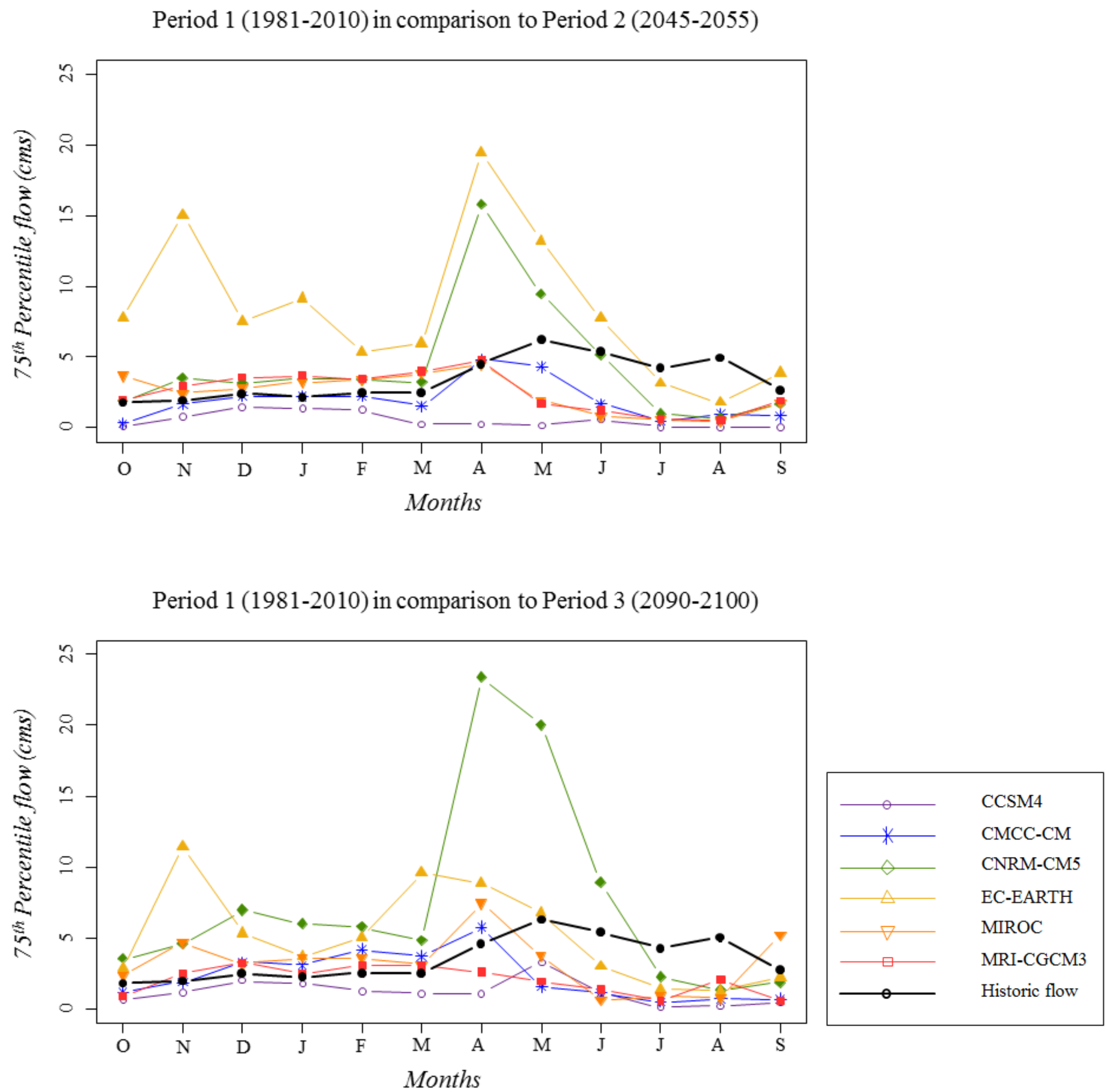

Figure 3.9: Comparison of extreme flow at Ellsworth between historical flow (period 1) and projected flow (period 2 and period 3).

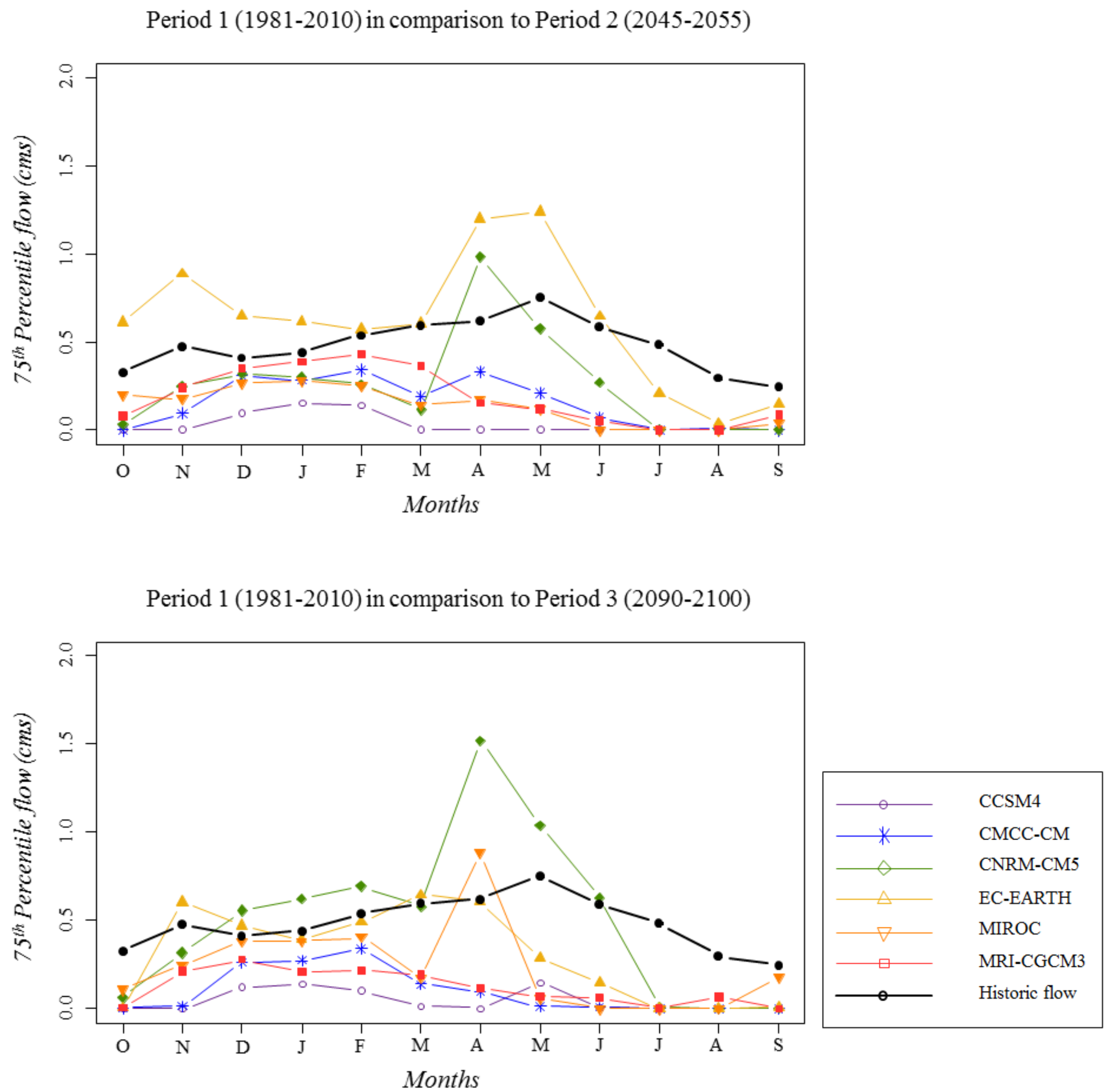

Figure 3.10: Comparison of extreme flow at Hays between historical flow (period 1) and projected flow (period 2 and period 3).

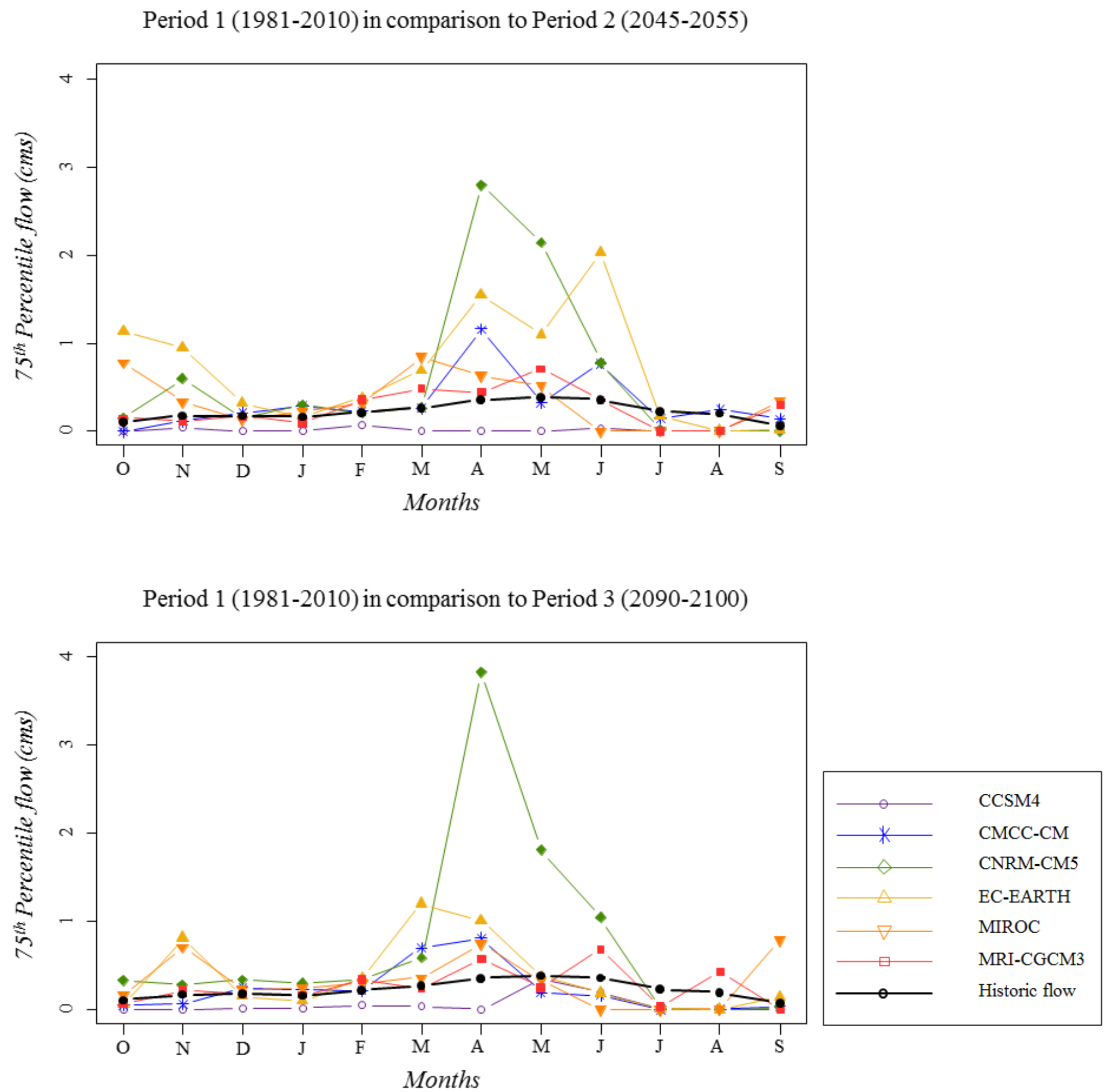

Figure 3.11: Comparison of extreme flow at Schoenchen between historical flow (period 1) and projected flow (period 2 and period 3).

Table 3.1: Variables for the IHA (adapted from Richter et al. 1996, Laize et al. 2014)

IHA Variables	IHA Group	Regime characteristics
Mean value for calender months- (12)	1	Magnitude, timing
Annual Minima- 7, 30, 90 days (3)	2	Magnitude, duration
Annual Maxima- 7, 30, 90 days (3)		
Julian days of 1-day minimum and 1-day maximum (2)	3	Timing
Number and duration of high and low pulses (4)	4	Magnitude, frequency, duration
Number of rise, fall and flow reversals (3)	5	Frequency, rate of change

Table 3.2: Estimation of mean annual discharge in different periods.

Stations and Models	Mean annual discharge (in cms) Period 1	Period 2	Period 3	% change between Period 1 and 2		Period 1 and 3	
Ellsworth	1872.35						
CCSM4		1386.79	2011.55	-26	***	7	***
CMCC-CM		984.35	1415.51	-47	***	-24	***
CNRM-CM5		1492.27	3107.79	-20	***	66	***
EC-EARTH		3206.94	2520.60	71	***	35	***
MIROC		1240.38	1866.36	-34	***	0	
MRI-CGCM3		1022.00	934.80	-45	***	-50	***
Mean		1555.45	1976.10	-17		6	
Hays	221.79						
CCSM4		172.29	268.35	-22	***	21	***
CMCC-CM		158.96	158.08	-28	***	-29	***
CNRM-CM5		181.42	421.67	-18	***	90	***
EC-EARTH		486.89	343.81	120	***	55	***
MIROC		184.58	349.74	-17	***	58	***
MRI-CGCM3		147.56	129.14	-33	***	-42	***
Mean		221.95	278.47	0		26	
Schoenchen	159.19						
CCSM4		314.10	445.22	97	***	180	***
CMCC-CM		256.71	357.99	61	***	125	***
CNRM-CM5		298.98	589.60	88	***	270	***
EC-EARTH		585.94	515.39	268	***	224	***
MIROC		326.02	401.67	105	***	152	***
MRI-CGCM3		235.03	257.80	48	***	62	***
Mean		336.13	427.95	111		169	

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, º $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.3: Percentage change in mean monthly flow between different periods, where Q is discharge.

	October Q		November Q		December Q		January Q	
Stations and Models	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3
Ellsworth								
CCSM4	-28 ***	-16 ***	253 ***	22 ***	77 ***	81 ***	48 ***	76 ***
CMCC-CM	-69 ***	62 ***	-26 ***	-48 ***	8 ***	50 ***	3 ***	57 ***
CNRM-CM5	-4 ***	78 ***	16 ***	174 ***	68 ***	264 ***	71 ***	148 ***
EC-EARTH	396 ***	409 ***	400 ***	337 ***	388 ***	142 ***	211 ***	100 ***
MIROC	60 ***	31 ***	103 ***	95 ***	39 ***	98 ***	46 ***	78 ***
MRI-CGCM3	0	-38 ***	-20 ***	-28 ***	46 ***	68 ***	49 ***	-4 ***
Mean	59	88	121	92	104	117	71	76
Hays								
CCSM4	-69 ***	-50 ***	152 ***	-47 ***	-18 ***	-12 ***	-18 ***	-20 ***
CMCC-CM	-78 ***	-74 ***	-56 ***	-88 ***	-34 ***	-29 ***	-41 ***	-25 ***
CNRM-CM5	-57 ***	27 ***	-58 ***	73 ***	-23 ***	141 ***	-21 ***	28 ***
EC-EARTH	739 ***	592 ***	222 ***	144 ***	194 ***	21 ***	48 ***	19 ***
MIROC	110 ***	-56 ***	70 ***	-18 ***	-25 ***	40 ***	-17 ***	12 ***
MRI-CGCM3	32	-14 ***	-48 ***	-62 ***	-5 ***	1 *	-5 ***	-58 ***
Mean	113	71	47	0	15	27	-9	-7
Schoenchen								
CCSM4	343 ***	438 ***	1035 ***	262 ***	3 ***	-19 ***	24 ***	14 ***
CMCC-CM	167 ***	309 ***	199 ***	-12 ***	38 ***	211 ***	24 ***	210 ***
CNRM-CM5	577 ***	924 ***	202 ***	586 ***	-1 *	352 ***	25 ***	105 ***
EC-EARTH	2596 ***	2559 ***	1455 ***	1347 ***	899 ***	22 ***	36 ***	-1 *
MIROC	1386 ***	432 ***	622 ***	572 ***	3 ***	251 ***	33 ***	188 ***
MRI-CGCM3	675 ***	427 ***	27 ***	109 ***	101 ***	267 ***	-16 ***	6 ***
Mean	957	848	590	477	174	181	21	87

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, ° $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.3 (cont.)

	February Q		March Q		April Q		May Q	
Stations and Models	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3
Ellsworth								
CCSM4	-25 ***	-13 ***	-40 ***	-22 ***	-28 ***	98 ***	-34 ***	59 ***
CMCC-CM	-42 ***	10 ***	-52 ***	-5 ***	2 ***	6 ***	-34 ***	-67 ***
CNRM-CM5	36 ***	135 ***	-23 ***	73 ***	21 ***	200 ***	-7 ***	84 ***
EC-EARTH	26 ***	60 ***	-26 ***	58 ***	225 ***	125 ***	112 ***	-14 ***
MIROC	-27 ***	-20 ***	3 ***	-31 ***	-31 ***	7 ***	-53 ***	-77 ***
MRI-CGCM3	-13 ***	-37 ***	-12 ***	-50 ***	-38 ***	-43 ***	-61 ***	-81 ***
Mean	-8	23	-25	4	25	66	-13	-16
Hays								
CCSM4	-44 ***	-48 ***	-2 ***	-23 ***	-24 ***	239 ***	-37 ***	79 ***
CMCC-CM	-40 ***	8 ***	-10 ***	43 ***	26 ***	-5 ***	34 ***	-85 ***
CNRM-CM5	4 ***	109 ***	8 ***	201 ***	34 ***	307 ***	14 ***	94 ***
EC-EARTH	4 ***	36 ***	-28 ***	98 ***	286 ***	211 ***	208 ***	-28 ***
MIROC	-48 ***	-30 ***	33 ***	-43 ***	-3 ***	120 ***	-39 ***	-87 ***
MRI-CGCM3	-23 ***	-52 ***	2 ***	-47 ***	-21 ***	-30 ***	-52 ***	-81 ***
Mean	-25	4	1	38	49	140	21	-18
Schoenchen								
CCSM4	52 ***	19 ***	81 ***	126 ***	139 ***	373 ***	135 ***	568 ***
CMCC-CM	9 ***	141 ***	50 ***	229 ***	219 ***	202 ***	95 ***	81 ***
CNRM-CM5	144 ***	397 ***	104 ***	362 ***	185 ***	641 ***	299 ***	464 ***
EC-EARTH	86 ***	366 ***	66 ***	330 ***	606 ***	482 ***	446 ***	147 ***
MIROC	46 ***	23 ***	243 ***	92 ***	67 ***	177 ***	113 ***	-12 ***
MRI-CGCM3	75 ***	75 ***	170 ***	55 ***	29 ***	93 ***	89 ***	25 ***
Mean	69	170	119	199	208	328	196	212

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, ° $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.3 (cont.)

	June Q				July Q				August Q				September Q			
Stations and Models	Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3	
Ellsworth																
CCSM4	35	***	55	***	-88	***	-60	***	-84	***	-79	***	-80	***	-64	***
CMCC-CM	-61	***	-20	***	-92	***	-92	***	-59	***	-70	***	-64	***	125	***
CNRM-CM5	2	***	141	***	-90	***	-71	***	-81	***	-82	***	-33	***	-4	***
EC-EARTH	10	***	-61	***	-66	***	-80	***	-77	***	-69	***	-11	***	120	***
MIROC	-74	***	-53	***	-77	***	-93	***	-62	***	43	***	-25	***	334	***
MRI-CGCM3	-44	***	-35	***	-92	***	-63	***	-87	***	-59	***	-21	***	-83	***
Mean	-22		5		-84		-76		-75		-53		-39		71	
Hays																
CCSM4	100	***	121	***	-88	***	-60	***	-85	***	-98	***	-70	***	-67	***
CMCC-CM	-63	***	-54	***	-61	***	-97	***	-62	***	-46	***	-79	***	219	***
CNRM-CM5	8	***	250	***	-86	***	-86	***	-79	***	-92	***	-1		2	**
EC-EARTH	197	***	-67	***	-49	***	-70	***	-82	***	-76	***	-19	***	282	***
MIROC	-76	***	29	***	-41	***	-89	***	-34	***	138	***	-12	***	833	***
MRI-CGCM3	0		22	***	-83	***	-37	***	-77	***	-53	***	-14	***	-82	***
Mean	28		50		-68		-73		-69		-38		-33		198	
Schoenchen																
CCSM4	445	***	500	***	-69	***	12	***	-59	***	-83	***	-44	***	21	***
CMCC-CM	128	***	297	***	-75	***	-86	***	35	***	30	***	82	***	596	***
CNRM-CM5	207	***	622	***	-79	***	-75	***	-55	***	-83	***	65	***	218	***
EC-EARTH	278	***	24	***	-48	***	-51	***	-69	***	-37	***	184	***	501	***
MIROC	5	***	32	***	-18	***	-63	***	32	***	200	***	244	***	1073	***
MRI-CGCM3	144	***	223	***	-69	***	-4	***	-66	***	18	***	232	***	-16	***
Mean	201		283		-60		-45		-30		7		127		399	

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, ° $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.4: Percentage change in the mean minimum discharge and number of zero flow days, where Q is discharge.

	7-day min Q		30-day min Q		90-day min Q		No of zero flow days	
Stations and Models	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3	Period 1 and 2	Period 1 and 3
Ellsworth								
CCSM4	-84 ***	-67 ***	-66 ***	-55 ***	-52 ***	-30 ***		
CMCC-CM	-86 ***	-88 ***	-76 ***	-81 ***	-54 ***	-44 ***		
CNRM-CM5	-68 ***	-12 ***	-45 ***	6 ***	-31 ***	29 ***		
EC-EARTH	-1	-52 ***	40 ***	-32 ***	60 ***	-13 ***		
MIROC	-90 ***	-79 ***	-71 ***	-71 ***	-48 ***	-62 ***		
MRI-CGCM3	-78 ***	-93 ***	-66 ***	-74 ***	-50 ***	-48 ***		
Mean	-68	-65	-47	-51	-29	-28		
Hays								
CCSM4	-100 ***	-100 ***	-99 ***	-100 ***	-80 ***	-88 ***	1209 ***	1172 ***
CMCC-CM	-100 ***	-100 ***	-98 ***	-100 ***	-80 ***	-80 ***	1374 ***	1475 ***
CNRM-CM5	-100 ***	-100 ***	-99 ***	-99 ***	-89 ***	-59 ***	1209 ***	1026 ***
EC-EARTH	-100 ***	-100 ***	-59 ***	-99 ***	-23 ***	-74 ***	886 ***	1192 ***
MIROC	-100 ***	-100 ***	-100 ***	-98 ***	-79 ***	-91 ***	1193 ***	1413 ***
MRI-CGCM3	-100 ***	-100 ***	-99 ***	-99 ***	-83 ***	-76 ***	1159 ***	1459 ***
Mean	-100	-100	-92	-99	-72	-78	1172	1290
Schoenchen								
CCSM4	-100 ***	-100 ***	-85 ***	-98 ***	32 ***	23 ***	30 ***	15 ***
CMCC-CM	-100 ***	-100 ***	-93 ***	-100 ***	58 ***	127 ***	29 ***	44 ***
CNRM-CM5	-100 ***	-100 ***	-90 ***	-76 ***	-30 ***	112 ***	39 ***	19 ***
EC-EARTH	-100 ***	-100 ***	-92 ***	-94 ***	213 ***	-11 ***	8 ***	28 ***
MIROC	-100 ***	-100 ***	-96 ***	-61 ***	-3 ***	-35 ***	27 ***	53 ***
MRI-CGCM3	-100 ***	-100 ***	-95 ***	-90 ***	25 ***	40 ***	27 ***	38 ***
Mean	-100	-100	-92	-86	49	43	27	33

Significant difference between two periods exists at *** $p \le 0.001$, ** $p \le 0.01$, * $p \le 0.05$, ° $p \le 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.5: Percentage change in the mean maximum discharge, where Q is discharge.

Stations and Models	7-day max Q				30-day max Q				90-day max Q			
	Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3	
Ellsworth												
CCSM4	-7	***	11	***	-7	***	11	***	-16	***	21	***
CMCC-CM	-49	***	-9	***	-48	***	-27	***	-46	***	-37	***
CNRM-CM5	-31	***	46	***	-27	***	61	***	-19	***	80	***
EC-EARTH	100	***	73	***	87	***	60	***	71	***	36	***
MIROC	-44	***	51	***	-44	***	32	***	-40	***	12	***
MRI-CGCM3	-62	***	-54	***	-61	***	-54	***	-52	***	-53	***
Mean	-15		20		-17		14		-17		10	
Hays												
CCSM4	38	***	112	***	25	***	83	***	4	***	73	***
CMCC-CM	20	***	29	***	5	***	-4	***	-8	***	-17	***
CNRM-CM5	30	***	166	***	15	***	163	***	11	***	162	***
EC-EARTH	322	***	199	***	240	***	142	***	189	***	95	***
MIROC	10	***	266	***	-7	***	192	***	-8	***	135	***
MRI-CGCM3	-25	***	-9	***	-35	***	-20	***	-27	***	-28	***
Mean	66		127		41		92		27		70	
Schoenchen												
CCSM4	132	***	150	***	134	***	180	***	124	***	241	***
CMCC-CM	25	***	137	***	45	***	112	***	63	***	108	***
CNRM-CM5	46	***	215	***	80	***	261	***	106	***	329	***
EC-EARTH	289	***	279	***	272	***	262	***	261	***	231	***
MIROC	43	***	227	***	56	***	206	***	89	***	187	***
MRI-CGCM3	3	***	16	***	12	***	39	***	39	***	63	***
Mean	90		171		100		177		114		193	

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, º $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.6: Timing of 1-day maximum and 1-day minimum discharge.

	Number of days different for maximum discharge				Number of days different for minimum discharge			
Stations and Models	Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3	
Ellsworth								
CCSM4	18	***	43	***	60	***	53	***
CMCC-CM	1	***	8	***	6	***	17	***
CNRM-CM5	29	***	31	***	44	***	1	***
EC-EARTH	20	***	36	***	42	***	8	***
MIROC	19	***	58	***	64	***	4	***
MRI-CGCM3	4	***	0	***	43	***	7	º
Mean	15		29		43		15	
Hays								
CCSM4	19	***	15	***	54	***	55	***
CMCC-CM	21	***	13	***	57	***	56	***
CNRM-CM5	42	***	2	***	57	***	55	***
EC-EARTH	30	***	6	***	3	***	46	***
MIROC	22	***	11	***	62	***	56	***
MRI-CGCM3	3	***	6	***	58	***	56	***
Mean	23		9		49		54	
Schoenchen								
CCSM4	11	***	44	***	25	***	25	***
CMCC-CM	13	***	9	***	26	***	28	***
CNRM-CM5	14	***	7	***	5	***	27	***
EC-EARTH	24	***	4	***	1	***	11	***
MIROC	38	***	29	***	33	***	29	***
MRI-CGCM3	21	***	3	***	34	***	28	***
Mean	20		16		21		24	

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, º $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.7: Percentage change in the means for high and low pulse number and duration.

	Low pulse count				Low pulse length				High pulse count				High pulse length			
Stations and Models	Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3		Period 1 and 2		Period 1 and 3	
Ellsworth																
CCSM4	294	***	76	***	-75	***	-272	***	-15	***	22	***	88	***	33	***
CMCC-CM	248	***	67	***	-67	***	-273	***	34	***	-23	***	7	***	36	***
CNRM-CM5	210	***	57	***	-65	**	-242	***	34	***	3	***	24	***	46	***
EC-EARTH	192	***	67	***	-63	***	-252	***	-30	***	-9	***	67	***	77	***
MIROC	252	***	61	***	-63	***	-268	***	40	***	-30	***	27	***	22	***
MRI-CGCM3	177	***	60	***	-63	***	-269	***	31	***	10	***	22	***	1	***
Mean	229		65		-66		-263		16		-5		39		36	
Hays																
CCSM4									8	***	12	***	21	***	1	***
CMCC-CM									24	***	12	***	-17	***	-25	***
CNRM-CM5									12	***	37	***	9	***	3	***
EC-EARTH									8	***	8	***	2	***	17	***
MIROC									45	***	-59	***	-11	***	24	***
MRI-CGCM3									24	***	24	***	8	***	-3	***
Mean									20		6		2		3	
Schoenchen																
CCSM4									150	***	244	***	15	***	8	***
CMCC-CM									219	***	144	***	4	***	3	***
CNRM-CM5									200	***	169	***	34	***	24	***
EC-EARTH									113	***	113	***	15	***	35	***
MIROC									294	***	88	***	7	***	-3	***
MRI-CGCM3									288	***	256	***	-1	***	1	**
Mean									210		169		13		11	

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, ° $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100)

Table 3.8: Percentage change in the means for hydrograph reversals and rise and fall rates.

Stations and Models	Rise rate: Period 1 and 2		Rise rate: Period 1 and 3		Fall rate: Period 1 and 2		Fall rate: Period 1 and 3		Reversals: Period 1 and 2		Reversals: Period 1 and 3	
Ellsworth												
CCSM4	-58	***	-69	***	-23	***	10	***	123	***	55	***
CMCC-CM	-64	***	-79	***	-35	***	-12	***	98	***	50	***
CNRM-CM5	-59	***	-32	***	-24	***	32	***	117	***	58	***
EC-EARTH	-6	***	-40	***	51	***	26	***	123	***	54	***
MIROC	-57	***	-66	***	-24	***	7	***	114	***	49	***
MRI-CGCM3	-70	***	-112	***	-45	***	-37		108	***	47	***
Mean	-52		-67		-17		4		114		52	
Hays												
CCSM4	36	***	105	***	66	***	159	***	-4	***	-3	***
CMCC-CM	36	***	62	***	59	***	83	***	-15	***	-20	***
CNRM-CM5	30	***	202	***	68	***	267	***	-5	***	-1	***
EC-EARTH	226	***	163	***	301	***	231	***	11	***	-2	***
MIROC	54	***	167	***	82	***	268	***	-7	***	-11	***
MRI-CGCM3	0		12	***	17	***	25	***	-3	***	-14	***
Mean	64		118		99		172		-4		-9	
Schoenchen												
CCSM4	24	***	59	***	75	***	140	***	78	***	89	***
CMCC-CM	0		73	***	36	***	123	***	76	***	64	***
CNRM-CM5	9	***	111	***	50	***	179	***	77	***	80	***
EC-EARTH	112	***	106	***	186	***	196	***	92	***	85	***
MIROC	35	***	71	***	83	***	135	***	74	***	51	***
MRI-CGCM3	-12	***	3	***	25	***	42	***	78	***	76	***
Mean	28		71		76		136		79		74	

Significant difference between two periods exists at *** $p \leq 0.001$, ** $p \leq 0.01$, *$p \leq 0.05$, ° $p \leq 0.1$
Note: Period 1or Historical flow (1981-2010), Period 2 (2045-2055), Period 3 (2090-2100

Chapter 4

PERCEPTIONS OF SURFACE WATER SUSTAINABILITY IN FRAGMENTED STREAM NETWORKS OF THE CENTRAL GREAT PLAINS

4.1 Introduction

Freshwater is a fundamental resource, integral to all ecological and societal activities, yet its uneven and irregular distribution leads to environment-resource conflicts (Gleick 1993, Postel 2000) and surface water unsustainability. Several studies investigating water resource vulnerability worldwide (Vorosmarty et al. 2000, Alcamo et al. 2007) and at regional scales (Cohen et al. 2006) have projected that rising water demand will outweigh climate change effects on freshwater vulnerability and that we are going to enter into an era of water scarcity (Postel 2000). According to estimates (Postel et al. 1996), humans have already appropriated half of all accessible surface runoff, either directly in the form of withdrawals for agriculture, cities and industries, or indirectly in the form of pollution dilution and other instream uses, creating obvious reasons for conflict. Drought and water scarcity following such environment-resource conflict is difficult to understand, quantify, define and cope, as it represents a series of complex relationship between physical aspects, environmental conditions, and socio-economic factors (Changnon et al. 1989). Semi-arid regions in particular are more vulnerable to such water scarcity problems due to existing climatic dryness, regular droughts, land degradation, water stress (based on water availability per person) and river basin fragmentation that combine to produce increasingly critical conditions (Fallenmark et al. 1989). Hence, providing an adequate supply of water for concerned communities and ecosystems is among the most pressing sustainability concerns worldwide currently, especially in arid regions that experiences intermittent stream flows, degraded water quality, and expected climate changes (Gober and Kirkwood 2010, Larson et al. 2011). As is true of other natural resource issues, the problems and vulnerabilities associated with arid areas and drought are clearly linked more closely with the social context in which water scarcity occurs, than with just the physical and climatological events that contribute to scarcity (Kennan and Krannich 1997). Water scarcity may increase in severity depending on the extent of human impacts, and is largely determined by our uses of the drought threatened resources (Kennan and Krannich 1997). Beyond problems of physical availability and quality of water; consumption patterns and conflicting views about how best to use, manage, and sustain resources pose significant challenges to sustainable development (Larson et al. 2011). It is as much as a social, economic, political, and institutional issue as physical scarcity (Zeitoun 2011) and hence any distinction between social and natural system would be arbitrary (Adger 2006).

The integration of the social and natural systems thus brings us to the fundamental assumption of human ecology which states that social systems are integrally linked to ecological systems (Duncan 1961) and has informed a number of analyses focusing on water resources (Burch and Cheek 1974). Many scholars in this regard argue that sociocultural attributes and processes shape people's understanding of and attitudinal judgments about human-ecological problems (Kennan and Krannich 1997, Schultz et al. 2000, Dietz et al. 2005, Adeola, 2007, Larson et al. 2011). Bradshaw, Vine, and Barth (1982) have also argued that lifestyles in a given locality are in part based upon resource use patterns. Water conserving lifestyles, for instance, may be voluntarily adopted as a value orientation by persons with higher income and education. In contrast, lower socio-economic status persons may be less willing to forego aspirations for water-related amenities (Bradshaw et al. 1982, Kennan and Krannich 1997). Culture, values, meanings, belief, basic environmental belief about people's relationship with nature, gender, income, education, political ideology, ethnicity and many other factors may conceptualize the environment in which they live in (Rohner 1984, Kempton et al. 1999, Larson et al. 2011). An objective of a sociological analysis of water resources, then, is to assess how water use patterns and vulnerabilities may be related to social structures and statuses (Kennan and Krannich 1997). Based on individual reference points, perception of the same event may vary differently, depending on the previously explained social norms (Tversky and Kahneman 1981, Murtinho et al. 2013). Researchers have also shown that the way people perceive water availability and scarcity can vary between generations (Alessa et al. 2008, Murtinho et al. 2013) and among stakeholder groups such as lay people, scientists, and policymakers (Larson et al. 2009, Murtinho et al. 2013). Apart from that, due to uncertain long-term social and environmental processes that determine water availability and scarcity, individuals' perceptions of the drivers of water scarcity are also subjective relying on various sources of knowledge, such as years of direct experiences and memories of past environmental and socioeconomic changes, and what is socially learned from other people (including previous generations) and media sources (Kasperson et al. 1988; Berkes and Turner 2006; Hulme et al. 2009; Frank et al. 2011, Murtinho et al. 2013). Differences in adaptation against drought risk are thus influenced not only by socio-economic variables, but also by cognitive perception of risk (Gebrehiwot and Veen 2015) and path dependency (Chhetri et al. 2010), implying the inability of users to respond appropriately. Adaptation is necessary and at many times can be adopted from narratives and blueprints developed from myths, ideologies and conventional wisdoms, after adding site-specific learning and improvements (Roe 1991), signifying stress on water literacy by communication at an inter-disciplinary level (Fallenmark et al. 2009), cutting excess water demand and adaptation to dryness (Postel

1997). However, while there is ample scientific evidence of climate change and water scarcity risks (Bell 1994, 1995, Wilson 2000, Brody et al. 2008), risk perception is dependent on personal lifestyle decisions, voting behavior and willingness to support various policy initiatives (Bostrom et al. 1994). Thus, political orientation, as well as beliefs regarding climate change, environmental degradation are all strong determinants of risk perception and communication (Safi et al. 2012), awareness and policy application is very important (Fallenmark et al. 2009) to adapt to any kind of resource vulnerability.

The United States Great Plains is a semi-arid region experiencing years of cyclic droughts, and serves as model areas for studying disturbances in ecology (Dodds et al. 2015). The landscapes are facing upheaval due to water scarcity and land use conversion associated with climate change, population growth, and changing economics (Fernald et al. 2014). The understanding of perception of surface water sustainability in this region is hence required to spread awareness about water use, excess water extraction and water diversification that can affect both surface water and ecology associated with it. The purpose of this research is to examine the perceptions of surface water sustainability and river basin damming on ecology using demographic characteristics and perception analysis from a written survey. The majority of these kinds of dams are not recorded with state level government bodies, if built within a certain limit, and hence there are limited restrictions on the growth of the number of dams in the area. An understanding of how people think about the process of damming the rivers would therefore guide us towards a prediction of whether or not a government intervention is required to restrict any kind of dam building in areas of intermittent drainage, to protect ecology and surface water in the long term. Thus the integration of perceptions of water scarcity and damming to social structural variables in a drought-prone region would be beneficial for conservation and efficient management of water resources through sustainable development (Del Saz-Salazar et al. 2015).

4.2 Study area

The study area for this research is located in the watershed of the Smoky Hill River, a major tributary to the Kansas River extending from western Colorado to central Kansas, joining the Kansas River near Junction City (Figure 4.1). The watershed extends across a steep natural gradient of increasing precipitation from west to east that is typical of the central Great Plains region and is associated with severe river-basin fragmentation from small scale damming. The density of small tributary dams increases towards the east (see Chapter 2, this dissertation), as precipitation increases. However, the western part of the basin is more vulnerable from the overuse of shallow alluvial aquifers (Gido et al. 2010) and growth of unaccounted private small dams (see Chapter 2, this dissertation). Although large dam construction and operation are coming under closer scrutiny to sustain runoff for critical habitat and native species (Postel 2000) in these areas and other parts of the world, not much focus has been garnered towards the impeccable growth of small artificial impoundments (Renwick et al. 2006) on the tributary systems. Rather these dams are often held up with quite a lot of praise and are mostly used for livestock ranching, domestic and other recreational uses (Renwick et al. 2006). These small dams are areas of fragmentation that are responsible for instream drying, decreased dissolved oxygen level and increased sedimentation and carbon level (Renwick et al. 2006) in the areas of fragmentation. Ecologically it creates strong breaks in native species community structure (Gido et al. 2010), extirpation in fishes, and introduction of non-native species (Propst et al. 2008). This study would be conducted using survey results from 15 counties located in the watershed and would provide us with a better understanding of whether or not people living in this area perceive damming as a threat to ecology and surface water sustainability.

4.3 Methodology

An exploratory questionnaire was designed to generate qualitative and quantitative responses with the purpose of providing a better understanding of a variety of perceptions, beliefs and actions towards surface water damming and ecology. The responses were then modelled with other social and demographical variables.

4.3.1 Survey design

Survey data for this study was generated as part of a larger survey conducted to understand about values, norms and beliefs regarding climate change and water sustainability in the study watershed. The 3 research questions that are used for this current study were developed and added into the larger survey to compare it with the other variables. This questionnaire asked a series of questions about participant's knowledge of wildlife, water, and the environment; how they interact with the environment in their area through recreation and water use; views on different environmental and water policy issues; values, beliefs, norms related to climate change, biodiversity and the environment; demographics; and political ideology.

The survey was thoroughly field tested in July 2015 and then fully administered in 3 waves from July 2015 to January 2016. The first wave was conducted in person at a series of five county fairs in communities within and around the watershed in July and August 2015. This venue was chosen to target younger residents and obtain a distribution of responses from participants across different income brackets and ethnicity. Respondents over 18 years of age and who resided in counties within and surrounding the watershed were randomly asked to complete the survey to receive a $15 stipend to spend at the county fair. A total of 679 surveys were handed out, of which 558 were completed and returned, providing an 82.2% response rate at this venue. A second wave of surveys was done from September to December 2015 to farmers within counties in the same area. Farmers were selected from a contact list obtained from FarmMarketID (www.farmmarketid.com). Farmers were directly surveyed to ensure that a large enough sample of farmers was obtained to conduct data analyses on this set of respondents. A total of 474 surveys were sent to farmers, of which 41 were non-deliverable for various reasons and 113 were returned completed, providing a 26.1% response rate. A third wave of surveys was sent to community residents in local communities within the same counties. Contact lists of individuals who were over the age of 18 and owned or rented a house were purchased on line from directmail.com. A random sample was then pulled for each county proportional to the population in that county from the contact list. Mail surveys in this wave were provided a $20 incentive to complete the survey. A total of 2526 surveys were mailed, of which 240 were non-deliverable for various reasons, and 717 were returned completed, providing a response rate of 31.4%. Combining the 3 waves, a total of 1388 surveys were completed, providing an effective response rate of 40.8% overall. The representativeness of the sample was tested and verified through the demographic characteristics of the survey respondents to the overall population by county and for the entire surveyed area using 2010 Census (IPSR, 2010).

4.3.2 Limitations of the study

Survey data may have inherent biases that complicate interpretation, which includes the tendency of people to disproportionately select certain response categories, regardless of the content of the question or to present themselves in a way that does not represent their true attitude (O'Neill 1967, Blekesaune and Quadagno 2003). For the current research, we focus only on surface water damming, and the analysis uses 15 out of the 87 questions from the original survey, that includes the 3 main questions developed for this study. Due to partial completions, and selection of respondents only within the watershed, about 843 surveys were usable for this research (81 farmers and/or ranchers, and 762 non-farmers). The 15 questions included single-answer, single-answer multiple choice, and ranking scale questions (based on Likert scale ranked one to seven or five), with a comment section to allow the participant to expand on any ideas (Noga and Wolbring 2013). The limitations of the study include the following:

- Nesh County that covers part of the Smoky-Hill River basin is not included in the study due to insufficient number of responses (only 1 respondent) from the county.
- The question on political lineage was also dropped from the analysis due to significant lower number of responses.

4.3.3 Measures of Perception

The analysis of perception studies for this research is being evaluated on 3 major research questions that serve as the independent variables for the analysis. The 3 research questions tests (1) how important and (2) how an individual is personally or jointly responsible, for damming and fragmenting of streams that affects fish and animals, and (3) their willingness to take action against the same. Each of these questions are measured in a 1-5 Likert scale, where 1 measure not at all important/strongly disagree and 5 measure very important/strongly agree (Table 4.1). These 3 questions are built on top of one another in the form of a hierarchy and the correlations from the responses are tested to see how these independent variables are related to each other.

From these research questions, the current research would identify whether or not, people living within the study area looks at stream network fragmentation and damming as a problem to surface water sustainability and ecology, and if they are willing to change their behavior for moving towards a sustainable watershed. To analyze the factors that shape up the perceptions of the 3 major research questions, other questions from the survey that looks at local environment, personal views and opinions and demographical characteristics are then tested. The explanatory variables include perception on vulnerability of native and stocked fishes in dams, understanding of the local environment and its protection, climate change and importance and responsibilities of water withdrawals from streams and rivers that affect fish and animals. The questions on vulnerability of stocked fishes in dams were included in the analysis to test whether or not there was a change in perception between small and large dams as observed by the survey respondents. The responses on vulnerability of fishes are recorded in a Likert scale of 1-7, where 1 is highly vulnerable and 7 is thriving (Table 4.2). The perception based questions on protecting the environment, agreeing that climate is changing and importance and responsibilities of water withdrawals are measured on a 1-5 Likert scale, where again, 1 measure not at all important/strongly disagree and 5 measure very important/strongly agree (Table 4.3). Besides these, other explanatory variables that are analyzed in the study include demographical characteristics- gender, education level, household income and occupation (Table 4.4). The 3 research questions are not treated as independent variables for one another due to an initial hypothesis of existing high correlation between them.

Combining the insights from previous work on perception studies on surface water sustainability and ecology, within the overarching social paradigm, we identify the following hypothesis for each of the 3 research questions:

Hypothesis 1: Individuals giving more importance to the negative impacts of damming would also be jointly responsible for damming and would have higher obligation to take action against damming and hence all these factors would be highly correlated to each other.

Hypothesis 2: Individuals who care for surface water sustainability and ecology would also realize the vulnerability of the native and stocked fishes in dams and would also be more caring towards the environment and would consider water withdrawal as a problem to fish and animals.

Hypothesis 3: Since female gender and higher education level are known to be related to be more compassionate about the environment, they are treated as controls to all the models and are expected to positively influence them. Individuals with higher income, and coming from a non-agricultural occupational background are expected to care more for the environment.

4.4 Statistical Analysis

Over the past few decades, multi-level also termed as hierarchical modeling is gaining importance in social science due to its ability to group individuals under specified given criterions (Blekesaune and Quadagno 2003, Murnaghan et al. 2007, Huang et al. 2008, Levecque et al. 2014 and many more). We use the 3 level hierarchical logistic regressions to model perception of damming and river fragmentation to understand more about people's perception towards water sustainability and ecology in the area. The 3 level hierarchical models helped us include the hydrological explanatory variables at the county level, besides analyzing the variables at the individual level.

For each of the 3 research questions, the first level of modeling (Model 1) involves testing of the 3 independent research questions with the different explanatory variables using multiple linear regression analysis. In the second step, a null model without any explanatory variable is developed to analyze if there is any significant variance among the counties. If any significant variance is found, the second level of modeling (Model 2) is carried out by adding the county effect on the explanatory variables. Finally, a third level of analysis (Model 3) is added to the model as county level explanatory variables that look at the hydrological alteration in the basin and relate it to the perception analysis. The major motivation for doing the third level multi-level modeling is to assess the effect of hydrologic alteration on the outcome of the multi-level model with the county-effect. To add the hydrological variables to the model, dam density at the county level (calculated by number of dams per 10 square kilometer area), and annual mean precipitation, obtained from Geographic Information System (GIS) PRISM dataset of mean annual average precipitation (1981-2010) are used. The models are evaluated at significant level of *p-values* ≤ 0.001, and are compared with Akaike Information Criterion (AIC) values.

For the demographic variables, the survey questions are coded such that females are recorded as 1 and males as 0. Apart from that, we looked at the distribution of the highest level of education completed and level of household income (Figure 4.2) and also tested the response level for both the variables as individual categories. Since, there was not any significant difference between the different level of educational attainment when looked beyond high-school level, and within the different income categories; we coded degree higher than high school level of education, and level of household income greater than $50,000 as 1 and the remaining as 0. Finally, in the demographic background, we are more interested to know about the perceptions of people who are involved in farming or ranching in the study area, as most of these small dams are used for livestock, ranching and other agricultural related purposes. Hence, for the occupation category, we coded occupation entitled farmers and/or ranchers as 1 and the rest as 0.

All the mapping and spatial analysis is done using Esri ArcGIS 10.4 and statistical calculations are accomplished using statistical software R: The R Project for Statistical Computing, more specifically, library lme4 and plot function lm and lmer.

4.5 Results

4.5.1 Demographics of Survey Respondents

The descriptive characteristics of the survey questions are presented in Table 4.5. Among the respondents, 403 (47.8%) are females and 440 (52.1%) are males. There are a total of 215 (27%) respondents who have below high-school level of education. Among the survey respondents who declared their household income, 394 (53.5%) people fall into the category of making more than $50,000 as a household. On the other hand, an almost equal percentage of people, 342 (46.5%) claimed to have ≤ $50,000 as household income. Overall, the main occupation in the study area is farming and ranching, and about 81 (11.9%) respondents within the study area are either farmers, ranchers or both.

The responses from the explanatory variables in Figure 4.3 indicate that, the average responses are centered towards a higher vulnerability of native and stocked fishes. Majority of the respondents also thinks that protecting the environment is important and agrees to the fact that climate is changing. Although water withdrawals are regarded as an important factor to affect fish and animals negatively, individuals on an average do not agree or disagree to bear its responsibility.

4.5.2 Relationship Among the Three Main Research Questions

The responses from the 3 research questions in Figure 4.4 show that majority of the responses are centered on the premise that damming and breaking up of streams and rivers that affect fish and animals is important. The majority of the survey respondents neither agrees nor disagrees to having a personal responsibility towards damming or to take any action against the same. However, these 3 questions are positively correlated to each other at statistically significant level of $p \leq 0.001$. Individuals who care about the negative impacts of damming on river ecology are also the ones who feel responsible for damming (r=0.27), and plan to take action against the same (r=0.48).

4.5.3 Regression Modeling to Relate Perceptions of River Fragmentation and Ecology

For all the 3 research questions the null model (results not included here) tested that there is a significant variance with the addition of county level analysis and hence the multi-level modeling has been used for all the 3 questions. Table 4.6 shows the test of the main effects of the control factors (gender and education), and the other factors that affects the perception of understanding the negative impacts of damming on fishes and animals for research question 1. For this particular research question, we are interested only to see how individuals give importance to water withdrawals as a factor affecting the ecology, among the two water withdrawal questions. The finding from all the 3 models shows that only the main effect of gender is positively related to the perception of importance towards the negative impacts of damming, among the control factors, and supports our hypothesis. Among the other main effects, the factors that affects the models positively and are statistically significant are– importance of protecting the environment, understanding the negative impacts of water withdrawals and agreeing that climate is changing. Vulnerability of fishes in the Kanopolis Reservoir is negatively related to all the model results, which also supports our initial hypothesis. Educational qualification, income and occupation however have no significant contribution towards the model predictions. Model 1 is significant at $p \leq 0.001$ and explains about 35% of the variation for research question 1. The AIC value drops from 1133.6 to 1129.8 from Model 2 to Model 3, with the addition of the hydrological variables, and is also significant at ≤ 0.05 when tested with likelihood ratio at 5% level of chi-squared distribution on 2 degrees of freedom (Table 4.11). Although there is not any county-effect for this particular research question, the predictions get better with the additional of the hydrological explanatory variables. About 45% and 44% of within county variance are explained by Model 2 and Model 3 respectively.

In research question 2, among the water withdrawal factors, we are interested only to see how individuals feel jointly responsible for water withdrawals as a factor affecting the ecology, as it is a responsibility related question. For this research question, Model 1 explains about 56% of the variation in research question 2 at $p \leq 0.001$. None of the control factors contributes significantly to the model predictions. Among the main effects, for all the model predictions, personal responsibilities towards damming is positively influenced by responsibility towards water withdrawals from streams that affects fish and animals. This is also the major factor that drives the predictions for all the models for this research questions. The model predictions for this question are also negatively related with higher income. No other factors contribute significantly to the models assessed here. Model 2 is a better fit than Model 3for this research question in terms of containing information and not overfitting the data, as seen from the AIC values (Table 4.10). The random intercept or variance for both Model 2 and Model 3 are close to 0, but do have some influence on the model predictions.

For the third and final research question, we consider both the questions on water withdrawals, as both the factors (importance and responsibility) are hypothesized to affect the models significantly for this particular question. None of the control factors contributes significantly to the model predictions (Table 4.8). The main effects that affect the models positively are importance of protecting the environment, importance of negative impacts of water withdrawals and feeling responsible for the same, and agreeing that the climate is changing. Income is negative related to the model predictions. Model 1 explains about 27% of the variation for research question 3 at $p \leq 0.001$. Similarly, to research question 2, Model 2 is also a better fit than Model 3for research question 3 in terms of containing information and avoiding overfitting of the data, as seen from the AIC values (Table 4.10). The random intercept or variance for Model 2 is 0 but is slightly higher than 0 for Model 3, where the hydrological explanatory variables have some influence on the model predictions.

4.6 Discussion

The study area is a naturally occurring water scarce region that is becoming more vulnerable due to the intensification of drought cycles and increased water demand from agriculture, industry, residential development and ecosystem maintenance (Caldas et al. 2015). For a better understanding of the survey data we looked at the distribution of whether people distinguished between large and small dams while answering their survey questions. From our analysis, we do not have enough evidence to determine if individuals treated small and large dam stocked fishes in a different way, but we also cannot conclude that they considered the fact that they are similar.

4.6.1 Perception of Stream Fragmentation and Ecology at the Individual Level

The study at the individual level identified that protecting stream water and ecology from fragmentation is supported by better understanding about climate change, water withdrawals from streams and protection of the environment. The major factors that dominated the predictions for all the models are having an understanding of the negative impacts of water withdrawals from streams and rivers that can affect fish and animals and jointly feeling responsible for it. Individuals having positive responses for these two categories also responded positively towards the questions on damming. From the demographic analysis, although female gender and higher education are often associated with a caring attitude towards the environmental, we did not observe this trend in this study. Gender is significantly contributing positively only to research question 1, which looks at the understanding of the negative impacts of damming on the ecology, and has no significant effects to take responsibility or action against damming. The contribution of education is also non-significant to the models and fails to support our hypothesis. A possible explanation of that can probably be tied to other factors like sociological, economic and political set-up. Apart from that, people with lower income are correlated with higher compassion towards ecology and surface water sustainability. From our research, the major findings at the individual level are as follows:

1. From the 3 main research questions we see that although negative impacts of damming are recognized by individuals, responsibility of personal obligation to damming and to take action against it is lacking, even when they consider the importance of the negative impacts of damming on ecology.

2. The lack of connection between awareness of fragmentation problem and fish vulnerability suggests lack of understanding of fish life cycles in intermittent streams or lack of value placed on native fishes versus stocked lake fishes.

3. The responsibility to restrict damming and river basin fragmentation is more common in individuals who understands the importance of water withdrawals, are willing to take responsibility for it, and believe in climate change and protection of the environment.

4. Higher income is negatively related to all the model predictions. Possible explanation of such an incidence may be related to the fact that the majority of the higher income people in the study area are engaging in agricultural businesses which inherently benefit from damming and other extractive water uses. Apart from that, studies from Piff et al. (2012) also found that individuals from upper-class backgrounds relative to lower-class individuals behaved more unethically and cared less for the environment.

4.6.2 Perception of Stream Fragmentation and Ecology at the County Level

From our analysis, variances at the county level for both the multi-level models are accounted only for research question 2 and only for the hydrological explanatory variables for research question 3. However, the addition of the hydrological parameters to the models strengthened the model predictions in case of research question 1, where we are looking at the importance given to the negative impacts of damming. Thus it can be concluded from here that dam density and precipitation as hydrological variables may have significant contributions towards predicting the behavior of damming in the watershed. Although understanding of the importance of damming and water withdrawals is present, the lack of taking responsibility to restrict damming in the area would allow more damming to occur, fragmenting the system even further. Hence, a restriction or check at the state or government level is required to control the nature of silent fragmentation in the Smoky-Hill River.

While our findings suggest that gender, education attainment and occupation are non-significant predicting factors for damming; at the theoretical level the challenges are that these cultural and social factors strongly affect coping and adaptive strategies (Chhetri et al. 2010). Attempts to more effectively address the need to plan for, and respond to, drought and other types of resource scarcity will inevitably fall short unless such differential vulnerability is recognized and taken into account as a key consideration in the overall planning effort (Kennan and Krannich 1997).

4.7 Conclusion

Research on water resource scarcity and river network fragmentation from small damming has been overlooked in areas of the central Great Plains. The perception of the same at the individual as well as county-level is important to understand, create awareness, and policy refinement to protect local watersheds and native biodiversity. Our study suggests that individuals who are more protective towards stream and environment and have better knowledge about climate change, and reservoir activities are more caring towards the negative effects of damming. However, there is no significant positive effect that shows that individuals who think damming has a negative impact on fish and animals would also take action against damming. Thus to address river basin fragmentation in the study area there is a requirement of a systematic planning from individuals, stake-holders and all levels of government. This can be achieved by promoting water conservation and improving water quality by funding initiatives, encouraging farmers to adopt best management practices and most importantly by infusing and promoting in people the culture-world views of information from climate and environmental science (Caldas et al. 2015).

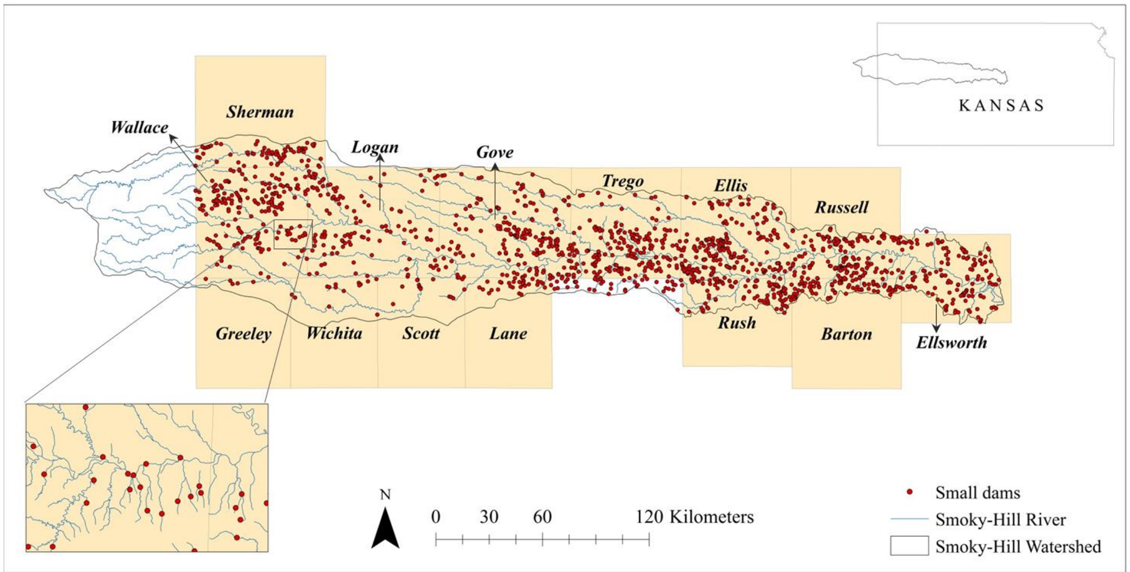

Figure 4.1: Study area consists of the Smoky-Hill River basin, covering fourteen counties.

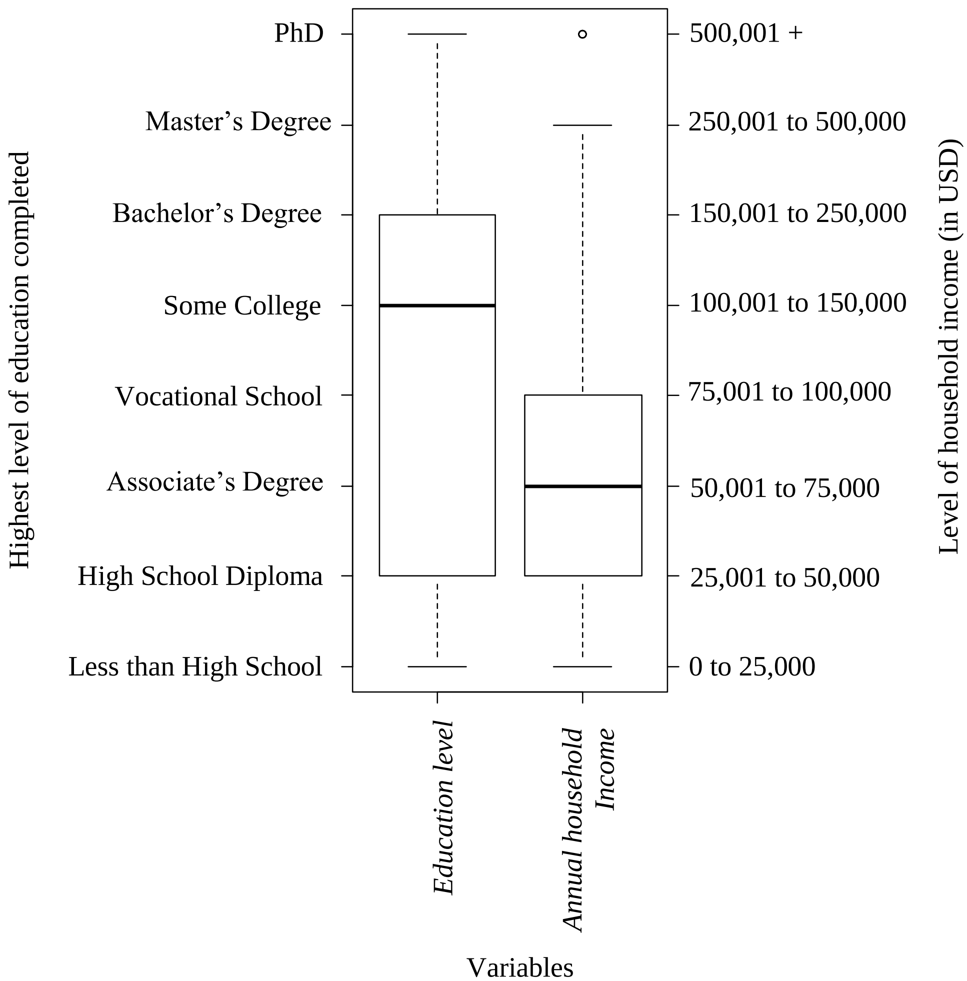

Figure 4.2: Distribution of attainment of highest level of education completed and level of household income of the respondents.

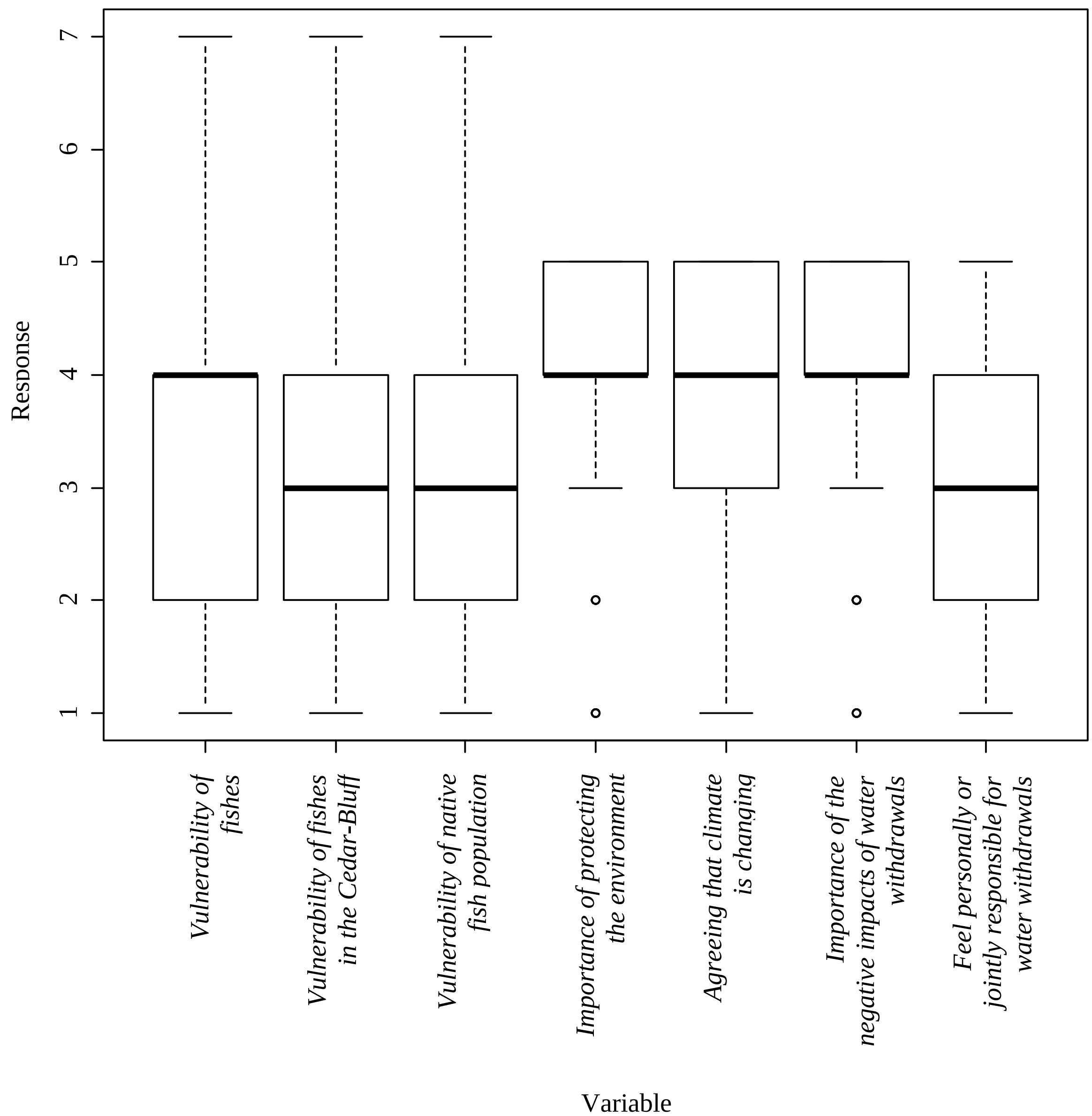

Figure 4.3: Distribution of the responses of fish vulnerability on a 1-7 Likert scale where 1 is highly vulnerable and 7 is thriving, and of perception and views on environment and climate change on a 1-5 Likert scale where, 1 measure not at all important/strongly disagree and 5 measure very important/strongly agree.

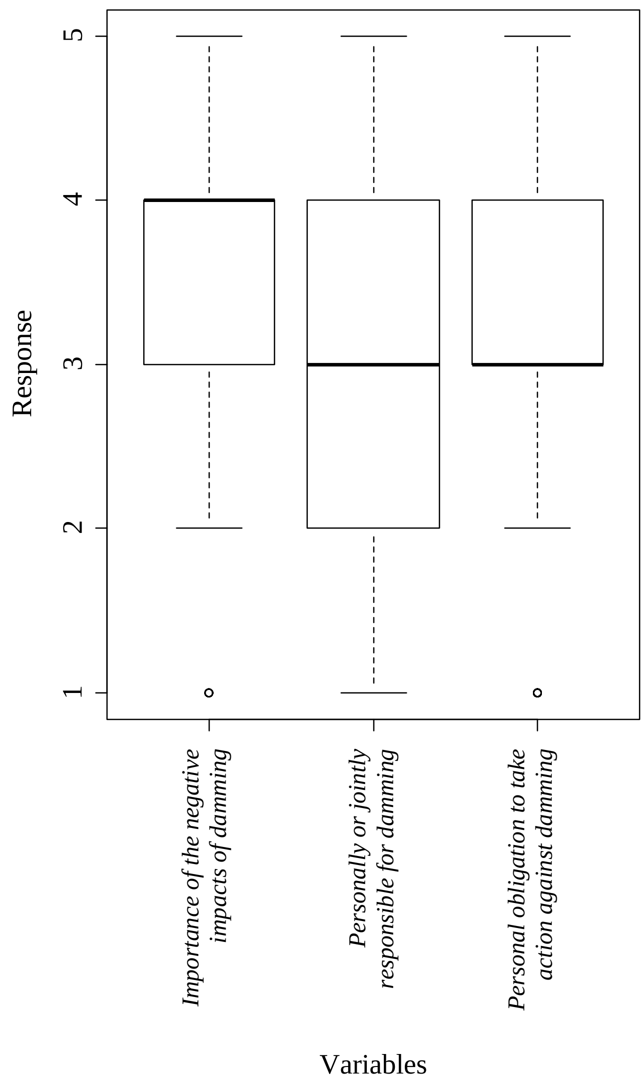

Figure 4.4: Distribution of the responses of the three major research questions on a 1-5 Likert scale where, 1 measure not at all important/strongly disagree and 5 measure very important/strongly agree.

Table 4.1: Survey questions on perspectives and views that are treated as independent variables for this study.

Please indicate the extent to which the situations in the table below are important or not important to you. 1 – Not at all important 2 – Unimportant 3 – Neither 4 – Important 5 – Very important					
Damming and breaking up streams and rivers that affect fish and animals.	1	2	3	4	5
Please indicate the extent to which you feel personally or jointly responsible for the following situations below. 1 – Strongly Disagree 2 – Disagree 3 – Neither Agree or Disagree 4 – Agree 5 – Strongly Agree					
Damming and breaking up streams and rivers that affect fish and animals	1	2	3	4	5
Please indicate the extent to which you feel a personal obligation to take action on the following issues. 1 – Strongly Disagree 2 – Disagree 3 – Neither Agree or Disagree 4 – Agree 5 – Strongly Agree					
I should do what I can to restrict damming of rivers and streams.	1	2	3	4	5

Table 4.2: Survey questions on local environment.

Please indicate to the best of your knowledge the condition of the following parts of the local environment on a scale of 1 to 7, with 1 being Highly Vulnerable and 7 being Thriving. The definitions of Thriving and Highly Vulnerable are provided below.

Thriving: For areas of land, lakes, and rivers, this means the area is unspoiled, is in a pristine state, and will likely remain that way into the near future. For fish and wildlife, this means they are common in the area and are not in danger of being lost in the near future.

Highly Vulnerable: For areas of land, lakes, and rivers, this means the area is in a degraded or depleted state and has a low probability of being restored in the near future. For fish and wildlife this means they are not comon in the area, numbers are declining, and there is strong likelihood they may dissappear in the near future.

	Highly Vulnerable						Thriving
Kanopolis Reservoir	1	2	3	4	5	6	7
Cedar Bluff Reservoir	1	2	3	4	5	6	7
Native fish populations	1	2	3	4	5	6	7

Table 4.3: Survey questions on perspectives and views.

Please indicate how important each of these is as a guiding principle in your life. 1 – Not at all important 2 – Unimportant 3 – Neither 4 – Important 5 – Very important	
Protecting the environment, preserving nature.	1 2 3 4 5
Please indicate how you agree with each statement about relationships between people and the environment. 1 – Strongly Disagree 2 – Disagree 3 – Neither Agree or Disagree 4 – Agree 5 – Strongly Agree	
The climate is changing.	1 2 3 4 5
Please indicate the extent to which the situations in the table below are important or not important to you. 1 – Not at all important 2 – Unimportant 3 – Neither 4 – Important 5 – Very important	
Water withdrawals from streams and rivers that affect fish and animals.	1 2 3 4 5
Please indicate the extent to which you feel personally or jointly responsible for the following situations below. 1 – Strongly Disagree 2 – Disagree 3 – Neither Agree or Disagree 4 – Agree 5 – Strongly Agree	
Water withdrawals from streams and rivers that affect fish and animals.	1 2 3 4 5

Table 4.4: Survey questions on demographical characteristics.

Gender □ Male □ Female

Highest Level of Education Completed
□ Less than High School (1)
□ High School Diploma (2)
□ Associate's Degree (3)
□ Vocational School (4)
□ Some College (5)
□ Bachelor's Degree (6)
□ Master's Degree (7)
□ PhD (8)
□ Other (please specify) _______

Level of Household Income
□ $0 to $25,000 (1)
□ $25,001 to $50,000 (2)
□ $50,001 to $75,000 (3)
□ $75,001 to $100,000 (4)
□ $100,001 to $150,000 (5)
□ $150,001 to $250,000 (6)
□ $250,001 to $500,000 (7)
□ $500,001 + (8)

What is your job _______

Generally speaking, do you usually think of yourself as a Republican, Democrat, Independent or other?
□ Republican (1)
□ Democrat (2)
□ Independent (3)
Others ____ (4)

Table 4.5: Description and summary statistics of the variables.

Metric Variable	N	No response	Mean	SD
1. Vulnerability of fishes in the Kanopolis Lake	721	122	3.436	1.479
2. Vulnerability of fishes in the Cedar-Bluff Reservoir	746	97	2.983	1.446
3. Vulnerability of native fish population	766	77	3.212	1.442
4. Importance of protecting the environment	818	25	4.247	0.778
5. Agreeing that climate is changing	820	23	3.713	1.104
6. Importance of the negative impacts of water withdrawals	820	23	4.106	0.813
7. Feel personally or jointly responsible for water withdrawals	813	30	2.935	1.201
8. Importance of the negative impacts of damming	820	23	3.815	0.877
9. Feel personally or jointly responsible for damming	812	31	2.768	1.268
10. Personal obligation to take action against damming	818	25	3.462	0.995
11. Gender	825	18	0.467	0.499
12. Above high school-level education	795	48	4.39	1.867
13. Annual household income above $50,000	736	107	2.864	1.526
14. Occupation	682	161	0.119	0.324
15. Political affiliation	531	312	1.2	0.4

Table 4.6: Factors associated with individual importance towards negative impacts of damming that affects fish and animals.

	Model 1			Model 2			Model 3		
	Coef		SE	Coef		SE	Coef		SE
Fixed effect									
γ0 = Intercept	1.060	***	0.241	1.060	***	0.238	0.545		0.319
Individual level									
γ1 = Vulnerability of fishes in the Kanopolis Reservoir	-0.058	º	0.029	-0.058	º	0.029	-0.063	*	0.028
γ2 = Vulnerability of fishes in the Cedar-Bluff Reservoir	0.010		0.031	0.010		0.030	0.008		0.030
γ3 = Vulnerability of native fish population	0.002		0.026	0.002		0.026	-0.005		0.026
γ4 = Importance of protecting the environment	0.165	**	0.044	0.165	**	0.044	0.154	**	0.044
γ5 = Agreeing that climate is changing	0.090	*	0.030	0.090	**	0.029	0.083	*	0.029
γ6 = Importance of the negative impacts of water withdrawals	0.461	***	0.042	0.461	***	0.041	0.460	***	0.041
γ7 = Gender	0.205	**	0.064	0.205	**	0.063	0.204	**	0.062
γ8 = Above high school-level education	-0.083		0.070	-0.083		0.069	-0.073		0.069
γ9 = Household income above $50,000	-0.003		0.061	-0.003		0.060	0.009		0.060
γ10 = Farming and/or ranching as occupation	-0.081		0.106	-0.081		0.105	-0.023		0.106
County level									
γ11 = Dam density							0.016		0.011
γ12 = Precipitation							0.007		0.004
Random effect									
Random intercept				0.000		0.000	0.000		0.000

'***' $p \leq 0.001$ '**' $p \leq 0.01$ '*' $p \leq 0.05$ 'º' $p \leq 0.1$

Table 4.7: Factors associated with personal responsibility towards damming that affects fish and animals.

	Model 1			Model 2			Model 3		
	Coef		SE	Coef		SE	Coef		SE
Fixed effect									
γ0 = Intercept	0.450		0.275	0.450		0.272	0.874	*	0.377
Individual level									
γ1 = Vulnerability of fishes in the Kanopolis Reservoir	-0.058		0.035	-0.058		0.035	-0.054		0.035
γ2 = Vulnerability of fishes in the Cedar-Bluff Reservoir	0.039		0.038	0.039		0.037	0.036		0.037
γ3 = Vulnerability of native fish population	0.049		0.032	0.049		0.032	0.056		0.032
γ4 = Importance of protecting the environment	0.049		0.050	0.049		0.050	0.058		0.050
γ5 = Agreeing that climate is changing	0.048		0.036	0.048		0.036	0.053		0.036
γ6 = Feel personally or jointly responsible for water withdrawals	0.740	***	0.031	0.740	***	0.031	0.741	***	0.030
γ7 = Gender	-0.077		0.077	-0.077		0.077	-0.075		0.076
γ8 = Above high school-level education	-0.119		0.086	-0.119		0.085	-0.127		0.085
γ9 = Household income above $50,000	-0.313	**	0.075	-0.313	**	0.075	-0.319	***	0.075
γ10 = Farming and/or ranching as occupation	0.057		0.129	0.057		0.128	0.022		0.130
County level									
γ11 = Dam density							0.006		0.014
γ12 = Precipitation							-0.009		0.005
Random effect									
Random intercept				0.000		0.000	0.000		0.000

'***' $p \leq 0.001$ '**' $p \leq 0.01$ '*' $p \leq 0.05$ '°' $p \leq 0.1$

Table 4.8: Factors associated with personal obligation to take action against damming.

	Model 1			Model 2			Model 3		
	Coef		SE	Coef		SE	Coef		SE
Fixed effect									
γ0 = Intercept	0.824	*	0.305	0.824	*	0.301	0.412		0.401
Individual level									
γ1 = Vulnerability of fishes in the Kanopolis Reservoir	-0.007		0.036	-0.007		0.036	-0.011		0.036
γ2 = Vulnerability of fishes in the Cedar-Bluff Reservoir	0.000		0.038	0.000		0.038	0.001		0.038
γ3 = Vulnerability of native fish population	-0.045		0.033	-0.045		0.033	-0.050		0.033
γ4 = Importance of protecting the environment	0.186	**	0.055	0.186	**	0.054	0.177	**	0.055
γ5 = Agreeing that climate is changing	0.075	º	0.037	0.075	º	0.037	0.069	º	0.037
γ6 = Importance of the negative impacts of water withdrawals	0.306	***	0.052	0.306	***	0.051	0.305	***	0.051
γ7 = Feel personally or jointly responsible for water withdrawals	0.202	***	0.031	0.202	***	0.031	0.202	***	0.031
γ8 = Gender	0.100		0.079	0.100		0.078	0.099		0.078
γ9 = Above high school-level education	-0.145		0.087	-0.145		0.086	-0.136		0.086
γ10 = Household income above $50,000	-0.142	º	0.077	-0.142	º	0.076	-0.134	º	0.076
γ11 = Farming and/or ranching as occupation	0.056		0.132	0.056		0.130	0.100		0.133
County level									
γ12 = Dam density							0.009		0.014
γ13 = Precipitation							0.006		0.005
Random effect									
Random intercept				0.000		0.000	0.000		0.000

'***' $p \leq 0.001$ '**' $p \leq 0.01$ '*' $p \leq 0.05$ 'º' $p \leq 0.1$

Table 4.9: Significance testing for the research questions for Model 1.

Research questions	*p-value*	Multiple R-squared	Adjusted R-squared
Factors associated with individual importance towards negative impacts of damming that affects fish and animals.	0.00	0.37	0.35
Factors associated with personal responsibility towards damming that affects fish and animals.	0.00	0.57	0.56
Factors associated with personal obligation to take action against damming.	0.00	0.28	0.27

Table 4.10: Evaluation and comparison of models using Akaike information criterion (AIC) for Model 2 and Model 3.

Research questions	Model 2	Model 3
Factors associated with individual importance towards negative impacts of damming that affects fish and animals.	1133.6	1129.8
Factors associated with personal responsibility towards damming that affects fish and animals.	1350.4	1351.5
Factors associated with personal obligation to take action against damming.	1361.8	1363.1

Table 4.11: Evaluation and comparison of models using p-values from likelihood ratio test statistic.

Research questions	Model 1 versus Model 2	Model 2 versus Model 3
Factors associated with individual importance towards negative impacts of damming that affects fish and animals.	0	7.77**
Factors associated with personal responsibility towards damming that affects fish and animals.	0	2.90
Factors associated with personal obligation to take action against damming.	0	2.71

'***' $p \leq 0.001$ '**' $p \leq 0.01$ '*' $p \leq 0.05$ '°' $p \leq 0.1$

Chapter 5

CONCLUSIONS

The dissertation investigated three complex and poorly understood elements of the coupled natural-human aquatic systems of the central Great Plains by addressing several research questions stated in the introduction of this project. The first research question looked at the distribution of small dams, which followed the precipitation gradient of the state and increased with the availability of water towards the east. Majority of these dams can hold less than 15 acre feet of water and are constructed in first order or smaller tributaries. While analyzing connectivity in the river basin across the watershed, using Dendritic Connectivity Index (Cote et al. 2009), the results showed that connectivity is mostly affected by the number of small dams within the sub-watershed. Connectivity is higher where precipitation and stream length associated with the sub-watershed are low, due to the absence of dams in it. To model dam removal scenarios, the results indicated that, in order to maximize connectivity within a network, dams should be removed where it forms cluster. An alternative option of dam removal for maximizing ecological connectivity would be to remove dams from the lower order streams (first and second order). For the second scenario, small dams in the lower order streams may lower the hydrologic connectivity index value but would minimize dissecting the stream, thereby not interfering with the fish movement. Hence, it is important to keep in mind the balance between ecological and hydrological connectivity and how restoration should be beneficial from various aspects.

The analysis of projected flow data from ArcSWAT modeling output, with historical flows in the three major USGS gages in the study area (Ellsworth, Hays and Schoenchen), located between the two federal reservoirs (the Cedar-Bluff and the Kanopolis), indicated a significant change in flow analysis, as analyzed from the second research question. As explained by Poff et al. (1997), Poff et al. (2009) and others, environmental flows are required to sustain freshwater and estuarine ecosystems and other livelihood that depends on the ecosystem, which requires more than just minimum low flows. From our study of future flow projections in the most vulnerable belt of the Smoky-Hill River, we see that the annual peak for the mean monthly discharge is expected to shift earlier with increased flow in late fall and decreased flow in summer. 7-, 30- and 90-day minima on an average are expected to fall and 7-, 30- and 90-day maxima on an average are expected to rise, with an increase in the number of zero flow days across the basin, increasing the variability and extremities of flow. A probable shift of 1-60 days is expected for both 1-day minimum and 1-day maximum discharge, with increase in the low and high pulse count and rise and fall rate. All these changes indicate a flashier flow in the basin at both inter and intra-annual level with a persistence of prolonged floods and droughts in the watershed.

A watershed that is already stressed from human-induced uncontrolled and unaccounted damming that forms a form of “silent fragmentation” in the basin, and expects a flashy intermittent flow with change in climate, is probably one of the most vulnerable ones. The analysis of how people in the watershed perceive this as a threat is the third and final research question and is a crucial finding of this research project. This is the field component of this dissertation and is compiled from mail surveys and surveys taken at county fairs held within the study area during July 2015 to January 2016. The major findings from this research component highlight that importance of the negative impacts of damming and river basin fragmentation to ecology is more common in individuals who understand and take responsibility for the negative impacts of water withdrawals from streams and rivers, believe in climate change and care for the protection of the environment. Although negative impacts of damming are recognized by individuals, responsibility of personal obligation to damming and to take action against it is lacking. There is a lack of understanding between what people perceives as a threat to water scarcity and ecology and the actions they are willing to take to protect it. Thus to achieve sustainability in this setting, it is important to understand, analyze, and integrate scientist, stake-holders and government through systematic planning, promotion of water conservation, and improved water quality initiatives. This integrated approach to economically acceptable outcomes that are environmentally sound can encourage farmers to adopt best management practices that promote culture-world views needed for sustainability (Caldas et al., 2015).

This dissertation identifies areas of stream network fragmentation that is detrimental to the native ecology in the study area and how the basin can change with change in climate and flow regimes. The integration of the physical vulnerabilities of the study area with the analysis of individual perceptions of surface water sustainability and ecology widens the scope of estimating integrated vulnerability in the basin and supports the incorporation of natural and social science to address issues of hydrology, environment and ecology. The study contributes significantly to a more complete understanding of the interaction between instream drying from both anthropogenic and climate change effects, and with the social perceptions associated with the problem. To address surface water sustainability in the central Great Plains, both these issues are necessary to study. This work can be applied to other river basins with similar or related climate, precipitation, land-use for an integrated river basin management. Increasing the scope and study area of this dissertation on a larger scale river basin would also be beneficial for managing surface water sustainability.

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Appendix A

DCI CALCULATION

Table A.1: Characteristics of the 30 sampled creeks

Stream ID	GNIS Creek	Highest stream order	No. of small dams	Length of the stream (kms)	Mean Precip. (cms)	DCI
1	Beaver	3	21	208.89	67.89	6.94
2	Buffalo	3	6	96.45	74.12	3.29
3	Cheyenne	3	5	79.08	52.53	18.09
4	Clear	3	9	63.12	74.12	7.68
5	Downer	3	12	156.11	54.71	12.39
6	Eagle	3	22	108.65	63.17	9.34
7	East Branch Sand	4	3	48.23	56.41	20.57
8	East Spring	3	3	91.20	50.83	15.70
9	Fossil	3	24	128.08	65.43	3.57
10	Hell	3	4	78.27	50.83	4.72
11	Indian	4	51	234.13	53.64	2.46
12	Landon	3	22	161.48	63.17	11.35
13	Middle Fork Lake	2	6	55.31	44.96	8.68
14	North Branch Hackberry	3	11	200.29	52.53	12.74
15	North Fork Big	3	1	53.57	44.96	3.20
16	Pond	4	22	111.57	48.90	10.31
17	Rose	3	7	63.78	48.90	12.71
18	Sand	3	19	118.89	48.90	6.79
19	Sandy	2	10	106.33	44.96	4.84
20	Shelter	3	8	57.32	63.17	19.99
21	Sixmile	3	0	74.91	48.90	100.00
22	Snake	4	3	142.28	59.08	9.72
23	Spring	3	3	166.83	59.08	15.99
24	Thompson	3	7	109.71	74.12	2.26
25	Turtle	2	1	68.13	44.96	6.60
26	Walker	4	6	148.97	63.17	1.86
27	West Salt	3	4	71.81	52.53	18.16
28	Wild Horse	3	12	137.77	56.41	17.14
29	Willow	3	8	84.53	44.96	7.08
30	Wolf	3	14	78.04	74.12	4.72

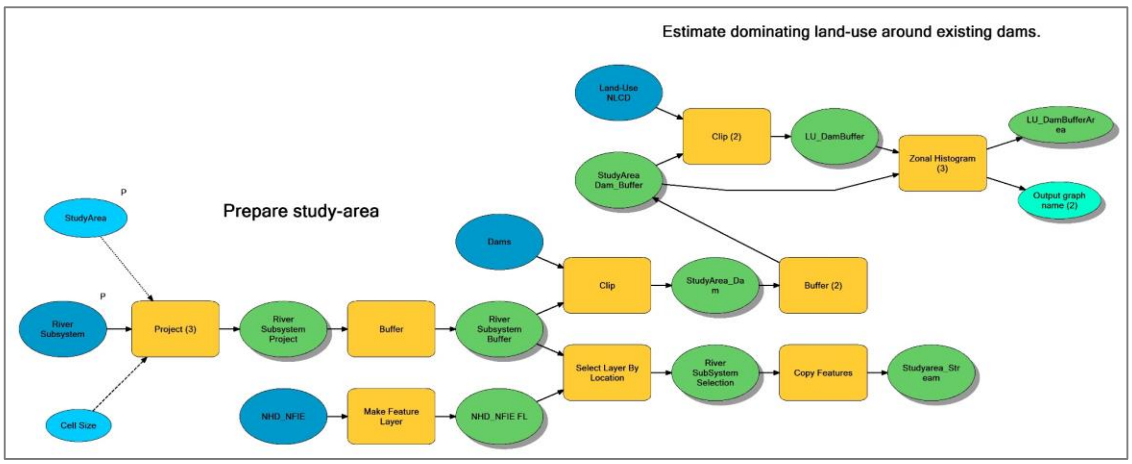
Table A.2: DCI values for all the small dams in the Indian Creek

Dam ID	Cij	Upstream (kms)	Downstream (kms)	DCI
1	0.95	2.25	23.28	0.091
2	0.95	1.02	23.28	0.041
3	0.95	10.08	23.28	0.408
4	0.95	71.71	2.25	0.281
5	0.95	0.99	1.02	0.002
6	0.95	1.25	10.08	0.022
7	0.95	1.54	10.08	0.027
8	0.95	2.8	71.71	0.349
9	0.95	0.29	71.71	0.036
10	0.95	7.72	71.71	0.963
11	0.95	2.19	71.71	0.273
12	0.95	0.46	71.71	0.057
13	0.95	0.957	71.71	0.119
14	0.95	8.27	71.71	1.032
15	0.95	7.99	0.99	0.014
16	0.95	0.26	1.54	0.001
17	0.95	2.28	0.29	0.001
18	0.95	1.69	7.72	0.023
19	0.95	4.99	7.72	0.067
20	0.95	0.35	2.19	0.001
21	0.95	14.03	0.46	0.011
22	0.95	0.65	0.57	0.001
23	0.95	1.56	8.27	0.022
24	0.95	3.77	8.27	0.054
25	0.95	16.89	7.99	0.235
26	0.95	0.37	0.26	0.000
27	0.95	0.18	2.28	0.001
28	0.95	1.72	4.99	0.015
29	0.95	5.91	14.03	0.144
30	0.95	1.92	14.03	0.047
31	0.95	1.01	14.03	0.025
32	0.95	2.01	14.03	0.049
33	0.95	0.16	0.65	0.000
34	0.95	2	1.56	0.005
35	0.95	1.85	3.77	0.012
36	0.95	1.57	3.77	0.010
37	0.95	4.66	16.89	0.137
38	0.95	2.65	16.89	0.078
39	0.95	0.93	16.89	0.027
40	0.95	0.11	0.37	0.000
41	0.95	6.72	0.18	0.002
42	0.95	1.26	1.72	0.004
43	0.95	1.46	5.91	0.015
44	0.95	0	0.16	0.000
45	0.95	1.78	1.85	0.006
46	0.95	1.15	0.93	0.002
47	0.95	2.1	0.11	0.000
48	0.95	0.36	1.46	0.001
49	0.95	1.78	1.78	0.006
50	0.95	0.83	1.15	0.002
51	0.95	0.32	2.1	0.001

Appendix B

GIS MODEL AND SCRIPT

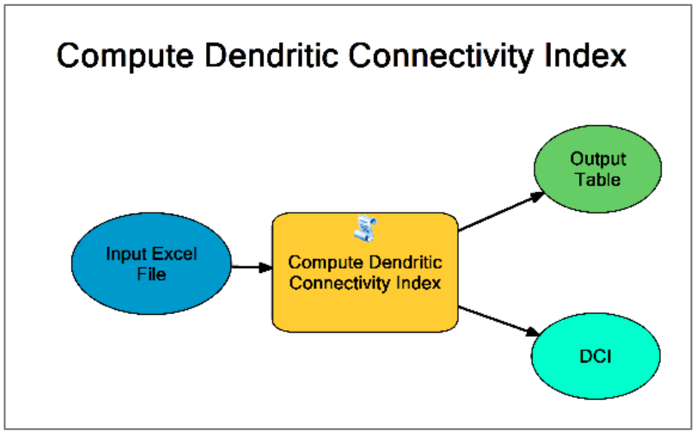
B.1 Extract study area from the NHD NFIE GIS Stream Layer to identify Dominating Land-use surrounding the Small Dams



B.2 Python Script to compute DCI

```
import os
import arcpy
import numpy
from arcpy import env
arcpy.env.overwriteOutput = True

# Get input parameter values and run main.
inputExcelFile = arcpy.GetParameterAsText(0) #inputExcelFile
outputTable = arcpy.GetParameterAsText(1)
excelSheet = arcpy.GetParameterAsText(2)

inputTableTemp = outputTable+"Tmp"
arcpy.ExcelToTable_conversion(inputExcelFile, inputTableTemp, Sheet=excelSheet)

#Convert Table to Array
conarr = arcpy.da.TableToNumPyArray(inputTableTemp,['BID', 'C', 'DIR', 'DIRTYPE', 'LENGTH'], null_value=-9999)

#FInd Size of Array
consize = conarr.shape

#Define Variables
n = consize[0] #number of record/rows
L = conarr[1][4] #Length of the total stream or upstream total length from sink

#Calculate DCI
DCI = 0.0
i = 3 #starting row
recs = [] #Creating List
while i < n-2:
    id = conarr[i][0]
    c = conarr[i][1]
    u = conarr[i][4]
    d = conarr[i+2][4]
    dcidam = c * u * d * 100 / (L * L)
    DCI = DCI + dcidam
    rec = [id,c, u, d, dcidam]
    recs.append(rec)
    i = i + 3

#Create a simple array from scratch using a list of values
newarr = numpy.rec.fromrecords(recs)

# Convert array to a geodatabase table
arcpy.da.NumPyArrayToTable(newarr, outputTable)

# Reporting the DCI value to a Text File
arcpy.AddMessage("The Dentric Connectivity Index is " + str(DCI))
arcpy.SetParameterAsText(3, str(DCI))
```

B.3 Creating the DCI tool from the Python Script developed in model B.2



B.4 Description of the GIS Toolbox and the Metadata developed for B.3

Compute Dendritic Connectivity Index

Title Compute Dendritic Connectivity Index

Summary

Dendritic Connectivity Index for Potadromous (DCIp) or riverine aquatic system developed by Cote et al. 2009 provides a means to quantify (longitudinal) connectivity within dendritic ecological networks.The tool takes the FiPex add-in extension output table as its input and converts it into an array to compute the DCI, DCI is a function of the length of the stream that is free from any dam. Therefore, mathematically it is a summation of the length of the stream upstream of a dam and the one downstream of it, signifying the river basin passage that is available to the aquatic biodiversity for free movement, devoid of anthropogenic barriers or fragments.

Illustration

$$\mathrm{DCI_P} = \sum_{i=1}^{n}\sum_{j=1}^{n} c_{ij}\frac{l_i}{L}\frac{l_j}{L} * 100.$$

Usage

The metrics help to quantify network-scale habitat connectivity in aquatic systems.

Syntax

ComputeDendriticConnectivityIndex (Input_Excel_File, Output_Table, {Sheet})

Parameter	Explanation	Data Type
Input_Excel_File	**Dialog Reference** Specify the location of the Fipex output Table as the input excel file for the DCI calculation. Before adding the excel sheet, please add a row to the excel sheet and change the name of the columns (case-sensitive) of the following variables as: • Barrier- BID • Value- C • Direction- DIR • Type- DIRTYPE • Quantity- LENGTH The other columns in the excel sheet can be named without any convention. There is no python reference for this parameter.	File
Output_Table	**Dialog Reference** The output table is a geodatabase table that gives the calculation of the particular DCI for each dam. The summation of the DCI index for the whole sub-system is attached as a Geoprocessing message. There is no python reference for this parameter.	Table
Sheet (Optional)	There is no explanation for this parameter.	String

Code Samples

DCI Computation Example (Stand alone script)

The following Python window script demonstrates how to use the Compute Dendritic Connectivity Index function as a stand alone script.

```
import arcpy

# Local variables:
Data = "C:\\Data\\Data.xls"
Table = "C:\\Data\\Data.gdb\\Table"

# Process: Compute Dendritic Connectivity Index
arcpy.gp.toolbox = "C:/DCIAnalysis/DCI.tbx";
arcpy.gp.ComputeDendriticConnectivityIndex(Data, Table, "")
```

Tags

DCI, Ecological Habitat, Streams and small dams

Credits

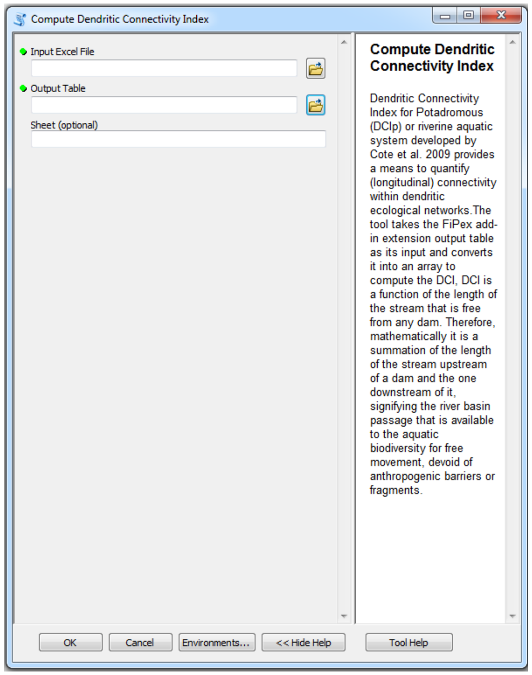
There are no credits for this item.

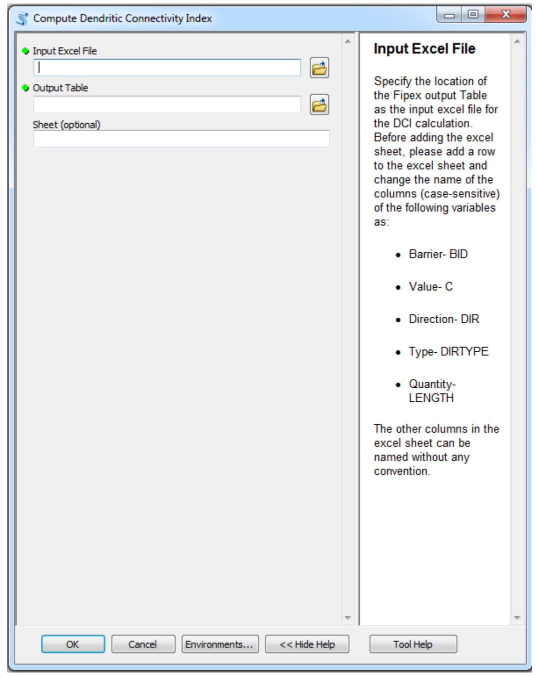
Use limitations

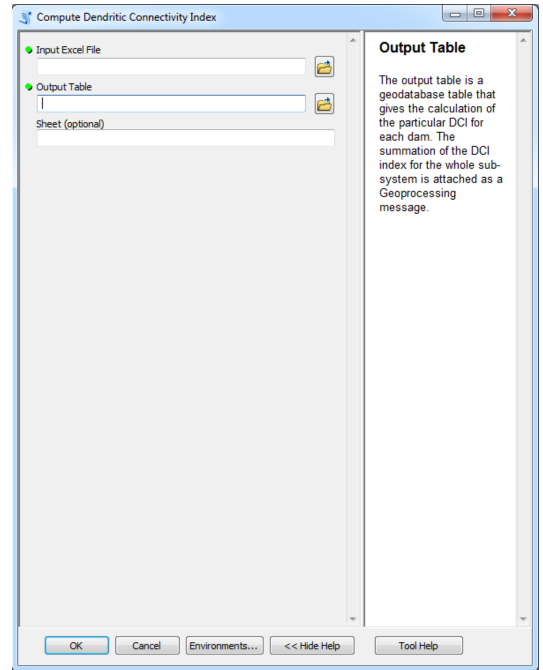
- The tool uses an add-in tool within ArcGIS- The Fish Passage Extension for ArcGIS 10.x or FiPex.
- The excel file that is used as an input to the tool must have a row added to it with specified column headings.

You are currently using the Item Description metadata style. Change your metadata style in the Options dialog box to see additional metadata content.

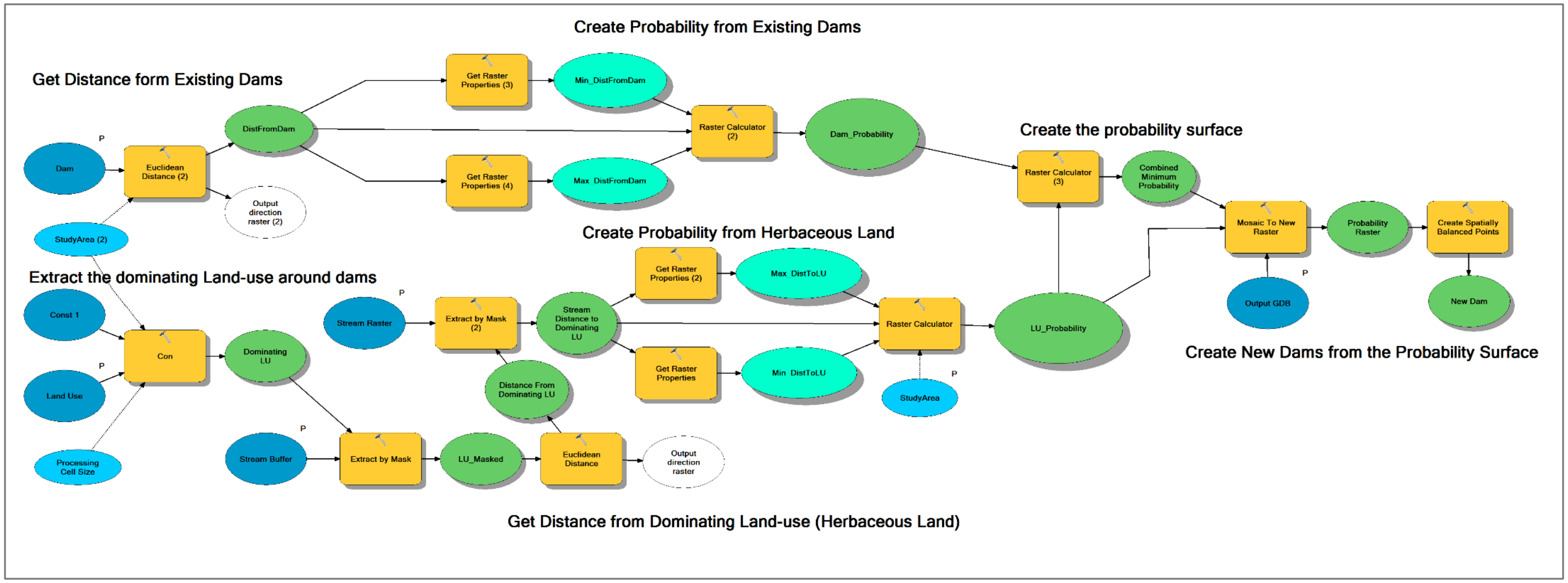
B.4 (contd.)


Compute Dendritic Connectivity Index
Input Excel File
Output Table
Sheet (optional)
Compute Dendritic Connectivity Index
Dendritic Connectivity Index for Potadromous (DCIp) or riverine aquatic system developed by Cote et al. 2009 provides a means to quantify (longitudinal) connectivity within dendritic ecological networks.The tool takes the FiPex add-in extension output table as its input and converts it into an array to compute the DCI, DCI is a function of the length of the stream that is free from any dam. Therefore, mathematically it is a summation of the length of the stream upstream of a dam and the one downstream of it, signifying the river basin passage that is available to the aquatic biodiversity for free movement, devoid of anthropogenic barriers or fragments.
OK
Cancel
Environments...
<< Hide Help
Tool Help


Compute Dendritic Connectivity Index
Input Excel File
Output Table
Sheet (optional)
Input Excel File
Specify the location of the Fipex output Table as the input excel file for the DCI calculation. Before adding the excel sheet, please add a row to the excel sheet and change the name of the columns (case-sensitive) of the following variables as:
• Barrier- BID
• Value- C
• Direction- DIR
• Type- DIRTYPE
• Quantity- LENGTH
The other columns in the excel sheet can be named without any convention.
OK
Cancel
Environments...
<< Hide Help
Tool Help


Compute Dendritic Connectivity Index
Input Excel File
Output Table
Sheet (optional)
Output Table
The output table is a geodatabase table that gives the calculation of the particular DCI for each dam. The summation of the DCI index for the whole sub-system is attached as a Geoprocessing message.
OK
Cancel
Environments...
<< Hide Help
Tool Help

B.5 Creating the Probability Surface Raster to Predict New Dams



B.6 Append the Number of Dams and Re-calculate DCI