WOODY PLANT REMOVAL IMPACTS ON SEDIMENT YIELD FROM NORTHCENTRAL OKLAHOMA GRASSLANDS

By

ADRIAN ALONSO SAENZ

Bachelor of Science in Civil Engineering
Oklahoma State University
Stillwater, Oklahoma
2016

Submitted to the Faculty of the
Graduate College of the
Oklahoma State University
in partial fulfillment of
the requirements for
the Degree of
MASTER OF SCIENCE
December, 2018

WOODY PLANT REMOVAL IMPACTS ON

SEDIMENT YIELD FROM NORTHCENTRAL

OKLAHOMA GRASSLANDS

Thesis Approved:

Dr. Daniel E. Storm

Thesis Adviser

Dr. Paul Weckler

Dr. Garey A Fox

Dr. Chris B Zou

.

ACKNOWLEDGEMENTS

First and foremost, I would like to acknowledge my various funding sources. Thank you to the **National Science Foundation Bridge to Doctorate Fellowship** (Grant Number 1408748) for providing me the opportunity and economic means to pursue and complete an advanced degree at Oklahoma State University, Stillwater. Next, thank you to the **United State Department of Agriculture's National Institute of Food and Agriculture** (Grant Number: 2014-67010-21653) for providing the research means and equipment by which I was able to study and complete this research project. And last, but not least, thank you to all the scholarships, awards, and opportunities that helped me make a dent in my undergraduate student loans.

Next, I would like to thank my committee and research team for helping me accomplish this degree. Special thanks to **Dr. Garey Fox** for taking me under his wing and introducing to BAE, model calibration/validation, and a very difficult hydrology course. Special thanks to **Dr. Daniel Storm** for providing me the foundation of statistics, career advice, and edits by which I was able to complete this thesis. I know I did not start as your student, but thank you for sticking by me and helping me finish. Special thanks to **Dr. Chris Zou** for serving on my committee and for sharing his vast ecohydrological knowledge and humor. Special thanks to **Elaine Stebler** for serving as my field work partner-in-data and for the vast gigabits of data and advice you provided not only me, but this project. Special thanks to **Rainee DeRoin** for serving as my mentee and for teaching me the value of mentorship. Special thanks to **Dr. Brad Rogers** for coming to my rescue when we had to remove 900 kg from my H-Flume. And a VERY special thanks to EVERY graduate student friend who made my graduate experience at OSU absolutely wonderful!

Next, I want to acknowledge critical friends, mentors, and family who helped shape me into the person I am today. To my mentor **Brenda Morales**; thank you for introducing me to research and for encouraging me to travel the world. I admit I was a difficult freshman with no direction, but I am eternally grateful for your guidance and for writing all those reference letters. To my mentor, **Dr. Sara Mata**; thank you for guiding my leadership abilities and emotional intelligence. Yes, people are still difficult, but at least now I can identify the ones who are truly worth my time. To my roommate **Eduardo Aguayo**; your cooking skills helped make sure I the mind power to complete this thesis. To my mother **Vicky Pando**; thank you for teaching me the value of education. I know if given the chance, you would probably be pursuing a PhD while I finish my masters, but know that this degree is for us. To **my siblings**; there are a lot of you, but I am glad you took care of the grandkids part. I am proud to say that I help establish the Saenz family education standard! And to **everyone else;** there are not enough words in the dictionary to describe what you mean to me, but unfortunately, there is a word count.

Lastly, special thanks to all the deer, snakes, armadillos, hornets, cows, hawks, birds, and lizards that did not attack me during the duration of my project! Chiggers and ticks are another story…

Stay Frosty my Friends!
-Adrian "Look At Me with My Grad Self" Saenz

Name: ADRIAN ALONSO SAENZ

Date of Degree: DECEMBER, 2018

Title of Study: WOODY PLANT REMOVAL IMPACTS ON SEDIMENT YIELD FROM NORTHCENTRAL OKLAHOMA GRASSLANDS

Major Field: BIOSYSTEMS ENGINEERING

Abstract:

Encroachment of *Juniperus virginiana* L. (eastern redcedar) into grassland ecosystems has been reported to increase water loss via evapotranspiration, potentially reducing water resources available to municipal and aquatic ecosystems. This concern, when coupled with increasing water demands of Oklahoma, has inspired research aimed at documenting the hydrologic implications of harvesting woody biomass from encroached rangelands. In order to quantify the water quality and quantity influences of woody plant removal from encroached watersheds, sediment yield and runoff of varied vegetation catchments were collected and compared across seven experimental watersheds near Stillwater, OK. The objective of this study was to determine the effects of encroached eastern redcedar removal and subsequent land use, i.e. restored prairie and *pancium virgatum* (switchgrass) cultivation, on annual sediment and water yield. Results showed grassland watersheds generated higher runoff compared to eastern redcedar woodland, while redcedar woodlands produced higher flow-weighted average sediment concentrations compared to grasslands. However, no significant difference between tallgrass and redcedar sediment means were found. Additionally, redcedar removal and one-year switchgrass cultivation or two-year grassland recolonization increased annual sediment yields. These results imply woody plant removal may increase watershed water yield and sediment, but longer time periods and quality indices are needed to assess the full hydrological implications of woody biomass removal.

TABLE OF CONTENTS

Chapter Page

LIST OF TABLES

Table Page

Table Page

Table Page

LIST OF FIGURES

Figure Page

Figure Page

Figure Page

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

1.1 GRASSLAND ECOSYSTEMS

Within Earth's vast biomes, grassland ecosystems provide essential ecosystem goods and services, which enabled civilizations to flourish throughout history. On a global perspective, grasslands represent approximately 26% of the earth's land area; yet compose 80% of the land necessary to fulfill society's food demand (Boval et al., 2012). However, as human population expanded throughout the millennia, society's need for food and services led to the tenacious conversion of grasslands to agricultural cropland, which contributed to the endangerment of these ecosystems and the degradation of their ecological services (Engle et al., 2008; Rowe, 2010). Today, North American grasslands cover less than 75% of their pre-European area, and the continual conversion of grasslands has adversely affected the carbon sequestration, soil fertility, and water and air quality services they provide (Fargione et al., 2009; Limb et al., 2010).

The root cause of grassland degradation is not just loss of surface area. Anthropogenic establishment of monocultures, introduction of invasive species, grassland fragmentation, herbaceous biodiversity decline, disease, erosion, and woody plant encroachment all represent numerous challenges afflicting grassland ecosystems within the 21st century (Engle et al., 1996; Engle et al., 2008; Hartman et al., 2011; Rowe, 2010). However, due to woody plant's rapid encroachment rate and its potential detrimental impacts on water resources (Engle et al., 1996), the primary focus of this research shall be analyzing the woody plant removal impacts on sediment yield within Northcentral Oklahoma grasslands.

1.2 WOODY PLANT ENCROACHMENT

Woody plant encroachment is a term used to describe the increase of woody plant density within its natural range, but is also considered to be the expansion of woody vegetation past its historic distribution. Woody plant encroachment is linked to both local and global drivers, such as fire, livestock, climate, and atmospheric carbon dioxide, and has been documented across several continents (Qiao et al., 2017; Saintilan et al., 2015; Sanjuán et al., 2018; Venter et al., 2018) and represents a modern issue of ecological deterioration. While consequences of woody plant encroachment vary among ecosystems, studies suggest that woody plant encroachment of grasslands foster alternative steady-states with increased vulnerability to erosion, decreased soil fertility, decreased runoff, decreased groundwater recharge, and nutrient leaching to surrounding aquatic ecosystems (Acharya et al., 2017; Puttock et al., 2014; Qiao et al., 2017; Saintilan & Rogers, 2015; Zou et al., 2014).

Puttock et al. (2014) used geochemical and ecohydrological techniques to quantify the impacts of woody plant encroachment on soil organic carbon distributions within arid environments. Puttock found woody plant's accelerated soil erosion, decreased soil infertility, and changed spatial distributions of dryland soil's soil organic carbon (Puttock et al., 2014). Puttock et al. (2014) also showed woody plant encroachment degraded water quality and de-stabilized arid watersheds, which would have been otherwise stable under herbaceous vegetation. Wilcox et al. (2010) evaluated 85-year runoff trends of four major rivers in the semi-arid Edwards Plateau in Texas to determine the effects of woody plant expansion on watershed degradation within this region. They found the expansion of woody plants increased baseflow contribution to annual stream flow and hypothesized that woody plant encroachment brought forth watershed recovery

(Wilcox & Huang, 2010). This discovery contradicted the notion that encroaching woody plants degraded ecosystems; however Heilman et al. (2014) found that the impacts of woody plants on water resources were highly dependent on local precipitation and geology. Ultimately, these studies underlined the crucial need to continue to research surface and subsurface influences of woody plants, as the overarching effects are still poorly understood (Wang et al., 2018).

Qiao et al. (2017), Starks et al. (2017), and Acharya et al. (2017) also studied the hydrological impacts of woody plant encroachment on sub-humid environments within the southern Great Plains of North America. Qiao et al. (2017) analyzed the impacts that woody plant encroachment had on runoff within tallgrass prairies, and found that eastern redcedar encroachment reduced surface and sub-surface runoff compared to grasslands. Starks and Moriasi (2017) used the Soil and Water Assessment Tool (SWAT) to simulate steam flow changes within the North Canadian River basin to determine the effects of increased woody plant biomass on municipal water supplies. Starks and Moriasi (2017) determined that woody conversion of 20% of grasslands could reduce stream discharge by 27% of Oklahoma City's municipal water demand. Acharya et al. (2017), observed soil moisture under encroached and grassland watersheds and found that woody plants reduced downward fluxes of water, water storage, and soil water content compared to grasslands. Qiao et al. (2017) also observed woody vegetation watersheds had frequently lower antecedent soil moisture conditions compared to grassland catchments. Ultimately, these studies suggest that woody plant encroachment could reduce groundwater recharge and runoff of grassland watersheds, altering two key hydrologic processes and influencing regional water budgets. Furthermore, continual small scale alterations to water budget partitioning would not only influence local water resources, but also impact regional water budgets across the Southern Great Plains. Thus it is imperative that proactive measures be taken in order to protect Oklahoma's water resources

1.3 EASTERN REDCEDAR

Juniperus virginiana L., commonly referred to as eastern redcedar, is an encroaching species of particular interest within Oklahoma land use investigations (Acharya et al., 2017; Qiao et al., 2017; Starks & Moriasi, 2017). Eastern redcedar is considered native to Oklahoma and can be found in all but three counties (McKinley, 2012). Early records indicate that eastern redcedar was planted around homesteads, shelterbelt's, and cemeteries to serve as windbreaks or to contrast to the Great Plains landscape (Engle et al., 2008; Stritzke et al., 1990). Due to its sensitivity to fire, eastern redcedar historically grew in areas sheltered from intense fire and its primary expansion mechanism was the consumption, transportation, and digestion of seeds via avian and mammal organisms (Engle et al., 2008; Holthuijzen et al., 1987; McKinley et al., 2008; Stritzke & Bidwell, 1990). However, anthropogenic suppression of fire and reduced wildfire fuel loads from unregulated livestock grazing of grasslands, allowed eastern redcedar to rapidly expand over the last 70 years (Engle et al., 2008; McKinley et al., 2008).

According to 1950 and 1985 Soil Conservation Service surveys of Oklahoma, eastern redcedar and Ashe juniper had already encroached approximately 607 and 1420 thousand hectares of land, respectfully (Engle et al., 1996; McKinley, 2012). By 1996 and 2002, juniper encroachment of Oklahoma was estimated to be 2.4 and 3.2 million hectares of land (McKinley, 2012; Smith, 2011) with an exponential encroachment growth rate (Engle et al., 1996). Smith (2011) also noted that of the 3.2 million hectares of encroached juniper, each hectare was estimated to contain at least 20 juniper trees (McKinley, 2012; Smith, 2011). More recently, Wang et al. (2018) used remote sensing data to establish a pixel and phenology algorithm which described eastern redcedar's encroachment of Oklahoma as a linear relationship of four thousand hectares per year since 1984. Moreover, while Wang et al. (2018) data had limitations, Wang's results emphasis the continual trend of eastern redcedar encroachment of Oklahoma.

Today, eastern redcedar represents an environmental concern for the state. Its growth rate allows for rapid expansion into grasslands and its leaf litter contains more than three times the lignin found in herbaceous grass species, which delays microbe decomposition of leaf litter while simultaneously increasing soil hydrophobicity (Engle et al., 2008; McKinley et al., 2008; Wine et al., 2012). Eastern redcedar also has a C3 photosynthetic pathway that provides additional growth advantages in elevated CO_2 environments (Auken et al., 2008). Furthermore, eastern redcedar is an evergreen species and can develop deeper root systems compared to herbaceous species if soil depth permits (Anderson, 2003). This allows eastern redcedar to access larger quantities of soil moisture, to transpire water all year, and to potentially consume as much of 95% of precipitation that reaches the soil surface (Caterina et al., 2014). Eastern redcedar has been shown to reduce soil sorptivity, exhaust soil nutrients, and degrade soil fertility (McKinley et al., 2008; Wine et al., 2012). Additionally, eastern redcedar has been shown to hinder and/or eliminate herbaceous species richness beneath the crown by as much as 90%, which weakens the resiliency of watersheds to fight disease and prevent erosion (Engle et al., 2008; Limb et al., 2010; Wayne et al., 2008). Ultimately, the combinations of these characteristics contribute to eastern redcedar's reputation as an "…irreversible change in ecosystem structure or an alternative state" (Knapp et al., 2008).

1.4 HYDROLOGIC IMPACTS OF EASTERN REDCEDAR ENCROACHMENT

What makes eastern redcedar the focus of many Oklahoma research projects is its potential adverse impacts on water resources. Due to eastern redcedar's large canopy size and high funneling ratio, i.e. 21:1, the tree redistributes rainfall into stemflow and its base receive more than 20 times the rainfall as a sized area without a juniper tree (Owens, 2008). This characteristic, in combination with eastern redcedar's low stomatal conductance, allows the tree to potentially consume up to 100% of total rainfall reaching the soil surface during drought years – making eastern redcedar a greater water resource concern during water-limited years (Caterina et al., 2014; Wine et al., 2015). Additionally, eastern redcedar has the potential to increase soil vulnerability to erosion via concentrated flow by reducing the productivity and growth of herbaceous grasses beneath the canopy (Engle et al., 1996; McKinley et al., 2008). Wilcox (2008) estimated that Ashe Juniper in central Texas used an average of 125 L per day, while Caterina et al. (2014) estimated eastern redcedar in Northern Oklahoma consumed an average of 24 L per day. This wide range of water consumption for the Juniperus species introduces considerable uncertainty in management recommendations, justifying greater research focused on estimating water consumption of these trees, determining water partitioning impacts of greater encroachment, and quantifying regional influences of continued eastern redcedar encroachment.

1.5 APPLICATION OF BIOMASS CROPS

Multiple studies have documented and suggested diverse methods to remove eastern redcedar (Fuhlendorf et al., 2008; Knapp et al., 2008; Lyons et al., 2009; Morton et al., 2010; Stritzke & Bidwell, 1990; Taylor, 2008). However, no long-term sustainable plan to address this grassland ecosystem threat exists. Based on the recent domestic energy production legislation, i.e. the Farm Security and Rural Investment Act of 2002, Energy policy Act of 2005, Energy Independence and Security Act of 2007, Food Conservation and Energy Act of 2008, American Recovery and Reinvestment Act of 2009, and the Clean Power Plan of 2015, several studies have suggested using these economic incentives to produce bioenergy feedstocks that depend on woody vegetation and simultaneously increased America's energy independence (Fargione et al., 2009; Feng et al., 2018; Gu et al., 2017; Wang et al., 2012). Currently, there are several forms of biofuel feedstocks that are investigated within the United States. These feedstocks include first generation biofuels, such as corn and maize, second generation biofuels, such as corn stover and *Pancium virgatum* (from now referred to as switchgrass), and various waste products that result from industrial systems (Liu et al., 2018). The importance of this research area is to identify ideal feedstock candidates for specific regions of the country and enable the United States to strategically offset its fossil fuel needs with lower emission biofuels. Wang et al. (2012) showed this potential by conducting well-to-wheel life cycle assessments of various biofuel feedstocks and petroleum products. In comparison to petroleum gasoline, Wang et al. (2012) determined that biofuel feedstocks such as sugarcane, corn stover, and switchgrass could reduce life-cycle emissions by 40-60%, 90-103%, and 77-97% respectfully.

Others studies have also begun comparing the prospective of varying biofuel feedstocks in order to determine optimal candidates for the Midwest (David et al., 2010; Feng et al., 2018; Fu et al., 2011; Gu & Wylie, 2017; Hartman et al., 2011; Sanford et al., 2017; Somerville et al., 2010; Zaibon et al., 2016). Sanford et al. (2017) compared biomass yields and sugar content for seven potential biofuel feedstocks and determined that perennial grass cropping systems had higher per hectare ethanol yields than the other potential feedstocks. Furthermore, they stressed the importance of choosing the most environmentally sustainable feedstock, as the cultivation would add additional stress to already unhealthy land and exacerbates poor watershed health. Somerville et al. (2010) also estimated biomass yield potential of various feedstocks and determined that C4 perennial plants have intrinsically higher light, water, and nitrogen use efficiencies as compared to C3 species. Further studies of perennial feedstocks also noted that perennial vegetation had broader cultivation ranges, lower agronomic input requirements, better biofuel conversion properties, and could be cultivated with conventional farming and harvesting techniques (David & Ragauskas, 2010; Fu et al., 2011), contributing to switchgrass's potential as a sustainable feedstock in the Great Plains.

However, what makes perennial crops most attractive for future biofuel investment in the Midwest are their vast cultivation range, beneficiary water and soil impacts, and their secondary environment services. Feng et al. (2018) used SWAT to determine the potential biomass production yield of two perennial feedstocks within the Mississippi water basin. They found that growing switchgrass and Miscanthus on marginal land could produce 37% of the 132 billion liter biofuel goal of the Energy Independence and Security Act (Feng et al., 2018). Gu and Wylie (2017) mapped suitable marginal land throughout the Great Plains and identified approximately 650,000 ha of marginal cropland suitable for switchgrass cultivation. Gu and Wylie (2017) took it one-step further by predicting a 5.9 million metric ton biomass productivity gain from this spatial region, excluding areas that had large uncertainty for switchgrass production in order to ensure the quality and reliability of their biofuel feedstock prediction. Zaibon et al. (2016) assessed the effects of varying levels of topsoil thickness in switchgrass and corn-soybean cropping systems. They determined that growing cellulosic biofuel feedstocks on degraded soil helped restore soil function and improved hydraulic properties by increasing water infiltration into the soil, reducing runoff velocity, and subsequently reducing soil erosion potential (Zaibon et al., 2016). Hartman et al. (2011) found similar soil benefits associated with switchgrass cultivation and suggested that switchgrass could provide needed habitat for bird and insect populations, while simultaneously protecting landscape biodiversity and minimizing disease outbreaks. Ultimately, all these studies suggest: (1) biofuels offer potential to ensure energy security, support rural economies, and reduce greenhouse emissions; (2) perennial biofuel feedstocks are particularly interesting due to their wider applicability, reduced system inputs, and countless environmental benefits; (3) marginal lands are ideal because utilization of these lands would minimize competition with food security; (4) cultivating perennial grasses in marginal lands could better soil and hydraulic properties; and (5) investigations of perennial feedstocks enable more stakeholder exposure to sustainable practices and improve perennial feedstock implementation strategies (David & Ragauskas, 2010; Fargione et al., 2009; Feng et al., 2018; Fu et al., 2011; Gu & Wylie, 2017; Hartman et al., 2011; Lisenbee, 2016; Sanford et al., 2017; Somerville et al., 2010; Wang et al., 2012; Zaibon et al., 2016).

The cultivation of feedstocks, however, does not directly answer the question of what to do with the woody plants occupying portions of Oklahoma marginal land, let alone provide guidance regarding the impacts that massive eastern redcedar removal would have on watershed water quality and quantity. Ramli et al. (2017) proposed creating a biofuel refinery for the harvested eastern redcedar and determined the minimum selling price of the biofuel using a mathematical model using 20-year transportation, production, and maintenance cost. Their results, however, showed that eastern redcedar feedstock alone would not be cost competitive with fossil fuels and several challenges would need to be overcome in order to make eastern redcedar biofuel production an economically feasible endeavor. Additionally, Wu et al. (2018) conducted a literature review of the environmental impacts of bioenergy production. They found that among bioenergy literature, water quantity/yield concerns were the most studied topic, yet soil health and soil loss research were limited. This research gap identifies a critical need for research to study the soil impacts of bioenergy production, as soil health is a crucial to the success of bioenergy feedstock production. Furthermore, water resources and soil erosion go hand in hand as changes in watershed hydrology impact sediment yields, and drastic increases of surface flow can diminish topsoil and reduce the overall productivity of natural and/or agricultural systems (Wu et al., 2018).

1.6 PROJECT OBJECTIVES

The objective of this project was to quantify the influences of encroached eastern redcedar vegetation removal and subsequent land use alterations on sediment yield within Northcentral Oklahoma watersheds compared to intact grassland and eastern redcedar encroached rangeland controls. In order to determine the water resource benefits or consequences of human-induced land use alterations within encroached eastern redcedar watersheds, the following research questions were pursued.

1. What were the differences in sediment yield between encroached eastern redcedar and grassland watersheds?

2. How did mechanical harvesting of eastern redcedar affect sediment yield compared to undisturbed watersheds?
3. Compared to undisturbed watersheds, what differences in sediment yield arose as eastern redcedar transitioned to re-established prairie?
4. Compared to undisturbed watersheds, what differences in sediment yield arose as eastern redcedar transitioned to cultivated switchgrass?
5. How does the application of herbicide to watersheds during transitional periods influence sediment yield compared to watersheds without herbicide?
6. What were the differences in sediment yield between cultivated switchgrass and recovering prairie compared to control eastern redcedar and prairie vegetation?

The broader objective of this study was to provide background on the sediment yield impacts associated with land use change necessary to support a proposed perennial grass and woody plant biomass feedstock. More specifically, this study aimed to document the sediment consequences and/or benefits of harvesting eastern redcedar and transitioning encroached Northcentral Oklahoma grasslands to alternative vegetation managements. Ultimately, this research is the first steps toward determining the potential role that a combined eastern redcedar and switchgrass feedstock would have on alleviate socio-ecological concerns associated with woody plant encroachment of Oklahoma.

CHAPTER II

METHODOLOGY

2.1 FIELD SITE

This research was conducted using seven small watersheds located within the Oklahoma State University (OSU) research rangelands, located approximately eleven kilometers southwest of Stillwater, Oklahoma, USA. More specifically, these watersheds exist within the Cross Timbers Experimental Range (CTER); a 710 hectare parcel of land within the Cross Timbers ecoregion that consisted of upland deciduous forest, savanna, and prairie (Lisenbee et al., 2017). Originally, much of the current CTER grassland and juniper encroached rangeland was cultivated after the 1889 Land Run to grow cotton, before later being abandoned in the 1940s (Qiao et al., 2017). Historic aerial photographs of the watersheds reveal only scattered juniper trees were present prior to the 1970s (Zou et al.,2014). In 1983, a multi-year return interval of prescribed fire was introduced to the CTER; however, fire has not carried over into heavily encroached areas. Both sides of the CTER experienced a moderate stocking rate of livestock grazing, and the seven small watersheds of this study were delineated between 2008 and 2010. Refer to Figure 1 for a topographic description of the seven watersheds and to Figure 2 for an aerial image of the seven watersheds prior to eastern redcedar removal.

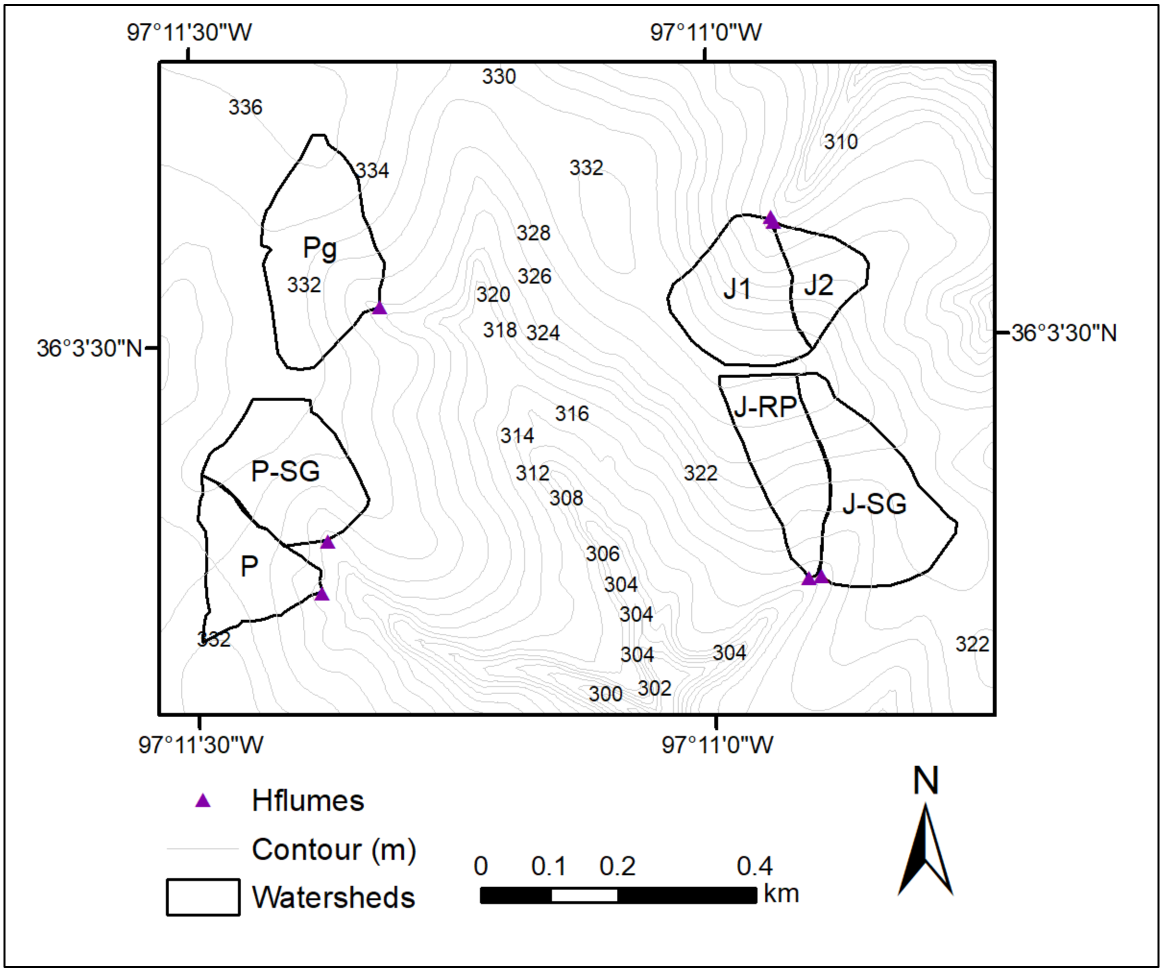


Figure 1: Topographic imagery of seven project watersheds within Oklahoma State University Cross Timbers Experimental Range near Stillwater, Oklahoma. Imagery watershed acronyms consist of Prairie with Grazing (P_g), Prairie to Switchgrass (P-SG,) Control Prairie (P), Juniper Control 1 (J1), Juniper Control 2 (J2), Juniper to Recovering Prairie (J-RP), and Juniper to Switchgrass (J-SG) respectfully. Image was created by Natural Resources Ecology and Management Graduate Research Assistant Yu Zhong on November 26, 2018 (Y. Zhong, personal communication, November 26, 2018).

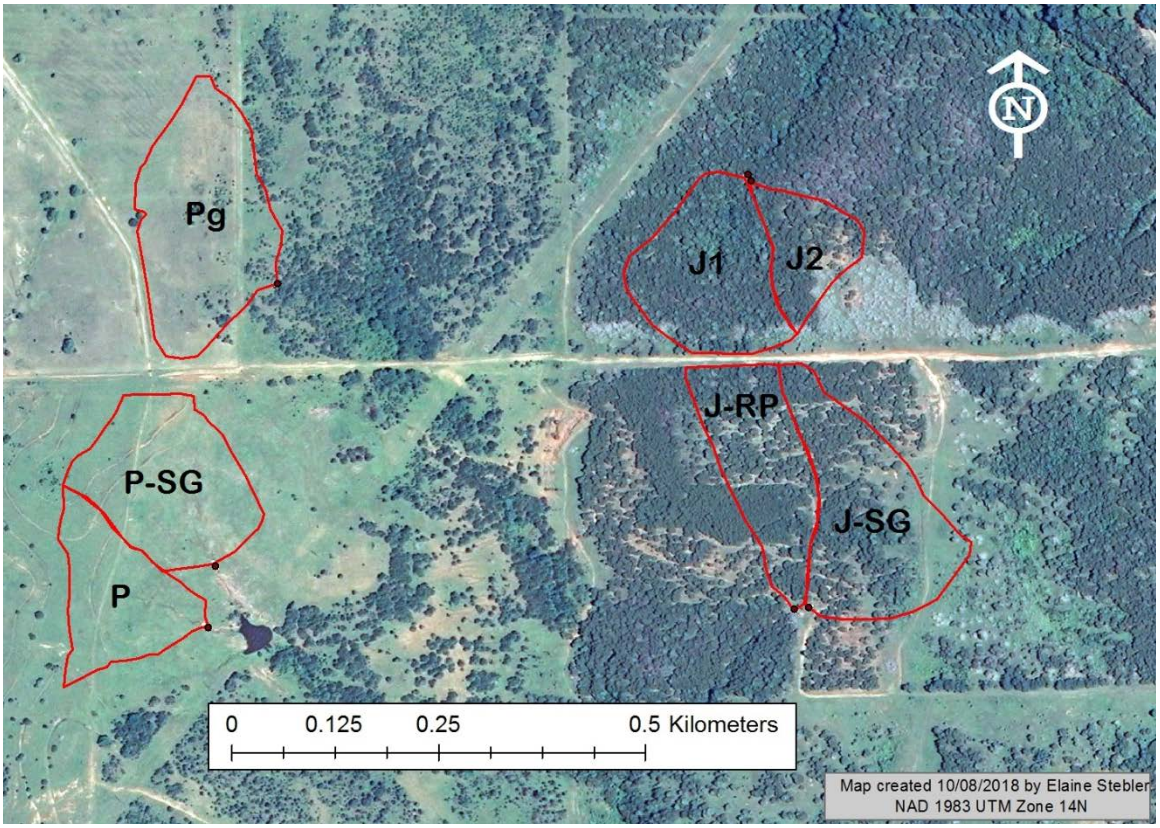


Figure 2: United States Department of Agriculture National Agriculture Imagery Program 2014 imagery of seven project watersheds within Oklahoma State University Cross Timbers Experimental Range near Stillwater, Oklahoma. Watersheds Prairie with Grazing (P_g), Prairie to Switchgrass (P-SG,) and Control Prairie (P) represent the three prairie management watersheds. Juniper Control 1 (J1), Juniper Control 2 (J2), Juniper to Recovering Prairie (J-RP), and Juniper to Switchgrass (J-SG) represent the four eastern redcedar management watersheds. At the time of this photograph, eastern redcedar had not been removed from watersheds J-RP and J-SG.

The most common soil type within the CTER was Stephenville Darnell complex which covered 38% of the total land area. Additionally, Stephenville Darnel had an individual watershed presence of greater than 50% for five of the seven CTER watersheds (Table 1). Renfrow and Grainola and Coyle and Zaneis where the other two major soil types present within the remaining two watersheds comprising less than 50% of the Stephenville Darnel soil coverage (Table 1). According to Web Soil Survey (Soil Survey Staff), these three major soil types possessed a well-drained natural drainage class with differences in hydrologic soil group classification and runoff class (Table 2).

Table 1: Watershed name, size, vegetation managements, and soil type percentage of seven watersheds located at Oklahoma State University Cross Timbers Experimental Range near Stillwater, Oklahoma. Listed soil types and watershed percentages were obtained from personal communication with Senior Research Specialist Elaine Stebler (E. Stebler, personal communication, November 26, 2018). Bolded soil types represent largest soil type present within watershed, except for watershed Juniper to Switchgrass, which had the two largest soil types bolded due to their < 50% watershed percentage.

Watershed Name	Area (m^2)	Vegetation Management Alterations		Soil Types Present Within Watershed(s)	Watershed Percentage (%)
		Initial	Treatment		
Juniper to Recovering Prairie (J-RP)	25700	Eastern Redcedar	Recovering Prairie	-Renfrow and Grainola soils, 3 to 8 percent slopes, severely eroded -Stephenville fine sandy loam, 3 to 5 percent slopes, severely eroded -Grainola-Lucien complex, 5 to 12 percent slopes, rocky **-Stephenville-Darnell complex, 3 to 8 percent slopes, rocky**	11.00 8.39 2.86 **77.75**
Juniper to Switchgrass (J-SG)	37900	Eastern Redcedar	Switchgrass	**-Renfrow and Grainola, 3 to 8 percent slopes, severely eroded** -Stephenville fine sandy loam, 3 to 5 percent slopes, severely eroded -Coyle-Lucien complex, 1 to 5 percent slopes -Grainola-Lucien complex, 5 to 12 percent slopes, rocky **-Stephenville-Darnell complex, 3 to 8 percent slopes, rocky**	**29.02** 8.55 20.08 13.04 **29.31**
Juniper Control 1 (J1)	29800	Eastern Redcedar	Eastern Redcedar	-Coyle and Zaneis soils, 3 to 5 percent slopes, severely eroded -Grainola-Lucien complex, 5 to 12 percent slopes **-Stephenville-Darnell complex, 3 to 8 percent slopes, rocky**	0.27 7.84 **91.90**
Juniper Control 2 (J2)	13500	Eastern Redcedar	Eastern Redcedar	**-Coyle and Zaneis soils, 3 to 5 percent slopes, severely eroded** -Grainola-Lucien complex, 5 to 12 percent slopes -Stephenville-Darnell complex, 3 to 8 percent slopes, rocky	**55.75** 21.83 22.42
Prairie to Switchgrass (P-SG)	33300	Prairie	Switchgrass	-Coyle Loam, 3 to 5 percent slopes -Coyle Loam, 1 to 3 percent slopes **-Stephenville-Darnell complex, 3 to 8 percent slopes, rocky**	18.15 14.49 **67.37**
Prairie Control (P)	22600	Prairie	Prairie	-Coyle Loam, 1 to 3 percent slopes -Harrah-Pulaski complex, 0 to 12 percent slopes, very rocky **-Stephenville-Darnell complex, 3 to 8 percent slopes, rocky** -Zaneis-Huska complex, 1 to 5 percent slopes	20.32 15.04 **63.67** 0.97
Prairie with Grazing (P_g)	40300	Prairie with Grazing	Prairie with Grazing	-Coyle Loam, 3 to 5 percent slopes -Coyle Loam, 1 to 3 percent slopes **-Stephenville-Darnell complex (StDD)**	22.35 22.90 **54.75**

Table 2: Soil and hydraulic characteristics of largest soil types present in seven watersheds located at Oklahoma State University Cross Timbers Experimental Range near Stillwater, Oklahoma. Listed soil types and watershed percentages were obtained from Web Soil Survey (Soil Survey Staff).

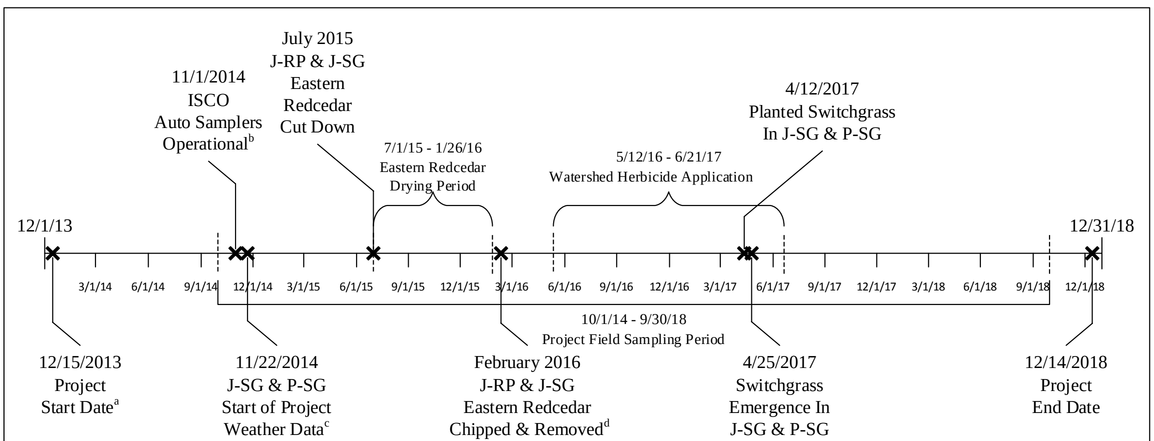
Soil Type	Slope (%)	Hydrologic Soil Group	Typical Soil Profile		Natural Drainage Class
			Depth	Soil Type	
Coyle and Zaneis soils, severely eroded	3 to 5	C	A - 0 to 7.62 cm Bt - 7.62 to 53.3 cm Cr - 53.3 to 78.7 cm	Loam Clay Loam Bedrock	Well Drained
Renfrow and Grainola, severely eroded	3 to 5	D	Ap - 0 to 7.62 cm Bt - 7.62 to 152 cm Cr - 152 to 178 cm	Silt Loam Silty Clay Bedrock	Well Drained
Stephenville-Darnell complex, rocky	3 to 8	C	A - 0 to 20.3 cm E - 20.3 to 33.0 cm Bt - 33.0 to 58.4 cm Cr - 58.4 to 83.8 cm	Fine Sandy Loam Fine Sandy Loam Sandy Clay Loam Bedrock	Well Drained

2.2 PROJECT SCOPE AND VEGETATION MANAGEMENT TIMELINE

The scope of this study spanned from October 2014 to September 2017, but runoff data from these watersheds were collected since August 2010. Unfortunately, due to water damage to the Teledyne ISCO 3700C Autosampler (Teledyne ISCO, Lincoln, NE, USA) wiring, sediment data from watershed Prairie with Grazing (P_g) was excluded from the analysis. The vegetation managements of each of the individual watersheds are as follows. The Prairie to Switchgrass (P-SG) watershed began as a mix-grass prairie at the start of the project, and in preparation for switchgrass seeding; it was sprayed several times with GrazonPD, Roundup, and/or 2,4-D herbicide from May 2016 through April 2017 (Table 3). Switchgrass had germinated by late April 2017. The Prairie Control (P) watershed consisted of mix-grass prairie, while the Juniper Control 1 (J1) and Juniper Control 2(J2) consisted of encroached eastern redcedar woodland. All control watersheds were undisturbed throughout the study. The Juniper to Recovering Prairie (J-RP) and the Juniper to Switchgrass (J-SG) watersheds, on the other hand, began as encroached eastern redcedar woodland at the start of the study and then eastern redcedar vegetation was cut during the transition from pretreatment to treatment conditions. Using a saw or shear attachment to a skid steer, in July 2015 both watersheds had eastern redcedar mechanically severed at the base of the tree and left to dry until January 2016. On February 2016, the dried biomass was chipped using an industrial wood chipper and hauled offsite using semi-trucks. Afterwards, J-RP was allowed to revegetate, while J-SG was sprayed with GrazonPD, Roundup, and/or 2,4-D herbicide until April 2017 (Table 3). Switchgrass was established in J-SG by late April 2017. Refer to Table 4 for a tabular outline of each watersheds vegetation management and Figure 3 for a comprehensive timeline of the various watershed vegetation managements, watershed alterations, and field sampling period.

Table 3: Herbicide application dates and composition for application to watersheds Juniper to Recovering Prairie (J-RP), Juniper to Switchgrass (J-SG), and Prairie to Switchgrass (P-SG).

Application Date	Watersheds Sprayed	Herbicide Composition
5/12/2016	J-RP, J-SG, and P-SG	GrazonPD + Roundup+ Surfactant
7/20/2016	J-RP, J-SG, and P-SG	Roundup + 2,4-D
4/7/2017	J-RP, J-SG, and P-SG	Roundup + 2,4-D
6/20/2017	J-RP, J-SG, and P-SG	2,4-D



[a] All watershed H-Flumes were constructed and operational by August 3rd 2010; prior to start of project
[b] ISCO 3700 Autosamplers were installed during the month of October 2014 and operational by November 1st 2014
[c] Both J-SG & P-SG weather stations were operational since January 2011. However, due to programming conflicts with the addition of ISCO sampling subroutine; the weather data for this project began November 22nd 2014.
[d] Eastern Redcedar was given 6.5 months before being chipped and removed from the site (i.e. curly bracket spanning 7/1/15 to 1/26/16). Chipping and removal began January 26th 2016 and extended into February 2016

Figure 3: Project timeline of watershed vegetation managements, land use alterations, and field data sampling period.

Table 4: Watershed vegetation management outline of seven watersheds located at Oklahoma State University Cross Timbers Experimental Range near Stillwater, Oklahoma.

Timeline		Vegetation Management of Eastern Redcedar Watersheds			
Start Date	End Date	Juniper to Recovering Prairie	Juniper to Switchgrass	Juniper Control 1	Juniper Control 2
10/1/14	6/30/15	Eastern Redcedar	Eastern Redcedar	Eastern Redcedar	Eastern Redcedar
7/1/15	2/29/16	Cut Eastern Redcedar	Cut Eastern Redcedar	Eastern Redcedar	Eastern Redcedar
3/1/16	4/30/16	Post-Grind	Post-Grind	Eastern Redcedar	Eastern Redcedar
5/1/16	4/30/17	Recovering Prairie Year 1	Cleared Herbicide Rangeland	Eastern Redcedar	Eastern Redcedar
5/1/17	9/30/17	Recovering Prairie Year 2	Switchgrass Cultivation Year 1	Eastern Redcedar	Eastern Redcedar
Timeline		**Vegetation Management of Prairie Watersheds**			
Start Date	**End Date**	**Prairie to Switchgrass**		**Prairie Control**	
10/1/14	5/31/16	Mix Grass Prairie		Mix Grass Prairie	
6/1/16	4/30/17	Sprayed		Mix Grass Prairie	
5/1/17	9/30/17	Switchgrass Cultivation Year 1		Mix Grass Prairie	

2.3 PRECIPITATION, RUNOFF, AND METEROROLOGICAL MEASUREMENTS

Precipitation was measured using three automatic tipping bucket rain gauges (model TB3, Hydrological Services America, Lake Worth, FL, USA) deployed in watersheds J-SG, J1, and P. These automatic tipping bucket rain gauges had a 0.25-mm resolution and were capable of measuring less than 250 mm/h rainfall intensities (Hydrological Services America, Lake Worth, FL, USA). Additionally, one manual stratus precision rain gauges were installed throughout each watershed to verify the automatic tipping bucket rain gauge measurements. Meteorological data, such as air temperature, relative humidity, wind speed, and incoming solar radiation were collected using two weather stations located in watersheds P-SG and J-SG (i.e. Figure 4).

Figure 4: Watershed outlet with weather station, H-flume and stilling well attachment, Shaft Encoder, ISCO 3700C Auotsampler, and stratus precision manual rain gauge equipment. Manual rain gauge was not visible due to herbaceous vegetation and shaft encoder was also not visible due to protective wooden green box cover. Photo was taken near Prairie to Switchgrass (P-SG) watershed within the Cross Timbers Experimental Range near Stillwater, OK, USA.

Runoff was measured using a 0.914-meter H-flume at watersheds J1, J2, J-RP, and J-SG, and a 1.219 meter H-Flume for watersheds P and P-SG. Every five minutes, Optical Shaft Encoders (50386SE-105, HydroLynx, West Sacramento, CA, USA) measured the stage reading at each stilling well attached to each H-flume. When sufficient surface flow was observed, a flow-weighted and time-weighted sampling strategy was employed to trigger ISCO runoff sample collection. In this sampling strategy, if the stage reading was greater than 21 mm for the 0.914 m H-flumes or 24 mm for the 1.219 m H-flumes, a 3700C ISCO Portable Sampler was triggered to collect an initial 250 mL runoff sample. Next, CR200 or CR1000 dataloggers (Campbell Scientific, Logan, UT, USA) would calculate the absolute difference between the initial and next five-minute stage reading. If the change was greater than 21 or 24 mm, then the ISCO sampler would take another runoff sample. However, if the change was not greater, then the ISCO Sample would continue to calculate the absolute difference between the previous and current stage reading until 40-minute maximum time between samples was reached and then another runoff sample would be taken. This sampling strategy allowed the ISCO sampler to capture more samples when the runoff changed significantly, allowing better characterization of flashy versus long duration runoff events.

Runoff samples were collected using an intake strainer located at the bottom of a 160 mm polyvinyl chloride (PVC) trough. Each trough was placed a minimum of 15 cm beneath each flume outlet and each strainer was made using a 25 mm PVC pipe with ten mm diameter holes and wire screening. The strainer prevented the ISCO intake strainer from collecting runoff debris and clogging the flexible ISCO intake tubing, while the trough prevented the intake strainer from sitting inside the H-flume and disturbing the H-flume stage-discharge relationship (Figure 5).

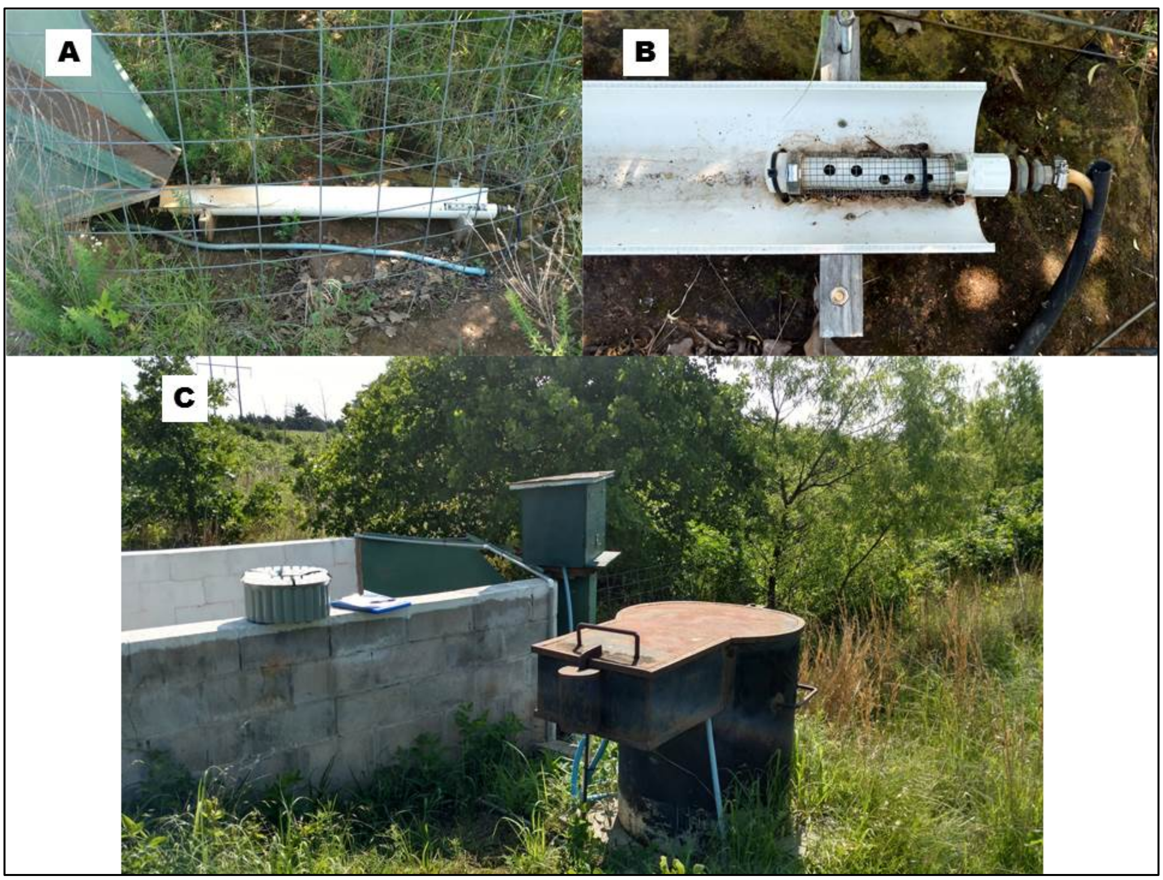


Figure 5: Photo A shows the location of troughs relative to H-flume discharge, photo B shows the location of the strainer within trough, and photo C shows their relative location to ISCO contained within the large iron enclosing. Photos were taken near Prairie Control (P) watershed within the Cross Timbers Experimental Range near Stillwater, OK, USA.

2.4 SEDIMENT YIELD

After every precipitation event, the Marena Mesonet station was checked for daily rainfall totals. Due to the site's close proximity to the CTER, i.e. < 3km, the Marena's daily rainfall totals were used to determine if field collection was needed. More specifically, if greater than 13 mm of rainfall was observed during the spring or summer and eight mm of rainfall was observed during the autumn or winter, ISCO samplers were manually inspected for runoff samples. If samples were present, samples were capped, labeled, and taken to the Biosystems and Agricultural Engineering Laboratory (BAEL) clean lab located on OSU's campus. ISCO bottle labels were promptly recorded onto corresponding data sheets and drying bottles. Next, total solids analysis was conducted on samples according to ASTM Standard D3977-97: Standard Test Methods for Determining Sediment Concentration in Water Samples ("Standard Test Methods for Determining Sediment Concentration in Water Samples," 2013). Container jar weight and sample dry weight were measured using a Citizen CT 603 analytical balance, while sample wet weight was measured using a Sartorius Quintix5102-1S top-loading balance. ISCO samples were dried at 105 degrees Celsius (°C) using a VWR Horizontal Air Flow Oven for a minimum of 72 hours and "all visible traces of water had evaporated" ("Standard Test Methods for Determining Sediment Concentration in Water Samples," 2013). Next, samples were placed in a desiccant chamber to prevent any air moisture from re-entering the samples as they cooled. Samples were quickly weighed and data were recorded onto datasheets, before being transferred to a digital form. Furthermore, in order to relate the mass of evaporated water to its respective volume and calculate sample sediment concentration, a specific gravity of water of 0.998 g/cm was assumed.

After the removal of eastern redcedar vegetation and the disruption of watersheds J-SG and J-RP, surface flow events deposited large quantities of sediment within their respected H-flumes. This deposited sediment had the potential to disrupted H-flume stage-discharge relationships and was part of the sediment yield observations, and thus it was manually removed using a shoved and 18 L buckets. The buckets were then manually transported to a truck parked nearby and dumped into BRUTE 121 L plastic trash cans. The 121 L trash cans of sediment were then taken to dry at the Oklahoma State University Agronomy Research Station, near Stillwater, OK. Sediment was transferred into 828 mm by 515 mm Scepter Drywall Mud Pans, placed inside 48.9°C drying ovens, and weighed after five days of drying. Refer to Appendix A for individual sediment depositing event data.

2.5 DATA PROCESSING

Precipitation, runoff, and sediment data were processed using Microsoft Excel™ and custom Visual Basic for Applications™ (VBA) coding macros. Data were sorted according to hydrologic-years and filtered according to precipitation, runoff, and sediment event definitions. Precipitation events were defined by the following three conditions: 1) precipitation events must trigger at least two of the three automatic tipping bucket rain gauges present at P, J1, and J-SG, 2) precipitation events must accumulate a minimum of 1.27 mm of rain over the duration of the storm, and 3) precipitation events must trigger two of the three automatic tipping bucket rain gauge readings around the same time . The end of a precipitation event, on the other hand, was defined by one of two alternative conditions: 1) no further rainfall was recorded over a six-hour time span since the last tipping bucket observation, or 2) no more than 0.762 cumulative mm of rain was recorded over a six-hour span since the declared end of the event. The alternative condition allowed precipitation events to not be influenced by small, late observations of precipitation caused by scattered showers, eventually prolonging the precipitation events and influencing percent time to peak intensities. Additionally, it is important to note that while all three tipping buckets influenced the identification of precipitation events, only precipitation from J-SG's tipping bucket was used to determine total rainfall (mm), rainfall intensity (mm/hr), and percent time to peak intensity (%) for each precipitation event. This was done to simplify small variations in precipitation data that existed between the three tipping buckets. These variations were likely caused by the natural variability of climate, even at small and relatively close distances. In all, 191 precipitation events were identified over the three hydrologic-year time span of this study.

Runoff events were defined by the following two conditions. First, a precipitation event must have preceded a runoff event and second, runoff must have been observed in at least one of the seven watershed's H-Flumes. The end of runoff events was characterized by the following condition; no more runoff was observed for a period of 24 hours since the last observed five minute runoff observation. This condition allowed ample time for runoff, which could freeze and stop during cold climate conditions, to thaw with the sun and be accounted within the runoff calculation of that event. In all, 139 runoff events were identified over the three hydrologic-year time span.

Sediment events were the simplest to define. First, both a precipitation and runoff event must have occurred prior to sediment event, and second, at least one sediment sample was taken by the ISCO 3700C Autosampler in one of the seven watersheds. Sample concentrations (mg/L) were paired using collective watershed information (i.e. sampling start times of other watershed) and the individual sampling time and date. This allowed for greater confidence of pairing sediment and runoff data as the ISCO individual date and time could be incorrect after 42 days of in-activity. After pairing, watershed runoff (L/five-minute) was multiplied with its corresponding concentration to determine the five-minute sediment yield (g/five-minute). Runoff observations that did not possess a matched sediment sample followed sediment yield determination via numeric integration guidelines outlined in Meals et al. (2013). Five minute sediment calculations were then summed up for the duration of the event and all variables were compiled on a per event bases. In total, 77 different sediment events were analyzed within this study.

2.6 PHASE OUTLINE, TOTALS, AND LONG-TERM COMPARISON

Due to unfavorable climate conditions after the eastern redcedar vegetation was chipped and hauled away, switchgrass seeding of J-SG was delayed a year and discrepancies between J-SG and J-RP vegetation management timelines were created. These unforeseen discrepancies made comparisons between the six experimental watersheds impossible to make as watershed vegetation timelines varied. In response, the six experimental watersheds were divided into two separate groups, an eastern redcedar group which included watersheds J-RP, J-SG. J1, and J2, and a grassland group that consisted of watersheds P-SG and P. Additionally, several "phases" or predetermined periods of time where watershed vegetation is constant; were outlined in order to facilitate the visual and statistical comparisons of this project's research questions. Cumulative totals for both unit runoff (mm) and sediment (g/m^2) were calculated by separating sediment events according to the group phase breakpoints and summing their observed runoff and sediment yield. Table 5 outlines the various phase breakpoints of both watershed groups, while Table 6 provides raw data information according to each outlined phase.

Table 5: Predetermined Phase breakpoints of both eastern redcedar and grassland groups. The term "phase" refers to a predetermined period of time where watershed vegetation was constant. Due to unfavorable climate conditions after eastern redcedar chipping, Juniper to Switchgrass's Treatment Year 1 phase consisted of disturbed herbicide rangeland.

Eastern Redcedar Group			Grassland Group		
Phase Name	**Start Date**	**End Date**	**Phase Name**	**Start Date**	**End Date**
Pretreatment	10/1/2014	6/30/2015	Pretreatment	10/1/2014	5/31/2016
Post-Cut	7/1/2015	2/29/2016	Sprayed	6/1/2016	4/30/2017
Post-Grind	3/1/2016	4/30/2016	Treatment Year 1	5/1/2017	9/30/2017
Treatment Year 1	5/1/2016	4/30/2017			
Treatment Year 2	5/1/2017	9/30/2017			

In order to provide additional details about each phase and to facilitate comparisons between the phases, the number of sediments events that occurred during each phase and their corresponding phase precipitation (mm/phase) were calculated using the designated phase breakpoints (Table 6). Due to phase duration differences, phase precipitation was normalized to account for time by dividing the phase precipitation by the number of days in each phase. Also, in order to add a relative scale to the normalized phase precipitation, 24 years of daily rainfall data were obtained from the Marena Mesonet site and a long-term average precipitation was calculated (mm/year). Next, wet and dry year precipitation was calculated and defined as 20% difference above and below the normalized average. Table 6 displays the results of this section.

Table 6: Normalized phase precipitation data for the Marena Mesonet station 24-year rainfall data, eastern redcedar watersheds, and prairie watersheds.

Mesonet Site Name	Number of Days	Long-Term Average Average Precipitation (mm/year)	Normalized Precipitation (mm/day)		
			Dry	Average	Wet
Marena	8766	879	1.97	2.41	2.95
Eastern Redcedar Group					
Phase Name	**Sediment Events Present (#/Phase)**	**Days in Each Phase (days)**	**Phase Precipitation (mm/phase)**	**Normalized Phase Precipitation (mm/day)**	
Pretreatment	17	272	476	1.75	
Post-Cut	11	244	388	1.59	
Post-Grind	5	61	149	2.44	
Treatment Year 1	28	365	745	2.04	
Treatment Year 2	16	153	372	2.43	
Prairie Group					
Phase Name	**Sediment Events Present (#/Phase)**	**Days in Each Phase (days)**	**Phase Precipitation (mm/phase)**	**Normalized Phase Precipitation (mm/month)**	
Pretreatment	33	608	1013	1.67	
Sprayed	28	334	745	2.23	
Treatment Year 1	16	153	372	2.43	

2.7 STATISTICAL ANALYSIS

At an alpha level of 10% (α=0.10), statistical comparisons of the 77 sediment events were conducted using Minitab Version 17™. Due to the multiple research questions of this study, Analysis of Covariance (ANCOVA) tests were designed using a combination of one-way and two-way statistical structure with slight variation in phase breakpoints. Kruskal Wallis test were applied when possible to identify differences or similarities between parametric and non-parametric analysis. Tukey's Multiple Comparison tests were applied to identify differences between group means in situations where ANCOVA variables were significant at an $\alpha=0.10$. Response variables consisted of sediment yield (g/m^2) and flow-weighted average concentration (ng/L), while treatment variables were watershed and phase. Table 7 gives an expanded explanation of the various phase breakpoints and watershed data incorporated within each research question of this study.

Table 7: Statistical outline of project research questions with expanded watershed and phase breakpoints. Watershed abbreviations are as follows: Juniper to Recovering Prairie (J-RP), Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG), and Prairie Control (P).

Research Questions	Statistical Test	Watersheds Included	Phase				
			Descriptor	Assigned Number	Time Span		
					Start	to	End
1	One-way ANCOVA	J-RP, J-SG, J1, J2, P-SG, & P	Pretreatment	0	10/1/2014	to	6/30/2015
2	Two-way ANCOVA	J-RP, J-SG, J1, J2, P-SG, & P	Pretreatment	0	10/1/2014	to	6/30/2015
			Post-Cut	1	7/1/2015	to	2/29/2016
3	Two-way ANCOVA	J-RP, J1, J2, & P	Pretreatment	0	10/1/2014	to	6/30/2015
			Post-Cut	1	7/1/2015	to	2/29/2016
			Transition	2	3/1/2016	to	4/30/2016
			Treatment	3	5/1/2016	to	9/30/2017
4	Two-way ANCOVA	J-SG, J1, J2, & P	Pretreatment	0	10/1/2014	to	6/30/2015
			Post-Cut	1	7/1/2015	to	2/29/2016
			Transition	2	3/1/2016	to	4/30/2017
			Treatment	3	5/1/2017	to	9/30/2017
5	Two-way ANCOVA	J-RP, J-SG, J1, J2, & P	Pretreatment	0	10/1/2014	to	6/30/2015
			Post-Cut	1	7/1/2015	to	2/29/2016
			Transition	2	3/1/2016	to	4/30/2016
			Treatment	3	5/1/2016	to	4/30/2017
6	Two-way ANCOVA	J-RP, J-SG, J1, J2, P-SG, & P	Pretreatment	0	10/1/2014	to	6/30/2015
			Treatment	3	5/1/2017	to	9/30/2017

In order to maintain the underlying normal distribution and equal variance assumptions of an ANCOVA, sediment yield and flow-weighted average concentration data were transformed.

Several transformations, such as the square root (SQRT), log base ten (Log_{10}), natural logarithm, and power raise of 0.09, were employed with various covariates (i.e. total rainfall (mm), rainfall duration (min), average rainfall intensity (mm/hr), and percent time to peak five minute intensity (%) to identify the ideal transformation and covariate combination. When applying transformations that mathematically do not allow for zero values, such as the Log_{10} transformation, units were altered to larger values using unit conversions, e.g. mg changed to ng, and an arbitrary value of one was added before all these data were transformed. In the end, the total rainfall (mm) covariate in conjunction with two separate response variable transformations were used to maintain the normal distribution and equal variance assumptions of an ANCOVA. The square root transformation was employed for sediment yield data (now referred to as SQRT(SY)), while a Log_{10} transformation was utilized for flow-weighted average concentration data (now referred to as Log_{10}(FWAC)).

CHAPTER III

RESULTS AND DISCUSSION

3.1 PHASE RUNOFF AND SEDIMENT TOTALS

Within the Pretreatment phase, watersheds J-RP, J-SG, and J2 all generated runoff greater than ten mm and yielded sediment less than ten g/m^2 except for J2, which had slightly higher sediment yield (Figure 6). These observations were expected as all three watersheds shared similar watershed conditions at the start of the project with slight variations in watershed slope, soil texture, and percent surface cover that likely contributed to the observed variation in runoff and sediment yield. Watershed J1, on the other hand, had a two and one order of magnitude difference of runoff and sediment yield compared to the other three eastern redcedar watersheds within the Pretreatment phase (Figure 6). Runoff and sediment differences of J1 were hypothesized to be due to J1's larger percent coverage of eastern redcedar vegetation compared to J2 and due to J1 lack of cultivation compared to the other eastern redcedar watersheds. A more in-depth comparison of the two control watersheds is recommended in order to determine the exact watershed characteristics that resulted in observed differences of runoff and sediment between the controls across the five phases. Furthermore, due to the increased the difficulty to draw inferences across the four watersheds as the two control watersheds vegetative cover varied, runoff and sediment yield comparisons were primarily compared to the J2 as this control watershed had closer vegetation coverage to that of the two treatment watersheds before the eastern redcedar was cut.

Within the Post-Cut phase, J-RP and J-SG had eastern redcedar vegetation mechanically severed at the soil surface and left to dry on the watershed. This change of watershed vegetation resulted in increased surface flow and sediment yields compared to control watershed J2 and predecessor observations (Figure 6). In other words, the removal of woody biomass from the watershed reduced eastern redcedar's influence on antecedent moisture conditions, which in turn increased the potential of less-intense precipitation events to produce runoff. This increase in runoff also increased sediment transport and more sediment was observed at the end of Post-Cut phase. Similarly, the Post-Grind phase also experienced greater than ten mm of runoff similar to the Post-Cut phase, but its runoff occurred in greater magnitude as the Post-Grind phase only consisted of only two months while the Post-Cut phase consisted of seven months.

Within Treatment Year 1, there was an order of magnitude difference within runoff associated with watersheds J-RP and J-SG compared to control watershed J2. This difference in runoff was hypothesized to be caused by the removal of eastern redcedar vegetation and the subsequent prevention of soil moisture depletion by the woody species, as discussed in Acharya et al. (2017) and Qiao et al. (2017). Moreover, the increase in runoff explained the increase in sediment yield of J-SG and J-RP compared to J2. Differences in sediment yields between J-SG and J-RP were hypothesized to be influenced by the rapid re-establishment of herbaceous vegetation in J-RP in comparison to J-SG, where the cultivation of switchgrass was delayed. This lack of vegetation cover resulted in higher runoff concentrations and greater sediment losses within J-SG. Note that runoff and sediment yield of J-RP and J-SG were reduced during Treatment Year 2 as compared to their predecessor totals in Treatment Year 1 (Figure 6). The decrease in runoff was hypothesized to be caused by the incremental influences of revegetation on antecedent soil moisture, while the subsequent decrease in sediment yield was hypothesized to be due to active vegetation armoring of the soil surface.

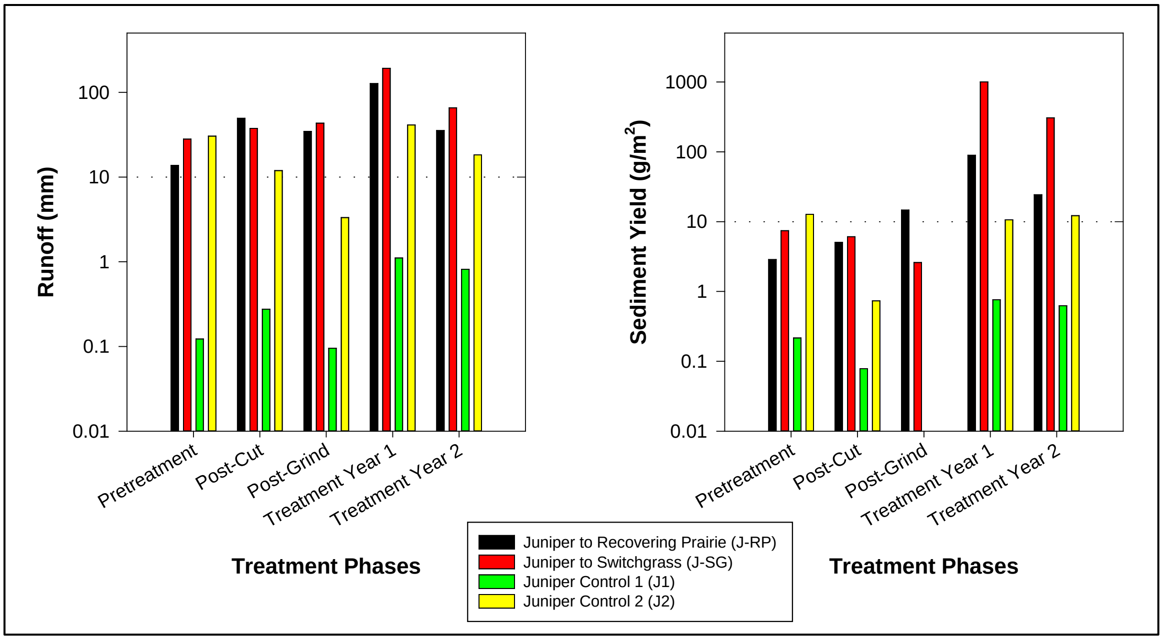


Figure 6: Cumulative Log_{10} transformed runoff (left) and sediment yield (right) comparisons of eastern redcedar group watersheds across five individual phases. The Pretreatment phase spanned 10/1/2014 to 6/30/2015, the Post-Cut phase spanned 7/1/2015 to 2/29/2016, the Post-Grind phase spanned 3/1/2016 to 4/30/2016, the Treatment Year 1 phase spanned 5/1/2016 to 4/30/2017, and the Treatment Year 2 phase spanned 5/1/2017 to 9/30/2017.

Within Pretreatment conditions of the prairie group, watershed P-SG began with greater runoff, but less sediment yield than control watershed P (Figure 7). However, as a result of P-SG being sprayed with herbicide in preparation for switchgrass seeding, the subsequent death of herbaceous vegetation was likely to have increased P-SG sediment yield and caused it to overcome the sediment yield of P during Sprayed conditions. In other words, the death of watershed flora resulted in the increase of the soil antecedent moisture within the watershed. Thus, when precipitation events occurred, soil saturation was achieved faster and increased surface flow contributed to increased sediment transport and sediment erosion within watershed P-SG.

When interpreting the differences between runoff and sediment yield across the three phases, it is important to note that Treatment Year 1 did not possess a comparable time span of data like the other two phases. This makes numerical interpretations of phase differences difficult due to the natural variability of climate. However, the relative difference between both watershed runoff and sediment yields during each specific phase was an acceptable indicator of vegetation influences. In other words, within each phase, both watersheds experienced similar climate due to their proximity to each other. Similar climate conditions mean that observed differences in sediment during each phase were a function of soil texture, slope, and vegetation influences. Watershed soil texture and slope varied slightly across the watersheds (Table 1 and Table 2), which means that the observed differences in sediment across the three phases were mostly due to vegetation alterations. This makes sense as the application of herbicide to P-SG resulted in the death of herbaceous vegetation, which contributed to an increased difference between P and P-SG during the Sprayed phase compare to their difference during the Pretreatment phase. More treatment effect data needs to be processed, analyzed, and interpreted in order to overcome the presumed influences of cultivation disturbance during the treatment phase (i.e. current treatment data may not be reflective of mature switchgrass vegetation).

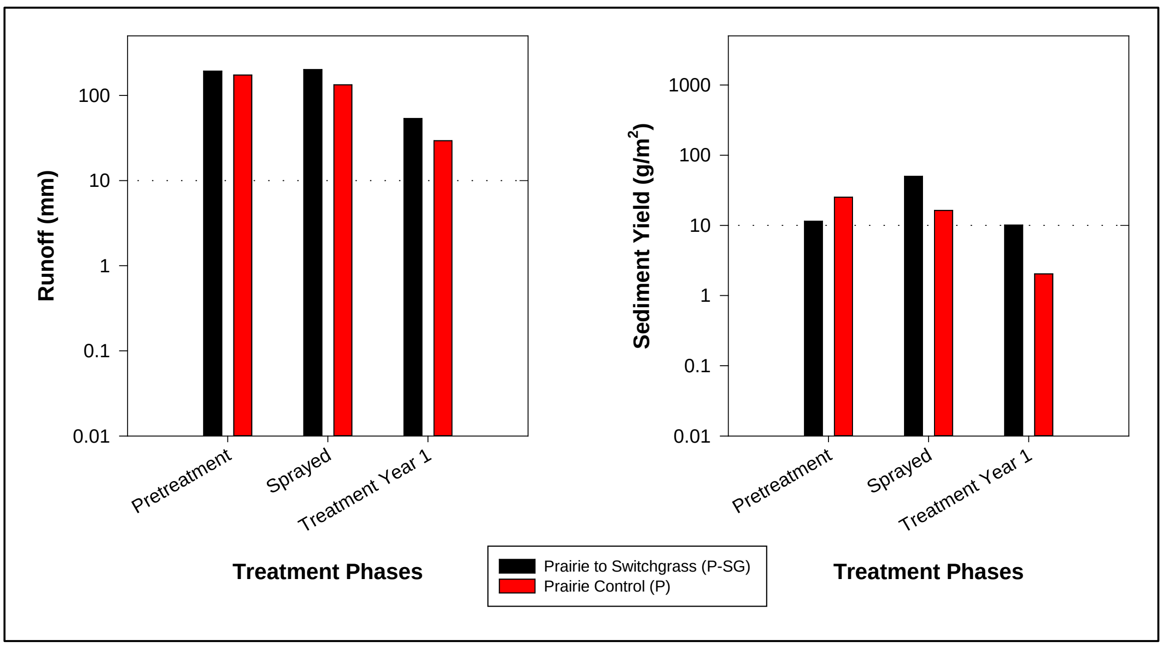


Figure 7: Cumulative Log_{10} transformed runoff (left) and sediment yield (right) comparisons of grassland group watersheds across three individual phases. The Pretreatment phase spanned 10/1/2014 to 5/31/2016, the Sprayed phase spanned 6/1/2016 to 4/30/2017, and the Treatment Year 1 phase spanned 5/1/2017 to 9/30/2017.

3.2 EASTERN REDCEDAR VS. GRASSLAND SEDIMENT YIELDS

According to a one-way ANCOVA comparison of the SQRT(SY) for all six watersheds during Pretreatment vegetation conditions, sediment means were statistically different at an α=0.10. However, results of a Tukey's Multiple Comparison showed all watersheds had statistically similar means at an α=0.10. A Kruskal Wallis comparison also suggested sediment medians statistically similar at an α=0.10. Therefore, it was concluded that the eastern redcedar and grassland watersheds produce statistically similar sediment yields. Table 8 shows the ANCOVA, Tukey's Multiple Comparison, and Kruskal Wallis results of this analysis.

Table 8: Results of one-way Analysis of Covariance (ANCOVA), Tukey's Multiple Comparison, and Kruskal Wallis comparison of the Watershed treatment variable on square root transformed sediment yields for six watersheds during Pretreatment phase.

	Variable		P-value
One-way ANCOVA	Response:	Sediment Yield, SQRT(g/m^2)	n/a
	Treatment:	Watershed	0.095
	Covariate:	Total Rainfall, (mm)	< 0.001
Kruskal Wallis	**Variable**		**P-value**
	Response:	Sediment Yield, SQRT(g/m^2)	n/a
	Treatment:	Watershed	0.125

	Watershed	Sediment Mean SQRT(g/m^2)	Sediment Mean g/m^2	Grouping
Tukey's Multiple Comparisons	Juniper Control 2 (J2)	0.426	0.181	A
	Prairie to Switchgrass (P-SG)	0.419	0.176	A
	Juniper to Switchgrass (J-SG)	0.338	0.114	A
	Prairie Control (P)	0.332	0.110	A
	Juniper to Recovering Prairie (J-RP)	0.161	0.026	A
	Juniper Control 1 (J1)	0.013	0.000	A

Figure 8 shows the four-in-one plot of the SQRT(SY) one-way ANCOVA and highlights two important items. First, while the normal distribution was sufficient, the normal distribution was not ideal and this ANCOVA had less power to determine differences between means. More data points are recommended to improve the normal distribution of the dataset. Second, the decreasing "linear" line of residual points within the Versus Fit plot (top right) correspond to zeros within these data. Every ANCOVA four-in-one plot hereafter shared this occurrence as sediment production varied between watersheds and events.

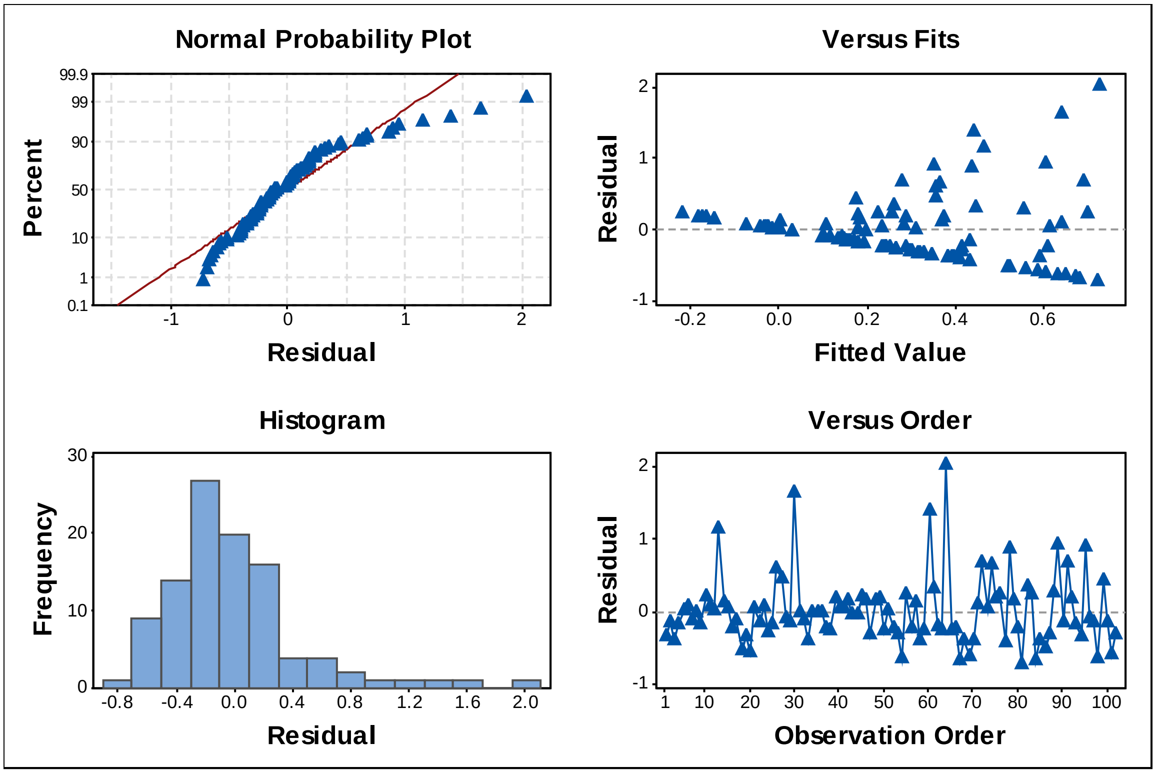


Figure 8: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for one-way Analysis of Covariance of the square root transformed sediment yields for six watersheds during Pretreatment phase.

A one-way ANCOVA comparison of Log_{10}(FWAC) for all six watersheds during Pretreatment conditions, on the other hand, showed sediment concentration means to be statistically similar at an α=0.10. A Kruskal Wallis comparison of Log_{10}(FWAC) also found the watershed medians to be statistically similar at an α=0.10. Table 9 shows the ANCOVA, Tukey's Multiple Comparison, and Kruskal Wallis results. Also, it is important to note that while the ANCOVA was not statistically significant, a Tukey's Multiple Comparison was run in order to obtain the mean hierarchy for the Log_{10}(FWAC) dataset. Interpreting the SQRT(SY) and Log_{10}(FWAC) sediment mean hierarchy of the Tukey's Multiple Comparisons, there was no specific watershed that produced consistently higher sediment means than other watersheds. This further supported the claim that both vegetation types produce similar sediment yields.

Table 9: Results of one-way Analysis of Covariance (ANCOVA), Tukey's Multiple Comparison, and Kruskal Wallis comparison of Watershed treatment variable on Log_{10} transformed flow-weighted average concentrations for six watersheds during Pretreatment phase.

<table>
<tr><td rowspan="4">One-way ANCOVA</td><td colspan="3">Variable</td><td colspan="2">P-value</td></tr>
<tr><td>Response:</td><td colspan="2">Flow-Weighted Avg. Conc., Log_{10}(ng/L)</td><td colspan="2">n/a</td></tr>
<tr><td>Treatment:</td><td colspan="2">Watershed</td><td colspan="2">0.301</td></tr>
<tr><td>Covariate:</td><td colspan="2">Total Rainfall, (mm)</td><td colspan="2">$<$ 0.001</td></tr>
<tr><td rowspan="3">Kruskal Wallis</td><td colspan="3">Variable</td><td colspan="2">P-value</td></tr>
<tr><td>Response:</td><td colspan="2">Flow-Weighted Avg. Conc., Log_{10}(ng/L)</td><td colspan="2">n/a</td></tr>
<tr><td>Treatment:</td><td colspan="2">Watershed</td><td colspan="2">0.474</td></tr>
<tr><td rowspan="8">Tukey's Multiple Comparisons</td><td colspan="2" rowspan="2">Watershed</td><td colspan="2">Concentration Mean</td><td rowspan="2">Grouping</td></tr>
<tr><td>Log_{10}(ng/L)</td><td>mg/L</td></tr>
<tr><td colspan="2">Juniper to Switchgrass (J-SG)</td><td>1.577</td><td>0.037</td><td>A</td></tr>
<tr><td colspan="2">Juniper Control 2 (J2)</td><td>1.285</td><td>0.018</td><td>A</td></tr>
<tr><td colspan="2">Juniper to Recovering Prairie (J-RP)</td><td>1.164</td><td>0.014</td><td>A</td></tr>
<tr><td colspan="2">Prairie to Switchgrass (P-SG)</td><td>0.766</td><td>0.005</td><td>A</td></tr>
<tr><td colspan="2">Prairie Control (P)</td><td>0.630</td><td>0.003</td><td>A</td></tr>
<tr><td colspan="2">Juniper Control 1 (J1)</td><td>0.586</td><td>0.003</td><td>A</td></tr>
</table>

Figure 9 shows the Log_{10}(FWAC) one-way ANCOVA model's normal distribution, histogram, and residual values. Moreover, Figure 9 agreed with the interpretations of the SQRT(SY) one-way ANCOVA mentioned earlier in this section.

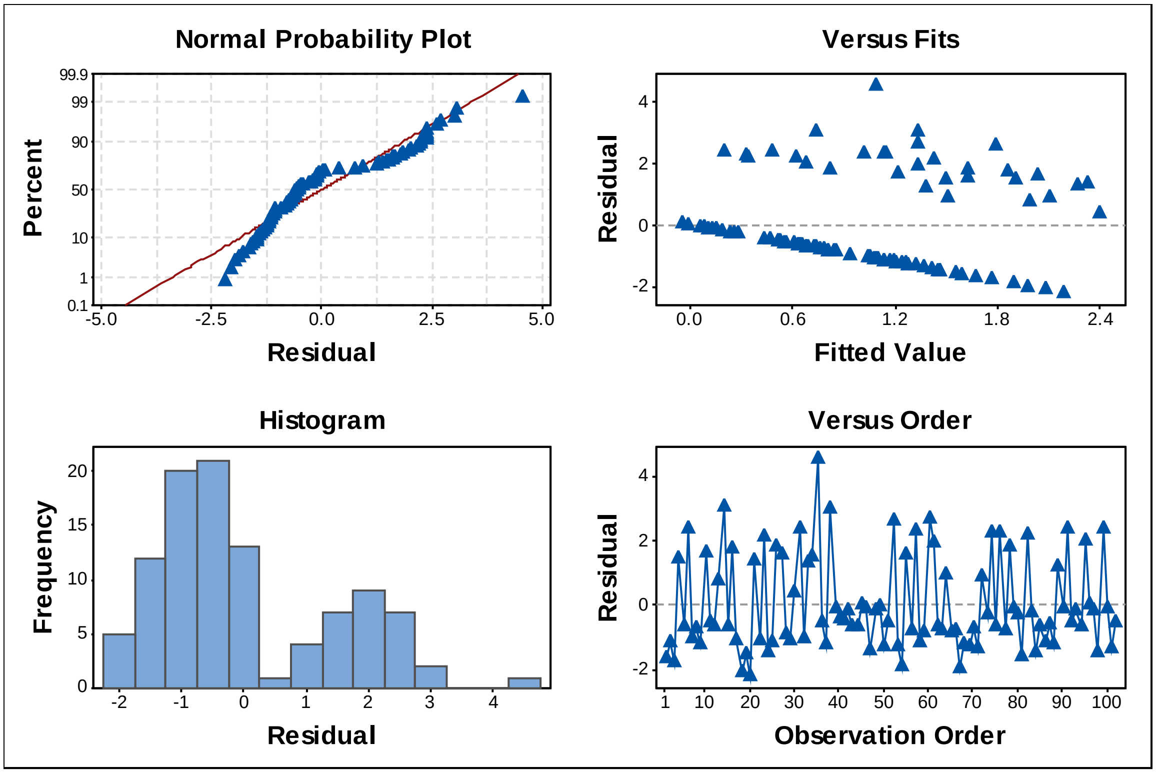


Figure 9: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for one-way Analysis of Covariance of the Log_{10} transformed flow-weighted average concentrations of six watersheds during Pretreatment phase.

The results of these statistical tests (both parametric and non-parametric) suggest no statistical differences between sediment yields and flow weighted average sediment concentrations of encroached eastern redcedar and grassland watersheds. This observation was also suggested by Figure 6 and Figure 7 as almost all watersheds generated sediment yields between one g/m^2 and ten g/m^2 during the Pretreatment phase. Furthermore, previous studies suggest that while herbaceous grasses produce greater surface flow than eastern redcedar watersheds, eastern redcedar altered surface flow paths and influenced more water to move into the soil profile while also reducing herbaceous vegetation beneath the crown, creating a more vulnerable surface for concentrated flow to transport sediment (Acharya et al., 2017; Limb et al., 2010; Qiao et al., 2017; Wayne & Van Auken, 2008). These less frequent, but more intense sediment producing events of eastern redcedar watersheds resulted in sediment yields that approached statistically similar yields of sediment to that of grasslands that have more consistent surface flow, but smaller sediment concentrations. Ultimately, these differences in soil erosion created two unique systems that produced similar amounts of sediment, answering the question regarding the differences in sediment yield between eastern redcedar and grassland watersheds. A greater sample size is recommended in order to better detect sediment differences between these two vegetation types (i.e. should differences exist) or to improve the normal distribution of the ANCOVAs, increasing the power of the ANCOVA to detect differences. Additionally, greater consideration of watershed erosion mechanics should be considered to better distinguish similarities or differences between these two vegetation types.

3.3 IMPACTS OF EASTERN REDCEDAR REMOVAL

A two-way ANCOVA comparison of SQRT(SY) for all six watersheds during two phases (i.e. Pretreatment and Post-Cut) found the Watershed variable was statistically significant at an $\alpha=0.10$, but the Phase variable was not. The Phase variable's greater p-valued suggests that Phase differences between Post-Cut and Pretreatment conditions did not have a significant effect on the sediment means. In response, a one-way ANCOVA was conducted to determine the significance of the Watershed variable alone. The Watershed variable was statistically significant at an $\alpha=0.10$. A Tukey's Multiple Comparison of the Watershed variable revealed that only watersheds J-SG and J1 had statistically different means and that both watersheds were statistically similar to all the rest. A Kruskal Wallis Multiple Comparison of sediment medians also showed the watershed variable to be statistically significant at an $\alpha=0.10$ and that watersheds J-SG, P-SG, and J-RP were all statistically different than J1. These results, however, should be taken with reservation as the J1 watershed had consistently fewer sampling data points compared to the other watersheds and may not be a true mean of the watershed. More J1 data points are recommended to increase the confidence and statistical validity of the ANCOVA and Kruskal Wallis results and to re-evaluate the effects of the Phase variable on sediment means. Table 10 outlines the results of the two ANCOVAs, the Tukey's Multiple Comparison, and Kruskal Wallis Multiple Comparison.

Table 10: Results of two-way Analysis of Covariance (ANCOVA), one-way ANCOVA, Tukey's Multiple Comparison, and Kruskal Wallis Multiple Comparison of Watershed and Phase treatment variables on square root transformed sediment yields for six watersheds during Pretreatment and Post-Cut phases.

Two-way ANCOVA	**Variable**			**P-value**
	Response:	Sediment Yield, SQRT(g/m^2)		n/a
	Treatment:	Watershed		0.047
	Treatment:	Phase		0.826
	Covariate:	Total Rainfall, (mm)		< 0.001
One-way ANCOVA	**Variable**			**P-value**
	Response:	Sediment Yield, SQRT(g/m^2)		n/a
	Treatment:	Watershed		0.045
	Covariate:	Total Rainfall, (mm)		< 0.001
Kruskal Wallis	**Variable**			**P-value**
	Response:	Sediment Yield, SQRT(g/m^2)		n/a
	Treatment:	Watershed		0.125

Tukey's Multiple Comparisons	**Watershed**	**Sediment Mean SQRT(g/m^2)**	**Sediment Mean g/m^2**	**Grouping**
	Juniper to Switchgrass (J-SG)	0.431	0.186	A
	Prairie Control (P)	0.375	0.141	A B
	Prairie to Switchgrass (P-SG)	0.341	0.116	A B
	Juniper Control 2 (J2)	0.316	0.100	A B
	Juniper to Recovering Prairie (J-RP)	0.308	0.095	A B
	Juniper Control 1 (J1)	0.039	0.002	B

Figure 10 shows the four-in-one plot of the one-way ANCOVA mentioned above. Again, the normal distribution was not ideal and ANCOVA had similar limitations as mentioned in section 3.2.2. ANCOVA normal distribution improved with the addition of Post-Cut phase data points.

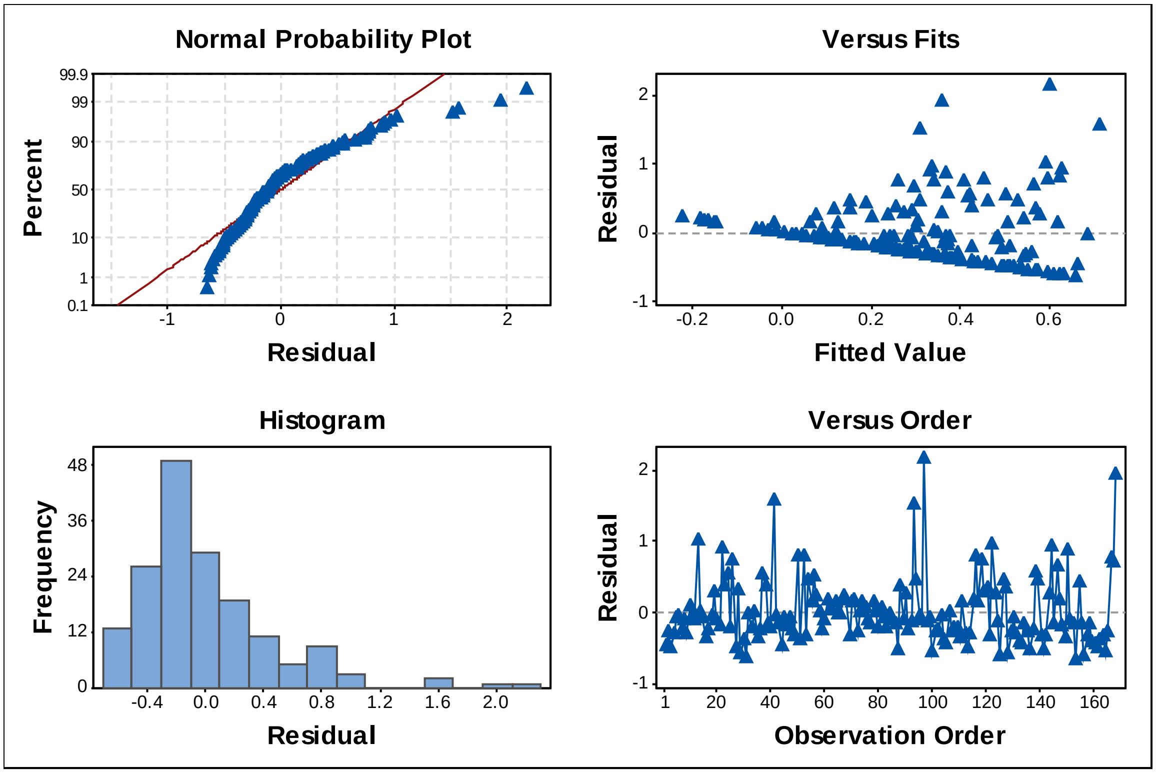


Figure 10: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for one-way Analysis of Covariance of the square root transformed sediment yields of six watersheds during Pretreatment and Post-Cut phases.

A two-way ANCOVA comparison of Log_{10}(FWAC) for all six watersheds during Pretreatment and Post-Cut phases showed that both the treatment variables were significant at an α=0.10. A Tukey's Multiple Comparisons of the Watershed variable revealed similar results as the SQRT(SY) counterpart, with watershed J-SG and J1 statistically different, but similar to the remaining watersheds. A Tukey's Multiple Comparison of the Phase variable showed Post-Cut as having a larger mean than Pretreatment. A Kruskal Wallis of the Phase variable suggested it to be statistically insignificant at an α=0.10, while a Kruskal Wallis comparison of the Watershed variable found two watershed groups to be statistically different (results not shown). Here, treatment watershed J-SG was statistically different than control watershed J1 and also treatment watershed J-RP was statistically different than control watershed P; both at an α=0.10. These results show similarities between the dataset, but again, must be taken with reservation as more data points are required in order to increase the statistical validity of these results. Table 11 shows the two-way ANCOVA, Tukey's Multiple Comparison, and Kruskal Wallis results of the Watershed and Phase variables. Figure 11 shows the ANCOVA model's normal distribution, histogram, and residual values, and has similar interpretations as those mentioned previously in the SQRT(SY) ANCOVA four-in-one plot.

Table 11: Results of two-way Analysis of Covariance, Tukey's Multiple Comparison, and Kruskal Wallis Multiple Comparison of Watershed and Phase variables on Log_{10} transformed flow-weighted average concentrations for six watersheds during Pretreatment and Post-Cut phases.

<table>
<tr><td rowspan="5">Two-way ANCOVA</td><td colspan="3">Variable</td><td>P-value</td></tr>
<tr><td colspan="3">Response: Flow-Weighted Avg. Conc., Log_{10}(ng/L)</td><td>n/a</td></tr>
<tr><td colspan="3">Treatment: Watershed</td><td>0.065</td></tr>
<tr><td colspan="3">Treatment: Phase</td><td>0.012</td></tr>
<tr><td colspan="3">Covariate: Total Rainfall, (mm)</td><td>0.005</td></tr>
<tr><td rowspan="3">Kruskal Wallis</td><td colspan="3">Variable</td><td>P-value</td></tr>
<tr><td colspan="3">Response: Flow-Weighted Avg. Conc., Log_{10}(ng/L)</td><td>n/a</td></tr>
<tr><td colspan="3">Treatment: Watershed</td><td>0.062</td></tr>
<tr><td rowspan="8">Tukey's Multiple Comparisons</td><td rowspan="2">Watershed</td><td colspan="2">Concentration Mean</td><td rowspan="2">Grouping</td></tr>
<tr><td>Log_{10}(ng/L)</td><td>mg/L</td></tr>
<tr><td>Juniper to Switchgrass (J-SG)</td><td>2.180</td><td>0.150</td><td>A</td></tr>
<tr><td>Juniper to Recovering Prairie (J-RP)</td><td>1.972</td><td>0.093</td><td>A B</td></tr>
<tr><td>Prairie to Switchgrass (P-SG)</td><td>1.478</td><td>0.029</td><td>A B</td></tr>
<tr><td>Juniper Control 2 (J2)</td><td>1.403</td><td>0.024</td><td>A B</td></tr>
<tr><td>Prairie Control (P)</td><td>1.243</td><td>0.016</td><td>A B</td></tr>
<tr><td>Juniper Control 1 (J1)</td><td>0.950</td><td>0.008</td><td>B</td></tr>
</table>

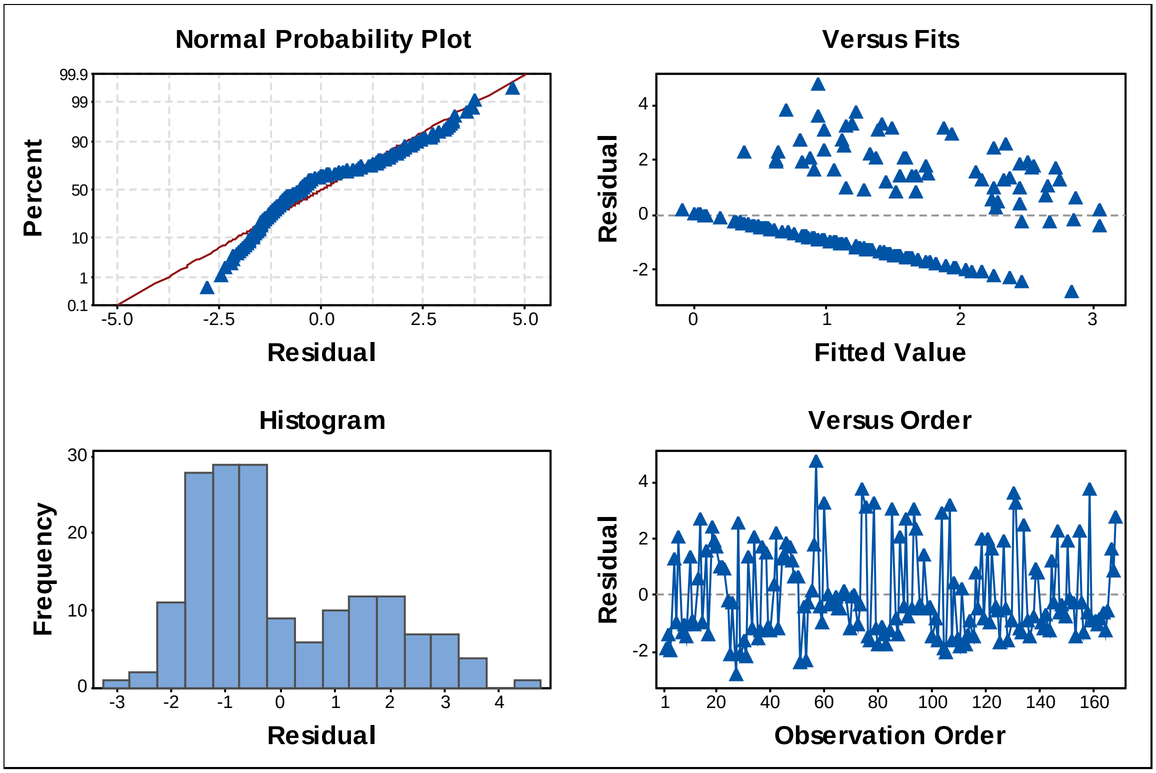


Figure 11: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for two-way Analysis of Covariance of the Log_{10} transformed flow-weighted average concentrations of six watersheds during Pretreatment and Post-Cut phases.

While the results of both response variables point towards statistical differences between watersheds J-SG and J1, the following limitations of the dataset add uncertainty to the statistical validity of the results. First, the dataset used in the ANCOVAs was small considering the fact that of the 28 sediment events, not all watersheds experienced sediment yield during each event. It is hypothesized that the numerous zeros of J1 skewed the mean smaller, and while the presence of zero sediment yields is not uncommon, the overabundance of zeros within J1's dataset resulted in statistical interpretations that did not account for the true sediment mean of J1. A second statistical limitation of these analyses was the seasonal influences of precipitation on the Post-Cut phase. While the Post-Cut and Post-Grind phases of this study were specifically designed to occur during periods of lower precipitation in order to reduce sediment losses, the lack of sediment data for autumn and winter events reduced the mean of J1 further. A greater Post-Cut phase timeline is recommended for superior statistical comparisons between intact eastern redcedar vegetation and mechanically harvest eastern redcedar. However, due to the fact that mechanically severed eastern redcedar distributed across a watershed does not have a large economic incentive for stakeholders compared to the other research questions of this study, it is likely that the results will suffice.

3.4 IMPACTS OF EASTERN REDCEDAR TRANSITIONED TO GRASSLANDS

A SQRT(SY) two-way ANCOVA of treatment watershed J-RP versus control watersheds J1, J2, and P across all phases suggested that both the Watersheds and Phase variable were statistically significant at an α=0.10. Additionally, the interaction variable, i.e. Watershed*Phase, was statistically significant at an α=0.10, which identified the need to analyze the individual watershed sediment means across each phase. A Tukey's Multiple Comparison of the Watershed variable revealed that both J-RP and P had statistically different means than that of J1 and J2, with a difference of nearly threefold SQRT(means). The Tukey's Multiple Comparison of the Phase variable, on the other hand, identified the Transition and Treatment phases (i.e. Phase 2 and 3) as the two highest SQRT(means) of the dataset. This was expected as the physical disturbance of vegetation removal reduced surface cover and disrupted the soil profile. Table 12 shows the two-way ANCOVA and the Tukey's Multiple Comparison of the watershed and phase variables.

Table 12: Results of two-way Analysis of Covariance and Tukey's Multiple Comparison of Watershed and Phase treatment variables on square root transformed sediment yields of four watersheds across Pretreatment, Post-Cut, Transition, and Treatment phases.

	Variable			P-value
Two-way ANCOVA	Response:	Sediment Yield, SQRT(g/m^2)		n/a
	Treatment:	Watershed		< 0.001
	Treatment:	Phase		0.009
	Interaction:	Watershed*Phase		0.002
	Covariate:	Total Rainfall, (mm)		< 0.001

	Watershed	**Sediment Mean**		**Grouping**
		SQRT(g/m^2)	**g/m^2**	
Tukey's Multiple Comparisons	Juniper to Recovering Prairie (J-RP)	0.665	0.442	A
	Prairie Control (P)	0.504	0.254	A
	Juniper Control 2 (J2)	0.170	0.029	B
	Juniper Control 1 (J1)	-0.008	0.000	B

	Phase	**Sediment Mean**		**Grouping**
		SQRT(g/m^2)	**g/m^2**	
Tukey's Multiple Comparisons	Transition (Phase 2)	0.596	0.355	A
	Treatment (Phase 3)	0.382	0.146	A B
	Pretreatment (Phase 0)	0.231	0.053	B C
	Post-Cut (Phase 1)	0.121	0.015	C

The Tukey's Multiple Comparison of the Interaction variable (Table 13) highlighted three important observations. First, the Transition phase 2 contained two of the highest watershed SQRT(means) of the four phases. Watershed J-RP's largest mean was likely due to reduced surface protection and disturbed soil profile influences, while watershed P's second highest mean was likely due to increased soil moisture as antecedent soil moisture has been shown to influence initial and overall soil detachment (Poesen et al., 1999). Second, there was a subsequent reduction in SQRT(means) between the Transition phase 2 and Treatment phase 3 of watershed J-RP. This change was hypothesized to be caused by both the incremental influence of vegetation on soil moisture as more biomass colonized the watershed and soil armoring as biomass provided increased protection to erosion. Lastly, Post-Cut phase 1 had the lowest SQRT(means) of all the watersheds. This was attributed to both the seasonal variability and smaller time span of this phase and the soil protection benefits of the woody biomass that remained on the soil surface.

Table 13: Results of Tukey's Multiple Comparison of Interaction variable on square root transformed sediment yields for watersheds Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) across Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3) vegetative conditions.

Tukey's Multiple Comparison of Interaction Variable Group Means						
Watersheds*Phase				**Sediment Mean**		**Grouping**
Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**SQRT(g/m2)**	**g/m2**	
		J-RP		1.343	1.804	A
		P		1.134	1.286	A B C
			J-RP	0.800	0.640	A C
J2				0.419	0.176	A B C D
	J-RP			0.365	0.133	A B C D
			J2	0.330	0.109	B D
P				0.324	0.105	B C D
			P	0.286	0.082	B D
	P			0.271	0.073	B C D
J-RP				0.153	0.023	B D
			J1	0.113	0.013	D
J1				0.029	0.001	D
	J2			-0.024	0.001	D
		J2		-0.047	0.002	B C D
		J1		-0.047	0.002	B C D
	J1			-0.127	0.016	D

Figure 12 shows the four-in-one plot of the two-way ANCOVA mentioned above and its normal distribution improved further as more data points were included within the ANCOVA. Also, the one isolated residual within the Versus Fit plot (top right) corresponded to a massive sediment event that occurred on 4/28/2017 that could potentially be seen as an outlier.

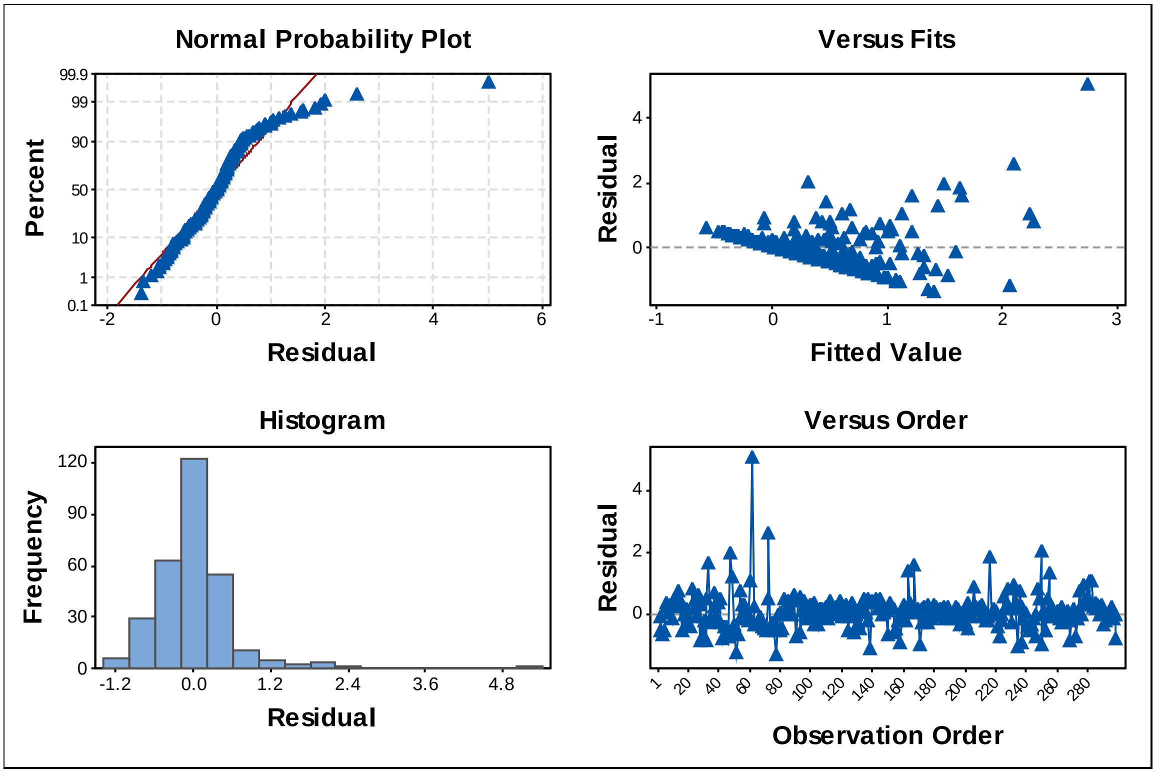


Figure 12: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for two-way Analysis of Covariance of the square root transformed sediment yields of four watersheds across Treatment, Transition, Post-Cut, and Pretreatment phases.

Comparable results are also shown by Main Effects analysis of these data. The lines between the four phases and the four watersheds were not parallel, signifying there were main effects present. Transition phases 2 and Treatment phase 3, as well as watersheds J-RP and P were above the overall SQRT(mean) of the dataset (i.e. dashed line in Figure 13) and produced greater SQRT(means) than the other two phases and watersheds. Furthermore, the greatest magnitude of main effect occurred between watershed J-RP and J1 and between phases 1 and 2, as shown by their steep slopes. These differences in main effect magnitude were hypothesized to be caused by the disturbance of watershed J-RP and J1's limited sampling numbers; however the compounded interaction between the Phase and Watershed was not shown within Figure 13. Figure 14 shows the interaction between the Phase and Watershed variable plotted in both possible scenarios. Within the Watershed*Phase plot of the Interaction variable (bottom left), Transition phase 2 had the greatest SQRT(means) within the J-RP watershed, the second highest SQRT(means) within the P watershed, and the slope of Transition phase 2 between the J-RP and J1 resulted in the greatest magnitude interaction. This is also shown by the Main Effects plot (i.e Figure 13) of the Phase variable where Transition phase 2 had the highest SQRT(means). Similar results were observed within the Phase*Watershed plot of Figure 14, were watersheds J-RP and P had the two highest SQRT(means) of Transition phase 2 and the greatest difference in slope occurred between watersheds J-RP and J1, which was linked to the greatest magnitude difference between two points of the watershed plot of the main effects graph.

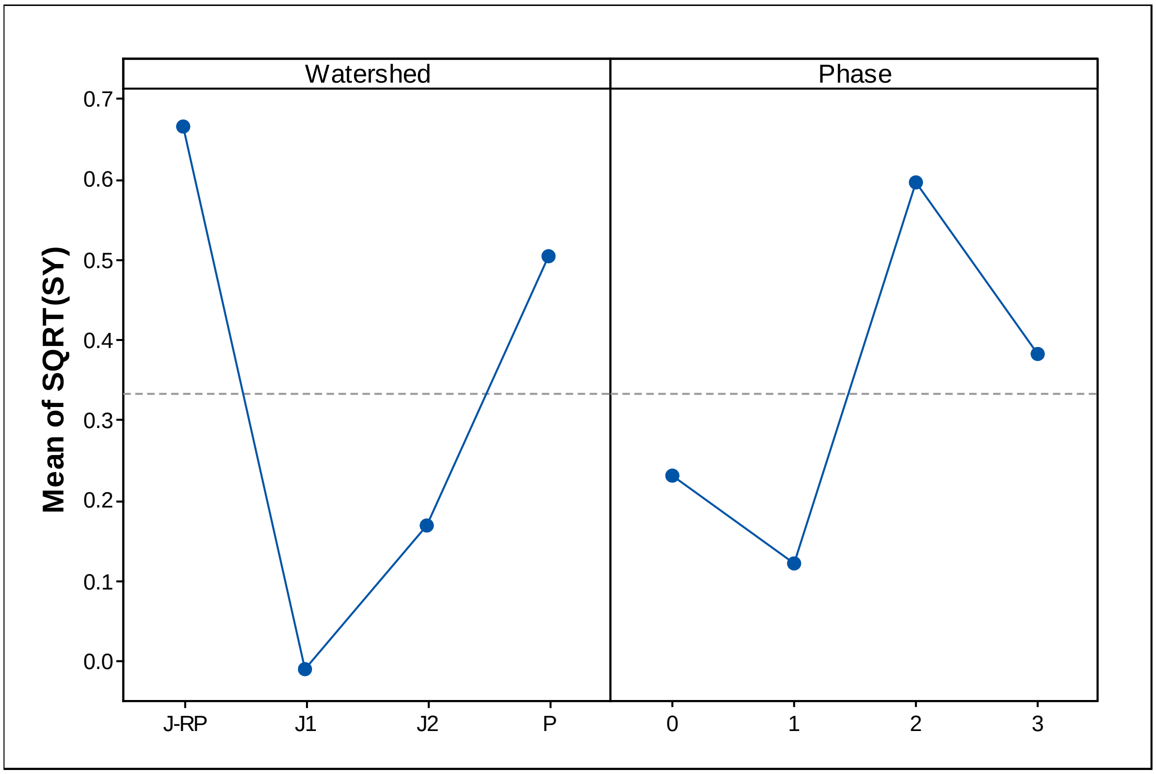


Figure 13: Main Effects plot of two-way Analysis of Covariance of the square root transformed sediment yields (SQRT(SY)) for watersheds Juniper Converted to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) across Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3) vegetative conditions. The units of SQRT(SY) are SQRT(g/m^2).

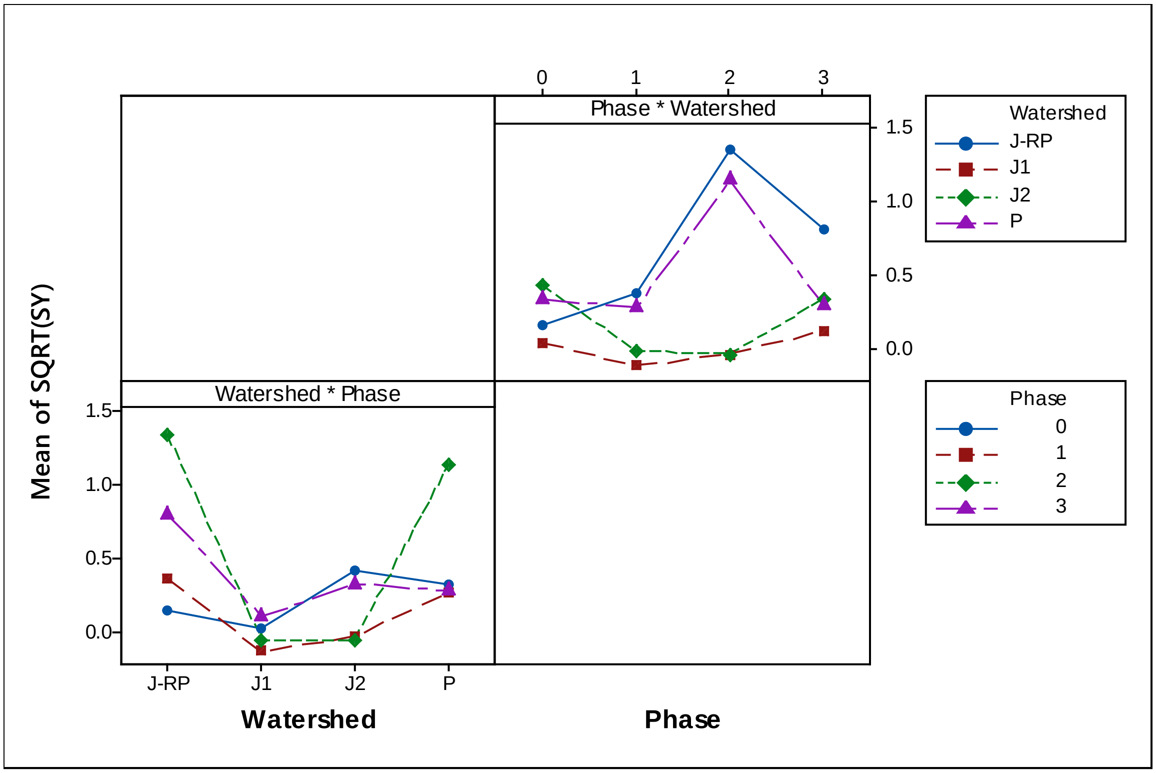


Figure 14: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of square root transformed sediment yields (SQRT(SY)). Watershed variable consisted of Juniper Converted to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3). Units of SQRT(SY) are SQRT(g/m^2).

Following a similar two-way ANCOVA setup except for a change in response variable from SQRT(SY) to Log_{10}(FWAC), ANCOVA results of the Log_{10}(FWAC) dataset revealed that only the Watershed variable was significant at an α=0.10, while the Interaction variable and the Phase variables were not. A two-way ANCOVA without the Interaction variable was then employed, but the Phase variable was still insignificant. Ultimately, a one-way ANCOVA analysis of these data showed the Watershed variable to be statistically significant at an α=0.10 and that the four watersheds had statistically different sediment means. A Tukey's Multiple Comparison of these data also suggested the treatment watershed J-RP to have a statistically different Log_{10}(mean) than the three control watersheds, with a magnitude difference of 150% greater than the second largest Log_{10}(mean) watershed, J2. Table 14 shows the results of the multiple two-way ANCOVA, one-way ANOVA, and Tukey Comparison results of the Log_{10}(FWAC) response variable.

Table 14: Results of two-way Analysis of Covariance (ANCOVA), one-way ANCOVA, Tukey's Multiple Comparison, and Kruskal Wallis Multiple Comparison of Watershed and Phase treatment variables on Log_{10} transformed flow-weighted average concentrations for four watersheds during Pretreatment, Post-Cut, Transition, and Treatment phases.

		Variable		P-value
Two-way ANCOVA	Response:	Flow-Weighted Avg. Conc., Log_{10}(ng/L)		n/a
	Treatment:	Watershed		< 0.001
	Treatment:	Phase		0.221
	Covariate:	Total Rainfall, (mm)		< 0.001
		Variable		**P-value**
One-way ANCOVA	Response:	Flow-Weighted Avg. Conc., Log_{10}(ng/L)		n/a
	Treatment:	Watershed		< 0.001
	Covariate:	Total Rainfall, (mm)		< 0.001
		Variable		**P-value**
Kruskal Wallis	Response:	Flow-Weighted Avg. Conc., Log_{10}(ng/L)		n/a
	Treatment:	Watershed		< 0.001

	Watershed	Concentration Mean		Grouping
		Log_{10}(ng/L)	**mg/L**	
Tukey's Multiple Comparisons	Juniper to Recovering Prairie (J-RP)	2.032	0.107	A
	Juniper Control 2 (J2)	1.288	0.018	B
	Juniper Control 1 (J1)	0.894	0.007	B
	Prairie Control (P)	0.858	0.006	B

Figure 15 shows the one-way ANCOVA model's normal distribution, histogram, and residual values. The normal distribution was worse than the SQRT(SY) four-in-one plot and this was hypothesized to be caused by greater noise present within these data. However, due to the natural noise of environmental data, there was not a "one transformation fits all" solution to these data and this ANCOVA's had less power to detect differences.

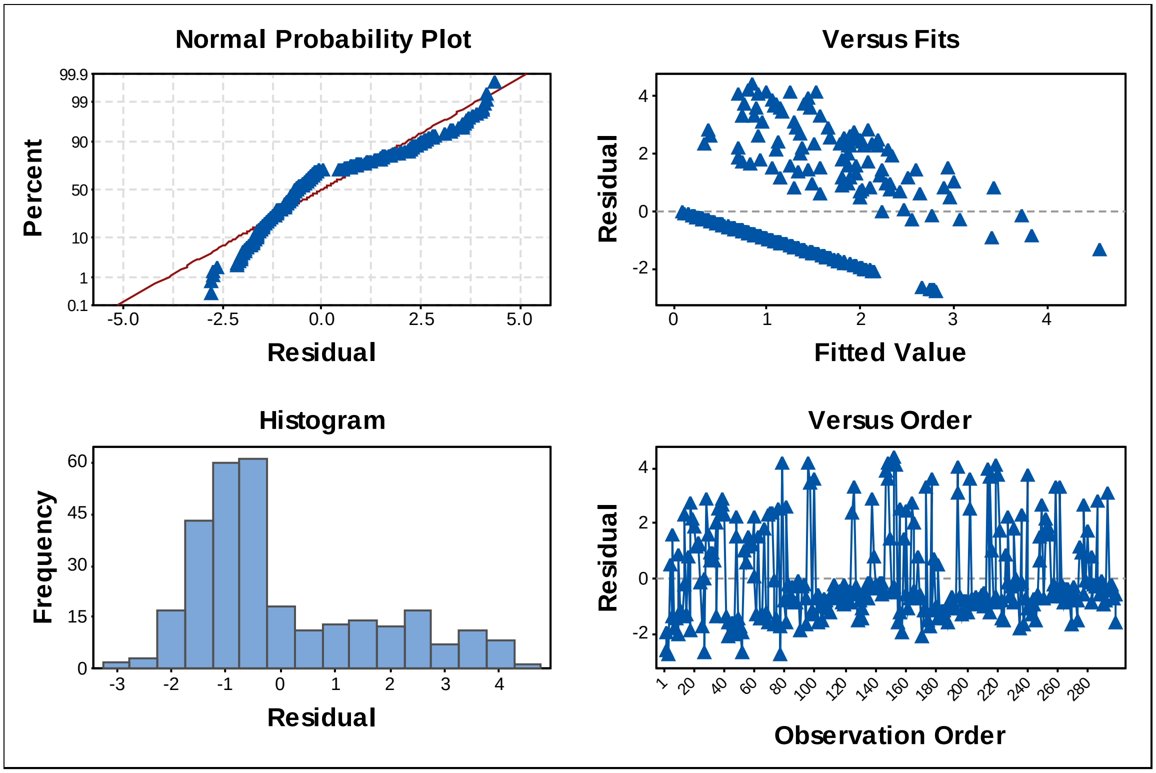


Figure 15: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a one-way Analysis of Variance of the Log_{10} transformed flow-weighted average concentrations of four watersheds across all Pretreatment, Post-Cut, Transition, and Treatment phases.

While the statistical results of the Phase variable were insignificant within the Log_{10}(FWAC) ANCOVA analysis, the similarities within the SQRT(SY) response variable reflected how removal of woody vegetation within watershed J-RP led to an observed increase and statistical differences of sediment yield compared to the three control watersheds. As expected, the physical disturbance of the soil profile by the removal of woody vegetation, when coupled with reduced vegetative cover and increased surface flow, resulted in larger sediment losses within J-RP. Thus it is critical to strategically schedule vegetation alterations and to develop best management practices in order to minimize soil losses and future fertilizer costs needed to reestablish soil fertility and sustain agricultural crops. Even if the ultimate goal is just to return encroached woodlands to grassland ecosystems, a coordinated and holistic strategy toward removing eastern redcedar vegetation will not only benefit the ecological and economical worth of the watersheds, but also protect various vital ecosystems downstream.

3.5 IMPACTS OF EASTERN REDCEDAR TRANSITIONED TO SWITCHGRASS

A SQRT(SY) two-way ANCOVA of treatment watershed J-SG versus control watersheds J1, J2, and P across all phases suggested that the Watershed, Phase, and the Interaction variables were all statistically significant at an α=0.10. A Tukey's Multiple Comparison of the Watershed variable revealed that treatment watershed J-RP was statistically different than the control watersheds J1, J2, and P, and had a SQRT(mean) more than four times larger than the second largest SQRT(mean). A Tukey's Multiple Comparison of the Phase variable, on the other hand, identified the Pretreatment, Transition, and Treatment phases (i.e. 0, 2 and 3, respectfully) to have similar group means, with Treatment phase 3 having the largest SQRT(mean) of the group. Moreover, Post-Cut phase 1 was found to be statistically different than Treatment phase 3 and Transition phase 2, but statistically similar to Pretreatment phase 0. These differences of Post-Cut phase 1 were likely caused by the seasonal variability, short time span, and unique vegetative cover of this phase. Table 15 shows the results of the two-way ANCOVA and the Tukey's Multiple Comparison of sediment differences across the four watersheds and phases.

Table 15: Results of two-way Analysis of Covariance and Tukey's Multiple Comparison of Watershed and Phase treatment variables on square root transformed sediment yields for four watersheds during Pretreatment, Post-Cut, Transition, and Treatment phases.

	Variable				P-value
Two-way ANCOVA	Response:	Sediment Yield, SQRT(g/m^2)			n/a
	Treatment:	Watershed			< 0.001
	Treatment:	Phase			0.010
	Interaction:	Watershed*Phase			0.041
	Covariate:	Total Rainfall, (mm)			< 0.001
Tukey's Multiple Comparisons	**Watershed**		**Sediment Mean SQRT(g/m^2)**	**Sediment Mean g/m^2**	**Grouping**
	Juniper to Switchgrass (J-SG)		1.407	1.980	A
	Prairie Control (P)		0.297	0.088	B
	Juniper Control 2 (J2)		0.231	0.053	B
	Juniper Control 1 (J1)		0.019	0.000	B
Tukey's Multiple Comparisons	**Phase**		**Sediment Mean SQRT(g/m^2)**	**Sediment Mean g/m^2**	**Grouping**
	Treatment (Phase 3)		0.952	0.906	A
	Transition (Phase 2)		0.778	0.605	A
	Pretreatment (Phase 0)		0.268	0.072	A B
	Post-Cut (Phase 1)		-0.043	0.002	B

The Tukey's Multiple Comparison of the Interaction variable identified three important observations (Table 16). First, Post-Cut phase 1 SQRT(means) were lower than any predecessors or precursor phase SQRT(means). This supports the claim that seasonal variability and short time span of this phase may have influenced lower sediment observations. However, an equally possible interpretation was that the presence of cut woody vegetation on the watershed increased the surface cover of the soil and altered flow paths to reduce the erosive force of water. Second, as the treatment watershed J-SG underwent change, its SQRT(mean) increase accordingly. This makes sense as disturbances within watersheds have been shown to increase sediment losses. More Treatment data is needed to better determine overall sediment differences between switchgrass, recovering prairie, and intact grassland. The high SQRT(means) of the Treatment phase were hypothesized to be caused by several early sediment events that skewed upwards and did not reflect mature switchgrass sediment yields. Lastly, the variability of SQRT(means) for control watersheds J1, J2, and P revealed the sediment influences associated with climate variability across the four phases.

Table 16: Results of Tukey's Multiple Comparison of Interaction variable on square root transformed sediment yields for watersheds Juniper to Switchgrass (J-SG), Juniper Control (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 0), Post-Cut (phase 1), Transition (Phase 2), and Treatment (Phase 3) vegetative conditions.

Tukey's Multiple Comparison of Interaction Variable Group Means						
Watersheds*Phase				**Sediment Mean**		**Grouping**
Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**SQRT(g/m2)**	**g/m2**	
			J-SG	2.715	7.371	A
		J-SG		2.361	5.574	A
			J2	0.496	0.246	B
		P		0.468	0.219	B
J2				0.412	0.170	B
J-SG				0.323	0.104	B
P				0.317	0.100	B
			P	0.306	0.094	B
			J1	0.292	0.085	B
	J-SG			0.230	0.053	B
		J2		0.216	0.047	B
	P			0.097	0.009	B
		J1		0.065	0.004	B
J1				0.021	0.000	B
	J2			-0.198	0.039	B
	J1			-0.301	0.091	B

The normal distribution and residual variance of the two-way ANCOVA were not ideal (Figure 16), but they were sufficient considering the environmental noise of these data. The Main Effects plot (Figure 17) reinforced the observations interpreted from the Tukey's Multiple Comparison of this section, as well as agreed with the Main Effects observations of section 4.2.3.

Watersheds J-RP and J1, as well as Phases 1 and 2 have the steepest slope between any two points, and had the greatest magnitude of main effects between the four watersheds and phases. Their non-parallel lines signify main effects occurred between the various variables and only watershed J-SG had a SQRT(mean) greater than the overall SQRT(mean). A important comparison to the Main Effects plot of section 4.2.3, as both J-RP and P had greater SQRT(means) than the overall SQRT(means). This difference suggested that the prolonged period of barren soil within watershed J-SG influenced the overall SQRT(means) of Figure 17 and increased it greater than control watershed P's SQRT(mean). The Interaction plot of Watershed*Phase (bottom left) revealed Treatment phase 3 and Transition phase 2 had the highest SQRT(means) within the J-RP watershed and that there was a decline in slopes between watershed J-SG and J1, relative to the Post-Cut phase 1's slope, signifying major effects were present. This was confirmed by both the Main Effect graph and the Tukey's Multiple Comparison of the Interaction variable as the SQRT(means) between the J-SG and the J1 watersheds varied tenfold or greater across Pretreatment, Transition, and Treatment phases. Lastly, the Phase*Watershed plot (top right) of Figure 18 suggests that watershed J-RP increased significantly between Post-Cut phase 1 and Transition phase 2, but reduced in magnitude as it approached Treatment phase 3. This reduction of slope was due to the incremental influence of switchgrass on soil moisture and its armoring of the soil surface.

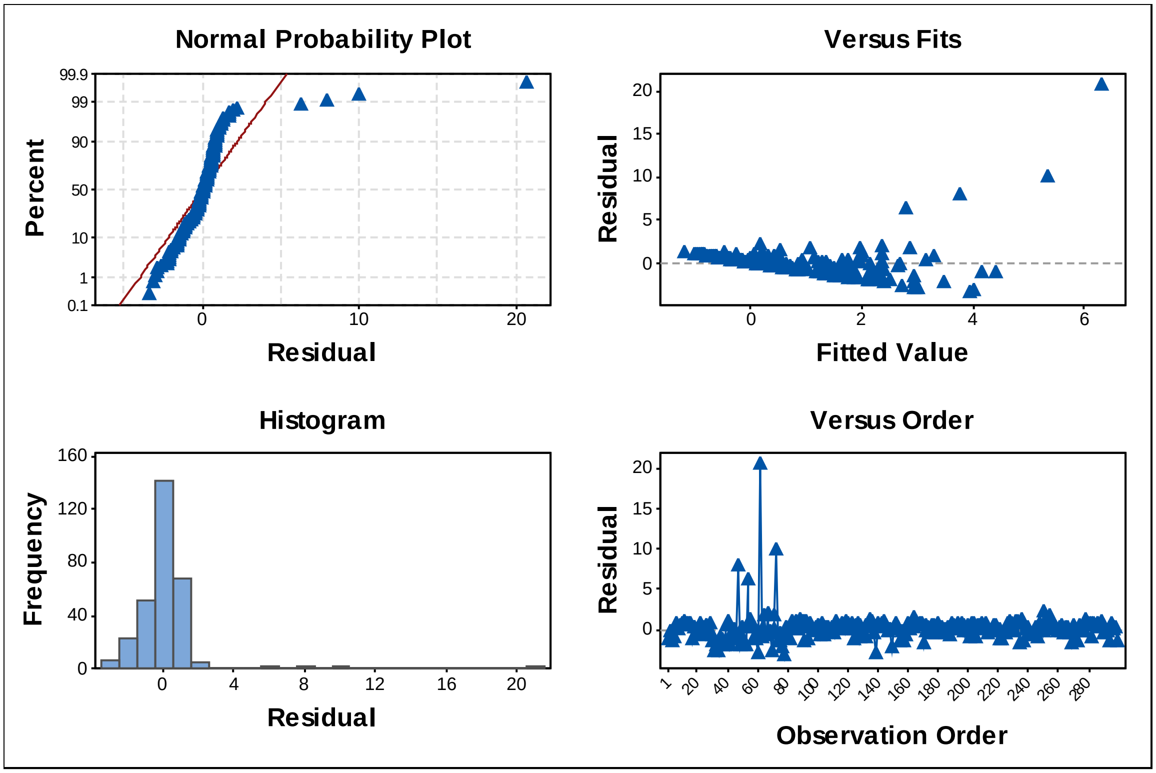


Figure 16: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a two-way Analysis of Covariance of the square root transformed sediment yields of four watersheds across treatment, transition, post-cut, and control vegetative conditions.

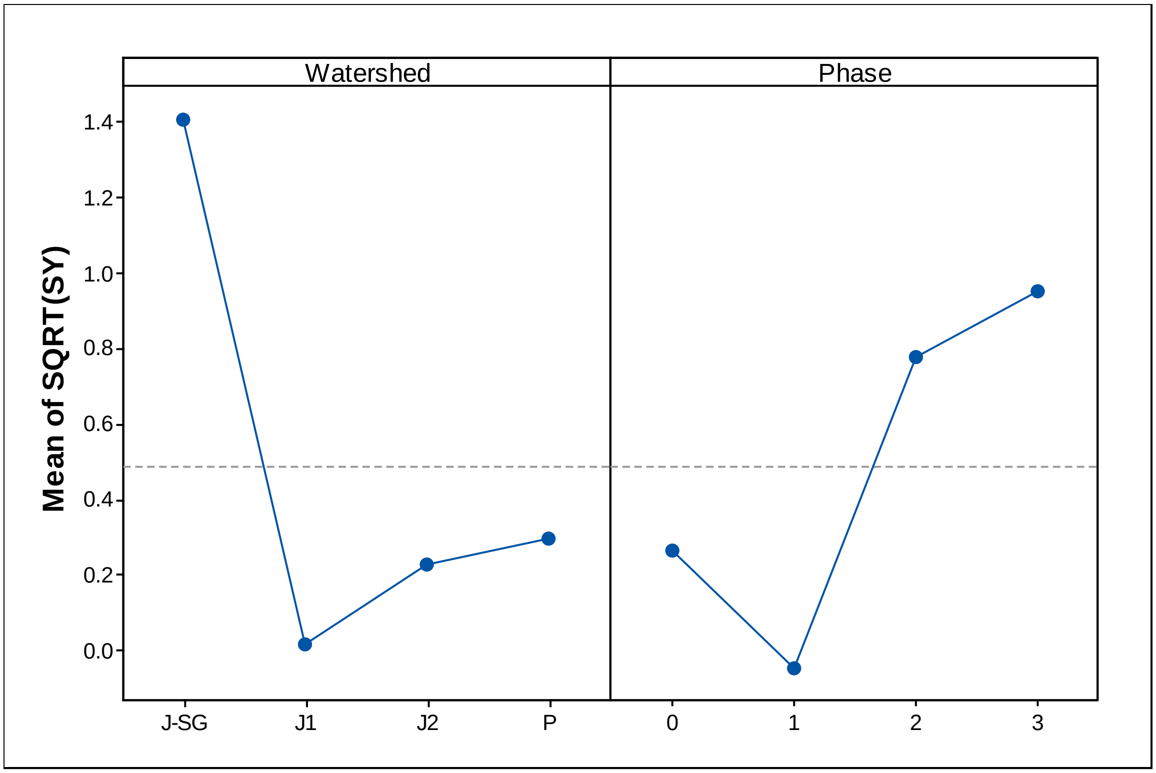


Figure 17: Main Effects plot of two-way Analysis of Covariance of the square root transformed sediment yields (SQRT(SY)) for watersheds Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 1), Post-Cut (Phase 2), Transition (Phase 2), and Treatment (Phase 3) vegetative conditions. The units of SQRT(SY) are SQRT(g/m^2).

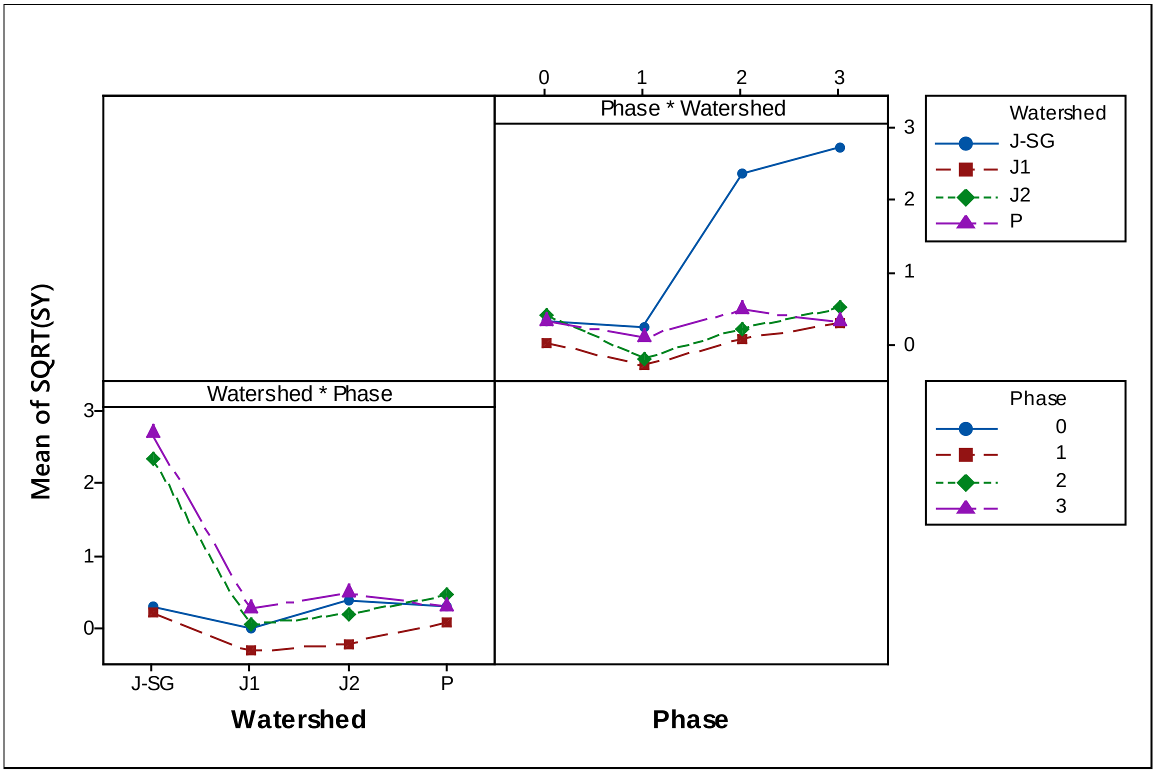


Figure 18: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of square root transformed sediment yields (SQRT(SY)). Watershed variable consisted of Juniper Converted to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3). Units of SQRT(SY) are SQRT(g/m^2).

A two-way ANCOVA of the response variable Log_{10}(FWAC) revealed similar interpretations as its SQRT(SY) counterpart. Within the Log_{10}(FWAC) two-way ANCOVA, all variables were statistically significant at an α=0.10(Table 17), justifying a Main Effects, Interaction Plot, and Tukey's Multiple comparison of the Interaction term. A Tukey's Multiple Comparison of the Watershed variable (Table 17) showed similar results as its SQRT(SY) counterpart, where treatment watershed J-SG was statically different from the three controls with a two-fold Log_{10}(mean). A Tukey's Multiple Comparison of the Phase variable, however, revealed slightly different results than the SQRT(SY) comparison whereas only Treatment phase 3 was statistically similar Post-Cut phase 1 and all other phases were statistically different from one another (Table 17).

Table 17: Results of two-way Analysis of Covariance and Tukey's Multiple Comparison of Watershed and Phase treatment variables on Log_{10} transformed flow-weighted average concentrations (Log_{10}(FWC)) for four watersheds during Pretreatment, Post-Cut, Transition, and Treatment phases.

	Variable		P-value
Two-way ANCOVA	Response:	Flow-Weighted Avg. Conc., Log_{10}(ng/L)	n/a
	Treatment:	Watershed	< 0.001
	Treatment:	Phase	< 0.001
	Interaction:	Watershed*Phase	0.032
	Covariate:	Total Rainfall, (mm)	< 0.001

	Watershed	Concentration Mean		Grouping
		Log_{10}(ng/L)	mg/L	
Tukey's Multiple Comparisons	Juniper to Switchgrass (J-SG)	2.939	0.868	A
	Juniper Control 2 (J2)	1.317	0.020	B
	Juniper Control 1 (J1)	1.016	0.009	B
	Prairie Control (P)	0.824	0.006	B

	Phase	Concentration Mean		Grouping
		Log_{10}(ng/L)	mg/L	
Tukey's Multiple Comparisons	Treatment (Phase 3)	2.240	0.173	A
	Post-Cut (Phase 1)	1.483	0.029	A B
	Transition (Phase 2)	1.361	0.022	B
	Pretreatment (Phase 0)	1.012	0.009	B

A Tukey's Multiple Comparison the interaction variable (Table 18) showed three important interpretations. First, by normalizing the influences of runoff with the flow-weighted average concentration response variable, the Log_{10}(concentration means) were more dispersed and enabled more diverse grouping labels of the various watersheds across their respected phases. Second, the influences of the four Phases, especially Post-Cut Phase 1, were more in line with what was expected to happen to sediment concentrations as soil disturbances occurred within the watershed – they increased. Lastly, even though the watersheds were close in proximity, the natural variability of climate influenced watershed Log_{10}(flow-weighted average concentrations) and there was no watershed that consistently had the lowest group mean. This claim excluded control watershed J1, whose greater surface cover resulted in continual lower group means compared to the other watersheds across the four phases.

Table 18: Results of Tukey's Multiple Comparison of Interaction variable on Log_{10} transformed flow weighted average concentrations for watersheds Juniper to Switchgrass (J-SG), Juniper Control (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3) vegetation conditions.

Tukey's Multiple Comparison of Interaction Variable Group Means						
Watersheds*Phase				**Concentration Mean**		**Grouping**
Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**Log_{10}(ng/L)**	**mg/L**	
			J-SG	4.528	33.728	A
		J-SG		2.959	0.909	A B
	J-SG			2.700	0.500	B C
			J1	1.874	0.074	B C D
			J2	1.866	0.072	B C D
J-SG				1.569	0.036	B C D
J2				1.277	0.018	C D
	J2			1.175	0.014	B C D
	J1			1.101	0.012	B C D
		P		1.026	0.010	C D
	P			0.954	0.008	C D
		J2		0.948	0.008	C D
			P	0.693	0.004	C D
P				0.622	0.003	C D
J1				0.578	0.003	D
		J1		0.512	0.002	D

Figure 19 shows the four-in-one plot of the two-way ANCOVA with superior normal distribution and equal variance compared to previous four-in-one plots. The Main Effects and Interaction Plot (Figure 20 and Figure 21) of this ANCOVA supported similar observations and were in line with SQRT(SY) interpretations of the Main Effects and Interpretation plots. The biggest difference, however, was the spread of Log_{10}(means) across the different watersheds and phases. This was attributed to Log_{10}(FWAC)'s normalization of runoff influences and more diverse group labeling, relative to the SQRT(SY) response variable.

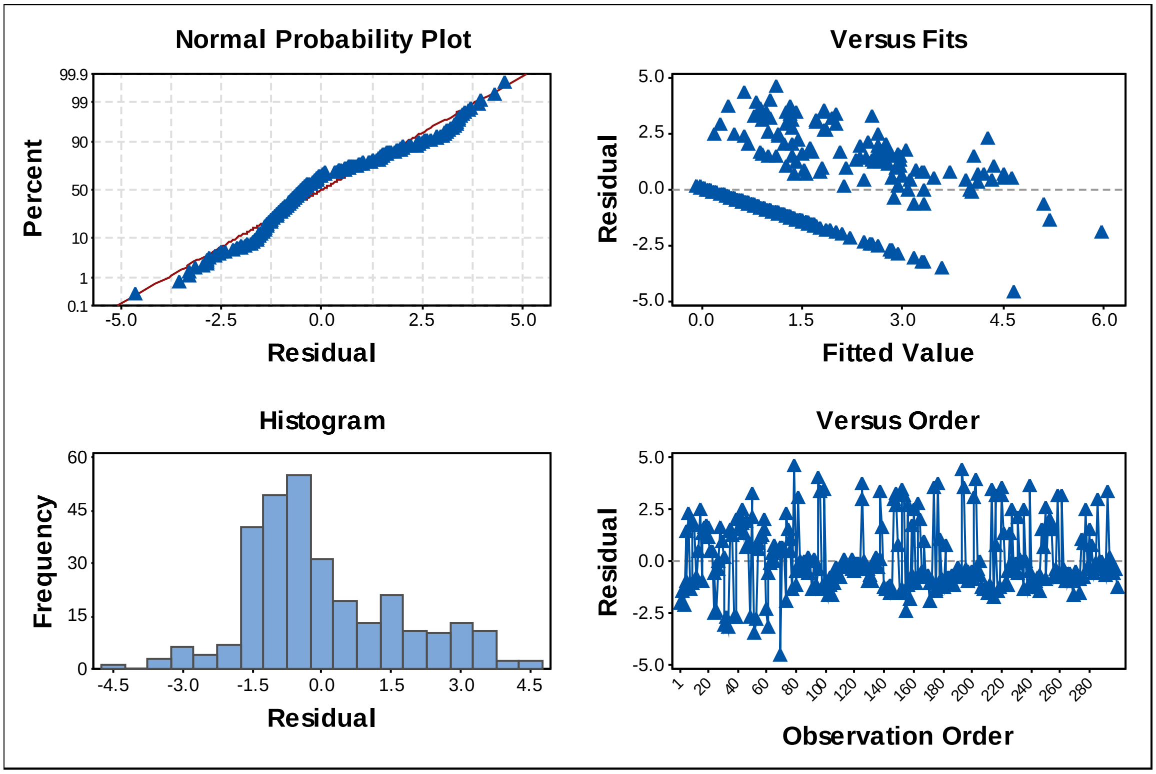


Figure 19: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a two-way Analysis of Covariance of the Log_{10} transformed flow-weighted average concentrations of four watersheds across treatment, transition, post-cut, and control vegetative conditions.

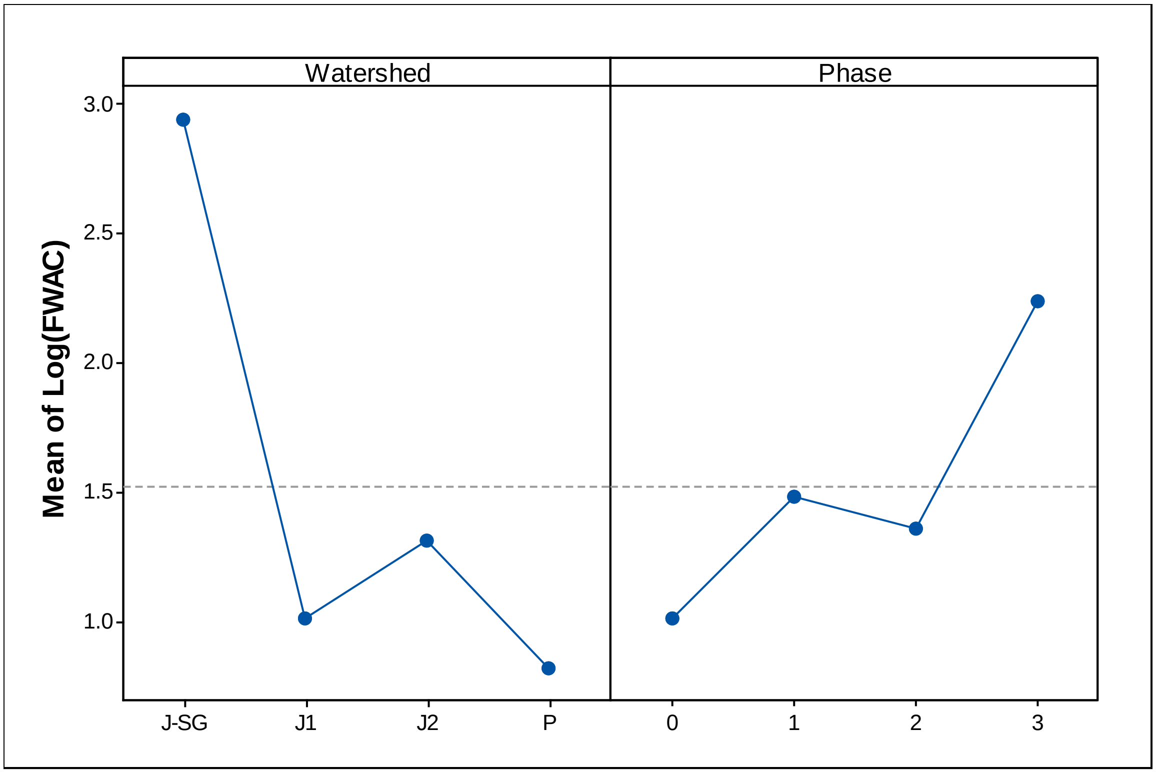


Figure 20: Main Effects plot of two-way Analysis of Covariance of the Log_{10} transformed flow-weighted average concentration (Log_{10}(FWAC)) for watersheds Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3) vegetative conditions. The units of Log_{10}(FWAC) are Log_{10}(ng/L).

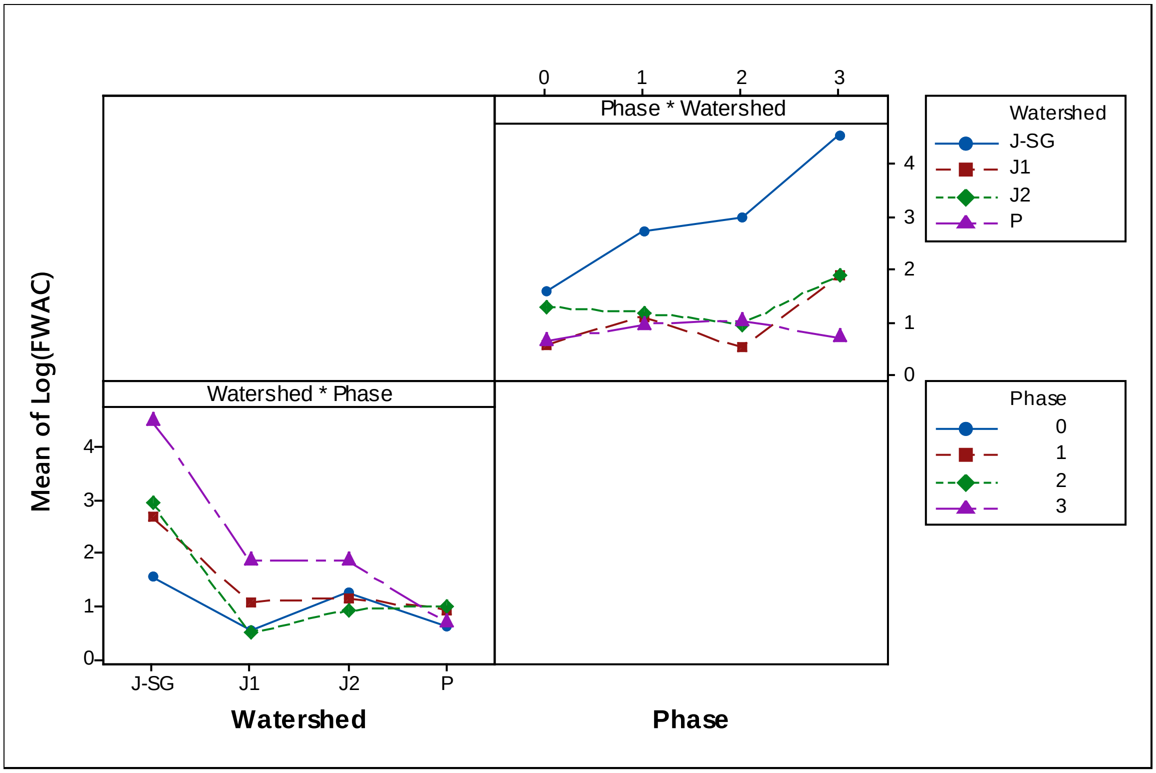


Figure 21: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of Log_{10} transformed flow-weighted average concentrations (Log_{10}(FWAC)). Watershed variable consisted of Juniper Converted to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3). Units of Log_{10}(FWAC) are Log_{10}(ng/L).

The key interpretations of sections 3.4 and 3.5 were that sediment yields increased as eastern redcedar was removed from the watersheds. This was expected as heavy machinery was required to cut and remove eastern redcedar biomass from the watershed, which not only diminished the surface cover, but also disturbed the soil profile. This conclusion identified the time sensitivity of watershed vegetation alterations and their needs to occur within periods of minimum precipitation; as runoff exploits soil vulnerability and erodes the soil health of a watershed. Also, implementation of conservation practices are encouraged in order to minimize the sediment yield of land use alterations.

3.6 IMPORTANCE OF SURFACE COVER

With the results of sections 3.4 and 3.5 showing statistical differences in means of sediment yield across the treatment watersheds, the next logical question was to determine the sediment impacts of transitioning eastern redcedar to switchgrass relative to native vegetation recolonization. However, due to the weather delay of the switchgrass planting during the first year, an additional year of transitional vegetation existed within the J-SG timeline that prevented one-to-one comparison with J-RP. The influences of preventing herbaceous vegetation growth with J-SG, i.e. herbicide-barren landscape, versus the influences of one-year of grassland revegetation were compared. To do this, only one year of revegetation data (i.e. treatment) was incorporated within a similar ANCOVA approach outlined in section 4.2.2.

A two-way ANCOVA of the SQRT(SY) showed that all model variables were statically significant at an $\alpha=0.10$. A Tukey's Multiple Comparison of the Watershed variable revealed that only watersheds J-SG and J1 were statistically different from each other, while the other watersheds were statistically similar to J1 and J-SG at an $\alpha=0.10$. A Tukey's Multiple Comparison of the Phase variable showed that Treatment phase 3 was only statistically similar to Transition phase 2, while Pretreatment phase 0 and Post-Cut phase 1 were statistically similar to Transition phase 2 using an $\alpha=0.10$. The Tukey's Multiple Comparison of the Interaction variable, on the other hand, showed that Post-Cut phase 1's watershed SQRT(means) were lower than the all other phases and that the alteration of vegetation increased J-SG and J-RP SQRT(means) compared to control watersheds and Pretreatment conditions. An observable difference in these statistical results, however, was that while the J-RP watershed was statistically similar to J-SG during Transition phase 2, the two watersheds became statistically different during Treatment phase 3 with a threefold difference in SQRT(means). This change from statistically similar to statistically different sediment means was hypothesized to be the influence of revegetation during Transition phase 3; however soil texture differences were also key factors to consider as J-RP had a greater diversity of soil types compared to J-RP (i.e. Table 1). Table 19 shows the statistical results of the two-way ANCOVA and the Tukey's Multiple Comparisons of the Phase and Watershed variables, while Table 20 shows the Tukey's Multiple Comparison of the Interaction variable.

Table 19: Results of two-way Analysis of Covariance (ANCOVA) and Tukey's Multiple Comparison of Watershed and Phase treatment variables on square root transformed sediment yields for five watersheds during Pretreatment, Post-Cut, Transition, and Treatment phases.

	Variable		P-value
Two-way ANCOVA	Response:	Sediment Yield, SQRT(g/m^2)	n/a
	Treatment:	Watershed	0.038
	Treatment:	Phase	0.002
	Interaction:	Watershed*Phase	0.012
	Covariate:	Total Rainfall, (mm)	< 0.001

	Watershed	Sediment Mean SQRT(g/m^2)	Sediment Mean g/m^2	Grouping
Tukey's Multiple Comparisons	Juniper to Switchgrass (J-SG)	0.963	0.927	A
	Juniper to Recovering Prairie (J-RP)	0.659	0.434	A B
	Prairie Control (P)	0.514	0.264	A B
	Juniper Control 2 (J2)	0.158	0.025	A B
	Juniper Control 1 (J1)	-0.012	0.000	B

	Phase	Sediment Mean SQRT(g/m^2)	Sediment Mean g/m^2	Grouping
Tukey's Multiple Comparisons	Treatment (Phase 3)	0.937	0.878	A
	Transition (Phase 2)	0.592	0.350	A B
	Pretreatment (Phase 0)	0.298	0.089	B
	Post-Cut (Phase 1)	-0.009	0.000	B

Table 20: Results of Tukey's Multiple Comparison of Interaction variable on square root transformed sediment yields for watersheds Juniper to Switchgrass (J-SG), Juniper to Recovering Prairie (J-RP), Junpier Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 0), Post-Cut (phase 1), Transition (Phase 2), and Treatment (Phase 3) watershed vegetation conditions.

Tukey's Multiple Comparison of Interaction Variable Group Means						
Watersheds*Phase				Sediment Mean		Grouping
Phase 0	Phase 1	Phase 2	Phase 3	SQRT(g/m2)	g/m2	
			J-SG	2.778	7.717	A
		P		1.331	1.772	A
		J-RP		1.226	1.503	A B
			J-RP	0.996	0.992	B
		J-SG		0.472	0.223	A B
J2				0.465	0.216	B
			P	0.411	0.169	B
J-SG				0.377	0.142	B
P				0.371	0.138	B
			J2	0.355	0.126	B
	J-SG			0.224	0.050	B
	J-RP			0.212	0.045	B
J-RP				0.200	0.040	B
			J1	0.147	0.022	B
J1				0.075	0.006	B
		J2		-0.034	0.001	B
		J1		-0.034	0.001	B
	P			-0.058	0.003	B
	J2			-0.154	0.024	B
	J1			-0.268	0.072	B

Figure 22 shows the four-in-one plot of the two-way ANCOVA mentioned above and there were two key interpretations. First, while the normal distribution of the data did not follow a normal distribution, the distribution was sufficient and the ANCOVA had slightly less power to determine differences between means. Second, the one isolated residual within the Versus Fit plot (top right) corresponds to a massive storm that occurred on 4/28/2017 and could be seen as an outlier.

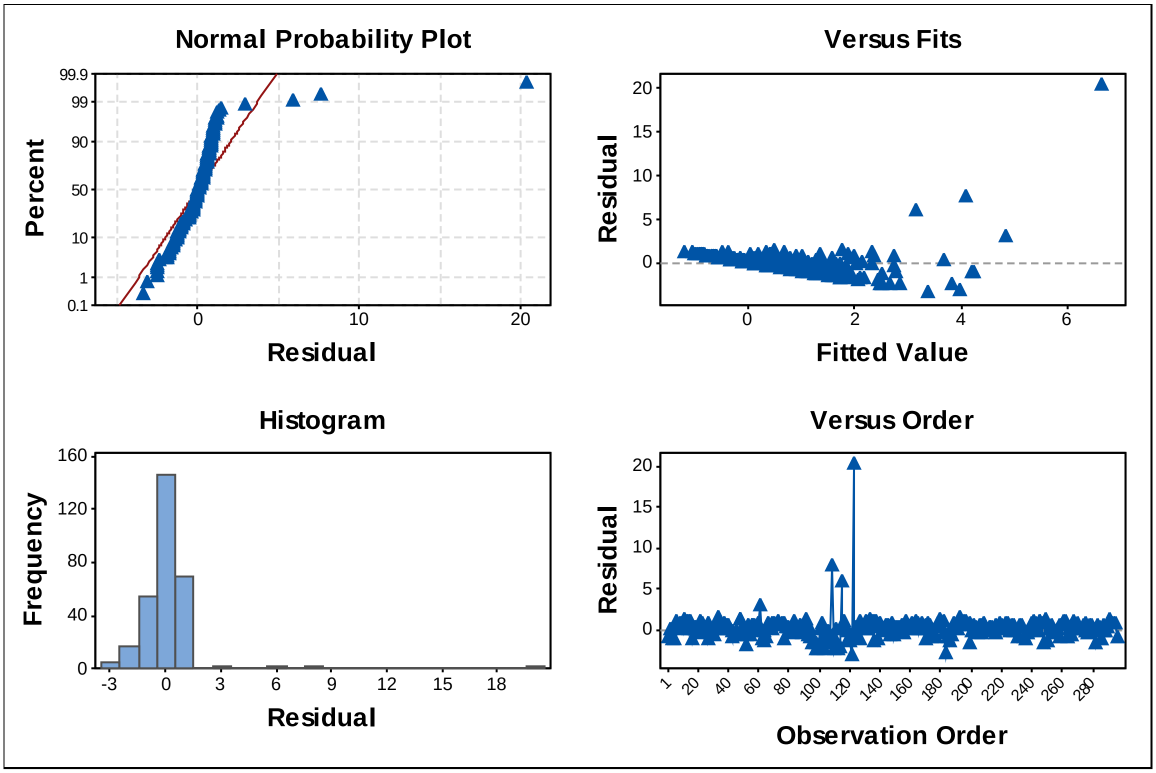


Figure 22: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a two-way Analysis of Covariance (ANCOVA) of the square root transformed sediment yields of five watersheds during control, post-cut, transitioning, and treatment watershed vegetation conditions.

Figure 23 and Figure 24 show the Main Effects Plot and the Interaction Plot of the two ANCOVA response variables. Within the watershed plot of the Main Effects plot, watersheds J-RP, J-SG, and P all had SQRT(means) above the overall SQRT(mean), implying that the low sediment events of J1 and J2 influenced the overall SQRT(mean) of the model. The phase plot of the Main Effects, on the other hand, identified Transition phase 2 and Treatment phase 3 as the largest SQRT(means). This was in line with the interpretations made within the Tukey's Multiple Comparisons of the variables. Additionally, the non-parallel lines between the watersheds and the phases indicated the presences of main effects within the dataset. Watersheds J-SG and J1, as well as Post-Cut phase 1 and Transition phase 2 possessed the greatest magnitude of main effects. Moreover, the Interaction Plot revealed two important comparisons. First, the interactions between Phase and Watershed influenced the magnitude of sediment eroded in J-SG. This relationship was observed physically during the field data collection portion of this project as numerous times during Treatment phase 3, manual labor was employed to remove substantial sediment from J-SG's H-Flume compared to the other watershed's H-flumes. The second comparison was the reduction of J-RP's slope between Transition phases 2 and Treatment phase 3 within the Phase*Watershed plot of the Interaction Plot. This decline in slope was likely due to soil armoring and soil moisture influences of revegetation on J-RP's SQRT(SY), which damped the interaction effects of Phase*Watershed on SQRT(means) of the J-RP watershed as compared to J-SG.

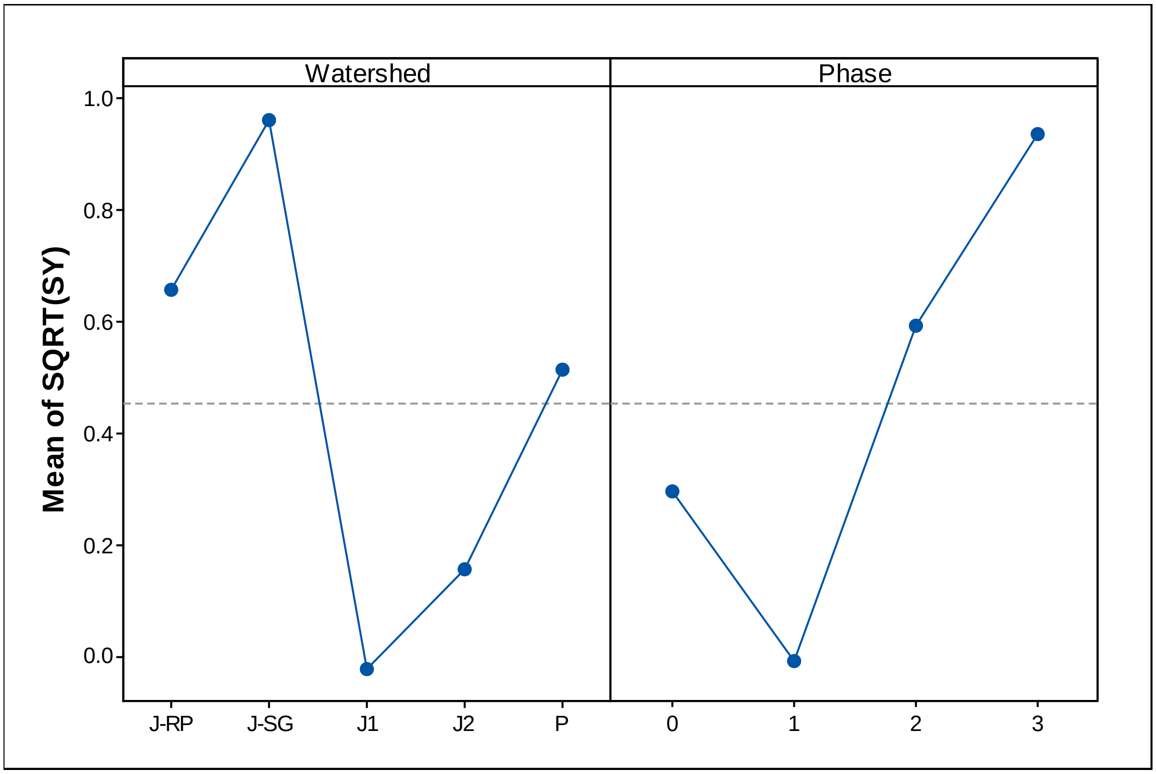


Figure 23: Main Effects plot of two-way Analysis of Covariance of the square root transformed sediment yields (SQRT(SY)) for watersheds Juniper to Recovering Prairie (J-RP), Juniper to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) across Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3) vegetative conditions. The units of SQRT(SY) are SQRT(g/m^2).

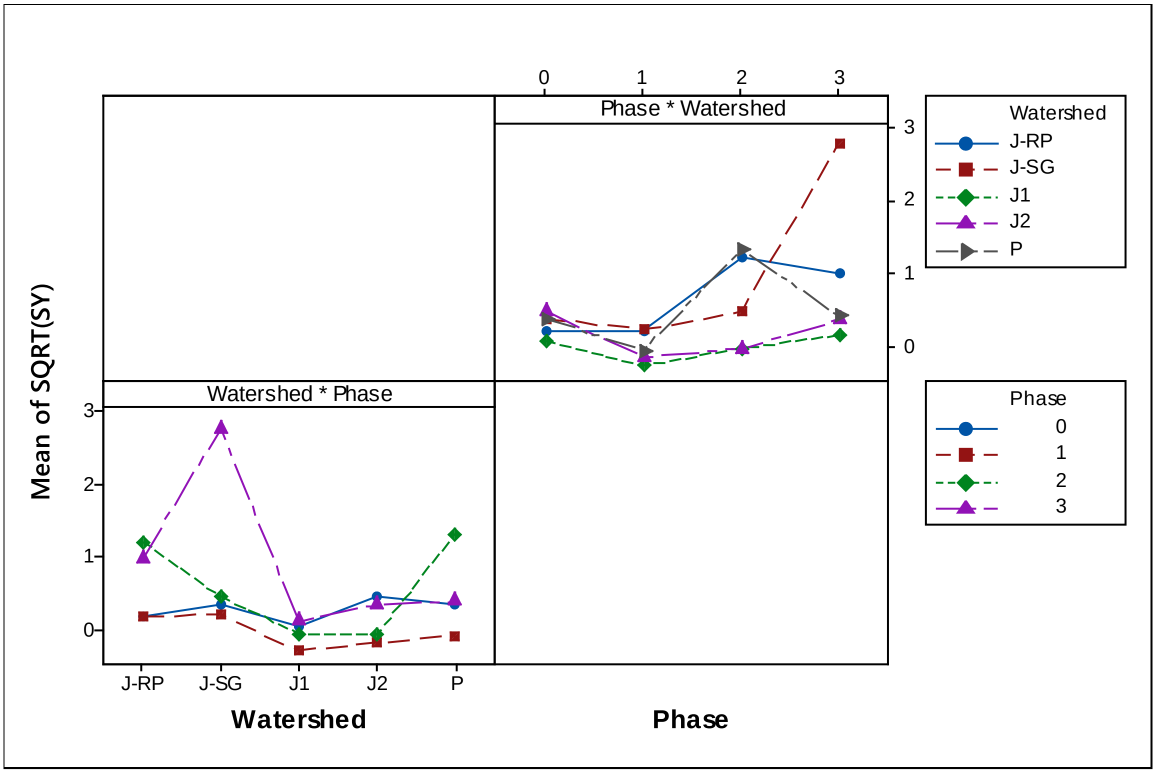


Figure 24: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of square root transformed sediment yields (SQRT(SY)). Watershed variable consisted of Juniper to Recovering Prairie (J-RP), Juniper Converted to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3). Units of SQRT(SY) are SQRT(g/m^2).

A two-way ANCOVA of the Log_{10}(FWAC) response variable showed that the Watershed, Phase, Covariate, and the Interaction variable were all statistically significant at an α=0.10. A Tukey's Multiple Comparison of the Watershed variable revealed that both the J-SG and J-RP watershed were statistically different compared to the three control watersheds with a slightly difference between the two treatment watersheds. A Tukey's Multiple Comparison of the Phase variable show that phases 0 and 3 were statistically different and that all the other two watersheds had similarities with both Phases 0 and 3 using an α=0.10. Table 21 shows the corresponding significance levels and Log_{10}(FWAC) means of the two-way ANCOVA and the two Tukey's Multiple Comparisons.

Table 21: Results of two-way Analysis of Covariance (ANCOVA) and Tukey's Multiple Comparison of Watershed and Phase treatment variables on Log_{10} transformed flow-weighted average concentrations for five watersheds during Pretreatment, Post-Cut, Transition, and Treatment phases.

	Variable		P-value
Two-way ANCOVA	Response:	Flow-Weighted Avg. Conc., Log_{10}(ng/L)	n/a
	Treatment:	Watershed	< 0.001
	Treatment:	Phase	0.049
	Interaction:	Watershed*Phase	0.013
	Covariate:	Total Rainfall, (mm)	< 0.001

	Watershed	**Concentration Mean**		**Grouping**
		Log_{10}(ng/L)	**mg/L**	
Tukey's Multiple Comparisons	Juniper to Recovering Prairie (J-RP)	2.341	0.218	A
	Juniper to Switchgrass (J-SG)	2.322	0.209	A
	Prairie Control (P)	1.158	0.013	B
	Juniper Control 2 (J2)	0.970	0.008	B
	Juniper Control 1 (J1)	0.622	0.003	B

	Phase	**Concentration Mean**		**Grouping**
		Log_{10}(ng/L)	**mg/L**	
Tukey's Multiple Comparisons	Post-Cut (Phase 1)	1.721	0.052	A B
	Treatment (Phase 3)	1.650	0.044	A
	Transition (Phase 2)	1.492	0.030	A B
	Pretreatment (Phase 0)	1.068	0.011	B

A Tukey Comparisons of the Interaction variable, however, showed three important interpretations. First, natural variability existed between the Log_{10}(means) of the three control watersheds as their means varied in position across the phases, but their respected groupings were mostly similar to one another. Second, the disturbance of the treatment watershed's vegetation led to an increase in Log_{10}(means) across the phases, but natural variability of runoff was also likely to impact these values. This variation was observed by the higher Log_{10}(means) of the treatment watersheds within the later phases compared to processor observations and by the control watershed's spike in Log_{10}(mean) during phase 2. The final interpretation deals with the change of J-RP and J-SG Log_{10}(means) across phases 2 and 3 specifically. During Phase 2, J-RP had a

180% larger Log_{10}(mean) than J-SG. However during Phase 3, J-SG's Log_{10}(mean) overcame J-RP's Log_{10}(mean) by 146%. This shift was likely due to the influences of vegetation armoring of the soil profile and its reduction of soil moisture, and while J-RP's Log_{10}(mean) was still relatively large compared to the controls; one can expect that as time passes, the influences of vegetation on sediment yield will increase. Refer to Table 22 for the Log_{10}(FWAC) means across the various phases of the Tukey's Multiple Comparison of the Interaction variable.

Table 22: Results of Tukey's Multiple Comparison of Interaction variable on Log_{10} transformed flow weighted average concentrations for watersheds Juniper to Switchgrass (J-SG), Juniper to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 0), Post-Cut (Phase 1), Transition (Phase 2), and Treatment (Phase 3) watershed vegetation conditions.

Tukey's Multiple Comparison of Interaction Variable Group Means						
Watersheds Hierarchy				**Concentration Mean**		**Grouping**
Phase 0	**Phase 1**	**Phase 2**	**Phase 3**	**Log_{10}(ng/L)**	**mg/L**	
		J-RP		3.293	1.962	A B
			J-SG	3.278	1.896	A
	J-RP			2.656	0.452	A B C
	J-SG			2.594	0.392	A B C D
		P		2.378	0.238	A B C D
			J-RP	2.232	0.170	A B C
		J-SG		1.821	0.065	A B C D
J-SG				1.596	0.038	B C D
	J2			1.343	0.021	A B C D
J2				1.304	0.019	B C D
	J1			1.262	0.017	B C D
			J2	1.249	0.017	B C D
J-RP				1.183	0.014	B C D
			P	0.853	0.006	C D
	P			0.751	0.005	B C D
P				0.649	0.003	C D
			J1	0.635	0.003	D
J1				0.605	0.003	C D
		J2		-0.017	0.000	C D
		J1		-0.017	0.000	C D

Figure 25 displays the four-in-one plot of the two-way ANCOVA's normal distribution, histogram, residual versus fit, and residual versus order plots. Within this ANCOVA model, the normal distribution of these data was fantastic and its residuals were good. The presence of zeros were still noticeable within the residual plot, but overall the assumptions of the ANCOVA were maintained and the model had full power to detect differences within the variables.

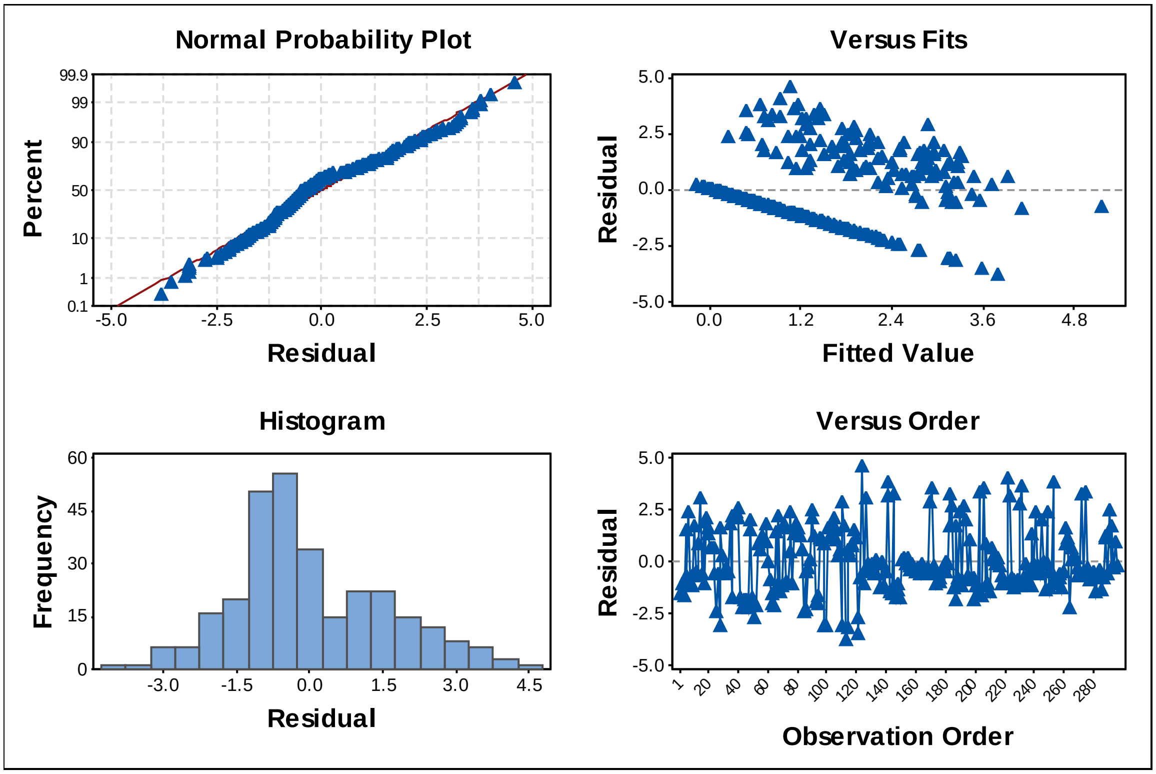


Figure 25: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a two-way Analysis of Covariance (ANCOVA) of the Log_{10} transformed flow-weighted average concentrations of five watersheds during control, post-cut, transitioning and treatment watershed vegetation conditions.

The greatest magnitude of main effects (Figure 26) occurred between the J-SG and the J1 watersheds and varied magnitudes of main effects existed between the other watersheds as their lines were not parallel to the x-axis. Within the phase pot of Figure 26, Phases 1, 2, and 3 were above the overall Log_{10}(mean), which showed relative Log_{10}(mean) size between the three points and also Phase 1's influence on the overall Log_{10}(mean). The greatest magnitude of main effect occurred within Phase 0 and 1 and the other phases had varied magnitudes of main effects.

Figure 26: Main Effects plot of two-way Analysis of Covariance of the Log_{10} transformed flow-weighted average concentration (Log_{10}(FWAC)) for watersheds Juniper to Recovering Prairie (J-RP), Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P) during Pretreatment (Phase 0), Post-Cut (Phase 2), Transition (Phase 3), and Treatment (Phase 3) vegetative conditions. The units of Log_{10}(FWAC) are Log_{10}(ng/L).

Figure 27, on the other hand, showed more complex interactions. According to the Phase*Watershed plot, watersheds J-RP, P, and J-SG were the highest Log_{10}(means) of Phase 2 and they had varied degrees of compounded influence between the watershed and phase variables. Juniper control watershed J1 and J2 appeared to follow the same magnitude of interaction and at times there appeared to be no interaction present between these two watersheds (i.e. between Phase 1 and 2). More importantly, all watersheds appeared to increase in Log_{10}(means) between phases 0 and 1, only watersheds P and J-RP increased Log_{10}(means) between Phases 1 and 2, and then all the watersheds switched during Phases 2 and 3. These changes result in varied amounts of interaction influence on the five watersheds Log_{10}(means).

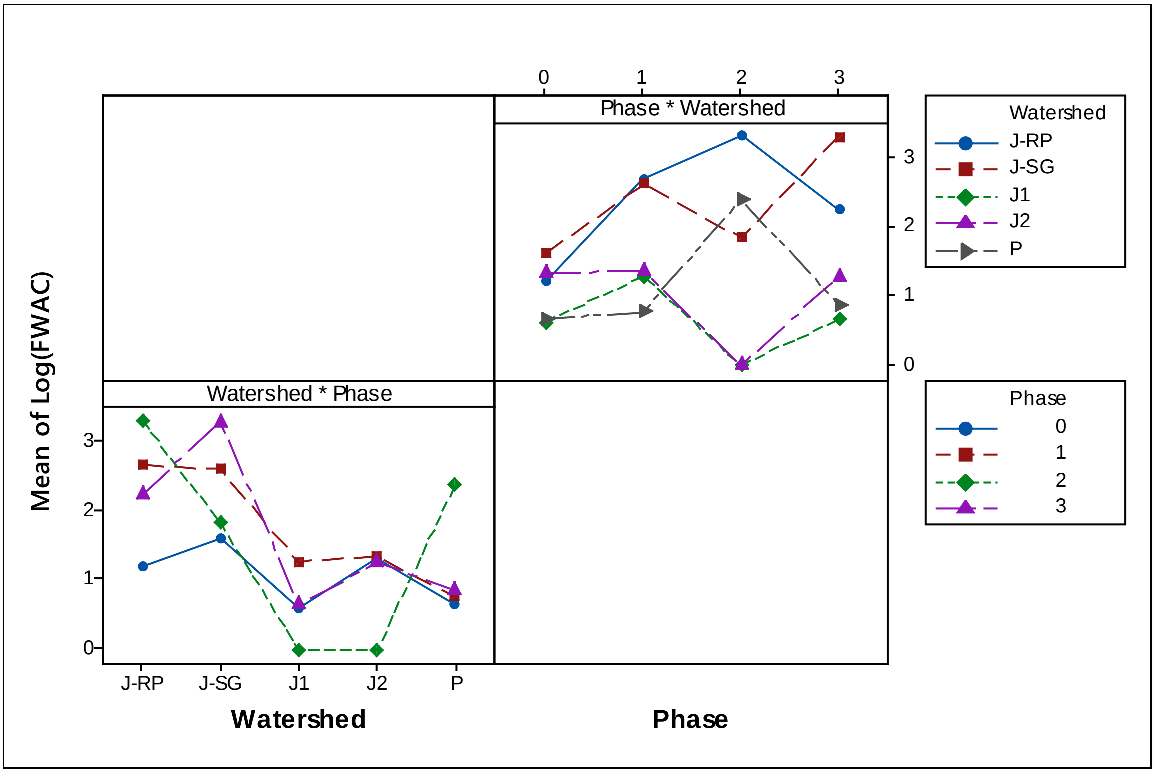


Figure 27: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of Log_{10} transformed flow-weighted average concentrations (Log_{10}(FWAC)). Watershed variable consisted of Juniper to Recovering Prairie (J-RP), Juniper Converted to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0), Post-Cut (Phase 2), Transition (Phase 3), and Treatment (Phase 3). Units of Log_{10}(FWAC) are Log_{10}(ng/L).

Overall, the most important distinction of this research question was the eventual reduction of sediment loss created by the revegetation of watershed J-RP. The transition of eastern redcedar vegetation resulted increased sediment yields, but the purposeful prevention of revegetation within watershed J-SG led to greater adverse soil health consequences and greater sediment loss compared to J-RP. Soil texture difference between J-RP and J-SG were responsible for some of the magnitude of sediment differences between the two watersheds, however vegetation influences were believed to have the greatest effect. Furthermore, even though oneyear of revegetation was not sufficient to produce sediment means similar to Pretreatment conditions, the continued influence of vegetation across time will lead to better watershed surface cover and reduced sediment loss. Previous research has cited two or three years as a minimal length of time required for disturbed watershed to return to Pretreatment levels (Alford et al., 2012; Pierce et al., 2010), however proactive soil protection measures taken early on will support the success of biofuel feedstock alternatives .

3.7 TREATMENT VS. CONTROL

A two-way ANCOVA comparison of the SQRT(SY) for all six watersheds during Pretreatment and Treatment conditions revealed that the Watershed and Phase variables were statistically significant at an $\alpha=0.10$. A Tukey's Multiple Comparisons of the Watershed variable identified watershed J-SG as statistically different than the other five watersheds with a SQRT(mean) more than four times greater than the second highest SQRT(mean). A Tukey's Multiple Comparison of the Phase variable showed Treatment phase 3 to be statistically different than Pretreatment phase 0 with nearly a three-fold difference in SQRT(means) using an $\alpha=0.10$. The Treatment phase's short time span and young maturity of switchgrass was hypothesized to be the cause of its larger SQRT(mean). More Treatment phase data should be compared in order to better compare sediment means between mature switchgrass and Pretreatment conditions. Within Tukey's Multiple Comparison of the Interaction variable, watersheds J-SG and J-RP had the highest group means during phase 3 of the project. J-SG was five times greater than J-RP SQRT(mean) and this sediment difference was hypothesized to be caused by the short time span of switchgrass cultivation and the influences of several early sediment events which skewed J-RP's SQRT(mean). Table 23 shows the results of the two-way ANCOVA and the Tukey's Multiple Comparisons of the Watershed, Phase, and Interaction variable. Figure 28 shows the ANCOVA model's normal distribution, histogram, and residual variance.

Table 23: Results of two-way Analysis of Covariance (ANCOVA) and Tukey's Multiple Comparison of Watershed, Phase, and Interaction variables on square root transformed sediment yields for six watersheds during Pretreatment (Phase 0) and Treatment (Phase 3) vegetative conditions.

	Variable		P-value
Two-way ANCOVA	Response:	Sediment Yield, SQRT(g/m^2)	n/a
	Treatment:	Watershed	< 0.001
	Treatment:	Phase	0.003
	Interaction:	Watershed*Phase	< 0.001
	Covariate:	Total Rainfall, (mm)	< 0.001

	Watershed	Sediment Mean SQRT(g/m^2)	Sediment Mean g/m^2	Grouping
Tukey's Multiple Comparisons	Juniper to Switchgrass (J-SG)	1.428	2.039	A
	Juniper Control 2 (J2)	0.363	0.132	B
	Prairie to Switchgrass (P-SG)	0.353	0.125	B
	Juniper to Recovering Prairie (J-RP)	0.327	0.107	B
	Prairie Control (P)	0.220	0.048	B
	Juniper Control 1 (J1)	0.065	0.004	B

	Phase	Sediment Mean SQRT(g/m^2)	Sediment Mean g/m^2	Grouping
Tukey's Multiple Comparisons	Treatment (Phase 3)	0.692	0.479	A
	Pretreatment (Phase 0)	0.226	0.051	B

Tukey's Multiple Comparison of Interaction Variable Group Means

Watersheds*Phase		Sediment Mean		Grouping
Phase 0	**Phase 3**	**SQRT(g/m2)**	**g/m2**	
	J-SG	2.576	6.636	A
	J-RP	0.553	0.306	B
J2		0.368	0.135	B
P-SG		0.360	0.130	B
	J2	0.357	0.127	B
	P-SG	0.346	0.120	B
J-SG		0.280	0.078	B
P		0.273	0.075	B
	P	0.167	0.028	B
	J1	0.153	0.023	B
J-RP		0.102	0.010	B
J1		-0.023	0.001	B

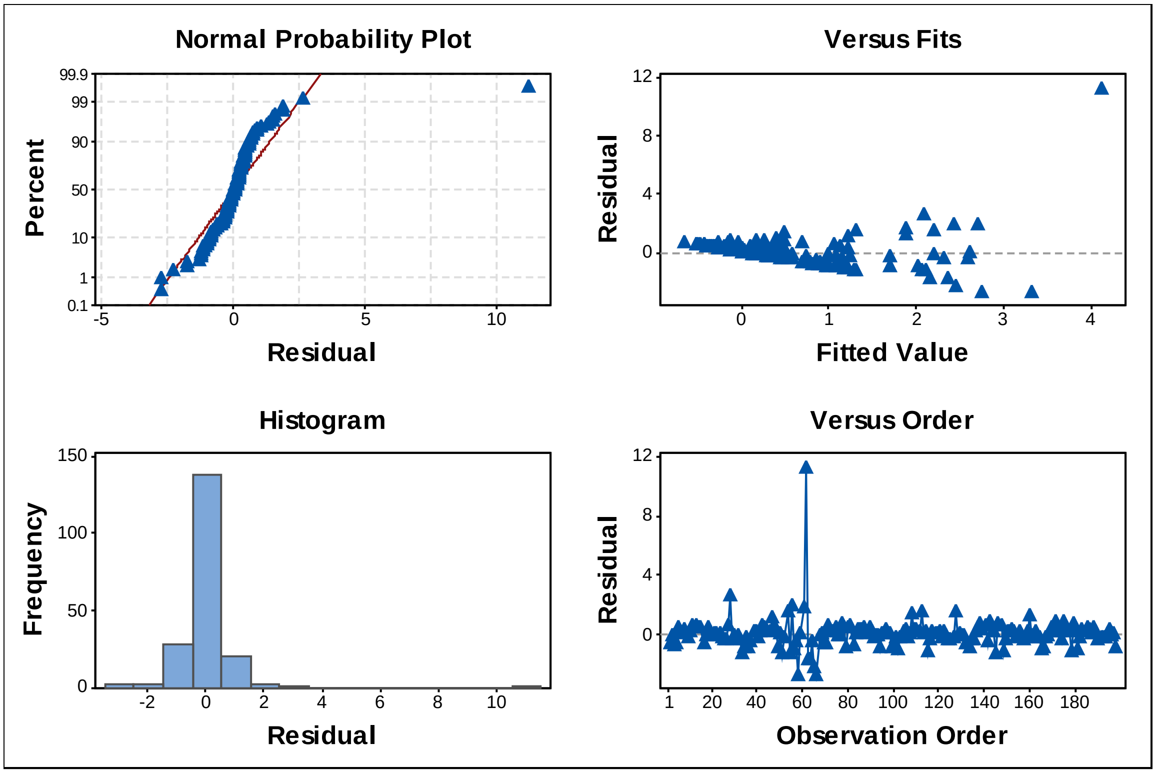


Figure 28: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a two-way Analysis of Covariance (ANCOVA) of the square root transformed sediment yields of six watersheds during control and treatment vegetative conditions only.

A Main Effects plot (Figure 29) of these data also highlighted J-SG's difference from the five other watersheds. J-SG's SQRT(mean) was greater than any of the other watersheds and even the overall SQRT(mean) of the dataset. The slopes between the watersheds, especially between J-SG and J1, are not parallel and this implied main effects occurred within the variables. Additionally, it is important to mention that the two grassland watersheds (P and P-SG) had SQRT(means) similar to that of the two eastern redcedar control watersheds (J1 and J2). This supported the claim of section 4.2.1 that the sediment yields between grassland and eastern redcedar vegetation were statistically similar. The Main Effects plot of the Phase variable suggested Treatment phase 3 had a greater SQRT(mean) than Pretreatment Phase 0 and that its non-parallel line showed influences of main effects. The Interaction Plot (Figure 30) revealed that within the Watershed*Phase plot (bottom left) there was a significant interaction between the J-

RP, J-SG, and J1 watersheds and the two phases. Similar interactions were observed in the Phase*Watershed plot where the three largest slope differences between Pretreatment phase 0 and Treatment phase 3 were between watersheds J-SG, J-RP, and J1, respectfully. The lesser slope difference between the control watersheds and P-SG, signaled a lesser interaction between the variables.

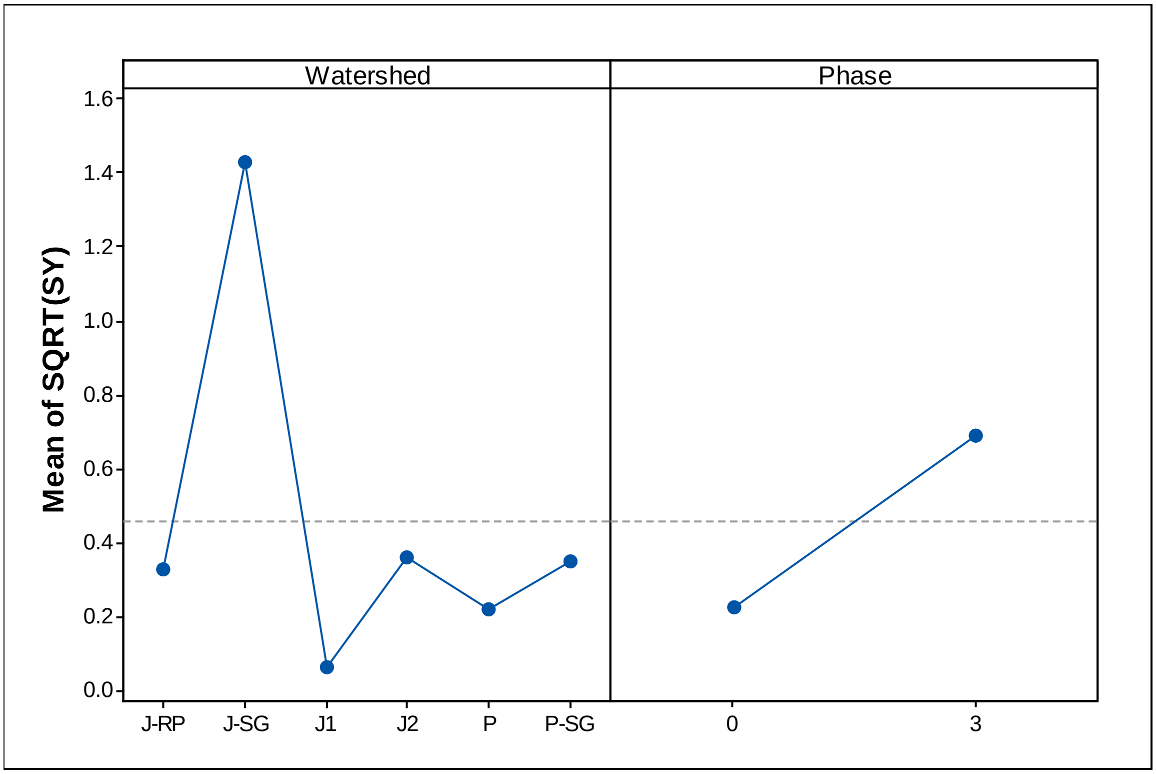


Figure 29: Main Effects plot of two-way Analysis of Covariance of the square root transformed sediment yields (SQRT(SY)) for watersheds Juniper to Recovering Prairie (J-RP), Juniper to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG), and Prairie Control (P) across Pretreatment (Phase 0) and Treatment (Phase 3) vegetative conditions. The units of SQRT(SY) are SQRT(g/m^2).

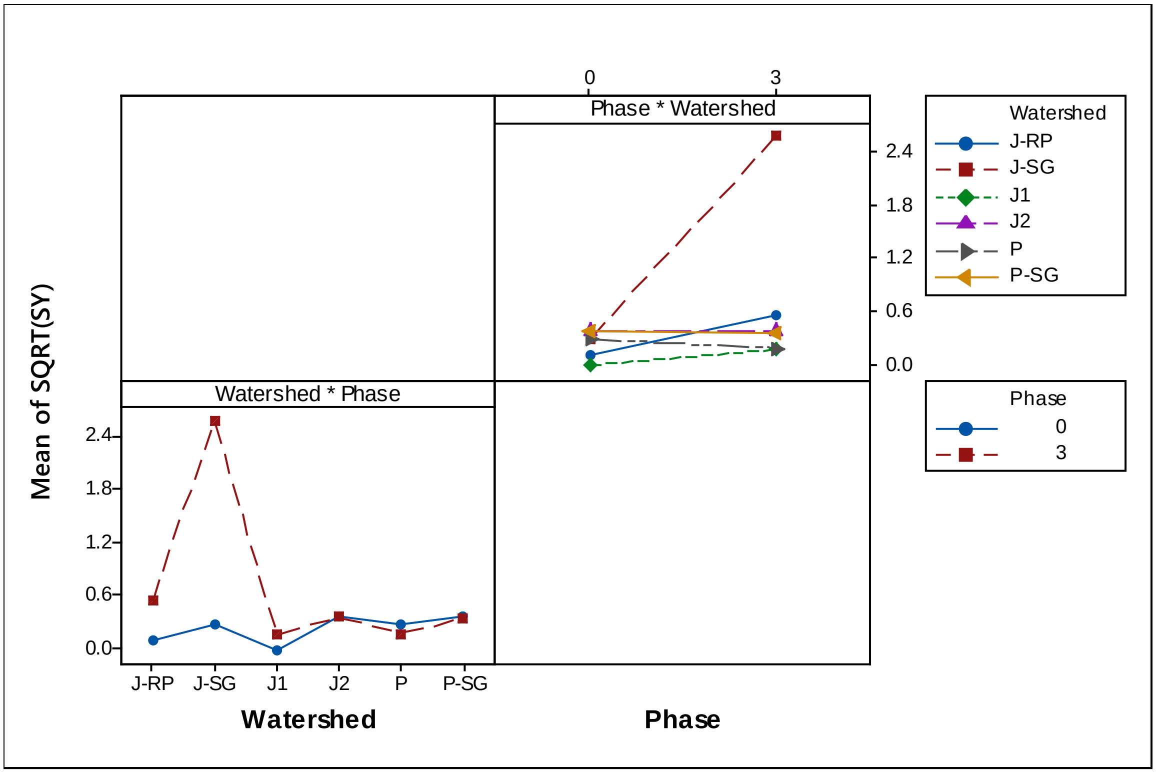


Figure 30: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of square root transformed sediment yields (SQRT(SY)). Watershed variable consisted of Juniper to Recovering Prairie (J-RP), Juniper Converted to Recovering Prairie (J-RP), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0) and Treatment (Phase 3). Units of SQRT(SY) are SQRT(g/m^2).

The results of a two-way ANCOVA of Log_{10}(FWAC) agreed with the results of the SQRT(SY) counterpart and showed all variables were statistically significant at an α=0.10. Similarly, a Tukey's Multiple Comparisons of the Watershed and Phase variables found similar results to that of the SQRT(SY) comparisons, where the Log_{10}(mean) of Treatment phase 3 was twice that of Pretreatment phase 0 and watershed J-SG had nearly double the Log_{10}(mean) than that of the second highest Log_{10}(mean). Within the Tukey's Multiple Comparison of the Interaction variable, all Treatment phase 3 Log_{10}(means) were larger than their Pretreatment phase 0 predecessors. Differences between Log_{10}(mean) hierarchy of Log_{10}(FWAC) and SQRT(SY) within the Tukey's Multiple Comparison were likely due to: the normalization of runoff by the response variable Log_{10}(FWAC), increased runoff within Treatment phase 3, and sediment influences of transitioning vegetation on flow-weighted average concentrations. Figure

31 shows the ANCOVA model's normal distribution, histogram, and residual values. The normal distribution of these data was not ideal, but had a better spread than the histogram of the SQRT(SY) ANCOVA. Table 24 shows the results of the two-way ANCOVA and Tukey's Multiple Comparisons analysis of the Watershed, Phase, and Interaction variables.

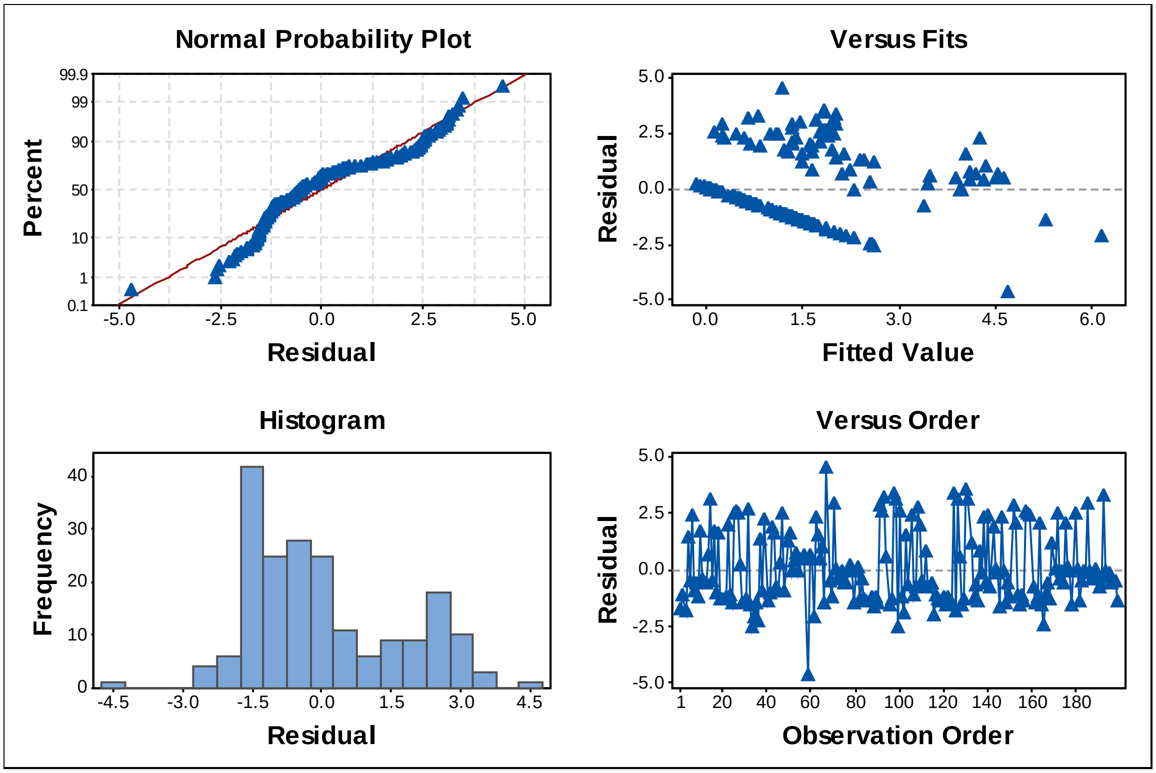


Figure 31: Four-in-one plot of residual normal distribution (top left), residual histogram (bottom left), residuals versus fits (top right), and residuals versus order (bottom right) for a two-way Analysis of Covariance (ANCOVA) of the Log_{10} transformed flow-weighted average concentrations of six watersheds during control and treatment vegetative conditions only.

Table 24: Results of two-way Analysis of Covariance (ANCOVA) and Tukey's Multiple Comparison of Watershed, Phase, and Interaction variables on Log_{10} transformed flow-weighted average concentrations for six watersheds during Pretreatment (Phase 0) and Treatment (Phase 3) vegetative conditions.

	Variable		P-value
Two-way ANCOVA	Response:	Flow-Weighted Avg. Conc., Log_{10}(ng/L)	n/a
	Treatment:	Watershed	< 0.001
	Treatment:	Phase	< 0.001
	Interaction:	Watershed*Phase	0.014
	Covariate:	Total Rainfall, (mm)	< 0.001

	Watershed	Concentration Mean		Grouping
		Log_{10}(ng/L)	mg/L	
Tukey's Multiple Comparisons	Juniper to Switchgrass (J-SG)	3.000	0.999	A
	Juniper Control 2 (J2)	1.524	0.032	B
	Juniper to Recovering Prairie (J-RP)	1.446	0.027	B
	Prairie to Switchgrass (P-SG)	1.223	0.016	B
	Prairie Control (P)	1.178	0.014	B
	Juniper Control 1 (J1)	0.609	0.003	B

	Phase	Concentration Mean		Grouping
		Log_{10}(ng/L)	mg/L	
Tukey's Multiple Comparisons	Treatment (Phase 3)	2.055	0.113	A
	Pretreatment (Phase 0)	0.938	0.008	B

Tukey's Multiple Comparison of Interaction Variable Group Means

Watershed*Phase		Concentration Mean		Grouping
Phase 0	Phase 3	Log_{10}(ng/L)	mg/L	
	J-SG	4.487	30.689	A
	J1	1.832	0.067	B
	J2	1.825	0.066	B
	J-RP	1.791	0.061	B
	P-SG	1.743	0.054	B
J-SG		1.514	0.032	B
J2		1.222	0.016	B
J-RP		1.101	0.012	B
P-SG		0.703	0.004	B
	P	0.651	0.003	B
P		0.567	0.003	B
J1		0.523	0.002	B

The Main Effects plot (i.e. Figure 32) showed that J-SG's and J2's SQRT(means) were greater than the overall SQRT(mean) and varied levels of main effects were present throughout the watersheds. The difference between this Main Effect plot and the SQRT(SY) counterpart was J1 and J2's greater Log_{10}(mean) than P. This supports section 4.2.1's claim that while eastern redcedar and grasslands had similar sediment yields, eastern redcedar watersheds had higher concentrations than grasslands. Analysis of the Phase plot of the Main Effects (Figure 32) shows Treatment phase 3 had greater Log10(means) than Pretreatment phase 1. This is in agreeance with the interpretations of the Main Effects plot of the SQRT(SY) data. Similarly, Figure 33 showed similar trends with the Interaction Plot of SQRT(SY). However, there was greater interaction between Juniper controls and P-SG. This was hypothesized to the influence of runoff on sediment concentrations and greater runoff interaction on the slopes of the Interaction plot.

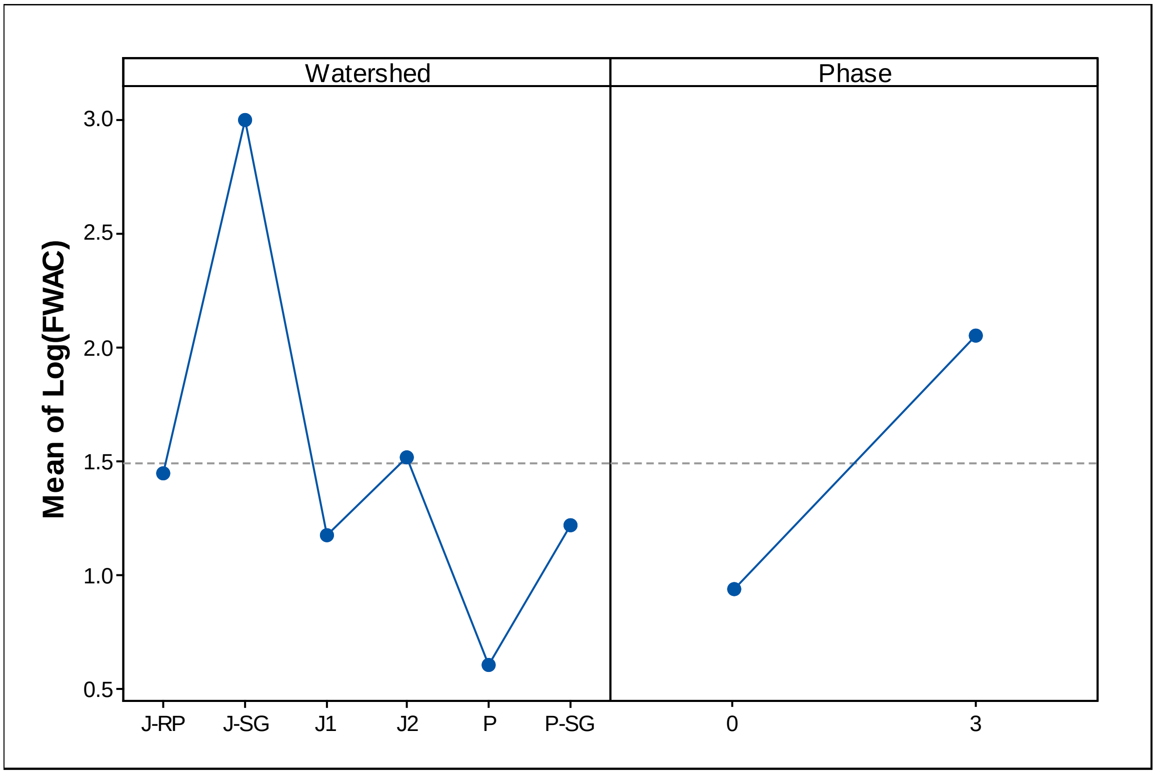


Figure 32: Main Effects plot of two-way Analysis of Covariance of the Log_{10} transformed flow-weighted average concentration (Log_{10}(FWAC)) for watersheds Juniper to Recovering Prairie (J-RP), Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG) and Prairie Control (P) during Pretreatment (Phase 0) and Treatment (Phase 3) vegetative conditions. The units of Log_{10}(FWAC) are Log_{10}(ng/L).

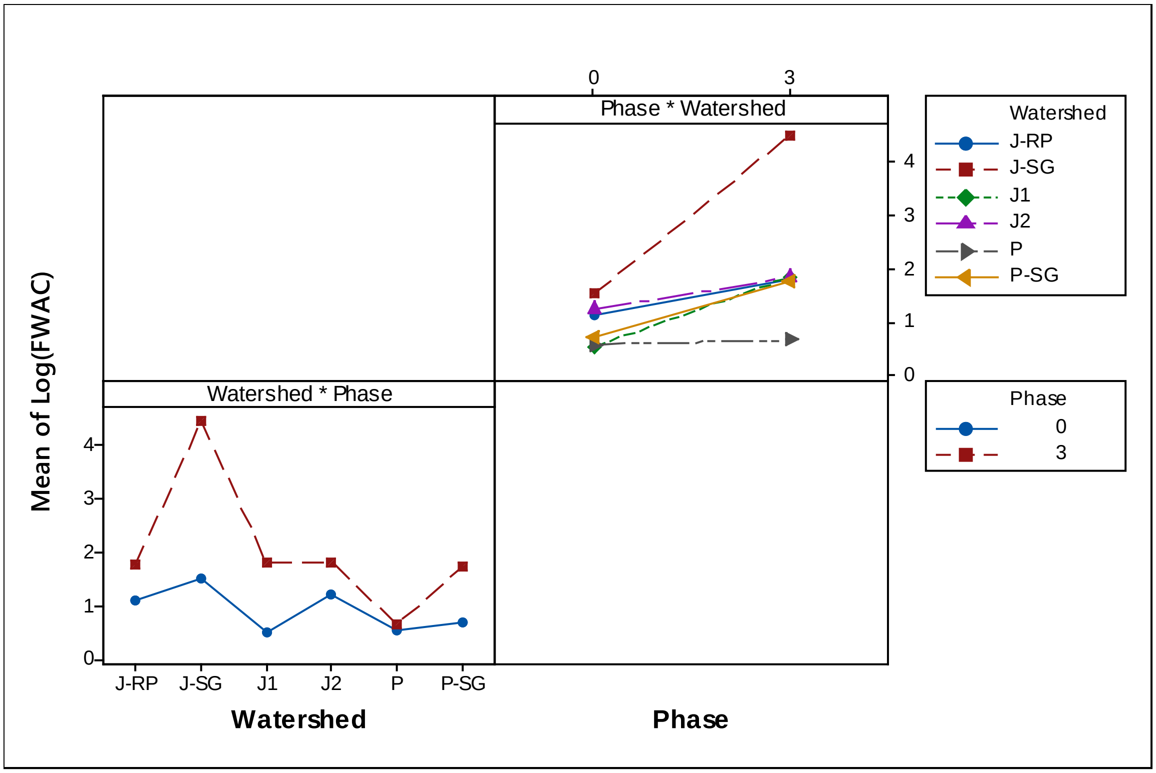


Figure 33: Interaction Plot of Watershed*Phase for two-way Analysis of Covariance (ANCOVA) of Log_{10} transformed flow-weighted average concentrations (Log_{10}(FWAC)). Watershed variable consisted of Juniper to Recovering Prairie (J-RP), Juniper Converted to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG), and Prairie Control (P), while the Phases variable consisted of Pretreatment (Phase 0) and Treatment (Phase 3). Units of Log_{10}(FWAC) are Log_{10}(ng/L).

The first concern with the transition of eastern redcedar vegetation to cultivated switchgrass, or even recovering prairie vegetation; was the observed increase of sediment yields caused by watershed land use alterations. Watershed vegetation alterations resulted in increased runoff and sediment within the three treatment watersheds. Therefore, the economic impacts of soil nutrient loss due to increased runoff must be considered when analyzing the cost-benefit analysis of this proposed solution to eastern redcedar encroachment. The second concern of these results was the greater sediment mean of J-SG compared to both J-RP and P-SG. Special preventative actions are recommended to minimize the sediment losses associated with altering encroached eastern redcedar rangelands and to reduce the future anthropogenic input required to grow suitable switchgrass biomass. Furthermore, while the sediment yields of J-SG were hypothesized to be skew due to the short timeframe of this phase (i.e. current sediment observation may not reflect mature switchgrass observation), preventative actions employed early on will economically offset sediment consequences in the future. Possible future benefits include: reduced fertilizer input required for establishing agricultural products, greater biomass yield due to raised soil health, or better ecosystem health to support the continued cultivation of agricultural products.

CHAPTER IV

CONCLUSIONS

No statistically significant differences were observed between sediment yield means of encroached eastern redcedar and grassland watersheds. However, grassland watersheds generated higher runoff volume compared to eastern redcedar rangelands, while eastern redcedar rangelands produced higher flow-weighted average sediment concentrations compared to grasslands. Furthermore, the mechanical harvest of eastern redcedar on the JS-G watershed resulted in statistically different sediment means compared to the control watershed J1; however more data are recommended to increase the statistical validity of the ANCOVA and corroborate the underlying assumptions. It should be noted that the analysis is based on using J1 as an eastern redcedar control, and there were statistical differences in sediment yield between the two eastern redcedar controls J1 and J2.

The conversion of eastern redcedar vegetation to either cultivated switchgrass or recovering prairie resulted in increased and statistically different sediment means compared to the eastern redcedar and prairie control. Delayed switchgrass planting influenced greater sediment yields from J-SG compared to J-RP. While no direct comparisons of eastern redcedar converted to switchgrass versus eastern redcedar converted to grasslands were available, the importance of watershed revegetation was highlighted in this study. Rainfall simulation of the various vegetation managements used in this study is recommended in order to better reduce the influences of climate variability on sediment data, while simultaneously increasing the sediment sample size for the statistical comparisons. Also, comparable vegetation timelines are needed to make direct comparisons between cultivated switchgrass and recovering prairie.

Statistical comparisons of treatment vegetation, i.e. switchgrass and recovering prairie, to control vegetation, i.e. eastern redcedar and prairie, showed significant differences in sediment means where treatment means were larger than the controls. More treatment sediment data are necessary to determine if current sediment means are reflective of mature treatment vegetation and to facilitate better comparisons between the watersheds. Additionally, socio-ecosystem indices are needed in order to further quantity the cost and life-cycle assessment of these proposed land use alterations. Ultimately, this research is the first steps toward determining the potential role of a combined eastern redcedar and switchgrass feedstock to alleviate socio-ecological concerns associated with woody plant encroachment in Oklahoma.

REFERENCES

Acharya, B. S., Hao, Y., Ochsner, T. E., & Zou, C. B. (2017). Woody plant encroachment alters soil hydrological properties and reduces downward flux of water in tallgrass prairie. *Plant and Soil, 414*(1-2), 379-391.

Alford, A. L., Hellgren, E. C., Limb, R., & Engle, D. M. (2012). Experimental tree removal in tallgrass prairie: variable responses of flora and fauna along a woody cover gradient. *Ecological Applications, 22*(3), 947-958.

Anderson, M. D. (2003). *Juniperus virginiana*. Available from United States Department of Agriculture Forest Service Fire Effects Information Systems Retrieved 10/2/2018 https://www.fs.fed.us/database/feis/plants/tree/junvir/all.html#REFERENCES

Auken, O., & Smeins, F. (2008). Western North American Juniperus communities: patterns and causes of distribution and abundance. *Western North American Juniperus Communities*, 3-18.

Boval, M., & Dixon, R. (2012). The importance of grasslands for animal production and other functions: a review on management and methodological progress in the tropics. *Animal, 6*(05), 748-762.

Caterina, G. L., Will, R. E., Turton, D. J., Wilson, D. S., & Zou, C. B. (2014). Water use of *Juniperus virginiana* trees encroached into mesic prairies in Oklahoma, USA. *Ecohydrology, 7*(4), 1124-1134.

David, K., & Ragauskas, A. J. (2010). Switchgrass as an energy crop for biofuel production: a review of its ligno-cellulosic chemical properties. *Energy & Environmental Science, 3*(9), 1182-1190.

Engle, D. M., Bidwell, T. G., & Moseley, M. E. (1996). *Invasion of Oklahoma rangelands and forests by eastern redcedar and ashe juniper*: Oklahoma Cooperative Extension Service, Division of Agricultural Sciences and Natural Resources, Oklahoma State University.

Engle, D. M., Coppedge, B. R., & Fuhlendorf, S. D. (2008). From the dust bowl to the green glacier: human activity and environmental change in Great Plains grasslands. *Western North American Juniperus Communities*, 253-271.

Fargione, J. E., Cooper, T. R., Flaspohler, D. J., Hill, J., Lehman, C., McCoy, T., . . . Tilman, D. (2009). Bioenergy and wildlife: threats and opportunities for grassland conservation. *Bioscience, 59*(9), 767-777.

Feng, Q., Chaubey, I., Cibin, R., Engel, B., Sudheer, K., Volenec, J., & Omani, N. (2018). Perennial biomass production from marginal land in the Upper Mississippi River Basin. *Land Degradation & Development*.

Fu, C., Mielenz, J. R., Xiao, X., Ge, Y., Hamilton, C. Y., Rodriguez, M., . . . Bouton, J. (2011). Genetic manipulation of lignin reduces recalcitrance and improves ethanol production from switchgrass. *Proceedings of the National Academy of Sciences, 108*(9), 3803-3808.

Fuhlendorf, S. D., Archer, S. A., Smeins, F., Engle, D. M., & Taylor, C. A. (2008). The combined influence of grazing, fire, and herbaceous productivity on tree–grass interactions. *Western North American Juniperus Communities*, 219-238.

Gu, Y., & Wylie, B. K. (2017). Mapping marginal croplands suitable for cellulosic feedstock crops in the Great Plains, United States. *Gcb Bioenergy, 9*(5), 836-844.

Hartman, J. C., Nippert, J. B., Orozco, R. A., & Springer, C. J. (2011). Potential ecological impacts of switchgrass (*Panicum virgatum L.*) biofuel cultivation in the Central Great Plains, USA. *biomass and bioenergy, 35*(8), 3415-3421.

Heilman, J. L., Litvak, M. E., McInnes, K. J., Kjelgaard, J. F., Kamps, R. H., & Schwinning, S. (2014). Water-storage capacity controls energy partitioning and water use in karst ecosystems on the Edwards Plateau, Texas. *Ecohydrology, 7*(1), 127-138.

Holthuijzen, A. M., Sharik, T. L., & Fraser, J. D. (1987). Dispersal of eastern red cedar (*Juniperus virginiana*) into pastures: an overview. *Canadian Journal of Botany, 65*(6), 1092-1095.

Knapp, A. K., McCarron, J., Silletti, A., Hoch, G., Heisler, J., Lett, M., . . . Smith, M. (2008). Ecological consequences of the replacement of native grassland by *Juniperus virginiana* and other woody plants *Western North American Juniperus Communities* (pp. 156-169): Springer.

Limb, R. F., Engle, D. M., Alford, A. L., & Hellgren, E. C. (2010). Tallgrass prairie plant community dynamics along a canopy cover gradient of eastern redcedar (*Juniperus virginiana L.*). *Rangeland Ecology & Management, 63*(6), 638-644.

Lisenbee, W. A. (2016). *Comparison of water quality and quantity in Eastern Redcedar-encroached woodland and native tallgrass prairie watersheds: A monitoring and modeling study*. Oklahoma State University.

Lisenbee, W. A., Fox, G. A., Saenz, A., & Miller, R. B. (2017). Comparison of Field Jet Erosion Tests and Wepp-Predicted Erodibility Parameters for Varying Land Cover. *Transactions of the Asabe, 60*(1), 173-184. doi:10.13031/trans.12012

Liu, X., Singh, S., Gibbemeyer, E. L., Tam, B. E., Urban, R. A., & Bakshi, B. R. (2018). The carbon-nitrogen nexus of transportation fuels. *Journal of Cleaner Production, 180*, 790-803.

Lyons, R. K., Owens, M. K., & Machen, R. V. (2009). Juniper biology and management in Texas. *Texas FARMER Collection*.

McKinley, C. R. (2012). The Oklahoma Redcedar resource and its potential biomass energy. *Oklahoma Cooperative Extension Service. NREM-5054*, 1-4.

McKinley, D. C., Norris, M. D., Blair, J. M., & Johnson, L. C. (2008). Altered ecosystem processes as a consequence of *Juniperus virginiana L.* encroachment into North American tallgrass prairie. *Western North American Juniperus Communities*, 170-187.

Meals, D., Richards, R., & Dressing, S. (2013). Pollutant load estimation for water quality monitoring projects. *Tech Notes, 8*, 1-21.

Morton, L. W., Regen, E., Engle, D. M., Miller, J. R., & Harr, R. N. (2010). Perceptions of landowners concerning conservation, grazing, fire, and eastern redcedar management in tallgrass prairie. *Rangeland Ecology & Management*, *63*(6), 645-654.

Owens, M. K. (2008). Juniper tree impacts on local water budgets. *Western North American Juniperus Communities*, 188-201.

Pierce, A. M., & Reich, P. B. (2010). The effects of eastern red cedar (*Juniperus virginiana*) invasion and removal on a dry bluff prairie ecosystem. *Biological Invasions, 12*(1), 241-252.

Poesen, J., De Luna, E., Franca, A., Nachtergaele, J., & Govers, G. (1999). Concentrated flow erosion rates as affected by rock fragment cover and initial soil moisture content. Catena, 36(4), 315-329.

Puttock, A., Dungait, J. A., Macleod, C. J., Bol, R., & Brazier, R. E. (2014). Woody plant encroachment into grasslands leads to accelerated erosion of previously stable organic carbon from dryland soils. *Journal of Geophysical Research: Biogeosciences, 119*(12), 2345-2357.

Qiao, L., Zou, C. B., Stebler, E., & Will, R. E. (2017). Woody plant encroachment reduces annual runoff and shifts runoff mechanisms in the tallgrass prairie, USA. *Water Resources Research*.

Ramli, N. N., & Epplin, F. M. (2017). Cost to produce liquid biofuel from invasive eastern redcedar biomass. *biomass and bioenergy, 104*, 45-52.

Rowe, H. I. (2010). Tricks of the Trade: Techniques and Opinions from 38 Experts in Tallgrass Prairie Restoration. *Restoration Ecology, 18*, 253-262. doi:10.1111/j.1526-100X.2010.00663.x

Saintilan, N., & Rogers, K. (2015). Woody plant encroachment of grasslands: a comparison of terrestrial and wetland settings. *New Phytologist, 205*(3), 1062-1070.

Sanford, G. R., Oates, L. G., Roley, S. S., Duncan, D. S., Jackson, R. D., Robertson, G. P., & Thelen, K. D. (2017). Biomass production a stronger driver of cellulosic ethanol yield than biomass quality. *Agronomy Journal, 109*(5), 1911-1922.

Sanjuán, Y., Arnáez, J., Beguería, S., Lana-Renault, N., Lasanta, T., Gómez-Villar, A., . . . García-Ruiz, J. M. (2018). Woody plant encroachment following grazing abandonment in the subalpine belt: a case study in northern Spain. *Regional Environmental Change, 18*(4), 1103-1115.

Smith, S. (2011). *Eastern red-cedar: positives, negatives and management*: Samuel Roberts Noble Foundation.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Available online at the following link: http://websoilsurvey.sc.egov.usda.gov/. Accessed 10/03 /2016

Somerville, C., Youngs, H., Taylor, C., Davis, S. C., & Long, S. P. (2010). Feedstocks for lignocellulosic biofuels. *science, 329*(5993), 790-792.

Standard Test Methods for Determining Sediment Concentration in Water Samples. (2013).

Starks, P., & Moriasi, D. (2017). Impact of Eastern redcedar encroachment on stream discharge in the North Canadian River basin. *Journal of soil and water conservation, 72*(1), 12-25.

Stebler, E. (2018, November 26). Personal interview.

Stritzke, J. F., & Bidwell, T. G. (1990). Eastern redcedar and its control. *Oklahoma State Univ Ext Facts F-2850*.

Taylor, C. A. (2008). Ecological consequences of using prescribed fire and herbivory to manage Juniperus encroachment. *Western North American Juniperus Communities*, 239-252.

Venter, Z., Cramer, M., & Hawkins, H.-J. (2018). Drivers of woody plant encroachment over Africa. *Nature communications, 9*(1), 2272.

Wang, J., Xiao, X., Qin, Y., Doughty, R. B., Dong, J., & Zou, Z. (2018). Characterizing the encroachment of juniper forests into sub-humid and semi-arid prairies from 1984 to 2010 using PALSAR and Landsat data. *Remote Sensing of Environment, 205*, 166-179.

Wang, M., Han, J., Dunn, J. B., Cai, H., & Elgowainy, A. (2012). Well-to-wheels energy use and greenhouse gas emissions of ethanol from corn, sugarcane and cellulosic biomass for US use. *Environmental research letters, 7*(4), 045905.

Wayne, R., & Van Auken, O. (2008). Comparison of the understory vegetation of Juniperus woodlands *Western North American Juniperus Communities* (pp. 93-110): Springer.

Wilcox, B. P. (2008). Juniperus woodlands and the water cycle on karst rangelands. *Western North American Juniperus Communities*, 202-215.

Wilcox, B. P., & Huang, Y. (2010). Woody plant encroachment paradox: Rivers rebound as degraded grasslands convert to woodlands. *Geophysical Research Letters, 37*(7).

Wine, M. L., Hendrickx, J. M., Cadol, D., Zou, C. B., & Ochsner, T. E. (2015). Deep drainage sensitivity to climate, edaphic factors, and woody encroachment, Oklahoma, USA. Hydrological Processes, 29(17), 3779-3789.

Wine, M. L., Ochsner, T. E., Sutradhar, A., & Pepin, R. (2012). Effects of eastern redcedar encroachment on soil hydraulic properties along Oklahoma's grassland-forest ecotone. *Hydrological Processes, 26*(11), 1720-1728.

Wu, Y., Zhao, F., Liu, S., Wang, L., Qiu, L., Alexandrov, G., & Jothiprakash, V. (2018). Bioenergy production and environmental impacts. *Geoscience Letters*, *5*(1), 14.

Zaibon, S., Anderson, S. H., Kitchen, N. R., & Haruna, S. I. (2016). Hydraulic properties affected by topsoil thickness in switchgrass and corn–soybean cropping systems. *Soil Science Society of America Journal, 80*(5), 1365-1376.

Zhong, Yu. (2018, November 26). Personal interview.

Zou, C. B., Turton, D. J., Will, R. E., Engle, D. M., & Fuhlendorf, S. D. (2014). Alteration of hydrological processes and streamflow with juniper (*Juniperus virginiana*) encroachment in a mesic grassland catchment. *Hydrological Processes, 28*(26), 6173-6182.

APPENDICES

APPENDIX A: H-FLUME DEPOSITED SEDIMENT

Table 25: Individual events that required manual removal of sediment deposited in H-flume across respected watersheds Juniper to Recovering Prairie (J-RP), Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG), and Prairie Control (P).

Event Number	Event Date	Dried Sediment (Kg) Deposited In Watershed H-Flumes					
		J-RP	J-SG	J1	J2	P-SG	P
1	1/17/2017	0.0	32.5	0.0	0.0	0.0	0.0
2	1/24/2017	0.0	6.0	0.0	0.0	0.0	0.0
3	2/19/2017	22.6	174.0	0.0	0.0	0.0	0.0
4	3/28/2017	5.6	58.6	0.0	0.0	0.0	0.0
5	4/2/2017	0.0	37.4	0.0	0.0	0.0	0.0
6	4/13/2017	0.0	8.2	0.0	0.0	0.0	0.0
7	4/17/2017	0.0	5.0	0.0	0.0	0.0	0.0
8	4/21/2017	6.2	214.4	0.0	0.0	0.0	0.0
9	4/29/2017	51.8	477.1	0.0	0.0	0.0	0.0
10	5/10/2017	0.0	84.6	0.0	0.0	0.0	0.0
11	5/19/2017	0.0	76.0	0.0	0.0	0.0	0.0
12	6/3/2017	0.0	18.9	0.0	0.0	0.0	0.0
13	6/18/2017	0.0	72.2	0.0	0.0	0.0	0.0
14	6/30/2017	0.0	59.0	0.0	0.0	0.0	0.0
15	7/2/2017	27.4	332.8	0.0	27.6	0.0	0.0
16	10/4/2017	6.4	12.6	0.0	15.4	0.0	0.0
17	10/21/2017	2.2	1.4	0.0	0.0	0.0	0.0

APPENDIX B: RAW DATA TABLE

Table 26: Raw data table of seventy seven sediment producing events within watersheds Juniper to Recovering Prairie (J-RP), Juniper to Switchgrass (J-SG), Juniper Control 1 (J1), Juniper Control 2 (J2), Prairie to Switchgrass (P-SG), and Prairie Control (P).

Event Number	Precipitation Start Date			Precipitation End Date			Total Rainfall	J-RP Event Runoff	J-RP Event Sediment	J-SG Event Runoff	J-SG Event Sediment	J1 Event Runoff	J1 Event Sediment	J2 Event Runoff	J2 Event Sediment	P-SG Event Runoff	P-SG Event Sediment	P Event Runoff	P Event Sediment
n/a	*date*		*time*	*date*	*@*	*time*	*mm*	*(mm)*	*(g/*m2)*	*(mm)*	*(g/*m2)*	*(mm)*	*(g/*m2)*	*(mm)*	*(g/*m2)*	*(mm)*	*(g/*m2)*	*(mm)*	*(g/*m2)*
1	11/3/2014	@	17:00	11/4/2014	@	8:40	49.0	0.0041	0.0000	0.0000	0.0000	0.0316	0.1825	0.1165	0.1430	0.0196	0.0000	0.0289	0.0000
2	4/13/2015	@	3:10	4/13/2015	@	14:35	26.7	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0082	0.0122	0.0000	0.0000	0.0125	0.0000
3	4/27/2015	@	4:45	4/28/2015	@	7:05	53.3	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0271	0.0000	2.4556	0.5296	2.5733	0.6846
4	5/5/2015	@	15:30	5/6/2015	@	3:25	59.2	0.4363	0.0729	1.0721	0.4316	0.0651	0.0335	1.7957	0.8548	13.6302	1.8750	12.8443	2.3812
5	5/7/2015	@	15:45	5/7/2015	@	19:35	6.6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.4540	0.0719	0.1834	0.0000
6	5/8/2015	@	16:20	5/8/2015	@	20:40	21.6	0.2157	0.0298	0.4332	0.1215	0.0000	0.0000	0.8050	0.2492	6.2754	1.0015	5.5235	0.9008
7	5/13/2015	@	7:55	5/14/2015	@	4:05	22.9	0.0000	0.0000	0.0031	0.0000	0.0000	0.0000	0.0172	0.0000	1.9036	0.3051	1.3342	0.2183
8	5/15/2015	@	5:00	5/15/2015	@	7:05	9.4	0.0187	0.0000	0.0141	0.0000	0.0000	0.0000	0.0000	0.0000	1.4171	0.2442	1.0191	0.0000
9	5/16/2015	@	19:35	5/16/2015	@	21:00	29.7	1.9353	0.0000	4.0706	0.9171	0.0000	0.0000	4.2374	3.3192	15.7632	0.0000	14.3722	0.0000
10	5/19/2015	@	13:05	5/19/2015	@	18:45	30.0	1.4324	0.1480	2.7983	0.6428	0.0000	0.0000	2.7018	0.5801	12.2545	1.6869	11.1939	1.5440
11	5/20/2015	@	14:55	5/20/2015	@	15:20	1.0	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.8396	0.1141	0.7578	0.0000
12	5/22/2015	@	6:10	5/22/2015	@	9:30	7.6	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0431	0.0000	0.4420	0.0000	0.3107	0.0000
13	5/23/2015	@	13:25	5/24/2015	@	18:35	62.5	9.1628	2.5737	18.6408	5.1652	0.0000	0.0000	20.4278	7.5834	48.5013	0.0000	43.4442	0.0000
14	5/26/2015	@	20:15	5/26/2015	@	23:10	9.7	0.0617	0.0137	0.1695	0.0319	0.0000	0.0000	0.0025	0.0000	2.8141	0.3746	2.3841	0.3679
15	5/28/2015	@	5:55	5/28/2015	@	7:25	5.6	0.0000	0.0000	0.0088	0.0012	0.0000	0.0000	0.0000	0.0000	1.1030	0.2059	1.0159	0.0000
16	6/12/2015	@	20:40	6/13/2015	@	12:45	56.9	0.1620	0.0333	0.2352	0.0379	0.0093	0.0000	0.0553	0.0000	0.0434	0.0000	0.0723	0.0000
17	6/17/2015	@	23:20	6/18/2015	@	10:10	24.6	0.2850	0.0000	0.6185	0.0930	0.0000	0.0000	0.0000	0.0000	0.4359	0.0000	0.3511	0.0000
18	7/9/2015	@	3:15	7/9/2015	@	12:35	24.1	0.0672	0.0381	0.1259	0.0373	0.0312	0.0161	0.0647	0.0000	0.1139	0.0443	0.0784	0.0224
19	8/22/2015	@	0:40	8/22/2015	@	7:55	36.6	0.8965	0.4005	0.4583	0.1626	0.0872	0.0202	0.1383	0.0987	0.0456	0.0089	0.0398	0.0000
20	9/11/2015	@	0:55	9/11/2015	@	8:10	37.9	0.1465	0.0641	0.2325	0.0585	0.0198	0.0000	0.0787	0.0000	0.0042	0.0000	0.0041	0.0000
21	10/30/2015	@	7:30	10/31/2015	@	2:05	43.7	0.1481	0.0481	0.2126	0.0506	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
22	11/5/2015	@	10:15	11/5/2015	@	11:40	33.3	3.9106	1.5048	5.9922	1.5185	0.0806	0.0421	0.1122	0.1242	0.2122	0.0400	0.2904	0.0000
23	11/16/2015	@	21:50	11/17/2015	@	8:25	24.6	1.4113	0.3840	0.8508	0.0000	0.0142	0.0000	0.0062	0.0000	0.0099	0.0000	0.0041	0.0000
24	11/26/2015	@	12:30	11/27/2015	@	16:20	52.3	6.2246	1.0792	10.7068	2.0146	0.0000	0.0000	1.0113	0.0851	0.0168	0.0000	0.0103	0.0000
25	11/28/2015	@	6:40	11/29/2015	@	13:20	20.1	6.5223	0.0000	6.4509	0.0000	0.0000	0.0000	0.7571	0.0000	0.4549	0.0000	0.1841	0.0000
26	12/13/2015	@	1:40	12/13/2015	@	10:40	34.3	7.5814	1.1721	6.7575	0.8447	0.0284	0.0000	6.3195	0.0000	7.5266	0.8857	6.5532	1.3284
27	12/26/2015	@	10:40	12/27/2015	@	19:45	51.8	17.3016	0.0000	3.9806	0.5650	0.0000	0.0000	3.2843	0.4239	9.9018	0.9613	16.4204	1.5987
28	2/1/2016	@	21:35	2/2/2016	@	1:40	29.0	0.5118	0.3746	1.3593	0.8554	0.0000	0.0000	0.0000	0.0000	0.1346	0.0000	2.8577	5.2314
29	3/8/2016	@	9:30	3/8/2016	@	12:15	24.6	0.6087	0.2036	0.9150	0.3945	0.0075	0.0000	0.0000	0.0000	0.0252	0.0000	0.0944	0.0000
30	3/13/2016	@	8:00	3/13/2016	@	13:55	26.2	4.3958	1.0910	6.7458	2.1950	0.0186	0.0000	0.0000	0.0000	12.5659	2.8043	8.0589	1.2114
31	4/17/2016	@	3:25	4/17/2016	@	13:30	35.6	1.6134	0.3731	3.4680	0.0000	0.0000	0.0000	0.0135	0.0000	0.8196	0.0000	1.7693	0.4523
32	4/17/2016	@	20:20	4/18/2016	@	2:10	21.6	8.6312	2.6508	8.9855	0.0000	0.0000	0.0000	0.3209	0.0000	14.3340	0.0000	11.6890	2.0773
33	4/26/2016	@	19:05	4/26/2016	@	22:00	40.9	13.6922	10.3397	16.8109	0.0000	0.0692	0.0000	2.4984	0.0000	18.9790	0.0000	17.0938	7.2342
34	5/15/2016	@	21:10	5/16/2016	@	5:50	21.6	0.4364	0.2035	0.3958	0.2544	0.0066	0.0000	0.0366	0.0000	0.0714	0.0000	0.0705	0.0000
35	5/17/2016	@	0:25	5/17/2016	@	4:20	6.9	0.1290	0.0000	0.1342	0.0430	0.0000	0.0000	0.0000	0.0000	0.0644	0.0000	0.0330	0.0000
36	5/24/2016	@	14:55	5/24/2016	@	22:45	15.0	0.4122	0.4163	0.4944	0.1364	0.0076	0.0000	0.0170	0.0000	0.1162	0.0000	0.0372	0.0000
37	5/31/2016	@	6:05	5/31/2016	@	7:20	22.9	1.7018	1.6468	3.0910	0.0000	0.0208	0.0000	0.0404	0.0000	2.7394	0.3181	0.0583	0.0143
38	6/18/2016	@	5:30	6/18/2016	@	6:30	22.6	0.3009	0.2543	0.6739	0.0000	0.0000	0.0000	0.0438	0.0000	1.0754	0.2647	0.0063	0.0000
39	7/3/2016	@	14:40	7/3/2016	@	15:05	14.2	0.6842	0.6457	2.4177	4.2813	0.0000	0.0000	0.0435	0.0388	3.8453	0.7159	0.0031	0.0000
40	7/8/2016	@	6:20	7/8/2016	@	8:15	27.7	1.3780	1.4148	4.9610	10.9667	0.0000	0.0000	0.0803	0.0382	8.5704	1.3252	0.0229	0.0025
41	7/14/2016	@	10:50	7/14/2016	@	11:40	7.6	0.2147	0.0000	0.1689	0.2441	0.0011	0.0000	0.0049	0.0000	0.0537	0.0000	0.0021	0.0000
42	8/25/2016	@	16:55	8/25/2016	@	23:45	30.7	0.0057	0.0000	0.0725	0.1133	0.0000	0.0000	0.0509	0.0000	0.0057	0.0000	0.0062	0.0000
43	8/31/2016	@	14:05	8/31/2016	@	17:35	13.7	0.0019	0.0000	0.0377	0.0824	0.0000	0.0000	0.0074	0.0000	0.0028	0.0000	0.0062	0.0000
44	9/9/2016	@	21:10	9/10/2016	@	2:05	27.7	0.0084	0.0000	2.4289	5.2887	0.0038	0.0000	0.0037	0.0000	1.8989	0.7580	0.0010	0.0000
45	9/17/2016	@	16:25	9/17/2016	@	17:35	13.7	0.0045	0.0000	0.1315	0.1331	0.0000	0.0000	0.0000	0.0000	0.5767	0.1878	0.0072	0.0000
46	9/24/2016	@	19:35	9/25/2016	@	11:10	28.5	0.0597	0.0000	1.7586	2.6028	0.0129	0.0000	0.0157	0.0000	0.0659	0.0000	0.0094	0.0000
47	10/6/2016	@	5:05	10/6/2016	@	7:10	57.9	8.9271	11.5412	27.9794	136.7712	0.1843	0.0321	0.3338	0.2282	29.7928	3.9628	0.4804	0.0000
48	10/6/2016	@	20:40	10/6/2016	@	21:45	22.1	4.0875	3.2504	12.6015	0.0000	0.0682	0.0087	0.2926	0.2380	16.0356	0.0000	0.4240	0.0000
49	10/26/2016	@	7:05	10/26/2016	@	11:25	10.4	0.0013	0.0000	0.0533	0.2002	0.0041	0.0000	0.0012	0.0000	0.0043	0.0000	0.0125	0.0000
50	11/2/2016	@	21:00	11/2/2016	@	23:45	19.1	0.0348	0.0000	1.1758	4.4343	0.0000	0.0000	0.0037	0.0000	0.0114	0.0000	0.0041	0.0000
51	1/14/2017	@	16:35	1/16/2017	@	1:40	52.1	0.0000	0.0000	7.1229	1.5875	0.0135	0.0000	0.0000	0.0000	0.0636	0.0000	0.0000	0.0000
52	2/13/2017	@	17:20	2/14/2017	@	13:05	26.4	0.0000	0.0000	0.0696	0.0648	0.0000	0.0000	0.0000	0.0000	0.0651	0.0000	0.0000	0.0000
53	2/19/2017	@	22:10	2/20/2017	@	4:40	37.1	5.1828	2.7893	12.5536	80.9625	0.0662	0.0000	0.0000	0.0000	10.6246	1.6075	7.8572	1.3678
54	3/28/2017	@	14:50	3/29/2017	@	5:25	48.3	2.7859	1.0901	7.1352	15.8424	0.0415	0.0000	0.0000	0.0000	0.6183	0.0000	4.4510	0.9450
55	4/2/2017	@	23:00	4/3/2017	@	5:25	19.8	2.7729	0.7318	5.1453	9.8825	0.0165	0.0000	0.0000	0.0000	3.0326	0.0000	3.7259	0.0000
56	4/4/2017	@	1:25	4/4/2017	@	2:40	11.7	2.1005	0.4060	3.5391	3.5489	0.0142	0.0000	0.0000	0.0000	4.9077	1.2027	3.7789	0.6577
57	4/4/2017	@	16:30	4/4/2017	@	16:40	3.6	0.5093	0.0990	0.4697	1.7824	0.0000	0.0000	0.0000	0.0000	1.0313	0.1333	2.1498	0.0000
58	4/13/2017	@	15:10	4/13/2017	@	21:40	22.9	0.5394	0.1529	0.6702	1.1260	0.0040	0.0000	0.0000	0.0000	1.6608	0.3068	2.4819	0.4390
59	4/17/2017	@	5:55	4/17/2017	@	10:20	5.3	0.1033	0.0273	0.0682	0.0000	0.0018	0.0000	0.0000	0.0000	0.1558	0.0000	0.6275	0.0000
60	4/20/2017	@	21:50	4/21/2017	@	13:20	41.9	12.1514	4.5079	15.9799	0.0000	0.0470	0.0162	2.3457	0.7234	20.7882	4.0749	19.1062	2.6859
61	4/29/2017	@	0:45	4/30/2017	@	3:10	113.8	80.9355	60.0977	73.2499	722.9881	0.5974	0.7056	37.7451	9.3436	94.1490	35.5767	84.0559	10.2688
62	5/3/2017	@	2:10	5/3/2017	@	8:10	7.1	0.6835	0.2518	0.2944	0.5690	0.0000	0.0000	0.0938	0.0000	0.4222	0.0000	1.5286	0.0000
63	5/10/2017	@	20:15	5/10/2017	@	21:05	10.7	0.3456	0.0000	0.8919	3.7536	0.0053	0.0000	0.0202	0.0000	0.0812	0.0275	0.1494	0.0000
64	5/11/2017	@	13:50	5/11/2017	@	14:20	10.7	0.7478	0.0000	2.0337	13.3744	0.0068	0.0000	0.0615	0.0000	0.2970	0.0803	0.1717	0.0269
65	5/11/2017	@	23:40	5/12/2017	@	2:55	5.3	0.3160	0.0000	0.4467	0.6016	0.0000	0.0000	0.1838	0.0000	0.4655	0.0000	0.5381	0.0000
66	5/18/2017	@	17:20	5/19/2017	@	8:55	19.3	0.3812	0.2268	2.2877	18.2964	0.0011	0.0000	0.0025	0.0000	0.0313	0.0000	0.1935	0.0000
67	5/19/2017	@	20:20	5/19/2017	@	21:25	3.6	0.0478	0.0000	0.3147	0.9715	0.0000	0.0000	0.0000	0.0000	0.0077	0.0000	0.0000	0.0000
68	6/3/2017	@	0:55	6/3/2017	@	18:00	14.7	0.1991	0.0000	0.5274	3.3580	0.0094	0.0000	0.0107	0.0000	0.0000	0.0000	0.0041	0.0000
69	6/18/2017	@	2:00	6/18/2017	@	5:00	32.5	0.1712	0.1132	3.0462	0.0000	0.0308	0.0149	0.0322	0.0275	0.0407	0.0091	0.0149	0.0000
70	6/30/2017	@	3:30	6/30/2017	@	6:25	26.7	0.0632	0.0289	1.8454	6.5921	0.0298	0.0075	0.0320	0.0000	0.0581	0.0133	0.0139	0.0000
71	7/2/2017	@	14:30	7/2/2017	@	15:10	30.7	1.7894	1.5984	6.8855	20.4893	0.0611	0.0545	0.0592	0.0577	1.3822	0.4295	0.0829	0.0103
72	7/3/2017	@	20:00	7/3/2017	@	23:45	85.3	30.1650	21.9052	42.4320	233.1810	0.5672	0.4831	17.1155	11.8129	50.5461	9.5496	26.5621	1.9985
73	8/11/2017	@	1:20	8/11/2017	@	6:20	16.5	0.0048	0.0000	0.0259	0.3045	0.0073	0.0000	0.0474	0.0000	0.0085	0.0000	0.0041	0.0000
74	8/15/2017	@	14:05	8/15/2017	@	19:30	8.6	0.0040	0.0000	0.0617	0.1186	0.0000	0.0000	0.0396	0.0000	0.0035	0.0000	0.0041	0.0000
75	8/16/2017	@	19:55	8/16/2017	@	20:25	25.9	0.3758	0.1773	3.9712	4.4080	0.0614	0.0572	0.0798	0.0955	0.2210	0.0171	0.0136	0.0000
76	9/25/2017	@	18:45	9/25/2017	@	19:55	20.6	0.0091	0.0000	0.0204	0.0121	0.0141	0.0061	0.0383	0.0197	0.0096	0.0000	0.0104	0.0000
77	9/26/2017	@	3:30	9/26/2017	@	16:00	54.1	0.0553	0.0000	0.6445	0.2745	0.0188	0.0000	0.3981	0.1823	0.0464	0.0000	0.0258	0.0000

VITA

Adrian Alonso Saenz, EIT

Candidate for the Degree of

Master of Science

Thesis: WOODY PLANT REMOVAL IMPACTS ON SEDIMENT YIELD FROM NORTHCENTRAL OKLAHOMA GRASSLANDS

Major Field: Biosystems and Agricultural Engineering

Biographical:

Education:

Completed the requirements for the Master of Science in Biosystems Engineering at Oklahoma State University, Stillwater, Oklahoma in December, 2018.

Completed the requirements for the Bachelor of Science in Civil Engineering with and Environmental Option at Oklahoma State University, Stillwater, Oklahoma in May, 2016.

Experience:

Graduate Research Assistant
Oklahoma State University, Stillwater, OK May ‘16 to Present

Research Intern, Environmental Sustainability Program
University of Colorado Boulder, Boulder, CO May ‘15 to Aug ‘15

Professional Memberships:

-American Ecological Engineering Society (AEES)
-Oklahoma State University Alumni Association
-Society for Advancement of Chicanos/Hispanics and Native Americans in Science (SACNAS)
-Society of Hispanic Professional Engineers (SHPE)