GEOMORPHIC FUNCTION OF LARGE WOODY DEBRIS WITHIN A HEADWATER TALLGRASS PRAIRIE STREAM NETWORK

by

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Abstract

Large woody debris, (LWD), defined as pieces measuring ≥ 1 meter in length and ≥ 10 centimeters in diameter (Swanson and Lienkaemper, 1978; Marston, 1982) is an influential stream component. Once stable LWD obstructs streamflow and regulates key processes, causing increases in storage capacity, scouring, and variations to the bed, the extent contingent upon LWD's average length of residence time within a system. Several North American studies have acknowledged the effects of interactions between wood, sediment, and flow regimes (Bilby, 1981; Keller, E.A., and Swanson, F.J., 1979; Montgomery et al., 1995; Wohl, E., 2008), linking the triad to geomorphic changes, the redistribution of bed materials, and ecological benefits. A consensual baseline reference for LWD's function over time does not exist however, partly due to previous research being primarily conducted in the Northeast and Pacific Northwest regions where historic actions of humans, particularly riparian logging and stream clearing, have greatly impacted the condition of the watersheds. Researchers having long-overlooked the Great Plains and other regions not commonly associated with woody vegetation has increased the ambiguity regarding the transferability of LWD findings between regions. By shifting the focus to a non-forested region, the goal of this thesis is to measure the dynamics and influence of a prairie stream's wood load on sediment storage and bed morphology. The Kings Creek network study area is located on the Konza Prairie Biological Station in northeastern Kansas, and drains one of few remaining unaltered North American watersheds. Results document the ongoing forest expansion into the surrounding pristine grassland, and provide a temporal context of the regions changing climate representative of atypical stream conditions caused by drought. In total, 406 individual pieces of wood were measured. The wood load was lower than most forest streams referenced (13.05 $m^3/100$ m), though higher than expected resulting from the absence of streamflow. LWD stored 108 m^3 of sediment within the channel, and the cumulative volume of LWD-formed pools was 169 m^3. Additionally, statistical analysis showed longitudinal bed variations to be strongly associated to LWD abundance, further indicating that LWD influences prairie stream processes similarly to those in a forest stream.

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Chapter 1 - Introduction

Stream and river ecosystems share a significant association with the surrounding terrestrial landscape (Naiman and Bilby, 1998; Naiman and Décamps, 1997), which is exemplified by frequent exchanges between the systems. The naturally occurring variables involved in guiding changes in channel morphology are known to differ spatially, relative to the surrounding environment. For instance, at the watershed scale, streams are shaped by geology, water flow, material deposition, climate and landforms (Beschta and Platts, 1986; Rosgen, 1996). At the local scale, however, streams are shaped by bed and bank material, channel slope, hydrology, average discharge, and riparian vegetation (Rosgen, 1996). These processes have been drastically altered over time, with shifts in stream characteristics instigated by natural disturbances such as flash flooding or fire being observed throughout history. Along with fluctuations in the physical environment, the integrity and health of streams and the ecosystems they support have also been compromised by anthropogenic influences on the landscape.

Human-driven phenomena such as rapid population growth, the development of megacities and major roadways that convert the natural land surface to an impermeable urban one, and the expansion of areas used for agricultural purposes are examples of the unnatural changes that have also shaped the physical environment. These types of modifications to the landscape have contributed to the degradation of streams, riparian zones, and watersheds worldwide by altering their capacity to perform critical ecosystem functions such as floodplain inundation, groundwater recharge, and organic matter exchange (Allan, 1995). By altering the riparian vegetation in particular, human and naturally induced changes combine to regulate the local wood source, as well as the amount of wood available for recruitment by a stream channel. This can be particularly damaging to the in-stream habitat because of the pivotal role wood plays in regulating a stream's ecological processes.

This knowledge and the need for a broader dataset, has led to a steady increase since the 1970's in the number of scientific studies regarding the functions of this influential organic stream component (Wohl et al., 2009). In North America, the number of wood-related studies has indeed risen, though problems still exist in synthesizing the findings of these studies, as there is little in the way of balance for the regions that are being researched, the methodologies, or the application of common metrics. For example, with the majority of wood-related studies conducted in predominantly forested regions, there has been far less attention paid to the function of wood in prairie streams. Hence, the definition of the term large woody debris (LWD) tends to differ by region and scientific discipline. For the purposes of this grassland-centric thesis, the definition of the term applies to logs, branches, and stumps that measure ≥ 10 centimeters in diameter (Marston, 1982) and ≥ 1 meter in length.

Streams in forested areas of North America (i.e. Oregon and Washington in the Pacific Northwest; Vermont and New Hampshire in the Northeast) have been the focus of multiple studies (Bilby, 1981; Marston, 1982; Montgomery et al., 1995; Thompson, 1995), and streams in grassland environments have been largely ignored. Data collection from similar stream settings over such a long period has produced far less research of non-forested watersheds, making it difficult to compare findings from different regions.

Because several different approaches exist regarding studies of LWD, including its collection, analysis and interpretation across disciplines, it remains unknown how much of the information on large woody debris from steep forested channels will transfer to other types of channels (Curran, 2010). With prior studies having found that the levels and functions of LWD within a stream channel vary because of regional differences in dominant forms of vegetation and human influence (Martin, 2001), the need for better management of activities that negatively influence streams and the surrounding watershed in every region has never been greater. Riparian forests are especially in need of protection, as several functionally complex relationships have been observed between the inputs of wood they provide and other physical, chemical, and ecological components of a stream.

One of these relationships is characterized by the substantial role of LWD in sedimentation processes, which enables it to exert considerable control over many of the characteristics that typify a given stream. Examples of this relationship can be found throughout the relevant body of literature, as many studies concur that sediment processes are inextricably linked to the amount and consistency of in-channel wood load (Bilby, 1981;

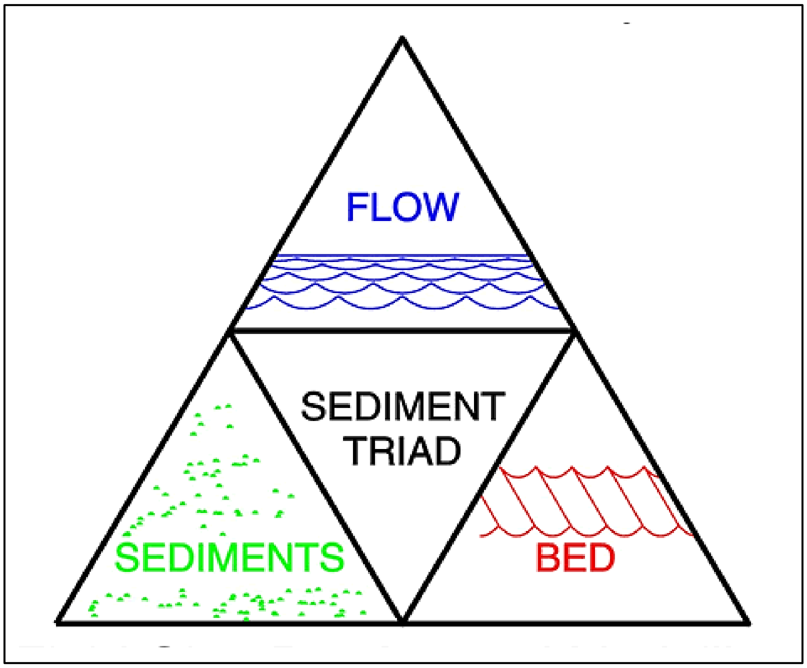
Carlson, Andrus, and Froehlich, 1990; Heede, 1972; Keller and Swanson, 1979; Marston, 1982; Montgomery et al., 2003; Nowakowski and Wohl, 2008; Thompson, 1995; Wohl et al., 2009).

LWD influences both sedimentation and streamflow, ultimately defining the morphology of a channel, since wood's regulation of these key stream processes enable it to create and alter morphologic structures while present within a stream (Keller and Swanson, 1979; Montgomery et al., 1995). LWD also forms a variety of bed features such as pools, riffles, and bars (Bilby, 1981; Lisle, 1986; Elliott, 1986; Friedman et al., 1996) produced by the sediment regulation and flow resistance it provides.

The importance of understanding the complex interactions between this triad of stream processes (Figure 1) has been acknowledged in previous studies (Bilby, 1981; Keller and Swanson, 1979; Montgomery et al., 1995; Wohl, 2008). It has been well established that the interdependent nature of the relationship between LWD, sediment, and streamflow, alteration of one of these variables will in turn alter the other two.

Figure 1: Sediment Triad

The concept of this sediment triad and the identified stream components that form it is to illustrate the relationship between the processes of streamflow, sediment size and availability, and the morphology of the streambed. Dynamics of this relationship vary according to the influence of a streams wood load. (Source: Baille, 2005).



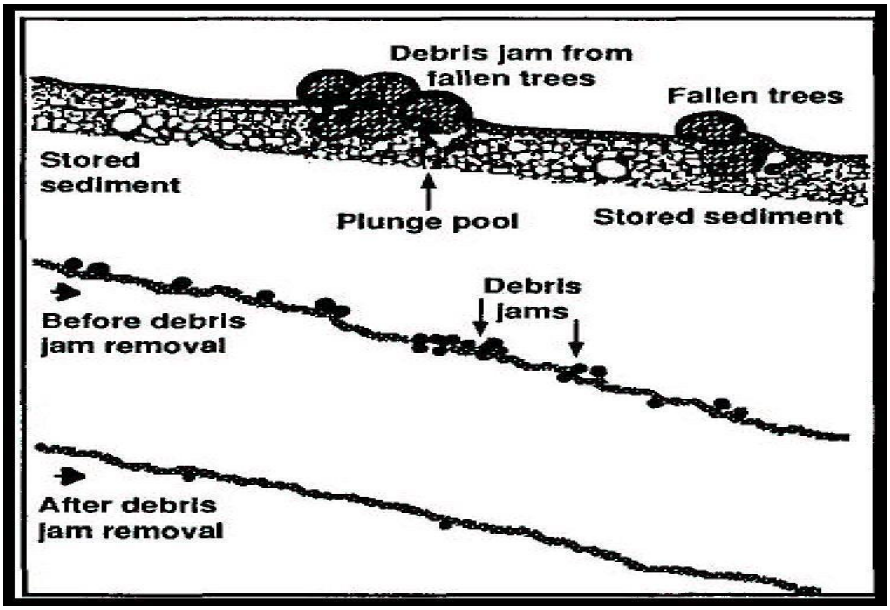
Because the association between LWD and the variables of sediment and streamflow directly influence the morphology of the bed, watershed-scale disturbances naturally influence the characteristics of the wood source contained therein, affecting the conditions of the stream. Being sensitive to the influence of external physical forces on organic inputs and processes, the system is inevitably forced to adjust in response to changes they might initiate. Typically, this response will trigger a substantial modification of the stream's preexisting wood, sediment and flow regimes. The magnitude of this is strongly influenced by the density and primary form of riparian vegetation, more specifically, the abundance of the local wood source (Magilligan et al., 2008).

As a result, it is important to account for the many variations between forested and grassland regions, e.g. logging in the Pacific Northwest or livestock grazing in the Midwest. In addition to the differing forms and scales of land use, consideration must also be made regarding the inherent characteristics of the region, and the level of impact they have endured as a result. The influence of these factors, combined with the regional climate and topography, determines the extent to which both sedimentation and streamflow can be regulated by wood.

Irrespective of the region, modifying a wood load by removing, relocating, or rapidly increasing it will influence streamflow and sediment processes. For instance, in forested watersheds with high wood loads, LWD dams within a channel can retain a substantial amount of sediment (Thompson, 1995; Fig. 2).

Figure 2: Debris Dam or LWD Structure

Role of woody debris in storing sediment and creating morphologic bed features in streams: The "stepped profile" is characteristic of stored sediments and plunge pools created by woody debris. The lowest segment illustrates how removal of a debris dam destroys and reduces the habitat features it previously created. (Source: Bisson et al., 1987).



The increased storage capacity that wood provides can have the opposite effect as well, because consistent and stable wood loads can also significantly dampen variability in sediment transport rates within the stream network (Massong and Montgomery, 2000).

Alternatively, the clearing of LWD and destruction of dams, via human or natural means, can result in a large and rapid decrease in the amount of material being stored, quickly instigating an increase in the rate of sediment transport (Beschta, 1979; Bilby 1981; Montgomery et al., 2003). In contrast to a forested channel, this latter scenario is characteristic of channels in prairie regions with primarily grassy vegetation, where wood loads are less stable and watersheds are prone to frequent flooding (Gray, 1997; Gray and Dodds, 1993; Juracek, 2000).

Dynamics of North American grassland streams in prairie regions like the Great Plains are comparatively less understood than streams in forested regions, for which a breadth of knowledge exists. Discrepancies within the published LWD literature continue to grow in response to the disparate number of studies between regions. One of the consequential issues to contend with is that most of the previously studied waterways are unable to function in a natural or near-natural state; an inescapable truth given that the majority of North American waterways have been altered in some form.

Ranging in scale from tributary streams to the high order main channel of the network, many forested watersheds have been degraded by activities such as riparian logging and dam building and removal. Large Midwestern Rivers like the Mississippi whose various alterations are well documented in historical records, have also been altered by anthropogenic changes. Arguably, however, to a lesser extent than those in the Pacific Northwest and Northeast region given that the abundance of trees in the Great Plains region is fractional by comparison.

For purposes typically related to research or conservation, a small number of watersheds have essentially been left alone to function in their natural state. Still, many of these unaltered streams are disregarded because of their location and corresponding vegetation structure. The main objective of this thesis is to shift focus to a non-forested region in order to identify the geomorphic function of large woody debris within an unaltered prairie stream, and to determine the degree to which it regulates sedimentation and flow processes. Findings are anticipated be useful in ultimately determining whether regional differences measurably influence stream wood loading and function. Methods and findings from previous studies in forested regions are referenced throughout data analysis for comparison and guidance.

Hypotheses

H_1: Wood loads in tallgrass prairie networks are significantly lower than what is reported for predominantly forested watersheds.

> H_{1o}: Wood loads in tallgrass prairie networks are not significantly different from those reported in forested watersheds.

H_2: Wood present in low order (1-3) tallgrass prairie headwater streams functions to store sediment and produce measurable variation in longitudinal bed elevation profiles; observable evidence of this functional role declines with increasing stream order throughout the network.

$H2_0$: Wood present within tallgrass prairie headwater streams does not significantly regulate geomorphic process and does not store sediment or alter longitudinal bed elevation profiles, irrespective of position in the network.

Thesis Structure

It is the intention of this thesis to address the described issues of inconsistency within LWD literature and current study approaches, stemming from what can be aptly described as an overall lack of diversity within many aspects of wood-related research. This will be done by, for the first time, measuring and documenting the nature of the geomorphic effects observed in a prairie stream that are attributed to large woody debris. In meeting the objectives outlined within this thesis and testing the proposed hypotheses, the function of LWD within streams of the Great Plains will be better understood. The findings will also be useful in defining the processes that enable LWD to alter the longitudinal bed morphology, and whether it exhibits any measurable control over stream storage capacity within the low-gradient headwaters of an unaltered, tallgrass prairie stream network.

Chapter two presents a review of the scientific literature relevant to LWD; the role of wood in North America and the impacts of historical management practices and land use are discussed, along with the resulting impacts faced by modern LWD research. The focus of Chapter three is on the role of wood in the Great Plains region. Characteristics of the climate and environment at the regional scale are discussed, in addition to those at the local-scale as these directly influence conditions in the study area. Sources of LWD and the impacts of land use are also discussed. Chapter four provides a detailed outline of the methodology applied, and separates actions taken and measurements used for each of the variables, i.e. wood, pools, and sediment. Chapter five presents findings as well as the analysis of collected data via graphics, charts, and statistical tables displaying the results of the study. Chapter six provides a discussion of these results.

Chapter 2 - Literature Review

Modern forests cover almost a third of Earth’s land surface (Atjay et al., 1979). This estimated amount of coverage is substantially less than the documented density of historical forests; ergo it has been deduced via scientific studies that considerable quantities of wood have been present within streams and rivers for no less than 400 million years (Montgomery et al., 2003). The function of the wood that remains in streams has evolved over time, and associated with altering the physical form of the channel, regulation of sediment processes, retention of organic matter, and the composition of the biological community (Bilby, 1989) it sustains. Growing recognition of this complex stream component has led to increased research in recent decades, as well as prompting the syntheses of in-stream wood characteristics and dynamics (Harmon et al., 1986; Maser et al., 1988; Wohl and Goode, 2008) amongst the scientific community.

The presence of LWD has been documented in numerous river systems, whose locations span a number of continents and physiographic regions (Gurnell et al., 2000; Haschenburger and Wilcock, 2003; Montgomery et al., 2003; Daniels and Rhoads, 2003). There is little doubt that vegetation greatly influenced ancient rivers; the first appearance of meandering stream deposits in the geologic record coincides with the evolution of land plants (Schumm, 1968; Cotter, 1978). A form of vegetation that is widely known to play a significant geomorphic role in the evolution of a stream is wood, because of its ability to regulate essential stream processes (Naiman et al., 2001). This characteristic is frequently referenced throughout the literature, which has continued to develop by way of growing interest across multiple disciplines.

Part 1 – Wood in North America

Regional Differences

While this increase has been beneficial to several areas of scientific research, the majority of basins commonly selected for study are located within similar environmental settings. For example, North American studies of LWD have primarily been conducted in watersheds located within the Pacific Northwest region. The factor of physical setting combined with variations in both methods and findings has consequently created an imbalance within the body of literature. The need for diversity has been revealed by this imbalance, and has ultimately driven recent efforts to synthesize in-stream wood characteristics and dynamics (Harmon et al., 1986; Maser et al., 1988; Wohl and Goode, 2008), as well as to expand wood studies beyond the scope of forested regions (Anderson et al., 2004; Trimble, 2004).

Differences between physical characteristics of previously studied regions have resulted in discrepancies within the current data, which in turn has proven the need for research within non-forested regions such as the Great Plains to be dire. While the role of LWD in forested streams has been well established for some time, much less is known about the role of LWD within prairie stream dynamics as it has been regularly overlooked. Because many of the resulting gaps in knowledge (Hassan et al., 2005) have yet to be sufficiently addressed by researchers, the task of increasing our understanding of how wood functions in other environments remains. Considering how research in the Great Plains has lagged behind other regions (Stagliano and Whiles, 2013), development of such a framework could be used to clarify some of the inconsistencies within the literature, as it remains to be seen whether or not findings from forested regions can be applied to North American prairie stream communities.

Findings from a prairie stream might inadvertently differ from those from a forested stream for a number of reasons, to include the riparian vegetation and its level of diversity, as well as the headwater characteristics of large stream systems within a given region. For instance, the hydrologic regimes of streams in the Great Plains are known to be highly variable, whereas that of the Columbia River Basin is much more stable, being fed by Columbia Lake, which lies within a glacial valley between the Canadian Rockies and the Columbia Mountains. The flow regime of Columbia River is consequently affected by climatic variables within its enormous basin, which are dominated by the temperature-sensitive cycle of snow accumulation and melts (Leung and Ghan, 1998).

Impacts of the regional climate naturally vary by stream. Prairie streams, for instance, typically flow intermittently, with peak discharge values most frequently observed during spring and summer months, which are considered the ‘wet’ season for the Great Plains region. Forest stream systems, however, typically flow annually because of the climate conditions in the Pacific Northwest region. This quality has proven to be appealing to LWD researchers, causing many previous studies to be conducted on streams in forested regions. Of these, the majority have been conducted on the Columbia River, the largest in the Pacific Northwest region.

Historic Impacts on Modern Management

Unquestionably, historical land-use and management practices significantly altered most, if not all of the natural environment with the anthropogenic modifications made to the landscape to better suit human needs. Of these, the geomorphological changes brought about by multiple human activities likely have produced lasting, complex, and often unappreciated changes in physical structure and hydrology of stream systems (Allan, 2004).

Fascination with the dynamism of free-flowing waters was apparent amongst early European settlers, yet the realization that clearing the landscape to accommodate a growing population would not come until later when the damage had already begun to occur. Since we have been able to do so, humans have unceasingly expended great effort to tame and clear the rivers we settle near for transportation, water supply, flood control, agriculture, and power generation (Naiman et al., 1995, NRC, 1992). With each of these attempts to control nature, there has been considerable degradation of the natural resources we have grown to depend on.

Perhaps one of the most damaging of historical alterations of the landscape has been the clearing of forests, which subsequently led to the homogenization of watershed vegetation that still characterizes many areas of the modern landscape. Though most forms of historical land use has negatively affected streams, it was the loss of riparian forests and removal of in-stream wood that deprived streams of shade and organic matter inputs, resulting in the loss of temperature regulation, food, and habitat heterogeneity.

Clearing of Forests

Human alteration of forests in Europe has been significant for at least 6,000 years (Williams, 2000). Goods produced from these resources, e.g. harvested timber and the economic gain it provides enabled the expansion of European colonies and military influence. Despite the rate of activity, it would take centuries and millennia for Europeans to clear these forests. In contrast, the exploitation of then-untouched North American forests would take significantly less time. Forests in the eastern region, for instance, were said to be ‘vast’ and ‘dense’ (Montgomery et al., 2003), prior to settlement by early Europeans, though rapid exploitation of the physical environment would begin shortly after their arrival, with North American forests becoming a source of seemingly endless resources.

Montgomery et al. (2003) proposed that given the knowledge we have today, it is a fair assumption that the rise of human civilization was fueled by the onset of deforestation. Besides building ships for the military, means of transportation, construction, and needs for fuel caused resources to diminish even more rapidly, with forests often disappearing over the course of decades (Whitney, 1996). The harvesting of North American forests was so complete and thorough that the Northeast and Midwest lost 96% of their old-growth timber by 1920. By late in the 20th century, estimates of original old-growth forest remaining in individual states ranged from less than 0.01% to 0.36% (Table 8-4 in Whitney, 1996).

Beginning when early Europeans first arrived and began to settle in the Northeast region of what would become the United States, unsustainable rates of wood removal and redistribution by humans quickly began to exhaust forested areas of their resources. Being that the mode of transportation around the year 1600 was primarily by means of log rafts, before eventually graduating to log drives around 1800 (Whitney, 1996), riparian forests were among the first to be harvested and cleared. The vegetation and soil structures of the riparian forests that remained were irreparably altered; their natural conditions difficult to determine save for referencing historical records, such as the 1751 writings of John Bartram.

Of the forests in the northeastern region, he wrote that the tree tops were “so close to one another for many miles together, that there [was] no seeing which way the clouds drive, nor which way the wind sets: and it seem[ed] almost as if the sun had never shown on the ground, since the creation” (quoted in Whitney, 1996). Having been significantly modified over the years that have passed since Bartram’s written description, the effects of the interference of natural systems by human actions remain observable. As a result, the legacy of deforestation and other historic activities that changed the landscape are frequently addressed by modern stream studies. The majority of these studies have focused on the interactions between LWD and variables such as channel morphology, sedimentation, ecology, and restoration (Beechie et al., 2010; Gurnell et al., 2002; Montgomery et al., 2003), and provide much needed perspective to the massive scale of anthropogenic modifications that have been made.

Stream Clearing

Stream clearing and engineering date as far back as the Roman era (Herget, 2000). North American stream networks, where pieces and accumulations of LWD were common prior to the 19th century, were no exception to this practice and were eventually removed by early European settlers. Streams responsible for draining the massive forests [Northeast and Midwest] were cleared of the large logs that would accumulate within them (Gurnell, 2002), in order to improve navigation, reduce flooding, and enhance ecosystems (Montgomery et al., 2003). The practice would become more urgent and thorough in the large rivers of the eastern and Midwestern United States being as they were critical transportation pathways.

The clearing of wood from channels (via snagging - or the removal of logs by a boat) became a great matter of both commercial and military importance (Hill, 1957). In the coming decades, snagging would spread to stream networks throughout the Southeast and Midwest (Montgomery et al., 2003) regions. By the late 19th century, the efforts to remove LWD would extend even further across the continent, allowing ships to reach the west coast of the United States (Sedell and Frogatt, 1984; Collins et al., 2002) by way of cleared channels. Because of these intense ‘stream cleaning’ efforts, humans have altered the natural structure and characteristics of North American waterways (Maser and Sedell, 1994). Such rapid removal of LWD has resulted in many streams located throughout the Pacific Northwest and elsewhere to maintain wood densities that are comparatively lower than historic levels (Harmon et al., 1986; Sedell and Frogatt, 1984).

Part 2 – Sources and Characteristics of Wood Loading

The primary sources of LWD are the forests found within the adjacent riparian zone (Fetherston et al., 1995; Moerke and Lamberti, 2004); therefore, in addition to stream size, hydrologic conditions, substrate, and topography, the characteristics of the riparian zone noticeably influence the rates of wood recruitment and depletion. These rates, in turn, determine the abundance and temporal variation of large woody debris (Naiman et al., 2002) within a channel reach. As corridors within watersheds, a riparian zone exerts substantial controls on the movements of water, nutrients, sediment, and species (Forman, 1995; Malanson, 1993). Hence, any alterations to riparian forests go far beyond the area of the specific activity, with the ecological consequences felt throughout the entire river corridor (Naiman et al., 2001), which can be intensified by the resulting changes to the wood load.

A stream's wood load refers to the amount of LWD that is present and maintained within the channel, and regulated by external factors, specifically the composition of the surrounding forest. Any changes affecting the wood regime (as described by the size and amount of wood being supplied to a stream) can result in effects as significant as changes arising from changes to the sediment supply or the discharge regimes (Montgomery et al., 2003). These changes propagate and affect both the sediment and flow regimes, which instigates a longitudinal shift in channel dynamics. Once introduced to the channel network, reach-specific wood loading is then controlled by physical characteristics of the channel (Magilligan et al., 2008; Fisher et al., 2010). For instance, if a disturbance were to occur, the volume of LWD redistributed from higher to lower energy reaches and factors such as channel gradient and size determine how quickly it is likely be transported.

Although local characteristics, such as the composition of bank materials and the stability of the hillslopes directly contributing to a stream provide some insight, stream size and topographic setting of the region are known to strongly influence the larger scale processes that recruit and redistribute wood within the channel network (May and Gresswell, 2003). Due to the multiple influences involved, it is the combined effects of these factors that are typically responsible for the abundance and availability of the wood source within a watershed, as opposed to a single source. Therefore, it is clear that historic and modern land use activities provided separate and combined influences that can originate either locally or regionally.

Part 3 – External Influences on Loading and Redistribution of Wood

Time and Space

Land use activities have dealt a considerable blow, as these types of activities had a direct influence on LWD, then and now, by altering the natural dynamics of the wood regime, particularly those related to loading (Diez et al., 2001; Gomi et al., 2001; Chen et al., 2005).

Various studies have concurred, finding that the influence of logging in reaches with dense riparian areas has inarguably led to a reduction of large woody debris recruitment in many North American streams (Andrus et al., 1988; Murphy and Koski, 1989). After the removal of all or part of an old-growth forest, new riparian trees will eventually begin to grow, forming a second-growth forest. However, in addition to being unavoidably time-consuming, this process can induce further decline long before the trees mature, because the remaining riparian forests are simply unable to provide sufficient amounts of new inputs to the channel to replace the LWD that decays or washes downstream (Grette, 1985; Andrus et al., 1988; Heimann, 1988).

Stability of the surrounding hillslope and bank materials also influence wood loading dynamics (Benda et al., 2003). Characteristics of the surrounding hillslope and their reach-scale influences are magnified by the stream size, and the topographic setting, and the exchanges between these variables do influence the recruitment and redistribution of wood throughout the channel network (May and Gresswell, 2003). Subsequently, hillslope failures as well as bank undercutting have been found to act as a wood recruitment mechanism (Swanson and Lienkaemper, 1978; May and Gresswell, 2003; Webb and Erskine, 2003). The importance of this mechanism is largely dependent upon forest characteristics. For example, the distance of trees from the channel is an important factor that influences and is related to the delivery of large woody debris (McDade et al., 1990), as trees bordering the banks are recruited most easily by a stream

Geomorphic studies of LWD have previously explored the concepts of time and space, finding that the temporal and spatial patterns of wood within the channel often exhibit even greater dynamics than those of sediment and its associated bedforms (Gurnell et al., 2002). The dynamics of LWD, including abundance, loading, redistribution processes help to illustrate the role of time and space in the geomorphic history of stream networks and their watersheds, because as the duration of time between observations decreases, spatially influenced variables (e.g. initial relief, extent of riparian vegetation, hillslope morphology, etc.) are more likely to become independent (Schumm and Lichty, 1965). Whether independent or combined, time and space have considerable influence over the variables involved in wood loading and distribution, and are most often the largest indicators of the types of changes that have and/or will likely occur, and how these changes may affect the area being observed.

Because of its large variability in space and time (Bisson et al., 1987; Naiman et al., 2002), consideration of scale is quite appropriate when studying any aspect of large woody debris. This includes the identification of all sources of input when possible, as local and regional activities are likely to affect the quantity of available wood. Unfortunately, since the complexity and cost of this undertaking varies by watershed, most of the current management and regulatory approaches do not consider spatial and temporal variability of the wood supply, specifically their relation to the abundance (Benda et al., 2002) of LWD in a stream. This approach has been largely ineffective, because as the watershed area, contributing to a channel grows in size, the dimensions of the channel and rates of flow increase (Curran, 2010). In response to conditions changing in the downstream direction, the mobility and spatial variability of LWD increases, consequently lowering the probability of accurately identifying the source of wood.

Given the susceptibility of LWD dynamics to external disturbances, the much needed extrapolation of reach-scale recruitment processes to whole watersheds has not yet been sufficiently achieved (Kasprak et al., 2011). While information at the reach-scale is useful, it may be insufficient for understanding the spatial variability exhibited by LWD (Naiman et al., 1992). Efforts to expand the spatial extent of LWD research have coincided with the progression of geomorphic research, and using high resolution light detection and ranging data (LIDAR) to achieve this is becoming more popular (Kasprak et al., 2011) amongst researchers. However, a number of key issues (such as delivery rates and persistence) remain to be elucidated before a comprehensive LWD model can be constructed (Naiman et al., 2002).

Part 4 – Relationship between Time, LWD Dynamics, and Stream Processes

Residence Time

Residence time measures the period of time LWD and debris jams remain stationary (the amount of time stored by the channel) and is often measured by indirect means (Martin, 2001). For example, residence time was estimated by a handful of studies that dated LWD based on the ages of saplings growing on LWD pieces, or by the scars left when trees fell into the channel (Swanson et al. 1976; Keller and Tally, 1979; Murphy and Koski, 1989). Most of the age estimates from prior research are from LWD in constrained, low-order channels flowing through old-growth coniferous forests in California, Oregon, and Alaska, where key pieces can reside in streams for up to ~260 yrs. (Keller and Tally 1979; Grette 1985; Murphy and Koski 1989).

Small channels are regularly observed as having a higher abundance of LWD per unit area than large channels, since large channels have a greater capacity to transport wood (Bilby and Ward 1989; Swanson et al., 1982). Naiman (2002) found that without disturbance, LWD might naturally reside in most channels for decades to centuries and move unhindered downstream. This is relevant to resource and stream managers, as research has firmly established that in order to be of benefit to a stream and the ecosystem it supports, LWD must be present within a channel for an extended period without breaking down (Gurnell, 2002; Moerke and Lamberti, 2004; Swanson and Lienkaemper, 1978, etc.), to ensure ample time for the wood to stabilize and begin to obstruct the processes of sediment and streamflow.

Riparian vegetation, climate, and land use have also been identified as factors that should be referenced in any attempt to maintain a wood load consistent with the physical features of the region. In doing so, the residence time can be estimated more efficiently given the fact that the dynamics of LWD, specifically how it is distributed within the channel, tend to reflect the characteristics and sources of wood loading. Mindful of this, an attempt to quantify both wood recruitment and redistribution mechanisms, and how they vary spatially throughout a basin, may be useful for determining how and where to protect the sources of wood to streams (Martin and Benda, 2001), and ensure adequate inputs of LWD.

Channel Stability

If large pieces or accumulations of wood are left undisturbed to function naturally, these can have a large influence on the lateral mobility of the channel, as well as the stability of its banks (Swanson and Lienkaemper, 1978). The reduction or elimination of large key pieces of wood from a system reduce the longevity of any LWD accumulations (Heimann, 1988), thereby decreasing the overall stability of the channel structure. Geomorphic changes attributed to LWD that are associated with increased channel stability are most frequently observed in streams with a relatively unaltered wood regime. These streams also exhibit less spatial variation and biodiversity when compared to the characteristics of streams that have been extensively altered (Adenlof and Wohl, 1994; Beschta, 1979; Curran, 2009).

Robison and Beschta (1990) determined that the position of wood within a channel could have a pronounced influence on its stability. The position of LWD and its orientation also indicate the potential of a piece of wood to regulate the hydraulic condition, sediment deposition, and in-stream habitat. The position and orientation of a piece of wood also controls whether the wood will form dams that result in scour pools (Bilby, 1981), increase sediment storage within the channel reach (Daniels, 2006), provide flow resistance that dissipates energy (Marston, 1982), or reduced sediment transport (Bilby and Ward, 1989). The various geomorphic and ecological processes that wood influences within the stream are closely related, and clearly, there are similarities in the influence of similarly oriented pieces. However, the multifaceted nature of LWD demands that all of its attributes, not only its positioning, be acknowledged and measured when studying any aspect or influence of in-channel wood.

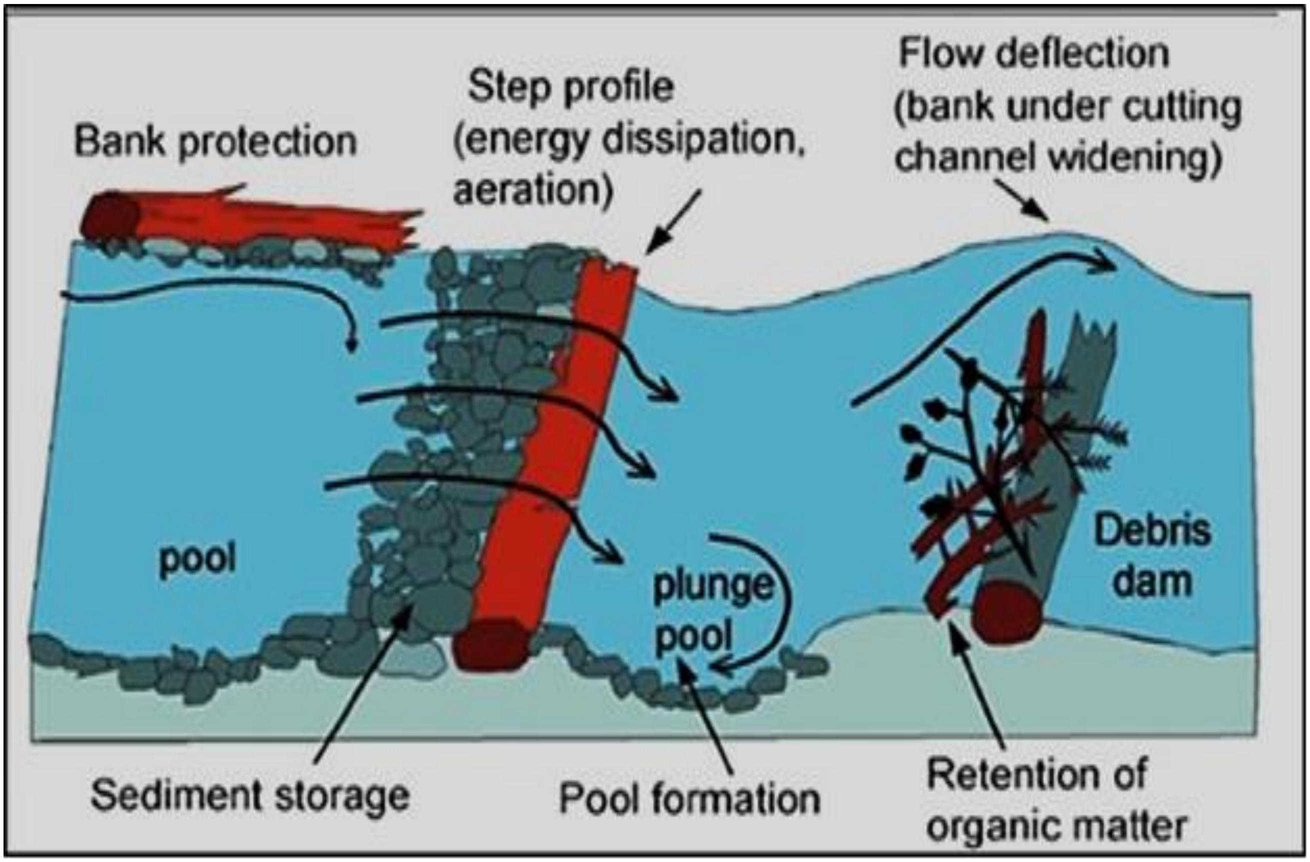
Geomorphic and Ecological Processes

The redirection of flow and sediment by large stable pieces of wood can have several influences on the channel, most of which serve as a connective bridge between several major processes that typify the stream. Whether a dam, a log that spans the channel, or an accumulation of smaller pieces, the influence of any form of LWD will vary by the characteristics of the stream and its wood load, though in many streams an increase in width and depth will soon propagate to reaches downstream of the LWD. This acts to increase the discrepancies between the dimensions of the channel along the longitudinal profile (Montgomery et al., 2003).

Reaches upstream of a wood jam quickly begin to experience backwater effects and reduced transportation of stream materials (Bilby and Ward, 1989; Curran and Wohl, 2003; Daniels, 2006; Nakumara and Swanson, 1993; Thompson, 1995), resulting in deposition of sediment and smaller organic materials, e.g. small sticks or leaves directly upstream of the dam. Materials trapped by the structure eventually help it to become nearly watertight and more forcefully divert water towards one or both stream banks. At this point, the obstruction of streamflow and the regulation of sediment processes enable the LWD to increase the erosive power of the water it redirects, forcing the channel to widen (Bilby, 1981) at the location of the dam. Eventually, the resulting disequilibrium affects more of the surrounding channel area, as the diversion of streamflow continues to erode the banks and bed of the stream (Figure 3).

Figure 3: Influences of Wood

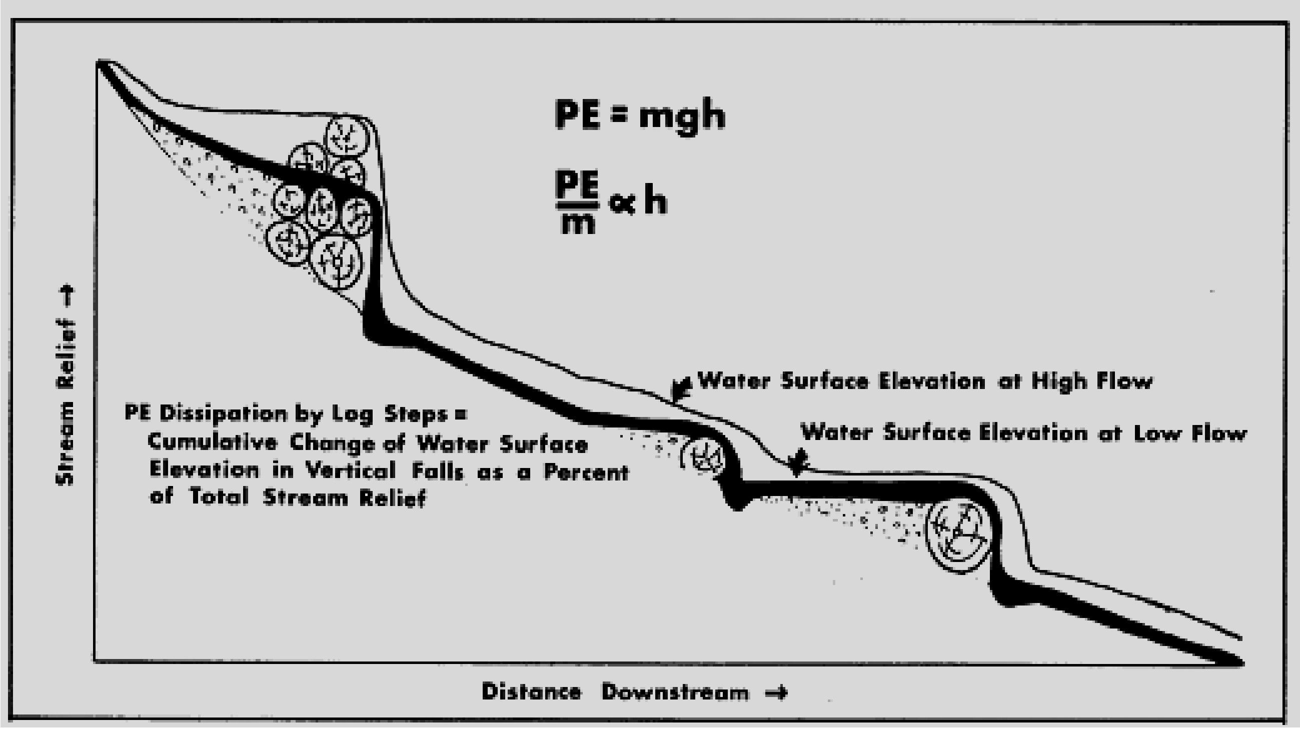
Graphic depiction of the functions of LWD: each provides some form of influence on the various geomorphic and ecological processes within a stream environment. (Source: Baille, 2005).



Steps can develop from pieces of LWD that extend across the entire active channel and create a change in the water surface elevation as water spills over the wood (Marston, 1982; Figure 4).

Figure 4: Function and Influence of Log Steps

The potential stream energy per unit mass of water (PE/m) is directly proportional to *h*, or the relief in a specific stream segment (*g* = constant of gravitational acceleration). Potential energy dissipation by log steps can increase or decrease with changes in river storage. (Source: Marston, 1982).



In the process of falling, the erosive power of the water becomes much greater, which induces scouring to the streambed directly below the step, which subsequently creates a pool. Regardless of form, LWD regulates the formation, frequency, and type of pools within the channel (Keller and Swanson, 1979; Bilby and Ward, 1991; Montgomery et al., 1995; Gurnell and Sweet, 1998; Kreutzweiser et al., 2005). These streambed features provide structure to the in-stream habitat in addition to enhancing the ecologic health and diversity of the stream.

The influence of wood on stream processes has led to greater involvement from stream ecologists, as well as other professionals with an assortment of scientific backgrounds and training, which has been to the advantage of wood studies as a whole. Of these, the work of stream ecologists has arguably been the most prominent, with interests ranging from the influence of residence time to the dynamics of wood loading, and most everything in between. Whereas research of these variables by geomorphologists is typically conducted to measure their influence on the physical extent of any changes driven by LWD, stream ecologists are more apt to use this same information for predicting species distribution (Poff, 1997), or assessing the conditions of the in-stream habitat. Increasing communication between disciplines means study approaches and methodologies are being shared and re-applied more frequently, and the distribution of information pertaining to studies of LWD in a variety of geographic settings has gradually become more accessible at the global scale.

Part 5 – Regional Distribution of Past LWD Research

Regional Characteristics

Findings from most previous studies of LWD are almost exclusively representative of heavily forested regions (Benda et al., 2002; Bilby and Ward, 1991; Bisson et al., 1987; Hyatt and Naiman, 2001; Magilligan et al., 2008; Marston, 1982; May and Gresswell, 2003; Murphy and Koski, 1989). Research conducted in non-forested or less-forested watersheds has been minimal because of the regional bias that influences the distribution of LWD study areas, and has impeded the development of the LWD literature and limited its relevance to other biomes (Hassan et al., 2005; Montgomery and Piegay, 2002; Thompson, 1995; Wohl et al., 2010). This knowledge has prompted the realization that other types of environments need to be selected for future studies in order to build a more widely applicable body of literature.

The observable functions of LWD is likely to fluctuate between stream types, since the role, function, and importance of large woody debris in rivers have been found to depend strongly on the characteristics of the environment and land use history (Magilligan et al., 2008). In regions with very wet climates during much of the year (e.g. Pacific Northwest), several studies have deduced that when LWD is normally exposed to wetting and drying, it generally remains in the channel for 70-100 years. Many pieces appear to remain for several centuries to millennia (Hyatt and Naiman, 2001; Murphy and Koski, 1989; Swanson and Lienkaemper, 1978; Swanson et al., 1984, 1976). Because vegetation is the most important intermediary through which climate and land-use modify geomorphic processes and landforms (Kirkby, 1995), accounting for the disturbance history within the watershed is necessary in addition to that of the region.

Since human-driven changes to the landscape are so varied, the impacts to a stream and its wood source are not always immediately observable, and as a result, the influence of land use is not always accounted for as fully as the influences of climate and vegetation. The impacts of historical land use in particular are difficult to ascertain, as there are few detailed records of the changing landscape aside from the journals of early Europeans. Insufficient empirical knowledge has amplified the already dire need to expound upon the current breadth of LWD literature (Collins et al., 2011; Hunsaker and Levine, 1995; Johnson et al., 1997; Osborne and Wiley, 1988; Van Sickle et al., 2004). Increasing research in less-studied regions is an important first step towards broadening our understanding of how LWD functions in more than one physical setting. By diversifying the areas selected for research, many of these issues could be addressed and potentially lead to further synthesis of the LWD literature.

Chapter 3 - Wood in the Great Plains

The physical variability present throughout the Great Plains of America has intrigued investigators since the discovery and settlement of the region by Europeans (Knight et al., 1994). In contrast to old-growth forests long present in Northwestern regions, the environmental diversity present in the Midwestern region is united collectively by factors such as: low relief, highly variable rainfall, and with the exception of stream borders, more open grassland than forest gallery. Pre-historic prairie wildfire sufficiently prevented the establishment of trees in large quantities, though bands of forest remain. Of the trees found in the cross-timbers region where the hardwood forest meets with the Great Plains' flora and fauna, nearly all seem dwarfed in size compared to their counterparts in other regions (Matthews, 1988). Because of this, minimal amounts of quantitative work have been conducted concerning the dynamics of the narrow bands of gallery forest along stream drainages within the tallgrass prairie ecosystem (Knight et al., 1994) that characterize the Flint Hills.

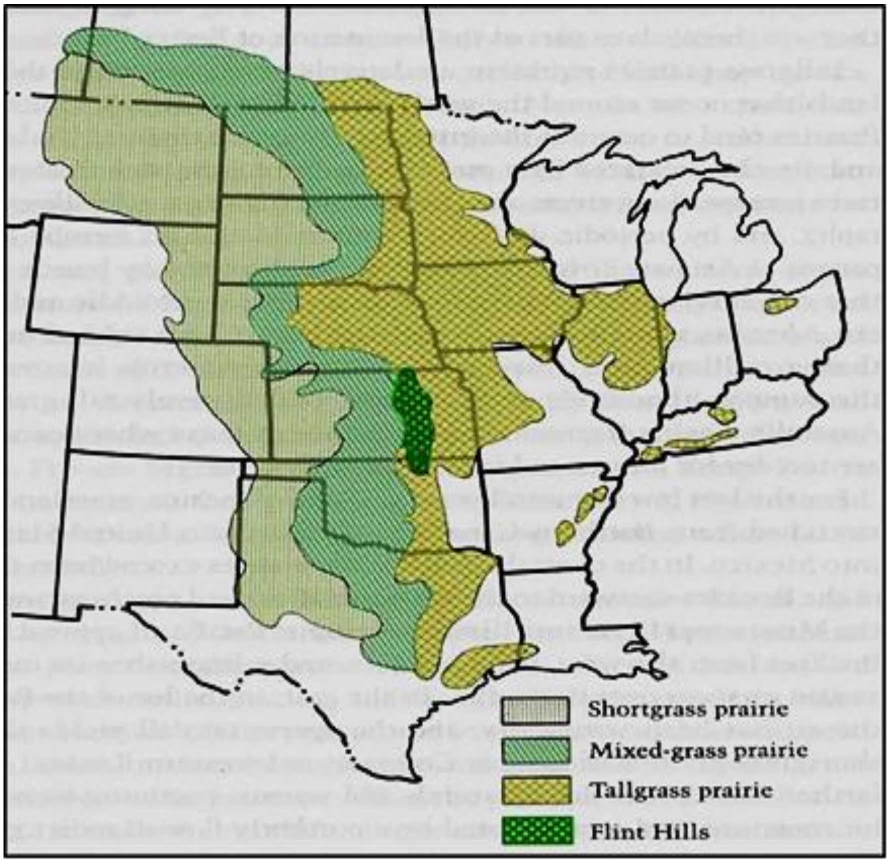
While grasslands may have been present on the North American continent for 20 million years (Benedict et al., 1996; Risser et al., 1981; Weaver, 1968), the Central Grassland, which includes the tallgrass prairies within the Great Plains and Flint Hills regions, is a relatively new biome. During much of the Pleistocene epoch the climate was cooler, with as much as 32 percent of the world covered by ice then, compared to about 10 percent today (Spurr and Barnes, 1980). With each period of glaciation then interglaciation that occurred during the Pleistocene, warming and cooling of the climate was intensified. The changing climate and the subsequent impact on the continental ice sheet resulted in the destruction of the mid-continent grassland or its replacement by other vegetation types (Anderson, 2006).

With glaciation ending in response to the warming climate, the decline of forested areas continued during the early Holocene. In the eastern tallgrass prairie for example, prairie and savanna replaced oak-hickory forest during the warm, dry period of the Hypsithermal. The replacement of trees by grasses was eventually accompanied and encouraged by the increasing frequency of fires in most locations (Anderson, 1998; Baker et al., 1996; Delcourt and Delcourt, 1981), used as a means to deter forest expansion. As our understanding of the influence of fire on vegetation has grown, many researchers have come to believe that the near-complete domination of much of the Great Plains by grassland during this period was due to frequent burning by Indians (Gleason, 1913; Sauer, 1950; Pyne, 1983), and fires caused by lightning.

It is unlikely, however, that the forests and woodlands that occupied the present plains were eliminated solely by fire, as regional fluctuations in patterns of precipitation and temperature have also been significant driving factors (Axelrod, 1985; Bailey, 1964) in the evolution of vegetation across the region. For example, grasslands located to the west of the Flint Hills differ in composition according to the natural conditions that typify their physical setting, specifically the annual amount of rainfall (Figure 5).

Figure 5: Grasslands in North America

This map provides a reference for the differing forms of grasslands and where they are located in North America. The Kings Creek stream network lies within the north-eastern portion of the Flint Hills, and is surrounded by tallgrass prairie. (Source: Kansas Historical Society).



In the last century or so most of the fluctuations occurring in resource abundance and disturbance regimes have remained driven primarily by changes in climate and fire regimes, as well as livestock grazing and other types of land use. Each of these factors has been implicated as being critical for the re-establishment and spread of woody plants within grasslands (Briggs et al., 2005). Prior to settlement within the Flint Hills region, the abundance of trees was relatively low when compared to modern amounts, and mostly scattered in small pockets along stream channels, suggesting that the role of LWD within prairie streams was less significant during that time, while climate and geology were the most influential extrinsic factors. With the settlement of early Europeans in the Great Plains, however, came the suppression of wildfires for reasons that likely included building roads and infrastructure (Bragg and Hulbert, 1976).

This decrease in the number, extent, and frequency of fires following early settlement quickly resulted in the rapid growth of forests (Bragg and Hulbert, 1976). In response, the once-open grasslands have transformed into a mosaic of cultivated crops, prairie remnants, and expanding woodlands (Johnson, 1994; Samson and Knopf, 1994). However, in contrast to the dense cover present along upstream reaches of most forested streams (Dodds, 2006; Grimm et al., 1981; Gurtz et al., 1982), the upstream reaches of many streams in the Flint Hills region remain characterized by sparse canopy cover and limited leaf litter inputs.

Part 1 – Study Area

In 1962, the Hydrologic Benchmark Network (HBN) was created with the hope that protecting some of the few remaining unaltered watersheds in North America would eventually provide a long-term database to track changes in the flow and water quality of rivers draining undeveloped lands (Leopold, 1962). As part of the HBN, the Kings Creek basin is unique in that it exclusively drains 10.62 km^2 of pristine, native tallgrass prairie (Knapp et al., 1998), and is the only basin in the network to do so. Although the Great Plains region is often dismissed as physically homogenous as a result of its perceived ‘flatness’, the divergent flow regimes and ecological variability present in its streams and surrounding ecosystems are in fact a result of the regions subtle and often overlooked diversity (Cross and Moss, 1987; Figure 6).

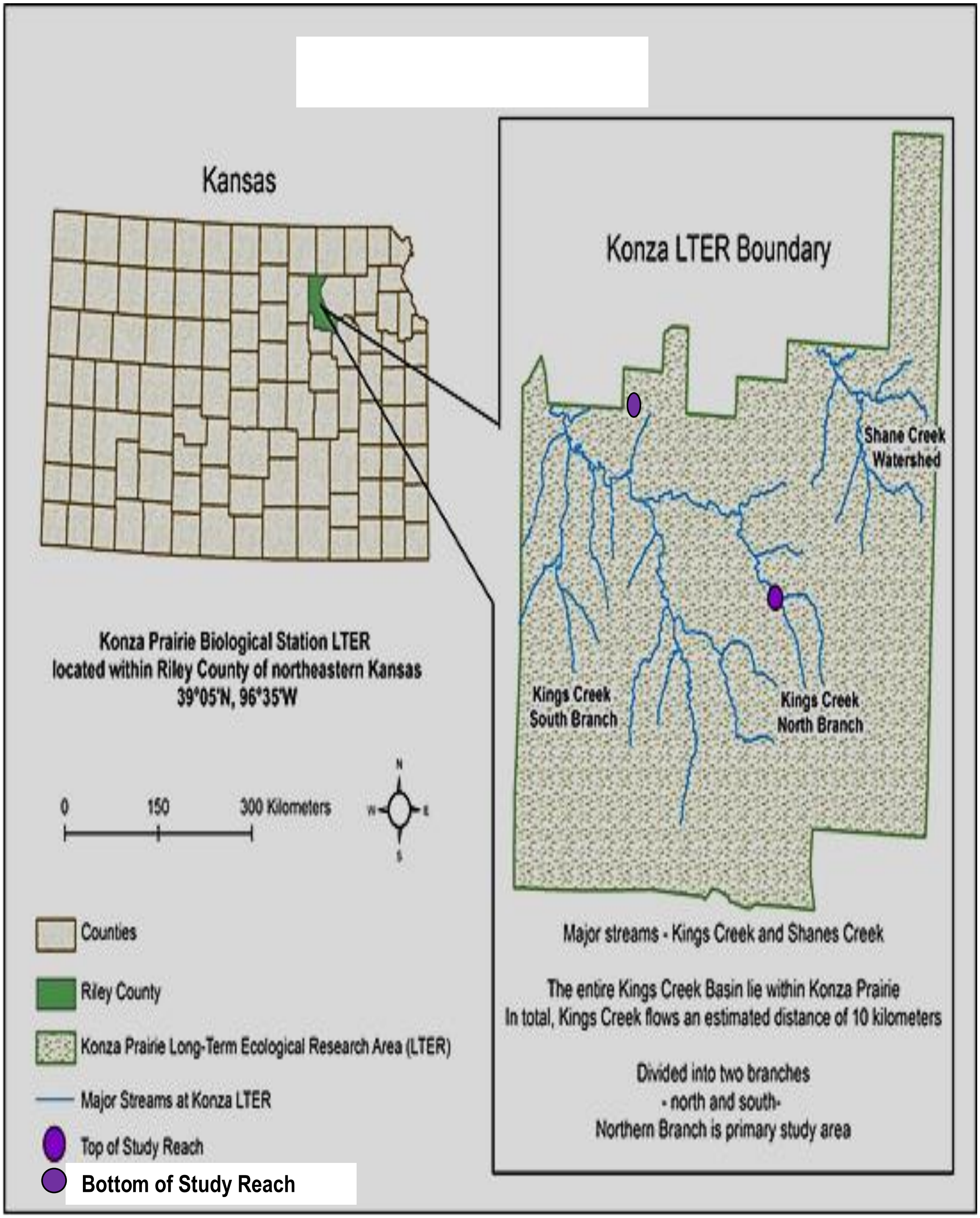
Figure 6: Konza Prairie Landscape

Photo from summer 2012 shows the variations in vegetation and topography throughout the prairie. Substantial tree growth is supported in the lower valley, in contrast to the surrounding steeply rolling hills dominated by tallgrasses.

Situated within the Central Lowland physiographic province (Fenneman, 1946), the Kings Creek basin serves as the main drainage for the 3,487-ha Konza Prairie LTER (Fritz et al., 2002), with the land being owned by the Nature Conservancy, and leased to Kansas State University for research purposes (Knapp et al., 1998). Kings Creeks is the largest stream on Konza Prairie, and is tributary to McDowell Creek, which ultimately drains into the Kansas River network. The length of the main channel is approximately 8 km from head to mouth, and the average slope is 1.7% (Clark et al., 2000). In total, the entire length of the study reach extends approximately 2 km in the downstream direction, over which the stream transitions from a 2nd to a 3rd order stream (Figure 7).

Figure 7: Reference Map of Study Area

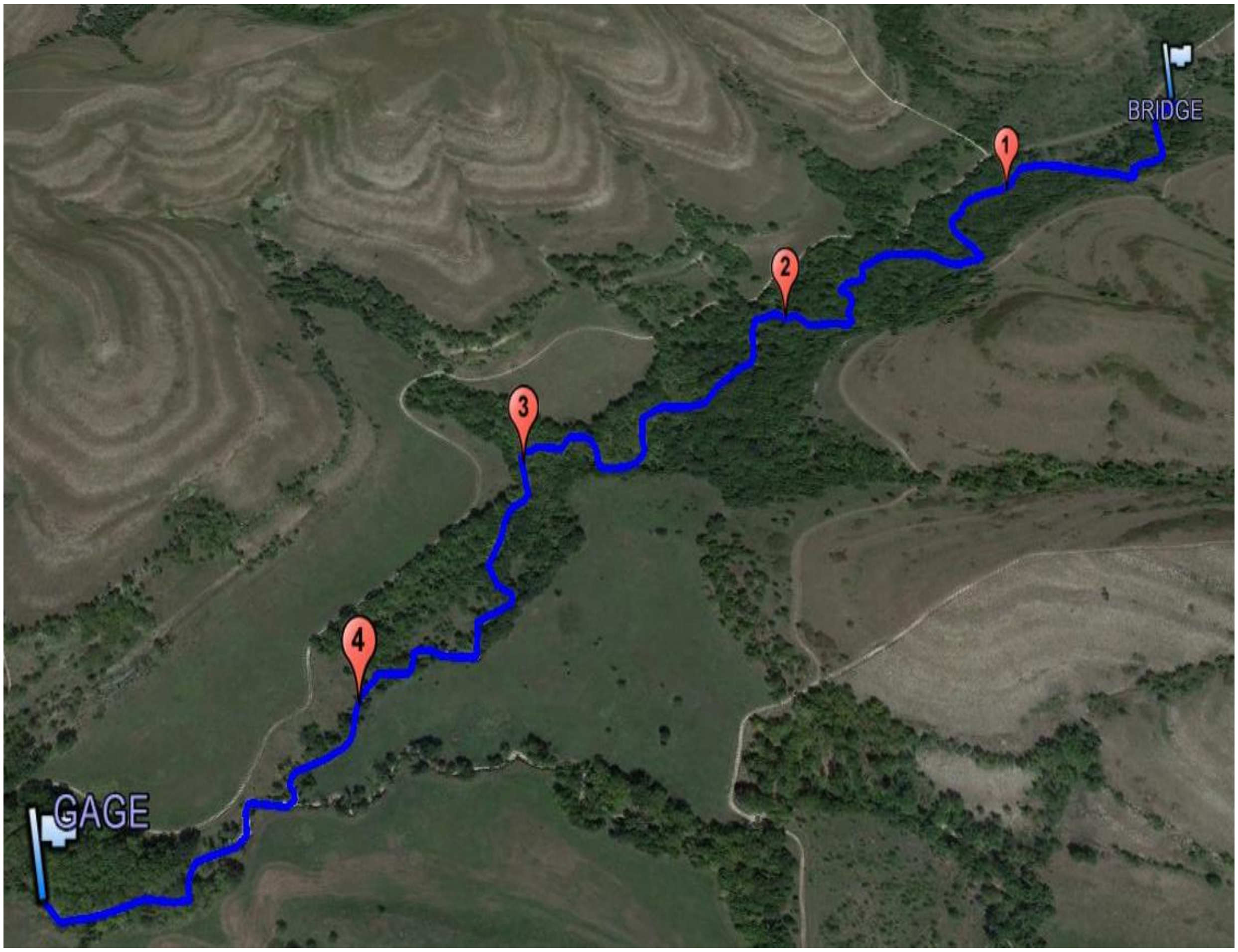
Map details Konza Prairie's location within Riley County in northeastern Kansas. Major streams are depicted, as well as the study reach, beginning in the headwaters, whose confluence forms the main stem of Kings Creek. (Source for GIS Data: Kansas GIS Commons).



The section of the upper main channel selected as the primary study area was divided longitudinally into four separate reaches, with the first beginning at the bridge marking the head of the channel (Figure 8).

Figure 8: Individual Reaches

Image shows entire study reach, separated into four reaches. Markers are labeled 1 – 4, and are placed at the bottom boundary of the corresponding reach. The bridge gage symbols mark the top and bottom boundaries, respectively, of the study reach. (Source of imagery: Google Earth).



Geology

Extrinsic factors such as the geology of the Flint Hills influence the behavior of the Kings Creek network (Oviatt, 1998). Consisting of alternating layers of permeable limestone and softer impermeable mudstones, the geomorphic structure of the surface geology has been instrumental in the formation and changing morphology of stream channels on Konza. Limestone layers act as grade-controlling knickpoints and are important conduits and storage zones for groundwater critical to seasonal baseflow in this intermittent stream network. In fact, some of the headwater tributaries of Kings Creek contain perennial springs associated with upper limestone layers in the upland prairie (Konza LTER site). It is the alternating layers of more resistant chert-bearing limestone and less resistant mudstones that give the terrain a benched appearance (Figure 9).

Figure 9: Rock Outcrop in Upper Reaches

Photo showing one of the many mature trees found growing under atypical conditions. In the 2nd reach, much of the left bank is comprised of rock outcrops such as this. The establishment of vegetation amidst exposed rock layers, and large limestone units that have accumulated along the bank below illustrate the interactions between stream characteristics and the geology and climate of the local environment.

In the upper channel, the stream and the adjacent terrain more clearly exhibit features that are unique to the prairie region than any other part of the channel, offering a rare glimpse into the mechanisms controlling the growth of vegetation and most of the related physical changes that make the Konza Prairie landscape unique. The exposed limestone units form benches throughout the prairie on steep-sided hills above valleys (Knapp et al., 1998), with the highest occurrence of visible limestone units observed in the upper reaches of the study reach, most frequently alongside other exposed rock layers (Figure 10).

Figure 10: Limestone Unit in Upper Reaches

Photo showing large, exposed units of limestone in the 1st reach. These were most often observed in the upper reaches, frequently in a setting similar to the photograph, where grassy vegetation was less abundant. Several mature trees were located on the banks above the limestone.

Climate Conditions

The variability of the region's climate produces the unpredictable weather cycle associated with the Great Plains, with the resulting extremes in seasonality exacerbated by the geographic setting and primary form of land cover. Because its location coincides with the dividing line between positive and negative mean annual precipitation-to-evaporation ratios for the region, the study area frequently receives a higher volume of precipitation than areas located on the negative side of this boundary. For instance, the volume of areal precipitation that Konza

Prairie receives annually is enough to sustain an ecosystem dominated by native tallgrass prairie species, whereas directly west of this dividing line the landscape is drier and characterized by communities of mixed and short grasses.

The rainfall received in the region enables the tallgrass prairie environment to support tree growth and maintain forested riparian corridors along many streams. However, the amount of precipitation can vary drastically by season, falling mostly in the form of rain during spring and early summer (National Climatic Data Center, 1996). Seasonal shifts are common for the region, and frequently leave isolated pools and reaches (Hax and Golladay, 1998) in many streams, with spates of rainfall generally followed by desiccation in late summer and autumn.

Because headwater streams are especially responsive to the influences of climatic instability, conditions present during this study were not exceptional. The state of Kansas has been experiencing recurring periods of moderate to severe drought in recent years, much to the detriment of its streams and the ecosystems they support. Most small streams have been unable to maintain consistent streamflow, including Kings Creek, whose bed remained dry while conducting fieldwork. No mobilization and/or transport of any channel materials occurred which eliminated the likelihood of missing an LWD piece or making duplicate measurements since the stream materials remained in situ.

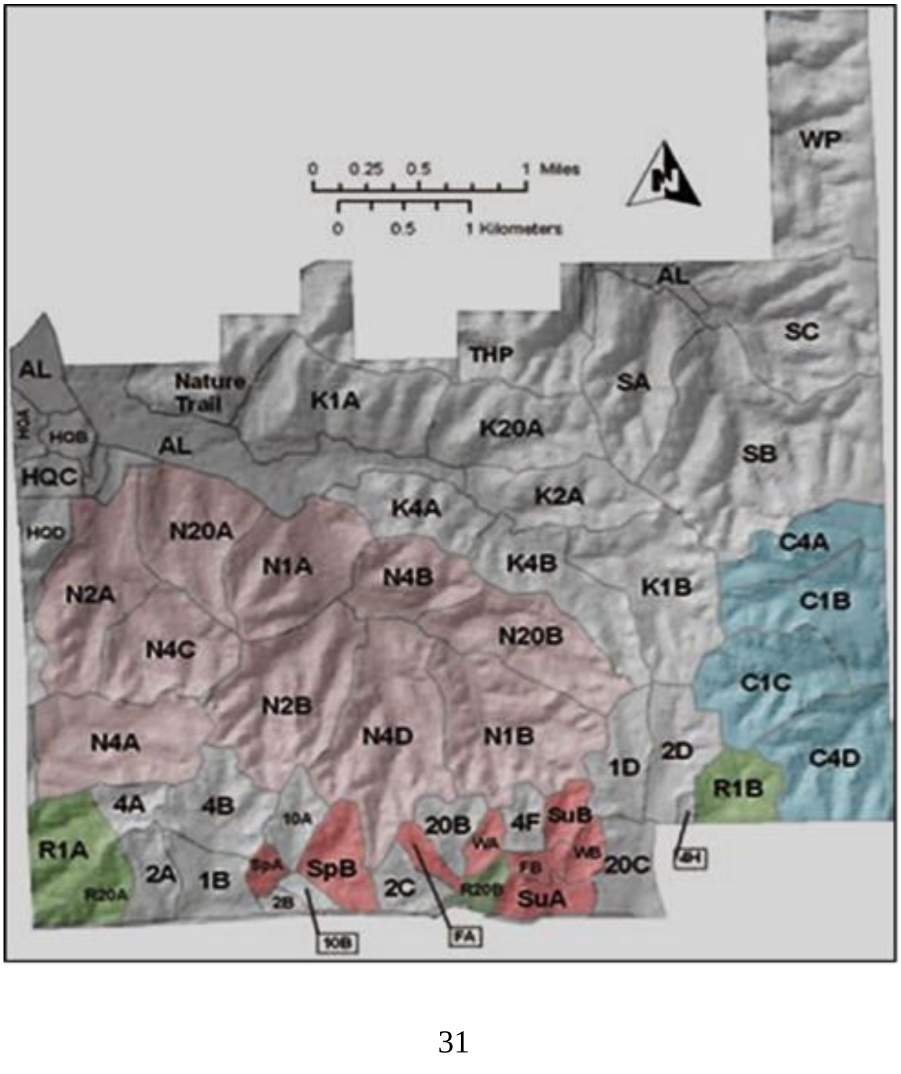
Given the overwhelming influence of the regional drought, data from climate (NCDC) and hydrology (USGS) stations on Konza Prairie were reviewed for a period of five years prior to this study to provide a better perspective of the average conditions specific to the Kings Creek basin. The total annual rainfall in 2007 was 1,012 mm, and the mean annual temperature was 55.8° F. In 2012, the year that fieldwork was completed, the total annual rainfall was significantly lower than in 2007, with an average of 568.9 mm. The mean annual temperature was actually higher, having steadily risen to 58.8° F over the previous five years. This wide range of annual average values reveals the extent to which conditions at Konza Prairie are influenced by those of the broader Great Plains climate. Under normal conditions, Kings Creek flows intermittently, and like most other prairie streams, sustained flows typically occur during periods of peak precipitation.

Land Use

Kings Creek forms at the confluence of two small (K2A and K20A) tributary channels and there are two additional headwater tributaries (K1A and K4A) that empty within the study reach portion of the main channel. These four tributary streams individually drain watersheds whose landscapes are managed differently; specifically, the time interval between prescribed burning varies for each (Figure 11).

Figure 11: Konza Prairie Land Use

Watersheds with bison (codes beginning with N) are highlighted in pink, and cattle-grazed watersheds (codes beginning with C) are blue. All other watersheds are ungrazed. Numbers in the watershed codes designate fire return intervals for spring-burned watersheds, and the letter A, B, C, or D at the end of a code identifies replicate watersheds of the same treatment (e.g., 4B = burned every 4 years, replicate B).Watersheds subject to different seasons of fire are highlighted in red, and the fire treatment reversal watersheds (codes beginning with R) are highlighted in green. Many plot-level experiments are located at the headquarters area (codes beginning with HQ) in the northwest portion of the site. Abbreviations: AL, alluvial soil; F, fall burns; K, Kings Creek watershed; Sp, spring burns; Su, summer burns; THP, Texas hog pasture; W, winter burns; WP, white pasture (leased for cattle grazing) (Source: Konza Prairie LTER).

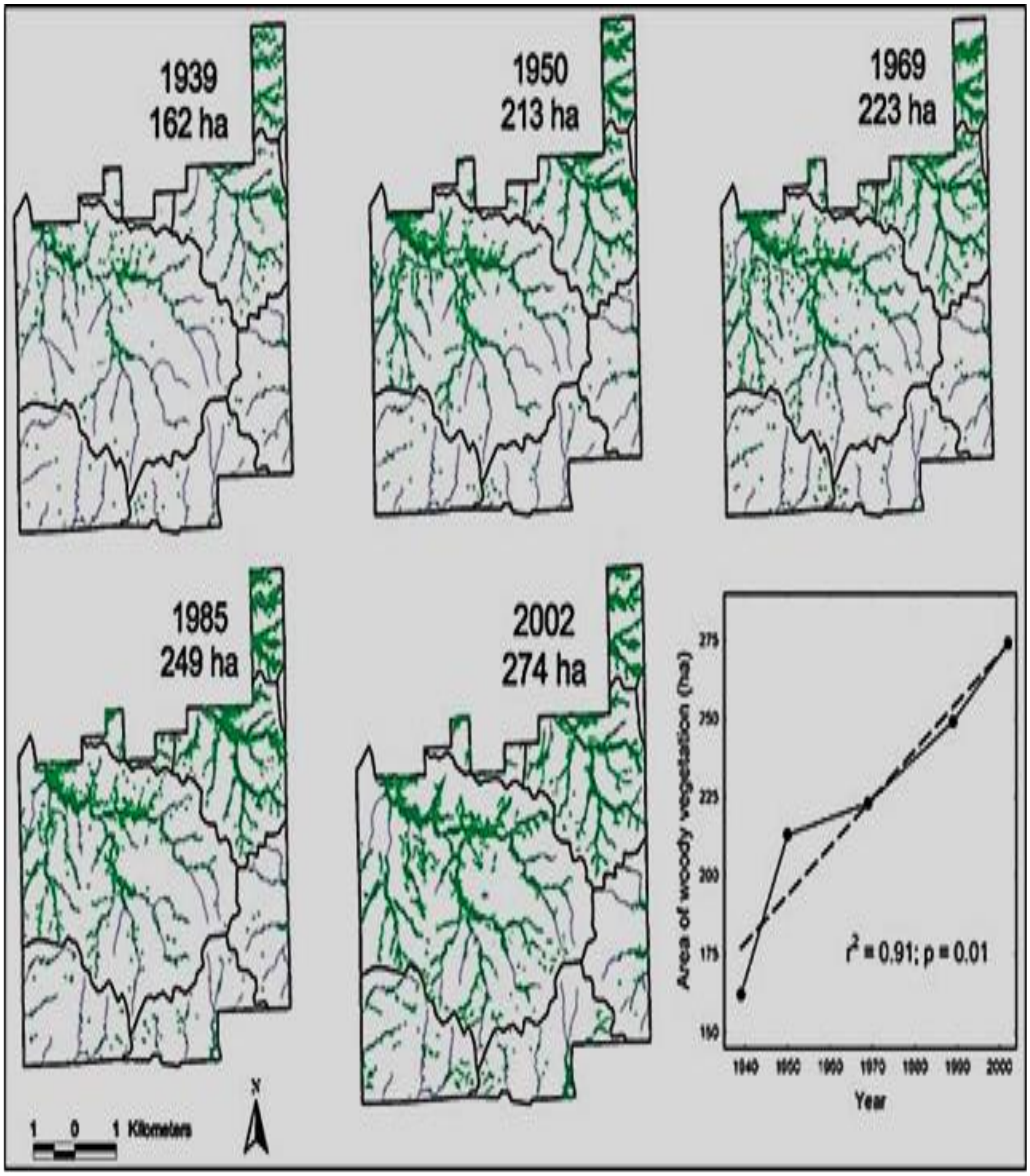


Long-term conservation efforts at Konza Prairie have favored a naturally alternating vegetation pattern of prairie and deciduous forest (Bailey, 1995), while protecting the tallgrass that has survived a century of human influence. At present, forest covers an estimated 7% of the preserve (Knapp et al., 1998; NSF Konza LTER, 2013), and the amount of woody vegetation within the Kings Creek Basin is increasing. Primary species include sumac (*Rhus Coriaria*), dogwood (*Cornus sanguinea*), and eastern red cedar (*Juniperus virginiania*). Additionally, gallery forests composed of oak (Quercus spp), hackberry (Celtis occidentalis), and American elm (*Ulmus americana*) grow in strips along the riparian zones of major stream courses (NSF Konza LTER, 2013). These provide riparian shading over the main channel, with the estimated extent of coverage found to vary from 0- 10% in the headwaters to 50-100% in the gallery forests (Gurtz et al., 1982) that dominate the lower reaches.

Generally, minimal riparian cover exists within the drier grassland environments (e.g. shortgrass prairie), even along the banks of rivers (Cross and Moss, 1987), where woody vegetation is most often supported. In more mesic grassland habitats however, the amount of riparian tree cover has expanded along perennial reaches (Dodds et al., 2004), with most modern tallgrass prairie stream networks able to sustain healthy gallery forests along their lower reaches (Briggs and Gibson, 1992; Knight et al., 1994; Matthews, 1988). In fact, the gallery forests bordering prairie streams in Kansas contribute greater quantities of organic matter to channels than the grasslands in upstream reaches (Gurtz et al., 1988). In 2005, Briggs et al. documented the historic expansion of the gallery forest for streams at Konza Prairie, revealing that the area of mapped forest had increased from the estimated 159 ha in 1939 to 274 ha (a 72% increase in areal extent in 63 years) (Figure 12).

Figure 12: Gallery Forest Expansion at Konza Prairie

This GIS representation was digitized using aerial photographs from 1939, 1950, 1969, 1985, and 2002. From 1939 to 2002, the extent of the gallery forest increased from 162 hectares (ha) to 274 ha (lower right panel). Major drainage boundaries at the Konza Prairie Biological Station are outlined in black; some of the major streams are outlined in blue. (Source: Briggs et al., 2005).



Clearly significant, and unlikely to decrease, the expansion of woody plants is now considered one of the greatest contemporary threats to mesic grasslands of the central United States (Briggs et al., 2005).

Climate records suggest that the expansion of forests into the tallgrass prairie is likely to have been most dramatic within the last 100 years (Abrams, 1986; Abrams, 1992; Bragg and Hulbert, 1976). Explanations include the increased rate of warming and precipitation values throughout the Midwest region in recent decades, which have favored increased tree growth. Between 1900 and 2010, the average air temperature in the region increased by more than 1.5º F (Kuhn et al. 2013). The annual precipitation trend also increased during the past century (by up to 20% in some locations), with much of the increase driven by intensification of the heaviest rainfalls (Pryor et al., 2009a; Pryor et al., 2009b; Virlarini et al., 2011).

In addition to climatic variables, long-lasting changes were made to the prairie landscape by early Europeans, including the replacement of native bison with cattle as the dominant grazers, the degradation of the waterways, and cutting down the gallery forests to provide firewood or lumber (Matthews, 1988). These disturbances influenced widespread changes within the prairie biome, and with the fear-driven European philosophy that fire suppression was tantamount to fire management (Ford and McPherson, 1996), the expansion of trees into some areas of grassland was further enabled by the absence of fire (Leopold, 1949). For these reasons, consideration of prior and current land use at the watershed scale has proven to be an important step when conducting wood-related research (Wohl et al., 2005; Harmon et al., 1986).

Fire

In spite of the forested areas contained therein, Konza Prairie’s ecosystem remains dominated by tallgrass, and is thought to be one of the most productive grasslands in North America (Clark et al., 2000). Much of this productivity is made possible by the cyclic burning implemented by Konza personnel, which has helped to create the present distribution of prairie and forest. Human's use of fire to control the landscape has been documented throughout history, as it has played an integral part in the management of grasslands worldwide, including its current use at Konza Prairie. Here, controlled burning is applied at the watershed-scale as part of an experimental treatment designed by the Konza Prairie LTER.

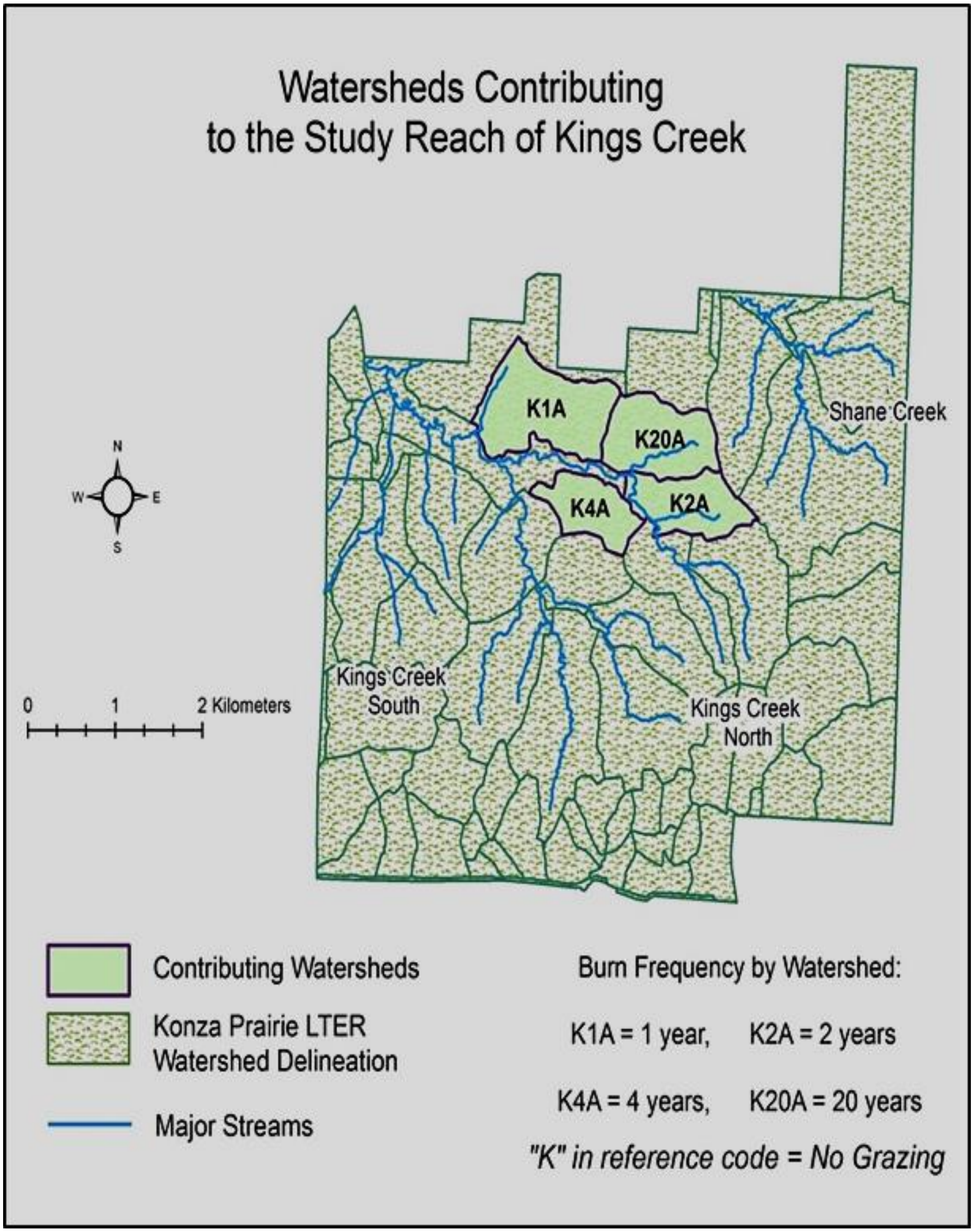
Along with its benefits to the health and re-growth of native grasses, fire has also proven to be an efficient method for curbing the expansion of forests, although the unburned watersheds still maintain significant amounts of woody vegetation. Since the natural dynamics within Kings Creek's basin and stream systems have not undergone a high amount of unnatural alterations, the riparian forest bordering the reaches of the main channel is comprised of a vast expanse of large, mature trees. Comparatively, the four tributaries emptying into the study reach drain watersheds whose vegetation is exposed to recurrent fires, causing each one to provide altered inputs to the study reach. This, in addition to the exclusion from burning and all other types of physical modifications, strongly suggest that the mature forested riparian zone bordering the main channel serves as the stream's primary wood source, while inputs from the four contributing watersheds to the study reach may be supplementary.

The annual extent of burning and the rate of recurrence for the entire preserve area is determined by an experimental treatment plan implemented at the watershed scale by the Konza Long-Term Ecological Research (LTER). A reference map has been produced which denotes all land use activities with a combination of letters and numbers that form the individual watershed reference codes (Figure 11). Each of the four study watersheds are burned in accordance with the 1, 2, 4, and 20 year interval-based management plan, thus, the tributaries draining into each of the four reaches provides inputs from watersheds whose burn schedule differs from the others. Since watershed vegetation has a direct influence on wood loading processes, the prediction was that these variations in burn frequency would have an observable effect on the spatial distribution of LWD throughout the study reach.

Beginning at the headwaters and ending at USGS stream gage (#06879650), the length of the entire study reach extends approximately 2 km downstream. Of the four watersheds that contribute to the study reach, three (K1A, K2A, and K20A) were burned in early 2012, and the fourth watershed (K4A) was last burned in 2009 (Figure 13).

Figure 13: Watersheds Contributing to Study Reach

Reference map shows the four watersheds whose primary streams are tributary to Kings Creek. Activities in these watersheds were accounted for in order to represent the influence of inputs each provides to the main channel. (Source of GIS Data: Kansas GIS Commons).



These intervals ensure that the characteristics of any inputs to the main channel differ by tributary, resulting from the different stages of tree growth in each watershed with respect to the burn frequency for each one. To account for the predicted inconsistencies in the spatial distribution of LWD throughout the main channel, the entire length of the study reach was divided longitudinally into four geomorphically distinct reaches (Table 3). The boundaries were then defined in accordance with the exhibited physical heterogeneity of the study reach and the locations of incoming tributaries.

Because two of the four tributaries (K2A and K20A) merge to form Kings Creek, and therefore drain into the same reach, it was necessary to reference aerial imagery of the study area in order to ensure that a secondary tributary from each of these watersheds connected to the main channel. Based upon imagery analysis, followed by on-site verification, the boundaries of the upper reaches (1 and 2) were determined. In each of the lower reaches (3 and 4), the primary tributary was easily discernible, so the boundaries were defined by their location relative to the main channel. In taking this approach, it was possible to account for the natural fluctuations in the quantity and condition of available wood throughout the study reach.

Agriculture

In addition to cyclic burning, the other major form of land use falls within the realm of agriculture, as depicted on the Konza LTER reference map (Figure 11), with several areas throughout the prairie grazed by either freely roaming bison or cattle. Though grazing is thought to be very detrimental to the health of the prairie and its streams (Belsky et al., 2000; Magilligan et al., 1997), alterations to the landscape made by either bison or cattle reach beyond the vegetation and are associated with localized changes to channel morphology (Belsky et al., 2000; Magilligan et al., 1997; Trimble, 1995). For example, while grazing or congregating in the riparian zone, the animals frequently introduce sediment and other materials to the stream when they redistribute large amounts of bank material while creating paths for cattle or wallowing areas for bison (Davies - Colley et al., 2004; Kondolf, 1993).

Native bison are thought to disturb stream processes less than domesticated cattle, which frequently cause more damage simply by entering the stream channel. Such behavior was observed during a study of how land-use variables, specifically grazing, affect the ecology of a mixed-prairie (Steuter and Hidinger, 1999). Side-by-side comparisons found that because bison prefer open upland areas, they spend less time grazing and loafing next to water sources, and therefore tend to cause less damage to the stream channels (Steuter and Hidinger, 1999).

In contrast to this, cattle tend to avoid upland areas, due to their attraction to the shaded areas that the woodlands and riparian zones provide (Christopherson, 1979). As the cattle seek relief here during the heat of the summer and protection from the wind and cold of winter (Smoliak and Peters 1955; Sneft et al. 1987; Van Vuren 1981), they cause considerably higher levels of degradation in the riparian zone. As such, overall findings from this and other studies reveal that in riparian zones of bison-grazed watersheds, the animal impact zone is smaller and less severe (Van Vuren 1981; Steuter and Hidinger, 1999) than riparian zones of watersheds grazed by cattle. Considering these impacts, selection of the north branch of Kings Creek's main channel as the study area was in large part due to the fact it is exempt from any grazing.

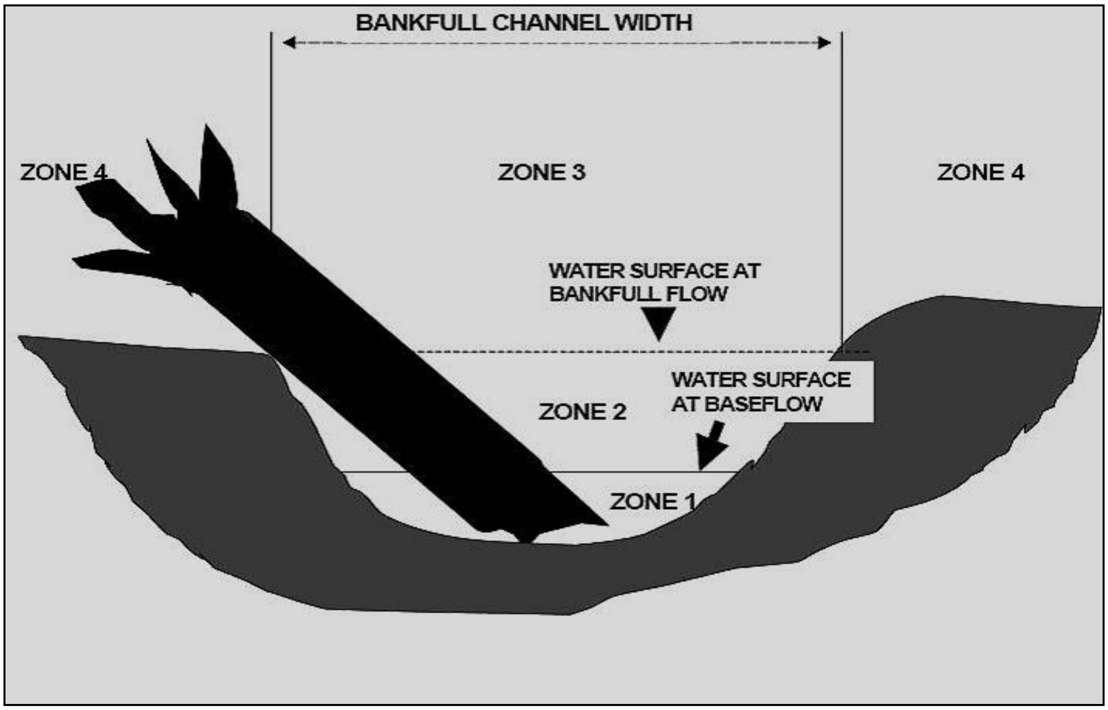
Chapter 4 - Methods

Nearly all quantitative data related to wood and sediment were collected from early June to September 2012. Additional trips made to the study area were to measure channel dimensions and mark GPS locations, with all fieldwork completed by December of that same year. In an attempt to address each of the proposed hypotheses as efficiently as possible, all measurements made within the stream channel adhere to the common metrics outlined by previous studies of wood and sediment. Specifically, two pieces of literature were referenced in creating a conceptual template for the methodology and guidelines that were applied to this study: *Large in-stream wood studies: a call for common metrics* (Wohl et al., 2009), and *The effects of large organic debris on sediment processes and stream morphology in Vermont* (Thompson, 1995).

The operational definition of LWD from these and similar studies (Swanson and Lienkaemper, 1978; Marston, 1982) was applied, therefore only those pieces measuring ≥ 1 meter in length and ≥ 10 centimeters in diameter were considered to be large woody debris. Dimensions of all pieces, jams, or other aggregations of LWD located within the bankfull width area of the channel were measured (Figure 14).

Figure 14: Bankfull Width Zones

Graphic Depiction of bankfull width area of the channel - defined by this study as being the area below the edge of perennial vegetation or at the top of the break in bank slope (Thompson, 1995). Pieces found here are most likely to influence stream characteristics. (Source: Robison and Beschta, 1990).



The bankfull channel width was recorded using a 30-meter tape measure and a stadia rod, with necessary consideration given to differences in topography, vegetation, and sediment texture at each site.

Initially, a wood census was conducted for the entire study reach, in which all forms of LWD found to meet both the size and location requirements were tallied, and the spatial distribution was documented using GPS. Data on piece length, diameter, and all other related field measurements were also recorded at this time.

Upon completion of the wood census, the individual volume of each piece was calculated. Individual pieces were then categorized according to the reach they were located in, and the summation of these piece volumes were used to determine both the quantity and volume of LWD per reach. Next, the total quantity and volume of wood were derived from the sum of the individual values for each of the four reaches.

If a piece was found to extend beyond the boundary of the channel, a stadia rod was used to take two separate measurements; the first being the entire length of the piece, and the second being the length of the portion located within the bankfull width area (Figure 14). The latter of these two measurements served as the official piece length when calculating the individual volume for a piece of wood. This helped to account for all of the LWD present within the bankfull width area more accurately, as well as to estimate the likelihood of the piece being mobilized and transported.

Live trees in the bankfull width area with most of their roots protruding into the channel were also accounted for, as this helped to provide a more accurate quantitative measurement of the volume of live wood mass within the channel, i.e. the volume of a tree's exposed root system. Live tree and wood mass data were analyzed separately as they are not technically defined as being LWD. Thus, related findings were not considered in the wood census, nor were they included in calculations related to LWD volume.

Two components influenced by wood are sediment and streamflow, thus quantitative data relevant to each one were collected in order to test the hypotheses proposed by this thesis and provide a better idea of the bed materials and morphologic characteristics that define the individual reaches. The average gradient of the bed was calculated from the values of four measurements taken at mid-channel points in each reach, equaling 16 total measurements. For example, the values from four points in reach 1 provide its average gradient, as is the case for the remaining three reaches. The sum of these four totals was then used to determine the average gradient for the entire study reach.

The elevation and length of the four reaches were determined by referencing aerial imagery via Google Earth to verify and measure the distances between waypoints marked throughout the study reach and stored on a Garmin Dakota-10 GPS device. The depth of the thalweg, bank height, and the width of the channel's cross-section were measured at intervals specific to the length of each channel unit using a 30-meter measuring tape and stadia rod.

Variations along the longitudinal profile of the streambed produced by the influence of LWD were also measured. Pools are bed features that frequently result from changes to the longitudinal profile instigated by the obstruction of streamflow and sediment by LWD. As such, pools located at the site of an LWD piece or dam, in addition to pools formed at the roots of a live tree, were accounted for. Each pool's location was recorded and their dimensions were then measured as these pools directly influence and reflect the morphology and storage capacity of the stream channel.

Similar to pool features, the obstruction of stream flow and sediment by wood is associated with the increased storage of stream materials. The dimensions of sediment wedges located either up or downstream of an LWD piece or dam were measured, and their locations were recorded to help determine their spatial distribution throughout the study reach. Data for individual wedges were then grouped according to the reach they were located. After calculating the volume of sediment being stored per reach, the sum of these four values provided the total volume of sediment stored within the channel for the entire study reach.

To determine how much of the total volume of sediment stored as wedges is attributable to LWD, only the values of wedges located upstream from LWD were calculated and totaled for each reach. The sum of these four totals then provided the total volume of sediment wedges stored directly by LWD for the entire study reach.

Variables selected for this study were identified through referencing the available scientific literature, recognizing the most commonly measured variables, and applying those found to be of relevance to the conceptual and methodological framework of this study. The variables selected for measurement are therefore similar to those of other studies related to LWD, given their role as fundamental components and characteristics of streams, regardless of the region, and are considered to be strongly related to the perceived functions of LWD and how they relate to the storage of sediment.

Wood Variables

Individual Pieces

The entire length, plus the diameter at the top and bottom of individual LWD pieces were measured, with the top being the smaller end and the bottom being the larger end of the piece. Used to calculate individual piece volume, the following equation has been aptly referenced by previous LWD studies (Chen et al., 2005; Wohl et al., 2009; Young et al., 2006), and is based on the assumption of cylindrical shapes:

Equation 1: Volume Formula for LWD

V is the piece volume in cubic meters, L is the length of the piece (m) within the bankfull width area, and d_1 and d_2 represent the diameter of the small and large end of a piece, respectively.

$$V = L\pi \left(\frac{d^1 + d^2}{4}\right)^2$$

The volume of wood per unit channel area, or the wood loading density (m^3/m^2) was then calculated using the following equation:

Equation 2: Area Formula Applied to Wood Loading Density Calculation

A is the channel area in meters squared. For this example, 125 is the length (m) of the reach and W_2 is the bankfull width (m) for the identified reach, i.e. the second reach in this example. Finally, the volume of wood (m^2) is divided by the value calculated for the area (m^2); this is done to ensure that the calculated volume of wood per unit channel area (m^3/m^2). Also referred to as the wood loading density, this value represents the spatial distribution of LWD found within the bankfull width area of the study reach as accurately as possible.

$$A = \sum (125W_2)$$

Also documented were the following characteristics for each piece (following Wohl et al., 2009; Schuett - Hames et al., 1999; Magilligan et al., 2007):

Orientation - the angle of the piece relative to the direction of streamflow to provide an idea of the likelihood of the piece being mobilized and/or transported.

Bankfull Zone – the zone(s) each piece was found within (1 – 4) helps determine possible sources and levels of wood loading, as well as the likelihood that a piece will be mobilized and/or transported in the event of high flow.

Rootwad – the presence or absence of a rootwad was noted for all logs and fallen trees, and the observed function - scour or storage - of the rootwad, if observable.

Individual/Dam – all LWD was categorized as being either an individual entity, or part of a jam. If a piece was found to be part of a dam, it was then determined whether or not it served as a key piece.

Function – when the function of an LWD piece or dam was discernible, it was categorized as either storage or scour, or both. If scour was identified, it was noted whether or not a pool was formed as a result.

Debris Dams/Structures

If 3 or more individual pieces were found grouped together, they were considered part of a dam. First, the length and width of the dam were measured, i.e. the intact piece extending furthest in either direction, as well as the height from the top to the bottom of the structure. In determining the height, care was taken to measure to the base of the structure and not to the bed, in order to provide accurate data regarding the size and abundance of dams, as well as the potential storage available within the study reach.

At the site of each dam, the presence of any pools directly up or downstream was noted, because similar to those found by individual pieces of LWD, these pools provide further insight into the dam’s primary function. Once the total number of pieces in each dam were tallied and measured, the key pieces were identified. For the purposes of this study, key pieces were defined as being intact and responsible for maintaining the structure and stability of the dam. This was most often pieces whose length and diameter were larger and supporting the smaller pieces (Figure 15).

Figure 15: Debris Dam/Structure

Photo of a one of the largest debris dams within the study reach; located in reach 3. LWD marked with an orange tag were identified as 'key pieces', which provide stability as well as the foundation for the entire dam.

Live Trees

Considering the disturbance to Kings Creek's flow and sediment regimes that rapid delivery of wood and bank materials would cause, the volume of live wood mass supported by live trees located at the edge of a bank, anchored to the inside of a bank, or growing anywhere else within the bankfull width area were accounted for by this study. The root systems of these trees were intricate and frequently exposed within the channel, providing a small element of roughness to the stream. Their functions are largely analogous to those of LWD, each one capable of impeding streamflow, regulating the transport and storage of organic materials, and instigating geomorphic change. However, unlike LWD, the stability of the trees increases their potential to influence steam processes with the unexpected introduction of live wood and any stored materials to the stream in the case of natural tree fall, bank failure, etc.

Dimensions of the protrusion formed by a live tree were measured for each live tree(s), to determine the volume of live wood mass within the channel. The length was defined as the area between the part of the tree or its roots that extend furthest into the channel - most frequently the base of the trunk or the longest intact root - and the part of the tree extending to meet the bank (Figure 16).

Figure 16: Live Trees

Photos of an individual and group of live trees in reach 2 and 3, respectively, growing within the bankfull width area of the channel.

For example, many of the live trees exhibited a sort of L-shape in that the roots were exposed, but still securely attached to the bank and the trunk of the tree was growing directly upwards. In this case, the space between the outside area of the trunk that faces the channel to where the roots connect to the bank would be considered as the length.

Width was defined as the area between the furthest extending roots in both the up and downstream direction, with height being the area between the part of a tree or its roots that reaches lowest into the channel and the top of the bank. Other information gathered from the live trees include the orientation (upright, spanning the channel, 90° angle in downstream direction, etc.), its location, and whether or not it was part of a debris dam.

Pools

Pools are important morphologic features associated with a vast array of benefits to a stream, such as increasing the availability of in-stream habitat. Frequently they form in response to the influence of a large obstruction, such as LWD, as a result of the localized increase in velocity and shear stress (Figure 17).

Figure 17: Large Pool

Photo showing a large pool, categorized as a live tree pool, located near the top of the study reach that was one of the few pools able to maintain a relatively stable water level, perhaps due to its location in the headwaters, or the shallow limestone soils that facilitates interaction between the stream and groundwater resources.

LWD Pools

At the site of each LWD piece or structure, the absence or presence of a pool was documented, and when present the dimensions of each pool were measured, defined by the furthest extending boundaries. Thus, the longest measurable boundary from the upstream to the downstream direction, and the widest measurable boundary beginning at the side of the pool closest to the bank served as the length and width, respectively. Height was defined as the distance from the bottom of the pool (stream bed) to the bottom of the LWD.

In addition to its dimensions, it was noted whether each pool held water and if no water was present, it was noted if the pool was storing other materials, such as leaf litter or large, coarse grains, which was most often the case. The location of each pool was recorded as up or downstream from the LWD, which helped to identify its primary influence. While dimensions of upstream pools were used to estimate the amount of active or potential storage provided by LWD pools, those of downstream pools were used to estimate the extent of changes to the bed morphology produced by LWD.

Live Tree Pools

In order to be classified as a live tree pool, the pool had to be located within a feasible distance (e.g. no further than the length of the longest extending root) from the tree and the bank it occupied. As with LWD, at the site of each live tree the absence or presence of a pool was determined, and when present, the dimensions were defined similarly to LWD pools. The longest measurable boundary from the upstream to the downstream direction, and the widest measurable boundary beginning at the side of the pool closest to the bank again served as the length and width, respectively. The only difference is that height for live tree pools was defined as the distance from the bottom of the pool to the part of the tree that is lowest in the channel, usually its roots.

In addition to its dimensions, it was noted whether each pool held water and if no water was present, it was noted if the pool was storing other materials, such as leaf litter or large, coarse grains. The location of each pool was recorded as being up or downstream from the live tree, which helped to determine if the tree was diverting flow and scouring the bed or storing materials. Many live tree pools were neither up nor downstream of the tree; rather they were directly below a tree that was located at the edge of the bank, or beneath the protruding root system, which were both quite common.

Sediment Wedges

At the site of each LWD piece or structure, whether or not the LWD had caused sediment to accumulate and form a wedge was recorded (Figure 18).

Figure 18: Sediment Wedge

Photograph of a medium-sized sediment wedge located upstream of a large piece of wood upon which smaller pieces of wood other organic debris has accumulated, forming a small debris structure in reach 3. The measurable accumulation of bed materials directly upstream is defined as being a sediment wedge.

If a wedge was present, its characteristics were recorded, and the location was specified as up or downstream of an LWD structure, piece, or a live tree, which helped to identify the functions of each wood variable, and provide a better understanding of the spatial distribution pattern of sediment wedges. Noted characteristics included whether or not leaf litter was present, and if so was it a high or low amount, and whether or not a pool was located either directly up or downstream of the wedge. Lastly, the types of bed materials that made up each wedge were documented and used to determine the amounts of coarse and fine grains by reach and whether amounts of materials are specified as being either high or low (Figure 25).

Dimensions of each sediment wedge were measured to determine the volume of material stored on each. Its length was measured from the top of the wedge's base, or front face to its end, typically the point where it connects to the streambed. Width was measured as the widest section of the wedge, usually across its middle, and wedge height, or thickness, was defined as the area between the top of the wedge's front side that faces downstream, to the point where the bottom of the wedge meets the streambed. Care was taken to ensure that the bed of the stream was the endpoint and not the bottom of the pool directly downstream of the wedge, if one was present. After calculating the individual volume for each sediment wedge, the values were then summed to determine the volume of sediment wedges stored per reach. Lastly, the sum of the four values from each channel unit provided the total volume of sediment being stored as wedges for the entire study reach.

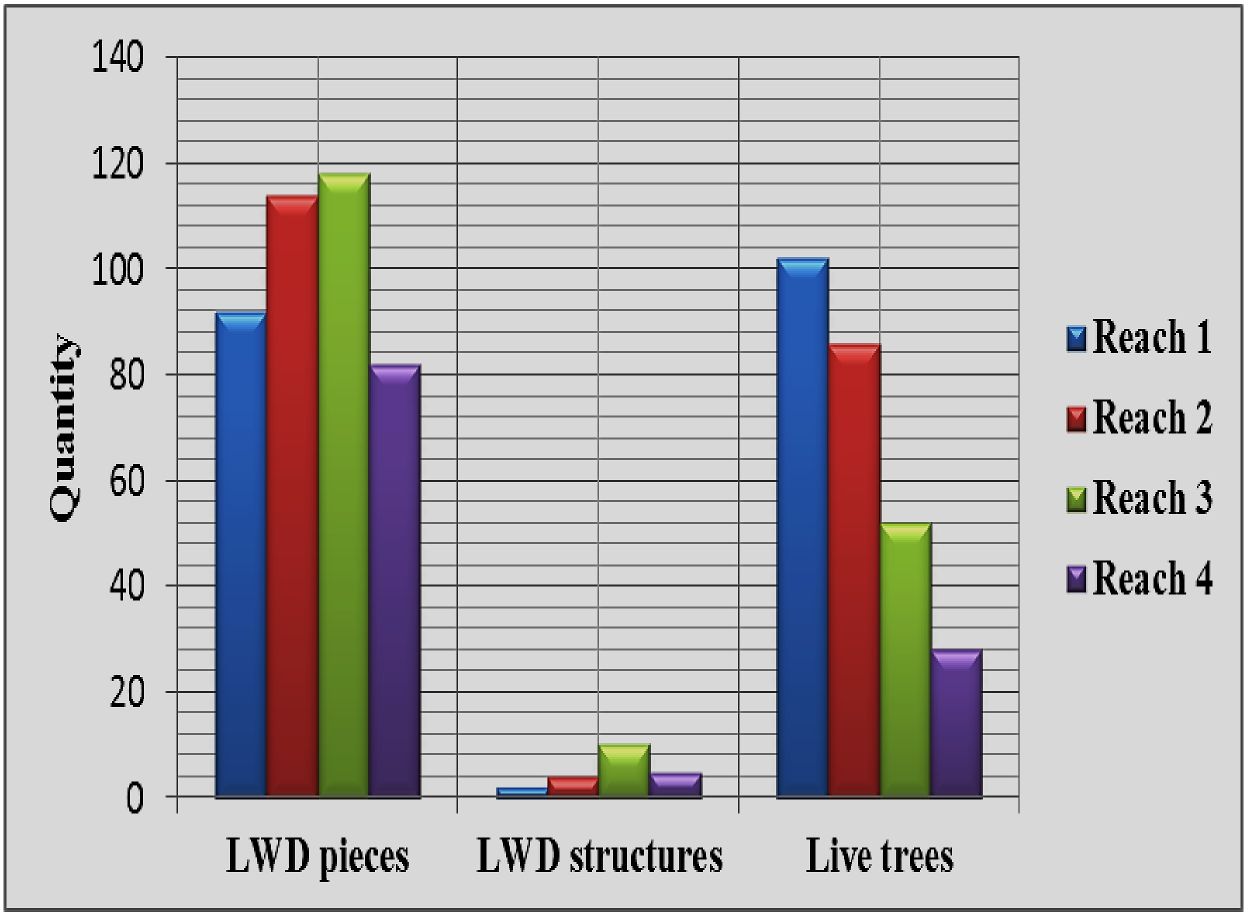
Chapter 5 - Results

Wood

In total, 1,880 meters of the main channel of Kings Creek's northern branch was surveyed, with the length of the study reach being divided into four separate reaches. A detailed wood census was conducted beginning in Reach 1 at the head of the main channel and ending in Reach 4, at the location of the USGS stream gage (#06879650) that marks the bottom of the study reach. In total, 406 individual pieces of LWD, 21 LWD structures or dams, and 268 live trees were present within the bankfull width area of the length of channel surveyed (Figure 19).

Figure 19: Wood Variables by Reach

Data was derived from wood census of entire study reach, and shows the quantities of LWD pieces, LWD structures, and live trees categorized by reach. Reaches are labelled from 1 (top of study reach) to 4 (bottom of study reach) at the right of the plot area, and represented by the corresponding color.



It should be noted that these values denote the minimum estimates, as the total counts and the calculated total volume of each of the three wood variables cannot be exact. Research limitations are the main source of these discrepancies, being that it was impossible to extract and measure pieces of LWD that were either partially buried or embedded in a bank. Likewise, there was no way to disassemble the elaborate structures that were frequently formed by several large pieces of wood, and at times one or more fallen trees.

Characteristics specific to each variable were also recorded (Table 1) while conducting a detailed wood census (Table 2). Information from the census was then analyzed further in order to determine the spatial distribution of LWD (Figure 20).

Table 1: Characteristics of Wood Variables

General information specific to each variable including: number of LWD pieces, both individual and within a structure, intact rootwads, the average number of key pieces for structures, and the average physical dimensions. The total number of live trees, and the number serving as part of a structure were identified, and the location of each were also categorized accordingly. Values are rounded up to nearest whole number.

Variable	Avg. length (m)	Avg. diameter (cm)	# rootwad
LWD pieces	4	21	36

Variable	Avg. length (m)	Avg. width (m)	Avg. height (m)	# key pieces
LWD structures	6	4	1	6

Variable	# part of structure	# right bank	# left bank	# mid-channel
Live trees	47	154	108	6

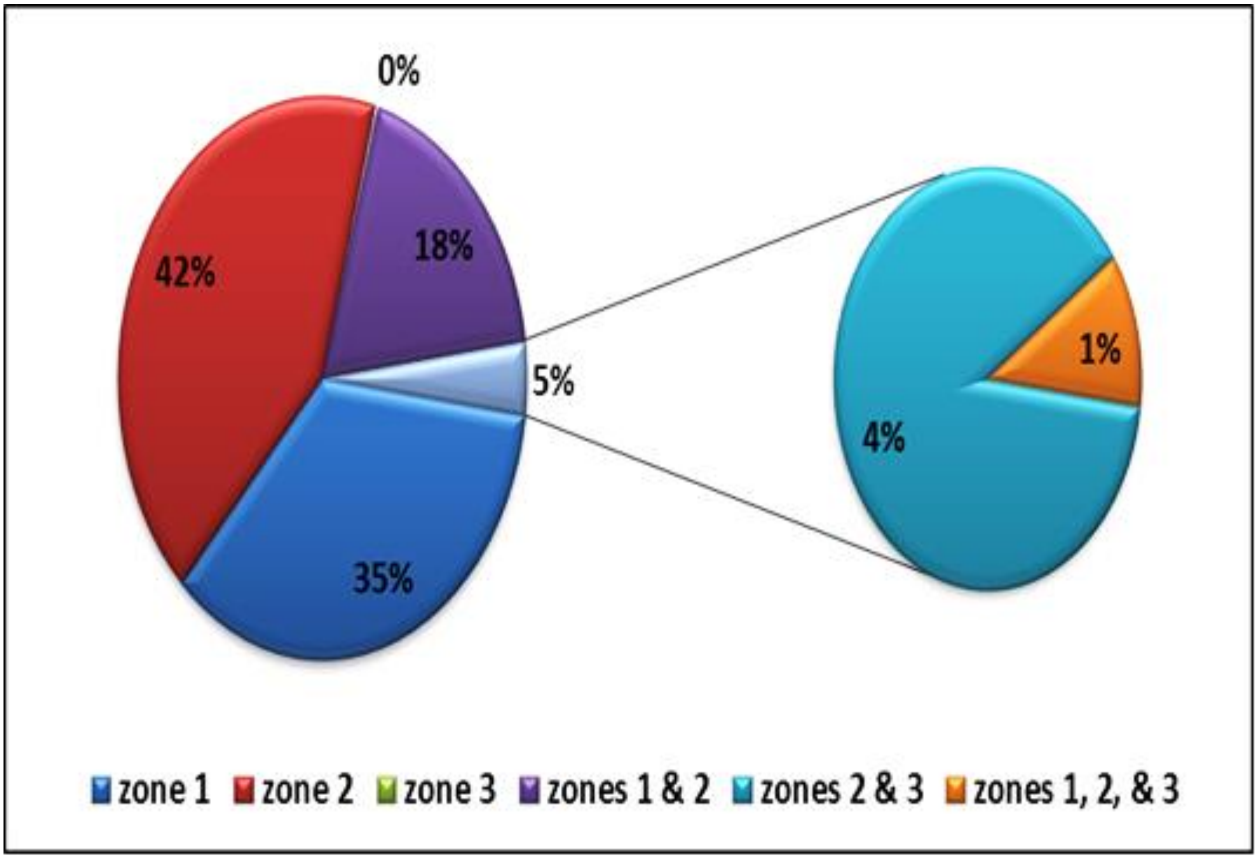
Table 2: Wood Census

Values listed by reach, from top to bottom of the study reach. Total values in bottom row are representative of the entire study reach. Values are rounded up to nearest whole number.

Reach	# pieces	Vol. lwd pieces (m^3)	# structures	Vol. lwd structures (m^3)	# live trees	Wood load (#/m)	Wood load (m^3/100m)	Loading density (m^3/m^2)
1	92	37	2	21	102	0.2	1	7
2	114	43	3	37	86	0.2	1	4
3	118	35	10	408	52	1	4	17
4	82	46	6	679	28	2	7	28
Total	**406**	**160**	**21**	**1145**	**268**	**3**	**13**	**56**

Figure 20: Spatial Distribution of LWD Pieces

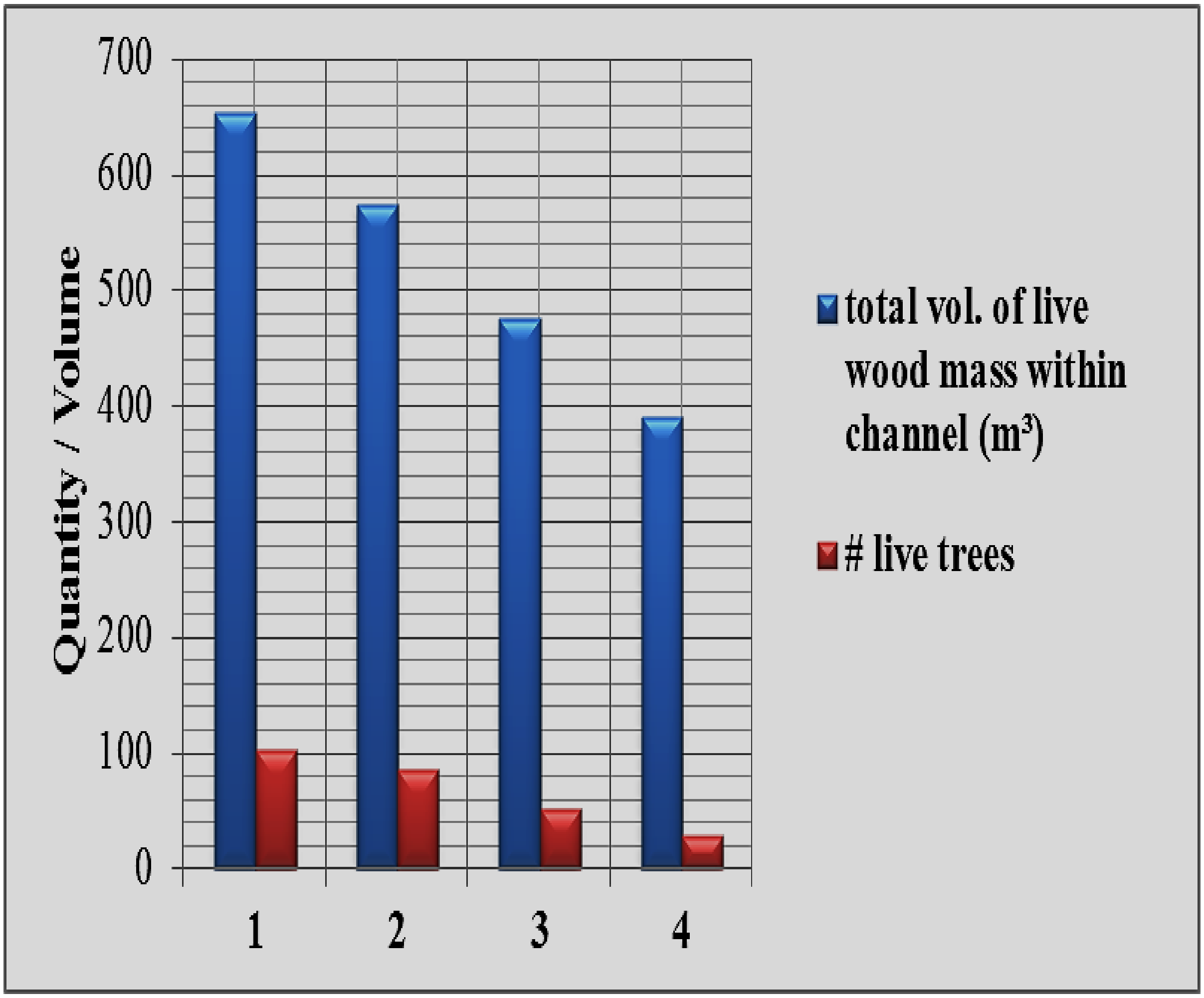
The total number of LWD pieces (406) located in each bankfull zone(s) is shown as a percentage.



In addition to the LWD stored within the channel, the volume of live wood mass protruding into the channel at the site of each live tree was measured by this study. This mass volume is representative of the total number of live trees (268) within the bankfull width area of the channel, and is an estimated 2094 m³ (Figure 21).

Figure 21: Volume of Live Wood Mass (m³) within Channel

Vertical axis represents the quantity of live trees and the volume of live wood mass by reach. The numbers on the x – axis represent the four individual reach numbers, whose values decrease in the downstream direction.



Wood’s Influence on Morphology of Bed and Channel

Morphologic variations exhibited by the channel structure were measured at 16 sites in total (four per reach) that were distributed along the entire length of the study reach, which totals 1,678 m. Total values for other dimensions measured were calculated to determine the average values including channel depth at thalweg (1.7 m), bankfull width (11.6 m), channel area (19.8 m²), and channel gradient (1.6%). Totals by study reach also shown (Table 3).

Table 3: Geomorphic Characteristics

Measurements from the table below were made at the reach scale, as shown in first column from top (reach 1) to bottom (reach 4) of study reach. Explanation of the column headings is as follows: *Length*: top to bottom of reach (m); *Width*: average bankfull width (m); *Depth*: mean channel depth measured at thalweg (m); *Bed elevation*: average elevation at mid-channel (m); *Area:* average cross-sectional area (m^2); *Gradient*: average gradient of bed (%); *R-Bank*: average gradient of right bank (%); *L-Bank*: average gradient of left bank (%). Values are rounded up to nearest number.

Reach	Length	Width	Depth	Bed Elevation	Area	Gradient	R-Bank	L-Bank
1	390	8	1	355	8	0.6%	0.2%	1%
2	549	13	2	346	19	2%	0.0%	0.2%
3	503	13	2	339	26	2%	0.3%	0.2%
4	438	13	2	331	26	2%	0.1%	0.2%

To measure the extent of wood's influence on the longitudinal bed elevation profile, regression analysis was performed for two variables: the average bed elevation (m) measured at mid-channel and the average depth at thalweg (m). The independent variables were wood load values in two units of measurement: (m^3/100 m) and (#/m^2). Results, presented in the same order as above, showed that the correlation with elevation (m) was the strongest ($R^2 = 0.89$, F value = 16 and $R^2 = 0.92$, F value = 24), though only slightly more than what was found for the thalweg depth (m) ($R^2 = 0.73$, F value = 5.386 and $R^2 = 0.88$, F value = 15).

Regression of the same two variables was performed again, substituting the downstream distance (m) as the x – variable. Again, elevation (m) had the stronger correlation of the two, as the slope of the model was positive, and able to explain roughly 80% of the variability present along the distance between the top and bottom of the study reach. Data from the 2nd and 3rd reaches are particularly supportive of the hypothesized influence of wood in producing variations along the profile of the bed.

A pool census was also conducted, with the results shown per reach. In total, 268 of the pool features along the entire study reach length were formed due to wood's influence on stream processes and categorized as an LWD (pieces and structures) pool or a live tree pool (Table 4).

Table 4: Pool Census:

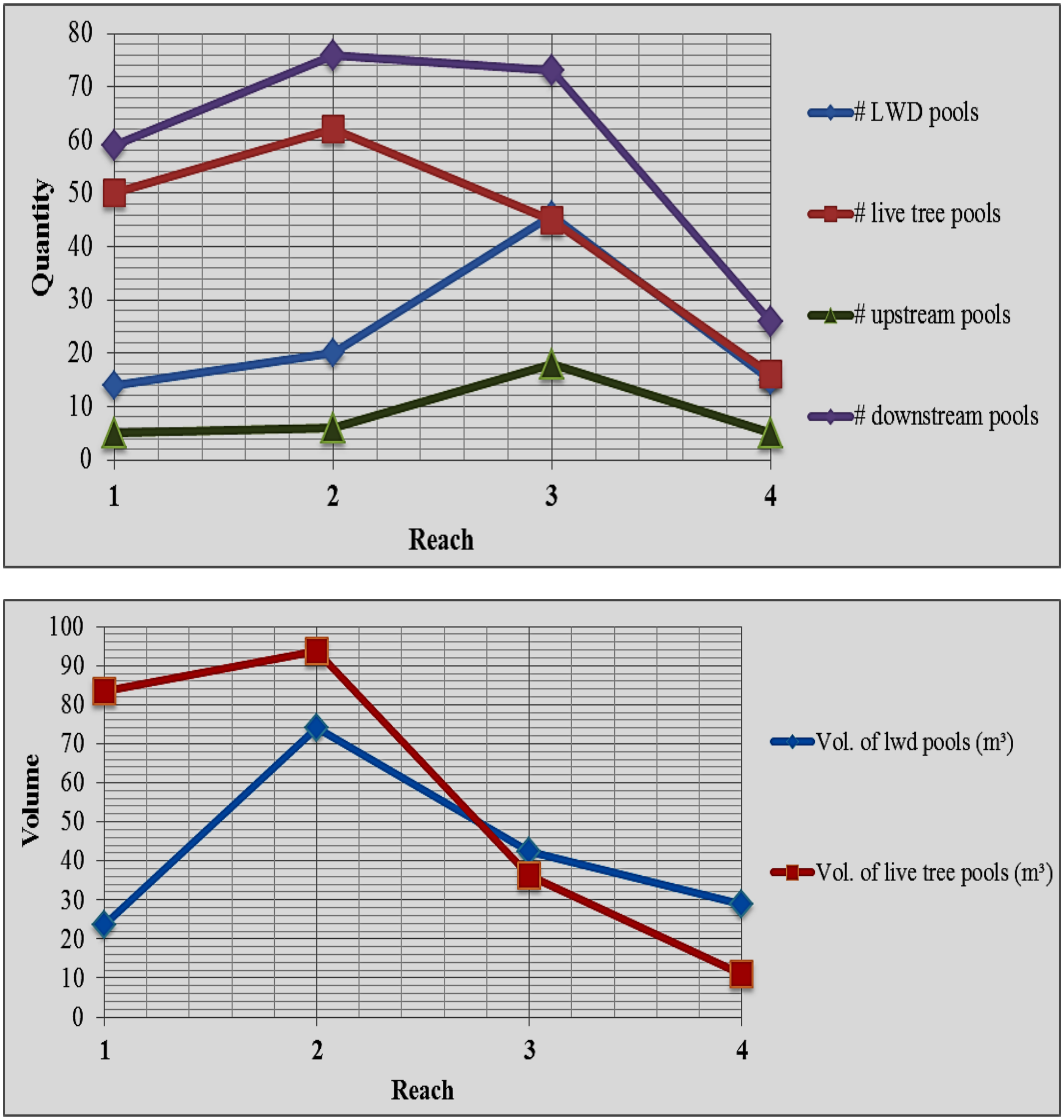
Total count of all pools by type and its location up or downstream. Total volume of each two pool types (LWD or live tree) for the entire study reach. Values are rounded up to nearest whole number.

Reach	**# lwd pools**	**# live tree pools**	**# downstream**	**# upstream pools**	**Vol. of lwd pools (m³)**	**Vol. of live tree pools (m³)**
1	14	50	59	5	24	84
2	20	62	76	6	74	94
3	46	45	73	18	42	36
4	15	16	26	5	29	11
Total	**95**	**173**	**234**	**34**	**169**	**224**

Data for each pool type was then used to construct a graphic depicting the total number and volume of both pool types by reach (Figure 22).

Figure 22: Quantity of Pools by Type and Location

Longitudinal distribution and quantity of the two pool types: those formed by LWD or by a live tree. Location of pool relative to the LWD or live tree that formed it was noted as up or downstream. Both sets of values are graphed by reach to identify if a spatial trend is present from the top (reach 1) to the bottom (reach 4) of the study reach.



Storage of Sediment by Wood

As it pertains to the influence of LWD on the stream's storage capacity, of the 119 sediment wedges observed, the formation and subsequent storage of all but 8 were located upstream of LWD and thus their storage was found to be the a direct result of wood within the channel. Characteristics of wedges as well as the results of a sediment wedge census, and the amount and volume of sediment wedges each wood variable store are all provided (Table 5; Table 6; Table 7).

Table 5: Sediment Wedge Characteristics

Total count of wedges and their dimensions (Length, width, height) shown as averages. Values are rounded up to nearest whole number.

Total # wedges	# upstream of LWD	Length (m)	Width (m)	Height (m)
119	101	3	1	0.3

Table 6: Sediment Wedge Census

Total count and estimated volume of sediment storage by reach. Values are rounded up to nearest whole number.

Reach	# wedges	# wedges upstream of LWD	Est. volume of storage by wedges (m^3)	Est. volume of storage by wood (m^3)
1	32	27	37	31
2	42	32	37	23
3	27	25	45	45
4	18	17	10	10

Table 7: Sediment Storage by Wood Variable

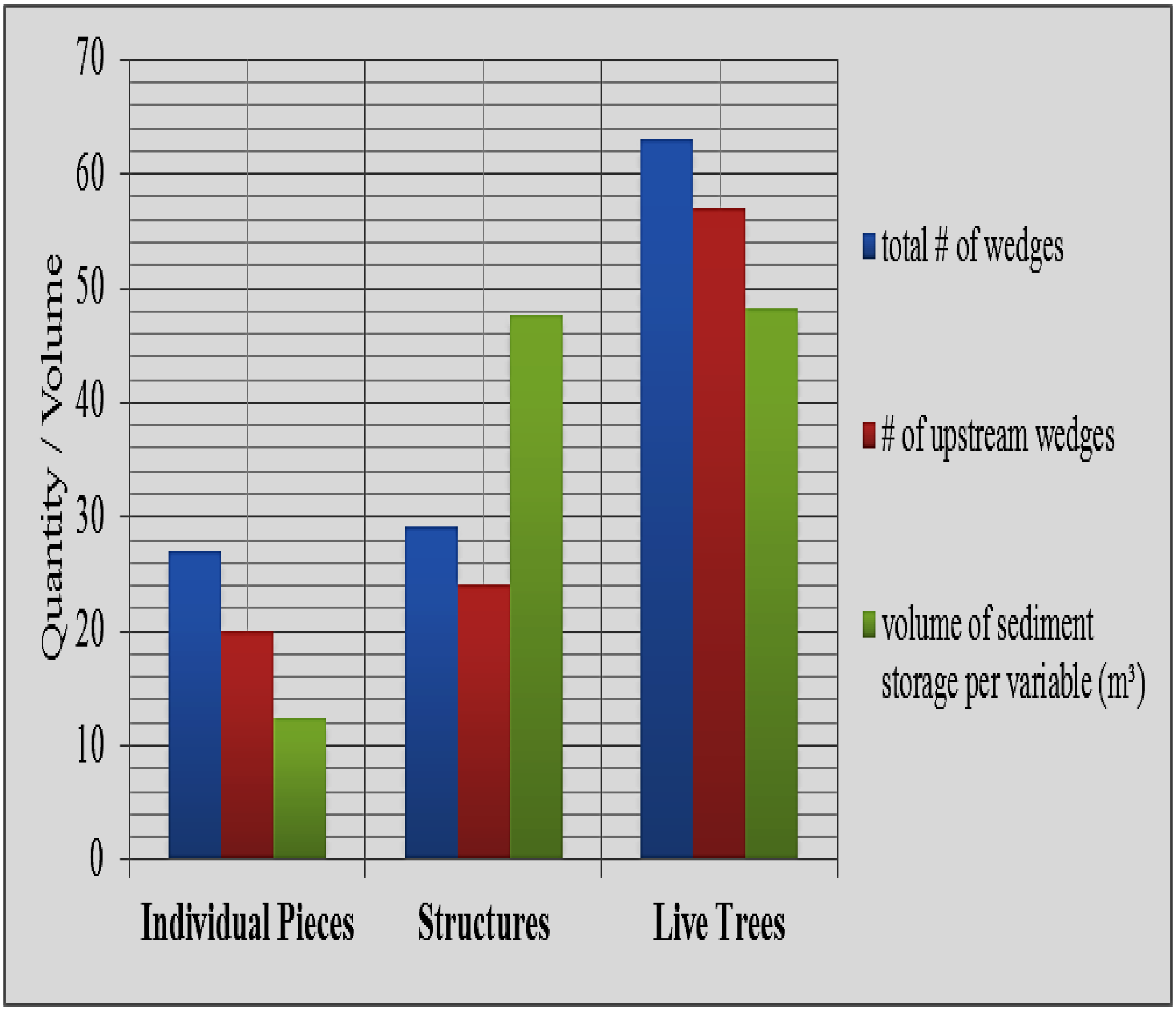
Total count and estimated volume of storage by each of the three variables of wood is provided. Values are rounded up to nearest whole number.

Wood Variable	Total # of wedges	# wedges upstream of LWD	Est. volume of sediment storage (m^3)
Individual Pieces	27	20	12
Structures	29	24	48
Live Trees	63	57	48

The total amount of material stored was then determined for each variable to better understand the dynamics and distribution of stored materials (Figure 23).

Figure 23: Comparison of Sediment Storage by Wood Variable

Columns depict the number of wedges and the volume of sediment wedges stored within the channel, categorized by wood variable as listed on the x - axis. Total number of wedges, the number of wedges upstream of LWD, and the total volume of sediment being stored by LWD pieces, structures, or live trees are each represented by a corresponding color, located to the right of the plot area.



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Regression analysis (ANOVA) of the total volume of sediment (m³) was also performed to determine if it was related to the total wood load (#/m²). Statistical analysis of the two variables is provided (Table 8; Figure 24).

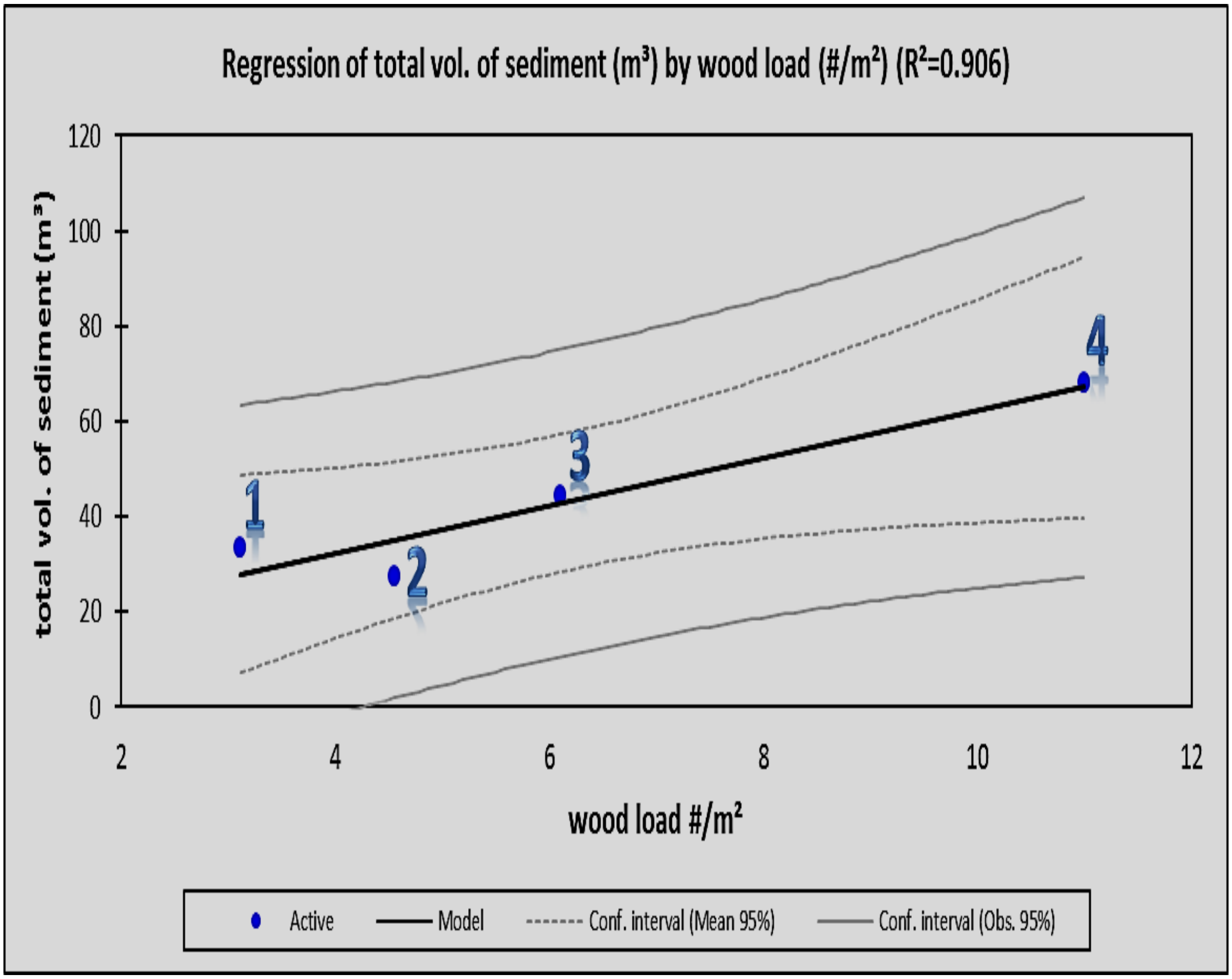
Table 8: Summary of Y – Variable

Final statistics from the regression of two variables, including the coefficients of determination (R^2), the F value, and the probability of the F value being accurate.

	Sediment volume (m^3)
R^2	0.91
F	19.4
Pr > F	0.048

Figure 24: Regression Model for Total Volume of Sediment / Wood Load (#/m^2)

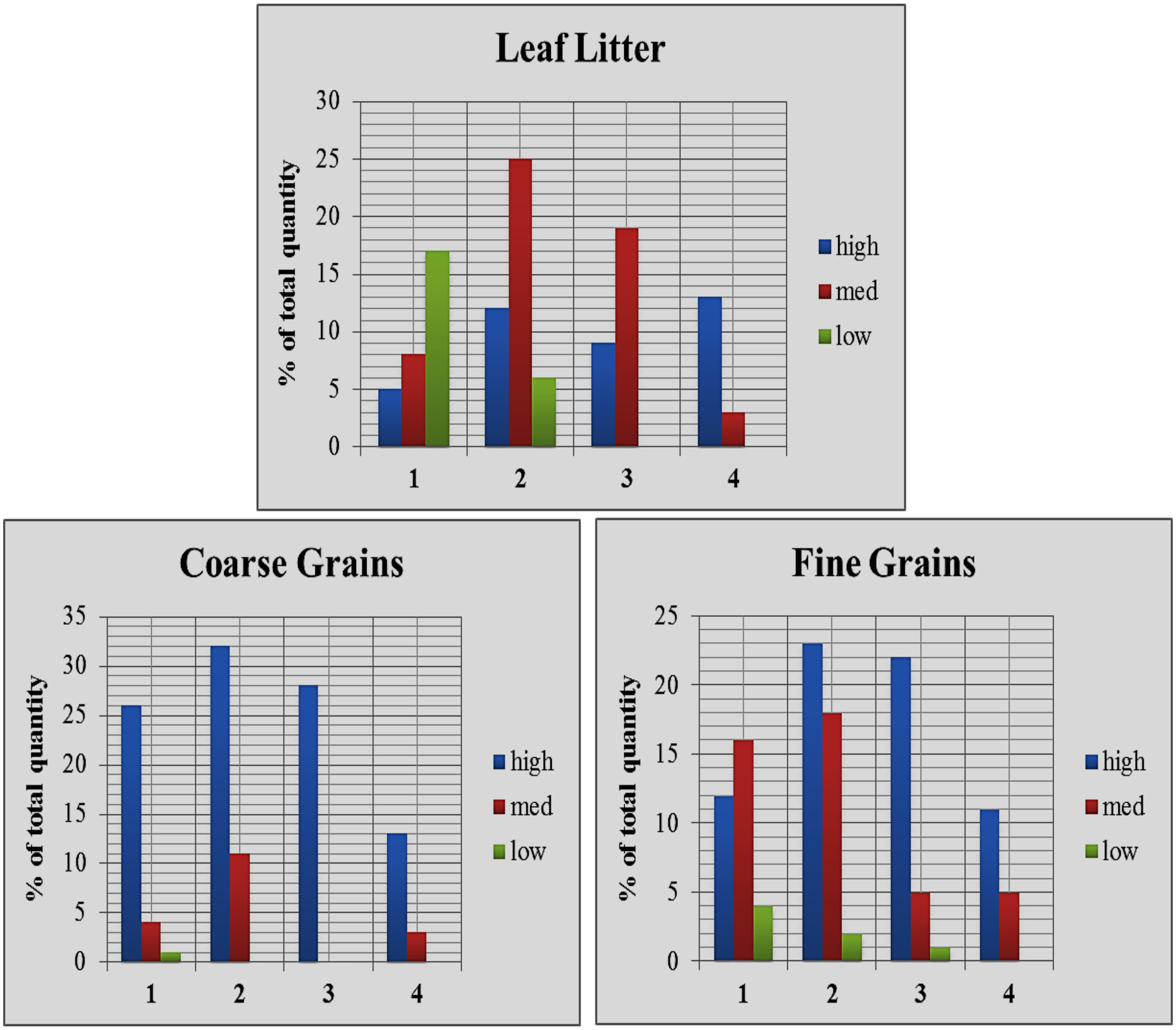
A total of 4 observations per variable were plotted to see if a correlation exists. Each observation represents the average of the four observations made in each of the four reaches. Points are labeled with reach number.



At the site of each sediment wedge measured, the characteristics of the wedge were documented, to include the amount of leaf litter that was present either on the sediment wedge itself and directly surrounding it. The presence and abundance of larger, coarse grains and/or smaller, fine grains were similarly documented, including the size and types of material each wedge consisted of, as well as the characteristics of the bed materials directly surrounding a wedge (Figure 25).

Figure 25: Distribution of Materials

The three charts below show the distribution of leaf litter, as well as coarse and fine grains. Each variable is shown individually, with the x – axis representative of the four reaches moving in downstream direction, and the values on the y – axis represent the percentage of the total observations per reach. Values for each variable graphed are categorized as high, medium, or low. For example, the first chart shows the amount of leaf litter was lowest in the first reach and highest in the fourth.



Finally, census data for both wood and sediment was separated by reach, and their distribution within the entire study reach was graphed, first by quantity and then by volume (Figure 26; Figure 27).

Figure 26: LWD and Sediment Wedge Quantitative Distribution

Vertical axis represents the total number of sediment wedges, LWD pieces, LWD structures, and live trees per reach. The x – axis shows the reach numbers, which increase in the downstream direction.

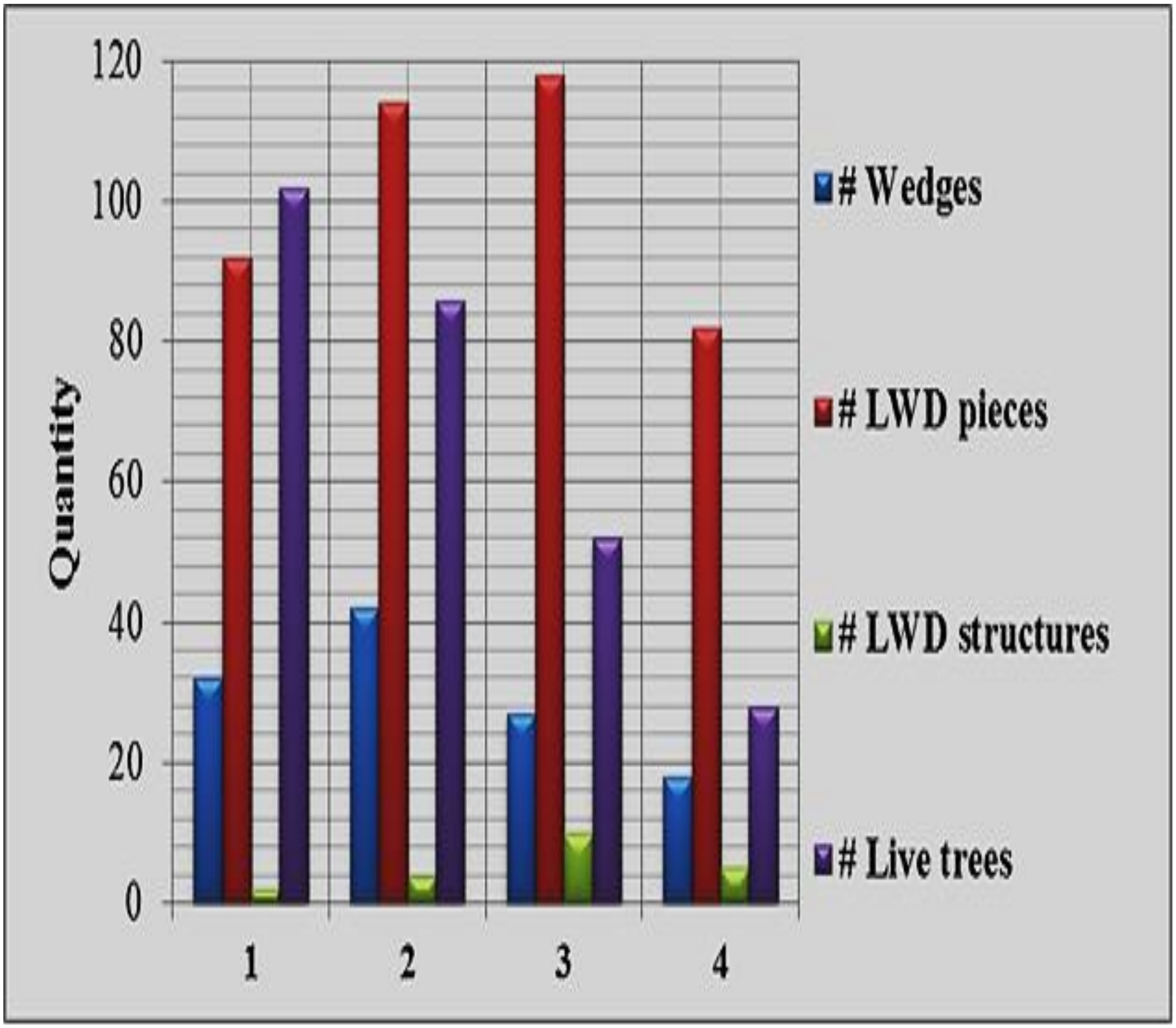
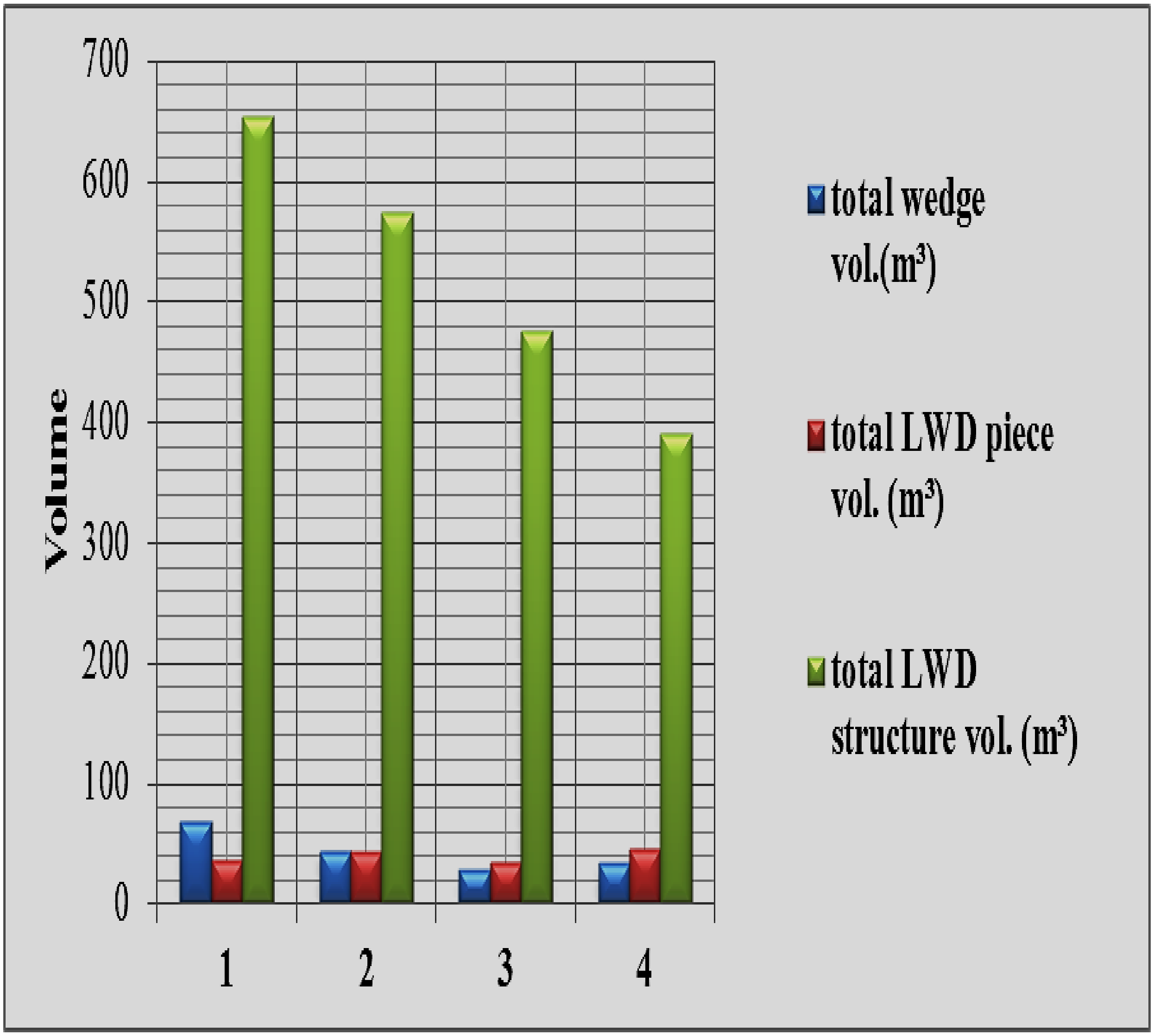


Figure 27: LWD and Sediment Wedge Volumetric Distribution

Vertical axis compares the total volumes of sediment wedges, individual LWD pieces, and LWD structures, per reach. The x – axis shows the reach numbers, which increase in the downstream direction.



Chapter 6 - Discussion

Comparisons of Wood Loading by Region

Several studies have highlighted that regional variability is important to consider in quantifying wood dynamics in streams (Richmond and Fausch, 1995; Berg et al., 1998; Gurnell et al., 2002). This is particularly true for this study, whose findings represent the dynamics of wood within a low-gradient, headwater stream channel located in a tallgrass prairie rather than a forested watershed where most studies of wood take place.

The estimated wood load for the study reach of Kings Creek was 13.05 m^3/100 m, which is a low value, but slightly higher than was originally anticipated. Efforts made to preserve the natural conditions of the watershed surrounding the main channel, such as excluding the area from burning and grazing treatments, researchers have been able to observe gallery forests expand, without interference, to reaches upstream. This process has transformed the vegetation surrounding the historically open canopied headwaters from grassland to riparian forests (Knight and others, 1994; Briggs and others, 2005), evident in the results of the wood census (Table 2).

Tree growth in the headwater riparian areas is not natural for prairie streams, so aside from the impacts of regional drought on the mobilization and transportation of LWD, the most probable reason for the higher than expected wood load is the quantity of live trees that border the length of the study reach, which was also higher than expected. Predictably, the two variables were strongly correlated ($R^2 = 0.97$, $F = 60$), with the trees providing inputs via natural processes. These include windthrow, tree limbs breaking and falling at random into the channel units, entire trees or large pieces of them either falling into the channel naturally or because the bank it occupies has been undercut or otherwise weakened. Such processes were observed during fieldwork, with the latter mechanism delivering the most frequent inputs of wood, sediment, and other bank materials to the stream.

As anticipated, the spatial distribution of live wood mass (m^3) throughout the study reach was nearly identical to the pattern exhibited by the number of live trees (Figure 19), with values for each variable decreasing congruently as the distance from the top of the study reach increases. Explanations for this include the increasing channel area (m^2) in addition to the decreasing bed elevation (m), with the magnitude of changes in both variables growing in the downstream direction. The first of these was found to have a strong statistical relationship with the number of live trees ($R^2 = 0.84$, $F = 10.11$), as well as the volume of live wood mass (m^3) within the study reach ($R^2 = 0.87$, $F = 13.83$). The second explanatory variable, bed elevation (m) was also found to be associated with both the number of live trees ($R^2 = 0.97$, $F = 63$) and the volume of live wood mass (m^3) they store ($R^2 = 0.99$, $F = 268$).

Still, in comparing the estimated wood load of this prairie stream to values reported for forest streams, the data is such that the first hypothesis (H_1) must be accepted, based on the estimated wood load values for the study reach of Kings Creek being consistently found to be lower than nearly all of the other streams referenced (Table 9).

Table 9: Wood Volumes by Region

Information is representative of regions outside of the Great Plains and ranked for comparison purposes. The Adirondacks has a wood volume listed for and old-growth forest and a mature forest, showing the influence of land use history and the age of the forest.

Regional Setting	Wood Volume (m^3/ha) or (m^3/100m)	Source
West Oregon	812 m^3/ha	Gregory, 1991 Gurnell et al., 2002
Salinas River, California (south-central)	222 m^3/ ha	Thompson et al., 2012
Adirondacks, New York (old-growth)	200 m^3/ ha	Keeton, Kraft, and Warren, 2007
Feliz Creek, California (central)	59 m^3/ha	Opperman and Merenlender, 2004
Adirondacks, New York (mature)	34 m^3/ ha	Keeton, Kraft, and Warren, 2007
Western Washington	78 m^3/100 m	Fox, 2001
Southeastern Alaska	58 m^3/100 m	Richmond and Fausch, 1995
Kings Creek, Kansas	**13.05 m^3/100 m**	**Roberts, 2012**
Colorado Rockies (average)	13 m^3/100 m	Richmond and Fausch, 1995

One instance where this prairie stream's wood load was higher than a forested stream came from a 2002 study of wood recruitment. In observing streams located in the Redwood

National Park in northern California, wood load values for the reaches measured were found to range from a high of 200 m^3/100 m along a distance of 800 m to a low of less than 50 m^3/100 m along a 1000-m reach (Benda et al., 2002). The wood load for the study reach was determined to be unrelated to channel length ($R^2 = 0.03$, F-value = 0.06), suggesting the fluctuations in wood load values reported in the 2002 study are more than likely the result of regional variations. As for the differences in wood load values the study stream on Konza Prairie and one in Redwood National Park, these are most attributable to the abundance and forms of riparian vegetation in each region.

In 2007, a study of wood dynamics for five headwater streams within the Rocky Mountains of Colorado reported wood loads ranging from 15.2 m^3/100 m for a 44 meter reach to 1.2 m^3/100 m (Wohl and Goode, 2008). In contrast to streams in Redwood National Park, the highest wood load reported by this study was only 2.15 m^3/ 100 m greater than that of Kings Creek, whereas the lowest value for the Colorado streams was 11.85 m^3/m 100 m less. Wohl and Goode (2008) hypothesized that wood loads were generally lower than expected in response to a peak discharge event occurring just prior to research. There was also the fact that only 40% of the individual pieces accounted for were part of a debris dam or structure (Wohl and Goode, 2008), resulting in increased piece mobility and transportation (Gurnell and Sweet, 1998).

Such factors did not affect wood dynamics in the headwaters of King’s Creek prior to fieldwork, as none of the wood was mobilized or transported due to the channel having been dry. Plus, the number of individual LWD pieces and the number of debris dams were not related ($R^2 = 0.19$, F value = 1.3) as they were in the Colorado stream study (Wohl and Goode, 2008). Thus, the differences this study and the one in the Rocky Mountains are most attributable to the variability in regional climate. This ranges from the flooding that transported a substantial amount of LWD downstream (Wohl and Goode, 2008), to the prolonged periods of drought when longer periods of wood accumulation are possible, as was the case with this study.

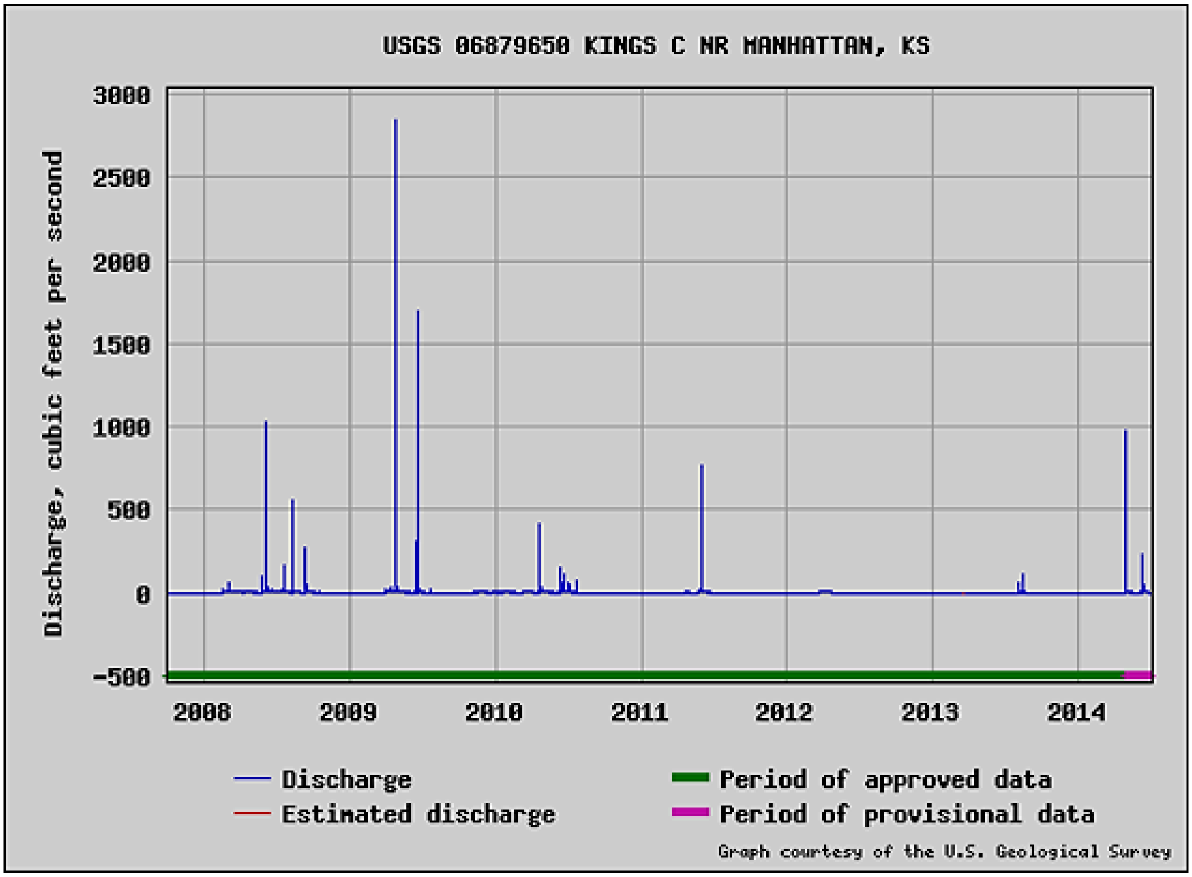
What was surprising was the small range in values between King’s Creek and the streams in Colorado (Wohl and Goode, 2008), in contrast to the other forest streams reported in the literature. In consideration of this the differences between the amount and dynamics of wood in a prairie stream versus a forest stream are still best explained by the multiple, naturally occurring variations that exist between the climate, environment, and land use history specific to a region, rather than a singular explanation (e.g. dominant form of vegetation).

Spatial Distribution of Wood by Variable

Drought conditions have plagued the Great Plains in recent years, which has had a negative impact on streams in the region due to the subsequent lack of precipitation and streamflow. As a result, the redistribution of organic materials has not been possible recently, with the highest peak streamflow in recent years having occurred in 2009 with a value of 2,850 cf/s according to USGS streamflow data. This was a much higher value than the one recorded in 2012, the year fieldwork was conducted (Figure 28).

Figure 28: Kings Creek Discharge 2008 – 2014

USGS graph depicting discharge values for Kings Creek in cubic feet per second for the past seven years. Though the gage has been operational since 1979, the most recent available data was used. In 2012, the value is noticeably lower than the most recent peak discharge in 2009. (Source: USGS Waterdata).



Given the overall conditions observed, most of the wood surveyed has quite possibly resided in the channel since the last significant flow event at Kings Creek in 2009; save for those burned pieces or fallen and/or broken trees whose appearance, breakability, intact bark, etc. clearly indicated the input was more recent.

Individual LWD pieces exhibited a random distribution pattern along the stream bed of the study reach; the highest number of pieces were in the 2nd and 3rd reaches, with the highest volume of pieces (m^3) in the 4th and 2nd reaches (Table 2). Of the 406 pieces measured, the highest amount (42%) of pieces was located within the second bankfull zone, while 35% of pieces were located in the first zone (Figure 20), which is the bed of the channel.

LWD structures were distributed in a similarly random fashion, with the highest number of LWD structures located in the 3rd reach. The highest volume of structures was found in the 4th reach, likely due the influence of structure #21, which was by far the largest in the entire study reach. This structure had the highest volume (591 m^2), the largest measured dimensions (L – 15, W – 11.3, H – 3.5, each in meters), and 2 out of 6 key pieces forming the structure were fallen trees with vegetation on the branches.

Unlike both forms of LWD, the spatial distribution of live trees did exhibit a measurable distribution pattern. In total, 102 trees were located in reach 1, which was the highest value for the entire length of the study reach. Quantities consistently declined as the distance from the top of the study reach increased, with the 4th reach containing only 28 live trees. Probable reasons for this include the measureable increases in channel area (m^2) and bankfull width (m) in the same direction, both of which are observable in downstream reaches (Table 3). It was found that as the dimensions of the channel increase, the potential for live trees along the bank to influence the channel hydraulics decreases.

Influences on Wood Volume and Loading

Longitudinal patterns of in-stream storage and the structure and density of riparian vegetation within the study reach made it difficult to predict any outcomes based on the widely recognized river continuum concept (RCC). For instance, in a hypothetical stream with headwaters draining a forested catchment, the RCC suggests that the storage of organic matter should be highest in headwater reaches and decrease in a downstream direction, with a shift in particle size from coarse to finer particles (Vannote et al., 1980). In regards to these characteristics, Kings Creek matched the description for forest streams more closely than that of prairie streams.

One example being that the volume of sediment stored in the channel was highest in reach 1, with values declining in the downstream direction. The distribution of grain sizes was similar, with the coarse grains that typify the upper reaches becoming less abundant as the presence of fine grains increased (Figure 25). Also, the numbers of live trees that border the study reach is highest in its headwaters, providing a substantial amount of riparian shading not typically associated with prairie stream environments.

Considering these characteristics, the expansion of forested areas on Konza Prairie over the last 100 or so years (Figure 12) undeniably influenced this study’s findings, as the ongoing transition from the predominantly tallgrass riparian vegetation, to a shifting mosaic of mixed hardwoods, grasses, and forbs to the landscape and ecosystem has driven changes to the landscape and ecosystem. Hence, the higher than expected quantity of live trees and the estimated wood load at the individual and entire study reach scales are thought to be an outcome of the historical increase in woody vegetation.

Although channel gradient (%) and the average bankfull width (m) were associated with one another ($R^2 = 0.79$, p-value = 0.04), neither variable had much of an influence ($R^2 = 0.02$ and 0.5, respectively) on the total volume of wood (m^3). This result came as a surprise given the range of literature on the topic (Bilby and Bisson, 1998); including a study of low-gradient, southeastern Alaska streams (Robison and Beschta, 1990). It determined that the difference in average bankfull width from the top to the bottom of a channel was best explained by the total wood volume (m^3) rather than the gradient of the channel (%). Based upon their observation that reaches with the highest volume of wood along their length also had the highest bankfull width (m).This is consistent with results for the study reach of Kings Creek, whose widest reaches indeed contained the highest volume of wood (m^3).

The linear trend identified within the raw data does suggest that a relationship exists between wood volume and average bankfull width (Table 2; Table 3). Even so, it should be noted that the former variable increases most substantially between the 2nd and 3rd reaches, whereas the latter increases by less than a meter here. Although it is uncertain how this discrepancy may have affected the test for correlation, it should also be noted that average bankfull width (m) and wood load values in a differing unit (#/m²) turned out to have a very strong correlation ($R^2 = 0.96$, F value = 47.7). Other explanations for the discrepancy include the corresponding increase of 7.21m² in channel area ($R^2 = 0.7$, F value = 4.4), and the influence of the tributaries draining the K4A and K2A watersheds, which both connect to the main channel within the boundaries of reaches 2 and 3.

Longitudinal Variations

Bed Elevation Profile

Findings of this study are in favor of the hypothesized association between wood and geomorphic changes to the stream bed. In the second and third reaches the volume of wood (m³), the channel area (m²), and the number of LWD pieces each increase, and the number and volume of LWD pools are also at their highest in this area, indicating the influence of LWD along the bed elevation profile varies spatially (Table 3, Figure 22). **I**nteractions between wood and bed morphology is evidenced by the increased amount of wood in the 2nd and 3rd reaches as well as the number of pools downstream of LWD, which are a direct result of the wood's obstruction of flow. By inducing scouring directly downstream of its location by diverting streamflow, LWD can instigate longitudinal increases in thalweg depth and other geomorphic changes along the stream bed.

Pools

Results of the pool census revealed a total of 95 pools formed by either an individual piece or LWD structure, and 173 pools formed by live trees (Table 5). The highest numbers and volumes of each pool type were found within reaches 2 and 3, while a high degree of variability was discovered amongst the values for the cumulative volume by pool type. Spatial distribution showed no pattern, save for the 4th reach where the volume for each pool type was at its lowest. Quantitative distribution of pools was comparable, though not quite as random as distribution by volume. Numbers of live tree pools and LWD pools follow a nearly identical trend from reach 3 to 4, where the lowest quantity of each pool type was located.

Regarding the influence of wood and channel dimensions on pool formation, regression analysis of the cumulative volume for each pool type by the loading density (m^3/m^2) per reach to identify any influence the volume of wood per unit channel area may have on the formation, distribution, and volume of the pools was completed. The volume of live tree pools (m^3) showed a weak correlation with loading density (m^3/m^2), as did the volume of LWD pools (m^3) and upstream pools (m^3), however the statistical relationship observed for live tree pools was significantly higher than those of the latter two variables were. In substituting the x – variable, with wood load ($\#/m^2$) and total volume of wood (m^3), the results were nearly identical, suggesting that inputs from live trees are not being mobilized and transported, therefore these inputs are exerting more of an influence at their point of entry into the channel, forming pools directly beneath the live tree that provided it.

Sediment Storage

It was determined that the geomorphic functions of LWD within the study reach of the channel exert considerable influence over the storage of sediment and other organic materials. In total, 119 sediment wedges were measured (Table 7), and only 8 of these wedges were located downstream of the LWD site, and therefore the sediment they stored could not attributed to wood. Reach 2 contained the highest total number of sediment wedges and upstream wedges, whereas the 4th reach contained the lowest number of each (Figure 23). Live trees store the highest number of sediment wedges, followed by LWD structures and individual pieces, which is the same sequence followed by the number of upstream wedges.

Along the entire length of the study reach, the total volume of sediment in storage was an estimated 128 m^3, with approximately 108 m^3 of this total value stored directly by wood. Regression analysis of the total number of sediment wedges revealed a statistically significant relationship with the volume of LWD structures (m^3) per reach ($R^2 = 0.82$, $F = 8.8$), and to a lesser degree, the number of live trees per reach ($R^2 = 0.66$, $F = 3.82$). A similar regression model was created for the total volume of sediment wedges (m^3), also revealing the two variables with the highest influence: the number of LWD pieces ($R^2 = 0.72$, $F = 5.3$) and the volume (m^3) of LWD pieces ($R^2 = 0.71$, $F = 5$).

Along with the measurable storage of sediment by wood, the geomorphic changes that are instigated as it diverts streamflow cause scouring of the bed and the forced deposition of bed material upstream of the wood. This further alters the stream bed as the sediment accumulates and backwater pools begin to form, and in response to the wood, streamflow and sedimentation processes are both modified, producing measurable variations along the longitudinal profile of the channel, which is evident in the spatial distribution of pool features along the length of the study reach (Table 4).

Determining the cumulative volume of the three identified types of pools (i.e. LWD, live tree, and upstream) offered insight into the changes to bed morphology that wood instigates, and the values representing upstream pools and live tree pools also provide an idea of potential storage sites within the channel. For instance, one or more sediment wedges upstream of an LWD structure have accumulated in an active storage site where the sediment can be temporarily preserved. Similarly, pools formed by LWD increase the availability of areas where materials can begin to accumulate.

Within the bankfull width area of the channel, there is an estimated 128 m^3 of sediment being stored via wedges on the bed of the channel. Of this total volume, 108 m^3 of sediment is stored directly by LWD, confirming that sedimentation has been influenced by wood to a measurable degree. Furthermore, ANOVA testing of the variables total sediment volume (m^3) and the number of LWD pieces per unit channel area, i.e. the wood load ($\#/m^2$) revealed a strong, positive correlation between the two (Figure 24). This indicates the extent to which both the amount of wood present and the physical dimensions of individual reaches influence sediment storage. Taking into consideration the fact that increased sediment storage and shifting morphodynamics are frequently observed in forest streams, these results were more or less anticipated.

Data supported the concept that sediment storage and spatial variability of physical characteristics are interrelated, with the extent of each being dependent upon the abundance of LWD within a channel. Therefore, the second hypothesis (H_2) was accepted, and the related findings for this study were determined to be consistent with much of the previously published LWD literature. This is particularly true in reference to the geomorphic function of wood within a channel. Thus, while the estimated wood load for the headwaters of Kings Creek may be comparatively lower than most forest streams, it is not so low that it suggests wood has been insignificant in helping to affect the geomorphology of the prairie stream channel.

Chapter 7 - Conclusion

Given that the results of data analysis revealed the wood load for Kings Creek to be comparatively lower than nearly every referenced forest stream, the null hypotheses posed by this study were rejected. Additionally, both the variations along the longitudinal profile of the bed and the amount of sediment stored via wedges were measurable throughout the study reach, with most found to have resulted from the presence of wood. Because it is a prairie stream, the most viable explanation for the higher-than-expected wood load values is the expansion of riparian forests in recent decades. These trees are the primary source of wood loading as they directly border the channel, and considering the higher wood load values the quantity of live trees also being surprisingly high was somewhat expected.

Nevertheless, results indeed confirmed that prairie streams are capable of maintaining a wood load, whose functions are consistent with those in forest streams. However, the wood and the materials stored in the channel and measured for this study are likely to have been stationary for several years, considering that data collection took place during a period of long-standing drought conditions that have yet to fully abate. As such, these findings are representative of a prolonged drought phase within the region, and future studies should monitor any changes following flood events given that the episodic nature of streamflow here is revealing of prairie stream wood loads being highly dynamic and subject to fluctuations over time.

This prairie stream’s wood dynamics have undergone substantial changes driven by a combination of factors, specifically the region’s climatic variability and the subsequent expansion of gallery forests. The number of trees has steadily increased in recent decades (Figure 12), specifically within the headwaters, spreading across the riparian zone and into the grassy vegetation that surrounds the head of the channel. Inputs from these trees are accumulating within the channel rather than being transported downstream due to the absence of streamflow resulting from drought conditions. This combined influence of climate and forest expansion has produced measurable effects on this prairie stream’s wood dynamics, and offers the most probable explanation for the higher-than-expected abundance of wood in the channel and on the floodplain.

Streams in the Great Plains may not support the higher wood loads common in streams of the Pacific Northwest, however because they are typically less altered they do provide an opportunity to develop the understanding and build the literature regarding the role of LWD in prairie streams, which is currently inadequate compared to forested regions. The lack of research on prairie streams has essentially created an untapped resource that has gone unnoticed by most researchers, who instead opt to study forested regions where many of the streams and basins have already been the focus of multiple studies.

As regional biases have yet to disappear, the need for future studies of LWD dynamics in Kings Creek and other underrepresented prairie streams remains dire, emphasized by the fact that the results of this study represent conditions unlikely to exhibit long-term stability in light of the discussed variability of the Great Plains region. Hence, the need to monitor changes at Kings Creek and increase the amount of LWD research on prairie streams, particularly over the long-term, and in this regard, the results of this study serve as an important reference for LWD research in an under-studied region.

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Figures

Bankfull Width Zones

Robison, E. G., and Beschta. R. L. 1990. Coarse woody debris and channel morphology interactions for undisturbed streams in southeast Alaska, USA. Earth Surface Processes and Landforms 15: 149 - 156.

Debris Dam or LWD Structure

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Function and Influence of Log Steps

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GIS representation of gallery forest on Konza Prairie

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Grasslands of North America

Kansas State Historical Society (http://kshs.org/places/kawmission/graphics)

Konza Prairie watershed-level burning and grazing treatments

Konza Prairie Core Long Term Ecological Research Program (http://www.konza.ksu.edu/default1.aspx)

Sediment Triad

Brenda Baille February 2005, Centre for Sustainable Forest Management and Research. (http://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/tree-grower-february-2005/wood-in-streams-size-really-does-matter/)

Various Influences of LWD

Brenda Baille February 2005, Centre for Sustainable Forest Management and Research (http://www.nzffa.org.nz/farm-forestry-model/resource-centre/tree-grower-articles/tree-grower-february-2005/wood-in-streams-size-really-does-matter/)

Watersheds Contributing to Study Reach and Study Area Reference Maps GIS Data

Konza Prairie Long Term Ecological Research Program (http://www.konza.ksu.edu/default1.aspx)

State of Kansas GIS Data Access and Support Center (DASC) (http://www.kansasgis.org/index.cfm)