ECOSYSTEM PROCESSES OF PRAIRIE STREAMS AND THE IMPACT OF ANTHROPOGENIC ALTERATION ON STREAM ECOLOGICAL INTEGRITY

by

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Abstract

North America has lost more than 95% of the original tallgrass prairie because of heavy land conversion, making prairie streams some of the most endangered habitats in North America. In order to effectively manage aquatic systems and improve biotic integrity of prairie streams research is needed that assesses the ecosystem characteristics of natural systems and evaluates the influence of anthropogenic alteration. I described the ecosystem characteristics of six ephemeral headwater streams draining tallgrass prairie within the Osage Plains of southwest Missouri. NO^-_3-N among all sites ranged from 2-91 µg L^{-1}, NH^+_4-N ranged from 5-228 µg L^{-1}, soluble reactive phosphorus ranged from below detection (1 µg L^{-1}) to 41 µg L^{-1}, TN ranged from 114-883 µg L^{-1}, and TP ranged from 8-159 µg L^{-1}during baseflow conditions. TN:TP molar ratios ranged from 22:1 to 53:1 indicating possible P was limiting relative to N in some streams. TSS during baseflow conditions ranged from 1-32 mg L^{-1}. Autotrophic and heterotrophic comparisons of our study sites and reference sites classified our study streams as oligo-, meso-, and eu-autotrophic (*N*= 1, 4, and 1, respectively) and oligo-, meso-, and eu-heterotrophic (*N*= 4, 1, and 1, respectively). This study suggests that good water quality and moderate heterotrophic condition, with greater GPP resulting from an open canopy, are common conditions of tallgrass prairie streams. I also investigated interactions among land use/land cover, discharge rate, hydrologic alteration, and in-stream total suspended solids concentration in 23 Kansas- Missouri streams. Most streams had break points in the TSS loading rates at discharge rates exceeded <25% of days. Our estimates showed that 88% of the total annual TSS load occurred during the 11% of days with the greatest discharge rates**.** Buffered **s**treams with greater percentages of grass and/or forest riparian areas had lower breakpoint values (indicating greater discharge rates were required to transport solid particles) and lower regression intercepts,

which correlated to lesser TSS concentrations relative to unbuffered streams during high discharge days. In addition, grass buffered streams had smaller flood peaks and slower rise rates and forest buffered streams had less frequent floods, which lead to less total TSS transport.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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INTRODUCTION

North America has lost more than 95% of the original tallgrass prairie because of land conversion from prairie to cropland or rangeland, making prairie streams some of the most endangered habitats in North America (Samson and Knopf 1994; Dodds et al. 2004). Rangelands make up nearly 61% of the land surface of the United States (Holechek et al. 1998), and much of that rangeland is within the Great Plains region where land is generally managed by private landowners. Private lands, typically, are used for agriculture where livestock or crop production is maximized (Holechek et al. 1998), but at the cost of biodiversity and a heterogeneous landscape (Fuhlendorf and Engle 2001).

Downstream water quality is greatly influenced by the transport from headwater streams (Dodds and Oakes 2006; Alexander et al. 2007), and can be heavily influenced by land use and land cover around first-order streams, even during times when those small streams are not flowing (Dodds and Oakes 2008). Headwater streams are key sites for nutrient and organic matter processing and storage (Alexander et al. 2007) because uptake of nutrients such as inorganic nitrogen is maximized in headwater streams and during seasons of high biological activity headwater streams can decrease input concentrations by more than half (Peterson et al. 2001).

Suspended solids are the most common contaminant of streams, but they have not been well studied in prairie streams (Dodds 2002, except see Whiles and Dodds 2002). Stream biotic integrity is linked to suspended solids and nutrient concentrations and is negatively influenced above threshold toxicity values (Evans-White et al. 2009). In order to effectively manage aquatic systems and improve biotic integrity of prairie streams research is needed that assesses the ecosystem characteristics of natural systems and evaluates the influence of anthropogenic alteration. My research goals were to (i) describe the ecosystem characteristics of ephemeral headwater prairie streams and (ii) evaluate the influences of land alteration and altered flow regimes on the loading rate of solids into prairie streams.

CHAPTER 1 - Ecosystem characteristics of ephemeral headwater tallgrass prairie streams

ABSTRACT

Very few characterizations of spatial and temporal variability of water quality and ecosystem processing rates have been published for mesic tallgrass prairie streams or wetland prairie streams. Few intact tallgrass prairie watersheds have been studied outside of the Flint Hills, in part because of their rarity. I described the ecosystem characteristics of six upland ephemeral headwater streams draining tallgrass prairie within the Osage Plains of southwest Missouri. One stream resembled more of a wetland habitat with accompanying differences in nutrient concentrations and net ecosystem productivity. NO_3^--N concentrations among all sites ranged from 2-91 µg L^{-1}, NH_4^+-N concentrations ranged from 5-228 µg L^{-1}, and soluble reactive phosphorus concentrations ranged from below detection (1µg L^{-1}) to 41 µg L^{-1} during baseflow conditions. Total nitrogen (TN) concentrations ranged from 114-883 µg L^{-1} and total phosphorus (TP) concentrations ranged from 8-159 µg L^{-1}. TN:TP molar ratios ranged from 22:1 to 53:1 indicating possible P limitation relative to N in some streams. Maximum measured total suspended solid concentration during baseflow conditions was 32 mg L^{-1} and the minimum was 1mg L^{-1}. Mean net ecosystem productivity (NEP) rates during 24 hour periods with sunny days tended toward net heterotrophy with the wetland stream being the most net heterotrophic (NEP= -9.84 g $O_2 m^{-2} d^{-1}$) and the other 5 streams ranged in NEP from -0.26 to -3.14 g O_2 m^{-2} d^{-1}. The trophic states of our study streams were oligo-autotrophic to eu-autotrophic and oligo-heterotrophic to eu-heterotrophic. Mean benthic chlorophyll *a* ranged from 0.8-7.1 µg cm^{-2} and water column chlorophyll *a* ranged from 0.5-5.9 µg L^{-1} across streams. Our highest nutrient concentrations were in the wetland stream, which were still generally lower than values reported

in the literature for urban and agricultural streams in this ecoregion. Streams varied significantly in physical, chemical, and biological properties, even though they occur in very close proximity to each other. This study suggests that good water quality and moderate heterotrophic condition, with greater GPP resulting from an open canopy, are common conditions of tallgrass prairie streams.

INTRODUCTION

Terrestrial environments interact with aquatic ecosystems, and ephemeral headwater streams represent the maximum interaction between aquatic and terrestrial environments (Vannote et al. 1980). Ephemeral and intermittent streams are common in many parts of the world (Dodds 1997) and have a recurrent dry phase most likely to occur during times with high rates of evapotranspiration (Williams 1996). Complete drying of tallgrass prairie streams generally occurs during the late summer season when evaporative demand by plants is high, and streams may only flow during days with ample precipitation. Headwater streams generally represent the greatest proportion of total stream length in most river networks (Vannote et al. 1980), therefore understanding the natural processes in headwater streams is crucial for evaluating influences of terrestrial inputs on aquatic systems (Matthews 1988).

Downstream water quality is greatly influenced by the transport from headwater streams (Dodds and Oakes 2006; Alexander et al. 2007), and headwater streams are key sites for nutrient and organic matter processing and storage (Alexander et al. 2007). Downstream water quality can be heavily influenced by land use and land cover around first-order streams, even during times when those small streams are not flowing (Dodds and Oakes 2008). Uptake of nutrients such as inorganic nitrogen is maximized in headwater streams and during seasons of high biological activity headwater streams can retain substantial amounts of nutrients (Peterson et al. 2001, Mulholland et al. 2008).

Suspended solids are the most common contaminant of streams, but they have not been studied well in prairie streams (Dodds 2002, except see Whiles and Dodds 2002). Significant break points between the total suspended solids concentration and stream discharge relationship can occur and in the Kansas- Missouri region that was historically dominated by grasslands, 88% of the total annual load of suspended solids in streams occurred during the 11% of days with the greatest discharge rates (Chapter 2).

The total metabolic capacity of a stream is an indicator of biotic activity and indicates carbon metabolism (heterotrophic and autotrophic state, Dodds 2006). For example, net ecosystem productivity (NEP) of a stream characterizes the organic matter processing (Roberts et al. 2007) and can influence downstream water quality. Fundamental ecosystem characteristics such as heterotrophic and autotrophic state, nutrient and suspended solids concentrations, and NEP have not been described for many upland ephemeral headwater tallgrass prairie streams (Matthews 1988), except at Konza Prairie Biological Station (Gray and Dodds 1998; Gray et al. 1998; Dodds et al. 2004). Konza Prairie occurs at the far western portion of the potential range of tallgrass prairie, and most sites that historically were tallgrass prairie that have since been converted to cropland occurred in areas with greater precipitation. Community structure and ecosystem function of ephemeral headwater prairie streams (which flow occasionally and generally occur above the groundwater level (are losing streams)), are not well characterized (Matthews 1988). Therefore, to increase the scientific knowledge of ecosystem characteristics of prairie streams I studied six upland ephemeral headwater streams draining tallgrass prairie to characterize the natural temporal and spatial variability of nutrient and organic and inorganic matter concentrations and net ecosystem productivity in small mesic tallgrass prairie watersheds. I hypothesized that relative to anthropogenically-influenced streams in the region, these natural streams would generally have low TSS and nutrient concentrations and like previously studied open-canopy streams would be slightly net heterotrophic with the ratios of gross primary production to respiration slightly <1.

METHODS

Site description

This study was conducted on Osage Prairie Conservation Area, which is located in the Osage Plains region of southwestern Missouri. Osage Prairie is a 628 hectare remnant prairie owned and managed by the Missouri Department of Conservation. Soil types of Osage Prairie Conservation Area consisted of Barco loam, Barden silt loam, and Coweta loam. This Barco-Barden-Coweta association was moderately well to well drained gently sloping upland soils that had a surface layer of fine sandy loam to silt loam and a subsoil layer of loam to silty clay loam and bedrock was generally within 50.8-101.6 cm of the surface (Soil Survey Staff 2004). Mean slopes of the watersheds ranged from 2 cm m^{-1}- 4 cm m^{-1} (USGS Seamless 2006) (Table 1.1). Prairie management consisted of biannual mowing of watersheds and removal of riparian trees >10cm diameter (Len Gilmore, Missouri Department of Conservation, personal communication). During the time period of this study riparian landcover was dominated by small shrubs which partially shaded the streams year-round.

I studied 6 streams in detail over a 2 year period (Figure 1.1). All streams were first-order headwater streams ranging in stream width from 0.77-2.60 meters, stream length from 465 to 1778 meters, and watersheds ranged in size from 9.83 to 53.87 hectares (0.0983 to 0.5387 km^2)

(Table 1.1). Streams 1 and 2 had the greatest amount of riparian tree removal and were unshaded (Table 1.1). Stream 2 resembled a wetland area that had complete flow only during spates and floods. All six study streams were ephemeral in flow with streamflow only persistent in the early spring and early fall and streams were typically completely dry during the summer (Jodi Vandermyde, Southern Illinois University, Carbondale, personal communication) (Table 1.1).

Physical properties

Water samples for baseflow total suspended solids (TSS) concentration analyses were collected monthly from date to date, when the streams were flowing, in acid-washed 1 L nalgene bottles from the stream thalweg. TSS water samples were transported at 4°C from Osage Prairie Conservation Area to the laboratory where they were filtered through precombusted (24-h at 475°C) pre-weighed glass-fiber filters (GFC Whatman, 1.2 µm porosity) within 24 hours. Filters with retained material were dried at 60°C and mass was determined. All filters were then heated in a muffle furnace to 475°C to constant mass (approximately 6 hours) in order to burn off all organic material retained on the filter, and re-weighed. Concentration of TSS (mg L^{-1}) was calculated as constant dry mass minus initial filter mass per 1 L filtered. The organic solids (OSS) portion was calculated as constant dry mass minus constant ash-free dry mass and the inorganic solids (ISS) portion was the TSS concentration minus the organic solids concentration (APHA 1995; Whiles and Dodds 2002).

TSS samples were targeted for at least 3-storm (mobilization) events per year. I used single-stage, US U-59B, samplers which filled via siphonage for water collection during highflows (Ford 2006; Subcommittee on Sedimentation 1961). Single-stage samplers consisted of four, 500 mL darkened nalgene bottles capped with two-hole rubber stoppers and were stacked vertically and fastened to a metal post driven into the streambed. Two cane-shaped copper tubes with openings separated 15 cm vertical were fitted into the two-hole rubber stoppers. With this equipment, bottles fill when the water level tops the peak of the arch on the bottom copper tube and stop filling when the water level reaches the arch peak of the upper copper tube. The height of the lowest single-stage sampler varied from 12-36 cm among sites depending on the depth of water at baseflow conditions. These samples were collected within 5 days, but usually within 2 days, after the high discharge and processed as above.

Stream height (provided by Jodi Vandermyde and Matt Whiles, Southern Illinois University, Carbondale) was continuously measured during days above 0°C during 10 min intervals using HOBO water level loggers.

Chemical properties

Simultaneous to baseflow TSS sample collection water samples for nutrient analyses were collected in acid-washed 125 mL nalgene bottles. Two nalgene bottles were filled at each site so that one bottle was filtered through a glass-fiber filter (Whatman GFF, 0.7 µm porosity) and analyzed for nitrate (NO_3^-), ammonium (NH_4^+), and soluble reactive phosphorus (SRP) concentrations and the other bottle was unfiltered and analyzed for total nitrogen (TN) and total phosphorus (TP) concentrations. Additional water samples that were collected from the single-stage samplers were used to characterize nutrient content during stormflows. These samples were filtered through Whatman GFF filters for TSS analyses and were then passed through Whatman GFC filters and analyzed for NO_3^-, SRP, and NH_4^+. Water samples were kept frozen until they could be analyzed. Unfiltered samples for TN and TP concentration estimates were persulfate oxidized and then analyzed for NO_3^- and SRP, respectively, within 48 hours (Ameel et al. 1993). Water samples were prepared for SRP analysis via the acid molybdate technique (APHA 1995). An autoanalyzer was used to determine the inorganic nutrient concentrations of the final prepared water samples. Three independent runs were performed using an autoanalyzer to measure: i) NO_3^- and SRP, ii) NH_4^+, and iii) TN and TP (analyzed as NO_3^- and SRP, respectively, after persulfate digestion). In most cases, the three independent runs were repeated on separate dates to ensure accuracy and precision of the autoanalyzer.

Biological properties

Whole-stream metabolism was estimated using the singe station method. Estimates of metabolism were calculated from measured light, dissolved oxygen, water temperature, and air-water exchange rate of oxygen. Measurements of light and dissolved oxygen (DO) were recorded at 10 min intervals. Intensity of photosynthetically active radiation (PAR) was continuously measured using a PAR light meter. One PAR light meter was placed in an open area at a central site (stream 3) and was assumed to represent total relative light intensity (exclusive of the effect of riparian canopy) for all 6 sites. Measurements of DO concentration and saturation were made using YSI sondes with YSI 6150 ROX optical DO probes, which were deployed at least 3 sunny days during baseflow over a minimum of a 24 h period. Water temperature was continuously measured using HOBO temperature loggers and verified with a thermometer while performing the sulfur hexafluoride (SF_6) and rhodamine release for an estimate of the reaeration rate at each site.

The exchange rate of oxygen with the atmosphere was calculated based on DO saturation and the reaeration rate determined from the decline in SF_6 concentration within the study stream reaches converted to DO rates (Mulholland et al. 2001). Reaeration rates were measured under conditions similar to metabolism measures during a steady release of SF_6 as a gas tracer and rhodamine dye as a conservative dissolved tracer and rates transformed so they applied to DO aeration rates and temperature corrected for each day metabolism was measured (Mulholland et al. 2001). In all streams except stream 2 sampling reaches consisted of the upstream 60 m. SF_6 and rhodamine were released in the stream 5-10 m above the sampling reach into a 10 cm diameter PVC pipe "T" which stream flow was diverted into so that gas and dye concentrations were thoroughly mixed with the water above the top of the sampling reach (Dodds et al. 2008). Fluorescence was measured using an AquaFlor fluorometer produced by Turner Designs, Sunnyvale, CA, and once fluorescence reached plateau at the bottom of the stream reach five, 5 mL water samples were collected with 60 mL syringes at the bottom, middle (30 m), and top (60 m) of each stream reach. These data were also used to determine water velocity (time for half of the peak fluorescence to be attained). Stream 2 did not exhibit measurable above ground flow >90% of days so a pulse release of SF_6 and rhodamine was followed and sampled every 10 min for exchange rates (expressed per minute). SF_6 was stripped from the water samples by pulling 20 mL of atmospheric air into each syringe and shaking for 5 min. The stripped gas in each syringe was ejected into an evacuated 20 mL glass vial and kept on ice and the water in each syringe was ejected into a cuvette and analyzed for fluorescence. SF_6 concentration and peak area were measured using a Shimadzu gas chromatograph GC-2014 with an electron capture detector. The GC-2014 specific settings for SF_6 analyses were current=2 nA, Mup (P5) =18 kPa, carrier gas (N_2) flow rate=25 mL min^{-1}, purge flow rate=0.5 mL min^{-1}, oven temperature=80.0°C, valve temperature=60.0°C, and detector temperature=320.0°C.

Reaeration rates of SF_6 were calculated as the difference between the natural log transformations of the mean SF_6 peak areas after correction for dilution rates of the rhodamine dye (Hauer and Lamberti 2006). The reaeration rates of SF_6 were converted to oxygen using a conversion factor of 1.345 (MacIntyre et al. 1995; Wanninkhof et al. 1990). In this case I measured aeration and used a modeling approach to estimate community respiration (CR) and gross primary production (GPP) rates in each stream. I used light to scale GPP rates, and made both CR and GPP rates dependent upon instream temperature. I used the "Solver" option in Excel to find the values for GPP and R that minimized the sum of square of errors between the observed and modeled dissolved oxygen concentrations (Alyssa Riley, Kansas State University, personal communication).

Approximately 20, 3 cm x 6 cm unglazed ceramic tiles were placed in the bottom riffle-pool complex of each stream at least 1 month prior to collection and used to estimate primary producer biomass (chlorophyll *a*). During sampling (3 times per year during stable flows), 5 ceramic tiles were randomly collected and replaced with new tiles and 1 L of water was collected and filtered through a glass-fiber filter (Whatman GFC), repeated per bottom riffle-pool per stream. Spectrophotometric benthic (tiles) and water column (filtered material) chlorophyll *a* determinations were made after extraction with ethanol and submersion in a warm water bath (Sartory and Grobbelaar 1984; Welschmeyer 1995).

Statistical analyses

Baseflow and highflow concentrations were log transformed and analyzed ungrouped and grouped together by site. An ANOVA was performed to assess interacting affects among the variables. An ANOVA blocked by season was used to compare among site variance because sampling date influenced measurements of dependent variables (i.e. season influenced TSS levels). Regression analyses were used to assess correlations among organic, inorganic nutrient concentrations, and net ecosystem productivity.

RESULTS

Physical and chemical properties

All 6 study streams were statistically similar in inorganic, organic and total suspended solids concentrations during baseflow and highflow conditions except ISS and TSS concentrations measured in stream 1 were significantly higher than all other streams (Table 1.2; Table 1.3). Maximum measured TSS concentration during baseflow conditions was in stream 1 and was 32 mg L^{-1} and the minimum was 1mg L^{-1} in stream 3 (Figure 1.2).

Inorganic solids were the dominant fraction of TSS mass where the inorganic portion of TSS ranged from 42-78% and was >60% in 5 of the six streams. Concentrations of inorganic and organic suspended solids varied greatly during high flows and no consistent pattern was found among sites, but high-flow TSS concentrations were several orders of magnitude greater than baseflow concentrations. TSS concentration was not well correlated to stage height, however, as the TSS concentration curve highly varied as compared to a hydrograph. Stated differently, TSS concentrations were greater during high flows, but stage height was not a statistically significant predictor of the concentration (R^2=0.03, p=0.27). During 9 of the 17 sampled highflow events TSS concentration decreased as stage height increased, and in 5 other events TSS concentration increased as stage height increased. Also, TSS concentration both increased and decreased as stage height increased in 3 of the 17 sampled highflow events.

Mean TN:TP molar ratios ranged from 22:1 in stream 2 to 53:1 in stream 4 (Figure 1.3). Organic N and P where the dominant fractions of TN and TP, respectively (Figure 1.3). Inorganic fractions of TN ranged from 9-26% and inorganic fractions of TP ranged from 15-34% among 5 streams, and in stream 4 inorganic P constituted 57% of TP. During baseflow conditions NO_3^- concentrations among all sites ranged from 2-91 µg L^{-1} with site 1 representing the site with the largest range from 3-91 µg L^{-1}. NH_4^+ concentrations ranged from 5-228 µg L^{-1} and SRP concentrations were below detection (1µg L^{-1}) on several occasions and as high as 41 µg L^{-1} during baseflow conditions. Overall, all 6 sites were statistically similar in nutrient concentrations and concentrations fluctuated on one or two orders of magnitude during baseflow. SRP concentrations were highly significantly correlated with NH_4^+ concentrations ($p=0.01$) and marginally significant with NO_3^- concentrations ($p=0.077$), but NH_4^+ and NO_3^- concentrations were not significantly correlated. Nutrient concentrations were greatest during highflow conditions, however, as previously described with the TSS concentrations no consistent patterns of increase/decrease as stage height increased were observed.

Minimum DO concentrations in stream 2 were 0.24 mg L^{-1} and 0.29 mg L^{-1} during 2 of the 3 sampling periods and all 5 other streams were always above 4.13 mg L^{-1}. Maximum range of daily DO concentrations (maximum DO minus minimum DO concentration measured within a 24 h period) was 6.43 mg O_2 L^{-1} in stream 2 and in the other 5 streams the range of daily DO concentration ranged from 0.97 mg O_2 L^{-1} to 5 mg O_2 L^{-1}.

Biological properties

GPP rates ranged from 0.12 g O_2 m^{-2} d^{-1} in stream 4 to 2.63 g O_2 m^{-2} d^{-1} in stream 1 and CR rates ranged from -0.38 g O_2 m^{-2} d^{-1} in stream 4 to -10.92 g O_2 m^{-2} d^{-1} in stream 2. All 6 ephemeral headwater prairie streams were slightly net heterotrophic where NEP ranged from -0.26 in stream 4 and -9.84 g O_2 m^{-2} d^{-1} in stream 2 (Table 1.5; Figure 1.4). Stream 2, which was a wetland stream, was an outlier in regards to NEP estimates as the other 5 of the 6 streams ranged from -0.26 to -3.14 g O_2 m^{-2} d^{-1}. On one date stream 1, which had the least canopy cover (Table 1.1), had a positive NEP of 0.01 g O_2 m^{-2} d^{-1}. Community respiration was highly correlated to the range of daily DO concentration (R^2=0.75, p=0.02) and TP concentrations (R^2=0.79, p=0.02). NEP was highly correlated to TN concentration (R^2=0.72, p=0.03) and TP concentration (R^2=0.71, p=0.03), however this relationship was not significant when stream 2 was removed from the analysis (Figure 1.5).

Mean benthic chlorophyll *a* ranged from 0.8-7.1 µg cm^{-2} and water column chlorophyll *a* ranged from 0.5-5.9 µg L^{-1} across streams. Mean benthic chlorophyll *a* measurements were significantly higher (p=0.03) in stream 4 than all other streams and mean water column chlorophyll *a* measurements were not significantly different among streams (Table 1.4). Benthic chlorophyll *a* measurements were not correlated to water column chlorophyll *a* measurements, and chlorophyll measurements of the benthic or water column were not correlated to any measured parameters.

DISCUSSION

Baseflow TSS and nutrient concentrations of the streams at Osage Prairie compared to the concentrations reported in other tallgrass prairie streams such as Kings Creek (O'Brien et al. 2007; Kemp and Dodds 2001), Shane Creek, and Natalie's Creek (O'Brien et al. 2007). Baseflow TSS concentrations in our study streams were lower than 70% of all the continental

U.S. streams studied by Dodds and Whiles (2004) and lower than 87% of Kansas and Missouri streams discussed in Chapter 2.

Reid and Laronne (1995) compared sediment transport in ephemeral, intermittent, and perennial desert prairie streams and concluded that sediment flux from ephemeral streams was on an order of magnitude higher than perennial streams likely due to an ample supply of sediment because of the lack of an armored layer. Lack of an armored layer could explain the large fluctuations in TSS and nutrient transport in our six study streams because long storage periods between rainfall events and the vulnerability of erosional substrates to sediment starved runoff can lead to large pulses of sediment and nutrient transport during storm events (Reid and Laronne 1995; Waters 1995). Storm events can account for disproportionate amounts of annual TP and TSS loads in streams where 88% of the total annual pollutant load occurred during the 11% of days with the greatest discharge rates (Banner et al. 2009; Chapter 2).

The inconsistent concentration-stage height correlations in our study streams could be explained by complex particle concentration and discharge relationships (Williams 1989). Gravel and pebbles that were present in our study streams were not numerous, but increased the storage of fine particles (Jodi Vandermyde, Southern Illinois University, Carbondale, personal communication). During storm events streamflows could have eventually become powerful enough to move gravel and pebbles and expose the underlying suspendable particles. Another explanation of why there was not an increasing concentration of suspended particles during rising flows could be that stored particles in these streams were flushed out quickly during storm events and after the initial pulse concentrations of suspended and dissolved particles decreased even as stream height continued to rise.

Nutrient deficiencies of N and P can be indicated by deviations from the Redfield ratio (molar TN:TP ratios 16:1(Dodds and Priscu 1990), so all of our study streams may be P limited relative to N (only one of the box plots in Figure 1.3 crosses below the 16:1 line). However, Kings Creek has a mean TN:TP of 75:1 (Dodds and Oakes 2004) yet exhibits co-limitation of autotrophic periphyton (Johnson et al. 2009).

Comparing total N and total P concentrations to the range of all reference values from Smith et al. (2003) and Dodds and Oakes (2004) I could classify 3 of our study streams as oligotrophic and 3 as mesotrophic (Dodds 2006). Relatively low nutrient concentrations in our study streams could be due to low inputs or high retention in non-dissolved pools (O'Brien et al. 2007). Empirical data from this study indicate that high biological process rates are responding to high NO_3^- concentrations, especially in stream 1.

Generally, GPP, CR, and NEP of our study streams compared to the rates reported in Kings Creek (the most studied low-order prairie stream) on Konza Prairie Biological Station (O'Brien et al. 2007). Comparing the GPP, CR, and NEP values from our six study streams on Osage Prairie to the range of reference values from Dodds (2006) and Dodds and Cole (2007) I classified our study streams into more descriptive trophic states based on reference boundaries of heterotrophic streams. This comparison classified our streams as oligo-, meso-, and eu-autotrophic (*N*= 1, 4, and 1, respectively) and oligo-, meso-, and eu-heterotrophic (*N*= 4, 1, and 1, respectively) (Dodds 2006; Dodds and Cole 2007) (Table 1.5).

A more recent analysis of trophic state used 24 reference streams across the United States (Bernot et al. 2010). Autotrophic and heterotrophic comparisons of our study sites and the reference values in Bernot et al. (in press) gave us similar results except that stream 5 was classified as meso-heterotrophic according to Bernot et al. (in press) rather than oligo-heterotrophic according to Dodds and Cole (2007).

Wetland prairie streams were probably historically common in mesic regions of the U.S., but many have been drained because of their suitability for crop production (Samson and Knopf 1994; Dodds et al. 2004); therefore it is necessary to establish reference characteristics of the remaining wetland prairie streams. Stream 2 resembled more of a wetland habitat and was functionally different than the other 5 streams in several ways, including differences in nutrient concentrations and net ecosystem productivity. Greater retention times and near anaerobic conditions in stream 2 could have lead to large conversions of NO_3^- to NH_4^+ and organic N and caused the TN concentrations to be higher (Buresch and Patrick, Jr. 1978). This wetland stream had the highest total N, total P, and respiration but was still much lower when compared to streams draining cropland within the respective ecoregion (Dodds and Oakes 2004). Our data suggest that while wetland prairie streams had higher nutrient concentrations, the absolute concentrations were substantially lower than mean concentrations currently observed in regions formerly dominated by tallgrass prairie and now dominated by cropland (Dodds et al. 2009)

I examined pristine upland ephemeral headwater streams in a never before described area. Very few characterizations of spatial and temporal variability of water quality and ecosystem processing rates have been published for mesic tallgrass prairie streams or wetland prairie streams. Descriptions of fundamental ecosystem characteristics in new regions are crucial for comparisons of water quality and ecosystem processing rates, which are necessary for supporting the applicability of other research (e.g. management and conservation activities). Despite the surprising variance in chemical and biological properties in these streams over relatively small spatial scales, this study suggests that good water quality and moderate heterotrophic condition, with greater GPP resulting from an open canopy, are common conditions of tallgrass prairie streams.

FIGURES AND TABLES

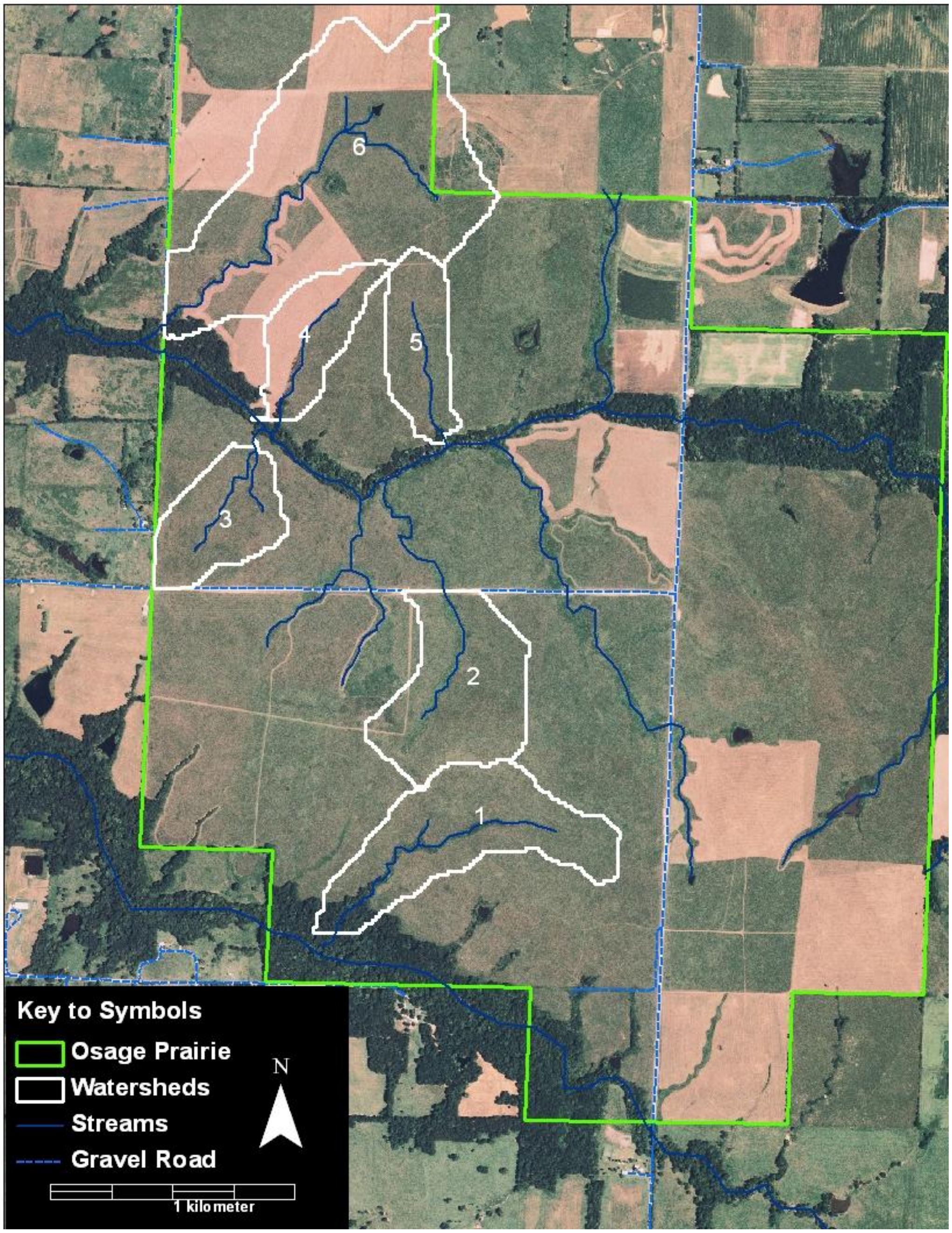


Figure 1.1 Site map of the six study streams at Osage Prairie Conservation Area. Average stream width ranged from 0.5 m at stream 3 to 2.1 m at stream 1, total stream length ranged from 465 m at stream 3 to 1778 m at stream 6, and watershed size ranged from 9.83 hectares at stream 5 to 53.87 hectares at stream 6.

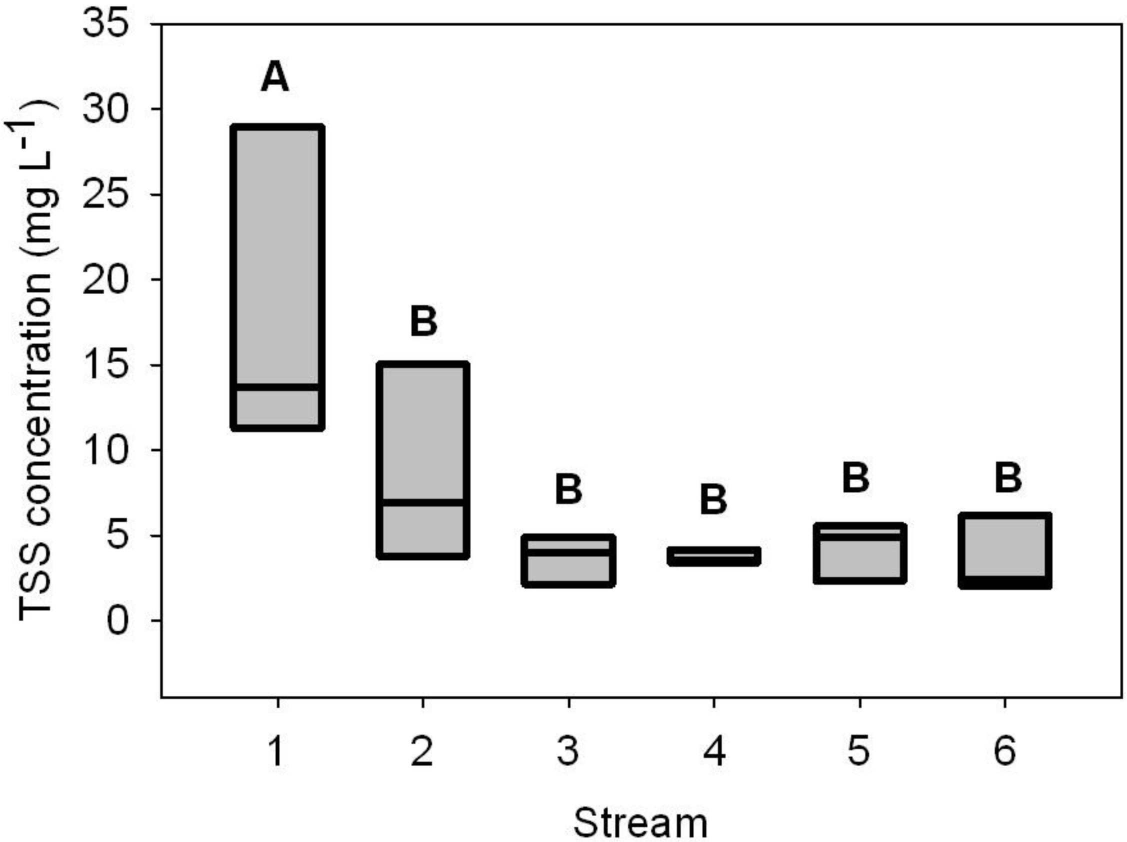


Figure 1.2 Boxplots by stream of all TSS concentrations collected during baseflow conditions. TSS concentrations in stream 1 were significantly greater than all other streams. Median concentration is shown by the black line inside each box and box height represents the range between the upper and lower quartiles.

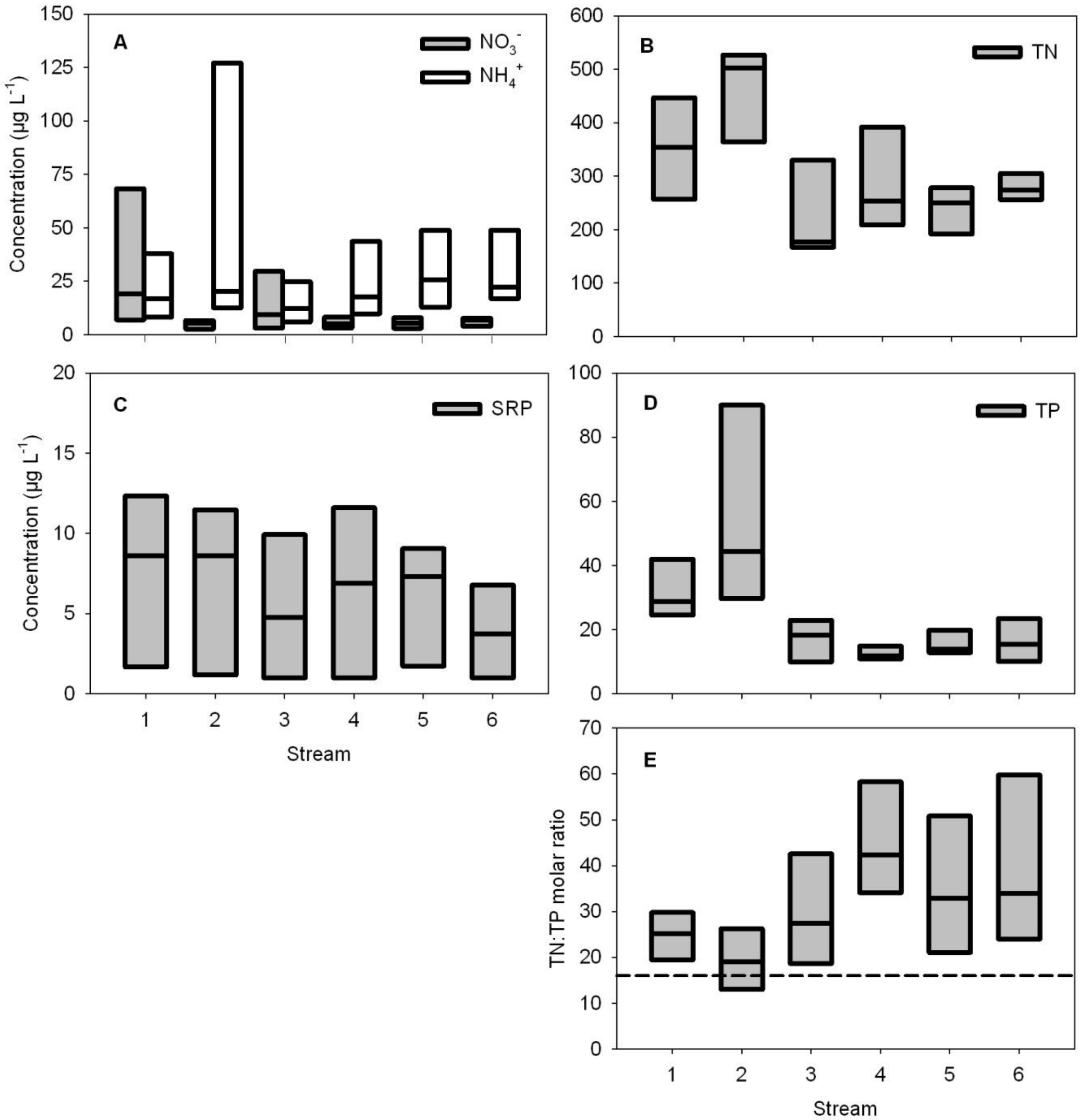


Figure 1.3 Boxplots of baseflow NO_3^-, NH_4^+ (A), and TN concentrations (B) and baseflow SRP (C) and TP concentrations (D). DO concentrations in stream 2 were low and were likely the reason for low NO_3^- concentrations and significantly higher NH_4^+ concentrations. Organic N and P were the dominant fractions of TN and TP, respectively. TN:TP molar ratios were generally >16:1 (the Redfield ratio, represented by the dashed line), above which streams may be P limited relative to N (E).

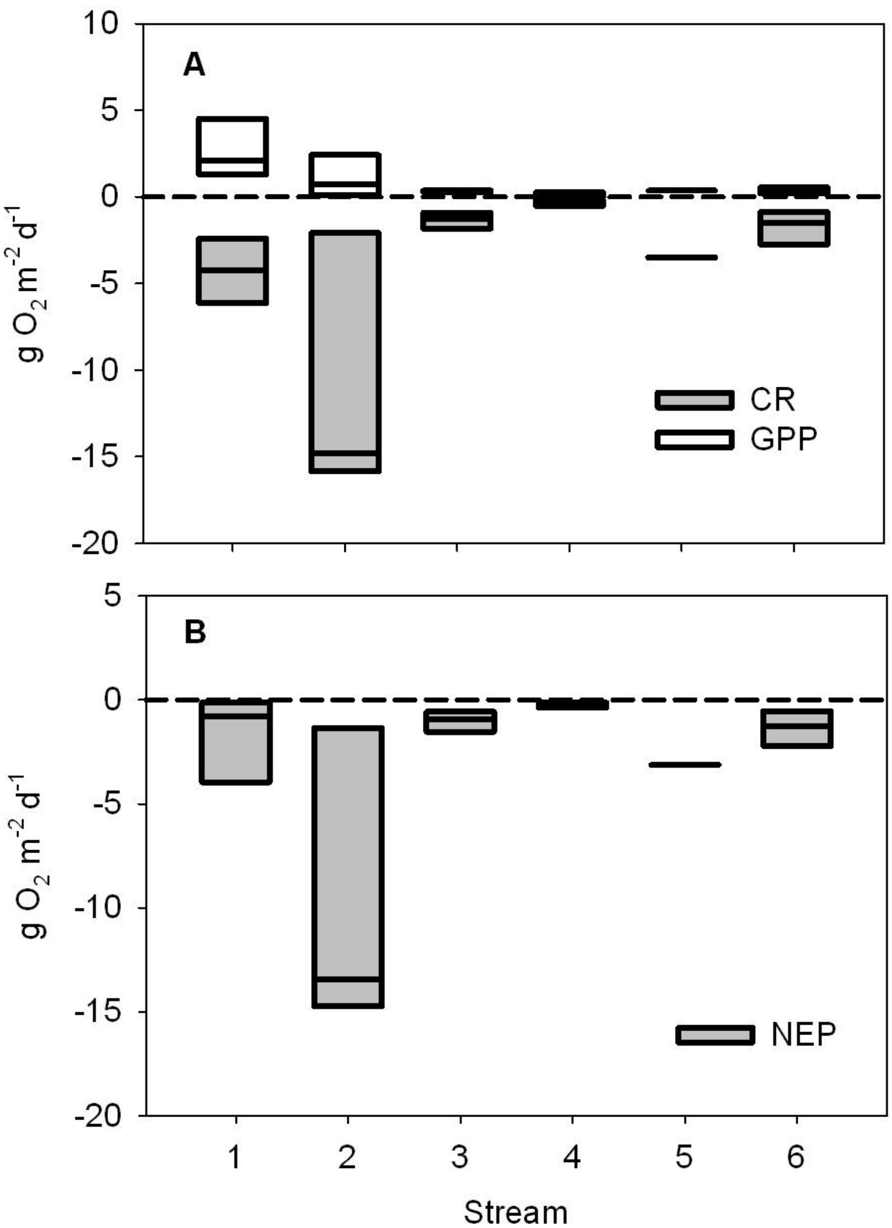


Figure 1.4 Community respiration (CR) rates were greater than gross primary production (GPP) rates in all streams (A), therefore the net ecosystem productivity (NEP) of all streams were negative indicating these upland ephemeral headwater prairie streams were net heterotrophic (B). On one occasion stream 1 was net autotrophic with a positive daily production rate of 0.01 g O_2 m^{-2} d^{-1}.

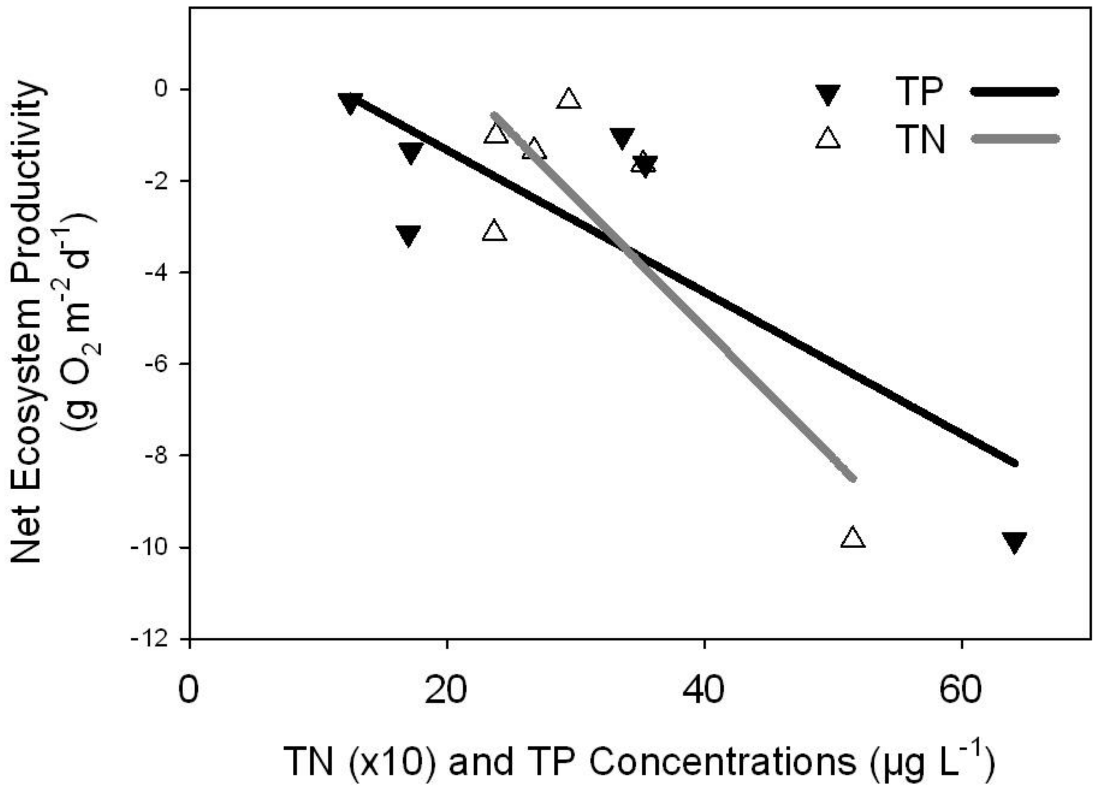


Figure 1.5 High total nitrogen (TN) and total phosphorus (TP) concentrations were correlated with more net heterotrophic streams. This relationship is not necessarily causal and was driven by the wetland stream. When the wetland stream was not included there was no significant relationship.

Table 1.1 Watershed area, average slope of the watershed, total stream length, mean stream width, mean stream depth, proportions of days with flow, and canopy cover characteristics of the six study streams. Mean stream width and mean stream depth where measured in the upstream 100 m and canopy cover was measured in the upstream 60 m stream reach. Width and depth were measured during times of baseflow. The proportions of days with flow are for April 24 to December 15 (HOBO level loggers had to be removed in December before freezing) (width, depth, and flow data provided by Jodi Vandermyde, Southern Illinois University, Carbondale). See figure 1.1 for relative locations of the 6 streams.

Stream	Watershed area (hectares)	Average slope of watershed ($cm\ m^{-1}$)	Stream length (m)	Mean stream width (m)	Mean stream depth (m)	Days with flow (%)	Canopy cover (%)
1	22.51	20	854.3	1.66	0.12	65	8.42
2	19.65	30	465.4	2.60	0.05	11	0.00
3	11.56	30	714.1	0.77	0.06	21	19.50
4	9.97	40	502.1	1.05	0.09	36	68.38
5	9.83	40	476.7	0.85	0.08	24	53.88
6	53.87	20	1778.0	2.19	0.10	54	59.75

Table 1.2 Mean (±SE) inorganic (ISS), organic (OSS), and total (TSS) suspended solids concentrations, and nitrate (NO_3^-), ammonium (NH_4^+), soluble reactive phosphorus (SRP), total nitrogen (TN), and total phosphorus (TP) concentrations during baseflow conditions. Sample size *N* represents the number of TSS samples/nutrient samples. See also Table A.1.

Stream	*N*	ISS (mg L^{-1})	OSS (mg L^{-1})	TSS (mg L^{-1})	NO_3^- (µg L^{-1})	NH_4^+ (µg L^{-1})	SRP (µg L^{-1})	TN (µg L^{-1})	TP (µg L^{-1})
1	7/8	14(±3)	4(±1)	18(±3)	34(±12)	28(±11)	9(±1)	352(±11)	35(±2)
2	6/7	4(±1)	6(±3)	10(±3)	5(±1)	65(±31)	12(±2)	515(±21)	64(±5)
3	7/8	3(±1)	1(±0)	4(±1)	14(±5)	16(±4)	5(±1)	238(±11)	34(±5)
4	6/7	2(±0)	2(±0)	4(±0)	6(±1)	24(±6)	7(±1)	295(±19)	13(±0)
5	7/8	5(±2)	2(±1)	7(±3)	12(±7)	52(±25)	6(±0)	237(±7)	17(±1)
6	7/8	3(±2)	2(±0)	5(±2)	8(±2)	43(±20)	4(±0)	268(±6)	17(±1)

Table 1.3 Mean (±SE) inorganic (ISS), organic (OSS), and total (TSS) suspended solids concentrations, and nitrate (NO_3^-), ammonium (NH_4^+), and soluble reactive phosphorus (SRP) concentrations during highflow stages. Highest possible stage of each stream was stage 4, which was rarely exceeded or met. See also Table A.2.

Stream	Stage	*N*	ISS (mg L^{-1})	OSS (mg L^{-1})	TSS (mg L^{-1})	NO_3^- (µg L^{-1})	NH_4^+ (µg L^{-1})	SRP (µg L^{-1})
1	1	3	99(±45)	11(±2)	109(±47)	36(±17)	4(±1)	169(±44)
	2	3	851(±431)	36±13)	887(±444)	127(±13)	19(±6)	56(±20)
	3	2	1466(±1010)	59(±19)	1525(±1028)	161(±0)	72(±2)	5(±3)
	4	2	208(±123)	28(±9)	236(±132)	133(±1)	64(±6)	91(±58)
2	1	3	65(±14)	33(±11)	99(±25)	6(±0)	82(±6)	53(±9)
	2	3	17(±5)	8(±1)	25(±7)	128(±51)	21(±7)	33(±10)
	3	3	12(±4)	6(±1)	17(±5)	50(±1)	35(±7)	62(±15)
3	1	3	20(±3)	8(±2)	28(±5)	59(±13)	43(±10)	18(±1)
	2	3	14(±4)	6(±1)	20(±5)	82(±15)	64(±12)	36(±9)
4	1	2/1	74(±31)	24(±9)	98(±40)	78	30	7
	2	2	19(±9)	10(±2)	28(±10)	87(±9)	32(±3)	4(±2)

	3	1	54	30	84	97	39	1
5	1	3	135(±69)	18(±6)	152(±75)	22(±2)	34(±9)	19(±9)
	2	3	330(±180)	17(±6)	347(±186)	131(±28)	260(±69)	67(±14)
6	1	1	18	4	22	8	10	27
	2	2	7(±3)	5(±1)	12(±2)	27(±1)	29(±14)	14(±9)
	3	3	625(±356)	22(±10)	647(±366)	46(±7)	48(±9)	14(±4)
	4	2	53(±26)	11(±6)	64(±31)	44(±15)	52(±23)	23(±2)

Table 1.4 Benthic and water column chlorophyll *a* measurements. Sample size *N* represents the number of benthic chlorophyll /water column chlorophyll sampling dates. See also Table A.3.

Stream	*N*	Benthic chl *a* (μg cm^{-2})	Water column chl *a* (μg L^{-1})
1	4/3	1.2(±0.2)	1.0(±0.6)
2	3/3	0.8(±0.1)	2.5(±0.8)
3	4/3	1.5(±0.2)	5.9(±1.8)
4	3/3	7.1(±3.7)	0.5(±0.3)
5	4/3	1.0(±0.1)	6.9(±3.2)
6	4/3	1.7(±0.2)	2.5(±1.4)

Table 1.5 Atmosphere-water oxygen exchange rate and mean (±SE) gross primary production (GPP), community respiration (CR), and net ecosystem productivity (NEP) rates in each stream. CR rates are negative because oxygen is consumed and GPP rates are positive because oxygen is produced. Negative NEP rates indicate streams are net heterotrophic. Compared to reference values of CR, GPP, and NEP reported by Dodds and Cole (2007) the autotrophic state of our study streams ranged from oligo-autotrophic to eu-autotrophic and the heterotrophic state ranged from oligo-heterotrophic to eu-heterotrophic. See also Table A.4.

Stream	*N*	O_2 exchange coefficient ($*10^{-3}$ min^{-1})	GPP (g O_2 m^{-2} d^{-1})	CR (g O_2 m^{-2} d^{-1})	NEP (g O_2 m^{-2} d^{-1})	Autotrophic State (Dodds and Coles 2007)	Heterotrophic State (Dodds and Coles 2007)
1	4	4.7	2.63(±0.4)	-4.26(±0.5)	-1.63(±0.6)	Eu-autotrophic	Meso-heterotrophic
2	3	5.8	1.08(±0.4)	-10.92(±2.6)	-9.84(±2.5)	Meso-autotrophic	Eu-heterotrophic
3	4	4.5	0.32(±0.0)	-1.33(±0.1)	-1.01(±0.1)	Meso-autotrophic	Oligo-heterotrophic
4	3	1.7	0.12(±0.0)	-0.38(±0.1)	-0.26(±0.0)	Oligo-autotrophic	Oligo-heterotrophic
5	2	8.6	0.35(±0.1)	-3.49(±0.4)	-3.14(±0.5)	Meso-autotrophic	Oligo-heterotrophic
6	4	3.3	0.38(±0.0)	-1.72(±0.2)	-1.34(±0.2)	Meso-autotrophic	Oligo-heterotrophic

CHAPTER 2 - Total suspended solids concentrations as influenced by land use and altered hydrologic regimes in central plains streams

ABSTRACT

I investigated interactions among discharge rate and in-stream total suspended solids concentration, land use/ land cover and in-stream total suspended solid (TSS) load rate, and land use/ land cover and hydrologic alteration in 23 streams from Missouri and Kansas. I extracted values for 2188 TSS samples from long-term datasets collected by Kansas Department of Health and Environment and Missouri Department of Natural Resources and paired them to same day discharge rates measured at nearby U.S. Geological Survey stream gaging stations. There were strong interactions between TSS concentration and discharge rates especially during elevated discharge events. Most streams had statistically significant break points in the TSS loading rates at discharge rates exceeded <25% of days. These mobilization events contributed accelerated amounts of TSS load per day with increasing discharge. Our estimates showed that 88% of the total annual TSS load occurred during the 11% of days with the greatest discharge rates**.** Streams with greater percentages of grass and/or forest riparian areas had a breakpoint that occurred at lower exceedence values (during rarer events) indicating greater relative discharge rates were required to transport solid particles. These streams also had generally lower TSS concentrations during high discharge days, relative to urban and cropland dominated streams. In addition, grass buffered streams had smaller flood peaks and slower rise rates, and forest buffered streams had less frequent floods relative to cropland-dominated watersheds. Streams with high proportions of cropland within their riparian area had higher breakpoint values and regression intercepts. Streams impacted by large proportions of cropland or human development experienced more frequent floods. Unbuffered streams in our study had more frequent

mobilizing events and therefore had greater TSS loading rates, whereas the mobilizing events in well buffered streams were less frequent and less severe leading to less total TSS transport.

INTRODUCTION

Eutrophication and sedimentation have become worldwide problems and are the focus of much aquatic resource management (Smith 2003). Problematic factors associated with total suspended solids (TSS) loads are their relationship to other pollutants such as fecal coliform (Marino and Gannon 1991), nutrients (e.g. phosphorus, Jones and Knowlton 2005; Uusitalo et al. 2000), metal elements (Sansalone et al. 2005) and in-stream biotic integrity (Berkman and Rabeni 1987; Waters 1995; Wood and Armitage 1997; Whiles and Dodds 2002; Evans-White et al. 2009) making TSS a high priority pollutant of conservation concern. The TSS effects can be due to direct or indirect relationships such as animal waste products containing high bacteria and nutrients or some inorganic solids absorbing phosphorus leading to its transport into and through aquatic systems. Suspended solids increase the refraction of light reducing the amount and depth of light penetration in water. With a reduction of light availability in-stream primary production is limited. Less diverse aquatic macroinvertebrate communities have also been correlated to higher levels of TSS likely because the suspended solids are transported then deposited on the stream substrate limiting the substrate utility of macroinvertebrates that use coarse bed material for survival and propagation (Evans-White et al. 2009). Deposition of solids is also a costly problem in reservoirs and wetlands (Dodds 2002).

In order to protect aquatic systems and their goods and services I must control the loading rates of pollutants (Dodds 2002; Dodds 2006). Total Maximum Daily Loads (TMDL) are set to protect aquatic systems from high pollutant levels. For example, TMDLs are set to meet state water quality standards such as in Kansas (KAR 28-16-28e(c)(2)(B)) which states "Suspended solids added to surface waters by artificial sources shall not interfere with the behavior, reproduction, physical habitat or other factor related to the survival and propagation of aquatic or semi-aquatic or terrestrial wildlife" (KAR 2008). The Kansas Department of Health and Environment has set TMDL criteria for TSS to support aquatic life in Soldier Creek and Little Arkansas River, two of our 23 study streams. Other TSS TMDLs have been developed to lessen the rate of deposition of solids in downstream lakes, reservoirs, or wetlands.

These TMDLs have been set to decrease the loads of all solids in streams. Much of the scientific background that has been published on the transport of suspended particles is focused on sediment only and not total suspended solids. Even though suspended sediment is the inorganic portion of TSS the two measures are not linearly related (Gray et al. 2000). In this paper I use the term suspended solids or total suspended solids to describe all of the inorganic and organic particles in suspension.

To regulate the rate of TSS loading in streams I must know the relationship between TSS loads and various land uses (Dodds and Whiles 2004), and consider the potential for threshold relationships between discharge and sediments (Dodds et al. 2010). Land use practices within riparian zones, especially the riparian zones of headwater streams, can be highly correlated with stream water quality (Dodds and Oakes 2006). Land practices likely influence downstream TSS loads because anthropogenic land alteration from native vegetation to cultivated crops has altered runoff rates so that peak discharge rates are now higher than historical rates (Gerla 2007) and leave sediments exposed to erosion. Anthropogenic actions have increased erosion rates and the frequency of pollutant mobilization events so that these discharge rates occur three times the natural rate (Smil 2000). A reversal of these actions by converting cropland back to grassland can reduce peak discharge by as much as 55% (Gerla 2007). Sediment loading in lotic systems has a complex relationship with discharge (Porterfield 1972) and is commonly expressed as an exponential function (Dodds and Whiles 2004), so land use practices that lead to higher peak discharge rates could likely lead to an exponential increase in sediment load.

Dodds and Oakes (2006) predicted that large runoff events would be expected to cause high loadings of pollutants. For phosphorus loading Banner et. al (2009) calculated that the 10% of days with the highest discharge rates accounted for 88% of the total phosphorus (TP) load in their Kansas study streams. Banner et al. (2009) also showed that the baseline levels of TP were strongly correlated to the percentage of agriculture within the riparian zone. Meade and Parker (1984) showed that at three discharge gaging stations nearly 50% and 90% of the sediment load was discharged during 1% and 10% of the days with the highest runoff, respectively. The source of sediment in streams is largely from overland erosion and is related to land cover quality. Streambank erosion can be a lesser contributor than overland erosion to suspended sediment in streams. The contribution of streambank erosion to the amount of suspended sediment has been estimated within the Midwestern U.S. at 30% to 40% in the East Nishnabotna and Des Moines Rivers, IO (Odgaard 1987), as much as 50% in two Illinois rivers (Wilkin and Hebel 1982), and 37% in the Blue Earth River, MN (Sekely et al. 2002).

Much of the published literature on suspended solids transport in streams has been done in more arid regions having much lower mean annual precipitation rates and more sparse vegetative cover than our study area (e.g. Reid and Frostick 2006; Campbell 1977). Additional work on suspended solids transport has been done in relatively large river basins where temporal variability in suspended solids concentration is generally less than in smaller basins (Meybeck et al. 2002). Therefore, I wanted the spatial scope of our study to represent both a precipitation gradient from arid to mesic regions and a large range in watershed size (Figure 2.1).

There are likely discharge exceedance break points as occur for total phosphorus (Banner et al. 2009). These likely occur because particles are not suspended below a specific turbulence intensity, but as discharge increases past this point turbulence leads to mobilization of larger and larger particles and disturbs the streambed leading to release of buried finer particles (Williams 1989). Extremely high runoff (mobilizing) events provide a primary mechanism for the movement of solids (Parker and Troutman 1989). More mobilizing events, or days with discharge rates above this threshold, will lead to greater total annual loads of TSS. Therefore, in this study I hypothesized that (i) high TSS loads could be explained in our study streams based on spatial and temporal patterns of discharge exceedance rates, (ii) there was a discharge exceedance threshold for which TSS levels increased more rapidly if surpassed, and (iii) land cover/ land use within our study watersheds were correlated to the timing, frequency, and duration of TSS mobilizing events.

METHODS

Site description

Our study locations were in the states of Kansas and Missouri. Site selections were based on the following criteria, (i) the TSS monitoring location was within 500 meters of a USGS gaging station that recorded mean daily discharge, (ii) the TSS and discharge data records were complete from the time period of 1990-2009, (iii) the site was not directly downstream of a reservoir, and (iv) each site was independent of all the other sites (i.e. no site was contained in the drainage network of another, they were unnested). Our site criteria left us with 23 monitoring stations which included 13 sites monitored by Kansas Department of Health and Environment (KDHE), 8 sites monitored by Missouri Department of Natural Resources (MODNR), and 2 sites monitored by both state agencies (Table 2.1). The watershed areas of the selected sites ranged from 318 km^2 to 57945 km^2. Average annual precipitation ranged from 63.5 cm at our northeastern most sites to 114.3 cm at our southwestern most sites. The remaining sites equally represented the gradual east-west and north-south precipitation gradient between the maximum and minimum (Figure 2.1). Our study sites represented 6 different Omernik level III ecoregions, (i) Central Great Plains, (ii) Southwest Tablelands, (iii) Flinthills, (iv) Central Irregular Plains, (v) Western Cornbelt, and (vi) Ozark Highlands (USEPA 2003).

Stream TSS data

I extracted values reported for 2188 TSS samples collected between 1990 and 2009 from long-term datasets based on samples collected and analyzed by KDHE and MODNR. Banner et al. (2009) describe KDHE's sampling schedule where each site is sampled bimonthly and is rotated from even months to odd months in consecutive years. With this schedule every station is sampled every month within a two year period. MODNR samples all sites 6 to 12 times a year (MODNR 1995). Both sampling schedules were year-round so that seasonal variances in TSS loads were accounted for. KDHE collected discrete water samples using a bridge and bucket technique where a stainless steel bucket was lowered from a stream crossing (i.e. bridge) to collect water from the thalweg of the stream 0-25 cm below the water surface during times of flow (Banner et al. 2009). MODNR collected water samples similarly but used Nalgene bottles as the sample container (MODNR 1995). Once water samples were collected they were either filtered immediately in a mobile laboratory or stored in a cooler at 4°C +/- 2°C and transported back to the KDHE laboratory in Topeka, KS or the MODNR laboratory in Jefferson City, MO. KDHE used a ProWeigh Filter for TSS, 47 mm diameter, and with a pore size of 1.5µm, to filter each water sample. MODNR used Pall Gelman type A/E, 25 mm diameter, and porosity of 1.0µm. Because porosity varied slightly between the two types of filters I considered the collecting agency to be a covariate among our sites. All filters were dried in a drying oven at 103-105°C and reweighed to calculate the weight of solids retained on each filter. The mass of suspended solids (mg) was then divided by the volume of the water sample filtered (L) to determine the amount of suspended solids per liter of water (mg/L).

Discharge data

USGS approved mean daily discharge data from 1990-2009 associated with each study stream site were downloaded from the National Water Information System: Web Interface. Mean daily discharge values were used to calculate flow duration curves for each site independently by converting each mean daily discharge value to a percent exceedance value (Banner et al. 2009). This approach allows comparison across streams with different mean discharge. Percent exceedance values are opposite of flood return times (i.e. a flood return time of 100 represents a discharge rate that is expected to occur every 100 years). Flood return times and magnitude-frequency analyses have been used by many researchers to study sediment transport rates (e.g. Wolman and Miller 1960; Nash 1994), however when using flood return time analyses it is difficult to model the annual load of a pollutant. I used percent exceedance values for the main purpose of condensing average discharge patterns for each site into a model year so that I could estimate annual TSS load and easily compare across sites with different mean discharges. Percent exceedance values for each site ranged from 0-100 where 100% indicates a discharge level that is met or exceeded all days, or the minimum discharge. Low percent exceedance values near 0 indicate discharge levels that are rarely exceeded, or maximum discharge. For example, a percent exceedance value of 20 indicates a discharge level that is exceeded 20 percent of the time (73 out of 365 days, on average over the years of discharge record). Percent exceedance values were then paired with same day TSS measurements.

Concentration and load modeling

TSS measurements were log-transformed and plotted as a dependent variable against our calculated percent exceedance values. A two segment piecewise regression analysis within the statistical package in SigmaPlot 11.0 was used to identify break points in the log-transformed TSS measurements for each site. Break points (bp%xc) were determined to be significant, $p \leq 0.05$, when the data was divided into two groups with statistically different regression lines.

To model daily load I created a model year where percent exceedance values represented Julian date. For example, percent exceedance of 100 became day 1 in our model year because the first day was exceeded 100 percent of the days. Day 365.25 represented a percent exceedance of 0 and was modeled to have the greatest discharge rate. TSS concentrations for each Julian date were estimated for sites by inputting percent exceedance values (%xc) representing each day into the output equation from the two segment piecewise regression analyses, and then untransformed the result by calculating the antilog (Equation 1). Discharge rates (DR) for each day were found using a lookup table based on percent exceedance. The estimated TSS concentration was multiplied by the discharge rate and extrapolated to a 24 hour period to model daily load (Equation 2).

If %xc≤bp%xc, Region1(TSS), Region2(TSS) (Equation 1)

Region1(TSS)=10^((y1*(bp%xc-%xc)+y2*(%xc-x1))/(bp%xc-x1))

Region2(TSS)=10^((y2*(x2-%xc)+y3*(%xc-bp%xc))/(x2-bp%xc))

Where TSS=untransformed TSS concentration estimate, %xc=percent exceedance, bp%xc=percent exceedance break point, x1=minimum %xc, x2=maximum %xc, y1=TSS at x2, y2=TSS at bp%xc, and y3=TSS at x1.

tdl(kg/d)=TSS (mg/L)*DR(L/s)*86400s/d*1kg/1000000mg (Equation 2)

Modeled total daily loads (tdl) were summed together to model the total annual load (TAL). I then calculated what proportion of the total annual load was contributed during each day and figured cumulative percentage rates for each day *k* (Equation 3).

$$\sum_{i=1}^{k}\left(\frac{TDL}{TAL}\right) \qquad \text{(Equation 3)}$$

The cumulative percentages of the total annual load for all selected sites were plotted against day and evaluated using another piecewise regression analysis to assess the most significant break point in TSS load accumulation. The break point signified the calendar day which separated the data into two groups with significantly different regression lines. The number of days greater than the break point day signified the percent of days with the greatest discharge rates that accounted for most of the total annual load.

Geospatial data

A geographical information system (GIS) was used to construct catchment areas for each stream site and summarize land use attributes within each catchment and riparian area. Catchment areas were derived using the ArcHydro 1.3 toolset to analyze a 30 meter digital elevation model (USGS Seamless 2006). Land use characterization was based on the National Land Cover Dataset (2001). I consolidated developed open space, developed low intensity, developed medium intensity, and developed high intensity land use classes into one developed class; deciduous forest, evergreen forest, mixed forest, and shrub/scrub land cover classes into one woodland class; grassland/herbaceous and pasture/hay land use classes into one grassland class; woody wetlands and emergent herbaceous wetlands land cover classes into one wetlands class. Land cover classes open water and cultivated crops were not consolidated with any other classes. Proportions of these six new land use land cover classes were summarized on three different scales related to stream integrity, (i) whole catchment, (ii) 150 meter total riparian width (60-m buffer), and (iii) 90 meter total riparian width (30-m buffer).

A stream layer was also created using the ArcHydro 1.3 toolset and was compared to the stream layer within the National Hydrography Dataset (1999), which contains some spatial inaccuracy (Sheng et al. 2007). There were many conflicts with spatial stream location between our two layers, but never more than 30 meters, so to account for error in our stream delineation I converted our stream line to a raster with a cell size of 30 meters. This stream raster was more likely to contain the actual spatial location of the stream. A new raster was created representing a 30 meter riparian area on each side of the stream raster. This gave us a total riparian width of 90 meters where the actual stream location was at least 30 meters from an edge and at most 60 meters from the other edge. Similarly, I created a new raster representing a 60 meter riparian area on each side of the stream so that the entire riparian buffer width was 150 meters. The actual stream distance to riparian edge of this 60 meter riparian area could have ranged from 60-90 meters.

Land use and hydrologic alteration

To evaluate the potential influence of human land alteration on the hydrologic regime of our study streams I used Indicators of Hydrologic Alteration (IHA) 7-1 software to parametrically summarize environmental flow components (EFC) using the 20-year daily discharge records (Richter et al. 1996). EFC parameters included timing, frequency, and duration of small and large floods and extreme low and high flow rates. High flows were defined as discharge rates that were exceeded on a fewer proportion of days than the %xc breakpoint (bp%xc). A principal component analysis (PCA) was used to condense redundant EFC variables into axis scores for each site (Olden and Poff 2003). Broken-stick analysis was used to test for significant PCA axes. Significant PCA axis site scores were regressed against land use proportions of the respective catchment area and a 60 and a 30 meter riparian area along the entire upstream drainage line.

Land use/ land cover attributes within the watershed, 60 meter riparian area, and 30 meter riparian area were plotted against the slope and intercept of each breakpoint regression and the breakpoint exceedance value to determine the interaction between land use/ land cover characteristics and TSS loading rate patterns.

RESULTS

Concentration and discharge relationships

Because of the blocked random sampling schedule and the low probability of randomly sampling a day where conditions occur infrequently such as minimum and maximum flows, our data points were not evenly distributed along the flow duration curves. Even in cases where the sample size was >100 there was not a sample for every integer along the flow duration curve, however our data points did well represent the stream discharge conditions from near minimum to near maximum (Table 2.2). All sites had negative correlations between all measured TSS concentrations and discharge percent exceedance indicating an interaction effect of increasing discharge and increasing TSS concentrations. Significant piecewise regressions were not found for the TSS loading rates at four sites. Two of these sites had relatively few data points (N = 14, 30) possibly explaining the lack of significance. The other two sites had significant linear regressions with a coefficient of determination = 66% and 60%, however the break points were only marginally significant (p=0.06 and 0.08, respectively) (Table 2.3). Where significant break points existed TSS concentration and discharge percent exceedance were not as well linked at low discharge rates (%xc>bp%xc) than at high discharge rates. Residuals from the concentration-percent exceedance regression line below the breakpoint may have been due to sampling during rising or falling limbs of mobilizing events. The concentration-discharge relationship could fluctuate during such hydrographs (Williams 1989), and since I had at most one TSS sample from a single hydrologic event I were unable to account for this.

Piecewise analysis of all significant sites together on a logarithmic scale suggested a regression line with a slope just slightly >0 of the TSS concentration and %xc data points representing discharge exceedance rates above the bp%xc (Figure 2.2). This regression line above the breakpoint approximated the overall median concentration across all sites, and the median concentration was a well representative measure of the TSS conditions during 75% of the days (Figure 2.3). At discharge rates greater than the break points the discharge percent exceedance and TSS concentration were strongly linked (R^2 $\bar{x}$ = 46.7%; range, 22-70%) and discharge had a greater interacting effect on TSS concentration (Table 2.3).

Total annual TSS load

Annual load models of TSS were created for the 19 sites where significant piecewise regressions existed. The piecewise regressions indicated a logarithmic interaction effect where increasing discharge lead to greater increases in TSS concentrations. The slope of the logarithmic interaction was even greater as discharge increased. When the flow duration curve was used to construct a model year (where discharge at day 1= 100%xc and discharge at day 365.25= 0%xc) the estimated daily load increased exponentially after the discharge breakpoint was exceeded. The estimated daily loads were summed together to estimate total annual load. Displaying the daily load estimates as a cumulative percentage of the total annual load made it possible to determine what proportion of days contributed the majority of the total load. This cumulative graph also made the results much easier to visually interpret. For example, it is much more apparent that greater than 50% of the total TSS annual load was modeled to occur during the 15 days with the greatest discharge. Breakpoint analysis of the cumulative load percentages of all 19 sites identified a significant change of slope during day 323. The 323 days modeled to have discharges representing the portion of the flow duration curve from 100-89% contributed 12% of the total annual TSS load. The remaining 42 days (day 323-365) represented the top 11% of discharge rates and were modeled to contribute 88% of the annual TSS load (Figure 2.4).

Land use and hydrologic alteration

Area of each land use class was summarized as a percentage of the total watershed or riparian area to reduce covariance in hydrologic parameters due to surface area (Table 2.5). The proportions of each land use/ land cover class within the three spatial scales were all similar, but generally the land use/ land cover characteristics within the two riparian scales were better than the watershed scale at predicting the site scores from the principal component analysis and breakpoint coefficients.

Principal component analysis condensed the IHA parameters into three significant axes. The first three axes accounted for 67.4% (43.1%, 14%, and 10.3%, respectively) of the variance in the IHA parameters. Principal component axis 1 scores (PC 1) were strongly loaded by high flow fall rate (+), large flood fall rate (+), high flow peak (-), high flow rise rate (-), and small and large flood peak (-). PC 2 scores were positively loaded by extreme low duration and small flood frequency and negatively loaded by extreme low and high flow frequency. PC 3 scores were positively loaded by large flood frequency and duration and small flood duration (Table 2.4).

The proportions of cultivated crops within each watershed were significantly positively correlated to site scores for PC 3. Watersheds that had large proportions of the total area in cultivated cropland tended to have more frequent large floods and small and large floods that remained at high flow for longer periods. The percentage of the watershed area covered in grassland was positively correlated to PC 2 site scores. Watersheds with greater surface area covered by grasses tended to have long periods of extreme low flow, frequent small floods, and low frequency of extreme low and high flow events.

Well buffered streams with greater proportions of the 30-m and 60-m riparian area either covered in grass or forest were positively correlated to PCA axis 1 or negatively correlated to PCA axis 3, respectively (Figure 2.5). Grass buffered streams had lower flood peaks and slower rise rates, but quicker fall rates. Forest buffered streams had shorter lasting floods and less frequent large floods. Streams that had a large proportion of human development within 30 and

60 meters were negatively correlated with PCA axis 2 and tended to have short-lived, but frequent extreme low discharge rates and very frequent high discharge rates.

All three spatial scales (whole watershed, 30 m or 60 m riparian buffer) had nearly identical results only differing in coefficient of determination when comparing the proportions of land use/ land cover to the breakpoint regression coefficients. I were unable to say for sure whether the 60-m riparian scale or the 30-m riparian scale was particularly better than the other because of the strong autocorrelation between the proportions of land cover within the 30-m and 60-m riparian scales. Streams that had greater proportions of cropland in their watersheds and riparian areas had greater regression intercepts meaning that the TSS concentrations during high discharge days were greater in streams draining cropland. The percentage of forest and grass were negatively correlated to regression intercepts meaning that buffered streams had lower TSS concentrations during high discharge days (Figure 2.6). Higher bp%xc values were significantly correlated to high human development rates and lower bp%xc values were correlated to high grass coverage.

DISCUSSION

Our results show that median may be more accurate than mean TSS concentration at estimating the stream suspended solids concentration during approximately 75% of the days. This is because rare events have a disproportionate effect on the mean, therefore median rather than mean values would indicate the most common conditions in the stream and better represent biological integrity of chronic exposure. The mean TSS concentration in our study streams was on average 5 times higher than the median concentration. The mean better estimates the total annual load of suspended solids transported downstream than does the median, therefore mean

TSS concentration could be a more appropriate variable than the overall median concentration when investigating the deposition rate in a reservoir or wetland.

Sampling schedules should be set with the intention of capturing discharge conditions that equally represent the entirety of the flow duration curve. High discharge events are rare, but should be targeted for sampling because the majority of the total annual TSS load occurred as pulses during high-discharge events. If there are no samples from the greatest 11% of discharge days, it could lead to an 88% underestimation of the total annual load.

Banner et al. (2009) investigated the loadings of phosphorus and reported nearly identical results as ours. None of the streams studied by Banner et al. (2009) (9 of which were included in our study) were downstream of point sources of phosphorus, so mobilization of TSS could possibly have lead to concurrent transportation of phosphorus that was absorbed on solid particles. Therefore, management of TSS loads could have equal improvements in phosphorus loads in these Central Plains streams.

Because our analysis was correlative and not causal, I cannot be sure of the mechanisms involved. Our results do show strong evidence of the importance of riparian buffers and provided some evidence of how land use/ land cover interacts with pollutant loads by altering hydrologic regimes. Many other studies support our relationships that the conversion from native grassland to cultivated cropland has likely lead to greater runoff rates (e.g. Gerla 2007; Smil 2000), and therefore more intense and more frequent mobilization events. The removal of plant cover can further influence the soil vulnerability, so it is likely that there is a combination of increased runoff rates and lower energy requirements of particle transport that could have multiplicative affects on the TSS loading rate.

Hydrologic regimes will be imperative in the future in protecting aquatic systems from global climate change. Trends of global climate change have lead to consistent projections of how precipitation patterns will change in the future. Generally, global climate change scenarios project areas from mid- to high-latitudes to only have a slight increase in mean annual precipitation but the intensity of extreme precipitation events will increase and there will be longer dry periods between storms (IPCC 2007). If these projections are correct, and land use/ land cover does not change, then pollutant mobilization events will become more intense leading to substantial increases in pollutant loading rates in streams.

The most efficient way to lower the loading rates of some pollutants and meet management goals such as TMDLs is suggested to be best accomplished by increasing hydrologic retention (e.g. phosphorus, Banner et al. 2009). An increase in hydrologic retention would lead to a flatter flow duration curve where extremely high-discharge mobilization events would occur less frequently and with less intensity leading to a decrease in pollutant loading. Possibly the best way to decrease runoff rates and increase the infiltration of precipitation is to convert agricultural land in headwater areas or riparian areas back to native vegetation (Gerla 2007). Detailed spatial mapping could be used by managers to identify high priority areas that have high runoff rates and that are in areas that accumulate large amounts of runoff (i.e. ephemeral gullies). Runoff rates can be estimated using land cover, hydrologic soil group, and precipitation (USDA 1986). With a GIS, these attributes and a digital elevation model can be used to estimate runoff accumulation (Stuebe and Johnston 1990; Smedt et al. 2000) and stream discharge, and by simulating land cover/ land use restoration projects it would be possible to model land management plans before initiating any action. Then, actions such as establishing riparian buffers in high priority areas could be targeted to restore the hydrologic regime and lessen pollutant loading rates.

FIGURES AND TABLES

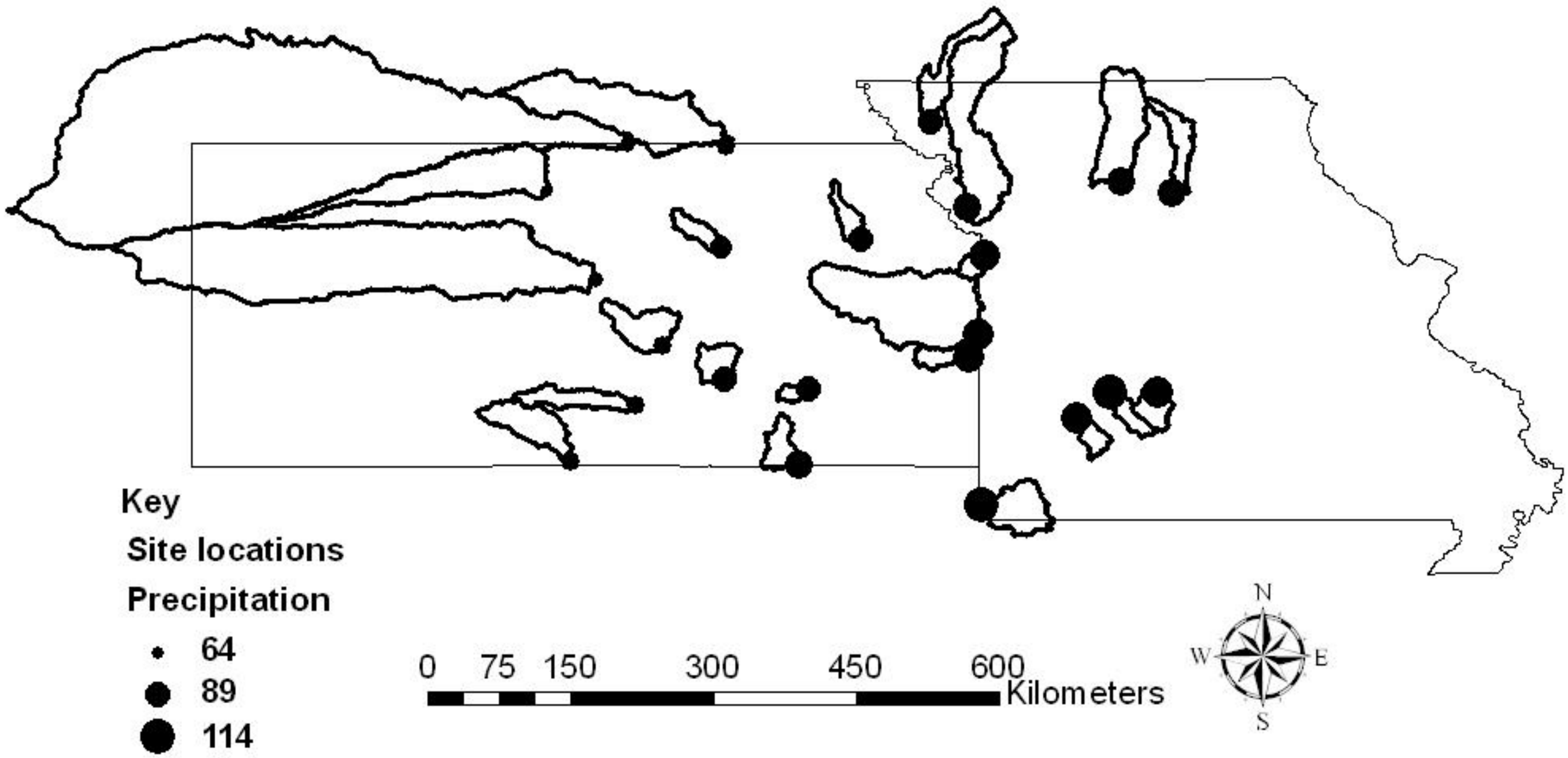


Figure 2.1 Site map of USGS daily discharge gaging stations and TSS monitoring stations. Site locations are represented by black dots with relative size depicting the range in average annual precipitation. Sites to the southeast of our study area received nearly double the precipitation as our furthest northwest sites. Watershed boundaries are depicted by the bolder lines and represented a large diversity of watershed size.

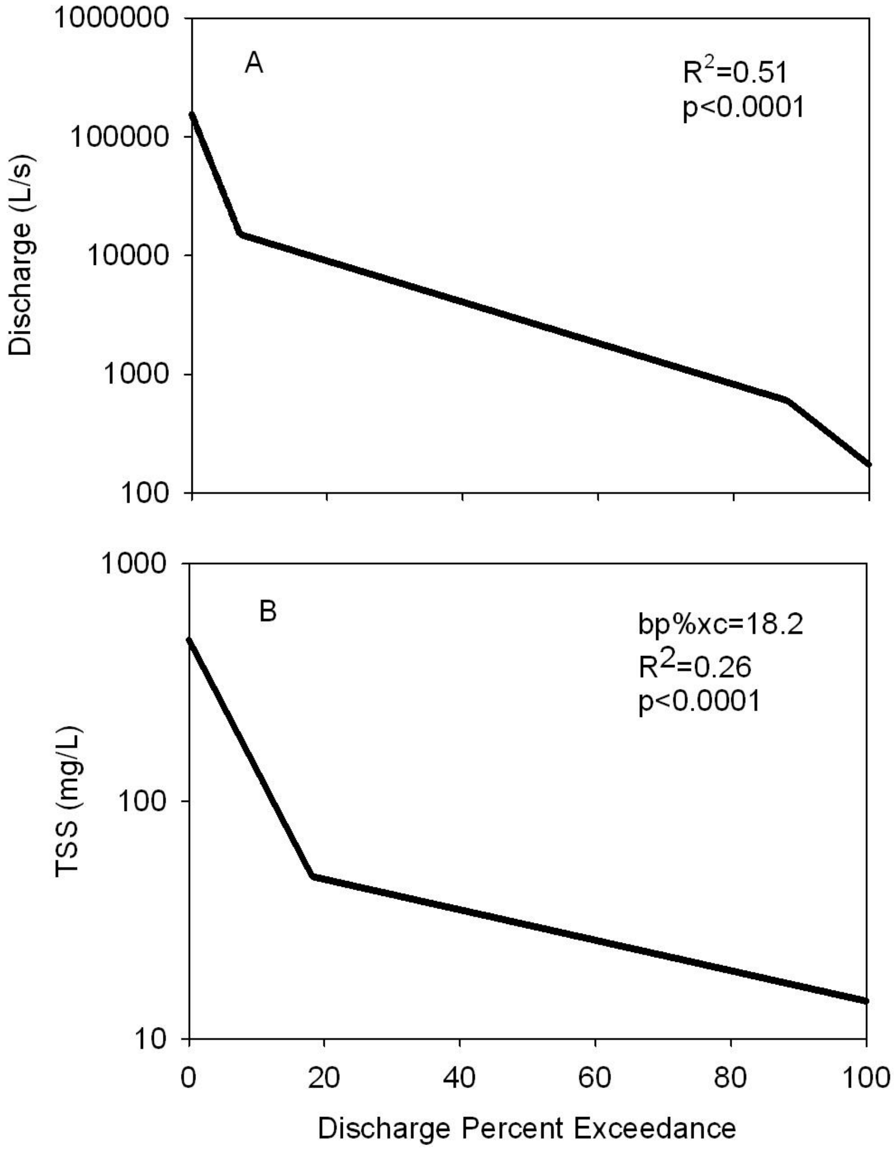


Figure 2.2 A 3-segment linear piecewise regression of the flow duration curves of log transformed discharge rates of all 23 sites (A) and a 2-segment piecewise linear regression of the paired discharge percent exceedance and log transformed TSS concentrations for all 23 sites (B). Two significant breaking points were present on the mean flow duration curve where extreme low discharge and high discharge events were exponentially rarer (A). The TSS loading rate significantly changed slopes at discharge rates exceeded less than 18.2% of days (B).

The bp%xc is the breakpoint on discharge exceedence value where one relationship transitions to another.

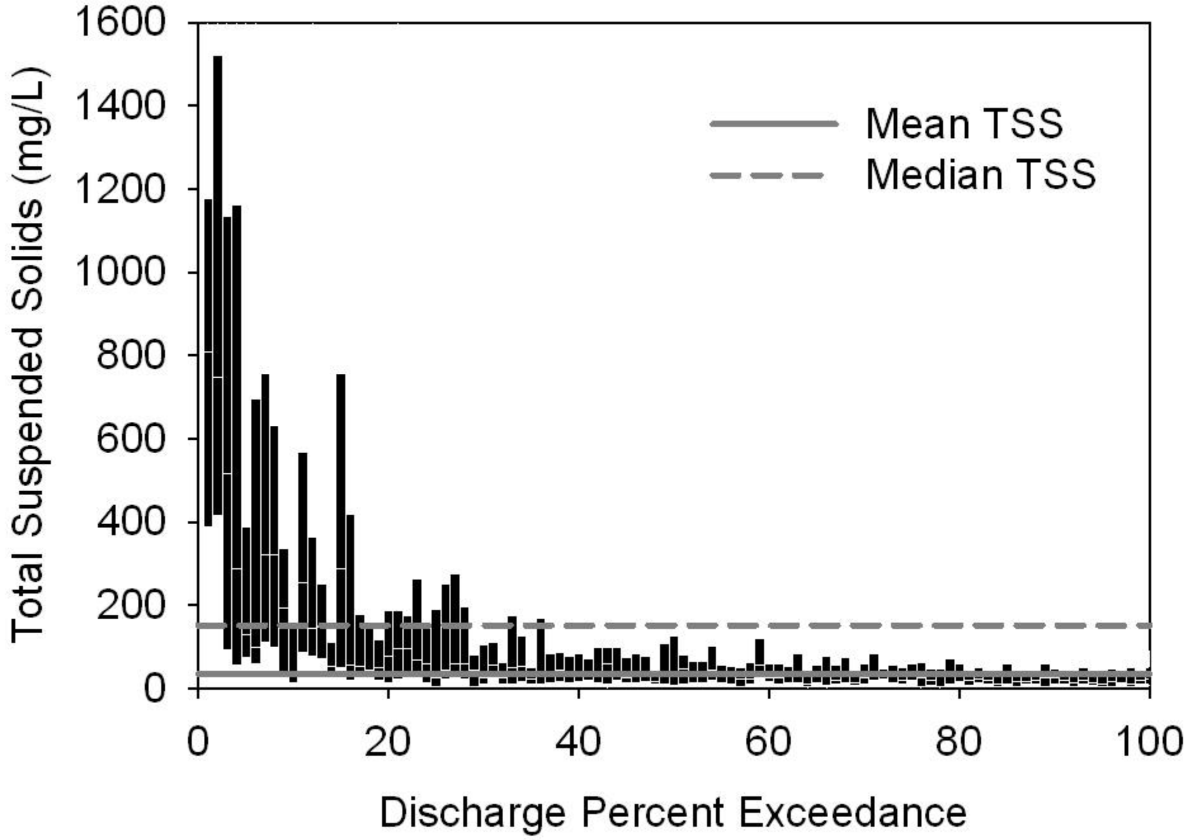


Figure 2.3 Boxplot of TSS concentration for all sites combined at paired discharge percent exceedance values calculated along a flow duration curve. Overall median TSS concentration (solid line) was nearer than the overall mean TSS concentration (dashed line) to the actual TSS concentration approximately 75% of days.

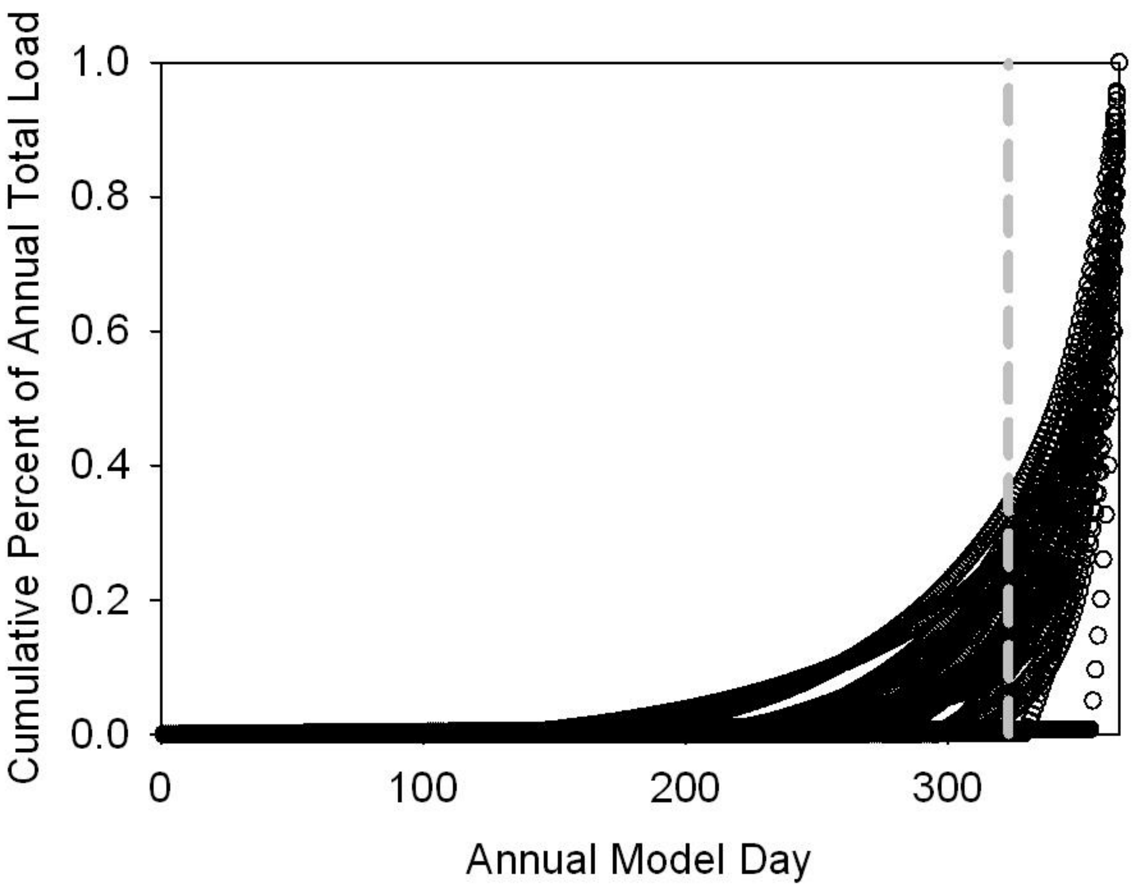


Figure 2.4 Total suspended solids load represented as the cumulative percent of the total annual load contributed during each model day. A breaking point at day 323 (at dashed line) represented a significant change in slope of the regression line. The percent of the annual total suspended solids load contributed after this day was estimated to be 88% of the total annual load. In other words, 88% of the total modeled annual TSS load occurred during the 11% of the days with the greatest discharge.

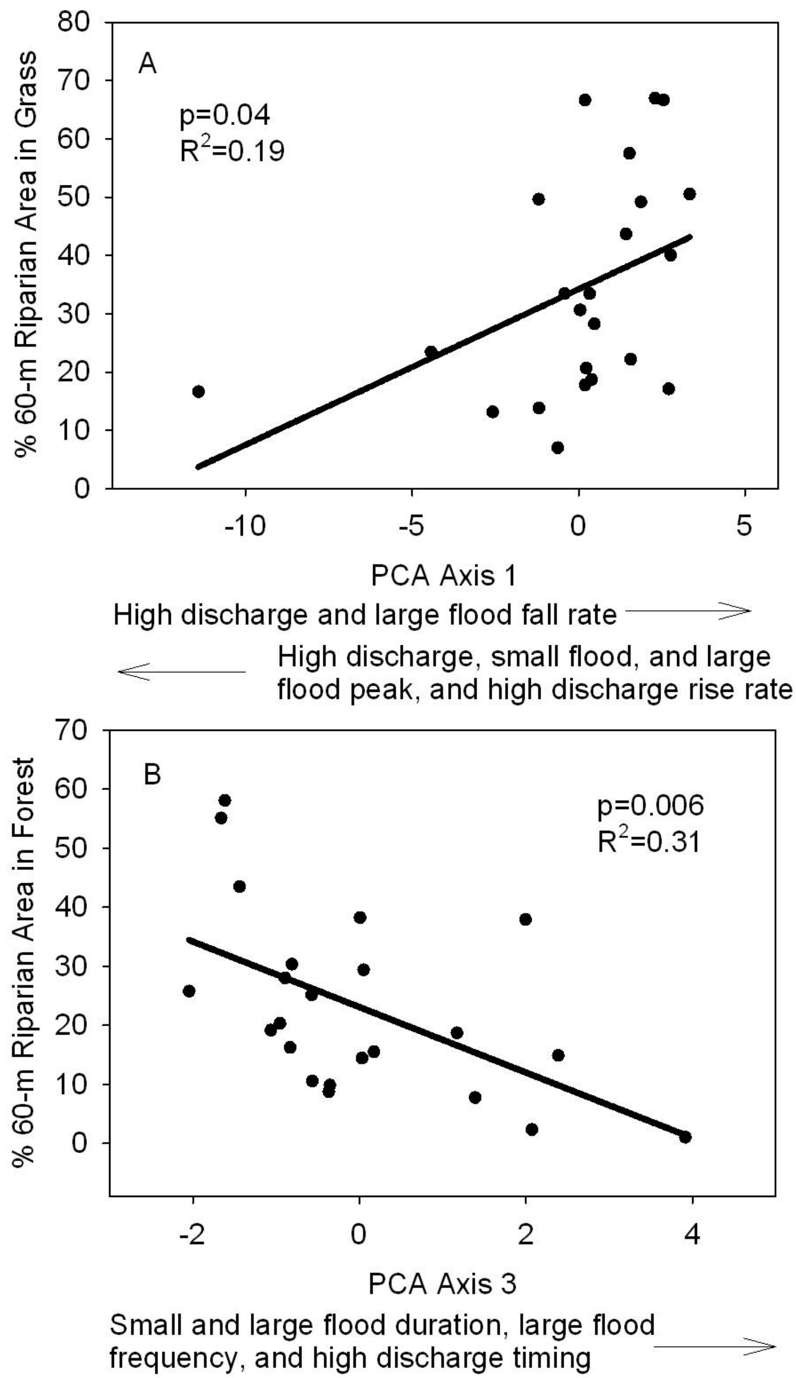
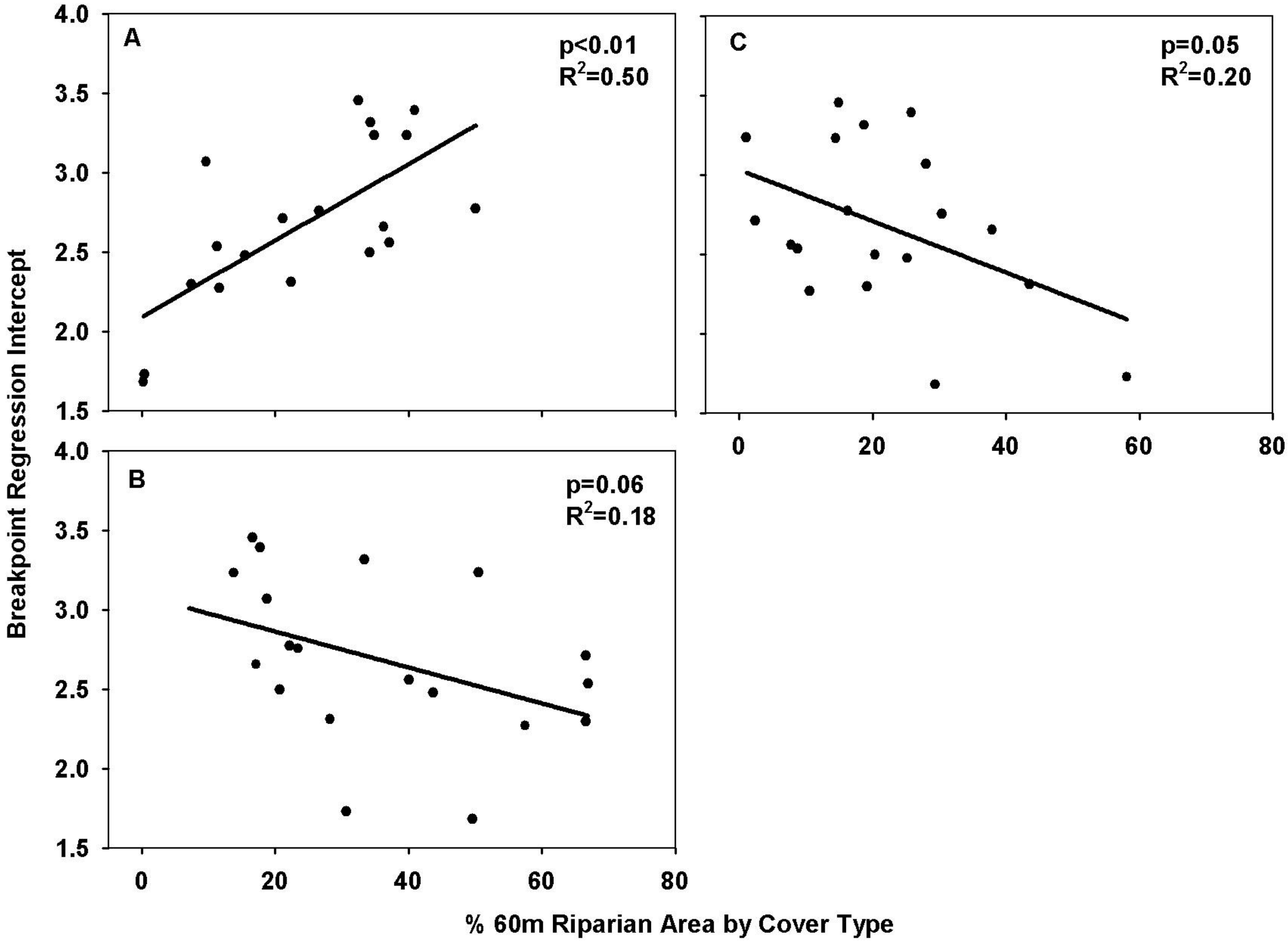


Figure 2.5 The proportions of grassland (both grassland/herbaceous and pasture/hay) within the 30-m and 60-m riparian areas were positively correlated to principal components axis 1 site scores (A) and the proportions of forest within each 30-m and 60-m riparian area were negatively correlated to the site scores from the third principal components axis (B).



A
p<0.01
R2=0.50
C
p=0.05
R2=0.20
B
p=0.06
R2=0.18
Breakpoint Regression Intercept
4.0
3.5
3.0
2.5
2.0
1.5
0
20
40
60
80
% 60m Riparian Area by Cover Type

Figure 2.6 Regression intercepts were positively correlated to the percentages of cropland (A) within the 60-m riparian area and were negatively correlated to the percentages of grassland (B) and forest (C) within the 60-m riparian area. The breakpoint regression intercepts indicate the TSS load rate during high discharge days.

Table 2.1 River names, USGS gaging station numbers, and GPS coordinates (NAD 1983) of our study sites.

River	USGS gage	Longitude	Latitude
Nodaway River	06817700	-95.070	40.203
Platte River (MO)	06821190	-94.727	39.401
Republican River	06853500	-97.933	39.993
Smoky Hill River	06864500	-98.234	38.727
NF Solomon River	06872500	-98.692	39.555
Chapman Creek	06878000	-97.040	39.031
Little Blue River	06884025	-97.005	39.980
Soldier Creek	06889500	-95.725	39.099
Blue River	06893500	-94.559	38.957
Grand River	06902000	-93.274	39.640
Chariton River	06905500	-92.791	39.540
Marais des Cygnes	06916600	-94.613	38.219
Little Osage River	06917000	-94.704	38.009
Sac River	06918440	-93.685	37.443
Pomme de Terre River	06921070	-93.370	37.683
Niangua River	06923250	-92.924	37.684
Little Arkansas River	07143665	-97.592	38.112
SF Ninnescah River	07145200	-97.853	37.562
Whitewater River	07147070	-97.015	37.796
Medicine Lodge River	07149000	-98.471	37.039

Otter Creek	07167500	-96.224	37.708
Caney River	07172000	-96.317	37.004
Elk River	07189000	-94.587	36.632

Table 2.2 The possible range of discharge percent exceedance was 0-100, however our paired samples did not cover the entire range of possible discharge rates. Most sites had at least one sample collected at flows near both the minimum discharge and maximum discharge rates. Generally, when TSS sample sizes were large I had paired samples closer to the possible 0-100 extreme discharge rates.

USGS gage	Minimum of Range	Maximum of Range	*N*
06817700	0.03	98.24	72
06821190	1.36	99.51	49
06853500	0.17	98.88	110
06864500	0.11	99.57	110
06872500	1.15	99.36	107
06878000	0.81	99.72	110
06884025	0.45	99.21	110
06889500	0.66	99.72	113
06893500	0.70	97.08	35
06902000	1.87	99.89	110
06905500	0.22	99.36	76
06916600	0.91	99.79	55
06917000	0.11	98.27	120
06918440	0.59	73.93	14
06921070	2.31	99.54	88
06923250	0.82	98.88	30
07143665	1.34	99.90	112

07145200	0.46	98.62	112
07147070	0.21	99.69	113
07149000	0.22	99.02	112
07167500	0.80	98.45	111
07172000	0.69	96.62	108
07189000	0.63	99.93	205

Table 2.3 Total suspended solids (TSS) median loads for each study site and results of break point regression analyses of log transformed concentrations.

USGS gage	Overall TSS median (mg/L)	TSS IQR (mg/L)	BfM TSS	Bp%xc	bpR	bpI	Discharge (L/s)	Bp p-value	Regression p-value	Regression R^2 (%)
06817700	94	189.25	94	[a]	[a]	[a]	[a]	0.0681	<0.0001	66
06821190	134	155.75	134	53	-0.023	3.233	14,385	0.0308	<0.0001	49
06853500	34	67.50	34	3	-0.448	3.235	36,529	0.0009	<0.0001	45
06864500	43	98.50	42	41	-0.029	2.711	2,520	<0.0001	<0.0001	53
06872500	50	104.75	50	31	-0.030	2.560	2,350	0.0011	<0.0001	28
06878000	65	102.50	65	29	-0.037	2.657	1,189	<0.0001	<0.0001	30
06884025	65.5	230.00	65.5	24	-0.054	3.315	10,137	<0.0001	<0.0001	56
06889500	36	50.50	36	18	-0.104	3.392	3,681	<0.0001	<0.0001	62
06893500	222	732.25	67.5	62	-0.025	3.068	1,416	<0.0001	<0.0001	67
06902000	89	239.00	89	43	-0.030	3.455	46,440	0.0211	<0.0001	70
06905500	123.5	221.25	123.5	[a]	[a]	[a]	[a]	0.0843	<0.0001	60
06916600	54	110.75	48	39	-0.024	2.757	31,149	0.0009	<0.0001	61

06917000	27.5	37.00	27	37	-0.026	2.312	2,209	0.0001	<0.0001	42
06918440	29	25.75	29	[b]	[b]	[b]	[b]	[b]	0.2879	[b]
06921070	10.5	15.01	10	26	-0.038	1.729	6,485	<0.0001	<0.0001	25
06923250	25.5	26.00	25.5	[b]	[b]	[b]	[b]	[b]	0.2929	[b]
07143665	53	100.50	46.5	54	-0.028	2.773	481	<0.0001	<0.0001	51
07145200	42	46.50	42	26	-0.028	2.271	5,720	<0.0001	<0.0001	22
07147070	39	49.00	36.5	46	-0.030	2.497	1,246	<0.0001	<0.0001	51
07149000	43.5	50.50	42.5	17	-0.038	2.536	6,343	0.0013	<0.0001	32
07167500	17	14.50	17	15	-0.087	2.477	2,633	<0.0001	<0.0001	42
07172000	16	13.25	16	19	-0.056	2.298	9,769	<0.0001	<0.0001	45
07189000	5	3.39	4	30	-0.042	1.681	20,275	<0.0001	<0.0001	37

Data columns represent median load of TSS of all measurements at each station, interquartile range (IQR), and median TSS load during baseflow (BfM). Regression columns are the results of the $\log_{10}$ transformed TSS as a function of %xc. Columns represent the break point for discharge percent exceedance (bp%xc), slope of regression line below bp%xc (bpR), intercept of regression line below bp%xc (bpI), mean daily discharge value for corresponding bp%xc, p-value of the break point, and the p-value of the regression.

[a] There was no significant break point at a significance level of $p<0.05$. In these cases a single line model was best (stations 6817700 and 6905500).

[b] There was no significant regression line at a significance level of $p<0.05$ (stations 6918440 and 6923250).

Table 2.4 Environmental Flow Components (EFC) output from the IHA software and their loadings associated with the first three principal components axes. The proportion of the variance explained by each axis is shown in parenthesis. High flows were defined as discharge rates that were exceeded on fewer than 25% of days between the years of 1990-2009.

EFC parameter	PC1 (43.1%)	PC2 (14%)	PC3 (10.3%)
Extreme low peak	-0.246	0.085	0.218
Extreme low duration	0.074	**0.415**	-0.078
Extreme low timing	-0.167	-0.072	-0.263
Extreme low frequency	-0.027	**-0.484**	0.002
High flow peak	**-0.315**	0.033	0.139
High flow duration	0.026	0.292	-0.131
High flow timing	0.119	-0.040	**0.342**
High flow frequency	-0.075	**-0.446**	-0.253
High flow rise rate	**-0.315**	0.018	0.121
High flow fall rate	**0.310**	0.001	-0.124
Small flood peak	**-0.316**	0.018	0.132
Small flood duration	0.146	0.213	**0.395**
Small flood timing	0.061	-0.186	0.217
Small flood frequency	-0.104	**0.314**	-0.146
Small flood rise rate	-0.288	-0.052	0.019
Small flood fall rate	0.312	0.053	-0.099
Large flood peak	**-0.312**	0.087	0.081
Large flood duration	0.116	0.066	**0.442**

Large flood timing	-0.110	0.230	-0.160
Large flood frequency	0.077	-0.052	**0.380**
Large flood rise rate	-0.230	0.200	-0.056
Large flood fall rate	**0.305**	-0.052	-0.047

Table 2.5 The proportions of crop, grass, and forest within each spatial scale. Crop, grass, and forest were generally the land use/ land cover classes most significantly correlated to breakpoint regression coefficients and hydrologic parameters.

USGS gage	Watershed area (km²)	Watershed (%)			60-m Riparian Area (%)			30-m Riparian Area (%)		
		Crop	Grass	Forest	Crop	Grass	Forest	Crop	Grass	Forest
06817700	1933.62	50.54	34.78	8.18	45.93	6.99	15.52	45.93	6.99	15.52
06821190	6228.14	44.38	35.99	10.33	39.71	13.81	14.45	39.71	13.81	14.45
06853500	57947.52	51.21	43.96	0.30	34.83	50.52	1.04	34.83	50.52	1.04
06864500	24494.90	49.38	45.29	0.27	21.10	66.63	2.35	21.10	66.63	2.35
06872500	6007.83	49.12	44.45	0.67	37.16	40.04	7.76	37.16	40.04	7.76
06878000	797.26	33.19	57.03	4.87	36.29	17.12	37.92	36.29	17.12	37.92
06884025	7223.63	66.98	24.29	2.50	34.33	33.42	18.72	34.33	33.42	18.72
06889500	775.13	18.75	65.65	9.25	40.93	17.77	25.79	40.93	17.77	25.79
06893500	479.52	12.78	24.67	9.27	9.63	18.72	27.99	9.63	18.72	27.99
06902000	3684.95	23.30	51.69	16.13	32.46	16.60	14.89	32.46	16.60	14.89
06905500	1370.37	21.03	35.99	35.98	48.81	13.15	9.89	48.81	13.15	9.88
06916600	8460.03	20.38	58.99	11.65	26.59	23.41	30.35	26.60	23.41	30.35

06917000	817.75	16.67	58.10	19.72	22.39	28.24	43.50	22.39	28.24	43.50
06918440	674.06	0.67	68.18	22.45	1.79	49.18	38.26	1.79	49.18	38.26
06921070	712.25	0.62	56.44	37.03	0.40	30.64	58.09	0.40	30.64	58.09
06923250	877.94	0.38	45.73	47.38	0.20	33.45	55.11	0.20	33.45	55.11
07143665	1916.54	63.22	26.22	2.88	50.09	22.18	16.25	50.09	22.18	16.25
07145200	1552.86	49.29	42.56	1.42	11.61	57.47	10.56	11.61	57.47	10.56
07147070	1098.20	47.50	41.74	3.73	34.18	20.66	20.33	34.18	20.66	20.33
07149000	2286.38	22.25	70.46	2.05	11.26	66.93	8.76	11.26	66.93	8.76
07167500	321.03	3.22	85.99	6.01	15.45	43.67	25.17	15.45	43.67	25.17
07172000	1116.05	3.87	83.07	5.39	7.45	66.61	19.19	7.44	66.61	19.19
07189000	2202.08	0.71	40.85	50.64	0.23	49.63	29.40	0.23	49.63	29.40

SUMMARY AND CONCLUSIONS

Stream ecosystems of North America are naturally highly variable within and among years due to frequent disturbances such as floods, but anthropogenic impacts have changed the dynamics of these floods. This thesis examined the natural variability of pristine tallgrass prairie streams and the impacts land use/ land cover change has had on the frequency and severity of floods and how that interaction has lead to greater loads of suspended solids in streams. I also documented water quality and stream metabolism in a mesic tallgrass prairie, showing both temporal and spatial variability. These are essential to both maintaining biotic integrity in streams as well as establishing reference conditions that predominated in much of North America prior to European settlement.

The first chapter examined the natural variability in nutrient and suspended solids concentrations and primary production and biomass in 6 southwest Missouri ephemeral headwater tallgrass prairie streams within the Osage Plains ecoregion. Ephemeral headwater prairie streams within the Osage Plains ecoregion have not been well studied and much documentation about the natural variability of streams in this region does not exist. I described the natural ecosystem characteristics of these 6 streams and found that large fluxes in TSS and nutrient transport in all six study streams were likely due to substrate dominated by fine sediment and lack of an armored layer in these upland ephemeral prairie streams, which makes these streams highly vulnerable to erosion (Ried and Laronne 1995). Relatively low nutrient concentrations in our study streams could be due to low inputs or high nutrient retention once the nutrients entered the watersheds (O'Brien et al. 2007). Downstream water quality can be heavily influenced by land use and land cover around first-order streams, so protection of these upland headwater streams is crucial for downstream water quality (Dodds and Oakes 2008, Alexander et al. 2007, Dodds and Oakes 2006).

Baseflow TSS and nutrient concentrations of the Osage Plains streams compare to the concentrations reported in other tallgrass prairie streams within the Great Plains such as Kings Creek (O'Brien et al. 2007, Kemp and Dodds 2001), Shane Creek, and Natalie's Creek (O'Brien et al. 2007). Also, GPP, CR, and NEP compare to the rates reported in Kings Creek-K2A and Natalie's Creek (O'Brien et al. 2007). Though the western Osage Plains prairie region contrasts geologically to other Great Plains regions, headwater prairie streams in these areas may function similarly. Chemical and biological properties in these streams were surprisingly variable even though they were relatively close spatially. This study suggests that good water quality and moderate heterotrophic condition, with greater GPP resulting from an open canopy, are common conditions of tallgrass prairie streams.

The second chapter examined the loading rates of suspended solids in 23 Great Plains streams and I concluded that because biological integrity of chronic exposure is more likely to be influenced by the condition occurring during the majority of the time, median rather than mean TSS concentrations would better represent stream biological integrity. This is because rare high discharge events have a disproportionate effect on the mean TSS concentration. The mean TSS concentration in our study streams was on average 5 times higher than the median concentration and better estimates the total annual load of suspended solids transported downstream. Mean TSS concentration could be a more appropriate variable than the overall median when investigating the deposition rate in a reservoir or wetland.

Banner et al. (2009) investigated the loadings of phosphorus and reported nearly identical results as ours. Mobilization of suspended solids could possibly have lead to concurrent transportation of phosphorus that was absorbed on solid particles. Therefore, management of TSS loads could have equal improvements in phosphorus loads in these Great Plains streams.

Many other studies support our relationships that greater runoff rates and unbuffered riparian edges can have multiplicative affects on the TSS loading rate. I were unable to say for sure whether the 60-m riparian scale or the 30-m riparian scale was particularly better than the other because of the strong autocorrelation between the two riparian scales, but our results do show strong evidence of the importance of riparian buffers and provided some evidence of how land use/ land cover interacts with pollutant loads by altering hydrologic regimes.

Future research needs to assess how resistant or delicate ecosystem functions are, especially to changes in land use/land cover. Also, future research needs to assess the effectiveness of land restoration on stream ecological integrity and the return time of natural ecosystem functions after restoration projects.

Combining results from the two chapters provides evidence for the importance of land management of upland watersheds and riparian edges and the potential benefits that such management could have on stream ecological integrity. More aggressive management for controlling pollutant loading could be necessary if climate change predictions are correct. Management actions that increase hydrologic retention and restore natural hydrologic regimes may be the best approach to combating the changes in pollutant loading rates due to climate change and anthropogenic alteration of landscapes.

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Appendix A - Supplemental material to Chapter 1

Table A. 1 Inorganic (ISS), organic (OSS), and total (TSS) suspended solids concentrations, and nitrate (NO_3^-), ammonium (NH_4^+), soluble reactive phosphorus (SRP), total nitrogen (TN), and total phosphorus (TP) concentrations during baseflow samples. Missing months and site samples are due to stream drying.

Stream	Sampling Date	ISS (mg L^{-1})	OSS (mg L^{-1})	TSS (mg L^{-1})	NO_3^- (µg L^{-1})	NH_4^+ (µg L^{-1})	SRP (µg L^{-1})	TN (µg L^{-1})	TP (µg L^{-1})
1	3/13/2009				91	25	9	409	25
	4/24/2009	6	3	9	21	42	13	374	78
	5/28/2009	10	2	11	4	8	9	333	25
	6/24/2009	10	6	16	3	97	24	459	36
	10/10/2009	9	2	11	79	21	11	501	44
	12/15/2009	28	4	32	36	13	4	221	19
	2/28/2010	23	6	29	17	8	-a	252	245
	4/5/2010	11	3	14	17	9	-a	268	32
2	3/13/2009				7	127	10	364	44

	4/24/2009	2	2	4	2	38	11	527	90
	5/28/2009	6	2	8	5	19	9	524	44
	6/24/2009	4	19	23	3	228	41	883	157
	10/10/2009	4	2	5	5	13	7	328	30
	12/15/2009								
	2/28/2010	2	2	4	6	20	1	502	59
	4/5/2010	6	6	12	7	12	-a	480	26
3	3/13/2009				7	19	5	167	9
	4/24/2009	1	1	2	3	27	7	434	159
	5/28/2009	4	1	5	3	8	5	150	12
	6/24/2009	8	3	11	2	5	11	169	19
	10/10/2009	2	1	3	37	5	11	184	9
	12/15/2009	2	2	4	36	41	-a	288	24
	2/28/2010	3	2	4	12	16	-a	344	18
	4/5/2010	0	0	0	12	7	-a	167	20
4	3/13/2009				5	28	17	114	8

	4/24/2009	3	2	5	3	44	5	607	11
	5/28/2009	3	1	3	3	15	7	269	12
	6/24/2009	1	3	4	10	44	12	209	11
	10/10/2009	3	1	3	5	10	7	218	14
	12/15/2009								
	2/28/2010	3	1	4	8	10	-a	254	17
	4/5/2010	2	1	3	6	18	-a	392	15
5	3/13/2009				5	225	10	279	11
	4/24/2009	3	3	6	2	24	10	277	17
	5/28/2009	2	0	2	2	10	3	186	14
	6/24/2009	0	2	2	5	46	7	335	13
	10/10/2009	3	1	4	6	28	8	110	13
	12/15/2009	18	7	25	60	50	1	272	21
	2/28/2010	3	2	5	6	21	-a	227	14
	4/5/2010	3	2	5	9	10	8	207	34
6	3/13/2009				4	158	7	294	14

4/24/2009	1	1	2	8	49	7	267	31
5/28/2009	2	0	2	3	17	4	266	16
6/24/2009	0	2	2				282	7
10/10/2009	5	2	6	7	14	7	309	24
12/15/2009	12	3	15	22	22	-a	143	14
2/28/2010	1	1	2	6	24	-a	252	9
4/5/2010	1	1	2	7	20	-a	329	23

-[a] Concentrations were below detectable range of 1 $\mu g L^{-1}$.

Table A. 2 Inorganic (ISS), organic (OSS), and total (TSS) suspended solids concentrations, and nitrate (NO_3^-), ammonium (NH_4^+), and soluble reactive phosphorus (SRP) concentrations during highflow stages.

Stream	Sampling Date	Stage	ISS ($mg\ L^{-1}$)	OSS ($mg\ L^{-1}$)	TSS ($mg\ L^{-1}$)	NO_3^- ($\mu g\ L^{-1}$)	NH_4^+ ($\mu g\ L^{-1}$)	SRP ($\mu g\ L^{-1}$)
1	10/10/2009	1	253	18	272	93	-[a]	24
		2	206	25	232	103	6	30
	5/19/2010	1	4	4	9	8	5	283
		2	6	5	11	172	13	13
		3	38	32	70	161	74	-[a]
		4	34	16	50	131	55	9
	5/22/2010	1	38	10	48	5	6	199
		2	2341	78	2418	105	40	125
		3	2894	85	2979	160	70	9
		4	382	40	422	135	73	173
2	10/10/2009	1	20	4	24	5	77	81
		2	9	6	15	303	2	40

		3	7	3	10	50	56	56
	5/19/2010	1	71	25	96	7	102	48
		2	35	13	48	42	42	56
		3	25	10	35	52	36	111
	5/22/2010	1	105	71	176	5	68	30
		2	7	6	13	38	21	-[a]
		3	4	4	8	48	11	20
3	10/10/2009	1	14	4	18	12	7	21
		2	8	2	10	32	22	54
	5/19/2010	1	30	14	45	82	59	17
		2	6	5	11	107	87	50
	5/22/2010	1	17	6	22	81	62	17
		2	28	10	37	108	83	5
4	10/10/2009	1	118	36	154			
	5/19/2010	2	6	7	14	74	28	6
		3	54	30	84	96	39	-[a]

	5/22/2010	1	30	12	41	78	30	7
		2	31	12	43	100	37	1
5	10/10/2009	1	12	7	19	17	4	49
		2	21	4	25	33	21	24
	5/19/2010	1	374	37	411	26	57	7
		2	955	37	992	181	379	105
	5/22/2010	1	18	8	27	22	42	-[a]
		2	13	10	23	179	381	72
6	10/10/2009	1	18	4	22	8	10	27
		2	11	3	14	29	9	27
		3	12	4	16	43	17	27
		4	17	2	19	24	19	26
	5/19/2010	3	1859	57	1916	26	59	15
		4	89	19	108	65	85	20
	5/22/2010	2	3	6	9	25	49	-[a]
		3	5	4	9	68	69	-[a]

-[a] Concentrations were below detectable range of 1 μgL^{-1}.

Table A. 3 Benthic and water column chlorophyll *a* measurements. Missing site samples are due to stream drying.

Stream	Date	Benthic chl *a* ($\mu g\ cm^{-2}$)	Water column chl *a* ($\mu g\ L^{-1}$)
1	3/13/2009	0.606	2.967
	10/10/2009	2.518	
	5/19/2010	1.287	0.000
	5/22/2010	0.377	0.000
2	3/13/2009	0.734	0.000
	10/10/2009		
	5/19/2010	0.759	2.967
	5/22/2010	1.055	4.450
3	3/13/2009	0.853	7.417
	10/10/2009	2.987	
	5/19/2010	1.261	0.000
	5/22/2010	0.912	10.383
4	3/13/2009	19.796	1.483
	10/10/2009		
	5/19/2010	0.679	0.000
	5/22/2010	0.888	0.000
5	3/13/2009	0.418	2.967
	10/10/2009	0.869	
	5/19/2010	1.332	17.800

	5/22/2010	1.262	0.000
6	3/13/2009	0.794	7.417
	10/10/2009	3.516	
	5/19/2010	1.387	0.000
	5/22/2010	0.922	0.000

Table A. 4 Community respiration (CR), gross primary production (GPP), and net ecosystem productivity (NEP) rates by stream and date. CR rates are negative because oxygen is consumed and GPP rates are positive because oxygen is produced. Negative NEP rates indicate streams are net heterotrophic and positive NEP rates indicate streams are net autotrophic.

Stream	Sampling Date	CR (g O_2 m^{-2} d^{-1})	GPP (g O_2 m^{-2} d^{-1})	NEP (g O_2 m^{-2} d^{-1})
1	3/13/2009	-6.21	1.20	-5.01
	4/24/2009	-5.92	5.15	-0.78
	5/28/2009	-2.51	2.59	+0.08
	5/20/2010	-2.39	1.58	-0.81
2	3/13/2009	-2.08	0.72	-1.35
	4/24/2009			
	5/28/2009	-14.82	0.10	-14.73
	5/20/2010	-15.85	2.41	-13.44
3	3/13/2009	-0.83	0.35	-0.48
	4/24/2009	-1.35	0.37	-0.98
	5/28/2009	-1.98	0.26	-1.72
	5/20/2010	-1.15	0.29	-0.85
4	3/13/2009	-0.51	0.24	-0.27
	4/24/2009	-0.23	0.09	-0.13
	5/28/2009			
	5/20/2010	-0.41	0.04	-0.37
*5	3/13/2009			
	4/24/2009			

	5/28/2009	-2.90	0.43	-2.47
	5/20/2010	-4.07	0.27	-3.80
6	3/13/2009	-0.81	0.43	-0.38
	4/24/2009	-3.04	0.58	-2.46
	5/28/2009	-1.85	0.37	-1.48
	5/20/2010	-1.18	0.15	-1.03

*DO measured on 3 occasions but 1 day was lost due to YSI sonde malfunctioning.