McGoodwin Williams & Yates
Engineering Confidence

December 17, 2009

Mr. Rene Langston, Executive Director
Springdale Water Utilities
Post Office Box 769
Springdale, Arkansas 72765

Mr. Tom S. McAlister, Manager
Rogers Water Utilities
Post Office Box 338
Rogers, Arkansas 72757

Re: Osage and Spring Creeks Water Quality and Ecological Assessment
Cities of Springdale and Rogers, Arkansas
MWY Project No. SP&R01

Dear Mr. Langston and Mr. McAlister:

As you know, the above study has been concluded and a report setting forth our findings has been completed in accordance with the terms of our contract.

Accordingly, I am enclosing three copies to each of you for your files. We would be happy to furnish you additional copies as you need them.

We appreciate very much the opportunity to be of service to the cities in this matter. In addition, we are available for consultation as you have the need.

Respectfully submitted,

L. Carl Yates, P. E.
Chief Executive Officer

Marty D. Matlock, Ph. D.
University of Arkansas
Fayetteville, Arkansas

Enclosure

909 Rolling Hills Drive • Fayetteville, AR 72703 P 479-443-3404 F 479-443-4340 • WWW.MWYUSA.COM

WATER QUALITY AND ECOLOGICAL ASSESSMENT
Osage and Spring Creeks

PROJECT TEAM

Marty D. Matlock, Ph.D., P.E., C.S.E.
Area Director and Professor
Center for Agricultural and Rural Sustainability
Department of Biological and Agricultural Engineering
University of Arkansas Division of Agriculture

Brian E. Haggard, Ph.D.
Director and Associate Professor
Arkansas Water Resources Center
Department of Biological and Agricultural Engineering
University of Arkansas Division of Agriculture

Arthur V. Brown, Ph.D.
Associate Professor
Department of Biological Sciences
J. William Fulbright College of Arts and Sciences

Eric Cummings
Program Associate
Department of Biological and Agricultural Engineering
University of Arkansas Division of Agriculture

L. Carl Yates, P.E., BCEE, FACEC
Chief Executive Officer
McGoodwin, Williams and Yates, Inc.

David G. Parker, Ph.D., P.E.
Senior Environmental Engineer
McGoodwin, Williams and Yates, Inc.

Center for Agricultural and Rural Sustainability

ARKANSAS WATER RESOURCES CENTER

UofA
UNIVERSITY OF ARKANSAS
DIVISION OF AGRICULTURE

McGoodwin Williams & Yates
Fayetteville, Arkansas

Prepared for

Springdale Water Utilities and Rogers Water Utilities

Water Quality and Ecological Assessment of Osage and Spring Creeks in the Illinois River Basin, Arkansas

Final Report

McGoodwin, Williams, and Yates

Prepared by:

Center for Agricultural and Rural Sustainability

University of Arkansas Division of Agriculture

Arkansas Cooperative Extension Service

Questions concerning this report should be directed to:

Marty D. Matlock, Ph.D., P.E., C.S.E.

233 Engineering Hall

Fayetteville, AR 72701

mmatlock@uark.edu

479/575-2849

December , 2009

EXECUTIVE SUMMARY

The cities of Springdale and Rogers, Arkansas contracted with McGoodwin, Williams and Yates , the University of Arkansas Center for Agricultural and Rural Sustainability and Arkansas Water Resources Center to conduct a study evaluating water quality and assessing biological conditions in Osage and Spring Creeks in Northwest Arkansas. More specifically, the team collected and analyzed water quality, benthic macroinvertebrate, fish, and periphyton samples from Osage and Spring Creeks in Northwest Arkansas to evaluate the status of attainment of the aquatic life designated use of the streams under Arkansas Pollution Control and Ecology Commission's Arkansas Department of Environmental Quality Regulation 2 (ADEQ Reg. 2). This project was designed to evaluate three tiers of impact: 1) above and below wastewater treatment plants (WWTP) of the Cities of Rogers and Springdale, Arkansas; 2) sites below wastewater treatment plants compared to reference conditions; and 3) gradients across stream reaches from upstream to downstream.

The reaches that were sampled were located in the Illinois River watershed and included five sites on Osage Creek (Reaches 030, 930), three sites on Spring Creek (Reach 931), and two reference sites (Chambers Springs and Little Osage Creek). Sampling began in the Critical Season of 2007 and continued through the Critical Season of 2009. Sites were analyzed for water quality, habitat, and biotic condition using scientifically approved methods, documented through a Quality Assurance Project Plan.

Results of the water quality assessment showed no violations of ADEQ Reg. 2 criteria, with the exception of the site upstream from the Springdale WWTP for dissolved oxygen during Critical Season 1. All other observations across all other sites met the criteria for designated use for water quality during all observation periods. The Tier 1 assessment determined that while upstream and downstream sites differed, discharge of wastewater from the Rogers WWTP to Osage Creek or the Springdale WWTP to Spring Creek resulted in no violation of water quality standards according to the criteria of ADEQ Reg. 2; data suggested that the site below the Springdale WWTP was less impacted than the site above the discharge. The Tier 2 assessment showed overall differences of sites downstream of the WWTPs when compared to the reference sites but no clear indication that nutrients caused these differences. The Tier 3 assessment of the reach continuum from upstream to downstream showed that the impacts of the WWTPs in Osage and Spring Creeks across all metrics were not significant, and any decline in metrics observed was fully or close to fully recovered by the lower site (OSG5). Water column phosphorus concentration did not cause biotic impairment, and the stream approached reference conditions by the downstream site (OSG5).

In conclusion, based upon the analyses performed during this project water quality in Spring and Osage Creeks met or exceeded designated use criteria for the period measured. Biological data indicated that stream ecosystem processes were not impaired by phosphorus, and biotic communities were not degraded by phosphorus. In fact, by the lower site (OSG5) biotic communities were similar to the reference sites. Phosphorus from the Rogers and Springdale wastewater treatment plants was not shown to cause impairment in water quality or biotic community function.

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Section 1: Introduction

1.1 Project Background

The headwaters of the Illinois River originate in northwest Arkansas and flow southwest into Oklahoma. The headwaters are influenced by agricultural run-off as well as effluent from the Cities of Fayetteville, Springdale, Rogers, Siloam Springs and Prairie Grove, Arkansas (NPDES permits number AR0020010, AR0022063, AR0020273, AR0043397, AR0022098, respectively). The Cities of Rogers and Springdale, Arkansas (Cities) discharge treated wastewater from publicly owned treatment works (POTWs) into Osage and Spring Creeks, respectively (Figure 1.01).

The Cities contracted with McGoodwin, Williams and Yates (MWY), the University of Arkansas Center for Agricultural and Rural Sustainability, and Arkansas Water Resources Center to collect and analyze water quality, benthic macroinvertebrate, fish, and periphyton samples from Osage and Spring Creeks in Northwest Arkansas to evaluate the status of attainment of the aquatic life designated use of the streams under ADEQ Reg. 2.

1.2 Scope and Objectives

The purpose of this project was to collect water quality and biological data from targeted water bodies in Spring and Osage Creek of the Illinois River watershed in northwest Arkansas in order to assess attainment of the aquatic life use in those stream reaches. This project was designed to evaluate three tiers of impact: 1) above and below wastewater treatment plants (WWTPs) of the Cities of Rogers and Springdale, Arkansas (Cities); 2) sites below WWTPs compared to reference conditions; and 3) gradients across stream reaches from upstream to downstream. The reaches that were sampled in the Illinois River watershed were Osage Creek (reaches 030, 930) and Spring Creek (reach 931) (Figure 1.01). In addition, sampling was performed on two regional reference streams for comparison. Little Osage Creek was selected as a non-point source impacted reference stream and Chambers Springs Creek was selected as a minimally impacted reference stream for this study (Figure 1.01). Samples were collected upstream of the zone of influence and downstream of the mixing zone for Tier 1 analyses. The total number of sampling sites for Tiers 2 and 3 analysis, including those above and below wastewater treatment plants, was 10 (Figure 1.01, Table 1.01). The data collected, in combination with other existing chemical and biological data, were used to assess the status of each reach with regard to ADEQ Reg. 2 criteria for listing in the ADEQ Section 303(d) list of water quality-impaired waters. All data were collected under a Quality Assurance Project Plan (QAPP) reviewed and approved by the Cities, MWY, ADEQ, and USEPA (Appendix A).

1.3 Existing Information and Data

Water quality studies have been conducted at sites throughout the Illinois River basin over the past 50 years; those reports that are relevant to this investigation are summarized in this section. The Ozark Highlands Ecoregion drains from northwest Arkansas to Missouri (White/Kings River), Kansas (Elk River) Oklahoma (Spavinaw Creek and Illinois River), and east to Arkansas (White River and tributaries to the Black River) (ADEQ, 2002). The Ozark Highlands Ecoregion, also referred to as the Ozark Plateau, is a rapidly urbanizing landscape with agricultural and forest land uses. The headwater of three major river basins (Illinois, Grand, and White) originate in this region. The predominant water quality parameter of investigation has been phosphorus, due in part to the sensitivity of headwater streams to nutrient enrichment. Phosphorus has been identified from point and nonpoint sources, though source allocation has been difficult due to P sorption to sediments, resulting in storage-release cycle that ameliorates the peak discharge concentrations and prolongs the elevated in-stream concentrations after the storm discharge abates (USGS, 1998a). In-stream sediment composition determines P sediment storage capacity (Haggard *et al*., 2001).

Sediment has been another contaminant of concern in this region. Urbanization is a major source of increased sediment to streams (USGS, 1999; Dogwiler, 2003; Chaubey *et al*., 2007). The process of land use change, including transition from forest to pasture and from forest to residential and commercial, results in increased landscape loading of phosphorus (Haggard *et al*., 2007). The impact of this rate of urbanization also affects the way streams respond to nutrient enrichment (USEPA, 2004; Chaubey *et al*., 2007). How and when water quality is sampled in streams determines whether these impacts are observed (Haggard *et al*., 2003).

Municipal WWTPs affect water chemistry at the point of discharge as well as whole-reach nutrient retention. The specific mechanisms of TP retention such as sediment sorption, biological uptake, and biotransformations have been investigated by Ekka *et al*. (2006); Haggard *et al*.

(2005); Haggard *et al*. (2001a); Dorioz *et al*. (1998); House and Denison (1997); and Reddy *et al*. (1996). The influence of effluent discharge on nutrient retention is variable, where nutrients are sometimes retained with a stream reach and under other conditions net release occurs. Nutrients, particularly P, are generally retained and stored within the fluvial channel when effluent concentrations are high; however, these stored nutrients are often released from within the fluvial channel when effluent discharge has lower than average concentrations (Haggard, 2000). Effluent discharged do have a significant impact on water quality chemistry, and this effect is often observed several kilometers downstream in the Ozark Highlands Ecoregion (Haggard *et al*., 2000; Haggard *et al*., 2003; Haggard *et al*., 2004). Sediment from Lake Francis, a small reservoir in the lower reach of the Illinois River, was determined under anaerobic sediment conditions to be as high as 15 mg TP m^{-2} day^{-1}, representing more TP load than all the WWTPs combined (Haggard and Soerens, 2006).

Stream biotic response (particularly algal growth) to increased P and nitrogen (N) is complicated by the number of additional variables besides nutrients. These variables include light, grazing, scouring, and temperature (Ludwig *et al*., 2008; Rodriguez and Matlock, 2008). Periphytic communities in streams dominated by agricultural land use in the Ozark Plateaus are composed of species adapted to higher nitrate, P, and dissolved organic carbon concentrations (USGS, 2002). These communities respond to very low levels of P increase then become saturated very quickly, resulting in a shift often to light limitation (Ludwig *et al*., 2008).

Fish community studies have been conducted in this region of Arkansas as far back as 1963, but more recent studies were conducted in the mid-1980s and 1990s, followed by a 2004 USEPA-funded study. A diverse community of fish species live in Ozark Plateau streams relative to other regions. Approximately 175 species (including protected species) are present in the Ozark Plateaus National Water-Quality Assessment (NAWQA) Program study unit; at least 19 of which are endemic to the Ozark Plateau area. Consequently, widespread and extreme degradation of water quality (chemical or aquatic habitat factors) could affect several species found nowhere else in the world. Many of these 175 species are intolerant of habitat or water chemistry degradation (USGS, 1998b). Land use, watershed size, biotic factors (competition, predator-prey interactions, and periphyton abundance), and riparian habitat characteristics have a significant influence on fish communities within the Illinois River (USEPA, 2004). Changes in land use from forestland to agriculture land over time have resulted in an increased relative abundance of stonerollers and members of the sucker family and a decreased relative abundance of members of the sunfish and darter families. Most species of darters and some species of sunfish are intolerant of degraded water chemistry and habitat (USGS, 1998b; USEPA, 2004). A common trait of fish communities of Ozark streams in agricultural basins or downstream from WWTPs is increased relative abundance of stonerollers. Increased periphyton production resulting from more nutrients and sunlight provides a more abundant food source for stonerollers and other grazers, such as southern redbelly dace. Often, darters and sunfish compose a smaller percentage of the fish communities of Ozark streams in agricultural basins than in forested basins. USGS (1998b) and USEPA (2004) demonstrated that several other environmental factors (*e.g.* nutrients, organic carbon, suspended sediment, and DO) caused primarily by land-based discharges frequently result in changes in fish communities.

Figure 1.01 Osage Creek basin with sites denoted by circle points and WWTPs denoted by stars. See Table 1.01 below for definition of abbreviations.

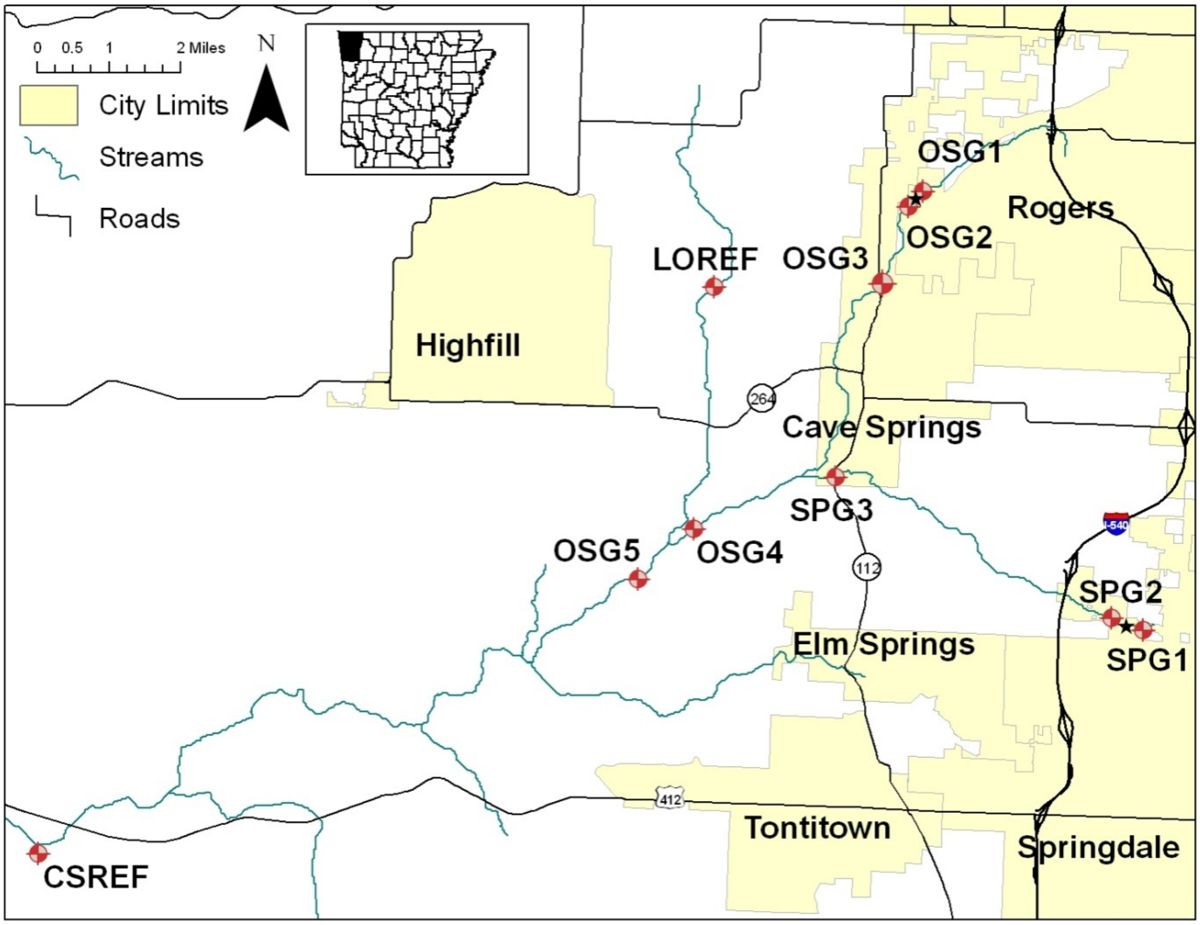

Table 1.01 Descriptions and locations for select sites in the Osage Creek and Illinois River basins.

Location	Abbreviated Identification	Coordinates
Osage Creek, Reach 930, upstream of City of Rogers WWTP	OSG1	Lat: 36°18'8.86"N Lon: 94°12'48.84"W
Osage Creek, Reach 930, downstream of City of Rogers WWTP	OSG2	Lat: 36°17'54.44"N Lon: 94°13'15.22"W
Osage Creek, Reach 930, downstream of City of Rogers WWTP and upstream of Spring Creek confluence	OSG3	Lat: 36°16'56.08"N Lon: 94°13'40.55"W
Spring Creek, Reach 931, upstream of City of Springdale WWTP	SPG1	Lat: 36°12'48.31"N Lon: 94° 9'21.93"W
Spring Creek, Reach 931, downstream of City of Springdale WWTP	SPG2	Lat: 36°12'56.79"N Lon: 94°10'5.38"W
Spring Creek, Reach 931, downstream of City of Springdale WWTP and upstream of Osage Creek confluence	SPG3	Lat: 36°14'38.44"N Lon: 94°14'18.30"W
Osage Creek Reach 030, downstream of Spring Creek confluence and upstream of Little Osage Creek confluence	OSG4	Lat: 36°13'56.40"N Lon: 94°16'21.52"W
Osage Creek Reach 030, downstream of Spring Creek confluence and downstream of Little Osage Creek confluence	OSG5	Lat: 36°13'19.69"N Lon: 94°17'14.11"W
Chambers Creek (Reference Site 1)	CSREF	Lat: 36° 09'53.60"N Lon: 94°26'10.99"W
Little Osage Creek (Reference Site 2)	LOREF	Lat: 36°16'54.20"N Lon: 94°16'8.53"W

Section 2: Methods and Results

2.1. Sample Site Descriptions

Ten sites were sampled for this study (Figure 1.01). Two sites, Chambers Springs and Little Osage (CSREF and LOREF, respectively) were considered reference sites. Little Osage Creek was considered moderately impacted by non-point sources but not point sources. Chambers Springs Creek was considered minimally impacted from human activity although there are several households in the basin, a gravel road travels the length of the stream, portions have been cleared for pasturing cattle, and part is used for pine silviculture in an otherwise oak-hickory forest. Sites upstream of the WWTP outfalls on Osage and Spring Creeks (OSG1 and SPG1, respectively) were selected to evaluate the direct impact, if any, of point sources from the City of Rogers WWTP (OSG1) and the City of Springdale WWTP (SPG1). Two sites were selected immediately downstream of the Cities' WWTP outfalls below the mixing zones (OSG2 and SPG2, respectively). Sites were selected on both Osage and Spring Creeks above the confluence of these two creeks (OSG3 and SPG3), and two more sites were selected on Osage Creek below the confluence with Spring Creek (OSG4 and OSG5).   These sites were selected to assess the impact of the WWTP effluent on the individual streams and the basin as a whole based on the three-tiered analysis strategy.   Sites were selected to insure safety, accessibility, representativeness, and habitat comparability. Sites varied in watershed size from 8.3 square miles to 130 square miles (Table 2.01). Urban land use varied from 43% to 61% (Table 2.01). Hay meadow/pasture land use varied from 23% to 79% (Table 2.01). Forest land use varied from 61% to 11% (Table 2.01). Each site is described below, and coordinates are presented in Table 1.01.

Site OSG1. Osage Creek 1 (OSG1) was located upstream of the Rogers' WWTP effluent outfall. The site was located on and accessed through the Rogers' WWTP property. This sites' watershed contained high urban land use percent though the immediate area surrounding the site was hay meadow/pasture dominated.

Site OSG2. Osage Creek 2 (OSG2) was located downstream of the Rogers' WWTP effluent outfall below the mixing zone. The site was located on and accessed through the Rogers' WWTP property. This watershed was almost identical to OSG1, as was the area surrounding the site.

Site OSG3. Osage Creek 3 (OSG3) was located upstream of the Highway 112 bridge, downstream of OSG2. The site was accessed across private property with permission from the owner. The watershed was similar to OSG1 and OSG2 with a slight increase in hay meadow/pasture and forested land use. The area immediately surrounding this site was predominantly hay meadow/pasture with a forested riparian zone.

Site OSG4. Osage Creek 4 (OSG4) was located downstream of the confluence of Osage and Spring Creeks. The site was located on City of Springdale property and was accessed across an adjacent land owner's property. The watershed was similar to the other Osage sites with slightly more hay meadow/pasture and forest land percent (Table 2.01). The area immediately surrounding the site was predominantly hay meadow/pasture with a mostly forested, yet disturbed, riparian zone.

Site OSG5. Osage Creek 5 (OSG5) was located downstream of the confluence of Osage and Little Osage Creeks. The site was located on and accessed through Northwest Arkansas Conservation Authority (NACA) property. The watershed contains considerably less urban percent and more hay meadow/pasture percent than other Osage sites (Table 2.01). The area immediately surrounding the site is predominantly hay meadow/pasture with a forested riparian zone.

Site SPG1. Spring Creek 1 (SPG1) was located upstream of the Springdale's WWTP effluent outfall. The site was located upstream of the Silent Grove Road bridge on Spring Creek and was accessed from Pump Station Road. This site had the highest urban percent land use of the study (Table 2.01). The area immediately surrounding the site was urban open space and forested riparian zone. A reservoir with a hydraulic gradient to the creek was adjacent to the south of the creek. There was evidence of seepage of very high redox potential water from the reservoir to the creek. The spring that provided the majority of the flow for the creek originated approximately 1,000 feet upstream of the site.

Site SPG2. Spring Creek 2 (SPG2) was located downstream of the Springdale's WWTP effluent outfall below the mixing zone. The site was located on and accessed through the Springdale's WWTP property. This sites' watershed was almost identical to SPG1 as was the area surrounding the site.

Site SPG3. Site Spring Creek 3 (SPG3) was located upstream of the Highway 112 bridge crossing Spring Creek. The site was located on private property and was accessed from the bridge and across the private property with the landowner's permission. The sites' watershed had substantially less urban percent than the other Spring Creek sites and was mostly replaced with hay meadow/pasture land use. The area immediately surrounding the site was predominantly hay meadow/pasture with a forested riparian zone.

Site LOREF. Little Osage Creek Reference site (LOREF) was located on upper Little Osage Creek immediately upstream of the Benton County Road 279 bridge and downstream of the Mill Dam Road bridge. This site was located on Osage Mills Baptist Church property and was accessed from that property with the Church's permission. The site's watershed contained the highest percent hay meadow/pasture of any site with a considerable portion (8%) in urban land use but no point source discharge. The area immediately surrounding the site was predominantly hay meadow/pasture with a forested riparian zone. This reference site was selected to represent the typical impacts of urban and hay meadow/pasture non-point source pollution on area streams in the absence of point source contribution.

Site CSREF. Chambers Creek, also referred to as Chambers Springs, Reference Site (CSREF) was located on National Forest Service land in the Lake Wedington unit. Chambers Springs is a small tributary of the Illinois River. The site was located upstream of Benton County Road 196 off of Chambers Springs Road. The sites' watershed was predominantly forest with some hay meadow/pasture. The area immediately surrounding the site was predominantly forest. This site was selected as a least impacted regional reference site, but see previous comments at the beginning of this section for a list of the minor impacts in the basin.

Table 2.01 Watershed areas and dominant land use areas by percent in 2006 for select sites in the Osage Creek and Illinois River Basins (Center for Advanced Spatial Technology, University of Arkansas, 2006).

	OSG1	OSG2	OSG3	OSG4	OSG5	SPG1	SPG2	SPG3	LOREF	CSREF
Watershed Area (Square Miles)	32.1	32.4	35.6	80.6	128.6	12.7	13.2	35.3	35.4	8.3
Percent Urban	43%	43%	40%	34%	24%	60%	60%	36%	8%	0%
Percent Pasture	40%	40%	43%	45%	57%	23%	24%	43%	79%	39%
Percent Forest	13%	13%	14%	17%	17%	13%	14%	17%	12%	61%

2.2 Water Chemistry Methods and Results

2.2.1 Water Chemistry Methods

2.2.1.1 Sample Collection

Water samples were collected during base flow conditions a total of 29 times from the summer of 2007 to the summer of 2009. Grab samples were collected from the vertical centroid of flow (VCF) of the stream and dissolved oxygen (DO), conductivity, and temperature (YSI Model 85, Yellow Springs, OH) and pH (pH Testr 30, Oakton Instruments, Vernon Hills, IL) were measured in the field. Water samples were divided into two unfiltered samples, an unfiltered acidified sample (pH < 2), a filtered unacidified sample (0.45 μm membrane, syringe filtration), and two filtered acidified samples (0.45 μm membrane, syringe filtration, pH < 2). Samples were transported on ice back to the laboratory, stored at 4^{o} C, and subsequently analyzed.

2.2.1.2 Laboratory Methods

The analytical methods for chemical analyses are summarized in Table 2.02 and described in this section. Filtered un-acidified samples were analyzed for Cl^{-} using the automated ferricyanide method (APHA, 2005), nitrite-N (NO_2–N) using the sulfanilamide NED dihydrochloride colorimetric method (APHA, 2005), and (nitrate plus nitrite)-N ((NO_3 + NO_2)–N) using the hydrazine reduction method (APHA, 2005) on a Skalar San Plus Wet Chemistry Autoanalyzer (Skalar, the Netherlands); nitrate–N was obtained mathematically by subtracting NO_2–N from (NO_3 + NO_2)–N. Orthophosphate (OP) and ammonium–nitrogen (NH_4–N) were measured from filtered, acidified samples using the automated ascorbic acid method (APHA, 2005) and the sodium nitroprusside and salicylate method (APHA, 2005). Total phosphorus (TP) was obtained using a persulfate digestion and subsequent automated ascorbic acid method (APHA, 2005). A Skalar San Plus Wet Chemistry Autoanalyzer (Skalar, the Netherlands) was used to determine total nitrogen (TN) in unfiltered acidified samples using an in-line persulfate-ultraviolet oxidation and hydrazine reduction method (Skalar Method, the Netherlands). Total Organic Carbon (TOC) was measured from unfiltered acidified samples using the persulfate-ultraviolet flow injection method (APHA, 2005). Total Suspended Solids (TSS) were obtained using the glass fiber filtration method (APHA, 2005), and turbidity was measured via the nephelometric method (APHA, 2005) on a VWR Scientific 66120-200 Turbidity Meter (VWR International, West

Chester, PA). Chlorophyll-a (Chl-a) was obtained by filtering 1L of stream water through a Pall Type A/E glass fiber filter (Pall Corporation, Ann Arbor, Michigan) which was then shredded in 5 mL of aqueous acetone saturated with $MgCO_3$ and centrifuged. The supernatant was analyzed for Chl–a using the trichromatic method (APHA, 2005).

2.2.1.3 General Quality Assurance and Quality Control Procedures

A field duplicate and a field blank were collected during each sampling event and were analyzed for all project parameters; the field duplicates were compared to collected water samples, and field blanks were evaluated against method reporting limits. All water sample analysis was performed on calibrated instruments using a laboratory control standard to verify method accuracy. Laboratory duplicates were performed on 10% of samples to ensure method precision, and these values were compared against that measured in the water samples. Method accuracy was evaluated by including 10% matrix spikes with each analytical run, and these values were compared against that calculated mathematically. Method blanks were used to reveal any possible analytical process contamination. Laboratory control standards, duplicates, and spikes were considered acceptable within 20% of expected recovery.

Table 2.02 Methods for field and laboratory parameters for water samples collected for the Osage Creek and Spring Creek use attainability assessment.

PARAMETER	UNITS	MATRIX	Method	Reporting Limit (RL)*
Field Parameters				
pH	pH units	water	EPA 150.1	0.1
DO	mg/L	water	EPA 360.1	0.1
Conductivity	uS/cm	water	EPA 120.1	1
Temperature	^{o} C	water	EPA 170.1	NA
Laboratory Parameters				
NH_4-N	mg/L	water	EPA 350.1	0.02
NO_3-N	mg/L	water	EPA 353.2	0.10
NO_2-N	mg/L	water	EPA 354.1	0.01
TN	mg/L	water	Persulfate-Ultraviolet Oxidation and Hydrazine Reduction	0.10
SRP	mg/L	water	EPA 365.1	0.01
TP	mg/L	water	EPA 365.3	0.01
Chl-a	µg/L	water	EPA 446.0	0.1
TOC	mg/L	water	EPA 415.2	0.1
Turbidity	NTU	water	EPA 180.1	0.1
TSS	mg/L	water	EPA 160.2	6.0

*This represents either the method detection limit (MDL) or the practical quantification limit (PQL); however, all concentrations were reported as a value not less than a reporting limit.

2.2.2 Water Chemistry Results

Water quality analyses met the QAPP criteria for quality control (Tables 2.17-2.19); water quality data was within the acceptable quality assurance and quality control ranges defined within the QAPP for water samples across all sites for any of the parameters measured (Tables 2.03 – 2.16). Water quality across all parameters showed significant differences from upstream to downstream sites across all parameters (Figures 2.01), but no violations of ADEQ Reg. 2 criteria were observed since numeric criteria do not exist for nutrients. Water chemistry parameters approached the reference stream conditions by site OSG5 (Figures 2.01 - 2.08), although concentrations were still significantly greater than the reference conditions for phosphorus.

Table 2.03 Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of dissolved reactive phosphorus (e.g., ortho-phosphate), and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	0.021	0.037	0.055	0.035	0.036	0.044	0.032	0.042
LOREF	29	0.021	0.031	0.057	0.031	0.034	0.036	0.028	0.028
OSG1	29	0.018	0.032	0.050	0.032	0.029	0.035	0.031	0.035
OSG2	29	0.029	0.093	0.434	0.114	0.110	0.111	0.077	0.060
OSG3	29	0.030	0.084	0.210	0.110	0.089	0.093	0.073	0.055
SPG1	29	0.042	0.056	0.077	0.060	0.054	0.058	0.056	0.054
SPG2	29	0.070	0.182	0.599	0.133	0.180	0.253	0.167	0.212
SPG3	29	0.092	0.155	0.241	0.170	0.129	0.158	0.145	0.191
OSG4	29	0.077	0.120	0.195	0.143	0.107	0.118	0.112	0.129
OSG5	29	0.061	0.100	0.296	0.121	0.100	0.096	0.086	0.105

Table 2.04 Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of total phosphorus, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	0.029	0.048	0.065	0.045	0.047	0.054	0.041	0.055
LOREF	29	0.029	0.046	0.113	0.047	0.053	0.048	0.040	0.045
OSG1	29	0.030	0.042	0.064	0.040	0.043	0.044	0.040	0.046
OSG2	29	0.040	0.124	0.473	0.143	0.159	0.133	0.104	0.082
OSG3	29	0.044	0.110	0.227	0.131	0.122	0.119	0.093	0.085
SPG1	29	0.051	0.070	0.204	0.073	0.068	0.080	0.063	0.066
SPG2	29	0.131	0.249	0.643	0.180	0.252	0.307	0.257	0.272
SPG3	29	0.112	0.174	0.263	0.189	0.152	0.170	0.164	0.215
OSG4	29	0.090	0.141	0.218	0.160	0.128	0.130	0.130	0.179
OSG5	29	0.074	0.113	0.178	0.139	0.106	0.107	0.100	0.126

Table 2.05. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of (nitrate+nitrite)-nitrogen, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	0.45	1.18	2.71	0.79	1.69	1.72	1.28	0.63
LOREF	29	3.84	5.37	6.88	4.87	5.65	5.62	5.43	5.28
OSG1	29	1.89	3.17	4.26	2.90	3.07	3.37	3.30	3.24
OSG2	29	3.16	4.73	6.69	4.25	4.51	4.59	5.21	5.25
OSG3	29	2.91	4.29	7.32	3.92	3.95	4.05	4.93	4.74
SPG1	29	2.04	2.99	8.32	2.43	3.05	3.27	3.61	2.50
SPG2	29	2.10	3.32	4.56	2.86	3.20	3.72	3.37	3.64
SPG3	29	2.64	3.91	5.40	3.19	4.22	4.18	4.19	3.77
OSG4	29	2.81	3.95	5.47	3.29	4.10	4.03	4.31	4.06
OSG5	29	2.87	4.14	8.14	3.39	4.21	4.22	4.82	4.01

Table 2.06. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of ammonia-nitrogen, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	<0.001	0.010	0.056	0.013	0.013	0.014	0.005	0.012
LOREF	29	0.001	0.013	0.048	0.019	0.011	0.009	0.012	0.019
OSG1	29	0.001	0.010	0.038	0.007	0.013	0.011	0.011	0.009
OSG2	29	0.015	0.032	0.123	0.034	0.039	0.024	0.033	0.031
OSG3	29	0.013	0.026	0.060	0.031	0.029	0.021	0.025	0.022
SPG1	29	0.002	0.013	0.063	0.026	0.012	0.010	0.014	0.008
SPG2	29	0.029	0.059	0.100	0.064	0.059	0.042	0.067	0.067
SPG3	29	0.016	0.029	0.060	0.046	0.026	0.024	0.027	0.027
OSG4	29	0.008	0.025	0.076	0.037	0.022	0.019	0.025	0.031
OSG5	29	0.005	0.020	0.077	0.028	0.019	0.016	0.021	0.016

Table 2.07. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of nitrite-nitrogen, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	<0.001	0.005	0.022	0.008	0.008	0.009	0.001	0.005
LOREF	29	0.005	0.014	0.024	0.016	0.014	0.014	0.011	0.016
OSG1	29	0.003	0.008	0.019	0.010	0.010	0.011	0.006	0.006
OSG2	29	<0.001	0.011	0.039	0.015	0.011	0.013	0.006	0.012
OSG3	29	0.001	0.012	0.024	0.013	0.013	0.015	0.008	0.012
SPG1	29	0.002	0.008	0.019	0.010	0.012	0.011	0.005	0.005
SPG2	29	<0.001	0.010	0.024	0.010	0.013	0.017	0.005	0.013
SPG3	29	<0.001	0.009	0.026	0.013	0.013	0.013	0.003	0.009
OSG4	29	<0.001	0.010	0.021	0.013	0.013	0.015	0.005	0.011
OSG5	29	<0.001	0.011	0.029	0.013	0.013	0.014	0.006	0.012

Table 2.08. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of total nitrogen, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	0.47	1.26	3.11	0.90	1.85	1.62	1.29	0.79
LOREF	29	4.10	5.43	7.37	4.99	6.13	5.06	5.49	5.58
OSG1	29	1.92	3.20	4.74	3.04	3.33	3.02	3.26	3.45
OSG2	29	3.41	4.95	7.23	4.57	5.11	4.21	5.44	5.75
OSG3	29	3.19	4.48	6.45	4.21	4.56	3.74	4.99	5.22
SPG1	29	2.19	2.97	4.31	2.67	3.29	2.97	3.15	2.72
SPG2	29	2.68	4.06	5.53	3.75	4.21	3.88	4.15	4.42
SPG3	29	3.00	4.19	6.00	3.73	4.81	3.90	4.39	4.17
OSG4	29	2.92	4.14	6.01	3.68	4.55	3.68	4.53	4.41
OSG5	29	3.02	4.23	6.21	3.70	4.79	3.85	4.59	4.28

Table 2.09. Overall minimum, geometric mean and maximum concentration (ug L^{-1}) of sestonic chlorophyll-α, and geometric mean concentration (ug L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (ug L^{-1})	Geomean (ug L^{-1})	Maximum (ug L^{-1})	Critical Season 2007 (ug L^{-1})	Primary Season 2007-8 (ug L^{-1})	Critical Season 2008 (ug L^{-1})	Primary Season 2008-9 (ug L^{-1})	Critical Season 2009 (ug L^{-1})
CSREF	29	<0.1	0.1	0.6	0.3	<0.1	0.1	0.3	0.4
LOREF	29	<0.1	0.4	2.8	0.7	<0.1	0.8	0.8	1.2
OSG1	29	0.2	0.7	1.8	0.6	0.9	0.5	0.6	0.8
OSG2	29	0.2	0.8	1.7	0.8	1.0	0.6	0.6	1.1
OSG3	29	0.1	0.8	2.6	0.7	1.1	0.4	0.9	1.3
SPG1	29	0.3	0.6	1.7	0.7	0.6	0.4	0.7	0.9
SPG2	29	<0.1	0.4	3.1	<0.1	0.9	0.4	0.9	1.2
SPG3	29	0.5	0.9	2.3	1.0	0.9	0.8	0.9	1.2
OSG4	29	0.3	1.0	3.9	0.8	1.0	0.8	1.1	2.0
OSG5	29	0.1	0.9	2.6	0.7	1.0	0.7	1.0	1.2

Table 2.10. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of total organic carbon, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	0.25	0.46	0.92	0.49	0.52	0.56	0.37	0.40
LOREF	29	0.26	0.49	1.81	0.59	0.62	0.40	0.44	0.43
OSG1	29	0.15	0.37	1.24	0.39	0.45	0.31	0.34	0.41
OSG2	29	0.92	1.33	2.20	1.51	1.44	1.08	1.30	1.40
OSG3	29	0.72	1.14	1.83	1.23	1.30	0.93	1.17	1.10
SPG1	29	0.24	0.52	1.39	0.62	0.59	0.45	0.40	0.65
SPG2	29	1.76	2.85	4.16	2.63	3.25	2.60	3.15	2.51
SPG3	29	0.76	1.54	2.18	1.77	1.68	1.17	1.62	1.54
OSG4	29	0.74	1.22	2.23	1.50	1.28	0.93	1.29	1.15
OSG5	29	0.66	0.99	1.83	1.24	1.09	0.74	1.02	0.90

Table 2.11. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of total suspended solids, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	<0.1	1.1	3.1	2.4	1.2	1.1	0.5	1.5
LOREF	29	<0.1	4.1	14.7	3.4	4.7	3.7	3.6	6.5
OSG1	29	0.1	1.6	7.0	1.8	2.6	1.8	0.7	2.1
OSG2	29	<0.1	2.0	5.5	2.0	3.3	2.4	1.0	2.2
OSG3	29	0.5	3.8	51.8	3.0	5.1	6.9	1.8	4.6
SPG1	29	<0.1	1.6	5.9	2.7	2.0	1.8	0.9	1.4
SPG2	29	0.2	2.2	15.6	1.8	1.9	2.2	2.3	3.6
SPG3	29	0.5	2.2	14.2	3.4	2.9	1.7	1.6	1.9
OSG4	29	<0.1	3.6	110.9	4.2	3.6	3.2	1.3	19.0
OSG5	29	1.1	3.4	7.2	4.2	4.0	3.6	2.2	3.9

Table 2.12. Overall minimum, geometric mean and maximum pH, and geometric mean during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum	Geomean	Maximum	Critical Season 2007	Primary Season 2007-8	Critical Season 2008	Primary Season 2008-9	Critical Season 2009
CSREF	29	7.1	7.9	8.3	8.0	7.8	7.9	7.9	7.5
LOREF	29	7.6	7.9	8.2	8.0	7.9	7.7	8.0	7.8
OSG1	29	7.5	7.8	8.3	7.7	7.8	7.8	7.9	7.5
OSG2	29	7.6	7.8	8.2	7.8	7.8	7.7	8.0	7.7
OSG3	29	7.6	8.0	8.8	8.0	7.9	7.9	8.2	7.9
SPG1	29	7.5	7.7	8.0	7.7	7.7	7.6	7.8	7.6
SPG2	29	7.5	7.9	8.1	8.0	7.8	7.8	7.9	7.8
SPG3	29	7.8	8.2	8.8	8.4	8.2	8.1	8.4	8.1
OSG4	29	7.8	8.1	8.7	8.2	8.0	8.1	8.3	8.0
OSG5	29	7.8	8.1	8.6	8.2	8.0	8.0	8.2	8.0

Table 2.13. Overall minimum, geometric mean and maximum specific conductance (µS cm^{-1}), and geometric mean (µS cm^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (µS cm^{-1})	Geomean (µS cm^{-1})	Maximum (µS cm^{-1})	Critical Season 2007 (µS cm^{-1})	Primary Season 2007-8 (µS cm^{-1})	Critical Season 2008 (µS cm^{-1})	Primary Season 2008-9 (µS cm^{-1})	Critical Season 2009 (µS cm^{-1})
CSREF	29	101	183	284	217	156	187	177	185
LOREF	29	111	262	378	270	208	285	263	312
OSG1	29	120	275	364	256	236	313	291	288
OSG2	29	172	377	536	430	297	392	370	428
OSG3	29	157	357	520	421	269	373	351	414
SPG1	29	244	321	401	355	279	331	312	340
SPG2	29	452	604	893	707	524	608	573	642
SPG3	29	241	455	800	526	385	456	447	482
OSG4	29	169	393	655	451	294	406	387	485
OSG5	29	260	364	588	441	295	367	335	427

Table 2.14. Overall minimum, geometric mean and maximum water temperature (˚C), and geometric mean (˚C) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (˚C)	Geomean (˚C)	Maximum (˚C)	Critical Season 2007 (˚C)	Primary Season 2007-8 (˚C)	Critical Season 2008 (˚C)	Primary Season 2008-9 (˚C)	Critical Season 2009 (˚C)
CSREF	29	2.9	15.2	24.0	18.9	11.2	19.1	11.0	21.9
LOREF	29	7.2	16.1	25.3	19.1	13.1	18.3	13.2	19.6
OSG1	29	8.0	16.6	23.8	18.6	13.7	19.3	14.0	20.4
OSG2	29	9.1	17.6	26.0	20.3	14.5	20.1	14.7	21.7
OSG3	29	6.9	17.4	27.6	20.8	13.8	20.1	14.2	21.9
SPG1	29	10.3	17.6	23.8	19.9	14.9	19.5	15.2	21.4
SPG2	29	12.3	21.1	30.5	24.9	17.8	23.4	17.3	25.9
SPG3	29	6.6	18.1	29.5	22.4	13.8	21.0	14.4	23.9
OSG4	29	4.6	16.9	27.3	20.4	12.7	20.3	13.2	23.1
OSG5	29	3.6	16.1	27.1	19.7	12.0	19.7	12.1	22.3

Table 2.15. Overall minimum, geometric mean and maximum concentration (mg L^{-1}) of dissolved oxygen, and geometric mean concentration (mg L^{-1}) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (mg L^{-1})	Geomean (mg L^{-1})	Maximum (mg L^{-1})	Critical Season 2007 (mg L^{-1})	Primary Season 2007-8 (mg L^{-1})	Critical Season 2008 (mg L^{-1})	Primary Season 2008-9 (mg L^{-1})	Critical Season 2009 (mg L^{-1})
CSREF	29	5.3	8.0	13.7	7.2	9.3	7.3	8.7	7.2
LOREF	29	5.4	9.2	12.5	8.6	10.0	8.8	9.3	9.4
OSG1	29	5.6	8.4	11.7	8.1	9.1	7.7	8.6	8.2
OSG2	29	6.1	8.4	12.0	7.9	9.0	7.7	9.1	8.6
OSG3	29	5.2	8.9	14.5	8.4	9.6	8.2	9.2	9.0
SPG1	29	5.5	8.5	11.0	8.5	9.1	7.8	8.4	8.6
SPG2	29	5.8	8.7	11.7	8.3	9.6	8.3	8.9	8.4
SPG3	29	4.5	9.1	13.6	8.5	10.0	8.4	9.7	9.0
OSG4	29	6.8	9.0	13.8	8.3	9.7	8.3	9.9	8.9
OSG5	29	6.5	8.6	13.3	7.9	9.5	7.9	9.5	8.4

Table 2.16. Overall minimum, geometric mean and maximum turbidity (NTU), and geometric mean (NTU) during critical and primary seasons at select sites in northwest Arkansas, 2007-2009.

Site	n	Minimum (NTU)	Geomean (NTU)	Maximum (NTU)	Critical Season 2007 (NTU)	Primary Season 2007-8 (NTU)	Critical Season 2008 (NTU)	Primary Season 2008-9 (NTU)	Critical Season 2009 (NTU)
CSREF	29	0.2	1.1	2.3	0.7	1.1	1.3	0.9	1.9
LOREF	29	0.5	3.1	13.6	3.1	3.4	2.9	2.6	4.4
OSG1	29	0.6	1.5	6.0	1.4	1.7	1.7	1.2	1.9
OSG2	29	0.8	1.5	4.9	1.3	2.1	1.6	1.4	1.4
OSG3	29	0.9	2.2	27.8	1.5	2.1	3.9	1.6	2.5
SPG1	29	0.6	1.2	4.5	1.1	1.4	1.4	1.1	1.1
SPG2	29	0.3	1.3	6.2	0.6	1.3	1.2	1.8	2.7
SPG3	29	0.6	1.3	2.4	1.4	1.5	1.2	1.0	1.4
OSG4	29	0.3	2.0	32.8	1.4	2.0	2.0	1.1	8.0
OSG5	29	0.8	2.1	6.2	1.6	2.6	2.3	1.7	2.6

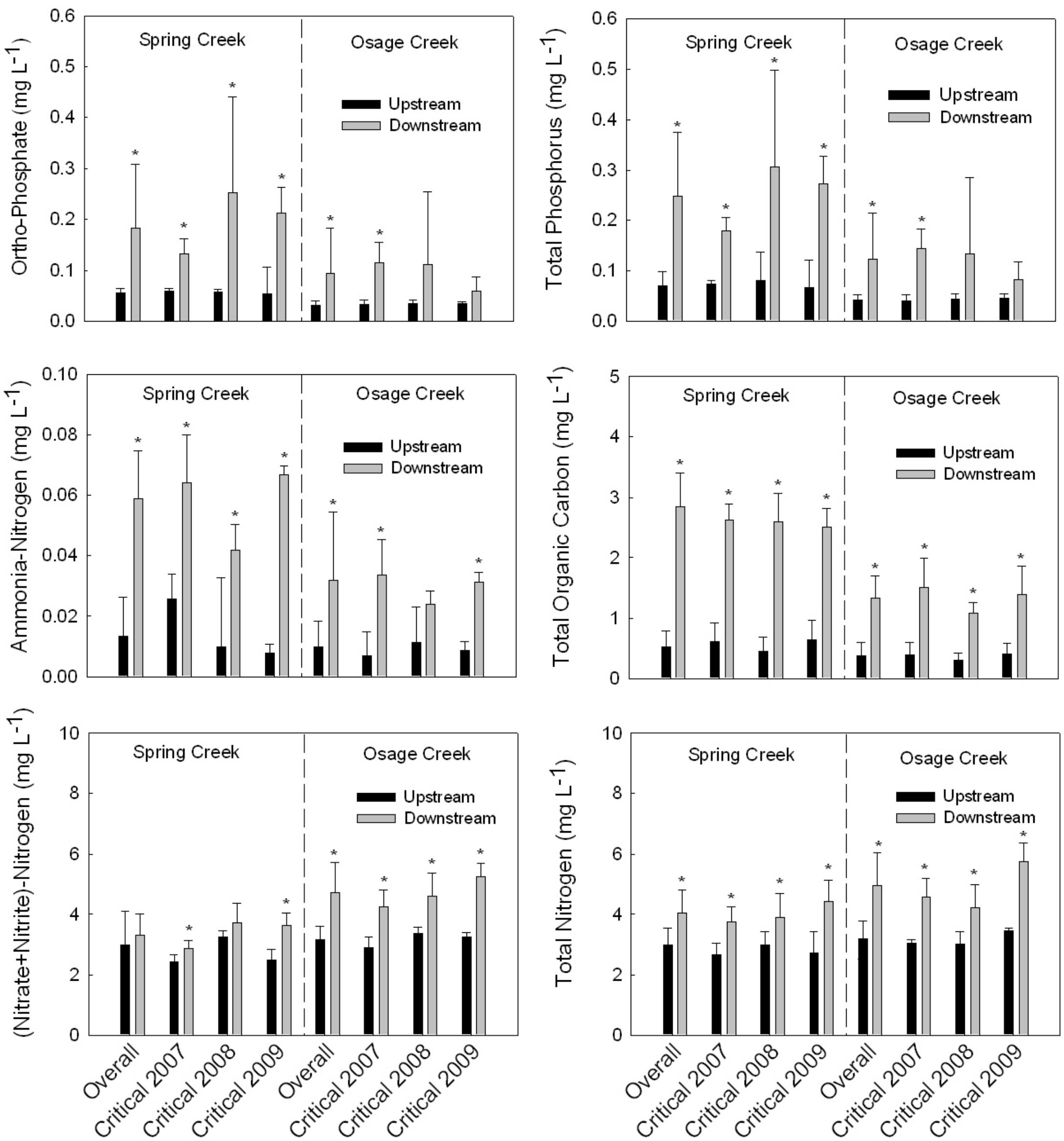

Figure 2.01. Comparisons (mean plus standard deviation) of nutrient concentrations upstream and downstream of the effluent discharges on Osage Creek and Spring Creek; asterisks (*) above the bars and standard deviation denote statistically significant differences (paired T-test, $P<0.05$).

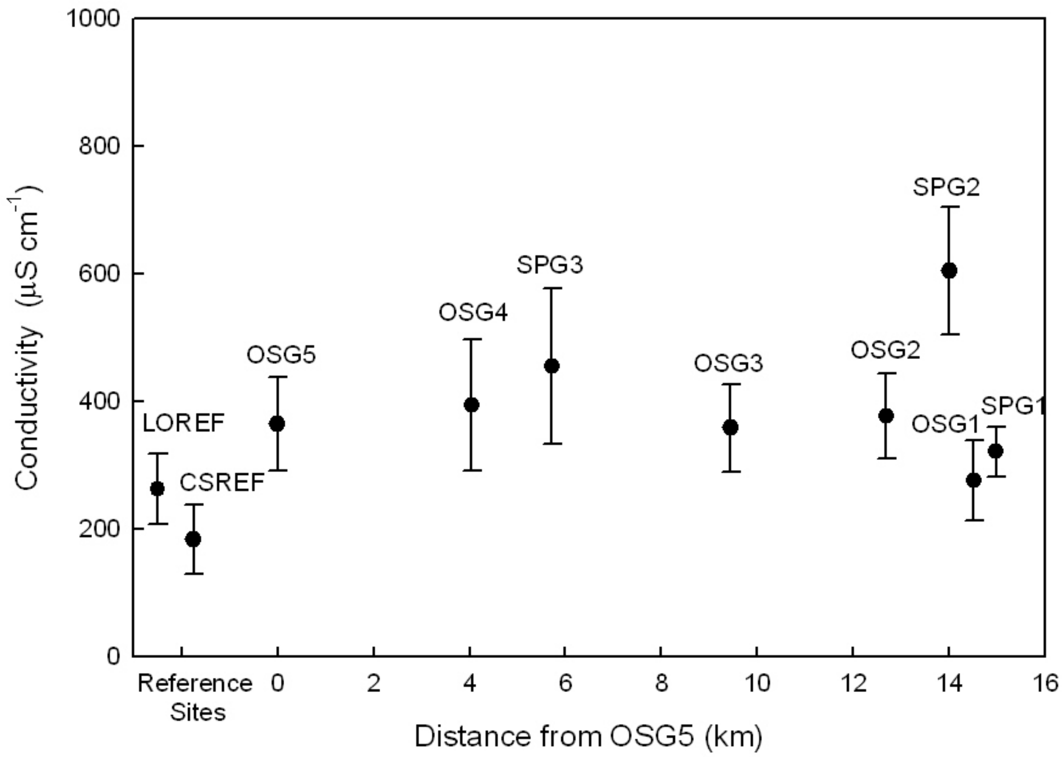

Figure 2.02 Specific Conductance (mean ± standard deviation) across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

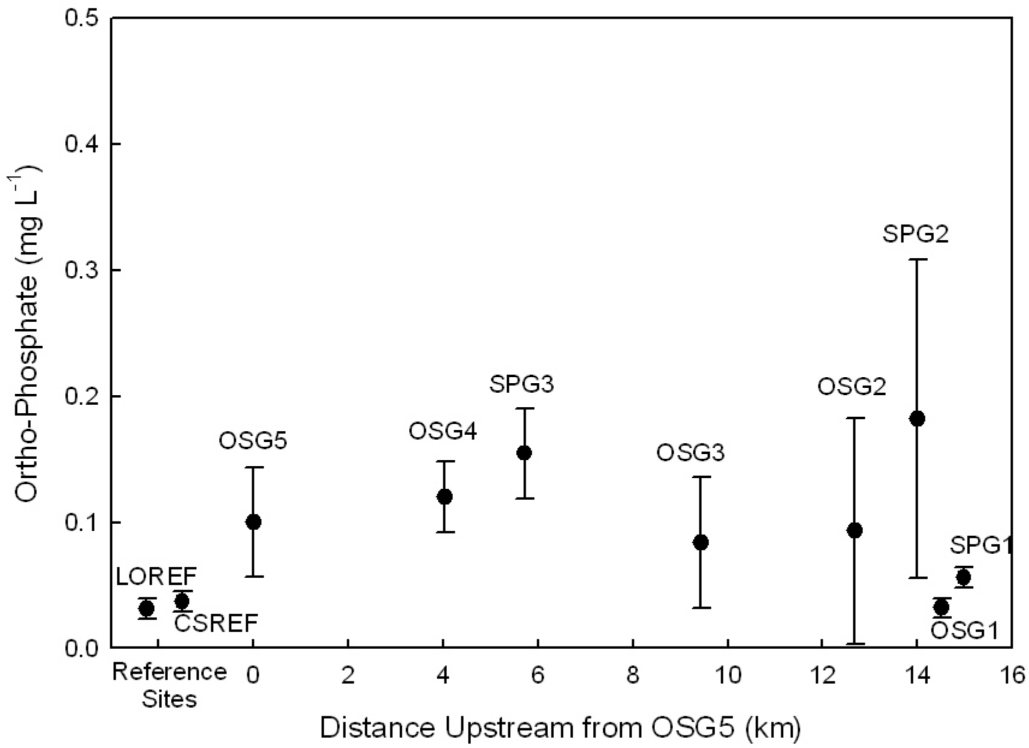

Figure 2.03 Dissolved reactive phosphorus (mean ± standard deviation) concentrations across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

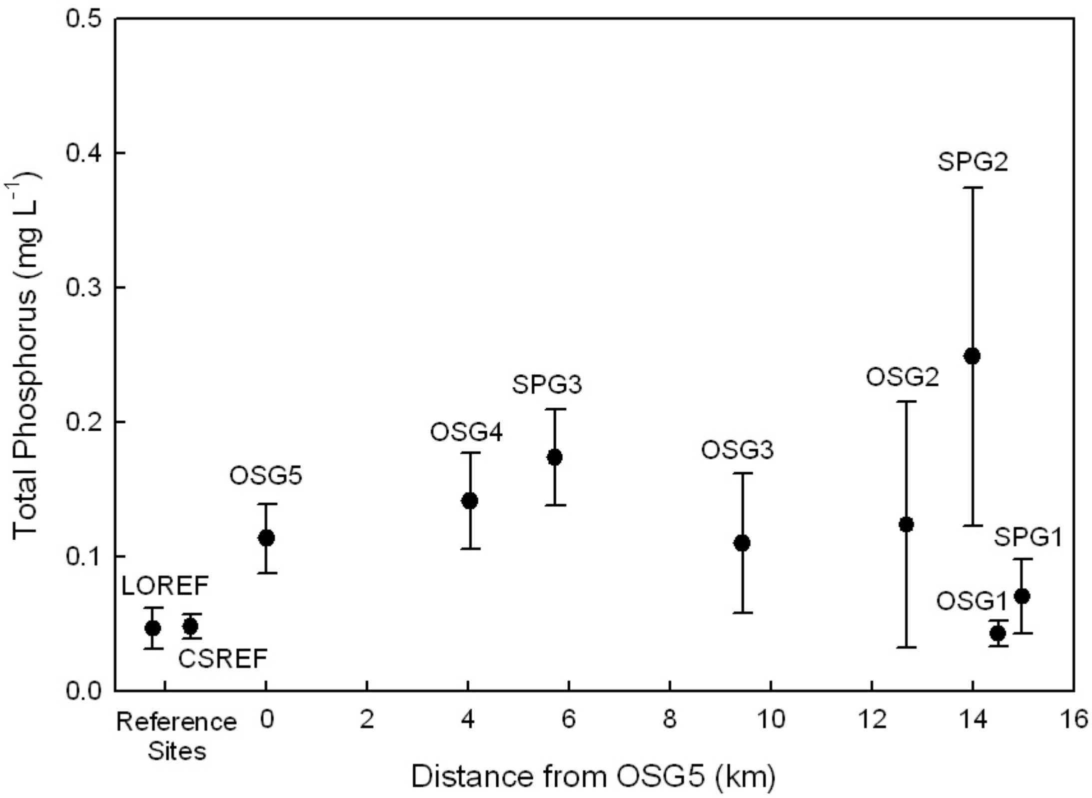

Figure 2.04 Total phosphorus (mean ± standard deviation) concentrations across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

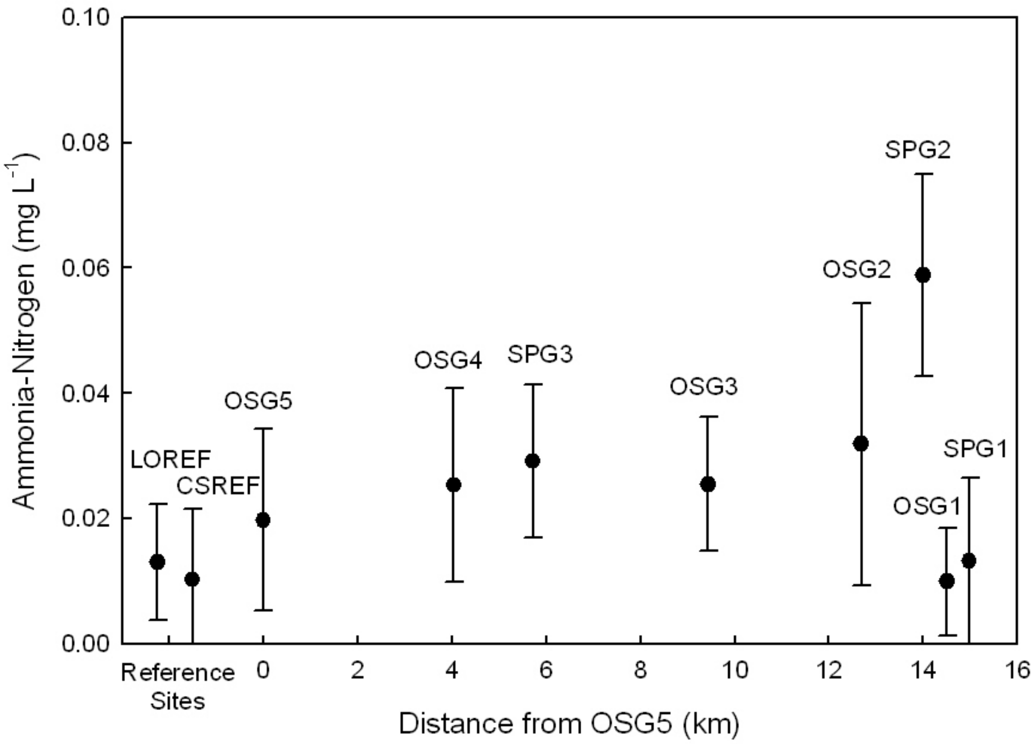

Figure 2.05 Ammonia-nitrogen (mean ± standard deviation) concentrations across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

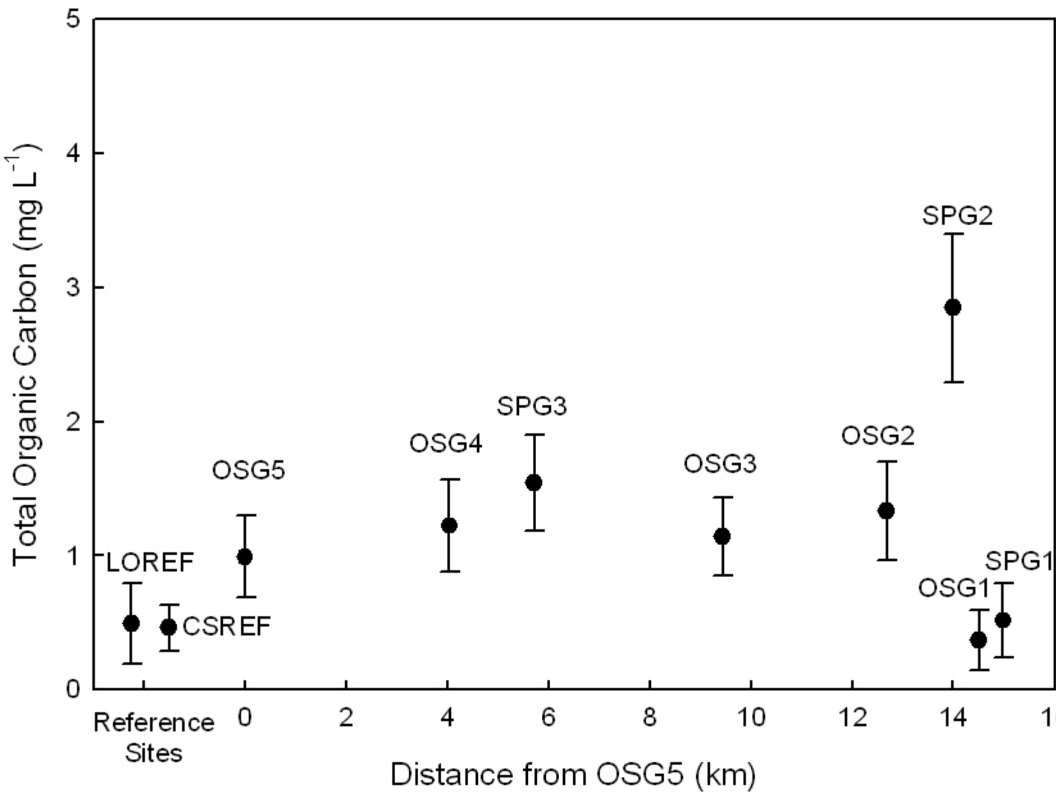

Figure 2.06 Total organic carbon (mean ± standard deviation) concentrations across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

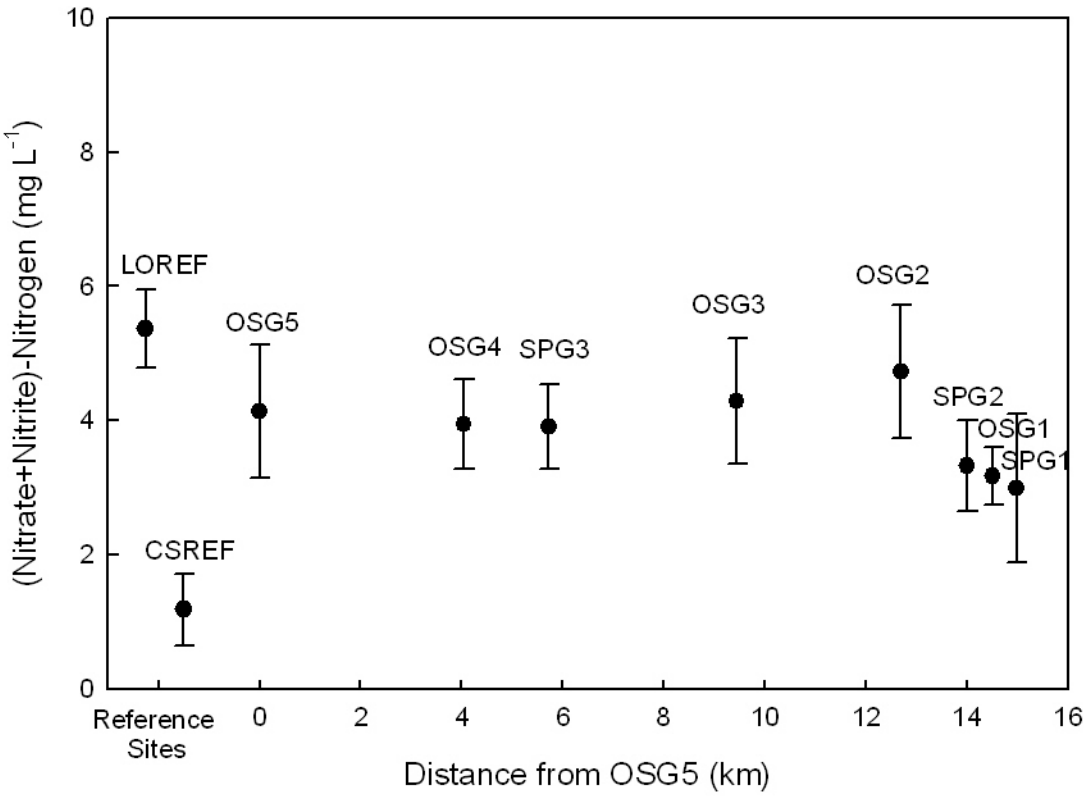

Figure 2.07 Nitrate plus nitrite as nitrogen (mean ± standard deviation) concentrations across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

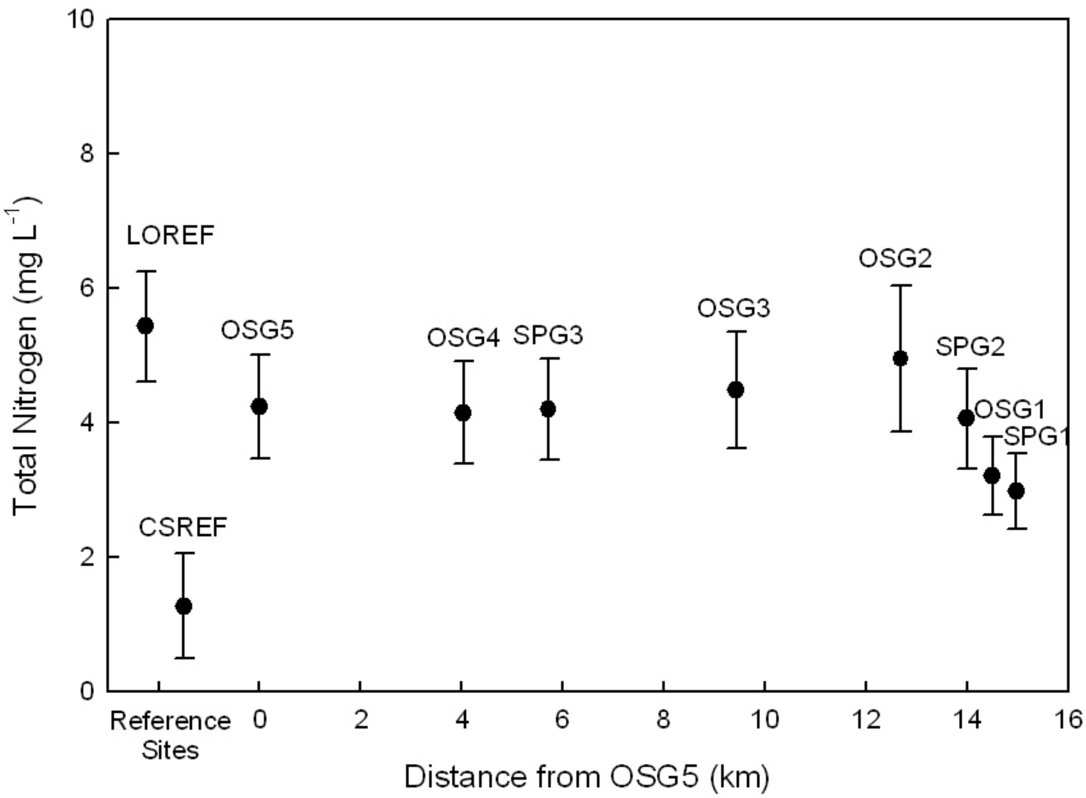

Figure 2.08 Total nitrogen (mean ± standard deviation) concentrations across selected sites within the upper Illinois River Watershed; distance represents approximate river kilometers upstream from the most downstream sampling site on Osage Creek.

Table 2.17 Range, Median and Mean of Percent Recoveries of Field Duplicate Samples Collected by the UA Division of Agriculture Water Quality Research Lab.

Parameter	Range % Recovered	Median % Recovered	Mean % Recovered
pH	99.4-102	100	100
Dissolved Oxygen	98.2-102	100	100
Conductivity	98.3-103	100	100
Temperature	93.9-104	100	99.9
Ammonia-Nitrogen	27.2-217	98.2	107
(Nitrate+Nitrite)-Nitrogen	51.1-116	100	98.7
Nitrite-Nitrogen	10.0-220	102	104
Total Nitrogen	80.2-134	102	105
Ortho-Phosphorus	96.5-103	99.6	99.8
Total Phosphorus	96.9-108	99.9	100
Chlorophyll-α	26.7-168	103	106
Total Organic Carbon	55.7-122	103	101
Turbidity	78.4-147	100	103
Total Suspended Solids	15.8-291	87.5	92.7

Table 2.18 Range, Median and Mean of Percent Recoveries of Laboratory Spikes analyzed by UA Division of Agriculture Water Quality Research Lab.

Parameter	Range % Recovered	Median % Recovered	Mean % Recovered
Ammonia-Nitrogen	84.5-137	101	101
(Nitrate+Nitrite)-Nitrogen	94.6-108	100	100
Nitrite-Nitrogen	85.0-149	100	101
Total Nitrogen	91.6-110	101	101
Ortho-Phosphorus	92.5-110	100	100
Total Phosphorus	90.8-131	101	101
Total Organic Carbon	81.5-111	103	102

Table 2.19. Range, Median and Mean of Percent Recoveries of Laboratory Duplicates analyzed by UA Division of Agriculture Water Quality Research Lab

Parameter	Range % Recovered	Median % Recovered	Mean % Recovered
Ammonia-Nitrogen	84.0-116	100	100
(Nitrate+Nitrite)-Nitrogen	90.3-109	98.6	98.6
Nitrite-Nitrogen	83.9-133	101	101
Total Nitrogen	82.1-112	97.6	97.6
Ortho-Phosphorus	90.0-110	100	100
Total Phosphorus	89.4-115	99.8	99.8
Total Organic Carbon	86.2-116	97.5	97.5

2.3 Diurnal In-Stream Parameter Methods and Results (Data Sondes)

2.3.1 Diurnal In-Stream Methods

An in-situ multi-probe data sonde (YSI 600xlm or YSI 6920 v2, TSI Inc., Yellow Springs, OH) was deployed for two 72-hour periods at each sample site for continuous recording of dissolved oxygen, temperature, pH, and specific conductance during each sampling season under stable base flow conditions. Probes were programmed to record the four field parameters each ten minutes and store the data in the probe's internal memory. Each sonde was deployed in a perforated pvc case for safety and security. The case was anchored to a steel t-post which was driven into the stream substrate. The deployment case was situated in an area which was in constant contact with the main flow of the stream. After retrieval the data were downloaded from the field probes and transferred to the project database. Each sampling event included a standard suite of pre-deployment and post-deployment calibration checks. Data were analyzed for deviations of parameters from ADEQ Reg. 2 standards. Parameter criteria for violation of Reg. 2 are defined below.

Reg. 2.502 Temperature. Heat shall not be added to any waterbody in excess of the amount that will elevate the natural temperature, outside the mixing zone, by more than 5°F (2.8°C) based upon the monthly average of the maximum daily temperatures measured at mid-depth or three feet (whichever is less) in streams, lakes or reservoirs. Maximum allowable temperatures from man-induced causes in the following waters are: Streams - Ozark Highlands 29 °C.

Reg. 2.504 pH. As a result of waste discharges, the pH of water in streams or lakes must not fluctuate in excess of 1.0 unit over a period of 24 hours and pH values shall not be below 6.0 or above 9.0.

Reg. 2.505 Dissolved Oxygen. In streams with watersheds of less than 10 mi^2, it is assumed that insufficient water exists to support a fishery during the critical season. During this time, a D.O. standard of 2 mg/l will apply to prevent nuisance conditions. However, field verification is required in areas suspected of having significant groundwater flows or enduring pools which may support unique aquatic biota. In such waters the critical season standard for the next size category of stream shall apply. All streams with watersheds of less than 10 mi^2 are expected to support a fishery during the primary season when stream flows, including discharges, equal or exceed 1 cubic foot per second (CFS); however, when site verification indicates that a fishery exists at flows below 1 CFS, such fishery will be protected by the primary standard. Also, in these streams with watersheds of less than 10 mi^2, where waste discharges are 1 CFS or more, they are assumed to provide sufficient water to support a perennial fishery and, therefore, must meet the dissolved oxygen standards of the next size category of streams. For purposes of determining effluent discharge limits, the following conditions shall apply:

(A). The primary season dissolved oxygen standard is to be met at a water temperature of 22°C (71.5°F) and at the minimum stream flow for that season. At water temperatures of 10°C (50°F), the dissolved oxygen standard is 6.5 mg/l.

(B). During March, April and May, when background stream flows are 15 CFS or higher, the D.O. standard is 6.5 mg/l in all areas except the Delta Ecoregion, where the primary season D.O. standard will remain at 5 mg/l.

(C). The critical season dissolved oxygen standard is to be met at maximum allowable water temperatures and at Q7-10 flows. However, when water temperatures exceed 22°C (71.6°F), a 1 mg/l diurnal depression will be allowed below the applicable critical standard for no more than 8 hours during any 24-hour period. The following dissolved oxygen standards must be met:

Table 2.20 Minimum dissolved oxygen standards for Ozark Highland Streams (ADEQ Reg. 2).

Waterbodies	**Limit (mg/l)**	
Streams	Primary	Critical
Ozark Highlands		
<10 mi2 watershed	6	2
10 to 100 mi2	6	5
>100 mi2 watershed	6	6

Reg. 2.509 Nutrients. Materials stimulating algal growth shall not be present in concentrations sufficient to cause objectionable algal densities or other nuisance aquatic vegetation or otherwise impair any designated use of the waterbody. Impairment of a waterbody from excess nutrients are dependent on the natural waterbody characteristics such as stream flow, residence time, stream slope, substrate type, canopy, riparian vegetation, primary use of waterbody, season of the year and ecoregion water chemistry. Because nutrient water column concentrations do not always correlate directly with stream impairments, impairments will be assessed by a combination of factors such as water clarity, periphyton or phytoplankton production, dissolved oxygen values,

dissolved oxygen saturation, diurnal dissolved oxygen fluctuations, pH values, aquatic-life community structure and possibly others.

2.3.2 Diurnal In-Stream Results

Diurnal in-stream results indicated one violation of Reg. 2 Numeric Criteria at SPG1 (upstream of the Springdale WWTP) during Critical Season 1, Event 1. (Appendix C). Maximum dissolved oxygen percent saturation measurements (Table 2.21), as well as diurnal dissolved oxygen and pH swings indicated increased primary production at multiple sites, but no violations of Reg. 2 Numeric Criteria were observed other than the one event at SPG1 during Event 1 Critical Season (Appendix C). Additional sampling events at some sites were collected when redeployment was required at other sites due to QA issues with a previous deployment. These deployments were analyzed as *additional events*.

Table 2.21 Diurnal in-stream dissolved oxygen percent saturation maximums from 72 hour data sonde deployments at select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009. Values greater than 120 are considered elevated.

	Sampling Sites									
Date	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Summer 2007 (Critical 1) Event 1	95	95	111	96	103	108	107	112	108	86
Summer 2007 (Critical 1) Event 2	90	100	96	94	98	103	107	120	117	88
Spring 2008 (Primary 1) Event 1	114	104	111	131	113	138	122	108	117	109
Spring 2008 (Primary 1) Event 2	104	100	110	105	108	102	119	131	124	108
Summer 2008 (Critical 2) Event 1	94	90	96	108	104	107	111	120	117	92
Summer 2008 (Critical 2) Event 2	103	99	111	127	117	106	104	113	115	93
Spring 2009 (Primary 2) Event 1	110	99	115	115	109	107	113	122	125	116
Spring 2009 (Primary 2) Event 2	110	104	131	139	129	124	115	127	115	105
Summer 2009 (Critical 3) Event 1	112	121	130	132	139	108	127	131	96	128
Summer 2009 (Critical 3) Event 2	109	108	146	165	151	122	141	121	120	115

2.4 Habitat and Geomorphology Methods and Results

2.4.1 Habitat and Geomorphology Assessment Methods

The ADEQ method for physical habitat assessment of Ozark Highlands, Boston and Ouachita mountain streams was used (modified from Barbour et al., 1999). Both qualitative (visual estimates, RBP Habitat Assessment) and quantitative (in-stream measurements, ADEQ In-stream and Riparian Assessment) approaches were used to develop a habitat profile for each sample reach. During each habitat assessment a measure of reach canopy openness was also conducted along with a measure of stream flow. Geomorphologic assessments were performed once at each site to define the general morphologic characteristics of the reach.

For the qualitative assessment ten broad habitat parameters were rated on a scale of zero to 20. The scores fall into one of four categories, optimal (20-16), sub-optimal (15-11), marginal (10-6), and poor (5-0). Habitat parameters assessed were epifaunal substrate/available cover, sediment deposition, channel flow status, channel alteration, bank stability, vegetative protection, riparian vegetative zone width, frequency of riffles (or bends), velocity/depth regime, and embeddedness. A sample scoring sheet is shown in Appendix D. The scores for the habitat parameters were then added together to give an overall rating score from zero to 200, with 200 being the highest.

For the quantitative assessment five parameters consisting of three to seven variables were measured or estimated. These parameters included: habitat type, habitat quantity, quantity of substrate based on fish use, quantity of in stream cover, and sediment on substrate. Each parameter for substrate type and in stream cover was given a score depending on its abundance. The scores given to the substrate parameters were multiplied by a factor to adjust these scores based on how they relate to fish habitat quality. Habitat type length, depth, and width measurements were measured for each habitat type. A sample scoring sheet is shown in Appendix D. The sediment on substrate parameter was scored according to the degree of embeddedness of substrate. A total score for each habitat type was calculated by summing the scores for the substrate type, in stream cover, and sediment on substrate. The scores from like habitats were averaged for each sampling station. The lengths of each habitat type were also summed. The total habitat type lengths were then divided by 100 and multiplied by the average habitat type score. This results in a single score for each habitat type for the reach for each sampling event.

Canopy openness measures were made at stations at approximately the bottom quarter, middle, and top quarter of each reach. The measurements were made using a convex densiometer. The densiometer was held level at approximately waist height while standing in the middle of the wetted channel. The densiometer face is divided into 24 squares. An estimate was made for each square of percent of canopy openness and a score given for each square from 0 to 4 with 0 denoting no canopy openness (complete vegetative coverage) and 4 denoting complete canopy openness (no vegetative coverage). This was done facing north, south, east, and west at all three stations. These readings were summed for each station, multiplied by 1.04, and subtracted from 100 to get overhead canopy cover. The three readings for the reach were averaged to get the canopy cover estimate for the reach.

Flow measures were taken by spanning the stream with a measuring tape and taking measures at approximately even increments of water depth and velocity. Depth and velocity reading were taken using a Flo-Mate Model 2000 Portable Flowmeter (Marsh-McBirney, Inc.). Flow was calculated using rectangular area estimation around each measured point. Some flow measures for OSG5 were taken from the USGS flow station "Osage Creek near Elm Springs".

Geomorphology assessments were conducted once at each site to characterize channel sinuosity, channel cross sectional area, channel slope, riffle and reach substrate characteristics, and bed-load particle size distribution. In the field the channels were surveyed using a total station (TPS 400 Series, Leica Geosystems). A representative riffle and representative pool cross section was measured at each site. Each cross section was monumented with capped rebar for future survey comparison. A longitudinal profile which included all areas sampled for habitat and biotics was measured at each site and was tied into the cross section monuments for future comparison. Two pebble counts were conducted at each site, a targeted riffle count, and a reach wide count. A bar sample was also collected at each site to assess bed load substrate distribution.

Pebble counts and bars samples were collected following methodology described in *Watershed Assessment of River Stability and Sediment Supply* (Rosgen, 2006) with some modification. Reach-wide and targeted riffle pebble counts were conducted. For the reach-wide count the relative percent of the reach in pool and riffle/run was estimated to 10%. Ten transects of the stream were sampled with the ratio in pools and runs/riffles being determined by the estimated percent, i.e. if 60% of the reach is pool, then 6 transects are in pools and 4 are in riffles/runs. For the targeted riffle counts 10 transects were conducted in a single representative riffle. For both types of count the same method was used for selecting and measuring the substrate. Ten equally spaced points on the streambed were sampled in each transect. The sample was selected by blindly touching the bottom of the stream and selecting the first object touched. The intermediate, or B, axis was measured and recorded.

Bar samples were collected by selecting an actively depositing gravel bar within the reach. At the bottom 1/3 of bar longitudinally and approximately 1/3 of the distance vertically from the thalweg the largest particle on the surface was found. After removing this particle, to be measured as the D100, approximately 6-8 inches of sediment from an approximately 10 inch in diameter circular area were removed and placed in a 5 gallon bucket and transported to the lab for analysis. In the lab sediment was dried at approximately 100 °C for approximately 24 hours. This was done to get a more accurate depiction of the fine sediment in the sample than wet sieving. D100 particles were measured and weighed after air drying for an extended period (greater than a week). Sieve sizes used were 4", 2.5", 1.25", 5/8", 5/16", No. 5, and No. 10 with the pan catching the remainder. All sieves were 8" diameter brass with steel mesh. The samples were passed through the 4" and 2.5" sieves manually and any particles which could not be passed through were examined for any clinging particles that would be removed if mechanically shaken then set aside for later weighing. The remaining sediment was placed in the remaining sieves in stages as necessary and shaken for 5 minutes. For some sites the No. 5, No. 10, and pan materials were processed a second time due to cohesion of fine clay particles. The materials from each tray were then weighed and the weight recorded. All data for geomorphologic assessment were entered into the computer program RIVERMorph (Version 3.1.0 Rivermorph LLC) for analysis. Longitudinal profiles were analyzed for slope. Cross sections were analyzed for cross sectional areas. Pebble counts and bars samples were analyzed for particle distribution.

2.4.2 Habitat and Geomorphology Results

Results of the qualitative habitat assessment show that while the reference sites have better habitat that most sites were comparable with the exception of SPG1 (Table 2.22), full results can be found in Appendix D. Results of the quantitative habitat assessment were more variable from season to season and among sites, this was mostly due to the transient nature of the woody debris and stage during time of sampling (Tables 2.23-2.27), full results can be found in Appendix D. Canopy cover was notably higher at the reference sites than at most test sites with the lowest values occurring at OSG4, OSG5, and SPG1 (Table 2.28). Flow varied from season to season at sites but was relatively consistent during biotic events with the increase due to WWTP effluent comprising as much as 50% of the flow at OSG5 (Table 2.29), full flow results for all times flow was measured can be found in Appendix D. Geomorphology results gave the best indication of substrate in each reach, demonstrating the predominance of bedrock at OSG2, SPG2, and SPG3 (Figure 2.09). Overall geomorphology results can be found in Appendix D.

Table 2.22 EPA Rapid Bioassessment Protocol habitat assessment scores at select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009..

	Sampling Sites									
Date	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Summer 2007 (Critical Season 1)	152	151	161	167	163	141	145	162	175	168
Summer 2008 (Critical Season 2)	117	130	150	136	142	134	140	149	155	170
Summer 2009 (Critical Season 3)	157	143	161	120	146	147	151	157	158	165
Spring 2008 (Primary Season 1)	156	146	158	150	164	135	146	152	156	179
Spring 2009 (Primary Season 2)	152	132	152	140	153	135	130	159	160	163
Averages	147	140	156	143	154	138	142	156	161	169

Table 2.23 ADEQ in-stream and riparian habitat assessment scores summary for select sites in the Osage Creek and Illinois River basins, Summer 2007 (Critical Season 1).

CSREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	42.6	209	89.0
Riffle	29.8	127	37.8
Run	35.6	107	38.1

LOREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	68.7	258	177.2
Riffle	57.5	200	115
Run	0	0	0

SPG1

	Average Habitat Score	Total Length (ft)	IHI
Pool	40.0	271	108.3
Riffle	21.5	84	18.0
Run	18.7	52	9.7

SPG2

	Average Habitat Score	Total Length (ft)	IHI
Pool	42.7	305	130.2
Riffle	27.7	164	45.3
Run	23.8	72	17.1

SPG3

	Average Habitat Score	Total Length (ft)	IHI
Pool	58.4	398	232.2
Riffle	60.3	241	145.3
Run	39.9	134	53.5

OSG1

	Average Habitat Score	Total Length (ft)	IHI
Pool	39.5	258	101.9
Riffle	30.2	201	60.7
Run	28.6	81	23.1

OSG2

	Average Habitat Score	Total Length (ft)	IHI
Pool	44.2	203	89.7
Riffle	35.5	56	19.9
Run	35.6	151	53.8

OSG3

	Average Habitat Score	Total Length (ft)	IHI
Pool	55.0	440	241.8
Riffle	58.5	378	221.1
Run	0	0	0

OSG4

	Average Habitat Score	Total Length (ft)	IHI
Pool	59	105	62.0
Riffle	49.4	243	120.0
Run	52.6	128	67.3

OSG5

	Average Habitat Score	Total Length (ft)	IHI
Pool	NS	NS	NS
Riffle	NS	NS	NS
Run	NS	NS	NS

Table 2.24 ADEQ in-stream and riparian habitat assessment scores summary for select sites in the Osage Creek and Illinois River basins, Summer 2008 (Critical Season 2).

CSREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	52	292	151.8
Riffle	51	135	68.9
Run	0	0	0

LOREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	20.6	255	52.4
Riffle	25.0	197	49.3
Run	0	0	0

SPG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	40.1	191	76.5
Riffle	29.5	180	53.1
Run	0	0	0

SPG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	25.4	150	38.1
Riffle	19	85	16.2
Run	27.9	222	61.9

SPG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	0	0	0
Riffle	26.8	239	63.9
Run	29.3	419	122.8

OSG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	40.3	440.9	177.7
Riffle	41.3	49.2	20.3
Run	0	0	0

OSG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	0	0	0
Riffle	32.9	95	31.2
Run	42.7	145	61.9

OSG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	29	210	60.9
Riffle	21.5	51	11.0
Run	25.5	169	43.1

OSG 4

	Average Habitat Score	Total Length (ft)	IHI
Pool	31.9	665	65.7
Riffle	0	0	0
Run	20.4	350	71.5

OSG 5

	Average Habitat Score	Total Length (ft)	IHI
Pool	26.5	159	42.1
Riffle	19.5	315	61.4
Run	0	0	0

Table 2.25 ADEQ in-stream and riparian habitat assessment scores summary for select sites in the Osage Creek and Illinois River basins, Summer 2009 (Critical Season 3).

CSREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	33.3	307	102.2
Riffle	31.8	187	59.5
Run	0	0	0

LOREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	31.9	214	68.3
Riffle	27.4	202	55.3
Run	29	91	26.4

SPG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	34.4	242	83.2
Riffle	22.6	85	19.2
Run	27.5	55	15.1

SPG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	0	0	0
Riffle	28.3	175	49.4
Run	29.2	356	104.0

SPG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	26.7	117	31.2
Riffle	26.1	146	38.0
Run	33.3	140	46.6

OSG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	31.7	372	118.0
Riffle	24.0	191	45.7
Run	32.8	83	27.2

OSG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	27.6	285	78.7
Riffle	24.6	373	91.6
Run	0	0	0

OSG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	24.9	188	46.8
Riffle	29.7	230	68.3
Run	29.9	193	57.7

OSG 4

	Average Habitat Score	Total Length (ft)	IHI
Pool	35.5	313	111.0
Riffle	19.9	229	45.6
Run	0	0	0

OSG 5

	Average Habitat Score	Total Length (ft)	IHI
Pool	28.6	82	23.5
Riffle	23.2	367	85.0
Run	31.6	215	67.9

Table 2.26 ADEQ in-stream and riparian habitat assessment scores summary for select sites in the Osage Creek and Illinois River basins, Spring 2008 (Primary Season 1).

CSREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	39.4	248	97.7
Riffle	37.6	156	58.7
Run	29.7	23	6.8

OSG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	30.6	235	71.8
Riffle	19.8	129	25.5
Run	31.0	164	50.8

LOREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	32.1	252	80.9
Riffle	21.9	90	19.7
Run	37.5	102	38.2

OSG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	0	0	0
Riffle	24.2	175	42.4
Run	21.9	278	60.9

SPG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	27.5	249	68.4
Riffle	28.5	133	37.9
Run	0	0	0

OSG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	32.7	166	54.3
Riffle	26.7	203	54.1
Run	30.9	135	41.7

SPG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	25.5	205	52.3
Riffle	17.8	32	5.7
Run	21.0	157	32.9

OSG 4

	Average Habitat Score	Total Length (ft)	IHI
Pool	36.9	272	100.2
Riffle	31.8	223	70.9
Run	26.2	137	35.9

SPG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	0	0	0
Riffle	22.1	189	41.8
Run	30.2	318	96.0

OSG 5

	Average Habitat Score	Total Length (ft)	IHI
Pool	0	0	0
Riffle	27.6	293	80.9
Run	45.6	155	70.7

Table 2.27 ADEQ in-stream and riparian habitat assessment scores summary for select sites in the Osage Creek and Illinois River basins, Spring 2009 (Primary Season 2).

CSREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	47.3	266	125.7
Riffle	29.2	145	42.3
Run	32.6	61	19.9

OSG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	29.2	284	82.8
Riffle	20.5	145	29.7
Run	21.8	150	32.7

LOREF

	Average Habitat Score	Total Length (ft)	IHI
Pool	29.6	241	71.3
Riffle	24.5	199	48.8
Run	26.6	88	23.4

OSG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	23.2	139	32.2
Riffle	16.5	181	29.9
Run	16.5	273	45.0

SPG 1

	Average Habitat Score	Total Length (ft)	IHI
Pool	28.0	251	70.2
Riffle	20.5	107	21.9
Run	19.5	41	8.0

OSG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	29.1	192	55.8
Riffle	85.4	144.5	123.3
Run	67.7	217.5	147.3

SPG 2

	Average Habitat Score	Total Length (ft)	IHI
Pool	24.2	75	18.2
Riffle	21.1	133	28.1
Run	23.3	183	42.6

OSG 4

	Average Habitat Score	Total Length (ft)	IHI
Pool	19.3	184	35.5
Riffle	20.2	336	67.9
Run	32.1	58	18.6

SPG 3

	Average Habitat Score	Total Length (ft)	IHI
Pool	33.5	150	50.3
Riffle	26.0	138	35.9
Run	34.5	146	50.4

OSG 5

	Average Habitat Score	Total Length (ft)	IHI
Pool	24.3	126	30.6
Riffle	16.9	319	53.8
Run	34.7	246	85.4

Table 2.28 Average reach canopy cover percent for select sites in the Osage Creek and Illinois River basins, critical season 2007 to critical season 2009.

Date	Sampling Sites									
	OSG1	OSG2	OSG3	OSG4	OSG5	SPG1	SPG2	SPG3	LOREF	CSREF
Summer 2007 (Critical Season 1)	40	70	72	18	n/s	28	41	75	63	62
Summer 2008 (Critical Season 2)	35	n/s	68	30	19	22	56	38	77	75
Summer 2009 (Critical Season 3)	46	39	62	9	12	22	31	26	62	69
Spring 2008 (Primary Season 1)	64	78	49	13	10	24	57	47	74	n/s
Spring 2009 (Primary Season 2)	61	37	55	3	17	27	27	33	72	66
Critical Season Averages	40	55	67	19	16	24	43	46	67	69

Table 2.29 Stream flow in cubic feet per second (cfs) for select sites in the Osage Creek and Illinois River basins, critical season 2007 to critical season 2009.

Date	Sampling Sites									
	OSG1	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Summer 2007 (Critical Season 1)	23.5	45.9	n/s	73.5	75.0	4.3	21.7	n/s	10.5	1.6
Spring 2008 (Primary Season 1)	44.5	57.5	48.2	146.3	257.0	10.4	37.1	71.8	46.5	14.6
Summer 2008 (Critical Season 2)	14.3	31.9	34.2	66.6	193.4	9.4	34.8	58.6	41.4	7.0
Spring 2009 (Primary Season 2)	45.2	36.5	54.2	102.6	190.0	11.3	34.3	74.6	43.4	6.9
Summer 2009 (Critical Season 3)	18.1	17.1	26.0	61.7	83.4	4.5	27.3	37.6	18.7	1.6

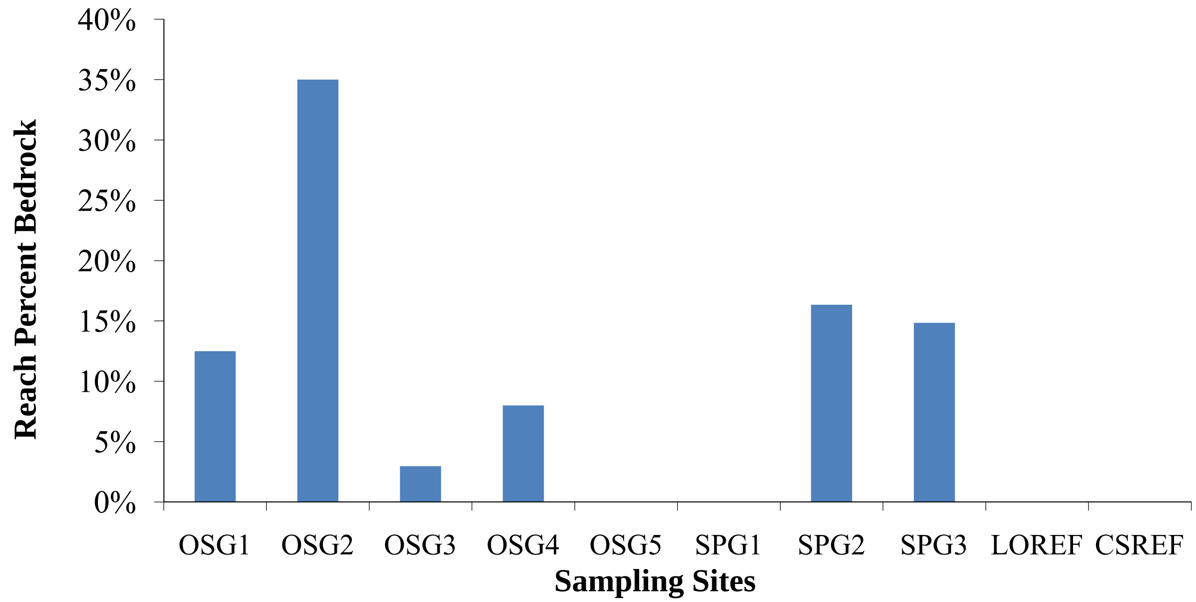

Figure 2.09 Reach percent bedrock for select sites in the Osage Creek and Illinois River basins. Notice that OSG2 and SPG2 have the highest percent bedrock.

2.5 Periphyton Assessment Methods and Results

2.5.1 Periphyton Assessment Methods

The sampling events for periphyton occurred August 2007 through October 2007, and in June 2008, November 2008, March 2009, and September 2009. The field data collections consisted of sampling from natural substrates, as well as two-week deployments of passive diffusion periphytometers (PDPs) at each site.

2.5.1.1 Passive Diffusion Periphytometers (PDPs)

The PDP method was used to measure the response of periphyton to nutrient enrichment. This periphytic response was then used to determine the limiting nutrients (P and/or N) for each stream. The PDPs were constructed of 250 ml polyethylene containers capped with a 0.45 um nylon membrane covered by a 1.5 um glass fiber filter. Each container was filled with treatments of either nitrogen, nitrogen and phosphorus, phosphorus, or a control consisting of reverse osmosis (RO) water. The nutrient treatments consisted of 30 mg/L Na_2HPO_4 and/or 30 mg/L $NaNO_3$. The treatment containers were attached to a flotation device in a random pattern, and covered with aluminum mesh screen to protect the glass fiber filters from grazing (Ludwig, 2007).

The PDPs were then deployed at each site. The flotation devices were oriented parallel to stream flow, with the treatment containers submerged. After a 14-day growth period, the PDPs were retrieved, the treatment arrangements on each flotation device were recorded, and the colonized fiber filters were removed from the treatment containers. The filters were placed in test tubes containing 5 mL of 90 percent acetone solution saturated with magnesium carbonate to preserve the chlorophyll in each sample. The test tubes were numbered according to the container's position on the flotation device in a blind identification system to prevent bias. The samples were then wrapped in aluminum foil, and transported to the laboratory (Ludwig, 2007).

The trichromatic method for spectrophotometric determination of chlorophyll a, b and c was performed on the solution extracted from each glass fiber filter (Method 10200H 2c, APHA 1998). The amount of chlorophyll a per unit exposed filter area was then determined. The Tukey-Kramer multiple comparison test along with a one-way ANOVA test was used to compare periphytic response of nutrient enrichment from each treatment, and between sites. The significance level α=0.05 was used. Significant differences ($P < 0.05$) between treatments were considered to be indications of nutrient limitation (Ludwig, 2007). In addition, periphyton growth on the control treatments from each site were compared to one another within each season using the one-way ANOVA and Tukey-Kramer tests.

2.5.1.2 Natural Substrate Periphyton Collection

At each site, periphyton grown on natural substrates was collected from a riffle considered to be representative of the sampling reach. Ten rocks were collected at random from across the riffle in a line perpendicular to stream flow. A circle of known area was scribed onto the face of each rock, and the material within the circle was removed and rinsed into sample vials. The vials were then placed on ice and returned to the laboratory for analysis (Barbour et al., 1999, Briggs and Kilroy, 2000).

Five of the samples from each site were analyzed for ash free dry mass composition. The samples were filtered onto 1.5 um glass fiber filters that had been previously ashed at 400°C to remove any organic material. The filtered samples were then placed in a drying oven at 105°C for 24 hours to remove all of the moisture from the filters. The samples were then cooled in a dessicator, weighed, and placed in a muffle furnace at 400°C for four hours. The samples were removed from the furnace, cooled in a dessicator, and weighed. The difference in the dry mass of the samples/filters and their final ashed mass was considered to be the amount of organic material present in the sample (Barbour et al., 1999, Briggs and Kilroy, 2000). The mass of the organic material from each sample per unit of area sampled was then determined, and the amounts were compared between sites using the Tukey-Kramer multiple comparison test along with a one-way ANOVA.

The five remaining samples were filtered onto 1.5 um glass fiber filters and analyzed using the trichromatic method for spectrophotometric determination of chlorophyll a, b, and c (Method 10200H 2c, APHA 1998). Chlorophyll a was expressed in terms of the mass per unit area, and the amounts at each site were compared using the Tukey-Kramer multiple comparison test along with a one-way ANOVA.

2.5.2 Periphyton Assessment Results

2.5.2.1 Passive Diffusion Periphytometers Results

No sampling events at any sites suggested nutrient limitation from the passive diffusion periphytometer nutrient treatments (Appendix E). An example of the results of the one-way ANOVA and Tukey-Kramer comparisons of the nutrient treatments is given in Figure 2.10. Means and Tukey-Kramer groupings are given in Table 2.30. The treatments are given on the y-axis, with the amount of chlorophyll a in mg/cm^2 given on the x-axis. The means diamonds in the one-way ANOVA analysis on the left illustrates the sample mean (central horizontal line) and 95% confidence interval (endpoints in the vertical direction). In addition, the comparison circles on the right can be used to visually compare each group mean by examining the intersection of the circles. If the means are significantly different, the circles do not intersect at all, or intersect such that the outside angle of intersection is smaller than 90°. If the means are not significantly different, the circles intersect such that the outside angle of intersection is greater than 90°. The table of means and Tukey-Kramer groupings also contains this information in that groups of the same letter are statistically the same.

Analysis between sites of the control treatment from the passive diffusion periphytometers showed differences in ambient periphyton growth from reference levels at multiple sites each season (Appendix E). An example of the results of the one-way ANOVA and Tukey-Kramer comparisons of the control treatments is given in Figure 2.11. Means and Tukey-Kramer groupings are given in Table 2.31. The sites are given on the y-axis, and the amount of chlorophyll a in mg/cm^2 is given on the x-axis.

During the PDP sampling events, there were three instances in which the PDPs were lost completely. During the first primary season, the PDP from SPG1 was lost due to high flow, as were the PDPs at OSG1 and OSG4 during the second Critical Season .

2.5.2.2 Natural Substrate Periphyton Collection Results

The statistical comparisons of the amount of organic material per unit area from each site determined by the ash free dry mass analysis showed no statistical differences during Critical Season 1 and Primary Season 2, in Primary Season 1 and Critical Season 2 two sites (a different one in each season) showed statistically higher amounts, and in Critical Season 3 five sites showed increased mass (Appendix F). An example of the results of the one-way ANOVA and Tukey-Kramer comparisons of the organic material is given in Figure 2.12. Means and Tukey-Kramer groupings are given in Table 2.32. The sites are given on the x-axis, and the amount of organic material per unit area in (g/m^2) is given on the y-axis.

The statistical comparisons of the amount of chlorophyll a per unit area from each site were very similar to the ash-free dry mass results (Appendix F). An example of the results of the one-way ANOVA and Tukey-Kramer comparisons of the organic material is given in Figure 2.13. Means and Tukey-Kramer groupings are given in Table 2.33. The sites are given on the x-axis, and the amount of chlorophyll a per unit area in (mg/cm^2) is given on the y-axis.

During the chlorophyll a analysis of natural substrate periphyton samples, several of the vials broke, and the samples were lost. As a result, only two samples from OSG5 in the second Critical Season , OSG5 in the first primary season, and OSG3 in the second Primary Season were analyzed. When reviewing the results of the means comparisons from these three seasons, it should be noted that $n < 3$ for these sites.

For both PDPs and natural substrate sampling canopy cover was measured with the same method as described in the habitat methods section with the exception that one measurement was taken at each sample area (one at the point of PDP deployment and one at the riffle of natural substrate collection) rather than three across the entire reach since the periphyton are responsive only to immediate light availability (Table 2.34 and 2.35).

Table 2.30 Tukey-Kramer means comparison table with chlorophyll-a (mg/cm^2) means and groupings by nutrient treatment (Level) for passive diffusion periphytometers for OSG5 Critical Season 1.

Level	Group	Mean
P	A	0.0033
NP	A	0.0028
N	A	0.0027
C	A	0.0024

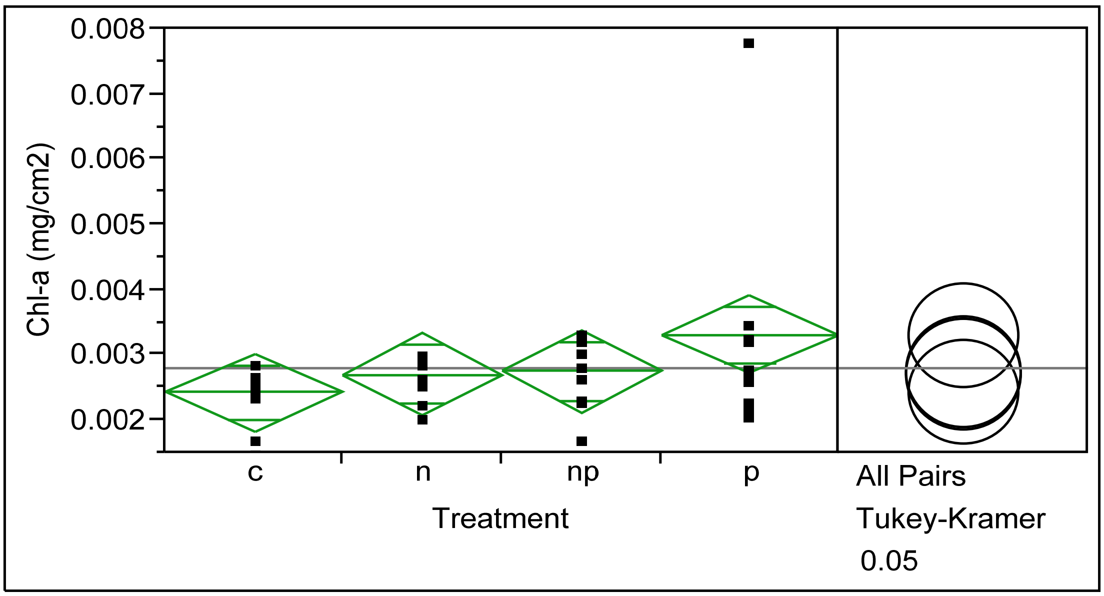

Figure 2.10 Statistical analysis figure for OSG5 Critical Season 1 passive diffusion periphytometer nutrient treatments. The x-axis is nutrient treatment (c – control, n – nitrogen, p – phosphorous, np – nitrogen and phosphorous) and the y-axis is chlorophyll-a concentration in mg/cm^2.

Table 2.31 Tukey-Kramer means comparison table with chlorophyll-a (mg/cm^2) means and groupings by sites (Level) for control treatments from passive diffusion periphytometers for Critical Season 1.

Level	Group		Mean
OSG4	A		0.0121
SPG1	B		0.0046
OSG2	B		0.0037
OSG5	B	C	0.0024
SPG2	B	C	0.0024
SPG3	B	C	0.0019
OSG1	B	C	0.0016
CSREF		C	0.0006
OSG3		C	0.0005
LOREF		C	0.0005

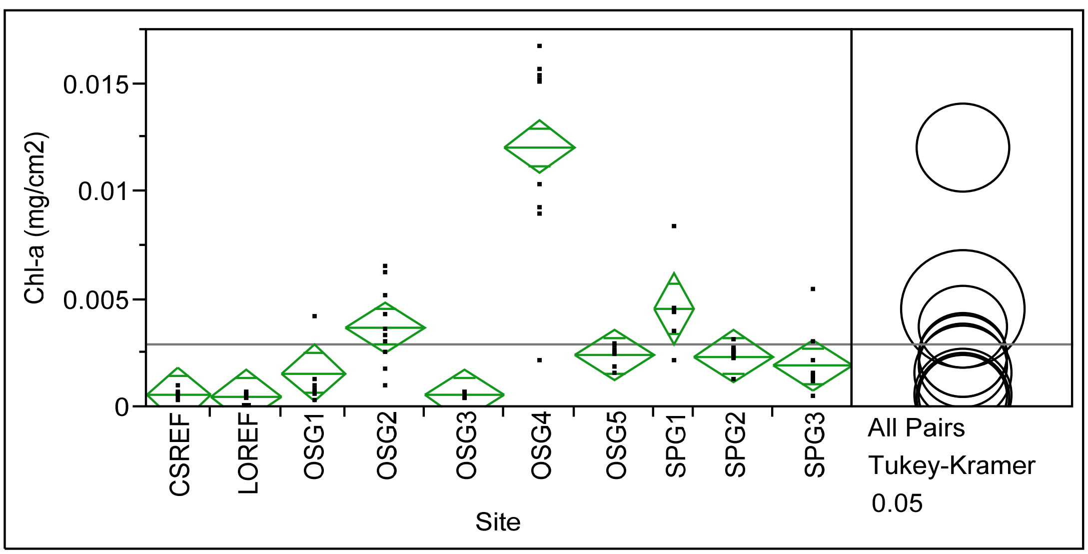

Figure 2.11 Statistical analysis figure for Critical Season 1 passive diffusion periphytometer control treatments. The x-axis is sites and the y-axis is chlorophyll-a concentration in mg/cm^2.

Table 2.32 Tukey-Kramer means comparison table with organic material (g/m^2) means and groupings by sites (Level) for natural substrate periphyton analysis for Critical Season 1.

Level	Group	Mean
OSG2	A	15.653
OSG4	A	8.315
OSG5	A	7.899
CSREF	A	6.148
LOREF	A	6.106
OSG1	A	5.691
SPG1	A	5.415
SPG2	A	4.272
OSG3	A	2.344
SPG3	A	1.741

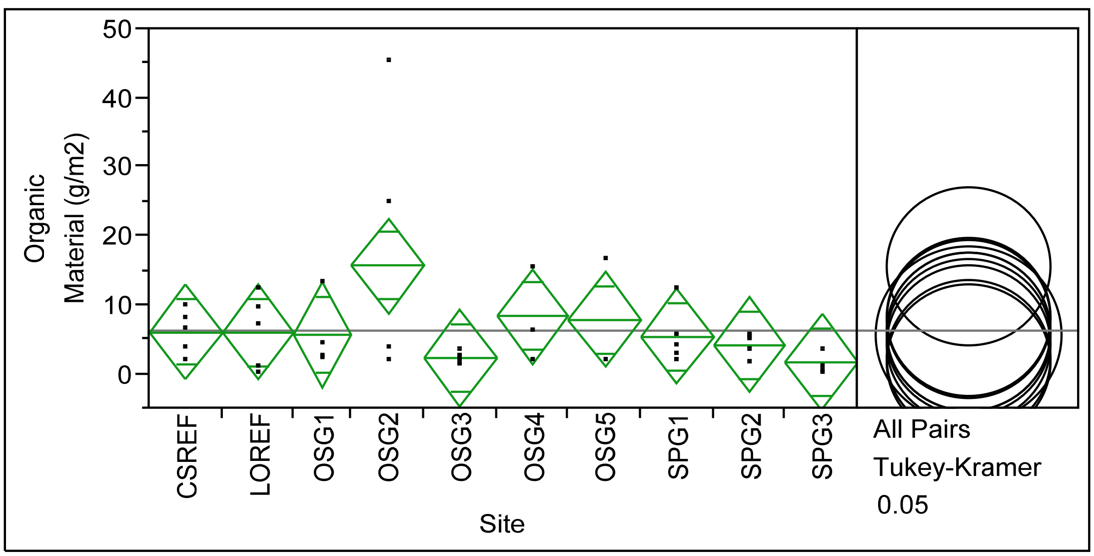

Figure 2.12 Statistical analysis figure for Critical Season 1 ash-free dry mass analysis of natural substrate periphyton samples. The x-axis is sites and the y-axis is organic material mass in g/m^2.

Table 2.33 Tukey-Kramer means comparison table with chlorophyll-a (mg/cm^2) means and groupings by sites (Level) for natural substrate periphyton analysis for Critical Season 1.

Level	Group	Mean
SPG2	A	0.0075
OSG5	A	0.0056
SPG1	A	0.0048
LOREF	A	0.0038
CSREF	A	0.0029
OSG3	A	0.0024
SPG3	A	0.0015
OSG1	A	0.0014
OSG4	A	0.0007
OSG2	A	0.0004

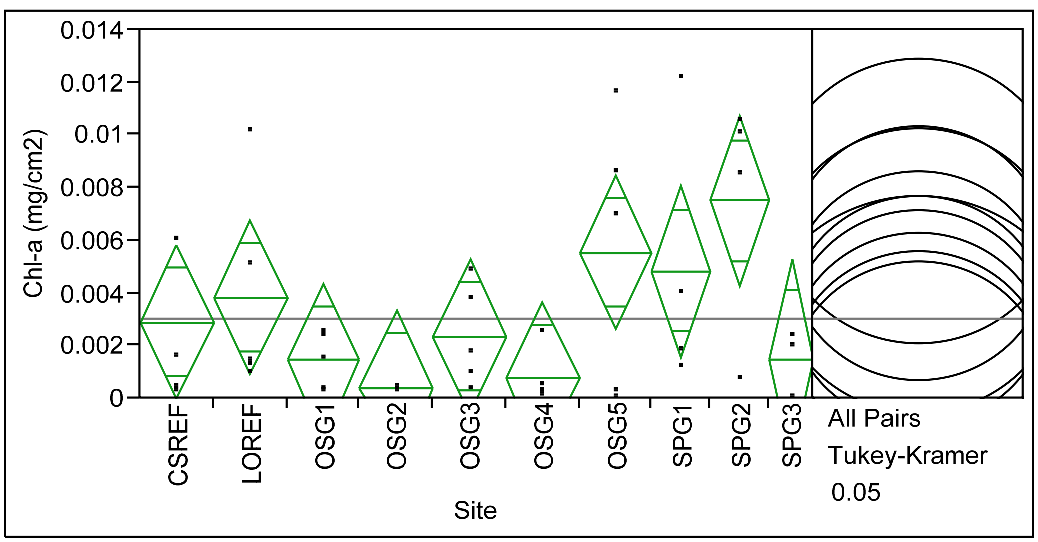

Figure 2.13 Statistical analysis figure for Critical Season 1 chlorophyll-a analysis of natural substrate periphyton samples. The x-axis is sites and the y-axis is chlorophyll-a concentration in mg/cm^2.

Table 2.34 Percent canopy cover results for passive diffusion periphytometer deployments at select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009.

Date	Sampling Sites									
	OSG1	OSG2	OSG3	OSG4	OSG5	SPG1	SPG2	SPG3	LOREF	CSREF
Summer 2007 (Critical Season 1)	26	19	42	0	49	44	26	39	61	61
Summer 2008 (Critical Season 2)	n/s	25	20	n/s	11	12	8	18	42	69
Summer 2009 (Critical Season 3)	67	49	42	11	31	29	56	38	63	85
Spring 2008 (Primary Season 1)	46	31	30	23	13	17	0	34	37	72
Spring 2009 (Primary Season 2)	46	19	18	9	14	12	2	1	28	24

Table 2.35 Percent canopy cover results for natural substrate periphyton collections at select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009.

Date	Sampling Sites									
	OSG1	OSG2	OSG3	OSG4	OSG5	SPG1	SPG2	SPG3	LOREF	CSREF
Summer 2007 (Critical Season 1)	41	51	38	0	14	38	14	10	53	61
Summer 2008 (Critical Season 2)	22	27	45	29	11	12	0	0	57	61
Summer 2009 (Critical Season 3)	72	23	36	20	8	21	22	6	54	69
Spring 2008 (Primary Season 1)	36	76	41	15	6	32	0	0	72	84
Spring 2009 (Primary Season 2)	1	19	28	9	3	12	0	25	19	29

2.6 Biotic Assessment Methods and Results

2.6.1 Biotic Assessment Methods

We adopted the methods described by the U. S. Environmental Protection Agency (EPA) and ADEQ (Rapid Bioassessment Protocols for Use in Streams and Wadeable Rivers: Periphyton, Benthic Macroinvertebrates and Fish, USEPA, http://www.epa.gov/owow/monitoring/rbp/ download.html). We analyzed fish and macroinvertebrate taxonomic assemblages with attendant habitat assessments at each of two reference and eight test sites (Figure 1.01) during summer of 2007, spring and summer 2008, and spring and summer 2009. Summer samples were planned to occur during the critical season of low flow and high temperatures (>22^{0}C) each year. However, no conditions representative of a critical season occurred during 2008, so an initially unplanned set of samples was collected in summer 2009 to enable analysis of two critical seasons. After completing analysis of the biological data, it could be seen that the data from September 2008 closely resembled results from the other two years. However, since it did not technically meet the conditions of a "critical season" those data were not included in calculations other than those used for setting scores for invertebrate biometrics.

The study was designed, particularly regarding location of data and sample collection sites, to evaluate water quality impairments, if any, resulting from the Waste Water Treatment Plants (WWTPs) of the cities of Springdale and Rogers on 1) the streams that immediately receive their effluent, and 2) the extended Osage Creek sub-basin of the Illinois River. A critical aspect of this was to obtain sets of samples and accompanying data that were fully comparable to each other among sampling locations. Obviously the samples had to be collected using the same methods, but also during stable weather conditions for the entire week or so required to complete each set.

2.6.1.1 Benthic Macroinvertebrate Methods

2.6.1.1.1 Benthic Macroinvertebrate Field Collections

Benthic macroinvertebrates were collected from two riffles in each of the study sites using a rectangular dip net and a slight modification of the single habitat approach described by USEPA (riffles only). The samples were taken using five locations for kick samples from areas representing the different water depths and flows from each of the two riffles; collections were biased toward the upstream ends of riffles. The heads of riffles in gravel bed streams with distinct riffle and pool structure have significantly more invertebrates than areas farther downstream (Brown and Brown 1984, Brussock and Brown 1991). The samples were pooled and placed in a tray for picking in the field. The net was examined and invertebrates clinging to it were collected. All visible macroinvertebrates were picked from the samples and placed into 75% ethyl alcohol. Large organic debris and rocks were examined for invertebrates and any found were collected before the organic debris or rocks were discarded. Larger insectivorous invertebrates (crayfish, hellgrammites) were temporarily placed in jars separate from the smaller invertebrates until the larger organisms had succumbed to the alcohol. This was necessary to prevent damage to smaller organisms by the large ones. Samples were appropriately labeled and returned to the lab for identification. Since the collectors and taxonomists were not different persons (Art & Kris Brown) there was no need for chain-of-custody forms to be completed. The biological samples were in the continuous custody of the same persons.

2.6.1.1.2 Benthic Macroinvertebrate Laboratory Methods

Benthic macroinvertebrates were processed in our laboratory following USEPA protocols (see also Barbour et al. 1999). Preserved benthic macroinvertebrates were washed from the respective sample bottles into a 500 um-mesh sieve, rinsed with tap water, and placed into a white tray with 6 cm X 6 cm grids marked on the bottom (total of 12 quadrants). The sample contents were gently mixed and spread in the tray so that they were reasonably homogenous. Numbers were then randomly selected to determine from which four of the 12 grids invertebrates would be picked. All invertebrates were removed from the first four randomly-selected grids and placed in a Petri dish while keeping track of the number picked. If 100 ± 20%, the target number, were picked from the first four grids, sorting was complete. If more than the target number were picked, the contents of the tray (the sample residue) were placed into a sample jar with 75% alcohol and the invertebrates in the Petri dish were returned to the gridded tray. A different set of numbers was randomly selected and corresponding grids were picked using the same method as before. If the number picked from the first four grids exceeded the target number, the whole process was repeated. If the number picked from the four grids was less than the target number, additional random grids were picked until the appropriate number of invertebrates was included. Invertebrates left from the secondary sortings were placed in separate vials and labeled as sorted residue.

Most of the benthic macroinvertebrates were identified to genus using taxonomic keys (e.g., Wiggins 1978, Poulton and Stewart 1991, Smith 2001, Thorp and Covich 2001, Merritt et al. 2008). An *a priori* decision was made to identify the Chironomidae only to family to save time and money required for further taxonomic refinement. Flat worms and leeches, having been preserved using only ethanol in the field, were not relaxed enough to identify past family or order. Instars too young or too badly damaged (missing legs, gills, mouth parts, etc.) were taken to the lowest taxonomic level, generally family, where certainty of identification was not comprised. Organisms were placed in vials with neoprene stoppers containing 75% alcohol and appropriately labeled and stored. Voucher specimens representing each taxon collected were preserved and labeled for subsequent verification and curation in the University of Arkansas Museum.

2.6.1.1.3 Benthic Macroinvertebrate Analysis

The analysis of the macroinvertebrate data is also rather completely prescribed by the USEPA and ADEQ, although ADEQ is still in the process of completing their decisions about analysis and interpretation of benthic macroinvertebrate data from the different ecoregions across the state. We followed their methods as closely as possible including conversing with ADEQ personnel regarding items about which we were unsure. The 11 biometrics we settled upon for the invertebrate Index of Biotic Integrity (IBI) are listed in Table 2.36. With the top score for each biometric assigned as 5, the highest possible total score was 55. It was necessary for us to establish scoring criteria (cut off values) for the biometrics based on our results. We chose to use all of our data from critical and primary seasons from all 10 collecting locations to determine these criteria, and to have them correspond to the 25% and 75% quartiles (Table 2.36). Note that there are only minor differences among the seasonal data (Fig. 2.11), which supports the decision to use all data instead of just those from the critical seasons for determining scoring limits, along with the fact that larger data sets tend to be more normally distributed.

2.6.1.2 Fish Methods

2.6.1.2.1 Fish Field Collections

Fish were collected from a 350 - 1000 foot long reach at each site that was selected to include the diverse habitats representative of each stream, i.e., riffles, pools, and flats (runs, glides). A one pass, upstream collection was made using a backpack electrofisher with block nets used where needed. The electrofisher output settings were adjusted to optimal performance levels at each site prior to each collection. At least three persons equipped with long-handled dip nets followed the person with the electrofisher to capture stunned fish and transfer them to another person for transport to a site established for holding the fish during identification and counting. The same person (Art Brown) was always responsible for identification of the fish at streamside, and for decisions regarding their release or collection for laboratory examination. Our goal was to release as many fish as quickly as possible to enhance their survival. Fish that were identifiable were released a sufficient distance downstream from the electrofisher to prevent them from being stunned again. Fish not readily identifiable in the field and those needed for voucher specimens were euthanized humanely and preserved in 10% buffered formalin solution, appropriately labeled, and taken to the laboratory for completion of identification and analysis. Fish, as with the macroinvertebrates, were in continuous custody of the same persons (Art and Kris Brown).

Stonerollers (*Campostoma* spp) are often identified only to genus due to the difficulty of identifying them to species and the requirement of microscopy for their specific identification, although it is known that there are two separate species that co-occur in these streams. We chose to separately account for both species of stonerollers. During the first collections (2007) we preserved all stonerollers that were not identifiable at streamside (males in breeding condition can be identified to species in the field), and identified them completely in the laboratory. There were such large numbers at some sites (> 400) that subsequently we began the practice of retaining 40-50 specimens for laboratory identification and applying a ratio of the species to the ones we released in the field. If there were fewer than 50 individuals, we preserved and examined all of them in the laboratory. This enabled us to count and identify each of these species independently of each other (central stoneroller = *C. anomalum,* largescale stoneroller = *C. oligolepis*). We felt that this was necessary because of the importance of these fish. They are very abundant in streams of the south central U. S., tolerant of pollution, primary feeders (grazers), and have a positive response to disturbances (Brown and Matthews 1995, Brown et al. 1998). Stonerollers have a strong impact on the IBI scores because they influence each of the biocriteria. One criterion is percent primary feeders. All but one of the criteria are based on percentages, and at disturbed sites they are very abundant, giving them a large impact. The other criterion is number of species, which is also affected by completely identifying the stonerollers.

2.6.1.2.2 Fish Laboratory Methods

In the laboratory, the preserved fish were washed in tap water to remove as much of the formalin as possible before close examination and manipulation. Fish were examined using a dissecting microscope and taxonomic keys (e. g., Pflieger 1975, Robison & Buchanan 1992). Difficult specimens were sent to Dr. Tom Buchanan at the University of Arkansas at Fort Smith for verification. Representative specimens were placed in museum jars, preserved in 75% ethanol, and appropriately labeled for deposition in the University of Arkansas Museum as voucher specimens. Remaining specimens were disposed of as hazardous waste by the University of Arkansas Office of Environmental Health and Safety.

2.6.1.2.3 Fish Analysis

The fish data were analyzed according to ADEQ methods for the Ozark Highlands Ecoregion as indicated in Table 2.37. This table, as well as tables designating key species and primary feeders were obtained through personal correspondence with ADEQ personnel.

2.6.2 Results of Biological Assessment

2.6.2.1 Benthic Macroinvertebrate Results

The invertebrate IBI scores showing results of individual biometrics (e. g., total taxa) are listed in Tables 2.38-2.42. A summary of the total IBI scores by season and site is in Table 2.43. Figure 2.14 illustrates the pattern of water quality among the sites as indicated by the invertebrate community analyses.

2.6.2.2 Fish Results

Results of the fish community analyses showing each biometric for each season and site are listed in Tables 2.44-2.48. The summary of total IBI scores for the fish community by season at each site is in Table 2.49. The patterns of water quality along Osage and Spring Creeks as indicated by variations in the fish community can be seen in Figure 2.15. The percent primary feeders at each site for each season was pulled out as an individual figure due to its importance in discerning impairment due to nutrients (Figure 2.16).

Table 2.36 Invertebrate metric scoring ranges established using the 25th and 75th percentile ranking of metric scores from all five collections performed during this study. Note that the % Isopoda metric was changed from "0.0%" indicated by the 25th percentile to "<2 " following our best professional judgment.

A. Invertebrate metric scoring ranges for the Osage and Spring Creek basins of the Illinois River, Arkansas.

Metric	5	3	1
Total Taxa	>17	17 – 12	<12
Number EPT Taxa	>8	8 – 5	<5
%EPT- %Hydropsychidae	>55	55 – 28	<28
% Scrapers	>33	5 – 33	<5
% Clingers	>68	68 – 23	<23
% Diptera	<4	4 – 24	>24
% Chironomidae	<3	3 – 22	>22
% Isopoda	<2	2 – 7	>7
% Tolerant Organisms	<2	2 – 12	>12
HBI	<4.1	4.1 - 5.2	>5.2
% Intolerant Organisms	>24	24 – 6	<6

B. Percentile ranking of metric scores from five collections from summer 2007 through summer 2009 used to establish scoring ranges for each of the biometrics.

Metric	Min	5th	25th	50th	75th	95th	Max
Total Taxa	8	8.45	12	15	17	19.55	23
Number EPT Taxa	2	2.45	5	6	7.75	10.55	14
%EPT- %Hydropsychidae	4.1%	9.3%	28.0%	44.4%	55.3%	67.1%	73.6%
% Scrapers	0.0%	0.0%	4.5%	17.1%	33.1%	48.4%	60.6%
% Clingers	2.8%	5.8%	23.4%	48.7%	67.7%	84.8%	92.1%
% Diptera	0.0%	0.0%	3.9%	10.6%	23.9%	55.9%	66.7%
% Chironomidae	0.0%	0.0%	2.5%	7.2%	21.6%	44.3%	57.5%
% Isopoda	0.0%	0.0%	0.0%	0.4%	6.8%	55.2%	72.5%
% Tolerant Organisms	0.0%	0.0%	1.7%	3.3%	12.1%	53.9%	67.0%
HBI	2.59	3.11	4.11	4.76	5.15	6.40	6.89
% Intolerant Organisms	0.0%	1.9%	5.7%	12.5%	23.8%	52.8%	64.7%

Table 2.37. Fish community biocriteria for Ozark Highland streams established by ADEQ (ADEQ personal communication).

A. Fish metric scoring ranges for the Osage and Spring Creek basins of the Illinois River, Arkansas. If a raw metric score is zero, score as zero, except for the % Primary Feeders metric. Total scores should be interpreted as: 37-45 mostly similar, 25-36 generally similar, 13-24 somewhat similar, and 12-0 not similar to reference streams in the Ozark Highland Ecoregion.

Metric	5	3	1
% Sensitive Individuals	>31	31 - 20	<20
% Cyprinidae (Minnows)	48 – 64	39 – 47 or 65 – 73	<39 or >73
% Ictaluridae (Catfishes)	>2[1]	1 - 2[1]	<1 or >3% bullheads
% Centrarchidae (Sunfishes)	4 - 15[2]	<4 or 15 - 20[2]	>20 or >2% Green sunfish
% Percidae (Darters)	>11	5 – 11	<5
% Primary Feeders	<42	42 – 49	>49
% "Key" Individuals	>23	23 – 16	<16
Diversity	>2.77	2.77 – 2.37	<2.37
# Species	>(watershed area**X**0.034)+16.45	(watershed area**X**0.034)+16.45 to (watershed area**X**0.034)+12.26	<(watershed area**X**0.034)+12.26

[1]no more than 3% bullheads
[2]no more than 2% Green sunfish

B. Watershed areas are used to calculate cut off scores for the # Species metric in Table 2.A above.

	Sampling Sites									
	OSG1	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Watershed Area (square miles)	32.1	32.4	35.6	80.6	128.6	12.7	13.2	35.3	35.4	8.3
(watershed area**X**0.034) + 16.45	18	18	18	19	21	17	17	18	18	17
(watershed area**X**0.034) + 12.26	13	13	13	15	17	13	13	13	13	13

Table 2.38 Invertebrate IBI individual and total metric scores at select sites in the Osage Creek and Illinois River basins for summer 2007 (Critical Season 1). See Table 2.36 for invertebrate metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Total Taxa	5	5	5	3	5	1	3	3	3	5
Number EPT Taxa	3	3	3	3	5	3	1	3	5	5
%EPT- %Hydropsychidae	5	1	1	3	3	1	3	1	3	5
% Scrapers	3	3	5	3	5	1	1	5	3	5
% Clingers	5	3	3	3	5	3	5	3	5	3
% Diptera	3	3	5	3	3	5	3	3	5	5
% Chironomidae	5	3	5	3	3	3	3	3	5	5
% Isopoda	5	1	1	5	5	1	1	1	5	5
% Tolerant Organisms	3	1	1	1	1	1	3	1	3	1
HBI	5	1	1	3	3	1	3	1	3	5
% Intolerant Organisms	5	5	5	1	5	5	5	5	5	5
Invertebrate IBI Total Scores	47	29	35	31	43	25	31	29	45	49

Table 2.39 Invertebrate IBI individual and total metric scores at select sites in the Osage Creek and Illinois River basins for spring 2008 (Primary Season 1). See Table 2.36 for invertebrate metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Total Taxa	3	3	3	1	5	1	1	3	5	5
Number EPT Taxa	3	3	3	3	5	1	1	3	3	5
%EPT- %Hydropsychidae	5	3	3	3	5	1	3	5	3	3
% Scrapers	5	3	3	5	5	1	1	3	5	5
% Clingers	3	3	3	3	3	3	3	3	3	3
% Diptera	3	1	3	3	3	3	3	3	3	5
% Chironomidae	3	1	3	3	3	5	3	3	5	5
% Isopoda	5	1	1	3	5	1	1	5	5	5
% Tolerant Organisms	3	1	3	5	3	1	3	5	3	3
HBI	5	3	3	3	5	1	3	3	5	5
% Intolerant Organisms	5	5	5	5	5	1	5	5	5	5
Invertebrate IBI Total Scores	43	27	33	37	47	19	27	41	45	49

Table 2.40 Invertebrate IBI individual and total metric scores at select sites in the Osage Creek and Illinois River basins for summer 2008 (Critical Season 2). See Table 2.36 for invertebrate metric cutoff values.

Metric	Sampling Sites									
	OSG1	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Total Taxa	3	3	3	3	5	3	1	5	5	5
Number EPT Taxa	3	3	3	3	5	1	1	5	3	5
%EPT- %Hydropsychidae	1	1	1	3	3	1	1	3	3	3
% Scrapers	3	3	1	5	5	1	1	3	3	5
% Clingers	3	3	3	3	5	3	3	3	3	3
% Diptera	3	1	1	3	3	1	1	1	3	5
% Chironomidae	3	1	1	3	3	1	1	3	3	5
% Isopoda	5	5	5	5	5	1	5	5	5	5
% Tolerant Organisms	5	5	3	5	5	3	3	3	5	3
HBI	3	3	1	3	3	1	3	3	3	5
% Intolerant Organisms	5	5	5	5	5	5	5	5	5	5
Invertebrate IBI Total Scores	37	33	27	41	47	21	25	39	41	49

Table 2.41 Invertebrate IBI individual and total metric scores at select sites in the Osage Creek and Illinois River basins for spring 2009 (Primary Season 2). See Table 2.36 for invertebrate metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Total Taxa	3	3	3	1	3	1	1	1	3	5
Number EPT Taxa	3	3	3	3	5	1	1	3	3	5
%EPT- %Hydropsychidae	5	3	3	5	5	3	3	5	5	5
% Scrapers	3	3	3	1	3	1	1	1	3	5
% Clingers	3	3	3	3	3	3	3	3	3	3
% Diptera	3	1	1	1	3	3	1	1	3	3
% Chironomidae	3	1	1	1	3	3	1	1	3	3
% Isopoda	5	1	5	5	5	1	3	5	5	5
% Tolerant Organisms	5	1	3	5	5	1	5	5	3	3
HBI	3	3	3	3	3	1	3	5	5	5
% Intolerant Organisms	5	5	5	5	5	1	1	5	5	5
Invertebrate IBI Total Scores	41	27	33	33	43	19	23	35	41	47

Table 2.42 Invertebrate IBI individual and total metric scores at select sites in the Osage Creek and Illinois River basins for summer 2009 (Critical Season 3). See Table 2.36 for invertebrate metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Total Taxa	3	1	3	3	3	3	3	1	3	5
Number EPT Taxa	3	3	3	5	5	3	3	3	1	5
%EPT- %Hydropsychidae	3	3	3	5	3	1	1	3	3	5
% Scrapers	3	3	3	3	3	1	1	3	3	3
% Clingers	5	5	5	5	5	3	3	5	3	5
% Diptera	3	5	5	5	3	5	1	5	5	5
% Chironomidae	3	3	5	5	3	5	1	5	5	5
% Isopoda	5	5	5	5	5	1	5	5	5	5
% Tolerant Organisms	5	5	5	3	3	1	3	5	5	5
HBI	3	1	3	3	3	1	1	3	5	5
% Intolerant Organisms	5	5	5	5	5	5	5	5	5	5
Invertebrate IBI Total Scores	41	39	45	47	41	29	27	43	43	53

Table 2.43 Invertebrate IBI total scores at select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009. The maximum possible score for a single sampling event is 55. Summer 2007 and 2009 collections were in critical seasons. During summer 2008 there was no critical season (i.e., low flow, temperature >22 C). Therefore critical season averages are for summer 2007 and summer 2009 only.

	Sampling Sites									
Date	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Summer 2007 (Critical Season 1)	47	29	35	31	43	25	31	29	45	49
Summer 2008 (Critical Season 2)	37	33	27	41	47	21	25	39	41	49
Summer 2009 (Critical Season 3)	41	39	45	47	41	29	27	43	43	53
Spring 2008 (Primary Season 1)	43	27	33	37	47	19	27	41	45	49
Spring 2009 (Primary Season 2)	41	27	33	33	43	19	23	35	41	47
Critical Season Averages	44	34	40	39	42	27	29	36	44	51

Table 2.44 Fish IBI individual metric and total scores at select sites in the Osage Creek and Illinois River basins for summer 2007 (Critical Season 1). See Table 2.37 for fish metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
% Sensitive Individuals	3	5	3	5	5	1	3	5	5	5
% Cyprinidae	5	5	1	5	1	1	3	5	5	3
% Ictaluridae	0	0	3	5	1	0	0	5	5	5
% Centrarchidae	1	1	1	5	5	3	5	1	3	5
% Percidae	5	5	3	5	3	3	5	3	5	5
% Primary Feeders	5	5	5	5	1	1	1	5	5	5
% Individuals Key Individuals	5	5	5	5	5	1	5	5	5	5
Diversity	5	3	3	1	1	1	1	1	1	3
Total Species	3	3	3	3	1	1	3	5	3	5
Fish IBI Total Scores	32	32	27	39	23	12	26	35	37	41

Table 2.45 Fish IBI individual metric and total scores at select sites in the Osage Creek and Illinois River basins for spring 2008 (Primary Season 1). See Table 2.37 for fish metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
% Sensitive Individuals	1	3	3	5	5	3	1	5	5	5
% Cyprinidae	5	1	1	1	3	1	1	5	1	1
% Ictaluridae	0	0	0	5	5	0	1	5	3	5
% Centrarchidae	1	1	1	5	3	3	5	1	5	5
% Percidae	5	5	5	3	3	5	3	3	5	3
% Primary Feeders	3	5	5	1	5	1	1	5	1	5
% Individuals Key Individuals	5	5	5	5	5	1	1	5	5	5
Diversity	5	1	1	3	1	1	5	1	1	3
Total Species	3	5	5	3	1	1	3	3	3	3
Fish IBI Total Scores	28	26	26	31	31	16	21	33	29	35

Table 2.46 Fish IBI individual metric and total scores at select sites in the Osage Creek and Illinois River basins for summer 2008 (Critical Season 2). See Table 2.37 for fish metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
% Sensitive Individuals	1	1	5	3	5	3	1	5	5	5
% Cyprinidae	3	1	5	1	3	1	1	1	3	1
% Ictaluridae	0	1	0	5	5	0	3	5	5	5
% Centrarchidae	1	1	1	0	3	3	5	5	1	5
% Percidae	5	3	3	3	5	1	1	3	5	3
% Primary Feeders	5	1	5	1	5	1	1	1	5	5
% Individuals Key Individuals	5	1	5	5	5	1	3	5	5	5
Diversity	5	3	3	1	1	1	1	1	1	3
Total Species	3	3	3	1	1	1	5	3	1	5
Fish IBI Total Scores	28	15	30	20	33	12	21	29	31	37

Table 2.47 Fish IBI individual metric and total scores at select sites in the Osage Creek and Illinois River basins for spring 2009 (Primary Season 2). See Table 2.37 for fish metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
% Sensitive Individuals	1	5	3	3	5	5	5	5	5	5
% Cyprinidae	3	3	5	1	1	5	1	5	5	1
% Ictaluridae	0	0	3	5	5	0	1	5	3	5
% Centrarchidae	1	1	1	1	3	0	3	1	1	3
% Percidae	5	5	5	3	5	5	1	5	5	5
% Primary Feeders	5	5	5	1	5	1	1	5	5	5
% Individuals Key Individuals	5	5	5	5	5	1	5	5	5	5
Diversity	3	5	5	5	3	1	5	5	5	5
Total Species	3	1	5	3	1	1	1	3	3	3
Fish IBI Total Scores	26	30	37	27	33	19	23	39	37	37

Table 2.48 Fish IBI individual metric and total scores at select sites in the Osage Creek and Illinois River basins for summer 2009 (Critical Season 3). See Table 2.37 for fish metric cutoff values.

	Sampling Sites									
Metric	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
% Sensitive Individuals	1	3	5	3	5	5	3	3	5	5
% Cyprinidae	5	3	5	5	1	1	1	1	1	5
% Ictaluridae	1	1	5	3	5	0	0	5	3	5
% Centrarchidae	1	1	1	3	5	0	3	3	1	3
% Percidae	5	3	5	5	5	5	1	5	5	5
% Primary Feeders	1	1	5	3	5	1	1	1	5	5
% Individuals Key Individuals	5	3	5	5	5	1	5	5	5	5
Diversity	5	5	5	5	5	1	1	3	5	1
Total Species	5	5	3	3	3	1	5	3	5	3
Fish IBI Total Scores	29	25	39	35	39	15	20	29	35	37

Table 2.49 Summary of fish IBI total scores at select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009. Summer 2007 and 2009 collections were in critical seasons. During summer 2008 there was no critical season (i.e., low flow, temperature >22 C). Therefore critical season averages are for summer 2007 and summer 2009 only.

	Sampling Sites									
Date	**OSG1**	**OSG2**	**OSG3**	**OSG4**	**OSG5**	**SPG1**	**SPG2**	**SPG3**	**LOREF**	**CSREF**
Summer 2007 (Critical Season 1)	32	32	27	39	23	12	26	35	37	41
Summer 2008 (Critical Season 2)	28	15	30	20	33	12	21	29	31	37
Summer 2009 (Critical Season 3)	29	25	39	35	39	15	20	29	35	37
Spring 2008 (Primary Season 1)	28	26	26	31	31	16	21	33	29	35
Spring 2009 (Primary Season 2)	26	30	37	27	33	19	23	39	37	37
Critical Season Averages	30.5	28.5	33.0	37.0	31.0	13.5	23.0	32.0	36.0	39.0

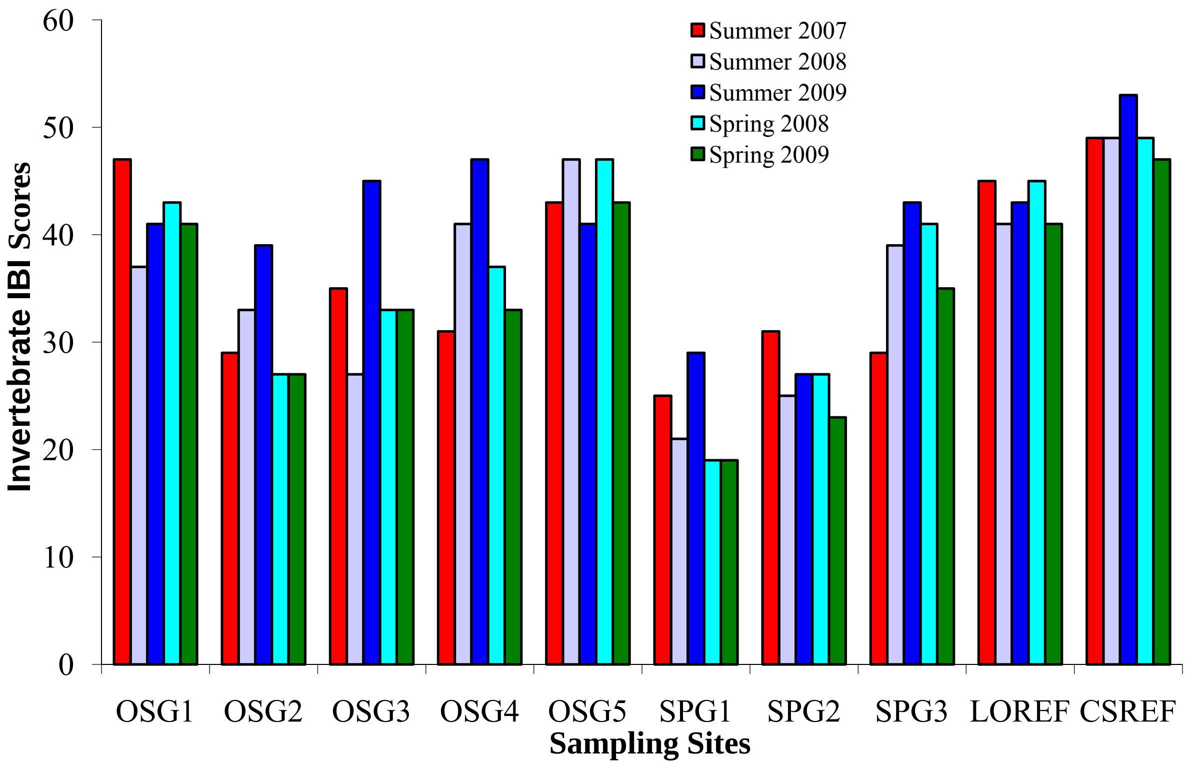

Figure 2.14 Invertebrate Index of Biotic Integrity (IBI) scores for select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009. Summer 2007 and 2009 collections were in critical seasons. During summer 2008 there was no critical season (i.e., low flow, temperature >22 C).

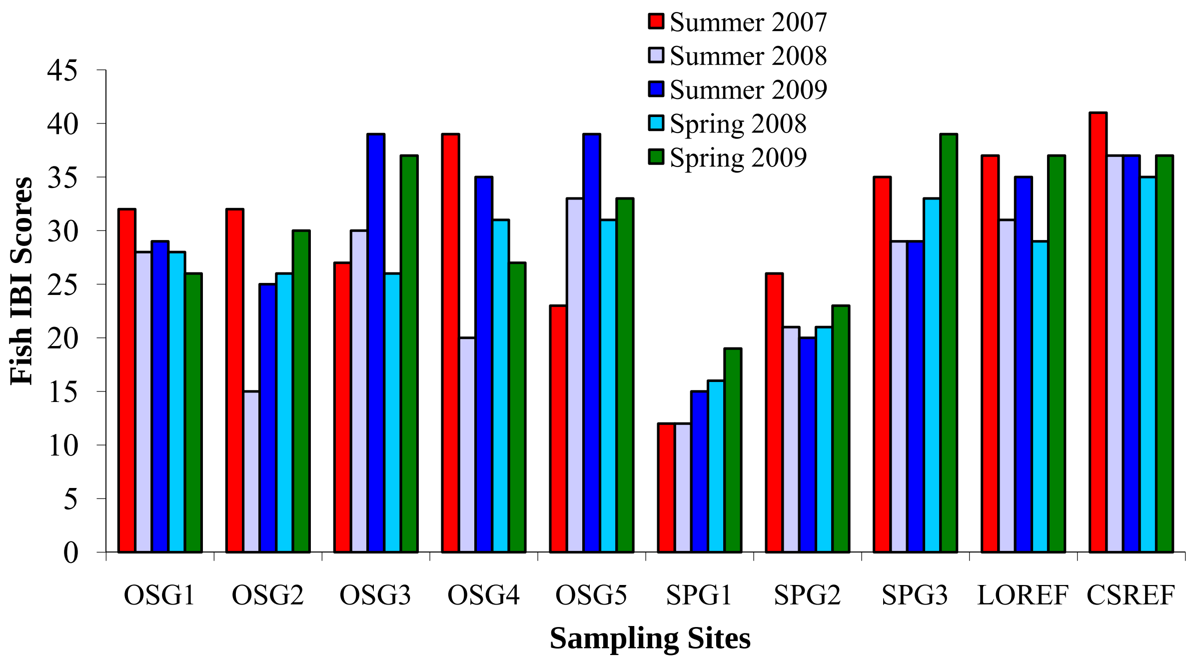

Figure 2.15 Fish Index of Biotic Integrity (IBI) scores for select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009. Summer 2007 and 2009 collections were in critical seasons. During summer 2008 there was no critical season (i.e., low flow, temperature >22 C).

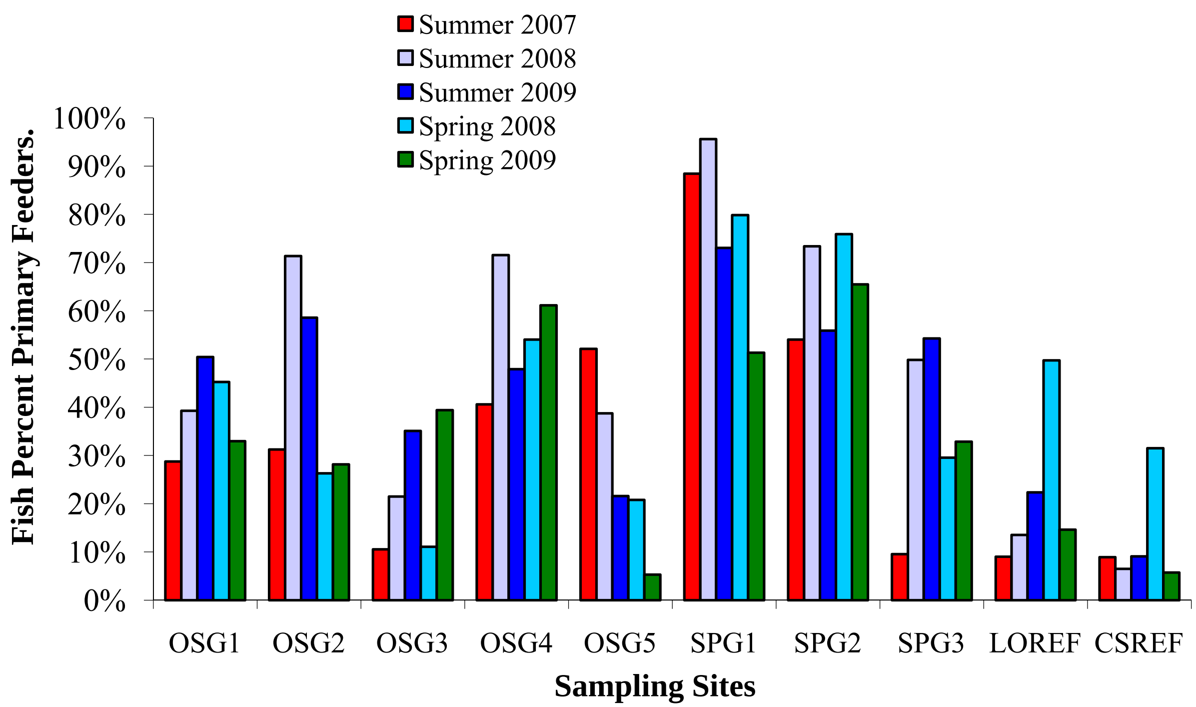

Figure 2.16 Percent primary feeders for select sites in the Osage Creek and Illinois River basins from critical season 2007 through critical season 2009. Summer 2007 and 2009 collections were in critical seasons. During summer 2008 there was no critical season (i.e., low flow, temperature >22 C).

Section 3: Discussion

3.1 Water Chemistry Discussion

3.1.1 Effect of Effluent Discharges – Upstream and Down

Osage Creek

The effluent discharge altered some of the measured physico-chemical properties in Osage Creek, while other parameters showed no statistical differences overall or in any individual season (i.e., primary and critical) (Tables 2.03 – 2.16, Figures 2.01-2.08). The effluent discharge did not significantly alter turbidity, total suspended solids, or sestonic chlorophyll-a concentrations compared to that observed upstream; there were no significant differences overall (all data) or within any critical or primary season (paired T-test, $P>0.05$). Overall, pH and dissolved oxygen concentrations were not significantly different downstream compared to upstream ($P>0.05$), except pH was significantly greater downstream (7.7) compared to upstream (7.5) during critical season 2009 ($P=0.03$) and dissolved oxygen was greater also in primary season 2008-9 (downstream 9.1 mg L^{-1} compared to upstream 8.6 mg L^{-1}, $P<0.01$). Overall nutrient concentrations (including SRP, TP, NH_4-N, NO_2-N, NO_3-N, TN and TOC) were generally greater downstream from the effluent discharge relative to upstream ($P<0.05$). However, there were random times where various nutrient concentrations were not statistically different in individual critical and primary seasons. The effluent discharge also significantly increased water temperature and conductivity relative to upstream ($P<0.05$).

Spring Creek

The effluent discharge at Spring Creek influenced some physico-chemical properties compared to that observed upstream (Tables 2.03 – 2.16, Figure 2.01). However, turbidity, total suspended solids, sestonic chlorophyll-a and nitrate-nitrogen concentrations were not significantly different downstream overall (all data, paired T-test, $P>0.05$); there were a few occurrences where seasonal differences were noted with nitrate-nitrogen, sestonic chlorophyll-a and turbidity, when comparing data upstream and down from the effluent discharge ($P<0.05$). For example, nitrate-nitrogen concentrations were greater downstream from the effluent discharge during the critical seasons ($P<0.05$). Overall, pH, conductivity, water temperature, dissolved oxygen and the other nutrients (including SRP, TP, NH_4-N, NO_2-N, TN and TOC concentrations) were greater downstream from the effluent discharge compared to upstream at Spring Creek ($P<0.05$). All of the aforementioned physico-chemical properties (except NO_2-N and dissolved oxygen) were generally greater downstream from the effluent discharge in all seasons ($P<0.05$), except pH and TN were not different during primary season 2007-8 ($P>0.05$). Nitrite-nitrogen concentrations were greater downstream compared to upstream in critical seasons 2008 and 2009 ($P\leq0.03$), and dissolved oxygen concentrations were greater downstream during 2008 through primary season 2008-9 ($P\leq0.05$).

Water Quality Standards

The numeric water quality standards that apply to these Ozark Highland streams were compared to the physico-chemical properties measured in the water samples collected upstream and downstream from the effluent discharges in Osage Creek and Spring Creek. The pH of the water samples was slightly basic, ranging from 7.5 to 8.3 across all data collected at these two streams; although pH significantly increased at Spring Creek, the increase was small from 7.7 upstream to only 7.9 downstream. There was a profound increase in conductivity downstream (range: 172-893 µS cm-1), where conductivity upstream (range: 120-401 µS cm-1) was reflective of streams draining catchments with urban and pasture land use. Water temperatures measured in water samples on-site showed a slight but significant increase from upstream to down at Osage Creek (means: 16.6 and 17.6 °C, respectively) while the increase at Spring Creek was greater from upstream to downstream (means: 17.6 and 21.1 °C, respectively), with some maximum values downstream that exceeded the ADEQ Reg. 2 standard of 29.0 °C. The dissolved oxygen concentrations represent single data points during day light hours (typically morning to early afternoon), and the range in concentrations (5.5-12 mg L-1) across all data collected was above the threshold for warm water fisheries (5 mg L-1, Arkansas Regulation 2). The turbidity criterion that applies to these streams is 10 NTU (specific to the Ozark Highlands); there were no values upstream or at the first site downstream that exceeded this criterion in the collected water samples. The effluent discharges did significantly increase nutrient concentrations in both streams, although the biological data needs to be evaluated to ascertain any violations of the narrative nutrient criteria as written in Arkansas Regulation 2.

3.1.2 Longitudinal Patterns in Physico-Chemical Properties

Water quality comparisons across multiple sampling sites are complex, and specific comparisons will be provided within the parameter tables. However, it is more informative to discuss general longitudinal gradients (upstream to downstream patterns), especially with regard to nutrient concentrations since only narrative nutrient criteria currently exist. Phosphorus (i.e., SRP and TP) concentrations significantly increased downstream (OSG2 and SPG2) of the effluent discharges compared to upstream (OSG1 and SPG1), and then concentrations in upper Osage Creek (OSG3) and Spring Creek (SPG3) decreased from dilution (groundwater and lateral inputs, i.e. tributaries) and possibly in-stream retention. The phosphorus concentrations in lower Osage Creek (OSG4) were increased downstream from its confluence with Spring Creek, but concentrations again decreased in this reach (OSG5). These observations are consistent with previous studies (Haggard et al., 2003a; Haggard, 2005; Ekka et al., 2006) that showed that phosphorus concentrations generally increased upstream in Osage Creek to each effluent discharge. However, phosphorus concentrations are much less in lower Osage Creek and Spring Creek than what was historically observed (see Haggard et al., 2003; Ekka et al., 2006). This change resulted from improved phosphorus management at the Springdale WWTP, and this watershed management change has resulted in decreased phosphorus transport in the Illinois River (B.E. Haggard, unpublished data).

The longitudinal patterns in ammonia-nitrogen and total organic carbon were similar to that observed with phosphorus, where the effluent discharge increased concentrations and then concentrations decreased downstream. The loss in ammonia downstream may be attributed to the incredible nitrification rates often observed in streams (e.g., see Haggard et al., 2005). The longitudinal decrease in total organic carbon was likely from dilution and mineralization of the organic carbon input from the effluent discharge.

The longitudinal gradient in nitrate-nitrogen and total nitrogen was not as consistent moving from upstream to downstream. These concentrations generally increased below the effluent discharge compared to that measured upstream. In Spring Creek, nitrate and total nitrogen increased downstream (from SPG2 to SPG3); this increase may be partially attributed to nitrification of reduced nitrogen in the effluent discharge. However, the concentrations slightly decreased in upper Osage Creek. Further downstream in lower Osage Creek, the concentration of these two constituents increased (from OSG4 to OSG5). The increases in Spring Creek and lower Osage Creek may also be from catchment sources. Several studies have shown that nitrate-nitrogen and total nitrogen concentrations during base flow conditions in streams increase with increases in pasture land use (or decreases in forested areas) within the catchment (e.g., Haggard et al., 2003b, 2007). Thus, the increased concentration likely reflects nitrogen sources from the catchment along the longitudinal profile.

3.1.3 Reference Condition Comparisons

The two selected reference streams, Chamber Springs (CSREF) and Little Osage Creek (LOREF), showed some distinct differences in select physico-chemical properties, while others were not different between the two streams overall (Tables 2.03 – 2.16, Figures 2.01 – 2.08). Total phosphorus concentrations were not significantly different between Chamber Springs (0.048 mg L^{-1}) and Little Osage Creek (0.046 mg L^{-1}), despite substantial differences in catchment land uses. However, dissolved phosphorus was greater at Chamber Springs (0.037 mg L^{-1}) compared to that observed at Little Osage Creek (0.031 mg L^{-1}) overall (all data, paired T-test, $P<0.01$) and particularly during the critical seasons ($P<0.05$). The difference in dissolved concentrations was small between these sites, only 0.006 mg L^{-1}.

Overall, nitrogen concentrations except ammonia-nitrogen were significantly greater at Little Osage Creek compared to Chamber Springs ($P<0.01$); these differences generally persisted across all seasons sampled. While total organic carbon was not different between sites, sestonic chlorophyll-a was greater ($P<0.01$) at Little Osage Creek (0.4 μg L^{-1}) compared to Chamber Springs (0.1 μg L^{-1}). Water temperature and pH were not significantly different between sites overall ($P>0.65$), but conductivity and dissolved oxygen concentration (from the single point samplings) were greater at Little Osage Creek overall ($P<0.01$). Total suspended solids and turbidity were different ($P<0.01$) with Little Osage Creek having three times greater concentrations (4.1 mg L^{-1}) and NTU (3.1), although the values at Little Osage Creek indicated little suspended solids within the water column.

The comparison between sites upstream from the effluent discharges (OSG1 and SPG1) and the reference sites were variable with nutrients, resulting from the variability between the two reference sites. With regard to phosphorus, concentrations were not significantly different between Little Osage Creek and Osage Creek upstream from the effluent discharge (OSG1); however, phosphorus concentrations at all other sites at Osage Creek and Spring Creek were significantly greater than that measured at the two reference sites (all data, paired T-test, $P<0.01$). The phosphorus concentrations at the most downstream site on Osage Creek (OSG5) had concentrations statistically greater than the reference sites.

Ammonia-nitrogen concentrations were not different between the upstream sites (OSG1 and SPG1) and the reference sites (CSREF and LOREF), whereas all other sites had concentrations greater than that observed at the reference streams (all data, paired T-test, $P<0.04$). Nitrite-nitrogen concentrations at Chamber Springs (0.005 mg L^{-1}) were less than that observed at all sites on Osage Creek and Spring Creek, whereas concentrations were not significantly different ($P>0.15$) at Little Osage Creek (0.014 mg L^{-1}) and select sites downstream from the effluent discharges (OSG2, OSG3 and SPG2). Nitrate-nitrogen and total nitrogen concentrations at all sites on Osage Creek and Spring Creek were significantly greater than concentrations observed at Chambers Springs (P,0.01), but less than concentrations at Little Osage Creek ($P<0.03$).

Total organic carbon was generally not different between the upstream sites on Osage Creek (OSG1) and Spring Creek (SPG1) and the two reference streams (CSREF and LOREF), whereas concentrations downstream from the effluent discharges were elevated above that observed in the reference streams. Sestonic chlorophyll-a was least at Chambers Springs compared to all sites on Osage Creek and Spring Creek ($P<0.01$), whereas suspended algae at Little Osage Creek was not different than the other sites. Turbidity and total suspended solids concentration at all sites on Osage and Spring Creek was in between that observed at the two reference streams, with Chambers Springs having the least and Little Osage the greatest. The most downstream site on Osage Creek (OSG5) generally had physico-chemical properties in the collected water samples that were significantly different than the two reference streams (paired T-test, $P<0.05$), but these conditions were approaching those observed at the reference sites (i.e., concentrations generally decreased the further downstream from effluent discharges).

3.2 Diurnal In-Stream Parameter Discussion

Exploration of the diurnal in-stream data began with comparison to ADEQ Reg. 2 standards for potential violations of numeric water quality criteria. The parameters for which there are numeric standards are pH, temperature (°C), and dissolved oxygen (mg/L). Each parameter was compared to the appropriate standard for the season, water temperature, and watershed size.

The criteria for pH is that values must be between 6 and 9 and not vary more than 1 standard unit (SU) over a 24 hour season. These criteria were never observed to be in violation during this investigation; only once was a site at risk of violating the criteria, during Primary Season 1 event 1 at site OSG4, where the pH varied by a maximum of 0.9 SU over a 48 hour season. Multiple sites showed signs of pH variability greater than that seen at the reference site. This will be discussed in more detail in the section on nutrient narrative criteria.

Temperature criteria are based on a monthly maximum average, which was not addressed in this study, and an instantaneous maximum (29°C). Maximum temperatures recorded in water chemistry samples on-site suggested a potential for exceedance of the standard below the Springdale WWTP. The maximum temperature recorded during the diurnal data sonde deployments occurred at SPG3 (28.9°C). Few other maximums exceeded or approached 28°C. It should be noted that temperature values increased below both WWTP outfalls but that the difference in temperatures from SPG1 to SPG2 was often greater than 4°C. SPG2 was frequently the warmest site during sampling seasons and SPG1 was frequently as cool or cooler than the reference sites. The low temperature at SPG1 is attributed to the fact that the majority of the flow at the site comes from a spring just upstream of the site. The increase in temperature from SPG1 to SPG2 reflects the fact that the WWTP effluent contributes as much as 70% or more of the base-flow of the stream (Appendix C).

Watershed areas can be found in Table 2.01. These areas are important because they set the levels for DO standards. Dissolved oxygen (mg/L) standards appear to have been violated in only one instance, during Critical Season 1 Event 1 at SPG1. Dissolved oxygen was below 5 mg/L for 0.7 hours and the temperature was below 22°C during that time so no 8 hour 1 mg/L deviation tolerance was in effect. The reason for the temperature being below the 22°C during that time is likely its proximity to the spring which contributes the majority of the flow for Spring Creek at SPG1. Other events came close to having criteria violations but did not exceed criteria. During Critical Season 1 sites OSG4, SPG3 and CSREF during event1 and SPG1 during event 2 had periods of DO below 6 mg/L. Since this occurred during the critical season the DO criteria at these sites was 5 mg/L resulting in no violation. During Primary Season 1 event 2 sites OSG3 and OSG4 went below 6.5 mg/L and OSG4 went below 6 mg/L for 2 hours. These do not appear to violate criteria since these occurred in June and water temperatures were above 22°C. During Critical Season 3 sites OSG4, SPG1, SPG3, and LOREF during event 1 and SPG1 and SPG3 during event 2 went below 6 mg/L. These were not violations since the critical season criteria is 5 mg/L for these sites. A minimum value of 4.5 mg/L for DO was measured during water chemistry sampling for site SPG3. Since water temperatures were over 22 °C at the time a measure of how long DO had been depressed below 5 mg/L would be needed to ascertain if this was a violation of ADEQ Reg. 2 criteria since an 8 hour depression is allowed if temperature exceeds 22 °C. No diurnal data at SPG3 showed a violation of DO criteria.

The narrative criteria for nutrients include analysis of "dissolved oxygen values, dissolved oxygen saturation, diurnal dissolved oxygen fluctuations, pH values..." (Arkansas Reg. 2). The values and daily fluctuations compared to reference site values and daily fluctuations as well as expected values were assessed. Minimum dissolved oxygen values were only in violation of regional standards once, and this above the Springdale outfall on Spring Creek (SPG1). Also values were typically at or near those at the reference sites, so no indication of narrative criteria violation was apparent. Dissolved oxygen saturation was typically high at many of the sites (Table 2.21). Sites upstream of the WWTP outfalls were typically near or below reference conditions, though SPG1 exceeded 120% saturation on three occasions. The sites immediately downstream of the treatment plants were typically higher than above, but still within the range seen at the reference sites with the exception of the last event at SPG2 (141%). Sites farther downstream from the WWTPs (OSG3, SPG3, OSG4, and OSG5) were consistently higher than the reference conditions and the sites farther upstream. Values at these sites routinely exceeded 120% saturation with maximums of 146%, 131%, 165%, and 151% respectively. Diurnal DO fluctuations were varied over sites and seasons. Reference sites (LOREF and CSREF) typically had the lowest swings, but this was not always the case. Some diurnal swings at the reference sites were greater than 3 mg/L. Sites below the treatment plants either had little change from upstream or actually showed a decrease in diurnal swing (SPG2). OSG3 showed increased swings but typically they were similar to OSG2. Sites that showed the greatest swings were SPG1, SPG3, OSG4, and OSG5. At these sites the swings were typically less than 3 mg/L, but with many up to 5 mg/L, and some as high as 6 mg/L. Fluctuations of pH values at the sites pretty much mirrored that of DO. The reference sites often had pH swings of between 0.25 to 0.5. SPG3 and OSG4 had the largest fluctuations. SPG2, OSG3, and OSG5 also exhibited swings that were somewhat elevated from the reference sites.

3.3 Habitat and Geomorphology Discussion

Qualitative habitat scores (EPA RBP Visual Assessment) were relatively comparable with averages for the five sampling events ranging from 138 (SPG1) to 169 (CSREF). Variability in visual habitat scores was mostly due to riparian condition, availability of stable cover, and bank stability. Sites were selected by visual comparison so it is not a surprise that the variability between sites is relatively low.

Quantitative habitat scores (ADEQ Habitat Assessment) varied more by site and season than did the visual score. Designation of areas as riffle, run, or pool varied from year to year depending on stage of flow and shifting substrate. Also many areas of the streams had multiple habitat types in one cross section so that the habitat would be noted in the field notes as partial pool with dominant run habitat, but that value is only entered as run habitat in the calculations.

Two of the most variable habitat parameters from site to site were canopy cover and percent bedrock substrate. Canopy cover variation from site to site was mostly due to width of channel but was also influenced by riparian zone quality and width. The reference sites had averages of close to 70% canopy cover over all five sampling seasons. Of the smaller sites only SPG1 had an average of less than 40% at 24%. Sites OSG4 and OSG5 had much lower canopy cover percents mostly due to natural stream widening, however OSG4 had a disturbed riparian corridor. Overall the test sites had much lower canopy cover than the reference sites. The percent of each reach with bedrock substrate was high at some sites. The reference sites contained no bed rock. Sites OSG1, OSG2, SPG2, and SPG3 all had over 10% of the reach with bedrock substrate. Site OSG2 stood out with 35% bedrock substrate while the other three sites with considerable bedrock had 15% or less.

Change of habitat was a frequent theme in our visits to the sites. Some of the changes were due to flood flows and some were due to direct human influence. Flood flows changed the channel pattern somewhat at all sites. The biggest changes occurred at SPG1, OSG4, and OSG5. At SPG1 the changes were mostly due to flashy flood flows and consisted of a large log jam that was frequently pushed out and replaced with newly fallen trees and brush. The channel changed courses a couple of times during the study but was always in the same general pattern when sampled for biotics. This frequent changing is likely due to hydrologic regime change caused by urban landuse. This site also experienced some direct impact from repairs to a part of the adjacent lake embankment that was heavily eroded during high flows. Visible impacts to the area immediately upstream were short term and gone after a couple of storm events. At OSG4 the area underwent extreme change of habitat due to transient trees and log jams as well as direct human influence. Areas that were deep scour pool at the beginning of the study were shallow riffles by the end due to root wads and entire trees washing through the reach. Just prior to the Spring 2009 sampling the stream was impacted in the middle of the sampling reach by an adjacent landowner creating a crossing by pushing bank material into the stream and moving material in-stream with a bulldozer. Approximately 200 ft of stream were affected by the immediate physical impacts. Technicians who were checking and deploying equipment and observed the event noted that water turbidity was noticeably increased at OSG5. Site OSG5 suffered from frequent movement of large woody debris though the reach just like OSG4. Prior to the Summer 2009 sampling event as part of the construction of pipelines for the NACA water treatment plant a low water crossing was placed at the upstream end of the sampling reach. This dramatically changed the nature of the upstream portion of the site creating a large scour pool just downstream of the crossing. Increased shallow habitat was created just downstream of the scour pool due to the deposition of the bed-load from the scour area.

3.4 Periphyton Discussion

Multiple methods were used for describing the periphyton communities at each site. Passive diffusion periphytometers (PDPs) were used to explore the possibility of nutrient limitation at sites as well as to explore scour and grazer excluded ambient periphyton growth. Natural substrate was sampled using ash-free dry mass and chlorophyll a methods to describe the standing crop periphyton mass.

In regards to the nutrient limitation no sites had statistically significant results suggesting nutrient limitation. Many sites during multiple seasons had variability in the nutrient treatments that suggested response to the treatments but the means were not statistically different than the controls. This suggests that some factor other than nutrients is limiting periphyton growth in the system. Possibilities include temperature, light, turbidity, or some combination of these factors.

The control treatments from the PDPs were compared between sites for each season to determine if ambient periphyton growth was greater. During Critical Season 1 OSG4, SPG1, OSG2, and OSG5 were significantly higher than the reference sites, with OSG4 being significantly higher than the other three sites listed above. During Critical Season 2 OSG5 and SPG3 were significantly higher than CSREF though OSG5 was not significantly higher than LOREF. During Critical Season 3 OSG4 and SPG3 were significantly higher than the reference sites. During Primary Season 1 OSG1 and SPG2 were significantly higher than CSREF while only OSG1 was significantly higher than LOREF. During Primary Season 2 SPG3 and OSG4 were significantly higher than the reference sites. Sites OSG4 and SPG3 appear to have the highest ambient periphyton growth from these results.

Natural substrate samples were collected to provide further understanding of periphyton standing crop in the system. Standing crop is affected by many things including nutrients, light, temperature, primary feeder grazing, and scour. The period sampled for this study included many and frequent high flow events. This appeared to have an impact on visible standing crop. Chlorophyll a provides the best assessment of periphyton primary producer standing crop. The chlorophyll a analysis shows very little as far as trends in increased standing crop at any given site. For Critical Season 1 and Primary Season 2 no sites were significantly different than the reference sites. Only SPG3 was significantly higher than the reference sites in Critical Season 2. In Critical Season 3 OSG2, OSG3, OSG4, OSG5 and SPG3 were significantly higher than the reference sites. In Primary Season 1 only SPG2 was significantly higher than the reference sites.

Ash-free dry mass analysis was also conducted on the natural substrate periphyton samples. During Critical Season 1, Primary Season 1, and Primary Season 2 no sites were statistically different than the reference sites. Site SPG3 was significantly higher during Critical Season 2. Sites OSG1, OSG2, OSG4, OSG5, and SPG3 were significantly higher than the reference sites during Critical Season 3. These analyses were from the same collections as the natural substrate chlorophyll a samples and were affected by the same factors in the streams.

Canopy cover is one of the factors that most directly influences periphyton growth on artificial and natural substrate. Measures of canopy cover varied by site and season for both natural and artificial substrate periphyton samples (Tables 2.34 and 2.35). Though it does not appear that all sites with decreased canopy cover always had increased periphyton production on artificial and natural substrate, there does seem to be a correlation in that the sites that did have increased periphyton were from sites with lower canopy cover for that event. It should be noted that this does not necessarily mean that the entire canopy cover for that site is low since periphyton was sampled from singular locations, but it does indicate that canopy cover is an important factor for periphyton productivity.

3.5 Biotic Discussion

3.5.1 Benthic Macroinvertebrates Discussion

Osage Creek – Comparison of the average critical season invertebrate IBI scores for site OSG1 just above the Rogers WWTP (44) with the average score from downstream at OSG2 (34) indicates a significant decrease in water quality (Table 2.43). The pattern of the water quality indicated by the invertebrate IBI scores can be seen in Figure 2.14. The invertebrate IBI scores substantially rebounded farther downstream in the Osage Creek basin. The upstream site (OSG1) and the farthest downstream site (OSG5) compare favorably with the reference sites (LOREF and CSREF). This pattern of scores indicates that although the effluent from the Rogers WWTP may have caused a decrease in water quality immediately downstream from the plant discharge, water quality recovered farther down Osage Creek and before entering the Illinois River mainstream.

The habitat for the macroinvertebrate species assemblage at the OSG2 site below the Rogers WWTP is not as good as the habitat quality upstream or downstream from that site (Figure 2.10). There were simply no other suitable places for the site, especially because of the golf course downstream. At OSG2 there is a lot of bedrock and little bedload (gravel) to provide interstitial refugia from flow and predators. This confounding factor could be partly responsible for the observed pattern of macroinvertebrates. The invertebrate assemblage showed some recovery at OSG3 where there is much better physical habitat for them (average critical season IBI = 40, Table 2.22).

Spring Creek – The average invertebrate IBI score during critical seasons below the Springdale WWTP (29) although very low, was not quite as low as the average IBI at SPG1 above the plant (27, Table 2.43, Fig. 2.15) indicating that the Springdale WWTP effluent did not lower the water quality of its immediate receiving stream. However, the invertebrate community at SPG1 above the WWTP and SPG2 downstream were both in very poor condition compared to the reference sites' average IBI (47.5, Fig. 2.15). The reason(s) for the poor water quality at SPG1 are not clear, but may be related to the small reservoir near the site. The invertebrate community began to recover from these low values by the SPG3 site (36), and even more by the OSG5 site farther downstream (42), which compares more favorably with the average critical season IBI scores of the reference sites (47.5). The habitat quality (Figure 2.09) at SPG2 below the Springdale WWTP is low compared to sites upstream and downstream principally in that, like OSG2 below the Rogers WWTP, there is insufficient gravel bedload at the site to provide interstitial refugia for the organisms.

3.5.2 Fish Discussion

Osage Creek – The average IBI scores for the fish assemblages above and below the Rogers WWTP (30.5 and 28.5 respectively) were not very dissimilar (Table 2.49, Fig. 2.16). However, they were lower than the average critical season scores for the reference streams (37.5). The fish IBI scores had increased substantially farther downstream (OSG4 = 37, OSG5 = 31) such that the slight impact seen below the plant did not continue down Osage Creek into the Illinois River.

The habitat at the OSG2 site is a potentially confounding factor for the fish as it is for the invertebrates, as explained earlier in this document. The poor habitat at this site could account for some of the decrease in fish IBI scores. Percent primary feeders, one of the biometrics, was very high at OSG2 (Ave. = 51.4) compared to the other sites, especially in the reference streams (Ave. = 9.6), contributing to the low scores at the site. This is an important metric because excess nutrients can result in excess periphyton, which is the food for "primary feeders" like stonerollers. However, the extensive bedrock at the OSG2 site is excellent substrate for the growth of periphyton. It is doubtful that the habitat, principally the extensive bedrock, accounted for a huge percentage of the average low scores seen there, but it probably was of some significance.

Spring Creek – The patterns of water quality indicated by analyses of the fish community are almost identical to those for the invertebrate community (Figs. 2.15 and 2.16). The fish assemblage at site SPG2 just below the WWTP compared to the fish assemblage just upstream (SPG1) indicated that the water quality below the plant was better, however both are very low compared to those farther downstream and compared to the reference streams. The fish data corroborate the invertebrate data indicating that although the fish assemblage shows low water quality below the plant, the receiving stream is even worse just upstream, so these data do not indicate that the Springdale effluent impairs the quality of the receiving stream. The fish IBI scores for OSG3 indicate that Spring Creek is reaching the level of water quality indicated by the reference stream IBI scores even before the confluence with Osage Creek. The previous comments regarding the habitat quality at this site for the invertebrates apply in much the same way for the fish. The percentage of primary feeders during critical seasons was high (52 – 88%) at all the Spring Creek sites compared to other sites in the basin, especially the reference sites (9 – 22%).

The total fish IBI scores for this study (Table 2.49) generally fall within the ADEQ designated guidelines for the Ozark Highland streams of "25-36 Generally Similar", meaning that they are generally similar to other streams in this ecoregion regarding the water quality indicated by their fish community total metric scores. One of the two reference streams that we used were at the high end of this range (Little Osage Creek – LOREF) with scores averaging 36 during critical seasons and an overall average of 34 for all five of our collections (Table 2.49). The other reference stream (Chambers Spring – CSREF) scored a little higher and was in the lower end of the highest range for Ozark Highland streams "Mostly Similar" with an average critical season score of 39 and an overall average score of 37. It is becoming very difficult to find high quality reference streams in northwestern Arkansas. Only SPG1 and SPG2 scored in the lower category "13-24 Somewhat Similar", with SPG1 at the lower end of this scale and SPG2 nearer the upper end, suggesting that the fish community was improving immediately below the Springdale WWTP outfall. None of our Osage Creek Basin stream sites scored in the "12-0 Not Similar" category. Farther down Spring Creek at site SPG3 the fish community (and invertebrates, but without a scale for comparison throughout the ecoregion) indicate that the stream had recovered at least to the point of being generally similar to others in the ecoregion. Even farther downstream after confluence with Osage Creek (OSG4 and OSG5) the stream maintained this "generally similar" status. These results for the downstream areas of Spring and Osage Creeks are encouraging because these stream segments are classified as "Ecologically Sensitive Waterbodies" by ADEQ due to their being habitat for the Neosho mucket, a bivalve mollusk that is becoming quite rare and endangered (ADEQ REG. 2).

Section 4: Conclusion and Recommendations

The purpose of this project was to assess attainment of designated aquatic life use in Osage and Spring Creeks in Northwest Arkansas, particularly to evaluate if the cities of Springdale and Rogers, Arkansas WWTP discharges resulted in violations of ADEQ Reg. 2 Criteria. This project was designed to evaluate three tiers of impact: 1) above and below WWTPs of the Cities of Rogers and Springdale, Arkansas; 2) sites below WWTPs compared to reference conditions; and 3) gradients across stream reaches from upstream to downstream.

The results clearly indicated that there are no upstream-downstream impacts from the WWTPs that rise to the level of impairment of water quality (Tier 1). The assessment of Tier 2 Impacts, comparing reference stream conditions to all sites, showed generally higher levels of nutrients at test sites (with the exception of nitrogen when compared to LOREF), lower dissolved oxygen depression and larger diurnal swings, higher standing crops and rates of growth of periphyton, and lower biotic IBI scores. The Tier 3 assessment of the reach continuum from upstream to downstream showed that the impact of the Rogers WWTP in Osage Creek (OSG2) across all metrics was not significant, and any decline in metrics observed was fully or close to fully recovered by the lower site (OSG5). The Springdale WWTP discharge actually appeared to improve water quality in the stream from SPG1, and like Osage Creek, all metrics recovered by OSG5.

Results of the water quality assessment showed no violations of ADEQ Reg. 2 Criteria, with the exception of SPG1 for DO during Critical Season 1. All other observations across all other sites met the criteria for designated use for water quality during all observation periods. The conclusion is that there is no evidence that discharge of wastewater from the Rogers WWTP to Osage Creek or the Springdale WWTP to Spring Creek results in any violation of water quality standards according to the criteria of ADEQ Reg. 2. There appears to be no justification from this data for placing Spring and Osage Creeks on the 303(d) list of impaired waters for impairment by nutrients.

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