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WATER QUALITY MONITORING AND CONSTITUENT LOAD ESTIMATION IN THE UPPER ILLINOIS RIVER WATERSHED, 2009

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Water Quality Monitoring and Constituent Load Estimation in the Upper Illinois River Watershed, 2009

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SUMMARY

The Arkansas Water Resources Center (AWRC) monitored water quality at eight sites in the Upper Illinois River Watershed during base flow conditions and storm events from July 1, 2009 through June 30, 2010. Water samples were collected manually with an alpha or Kemmerer style sampler and analyzed for nitrate-nitrogen (NO_3-N), sulfate (SO_4), chloride (Cl), soluble reactive phosphorus (SRP), total phosphorus (TP), dissolved ammonia (NH_3-N), total N (TN), total suspended solids (TSS), and turbidity. Physico-chemical parameters were measured in the field including pH, conductivity, water temperature, and dissolved oxygen concentration. The selected sites were at established discharge monitoring stations maintained by the US Geological Survey or AWRC, and constituent loads were determined using regression models between constituent concentrations, discharge, and seasonal factors to estimate daily loads, which were then summed to produce monthly, seasonal and annual load estimates. The constituent loads and annual flow-weighted concentrations for the 2009 calendar year are summarized in the table below, using the data collected in this study. The regression models were applied throughout the discharge record of the entire calendar year to estimate loads.

Summary of calculated total loads (kg) for each parameter at the sampled sites in the Upper Illinois River Watershed for the period, January through December 2009.

Site	Cl^-	SO_4	NH_3-N	NO_3-N	SRP	TN	TP	TSS
Ballard Creek	461,000	767,000	5,300	119,000	21,000	139,000	29,000	6,492,000
Baron Fork	258,000	748,000	2,800	81,000	6,100	117,000	9,800	1,290,000
Flint Creek (W. Siloam)	521,000	1,201,000	1,300	116,000	2,400	130,000	5,300	1,852,000
Flint Creek (Springtown)	101,000	92,000	1,300	56,000	1,700	62,000	2,600	447,000
Illinois River @ AR59	8,011,000	9,546,000	31,000	1,740,000	82,000	1,970,000	236,000	111,961,000
Illinois River @ Savoy	1,656,000	3,144,000	21,000	392,000	39,000	530,000	72,000	20,556,000
Mud Creek Tributary	14,000	18,000	100	900	60	1,600	300	1,342,000
Osage Creek	3,110,000	3,260,000	17,000	562,000	16,000	633,000	42,000	29,272,000

Summary of calculated flow weighted concentrations (FWC, mg L^{-1}) for each parameter at the sampled sites in the Upper Illinois River Watershed for the period, January through December 2009.

Site	Cl^-	SO_4	NH_3-N	NO_3-N	SRP	TN	TP	TSS
Ballard Creek	7.61	12.67	0.09	1.97	0.34	2.29	0.49	107
Baron Fork	4.63	13.45	0.05	1.46	0.11	2.10	0.18	23
Flint Creek (W. Siloam)	9.56	21.93	0.02	2.12	0.04	2.37	0.10	34
Flint Creek (Springtown)	5.76	5.21	0.07	3.18	0.10	3.52	0.15	322
Illinois River @ AR59	10.93	13.02	0.04	2.37	0.11	2.69	0.32	153
Illinois River @ Savoy	6.97	13.24	0.09	1.65	0.16	2.23	0.30	87
Mud Creek Tributary	8.53	11.14	0.07	0.56	0.04	0.95	0.16	824
Osage Creek	16.24	16.81	0.08	3.08	0.08	3.40	0.22	149

ABBREVIATIONS: Chloride (Cl^-), Sulfate (SO_4), Ammonia-Nitrogen (NH_3-N), Nitrate-Nitrogen (NO_3-N), Soluble Reactive Phosphorus (SRP), Total Nitrogen (TN), Total Phosphorus (TP), Total Suspended Solids (TSS), Upper Illinois River Watershed (UIRW), Arkansas Water Resources Center (AWRC), Arkansas Natural Resources Commission (ANRC), Arkansas Department of Environmental Quality (ADEQ)

INTRODUCTION

The headwaters of the Illinois River originate near Hogeye in northwest Arkansas, and the river flows northwesterly through the Ozarks, into Oklahoma and eventually into Lake Tenkiller Ferry. The main tributaries to the Illinois River in northwest Arkansas include Osage Creek, Clear Creek, Flint Creek, Baron Fork and Muddy Fork. The Illinois River and its tributaries drain 1960 km^2 that are forest (41%) and agricultural lands (i.e., primarily pasture and forages; 46%); however, over the past decade increases in residential, commercial and industrial development have been observed (i.e., urban land use has increased to 13%). The Illinois River is used for recreation, aquatic life and refuge, and agricultural, industrial and residential water supply by some communities in northwest Arkansas and northeast Oklahoma. The Illinois River and its tributaries also provide the ecological service of wastewater treatment as several headwater tributaries receive treated effluent from wastewater treatment plants.

Because of the Illinois River's varying designated uses in Arkansas and Oklahoma, the river is center to many political, scientific and legal debates. Several stream reaches within the Illinois River and its tributaries (including Muddy Fork, Clear Creek, Osage Creek, Spring Creek and Little Osage Creek) were either included on Arkansas Department of Environmental Quality's (ADEQ) 2008 303d list (ADEQ, 2008) or added to the list by the U.S. Environmental Protection Agency (USEPA); the Arkansas Natural Resources Commission (ANRC) has also listed the Illinois River drainage area as a priority 319 watershed. Therefore, monitoring water quality at multiple sites spanning the Upper Illinois River Watershed (UIRW) is important, and the catchments of the selected sites need to represent a myriad of land uses from mostly residential development to that dominated by pasture.

The focus within the UIRW has primarily been on phosphorus (P), but stream reaches on ADEQ's 303(d) list in 2008 also identified pathogens, sediment and nitrate as the pollutants of concern. However, much of the monitoring and scientific investigations have addressed P sources, concentrations and loads within this catchment. The long term monitoring of the Illinois River in northwest Arkansas has shown that flow-adjusted P loads were decreasing from 2002 through 2008 (Haggard, 2010). Massey et al. (2009) showed that the transport of P and other constituents was clearly related to the amount of water flowing past a site.

Water quality monitoring within the UIRW is critical to understanding the contribution from different land uses and how water quality is changing over time. Eight sites were selected within the UIRW in July 2009, where these sites drained catchments representing urban, pasture and mixed land uses. The selected sites have been historically monitored for water quality by the ADEQ, Arkansas Water Resources Center (AWRC) and or the US Geological Survey (USGS). Continuous discharge (i.e., daily discharge records) was available at the selected sites through the AWRC or USGS. This report presents the annual loads and flow-weighted concentrations (FWC) of select constituents at this site for the 2009 calendar year. Semi-annual loads from 1 January to 30 June 2010 are also presented for all sampled sites in the appendix.

STUDY SITE DESCRIPTIONS

The selected sites encompass the UIRW including sites on the Illinois River and its tributaries, Ballard Creek, Baron Fork, Flint Creek, and Osage Creek. These sites are representative of various geographic positions in the UIRW and land uses, including catchments dominated by urban development (Mud Creek Tributary), pasture (Ballard Creek and Flint Creek), and mixed land uses. Many of these sites are downstream from effluent discharges, which have been shown to change water chemistry in streams during base flow conditions (Ekka et al., 2006).

Ballard Creek (AWRC Discharge and Water Quality Monitoring Station)

Ballard Creek lies in the south-central and western portion of the UIRW and flows northwesterly into Oklahoma. Ballard Creek drains approximately 62 km^2 in Arkansas of which 36% is forest, 59% is pasture and 4% is urban land use. A sampling station was installed in 2001 at the Washington County Road 76 Bridge over Ballard Creek to monitor water quality and discharge. Since July 2002, continuous stage and discharge measurements and water quality samples have been used to determine loads and flow-weighted concentrations (FWC) from Ballard Creek. Average annual discharge at this site over the past decade has ranged from 0.9 $m^3\ s^{-1}$ in 2006 to 1.8 $m^3\ s^{-1}$ in 2008.

Baron Fork (USGS Station No. 07196900)

Baron Fork lies in the southern portion of the UIRW and drains a 105 km^2 area; land use distribution is 57% forest, 40% pasture and 3% urban within the drainage area. The USGS began monitoring discharge at Baron Fork (near Dutch Mills, AR) in 1954. Average annual discharge at this site has ranged from 0.4 to 2.4 $m^3\ s^{-1}$ over the past decade.

Flint Creek near Springtown (USGS Station No. 07195800)

Flint Creek lies in the northern portion of the UIRW flowing southwesterly into Oklahoma. At this site, Flint Creek drains a 104 km^2 of which 39% is forest, 53% is pasture and 8% is urban. The USGS began monitoring discharge at Flint Creek (near Springtown, AR) in 1962. Average annual discharge at this site over the past decade ranged from 0.3 $m^3\ s^{-1}$ in 2006 to 2.1 $m^3\ s^{-1}$ in 2008.

Flint Creek near West Siloam Springs (USGS Station No. 07195855)

Flint Creek near West Siloam Springs, Oklahoma lies just across the state border. At this site, Flint Creek drains 180 km^2 of which 30% is forest, 57% is pasture and 13% is urban. The USGS began monitoring discharge at Flint Creak (near West Siloam Springs, OK) in 1979. Average annual discharge at this site over the past decade ranged from 0.1 $m^3\ s^{-1}$ in 2006 to 0.7 $m^3\ s^{-1}$ in 2008. This site is upstream of the influence of the effluent discharge from the City of Siloam Springs into Sager Creek, which is a tributary to Flint Creek.

Illinois River at Highway 59 (USGS Station No. 07195430)

The Illinois River at Highway 59 (AR59, South of Siloam Springs, Arkansas) is the outlet of the Illinois River drainage area in the UIRW. At this point, the Illinois River drains 1490 km^2 of which 41% is forest, 46% is pasture and 13% is urban. The USGS began monitoring discharge at this site in 1995, and the AWRC has monitored this site since 1997. Average annual discharge over the past decade has ranged from 5.2 m^3 s^{-1} in 2006 to 30 m^3 s^{-1} in 2008. The water quality at this site is influenced by upstream tributaries in the watershed including Osage Creek, Clear Creek, and the Muddy Fork. Treated wastewater effluent from the Cites of Rogers, Springdale, and Fayetteville, along with other smaller cities are discharged into tributaries to the Illinois River upstream of this site.

Illinois River at Savoy (USGS Station No. 07194800).

The Illinois River at Savoy drains 433 km^2 of which 70% is forest, 28% is pasture and 2% is urban. The USGS began monitoring discharge at this site in 1979; average annual discharge over the past decade has ranged from 1.3 m^3 s^{-1} in 2006 to 7.9 ft^3 s^{-1} in 2008. The Illinois River at Savoy is downstream of the convergence of Goose Creek and the Illinois River; Goose Creek receives the treated wastewater effluent from the City of Fayetteville's Westside facility.

Mud Creek Tributary (USGS Station No. 07194809)

Niokaska Creek, a tributary to Mud Creek, originates in the western portion of the UIRW, within the City of Fayetteville, and drains a 3 km^2 which is 25% forest, 14% pasture and 61% urban. The USGS began monitoring discharge at Niokaska Creek (at Township Street in Fayetteville, AR) in 1996. Average annual discharge at this site over the past decade ranged from 0.01 m^3 s^{-1} in 2005 to 0.1 m^3 s^{-1} in 2008.

Osage Creek (USGS Station No. 07195000)

Osage Creek, originates in the northwestern portion of the UIRW, and drains a 337 km^2 which is 20% forest, 36% pasture and 44% urban; the Cities of Rogers and Springdale lie within this drainage area. The USGS began monitoring discharge at Osage Creek (near Elm Springs, AR) in 1951. Average annual discharge at this site over the past decade ranged from 2.2 m^3 s^{-1} in 2006 to 8.5 m^3 s^{-1} in 2008. The treated effluent from the municipalities in Rogers and Springdale are discharged into Osage Creek upstream from this monitoring site.

METHODS

Sample Collection

Storm and base flow events in the Illinois River Drainage Area were sampled from July 1, 2009 through June 30, 2010 at eight locations on selected streams, including Mud Creek tributary, Baron Fork, Flint Creek, Osage Creek, Ballard Creek and the Illinois River just upstream of the Arkansas-Oklahoma border. The water samples were collected at the bridges on the Mud Creek tributary at Township Road, on Osage Creek near Elm Springs, on Ballard Creek at County Road 76, on the Baron Fork near Dutch Mills, on Flint Creek near West Siloam Springs and at Springtown, on the Illinois River at Arkansas Highway 59 and at Savoy. Water samples were collected using an Alpha style horizontal sampler or a Kemmerer type vertical sampler near the vertical centroid of flow (i.e., middle of the channel where water is actively moving). Water samples were collected every 168 hours, on average, at each site where up to 25% of the collected samples represented storm event or surface runoff conditions following episodic rainfall events, including small and large storm events.

Physico-chemical parameters including pH, conductivity, temperature, and dissolved oxygen concentration were measured on site. All water samples were delivered to the AWRC Water Quality Laboratory (WQL) and analyzed for nitrate-nitrogen (NO_3-N), sulfate (SO_4), chloride (Cl), soluble reactive phosphate (SRP), total phosphorus (TP), dissolved ammonia (NH_3-N), total nitrogen (TN), total suspended solids (TSS), and turbidity. Duplicate samples were collected at a frequency of 10% throughout the duration of the project for quality assurance and quality control purposes. All water samples were analyzed following analytical procedures as outlined in the quality assurance project plan.

Load Determination and Mean Concentrations

Constituent loads (L) were calculated at all sites using the constituent concentration data from the collected samples and average daily discharge data (Q_d) from the USGS from desired time periods. Daily measured loads were calculated by multiplying Q_d by a corresponding constituent concentration. The measured loads were plotted as a function of Q_d and then linear regression was used to develop an equation that describes daily constituent loads (L_d) at each site as a function of measured discharge. The basic log-log linear regression model for L_d can be expressed solely as a function of discharge:

$$\ln(L_d) = \beta_0 + \beta_1 \ln(\mathrm{Q_d}) \qquad \text{(Equation 1)}$$

where ln represents the natural logarithm function, β_o is a constant, β_1 is the coefficient for discharge and Q_d is the daily mean discharge (cfs). Regression models were also developed to consider seasonal influences:

$$\ln(\mathrm{L_d}) = \beta_0 + \beta_1 \ln(\mathrm{Q_d}) + \beta_2 \sin(2\pi \mathrm{T}) + \beta_3 \cos(2\pi \mathrm{T}) \qquad \text{(Equation 2)}$$

where β_2 and β_3 are the coefficients for seasonal variation and T is decimal time.

Log-log regression often results in bias when transforming the log values where the values are often under-estimated. Therefore, a nonparametric bias correction factor (BCF; Helsel and Hirsh, 2002) was calculated and used when transforming the logarithmic results back to actual daily loads. BCF for natural logarithmic transformation is:

$$BCF = \frac{\sum e^{e_i}}{n} \qquad \text{(Equation 3)}$$

where n is the number of samples and e_i is the residual or difference between measured and estimated loads in natural log units. This factor was multiplied by the re-transformed value to account for any bias.

Daily loads often show two distinct relations with Q_d representing different flow regimes (e.g., base flow conditions and storm events). Thus, load estimation using regression models can be complex requiring the model developer to really get to know the data. This project evaluated whether all the data could be used to develop regression models, or whether the data needed to be split at some breakpoint separating the data into flow regimes. Then, separate regression models would be developed based on the breakpoint. The appropriate regression model (i.e., equation 1 or 2) was selected based upon the coefficient of determination (R^2), calculated BCFs, and visual observation of any breakpoints in the relations between L_d and Q_d. Season factors were included in the regression models (i.e., Equation 2) for all data or data representing the low flow regimes, when the regression coefficients were both significant and or when the regression model with seasonal factors explained an additional 5% of the variation in L_d. Whereas, only equation 1 was used with the data representing the high flow regime or storm event conditions.

The selected regression model was then used to estimate L_d. The estimated loads were multiplied by the calculated BCF and summed into annual loads during the calendar year. The annual FWC (mg L^{-1}) was determined by dividing the total load (kg) by the annual discharge volume (m^3).

RESULTS

Illinois River at Highway 59

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). Physico-chemical parameters varied seasonally and with episodic rainfall events; a summary of the parameters measured at Illinois River at AR59 are provided in Table 1. The physico-chemical properties of the Illinois River at this site were within the expected range, relative to a stream influenced by effluent discharges in the headwaters and mixed land uses.

Table 1. Minimum, Maximum and geometric mean of physico-chemical parameters at the Illinois River at Highway 59 from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.7	8.9	8.0
Conductivity (µS cm^{-1})	182	343	296
Dissolved Oxygen (mg L^{-1})	5.8	16.6	8.9
Temperature (^{o}C)	1.7	26.4	11.1

Discharge and constituent concentrations were variable throughout the year showing the effects of episodic rainfall events and seasonal influences. Average daily flow during 2009 at the Illinois River at the AR59 bridge was 1,986,000 m^3, but was as great as 50,077,440 m^3 during storm events. Total annual discharge was 733,084,000 m^3 which is approximately 75% of that observed during 2008. A total of 49 samples collected during the study period at Illinois River at AR59 were used in linear regression with flow to estimate annual loads for 2009; two data points were not used, because corresponding flow data was not available from the USGS. Five parameters (i.e., NO_3-N, SO_4, Cl, TN, and NH_3-N) were adequately described by one equation for all flow regimes, while three parameters (i.e., SRP, TP, and TSS) required separate equations for low flow and high flow regimes. The amount of variation in the dependent variable explained by the selected linear regression models ranged from 70% to 98% for all equations (P<0.001). A summary of the regression equations used and statistical significance of the selected models is provided in Table 2.

Table 2. Regression equations and statistics of linear regression model(s) used to estimate constituent loads at Illinois River at Highway 59 Bridge during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = 2.35 + 0.92\ln(Q_d) + 0.13\sin(2\pi T) + 0.83\cos(2\pi T)$	All	0.98	<0.001
SO_4	$\ln(L_d) = 3.96 + 0.93\ln(Q_d)$	All	0.98	<0.001
Cl	$\ln(L_d) = 4.40 + 0.85\ln(Q_d)$	All	0.95	<0.001
SRP	$\ln(L_d) = -3.33 + 1.13\ln(Q_d) - 0.71\sin(2\pi T) - 0.67\cos 2\pi T)$	Low	0.79	<0.001
	$\ln(L_d) = -8.04 + 1.81\ln(Q_d)$	High	0.96	<0.001
TP	$\ln(L_d) = -4.78 + 1.47\ln(Q_d) - 0.51\sin(2\pi T) - 0.61\cos(2\pi T)$	Low	0.87	<0.001
	$\ln(L_d) = -10.11 + 2.17\ln(Q_d)$	High	0.95	<0.001
TN	$\ln(L_d) = 2.08 + 0.97\ln(Q_d) - 0.08\sin(2\pi T) - 0.09\cos(2\pi T)$	All	0.99	<0.001
NH_3-N	$\ln(L_d) = -4.85 + 1.28\ln(Q_d) - 0.33\sin(2\pi T) - 0.34\cos(2\pi T)$	All	0.70	<0.001
TSS	$\ln(L_d) = -1.28 + 1.64\ln(Q_d) + 0.34\sin(2\pi T) - 0.69\cos(2\pi T)$	Low	0.88	<0.001
	$\ln(L_d) = -9.75 + 2.79\ln(Q_d)$	High	0.92	<0.001

The calculated BCFs ranged from 1.00 (for TN across all flows) to 1.39 (for NH_3-N across all flows) for the selected parameters at Illinois River at AR59. Illinois River at AR59 exhibited the highest parameter loads of all monitored sites, because this site is the drains the largest catchment area and is the watershed outlet. However, the calculated loads at this site for calendar year 2009 were less than those observed in 2008 [as expected], because total discharge volume in 2009 was less than that observed in 2008. FWC decreased or remained constant for most parameters, except for Cl and SO_4, for which FWC increased 27% and 22%, respectively. The BCF, total loads and FWC during 2009 are shown in Table 3.

Table 3. Bias Correction Factors (BCF), annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Illinois River at Highway 59 during 2009.

Parameter	BCF All Flows	BCF Low Flow	BCF High Flow	Total Load (kg)	FWC (mg L^{-1})
Cl	1.02	--	--	8,011,000	10.93
SO_4	1.01	--	--	9,546,000	13.02
NH_3-N	1.39	--	--	31,000	0.04
NO_3-N	1.01	--	--	1,740,000	2.37
SRP	--	1.08	1.03	82,000	0.11
TN	1.00	--	--	1,970,000	2.69
TP	--	1.05	1.04	236,000	0.32
TSS	--	1.06	1.13	111,961,000	153

Daily loads are presented in Figure 1, and this figure shows the order of magnitude difference between daily constituent loads and flow regimes at the Illinois River at Highway 59. The daily constituent loads clearly show the influence of episodic storm events which re-suspend materials from within the fluvial channel and transport these materials from the landscape to tributary streams.

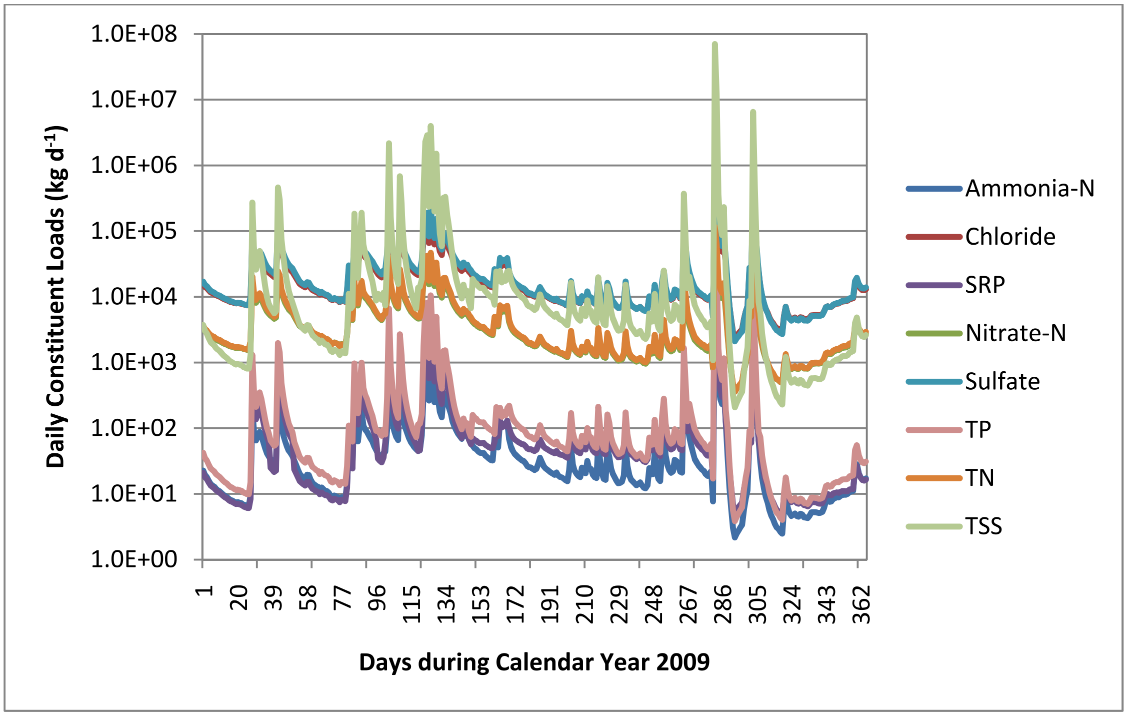


Figure 1. Daily constituent loads (kg d^{-1}) as a function of time (d) at the Illinois River at Highway 59 during 2009.

Ballard Creek

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). A summary of the physico-chemical parameters at Ballard Creek is provided in Table 4. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions, and pasture land use within the catchment.

Table 4. Minimum, Maximum and geometric mean of physico-chemical parameters at Ballard Creek from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.4	8.4	7.9
Conductivity (µS cm^{-1})	99	384	285
Dissolved Oxygen (mg L^{-1})	2.6	16.6	8.5
Temperature (^{o}C)	0.6	26.0	8.8

Average daily flow during 2009 at Ballard Creek was 150,000 m^3 and total annual discharge was 60,545,000 m^3; annual discharge was similar to that observed during 2008. From the period July 1 to December 30, 2009, a total of 54 samples were collected at Ballard Creek, analyzed, and used in linear regression with flow to estimate annual loads for 2009. Chloride, NH_3-N and TSS were adequately described by one equation for all flow regimes, while the other parameters required separate equations for low flow and high flow regimes. Select constituents were better represented when seasonal influences were considered, including NH_3-N, SRP, TP and SO_4. The amount of variation in the dependent variable explained by the selected linear regression equations ranged from 53% to 96% for all equations ($P \leq 0.002$). A summary of the regressions equation used and statistical significance of the selected model is provided in Table 5.

Table 5. Regression equation and statistics of linear regression model used to estimate constituent loads at Ballard Creek during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = -0.44 + 1.64\ln(Q_d)$	Low	0.71	<0.001
	$\ln(L_d) = 1.47 + 0.91\ln(Q_d)$	High	0.76	0.002
SO_4	$\ln(L_d) = 3.43 + 1.07\ln(Q_d) + 0.17\sin(2\pi T) + 0.29\cos(2\pi T)$	Low	0.96	<0.001
	$\ln(L_d) = 0.93 + 0.92\ln(Q_d)$	High	0.93	<0.001
Cl	$\ln(L_d) = 4.45 + 0.67\ln(Q_d)$	All	0.93	<0.001
SRP	$\ln(L_d) = -8.94 + 2.90\ln(Q_d) - 0.63\sin(2\pi T) - 1.26\cos(2\pi T)$	Low	0.62	<0.001
	$\ln(L_d) = -1.66 + 1.28\ln(Q_d)$	High	0.92	<0.001
TP	$\ln(L_d) = -6.46 + 2.36\ln(Q_d) - 0.53\sin(2\pi T) - 0.98\cos(2\pi T)$	Low	0.53	<0.001
	$\ln(L_d) = -0.65 + 1.18\ln(Q_d)$	High	0.82	<0.001
TN	$\ln(L_d) = 0.27 + 1.47\ln(Q_d)$	Low	0.75	<0.001
	$\ln(L_d) = 2.12 + 0.89\ln(Q_d)$	High	0.95	<0.001
NH_3-N	$\ln(L_d) = -3.61 + 1.30\ln(Q_d) - 0.16\sin(2\pi T) - 0.95\cos(2\pi T)$	All	0.68	<0.001
TSS	$\ln(L_d) = -1.10 + 1.91\ln(Q_d) - 0.08\sin(2\pi T) - 0.95\cos(2\pi T)$	All	0.75	<0.001

The calculated BCFs ranged from 1.00 (SO_4) to 2.03 (TSS) for the selected parameters at Ballard Creek. Calculated loads at this site for calendar year 2009 were less than those observed in 2008, for all parameters except SRP, TP and TSS which increased by 44%, 9%, and 24%, respectively. However, flow at Ballard Creek increased 10% compared to 2008, and observed loads are often closely tied to annual flow volume. FWC for SRP and TSS also increased 30 and 15%, respectively, but remained similar for TP. The BCF, total loads and FWC for each parameter during 2009 are presented in Table 6.

Table 6. Bias correction factors (BCF), calculated annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Ballard Creek during 2009.

Parameter	BCF			Total Load	FWC
	All Flows	Low Flow	High Flow	(kg)	(mg L^{-1})
Cl	1.01	--	--	461,000	7.61
SO_4	--	1.00	1.02	767,000	12.67
NH_3-N	1.37	--	--	5,300	0.09
NO_3-N	--	1.03	1.19	119,000	1.97
SRP	--	1.15	1.11	21,000	0.34
TN	--	1.02	1.03	139,000	2.29
TP	--	1.14	1.27	29,000	0.49
TSS	2.03	--	--	6,492,000	107

The daily loads are depicted in Figure 2 below, showing the variability in loads associated with seasonal precipitation patterns (i.e., rainy spring and fall) typical for this region. The hydrologic nature of Ballard Creek is very flashy during spring and fall, while relatively buffered during summer and winter.

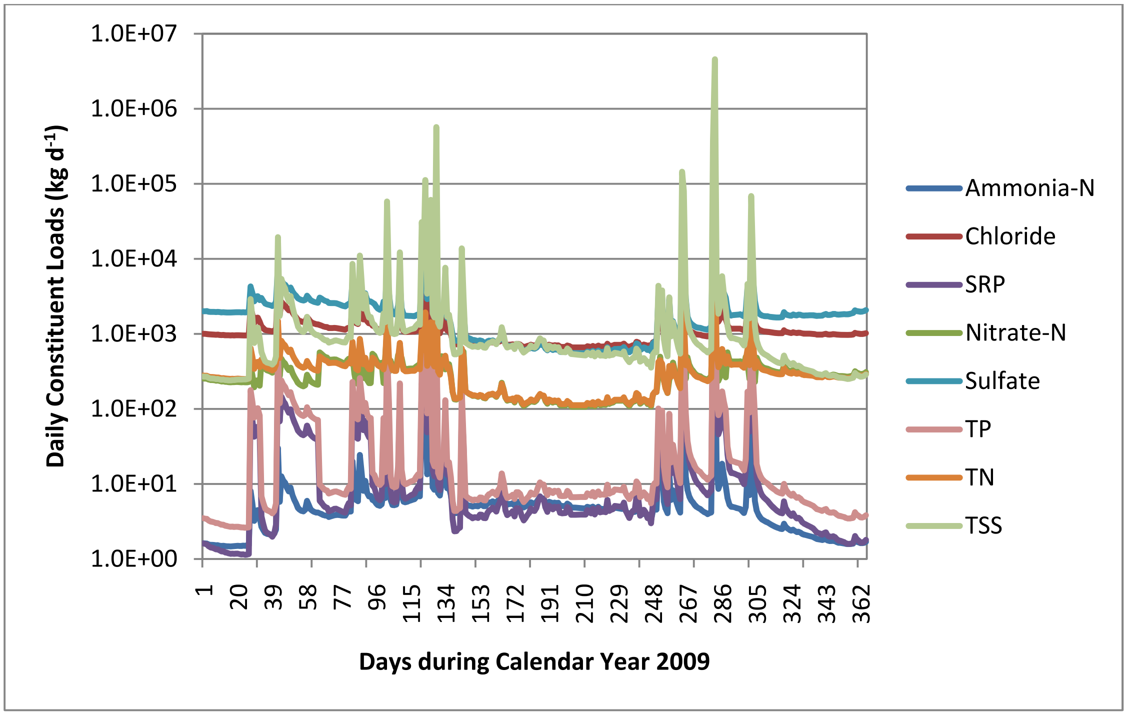


Figure 2. Daily constituent loads (kg d^{-1}) as a function of time (d) at Ballard Creek during 2009.

Baron Fork

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). A summary of the physico-chemical parameters at Baron Fork is provided in Table 7. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions and mixed land uses.

Table 7. Minimum, Maximum and geometric mean of physico-chemical parameters at Baron Fork from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.7	8.5	7.9
Conductivity (µS cm^{-1})	129	334	274
Dissolved Oxygen (mg L^{-1})	4.6	16.6	8.8
Temperature (^{o}C)	0.70	27.2	9.3

Average daily flow during 2009 at Baron Fork was 151,000 m^3 and total annual discharge was 60,545,000 m^3. From the period July 1 to December 30, 2009, a total of 55 samples were collected at Baron Fork, analyzed, and used in linear regression with flow to estimate annual loads for 2009. Most parameters (6 of 8) were adequately described by one equation for all flow regimes, while NO_3-N and TN were better described by separate equations for low flow and high flow regimes. Several constituents used regression models to estimate loads that included seasonal influences, except NO_3-N and TN which relied solely on the relation between L_d and Q_d. The amount of variation in the dependent variable explained by the selected linear regression equations ranged from 69% to 99% for all equations ($P \leq 0.006$). A summary of the regression equations used and statistical significance of the selected regression models is provided in Table 8.

Table 8. Regression equations and statistics of linear regression models used to estimate constituent loads at Baron Fork during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = 0.08 + 1.42\ln(Q_d)$	Low	0.94	<0.001
	$\ln(L_d) = 2.00653 + 0.85\ln(Q_d)$	High	0.69	0.006
SO_4	$\ln(L_d) = 4.05 + 0.88\ln(Q_d) + 0.17\sin(2\pi T) + 0.25\cos(2\pi T)$	All	0.99	<0.001
Cl	$\ln(L_d) = 3.58 + 0.76\ln(Q_d) + 0.07\sin(2\pi T) + 0.11\cos(2\pi T)$	All	0.98	<0.001
SRP	$\ln(L_d) = -3.64 + 1.39\ln(Q_d) - 0.45\sin(2\pi T) - 0.68\cos(2\pi T)$	All	0.98	<0.001
TP	$\ln(L_d) = -3.36 + 1.42\ln(Q_d) - 0.47\sin(2\pi T) - 0.93\cos(2\pi T)$	All	0.96	<0.001
TN	$\ln(L_d) = 0.47 + 1.34\ln(Q_d)$	Low	0.76	<0.001
	$\ln(L_d) = 1.91 + 0.93\ln(Q_d)$	High	0.89	<0.001
NH_3-N	$\ln(L_d) = -3.47 + 1.19\ln(Q_d) - 0.43\sin(2\pi T) - 1.08\cos(2\pi T)$	All	0.84	<0.001
TSS	$\ln(L_d) = -0.02 + 1.60\ln(Q_d) - 0.47\sin(2\pi T) - 1.61\cos(2\pi T)$	All	0.87	<0.001

The calculated BCFs ranged from 1.01 to 1.27 for the selected parameters at Baron Fork, and the BCFs, total loads and FWC for each parameter during 2009 are presented in Table 9. These are the first load estimates and annual FWCs available at the Baron Fork, which had not been previously monitored by the AWRC. This information is vital to future watershed modeling efforts in the Illinois River drainage area in northwest Arkansas, because little information is available about constituent transport in the southern portion of this watershed. The southern portion of this watershed likely has different soils, topography, and landscape influences compared to the parts of the watershed that have been historically monitored by the AWRC.

Table 9. Bias correction factors (BCF), calculated annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Baron Fork during 2009.

Parameter	BCF			Total Load (kg)	FWC (mg L^{-1})
	All Flows	Low Flow	High Flow		
Cl	1.01	--	--	258,000	4.63
SO_4	1.01	--	--	748,000	13.45
NH_3-N	1.27	--	--	2,800	0.05
NO_3-N	--	1.07	0.82	81,000	1.46
SRP	1.06	--	--	6,100	0.11
TN	--	1.04	0.77	117,000	2.10
TP	1.08	--	--	9,800	0.18
TSS	1.53	--	--	1,290,000	23

Daily loads are presented in Figure 3, showing order of magnitude differences in L_d between flow regimes at the Baron Fork. This load graph also shows differences in hydrologic response during the summer season, where some variation in L_d occurs; this contrasts the observations at Ballard Creek. Daily loads clearly show the influence of episodic storm events on constituent transport.

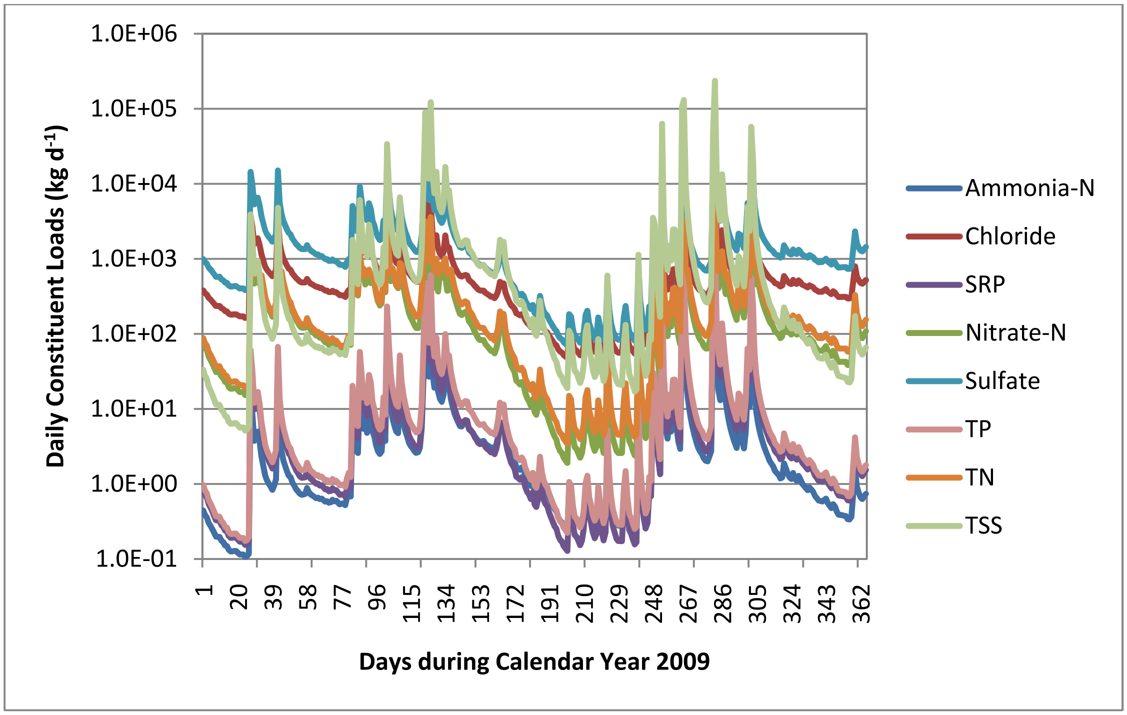


Figure 3. Daily constituent loads (kg d^{-1}) as a function of time (d) at the Baron fork during 2009.

Flint Creek at Springtown

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). A summary of the physico-chemical parameters at Baron Fork is provided in Table 10. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions and pasture land use within the drainage area.

Table 10. Minimum, Maximum and geometric mean of physico-chemical parameters at Flint Creek at Springtown from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.5	8.1	7.8
Conductivity (µS cm^{-1})	132	238	211
Dissolved Oxygen (mg L^{-1})	7.8	13.3	9.7
Temperature (^{o}C)	6.8	19.1	11.9

Average daily flow during 2009 at Flint Creek at Springtown was 48,000 m^3 and total annual discharge was 17,575,000 m^3. From the period July 1 to December 30, 2009, a total of 54 samples were collected at Flint Creek, analyzed, and used in linear regression with flow to estimate annual loads for 2009. All parameters, except TSS, were adequately described by one equation for all flow regimes, while TSS was better described by separate equations for low flow and high flow regimes. Several regression models utilized seasonal factors to estimate L_d, including those developed for NO_3-N, TN, SRP, TP, and TSS. The amount of variation in the dependent variable explained by the selected linear regression equations ranged from 64% to 99% for all equations ($P \leq 0.002$). A summary of the regression equation used and statistical significance of the selected models is provided in Table 11.

Table 11. Regression equations and statistics of linear regression models used to estimate constituent loads at Flint Creek at Springtown during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = 2.14 + 0.97\ln(Q_d) + 0.10\sin(2\pi T) + 0.08\cos(2\pi T)$	All Flows	0.98	<0.001
SO_4	$\ln(L_d) = 2.13 + 1.11\ln(Q_d))$	All Flows	0.98	<0.001
Cl	$\ln(L_d) = 3.23 + 0.83\ln(Q_d)$	All Flows	0.98	<0.001
SRP	$\ln(L_d) = -3.21 + 1.40\ln(Q_d) - 0.31\sin(2\pi T) - 0.23\cos(2\pi T)$	All Flows	0.93	<0.001
TP	$\ln(L_d) = -3.13 + 1.45\ln(Q_d) - 0.37\sin(2\pi T) - 0.22\cos(2\pi T)$	All Flows	0.90	<0.001
TN	$\ln(L_d) = 2.04 + 1.03\ln(Q_d) + 0.07\sin(2\pi T) + 0.07\cos(2\pi T)$	All Flows	0.99	<0.001
NH_3-N	$\ln(L_d) = -3.78 + 1.26\ln(Q_d)$	All Flows	0.64	<0.001
TSS	$\ln(L_d) = 0.54 + 0.98\ln(Q_d) + 0.33\sin(2\pi T) - 0.68\cos(2\pi T)$	Low Flow	0.65	<0.001
	$\ln(L_d) = -9.20 + 3.59\ln(Q_d)$	High Flow	0.71	0.002

The calculated BCFs ranged from 1.01 to 2.81 for the selected parameters at Flint Creek at Springtown, and the BCF, total loads and FWC for each parameter during 2009 are presented in Table 12. These are the first load estimates and annual FWCs available at Flint Creek at Springtown, which has not been previously monitored by the AWRC. These loading data will assist in future modeling efforts with the Illinois River drainage area in northwest Arkansas, providing load estimates for a relatively small watershed the has unique hydrology and geology. This catchment is split between forested and pasture land uses, which is typical of many subwatersheds within the UIRW.

Table 12. Bias correction factors (BCF), calculated annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Flint Creek at Springtown during 2009.

Parameter	BCF			Total Load	FWC
	All Flows	Low Flow	High Flow	(kg)	(mg L^{-1})
Cl	1.01	--	--	101,000	5.76
SO_4	1.02	--	--	92,000	5.21
NH_3-N	2.81	--	--	1,300	0.07
NO_3-N	1.01	--	--	56,000	3.18
SRP	1.10	--	--	1,700	0.10
TN	1.01	--	--	62,000	3.52
TP	1.18	--	--	2,600	0.15
TSS	--	1.23	2.56	447,000	322

Daily loads are presented in Figure 4, showing the influence of local hydrology and precipitation patterns. This graph shows the influence of episodic storm events on the transport of constituents at Flint Creek at Springtown, reflecting the re-suspension of materials from within the fluvial channel during high flows and the hydrologic connection to the landscape. Constituent transport at this site is unique, and it shows the importance of having water quality monitoring program target multiple sites within a larger watershed such as the UIRW.

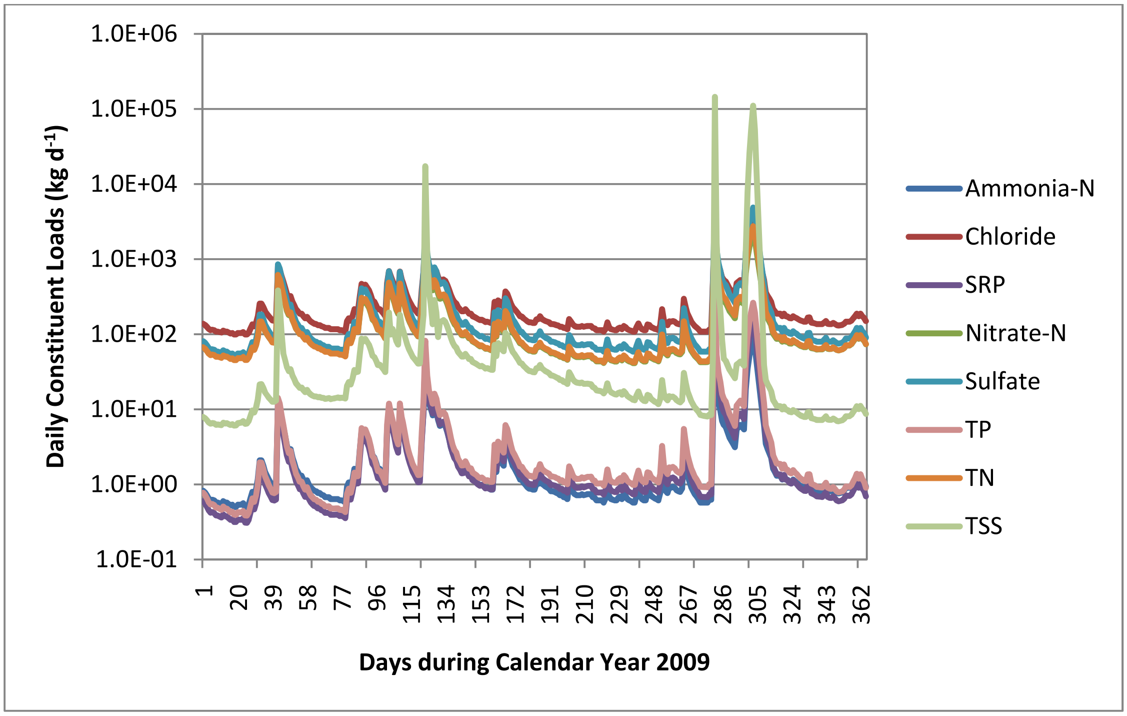


Figure 4. Daily constituent loads (kg d^{-1}) as a function of time (d) at Flint Creek at Springtown during 2009.

Flint Creek near West Siloam Springs

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). A summary of the physico-chemical parameters at Flint Creek near West Siloam Springs is provided in Table 13. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions and pasture land use within the catchment.

Table 13. Minimum, Maximum and geometric mean of physico-chemical parameters at Flint Creek near West Siloam Springs from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.7	8.7	7.9
Conductivity (µS cm^{-1})	206	332	292
Dissolved Oxygen (mg L^{-1})	6.4	14.0	9.0
Temperature (^{o}C)	5.3	25.2	12.4

Average daily flow during 2009 at Flint Creek near West Siloam Springs was 148,000 m^3 and total annual discharge was 54,764,000 m^3. From the period July 1 to December 30, 2009, a total of 54 samples were collected at Flint Creek West Siloam Springs, analyzed, and used in linear regression with flow to estimate annual loads for 2009. Cl and NH_3-N were sufficiently described by one equation for all flow regimes, while the other parameters were better described by separate equations for low flow and high flow regimes. All regression models representing the low flow regime included seasonal factors, whereas the only the regression model for Cl based on all data included seasonal factors. The amount of variation in the dependent variable explained by the selected linear regression equations ranged from 66% to 99% for all equations ($P \leq 0.001$). A summary of the regression equations used and statistical significance of the selected models is provided in Table 14.

Table 14. Regression equations and coefficients of linear regression models used to estimate constituent loads at Flint Creek near West Siloam Springs during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = -0.71 + 1.57\ln(Q_d) + 0.02\mathrm{in}(2\pi T) + 0.31\cos(2\pi T)$	Low	0.91	<0.001
	$\ln(L_d) = 2.57 + 0.86\ln(Q_d)$	High	0.99	<0.001
SO_4	$\ln(L_d) = 4.71 + 0.84\ln(Q_d) + 0.22\sin(2\pi T) + 0.10\cos(2\pi T)$	Low	0.62	<0.001
	$\ln(L_d) = 6.25 + 0.51\ln(Q_d)$	High	0.98	0.001
Cl	$\ln(L_d) = 4.11 + 0.78\ln(Q_d) - 0.09\sin(2\pi T) - 0.59\cos(2\pi T)$	All	0.98	<0.001
SRP	$\ln(L_d) = -4.13 + 1.32\ln(Q_d) - 0.39\sin(2\pi T) - 0.40\cos(2\pi T)$	Low	0.81	<0.001
	$\ln(L_d) = -7.07 + 1.90\ln(Q_d)$	High	0.99	<0.001
TP	$\ln(L_d) = -3.59 + 1.30\ln(Q_d) - 0.29\sin(2\pi T) - 0.47\cos(2\pi T)$	Low	0.74	<0.001
	$\ln(L_d) = -9.06 + 2.34\ln(Q_d)$	High	0.99	<0.001
TN	$\ln(L_d) = -0.59 + 1.56\ln(Q_d) - 0.00\sin(2\pi T) - 0.26\cos(2\pi T)$	Low	0.91	<0.001
	$\ln(L_d) = 2.09 + 0.97\ln(Q_d)$	High	0.95	<0.001
NH_3-N	$\ln(L_d) = -3.49 + 1.07\ln(Q_d)$	All	0.66	<0.001
TSS	$\ln(L_d) = -0.64 + 1.65\ln(Q_d) + 0.03\sin(2\pi T) - 0.86\cos(2\pi T)$	Low	0.72	<0.001
	$\ln(L_d) = -8.36 + 1.05\ln(Q_d)$	High	0.99	<0.001

The calculated BCFs ranged from 1.00 to 1.34 for the selected parameters at Flint Creek near West Siloam Springs, and the BCFs, total loads and FWC for each parameter during 2009 are presented in Table 15. This site is downstream from Flint Creek at Springtown, and all constituent loads increased relative to that measured upstream. There was about a three-fold increase in total water volume from upstream to downstream sites on Flint Creek, and if loads were simply tied to hydrology then loads would show similar increases. However, loads generally increased less than three-fold, except for Cl, SO_4 and TSS which showed much larger increases downstream relative to upstream.

Table 15. Bias correction factors (BCF), annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Flint Creek near West Siloam Springs during 2009.

Parameter	BCF All Flows	 Low Flow	 High Flow	Total Load (kg)	FWC (mg L^{-1})
Cl	1.01	--	--	521,000	5.76
SO_4	--	1.04	1.00	1,201,000	5.21
NH_3-N	1.34	--	--	1,300	0.07
NO_3-N	--	1.03	1.00	116,000	3.18
SRP	--	1.02	1.01	2,400	0.10
TN	--	1.03	1.00	130,000	3.52
TP	--	1.03	1.01	5,300	0.15
TSS	--	1.12	1.06	1,852,000	322

Daily loads are depicted below in Figure 5 and show some differences relative to the upstream site on Flint Creek at Springtown; this graph of L_d shows the importance of episodic storm events.

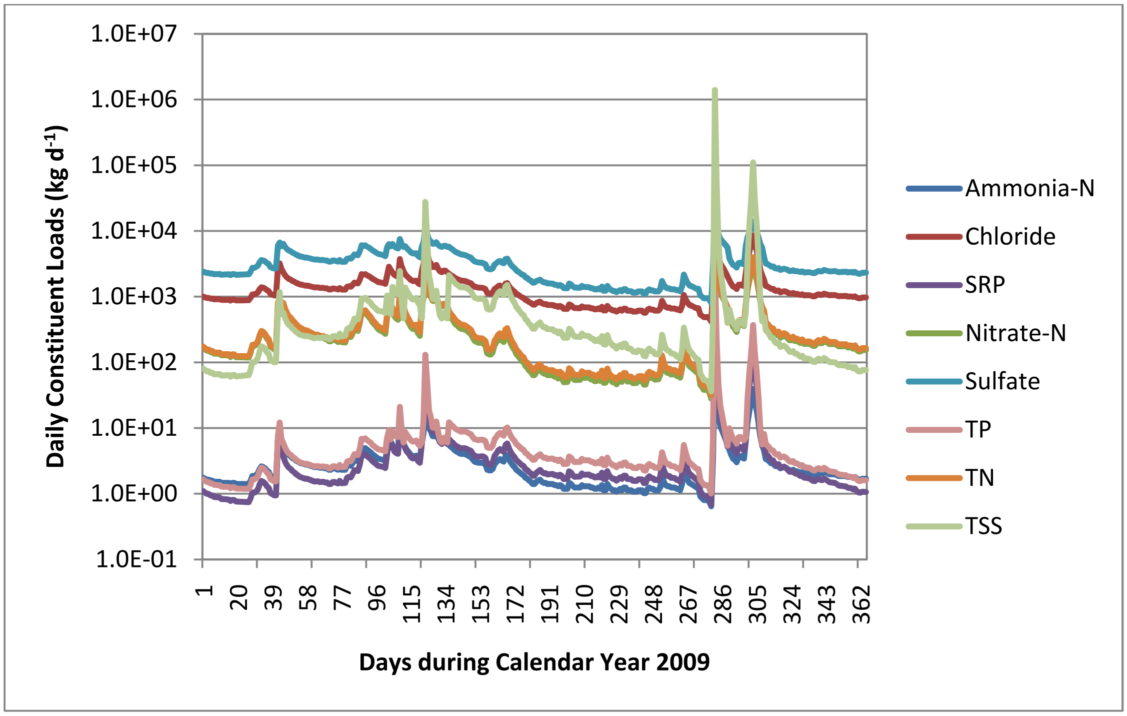


Figure 5. Daily constituent loads (kg d^{-1}) as a function of time (d) at Flint Creek near West Siloam Springs in 2009.

Illinois River at Savoy

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). A summary of the physico-chemical parameters at the Illinois River at Savoy is provided in Table 16. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions, effluent discharges in the headwaters and mixed land uses.

Table 16. Minimum, Maximum and geometric mean of physico-chemical parameters at the Illinois River at Savoy from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.4	8.5	7.9
Conductivity ($\mu S\ cm^{-1}$)	134	364	266
Dissolved Oxygen ($mg\ L^{-1}$)	5.8	15.3	8.9
Temperature (^{o}C)	1.0	26.7	9.9

Average daily flow during 2009 at the Illinois River at Savoy was 644,000 m^3 and total annual discharge was 237,547,000 m^3. From the period July 1 to December 30, 2009, a total of 56 samples were collected at Illinois River at Savoy, analyzed, and used in linear regression with flow to estimate annual loads for 2009. All parameters were described by one equation for all flow regimes, but select constituents (i.e., SRP, TP and TSS) included seasonal factors in these regression models. The amount of variation in the dependent variable explained by the selected linear regression equations ranged from 77% to 97% for all equations (P<0.001), and the explanation of variability in the data was similar between the Illinois River at Highway 59 and at Savoy. However, separate regression equations were need for low and high flow regimes at the Illinois River at Highway 59. A summary of the regression equation used and statistical significance of the selected model is provided in Table 17.

Table 17. Regression equations and coefficients of linear regression models used to estimate constituent loads at Illinois River at Savoy during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = 2.44 + 0.83\ln(Q_d))$	All	0.95	<0.001
SO_4	$\ln(L_d) = 4.43 + 0.85\ln(Q_d)$	All	0.97	<0.001
Cl	$\ln(L_d) = 4.63 + 0.71\ln(Q_d)$	All	0.96	<0.001
SRP	$\ln(L_d) = -4.03 + 1.37n(Q_d) - 0.84\sin(2\pi T) - 0.71\cos(2\pi T)$	All	0.86	<0.001
TP	$\ln(L_d) = -3.46 + 1.40\ln(Q_d) - 0.55\sin(2\pi T) - 0.65\cos(2\pi T)$	All	0.91	<0.001
TN	$\ln(L_d) = 2.26 + 0.91\ln(Q_d)$	All	0.97	<0.001
NH_3-N	$\ln(L_d) = -3.85 + 1.28\ln(Q_d)$	All	0.77	<0.001
TSS	$\ln(L_d) = 0.005 + 1.64\ln(Q_d) - 0.48in(2\pi T) - 1.12\cos(2\pi T)l$	All	0.85	<0.001

The calculated BCFs ranged from 1.02 to 1.55 for the selected parameters at Illinois River at Savoy, and the BCF, total loads and FWC for each parameter during 2009 are presented in Table 18. This site is upstream from the Illinois River at AR59, and it had about one third of the total discharge that was observed downstream near the Arkansas-Oklahoma border. The constituent loads were generally one third or less at the Illinois River at Savoy compared to that observed downstream at AR59, except for SRP. The annual SRP load at Illinois River at Savoy was about half that observed at AR59, whereas the annual TP load was much closer to one third that observed downstream. This shows the importance of SRP storage within the reaches downstream from Savoy along the Illinois River, as well as within tributary inflows along this section.

Table 18. Bias correction factors (BCF), annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Illinois River at Savoy during 2009.

Parameter	BCF			Total Load	FWC
	All Flows	Low Flow	High Flow	(kg)	(mg L^{-1})
Cl	1.02	--	--	1,656,000	6.97
SO_4	1.02	--	--	3,144,000	13.24
NH_3-N	1.45	--	--	21,000	0.09
NO_3-N	1.03	--	--	392,000	1.65
SRP	1.28	--	--	39,000	0.16
TN	1.02	--	--	530,000	2.23
TP	1.19	--	--	72,000	0.30
TSS	1.55	--	--	20,556,000	87

Daily loads are depicted in Figure 6 below, showing the influence of episodic storm events on constituent transport in the Illinois River at Savoy. The graphs of L_d show some similarities between sites along the Illinois River (i.e., AR59 and Savoy), but also some differences. These differences likely reflect variation in the relation between L_d and Q_d, as well as differences in catchment land use and other constituent sources such as effluent discharges.

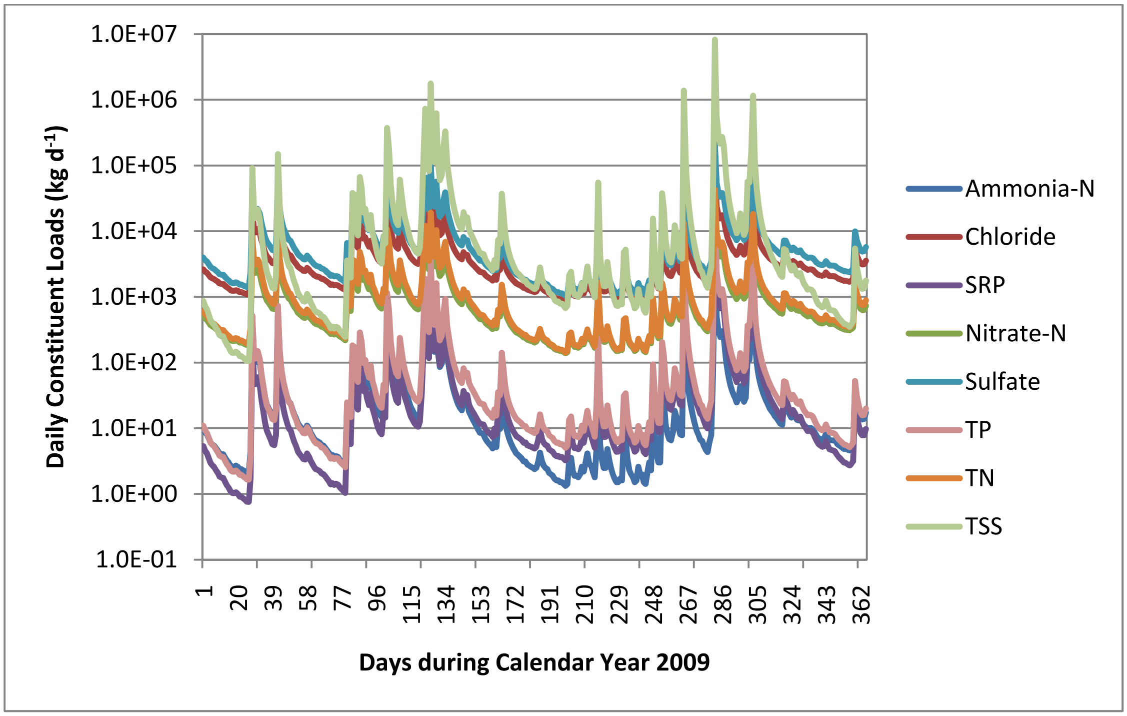


Figure 6. Daily constituent loads (kg d^{-1}) as a function of time (d) at the Illinois River at Savoy during 2009.

Mud Creek Tributary

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). Physico-chemical parameters varied seasonally and with episodic rainfall events. A summary of the physico-chemical parameters at Mud Creek Tributary is provided in Table 19. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions and urban land use.

Table 19. Minimum, Maximum and geometric mean of physico-chemical parameters Mud Creek Tributary from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.7	8.3	8.1
Conductivity (µS cm^{-1})	68	453	355
Dissolved Oxygen (mg L^{-1})	4.2	15.4	10.0
Temperature (^{o}C)	0.8	25.2	8.0

Average daily flow during 2009 at Mud Creek Tributary was 4,400 m^3 and total annual discharge was 1,629,000 m^3; this is the smallest catchment monitored within the UIRW and the only one that is primarily urban development. From the period July 1 to December 30, 2009, a total of 56 samples were collected at Mud Creek Tributary, analyzed, and used in linear regression with flow to estimate annual loads for 2009. All parameters were adequately described by one equation for all flow regimes where variation in the dependent variable explained by the selected linear regression equations ranged from 86% to 94% for all equations (P <0.001). The regression models also included seasonal factors when estimating constituent loads, except NO_3-N, TN and SO_4. A summary of the regression equation(s) used and statistical significance of the selected model(s) is provided in Table 20.

Table 20. Regression equations and coefficients of linear regression models used to estimate constituent loads at Mud Creek Tributary during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(\mathrm{L_d}) = -0.27 + 1.20\ln(\mathrm{Q_d})$	All	0.88	<0.001
SO_4	$\ln(\mathrm{L_d}) = 3.55 + 0.78\ln(\mathrm{Q_d})$	All	0.86	<0.001
Cl	$\ln(\mathrm{L_d}) = 3.23 + 0.78\ln(\mathrm{Q_d}) + 0.41\mathrm{in}(2\pi\mathrm{T}) + 0.44\cos(2\pi\mathrm{T})$	All	0.88	<0.001
SRP	$\ln(\mathrm{L_d}) = -3.37 + 1.44\mathrm{n}(\mathrm{Q_d}) - 0.45\sin(2\pi\mathrm{T}) - 0.99\cos(2\pi\mathrm{T})$	All	0.86	<0.001
TP	$\ln(\mathrm{L_d}) = -2.52 + 1.40\ln(\mathrm{Q_d}) - 0.55\sin(2\pi\mathrm{T}) - 0.65\cos(2\pi\mathrm{T})$	All	0.91	<0.001
TN	$\ln(\mathrm{L_d}) = 0.28 + 1.24\ln(\mathrm{Q_d})$	All	0.94	<0.001
NH_3-N	$\ln(\mathrm{L_d}) = -2.77 + 1.28\ln(\mathrm{Q_d}) - 0.09\mathrm{in}(2\pi\mathrm{T}) - 0.79\cos(2\pi\mathrm{T})$	All	0.87	<0.001
TSS	$\ln(\mathrm{L_d}) = 2.19 + 1.66\ln(\mathrm{Q_d}) - 0.28\mathrm{in}(2\pi\mathrm{T}) - 1.38\cos(2\pi\mathrm{T})$	All	0.81	<0.001

The calculated BCFs ranged from 1.10 to 6.48 for the selected parameters at Mud Creek Tributary, and the BCF, total loads and FWC for each parameter during 2009 are presented in Table 21. The largest BCF was observed for TSS, suggesting that some [relatively] larger differences were observed between measured and predicted L_d for TSS. This site is extremely important, because it is the only site which truly reflects constituent transport from an urban catchment; all the other monitoring stations within the UIRW generally drain mixed land uses, whereas this catchment is totally within the City of Fayetteville. The data from this site should be extremely useful in future watershed modeling efforts, as it provides the ability to calibrate watershed models to estimate constituent loads from well-established urban catchments.

Table 21. Bias Correction Factors (BCF), annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Mud Creek Tributary during 2009.

Parameter	BCF			Total Load	FWC
	All Flows	Low Flow	High Flow	(kg)	(mg L^{-1})
Cl	1.35	--	--	14,000	8.53
SO_4	1.10	--	--	18,000	11.14
NH_3-N	1.21	--	--	100	0.07
NO_3-N	1.65	--	--	900	0.56
SRP	1.09	--	--	60	0.04
TN	1.11	--	--	1,600	0.95
TP	1.45	--	--	300	0.16
TSS	6.48	--	--	1,342,000	824.19

Daily loads are shown in Figure 7, and the lines on these graphs clearly show the influence of flashy hydrology typical of urban streams on constituent transport. This shows that every rainfall event results in runoff, and the regression models predict episodic sharp increases in constituent transport base on the changes in hydrology. The flashy nature of these streams make sampling more difficult, but it is critically important to sample storm events on the rising, peak and falling limbs of the hydrograph.

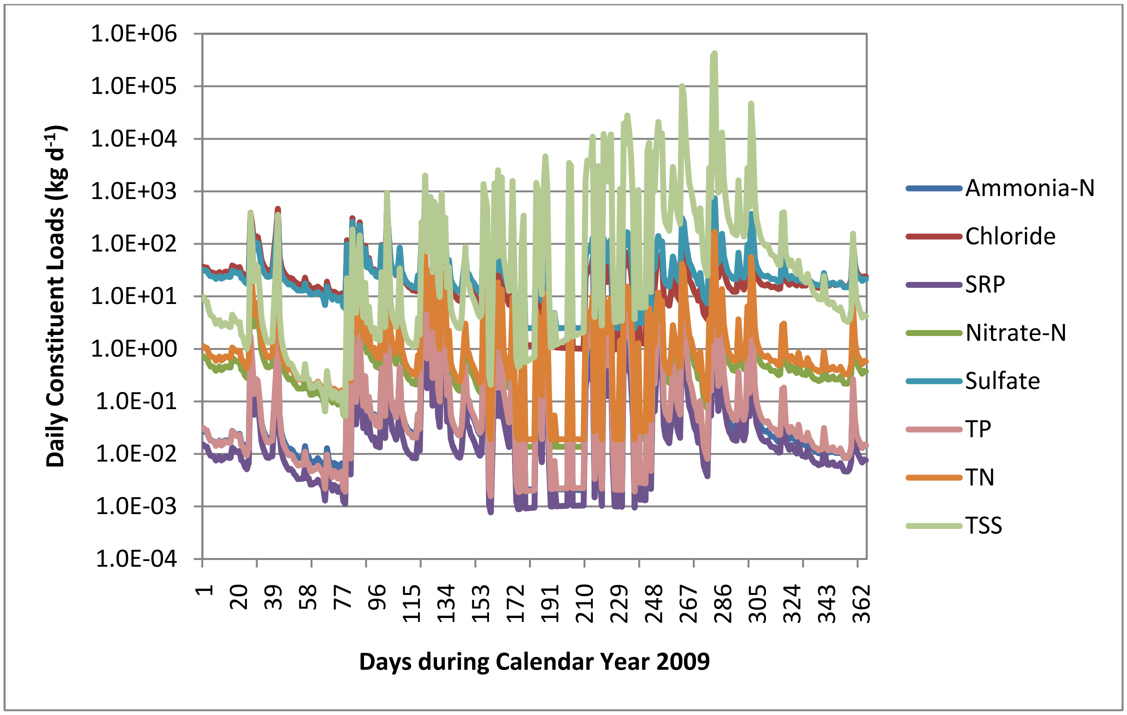


Figure 7. Daily constituent loads (kg d^{-1}) as a function of time (d) at Mud Creek Tributary during 2009.

Osage Creek

Physico-chemical parameters were measured on-site during this project period (i.e., from 1 July 2009 to 30 June 2010). Physico-chemical parameters varied seasonally and with episodic rainfall events. A summary of the physico-chemical parameters at Osage Creek is provided in Table 22. The physico-chemical properties of this site were within the expected range, relative to a stream influenced by sample collection timing, variable hydrology, local geology, climatic conditions, effluent discharge from the Cities of Springdale and Rogers and mixed land use.

Table 22. Minimum, Maximum and geometric mean of physico-chemical parameters at Osage Creek from 1 July 2009 to 30 June 2010.

Parameter	Minimum	Maximum	Geometric Mean
pH	7.9	8.6	8.1
Conductivity (µS cm^{-1})	154	447	356
Dissolved Oxygen (mg L^{-1})	7.6	15.1	9.9
Temperature (^{o}C)	4.7	23.8	12.1

Average daily flow during 2009 at the Osage Creek was 534,000 m^3 and total annual discharge was 196,999,000 m^3; annual discharge was approximately 75% of that observed during 2008. From the period July 1 to December 30, 2009, a total of 54 samples were collected at Osage Creek, analyzed, and used in linear regression with flow to estimate annual loads for 2009. All parameters were adequately described by one equation for all flow regimes, and the amount of variation in the dependent variable explained by the selected linear regression equations ranged from 71% to 93% for all equations ($P<0.001$). Only the regression model for SO_4 included seasonal components, whereas the other regression models were solely based on Q_d. A summary of the regression models used and statistical significance of the selected models is provided in Table 23.

Table 23. Regression equations and coefficients of linear regression models used to estimate constituent loads at Osage Creek during calendar year 2009.

Parameter	Regression Equation	Flow Regime	R^2	P
NO_3-N	$\ln(L_d) = 3.91 + 0.66\ln(Q_d)$	All	0.76	<0.001
SO_4	$\ln(L_d) = 6.00 + 0.59\ln(Q_d) - 0.34\sin(2\pi T) - 0.07\cos(2\pi T)$	All	0.84	<0.001
Cl	$\ln(L_d) = 6.30 + 0.53\ln(Q_d)$	All	0.78	<0.001
SRP	$\ln(L_d) = -2.79 + 1.18n(Q_d) - 0.39\sin(2\pi T) - 0.40\cos(2\pi T)$	All	0.93	<0.001
TP	$\ln(L_d) = -3.98 + 1.50\ln(Q_d) - 0.27\sin(2\pi T) - 0.41\cos(2\pi T)$	All	0.80	<0.001
TN	$\ln(L_d) = 3.53 + 0.75\ln(Q_d)$	All	0.87	<0.001
NH_3-N	$\ln(L_d) = -7.38 + 1.86\ln(Q_d)$	All	0.71	<0.001
TSS	$\ln(L_d) = -5.65 + 2.58\ln(Q_d) - 0.18in(2\pi T) - 0.52\cos(2\pi T)$	All	0.83	<0.001

The BCFs range from 1.01 (Cl, SO_4 and TN) to 1.38 (TSS) and the BCF, total loads and FWC for each parameter during 2009 are presented in Table 24. At this site, some regression models had seasonal coefficients that we significant but these were not used because constituent loads were not similar to that previously measured at this site. This shows the importance of understanding the system that is being modeled, and not simply relying on higher R^2 values to indicate better regression model predictions.

Table 24. Bias Correction Factors (BCF), annual loads (kg) and flow-weighted concentrations (FWC) for each constituent at Osage Creek during 2009.

Parameter	BCF			Total Load	FWC
	All Flows	Low Flow	High Flow	(kg)	(mg L^{-1})
Cl	1.01	--	--	3,110,000	16.24
SO_4	1.01	--	--	3,260,000	16.81
NH_3-N	1.26	--	--	17,000	0.08
NO_3-N	1.02	--	--	562,000	3.08
SRP	1.02	--	--	16,000	0.08
TN	1.01	--	--	633,000	3.40
TP	1.19	--	--	42,000	0.22
TSS	1.38	--	--	29,272,000	149

Daily loads are shown below in Figure 8, reflecting the hydrologic nature of Osage Creek. This graph shoes the influence of episodic storm events on the transport of constituents at Osage Creek, reflecting the re-suspension of materials from within the fluvial channel during high flows and the hydrologic connection to the landscape. This graph clearly shows the influence of local hydrology and precipitation patterns at Osage Creek typical for this region.

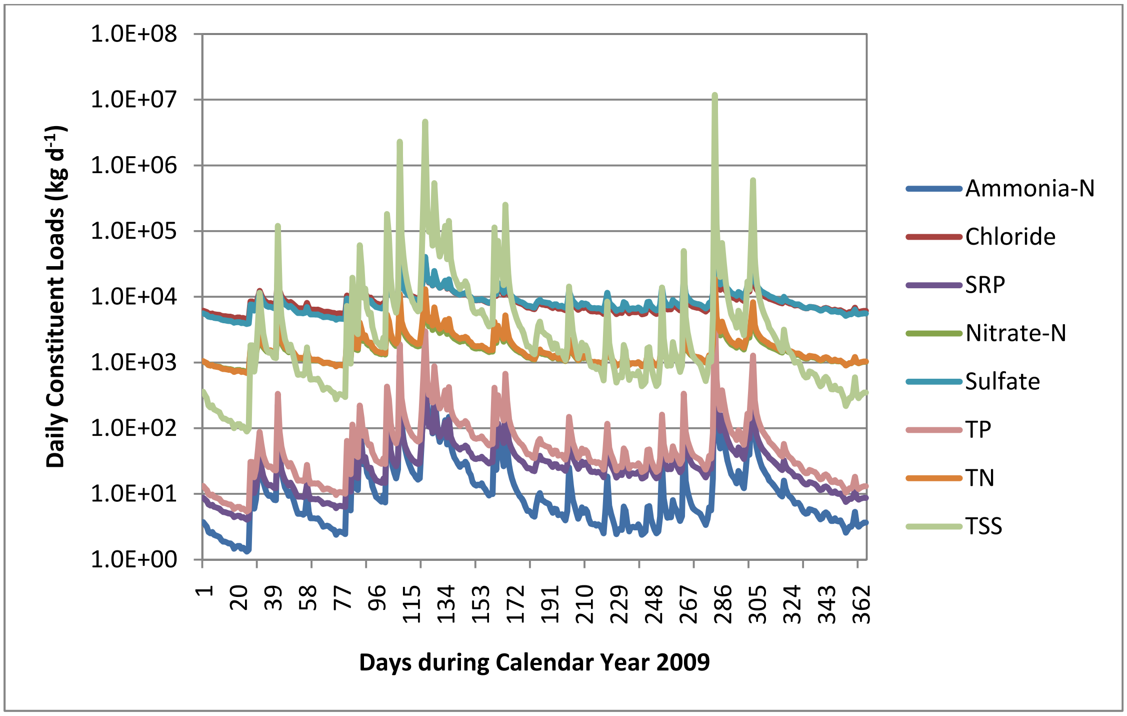


Figure 8. Daily constituent loads (kg d^{-1}) as a function of time (d) at Osage Creek during 2009.

SUMMARY

This project successfully estimated constituent loads in calendar year 2009 using water samples collected in this project period. Historical constituent loads at the Illinois River generally follow the same pattern as annual discharge, and loads in 2009 were less than the previous year because annual discharge was only 75% of that observed in 2008. Estimating annual loads a multiple sites in the watershed provides valuable loading information for prioritizing restoration needs and modeling efforts in the future.

REFERENCES OR PREVIOUS WHITE RIVER BASIN LOAD REPORTS

ADEQ. ADEQ. 2008. 2008 List of impaired water-bodies (303(d) List). Arkansas Department of Environmental Quality, Little Rock, Arkansas. 18 pp.

Ekka, S. A., B.E. Haggard, M.D. Matlock, and I. Chaubey. 2006. Dissolved phosphorus concentrations and sediment interactions in effluent-dominated Ozark streams. Ecol. Engr. 26: 375-391.

Haggard, B.E. Haggard, B.E. 2010. Phosphorus concentrations, loads and sources within the Illinois River Drainage Area, Northwest Arkansas, 1997-2008. Journal of Environ-mental Quality. *In Press.*

Helsel, D.R., and R.M. Hirsch. 2002. Statistical methods in water resources—hydrologic analysis and interpretation: U.S. Geological Survey Techniques of Water-Resources Investigations, book 4, chap. A3, 510 p.

Massey, L.B. and Others. 2009. Water Quality Sampling, Analysis and Annual Load Determinations for the Illinois River at Arkansas Highway 59 Bridge, 2008. Arkansas Water Resources Center Miscellaneous Publication No. 352.

Massey, L.B. and Others. 2009. Water Quality Sampling, Analysis and Annual Load Determinations for Nutrients and Solids on the Ballard Creek, 2008. Arkansas Water Resources Center Miscellaneous Publication No. 353.

Nelson, M.A. 1998. 1997 Pollutant Loads at Arkansas Highway 59 Bridge (Prepared for AR-OK Illinois River Compact Commission). Arkansas Water Resources Center Miscellaneous Publication No. 225.

Nelson, M.A. and T.S. Soerens. 2002. Illinois River 1999 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 279.

Nelson, M.A. and T.S. Soerens. 2001. Illinois River 2000 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 298.

Nelson, M.A. and T.S. Soerens. 2002. Illinois River 2001 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 305.

Soerens, T.S. and M.A. Nelson. 2003. Evaluation of Sampling Strategies on Load Estimation for Illinois River at Highway 59. Arkansas Water Resources Center Miscellaneous Publication No. 306.

Nelson, M.A. and W. Cash. 2003. Illinois River 2002 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 308.

Nelson, M.A. and W. Cash. 2003. Water Quality Sampling, Analysis and Annual Load Determinations for TSS, Nitrogen and Phosphorus at the Washington County Road 76 Bridge on Ballard Creek. Arkansas Water Resources Center Miscellaneous Publication No. 309.

Nelson, M.A. and Others. 2004. Illinois River 2003 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 317.

Nelson, M.A. and Others. 2004. Water Quality Sampling, Analysis and Annual Load Determinations for TSS, Nitrogen and Phosphorus at the Washington County Road 76 Bridge on Ballard Creek. Arkansas Water Resources Center Miscellaneous Publication No. 323.

Nelson, M.A. and Others. 2004. Illinois River 2004 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 325.

Nelson, M.A. and Others. 2006. 2005 Nutrient and Sediment Monitoring Report Ballard Creek Near Arkansas/Oklahoma Line. Arkansas Water Resources Center Miscellaneous Publication No. 329.

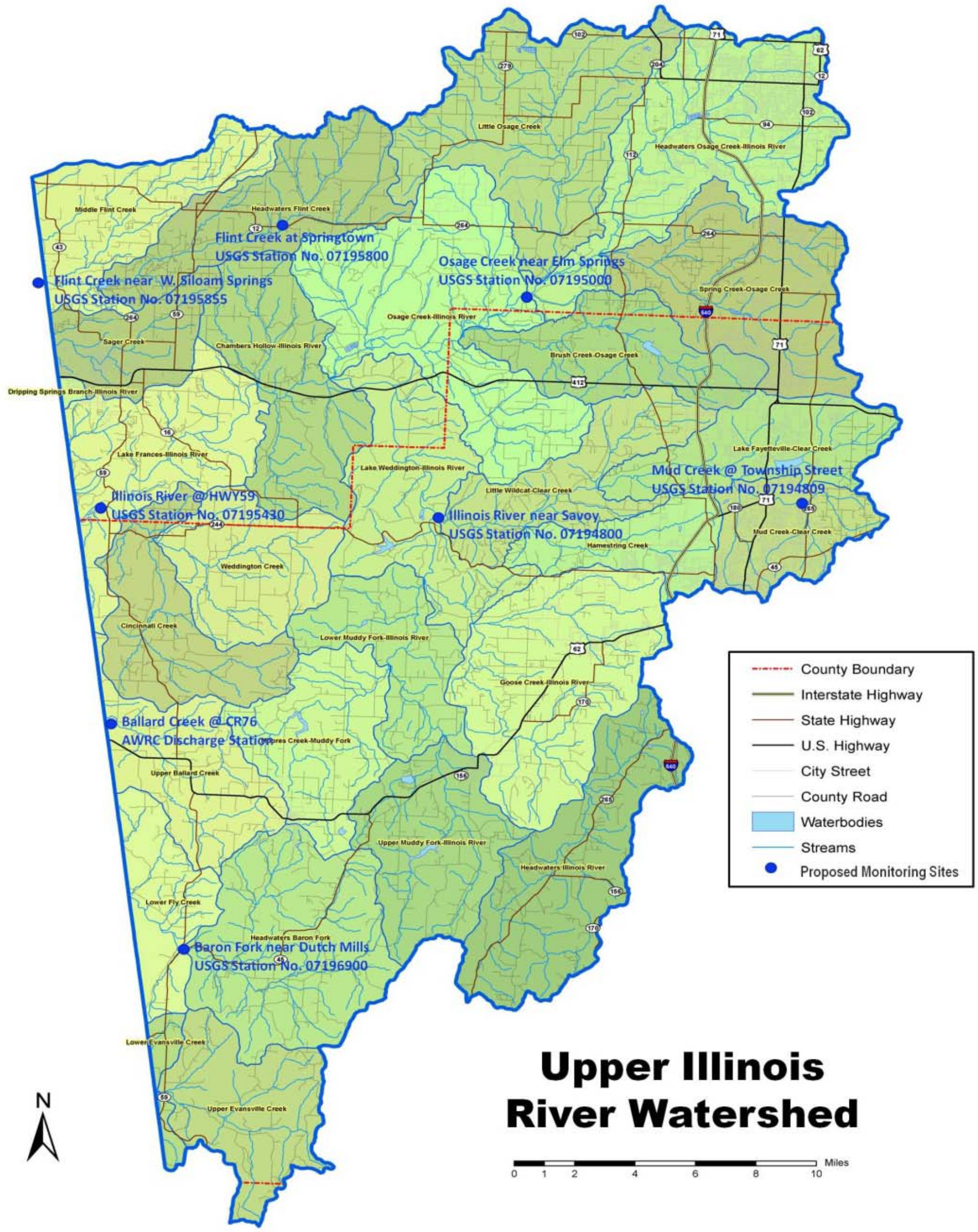
Nelson, M.A. and Others. 2006. Illinois River 2005 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 332.

Nelson, M.A. and Others. Continuation of Water Quality Monitoring of the Osage Creek Above the Highway 112 Bridge Near Cave Springs. Arkansas Water Resources Center Miscellaneous Publication No. 338.

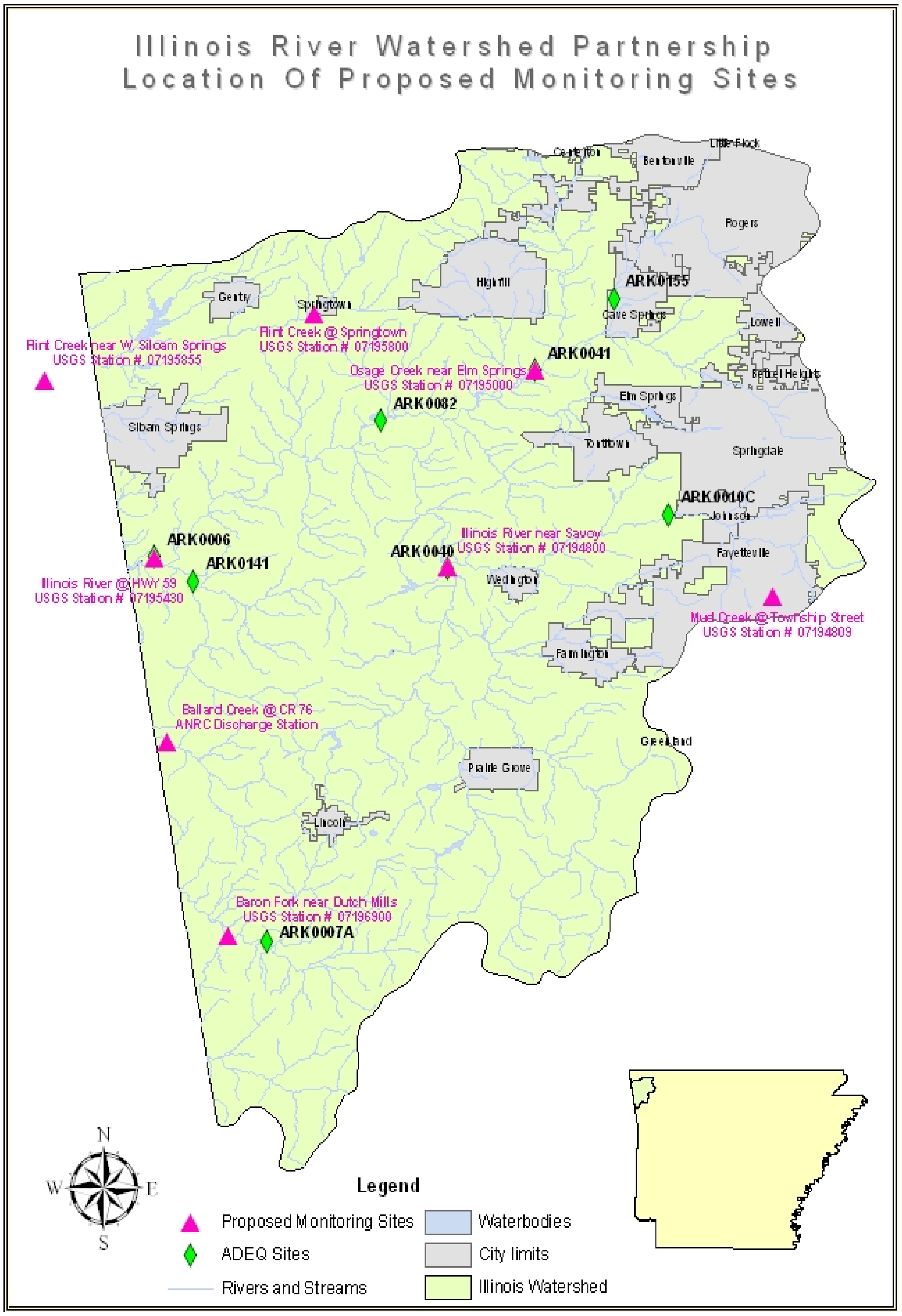
Nelson, M.A. and Others. Water Quality Sampling, Analysis and Annual Load Determinations for TSS, Nitrogen and Phosphorus at the Ballard Creek Near Arkansas/Oklahoma Line. Arkansas Water Resources Center Miscellaneous Publication No. 340.

Nelson, M.A. and Others. 2007. Illinois River 2006 Pollutant Loads at Arkansas Highway 59 Bridge. Arkansas Water Resources Center Miscellaneous Publication No. 341.

APPENDIX 1. Location of the sampling stations In the Illinois River Watershed, northwest Arkansas.



APPENDIX 2. Location of the sampling stations In the Illinois River Watershed, northwest Arkansas and location of ADEQ monitoring sites in the Illinois River Watershed, northwest Arkansas.



Appendix 3. Summary of estimated semi-annual loads and flow-weighted concentrations for each consistent at each sampled site in the Upper Illinois River Watershed from 1 January through 30 June 2010.

Summary of estimated semi-annual loads (kg) for each consistent at each sampled site in the Upper Illinois River Watershed for the period, 1 January through 30 June 2010.

Site	Cl^-	SO_4	NH_3-N	NO_3-N	SRP	TN	TP	TSS
Ballard Creek	205,000	363,000	1,100	55,000	3,000	59,000	4,900	290,000
Baron Fork	155,000	472,000	942	56,000	1,600	68,000	2,600	339,000
Flint Creek (W. Siloam)	303,000	724,000	700	66,700	1,100	73,000	2,200	586,000
Flint Creek (Springtown)	82,000	78,000	1,100	49,000	1,100	54,200	1,600	115,000
Illinois River @ AR59	4,344,000	5,031,000	10,000	989,000	19,400	1,074,000	37,000	6,571,000
Illinois River @ Savoy	948,000	1,747,000	8,900	219,000	6,400	289,000	16,000	3,985,000
Mud Creek Tributary	8,000	7,800	50	400	20	700	80	17,000
Osage Creek	1,537,000	1,503,000	3,800	287,000	6,000	310,000	13,000	2,248,000

Summary of calculated flow weighted concentrations (FWC, mg L^{-1}) for each constituent at the sampled sites in the Upper Illinois River Watershed for the period, 1 January through 30 June 2010.

Site	Cl^-	SO_4	NH_3-N	NO_3-N	SRP	TN	TP	TSS
Ballard Creek	9.68	17.11	0.05	2.59	0.14	2.76	0.23	14
Baron Fork	5.24	15.97	0.03	1.88	0.06	2.30	0.09	11
Flint Creek (W. Siloam)	10.05	24.02	0.02	2.21	0.04	2.43	0.07	19
Flint Creek (Springtown)	5.51	5.28	0.07	3.34	0.08	3.66	0.11	8
Illinois River @ AR59	11.57	13.40	0.03	2.63	0.05	2.86	0.10	18
Illinois River @ Savoy	7.64	14.07	0.07	1.76	0.05	2.32	0.13	32
Mud Creek Tributary	11.54	11.28	0.07	0.56	0.03	0.95	0.12	25
Osage Creek	18.23	17.10	0.04	3.39	0.07	3.67	0.16	26