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Urban Stream Syndrome in a Small Town: A Comparative Study of Sager and Flint Creeks

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Running Title: Urban Stream Syndrome in a Small Town

Abstract

Utilizing rapid bioassessment procedures and aquatic physiochemical techniques, a three-year investigation of Sager and Flint creeks was completed. Bioassessment indices and physiochemical parameters of the 2 streams were compared and the effects of urbanization on both watersheds were assessed. Correlating data concerning land usage in both watersheds and alterations of both streams' geomorphology were also utilized to conclude that Sager Creek shows a higher degree of urban stream syndrome than Flint Creek.

Key words:--- Aquatic insects, macroinvertebrates, urban stream syndrome, water quality

Introduction

Urban stream syndrome (Meyer et al. 2005, Walsh et al. 2005, Korminkova 2012) is a condition used to describe the effects of urbanization on stream ecosystems. Symptoms of the syndrome include elevated levels of contaminants and nutrients, altered channel morphology, more frequent occurrences of flood events, and a reduction in biotic richness with a corresponding increase in pollution tolerant species (Paul and Meyer 2001, Meyer et al. 2005).

From 1999-2004, the United States Geological Survey (USGS) conducted a comprehensive study of urban stream syndrome in 9 metropolitan areas around the country. One of the primary objectives of this study was to determine the response of chemical, biological and physical processes to increasing urbanization (USGS 2013). Since temporal studies of increasing urbanization were impossible, similarly sized watersheds, within the same geographic area, were selected to represent a gradient of urbanization. This gradient, called the urban intensity index ranked watersheds from 0 to 100 (low to high) according to the level of urbanization (Falcone et al. 2007). In theory, all continental United States watersheds would fall within the urban intensity index ranking dependent upon each watershed's level of urbanization.

The urban intensity index was computed by analyzing approximately 300 geographic information system (GIS) variables for each watershed (Falcone et al. 2007). This level of analysis would not be possible for all watersheds, thus a precise urban intensity index ranking of many streams may be impossible. However, Steuer (2010) computed a much simpler disturbance metric based off the GIS derived landcover characteristics of watersheds, **{** % impervious surface + (0.15 x (% agriculture + grasslands))**}**, and correlated this to invertebrate diversity to produce a regression curve. According to Steuer (2010), invertebrate diversity sharply declines with increased impervious surfaces and agriculture and grassland cover, changes that are indicative of increased urbanization.

The 40 km^2 Sager Creek watershed is located in an Ozark Highlands Ecoregion of Northwest Arkansas (Omernick 1987). Pastures for grazing or hay production dominate this watershed (55%). The main channel of Sager Creek flows through the city of Siloam Springs and the downtown area is built around it. An estimated 30.5% of the watershed is occupied by urbanized land. Only a small fraction (11%) of the watershed remains forested (AWIS 2006a). An application of the Steuer formula (2010) on the Sager Creek watershed produces a disturbance metric of 38.7.

The somewhat larger Flint Creek watershed (74 km^2) lies adjacent to the Sager Creek watershed on its northern border. Pastures for hay production and grazing also dominate this watershed (53%). The small city of Gentry lies within the Flint Creek watershed, however, the main channel of the stream does not flow through the city limits, and only 7% of the watershed is occupied by urbanized land. Unlike Sager Creek, 35% the Flint Creek watershed is still forested (AWIS 2006b). Based on the Steuer formula (2010), Flint Creek would have a disturbance metric of 15.1.

In a previous publication, the author indicated that wastewater treatment effluent had compromised the integrity of one reach of Sager Creek compared to other portions of the stream (Wakefield 2013). However, there is reason to suspect that the entire Sager Creek watershed may be affected, at some level, by urban stream syndrome as indicated by the Steuer formula. Because of its geographic location and similar land usage, but contrasting reduced amount of urban influence, Flint Creek serves as a reference stream for comparison to the ostensibly more urbanized Sager Creek (ADEQ 1987).

If the Steuer formulation is accurate then Sager Creek should show a higher degree of urban stream syndrome than Flint Creek. The purpose of this study was to utilize physiochemical testing of stream water as well as stream macroinvertebrate populations to test this hypothesis.

Materials and Methods

Both Sager and Flint creeks are relatively small 1-3 order streams (Vannote et al. 1980). Three sampling reaches on each stream, {Honeycutt (Hon), John Brown University (JBU), and Waste Water (WW) for Sager Creek; Ozark Academy (OA), Siloam Springs City Lake (Lake) & North (Nor) for Flint Creek}, were chosen based on accessibility and geomorphic conditions (Fig. 1). Each sampling reach was further divided into 8 riffle-dominated sampling sites, labeled A-H with A being the most downstream site. Sampling of Sager and Flint creeks began in August of 2010 and continued until April of 2013. A total of 16 samples were collected from each reach over the 32 month period.

Macroinvertebrate samples were collected using a 500-µm D-net. At each sample site, the net was placed downstream of the water-flow, and an approximate 0.30 m^2 area in front of the net was kicked for 30 seconds to dislodge organisms. This process was repeated at a different location in the site to insure an adequate collection of organisms. A 0.5 cm^2 mesh rock screen was used to catch large rocks and debris as the net contents were transferred to a bucket. Accumulated rocks, algae or other debris collected in the rock screen, were inspected and observed clinging organisms were removed and placed in the bucket. All clinging organisms found in the net were also placed in the bucket. A 500 µm screen was used to eliminate excess water from the bucket before the final sample was transferred to a collection container and preserved with 95% v/v ethyl alcohol. This process was repeated for all sites, A-H, within each reach. However, due to limited time and assistance during the summer months, collections in June and July were made at only 4 of the 8 sampling sites.

In the laboratory, samples were emptied into a gridded counting tray. A random number generator was used to determine a starting grid and then a 100-organism subsample was separated, identified to the family level (Needham and Needham 1962, Voshell 2002), and recorded. Using a method created by Hilsenhoff (1988) a family-level biotic index (FBI) was generated from each subsample. Sixty-six insect families, in 8 different orders, as well as 2 crustacean groups, (Isopoda and Amphipoda), could be utilized in the production of a FBI. The FBI represented the presence of higher levels of organic pollution with higher numeric values on a scale of 0 to 10. However, the FBI was developed utilizing arthropods native to Wisconsin. To more accurately reflect the sensitivity of the arthropods found in Sager and Flint creeks, organic pollution tolerance values were assigned according to a database provided by the Missouri Department of Natural Resources. These values also ranged from 0 to 10, on a low to high pollution tolerance scale (Sarver 2005).

Utilizing the same subsample from each site, a family-level Simpson's Index of Diversity (SID) was also calculated from each subsample (Simpson 1949). SID indicates the probability of 2 repeated samples being different. In other words, on a scale of 0 to 1, as

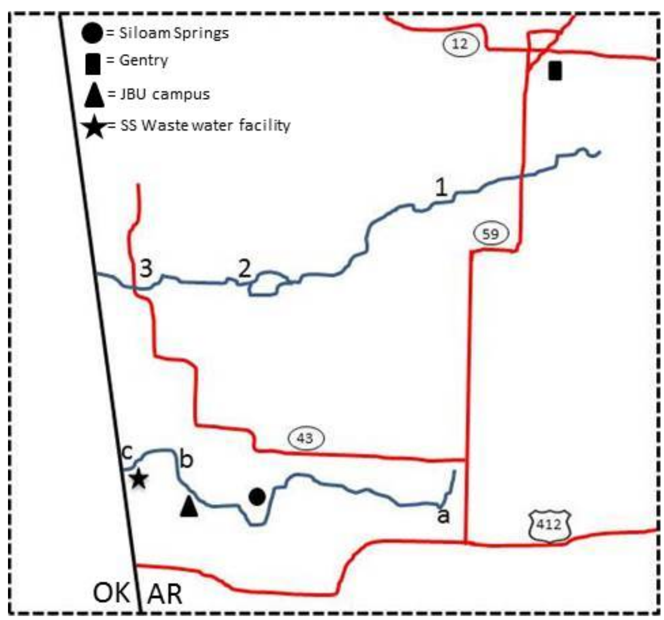

Fig. 1. Map of the study areas in Benton County, AR. Flint Creek study sites; 1=OA, 2=Lake, 3=Nor. Sager Creek study sites; a=Hon, b=JBU, c=WW. Both streams flow east to west.

the diversity within a stream increases the probability that a second sample will be different from the first also increases.

Utilizing all 8 of the individual site FBI and SID, a mean FBI and mean SID was calculated for each reach per sample day. All June and July mean FBI and mean SID were calculated utilizing the 4 individual site's data. Both the mean FBI and mean SID were pooled in 2 different manners for statistical analysis. An overall stream-specific mean FBI (Overall Index) and overall stream-specific SID (Overall Diversity) were calculated by pooling all 48 mean FBI and mean SID values collected over the 3years of study. Also a stream reach-specific mean FBI (Reach Index) and stream reach-specific mean SID (Reach Diversity) were produced utilizing the 16 individual mean FBI and mean SID for each reach.

The mean number of individuals of each recorded family per reach (M/R) was also generated from the total number of individuals identified in each 100 organism subsample. These values were utilized to compare the overall diversity of pollution tolerant versus pollution intolerant species within each stream.

Environmental Protection Agency (EPA) standard procedures were used to calculate stream water flow for both Sager and Flint creeks (USEPA 2004). Physiochemical data was collected using several different methods. A Hanna Instruments HI 991300 Multiparameter Water Quality Meter was used to record stream temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS). Utilizing EPA standard procedures (USEPA 2004), approximately 120 ml of water was collected from each of these sites for additional physiochemical testing. Tests for dissolved oxygen (O_2), (HRDO method 8166), nitrate (NO_3^-), (cadmium reduction method 8039), and phosphate (PO_4^{3-}), (USEPA method 365.2), concentrations were performed on unfiltered water using a Hach™ colorimeter (model DR/850). All tests were performed three times from randomly selected sites within each reach. A mean value for each parameter was then calculated and recorded. Mean values for each parameter were then pooled in the same manner as mean FBI and mean SID to produce an overall stream-specific mean (Stream Mean) and a stream reach-specific mean (Reach Mean) for each parameter.

Overall Index, Overall Diversity, M/R and Stream Mean data for Sager Creek versus Flint Creek were all compared using paired t-tests with an α=0.05. Reach Index, Reach Diversity, and Reach Mean values for each parameter were first tested with an ANOVA (α=0.05). Then, for each parameter, paired t-tests were performed between each Sager Creek reach compared to each Flint Creek reach. To avoid a Type I error, the Bonferroni Correction was applied to all stream reach-specific comparisons (α = 0.016) (Triola and Triola 2006).

Results

Table 1. The overall stream-specific mean FBI (Overall Index), overall stream-specific mean SID (Overall Diversity) and overall mean for each physiochemical parameter (Stream Mean), n=48. Diff= t-test results; ppm= parts per million; µS= microsiemen

Parameter	Sager $\bar{X}$±SE	Flint $\bar{X}$±SE	Diff
Overall Index	4.97±0.059	4.84±0.074	n.d.
Overall Diversity	0.723±0.017	0.805±0.015	*p=1.12E-04*
Stream Mean Waterflow (m^3/s)	0.479±0.058	0.956±0.108	*p=1.91E-06*
Stream Mean TDS (ppm)	164.39±9.46	122.86±2.08	*p=1.43E-05*
Stream Mean EC (µS)	327.96±19.16	247.50±3.95	*p=3.13E-05*
Stream Mean Temp. (^{o}C)	17.71±0.691	17.17±1.27	n.d.
Stream Mean pH	7.66±0.079	7.80±0.065	*p=3.04E-02*
Stream Mean NO_3^- (ppm)	2.92±0.155	3.05±0.168	n.d.
Stream Mean PO_4^{3-} (ppm)	0.512±0.098	0.171±0.012	*p=8.00E-04*
Stream Mean O_2 (ppm)	10.55±0.244	10.07±0.267	*p=2.48E-02*

Biotic Index.--- All 8 of the insect orders and both crustacean groups utilized by Hilsenhoff (1988) were collected in this study. However, only 30 of the 66 distinct families were collected. There was no difference in the Overall Index between Sager Creek and Flint Creek (Table 1). These values fell within the "good" ranking on the Hilsenhoff (1988) FBI scale, and would suggest that both streams are showing some level of organic pollution. However, the ANOVA of the Reach Index from all 6 reaches did indicate a statistical difference and the subsequent t-test analysis revealed that although both streams have some reaches with organic pollution, Sager Creek seems to have higher levels (Table 2 and Fig. 2).

Table 2. The stream reach-specific mean FBI (Reach Index), stream reach-specific mean SID (Reach Diversity) and stream reach-specific mean (Reach Mean) physiochemical comparisons, n=16. Significant differences in ANOVA values are indicated for comparisons on all six reaches. Comparisons of individual Sager Creek reaches (SCR) and Flint Creek reaches (FCR) are indicated in each row. P-values in grey boxes with bold type indicate that the SCR had the larger mean value. ppm= parts per million; μS/cm= microsiemen per centimeter.

Parameter	ANOVA	SCR	FCR	Difference
Reach Index	*p=9.94E-11*	Hon	OA	***p=1.25E-05***
			Lake	*p=9.73E-05*
			Nor	nod.
		JBU	OA	***p=4.46E-03***
			Lake	*p=2.18E-05*
			Nor	nod.
		WW	OA	***p=2.55E-09***
			Lake	nod.
			Nor	***p=1.22E-05***
Reach Mean Waterflow (m^3/S)	*p=4.09E-03*	Hon	OA	*p=2.73E-05*
			Lake	*p=2.73E-03*
			Nor	*p=9.75E-04*
		JBU	OA	*p=2.15E-03*
			Lake	*p=1.37E-03*
			Nor	nod.
		WW	OA	nod.
			Lake	nod.
			Nor	nod.
Reach Mean TDS (ppm)	*p=1.17E-22*	Hon	OA	*p=5.59E-03*
			Lake	nod.
			Nor	*p=2.21E-03*
		JBU	OA	***p=4.29E-05***
			Lake	***p=2.37E-07***
			Nor	***p=6.52E-04***
		WW	OA	***p=4.28E-07***
			Lake	***p=3.80E-07***
			Nor	***p=7.63E-07***
Reach Mean EC (μS)	*p=1.13E-21*	Hon	OA	*p=1.48E-03*
			Lake	*nod.*
			Nor	*p=2.66E-03*
		JBU	OA	***p=6.17E-04***
			Lake	***p=9.78E-06***
			Nor	***p=3.40E-03***
		WW	OA	***p=6.16E-07***
			Lake	***p=6.21E-07***
			Nor	***p=1.31E-06***
Reach Mean Temp (°C)	nod.			

Parameter	ANOVA	SCR	FCR	Difference
Reach Diversity	*p=7.49E-08*	Hon	OA	*p=1.34E-07*
			Lake	nod.
			Nor	*p=4.46E-03*
		JBU	OA	*p=1.12E-04*
			Lake	nod.
			Nor	*p=8.57E-03*
		WW	OA	*p=6.32E-05*
			Lake	nod.
			Nor	*p=3.18E-04*
Reach Mean pH	*p=2.72E-07*	Hon	OA	*p=4.79E-05*
			Lake	*p=4.52E-05*
			Nor	*p=5.42E-05*
		JBU	OA	***p=1.03E-02***
			Lake	nod.
			Nor	***p=3.63E-03***
		WW	OA	nod.
			Lake	nod.
			Nor	nod.
Reach Mean NO_3^- (ppm)	*p=1.04E-05*	Hon	OA	nod.
			Lake	nod.
			Nor	*p=6.41E-03*
		JBU	OA	*p=2.73E-05*
			Lake	*p=1.22E-03*
			Nor	nod.
		WW	OA	nod.
			Lake	nod.
			Nor	***p=2.84E-03***
Reach Mean PO_4^{3-} (ppm)	*p=8.64E-12*	Hon	OA	nod.
			Lake	nod.
			Nor	nod.
		JBU	OA	nod.
			Lake	nod.
			Nor	nod.
		WW	OA	***p=3.64E-04***
			Lake	***p=2.97E-04***
			Nor	***p=2.61E-04***
Reach Mean O_2 (ppm)	n.d.			

Table 3. List of orders and families of aquatic insects and crustacean taxa collected, identified, and counted in Sager and Flint creeks. Numbers at the end of each taxon indicates the pollution-tolerance value according to Sarver (2005). Mean number of individuals of each recorded family per reach (M/R) value indicates either no significant difference in the abundance between the streams (n.d.) or the stream in which the taxon dominated (Sager Creek=SC, Flint Creek-FC) and the p-value of the difference in abundance; n=48 for each mean calculation.

Insecta							
Coleoptera	**M/R**	**Diptera**	**M/R**	**Ephemeroptera**	**M/R**	**Lepidoptera**	**M/R**
Elmidae(4)	nd	Ceratopogonidae(6)	nd	Baetidae(4)	SC *p=7.6E-03*	Pyralidae(5)	nd
Psephenidae(4)	nd	Chironomidae(6)	SC *p=1.0E-02*	Caenidae(7)	nd		
		Empididae(6)	nd	Ephemiridae(4)	FC *p=1.5E-03*		
		Simuliidae(6)	nd	Heptageniidae(4)	nd		
		Tipulidae(3)	FC *p=9.7E-03*	Isonychiidae(2)	FC *p=2.1E-06*		
				Leptohyphidae(4)	FC *p=3.6E-04*		
				Leptophlebiidae(2)	nd		
Megaloptera		**Odonata**		**Plecoptera**		**Trichoptera**	
Corydalidae(4)	FC *p=1.02E-07*	Calopterygidae(5)	nd	Capniidae(1)	FC *p=3.2E-03*	Helicopsychidae(3)	FC *p=5.2E-04*
Sialidae(7.5)	nd	Coenagrionidae(9)	SC *p=3.6E-06*	Perlidae(3)	FC *p=2.4E-09*	Hydropsychidae(4)	nd
		Gomphidae(7)	FC *p=7.0E-04*			Hydroptilidae(4)	nd
		Libellulidae(9)	nd			Leptoceridae(4)	nd
						Limnephilidae(3)	nd
						Philopotamidae(3)	nd
						Polycentropidae(6)	nd

Crustacea	
	M/R
Amphipoda(6.9)	FC *p=4.5E-04*
Isopoda(8)	FC *p=5.6E-05*

The Hon, JBU, and WW Reach Indices were all significantly higher when compared to the OA Reach Index (Table 2). The WW Reach Index was also significantly higher than the Nor Reach Index (Table 2). However, the Lake Reach Index was significantly higher than both the Hon and JBU Reach Indices (Table 2). There were no significant differences between the other comparisons.

Diversity Index.--- The t-test analysis of the Overall Diversity of Sager Creek and Flint Creek indicated that Flint Creek had significantly higher diversity than Sager Creek (Table 1). As expected, the ANOVA of the Reach Diversity from all 6 reaches also indicated a statistical difference (Table 2). The t-test analysis of the 6 reaches also revealed statistical difference between most reaches (Fig. 3). The Reach Diversity for OA was significantly higher than that of the Hon, JBU and WW reaches (Table 2). The Nor Reach Diversity was also significantly higher than that of the Hon, JBU and WW reaches (Table 2). Only the Lake reach showed no significant difference with any of the Sager Creek reaches.

Overall Diversity.--- The t-test analysis of the M/R values for each of the insect families and 2 crustacean taxa revealed no significant differences in 18 of the 32 groups. However, 14 groups did show significant differences in abundance per stream. Of these, 3 groups were significantly more abundant in Sager Creek, while 11 were more abundant in Flint Creek. Of the 3 Sager Creek groups, 2 ranked in the top-half

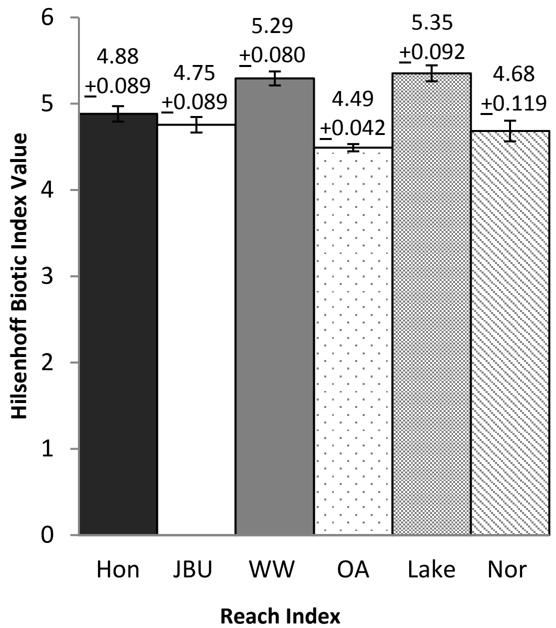

Fig. 2. The stream reach-specific mean FBI (Reach Index) for both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Standard error bars, and mean ± standard error are indicated.

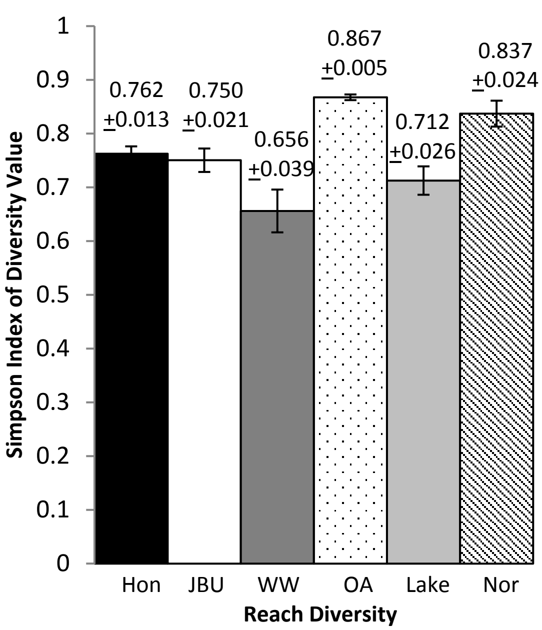

Fig. 3. The stream reach-specific mean SID (Reach Diversity) for both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Standard error bars, and mean ± standard error are indicated.

(6-10) of the pollution tolerance values. Of the 11 Flint Creek groups, only 3 were ranked in the top-half of pollution tolerance while 8 were ranked in the lower half (0-4) (Table 3).

Physiochemical Parameters.---The t-test analysis of the Stream Mean for water-flow and all tested physiochemical properties are found in Table 1. The most significant differences were seen in water-flow, TDS, EC and dissolved PO_4^{3-}. Significant differences were also found in pH and dissolved O_2. Only temperature and dissolved NO_3^- showed no significant differences at the overall stream level.

ANOVA tests of Reach Mean for water-flow and all tested physiochemical properties are found in Table 2. As in the Stream Mean, the ANOVA for the Reach Mean for temperature showed no significant differences across all 6 stream reaches. Interestingly, the Reach Mean for dissolved NO_3^- did show significant differences at the stream-reach level counter to what was seen at the overall-stream level, and the Reach Mean for dissolved O_2 did not show any significant differences at the stream-reach level, counter to the overall-stream level. The largest differences were seen in water-flow, TDS, EC and dissolved PO_4^{3-}.

Table 2 also contains the t-test analyses of the Reach Mean, for all physiochemical parameters, across the 6 stream reaches. These tests reveal that the Flint Creek flow is relatively stable throughout the study area. However, Sager Creek begins with relatively low flow and increases throughout the study area (Fig. 4). Flow in the Hon reach was significantly lower when compared to the OA, Lake, and Nor reaches. The same was true of the JBU reach when compared to the OA and Lake reaches, however it was not significantly different from the Nor reach. Only the WW reach had sufficient flow to show no significant difference with any of the Flint Creek reaches (Table 2).

T-tests of the Reach Mean for TDS revealed that Flint Creek has a relatively stable level of TDS, while Sager Creek has an ever-increasing level throughout the study area (Fig. 5). It also revealed that there were significant differences in almost every comparison. Only the Hon reach when compared to the Lake reach showed no significant differences (Table. 2).

Electrical conductivity (EC) is directly correlated to TDS, thus it is not surprising that the t-test analyses of the Reach Mean for EC are essentially the same as for TDS. EC is relatively stable throughout the Flint Creek study area while showing an ever increasing level throughout Sager Creek (Fig. 6). Again, with the exception of the Hon to Lake comparison, all other cross stream-reach comparisons showed significant differences (Table 2).

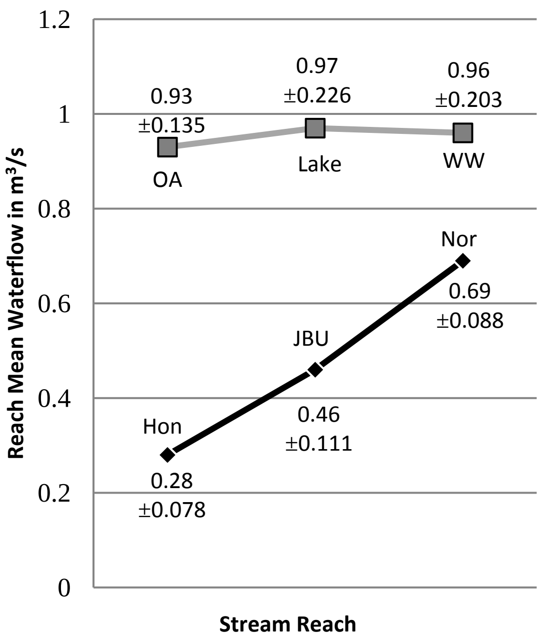

Fig. 4. The stream reach-specific mean (Reach Mean) for waterflow in both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Mean ± standard error are indicated.

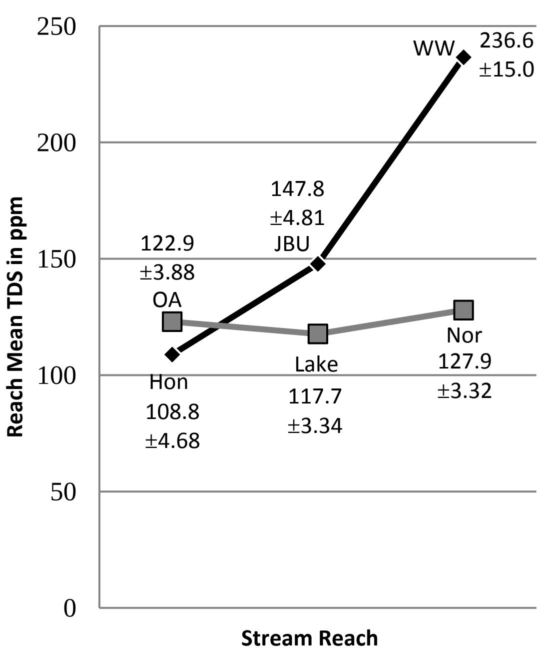

Fig. 5. The stream reach-specific mean (Reach Mean) for total dissolved solids (TDS) in both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Mean ± standard error are indicated. ppm=parts per million.

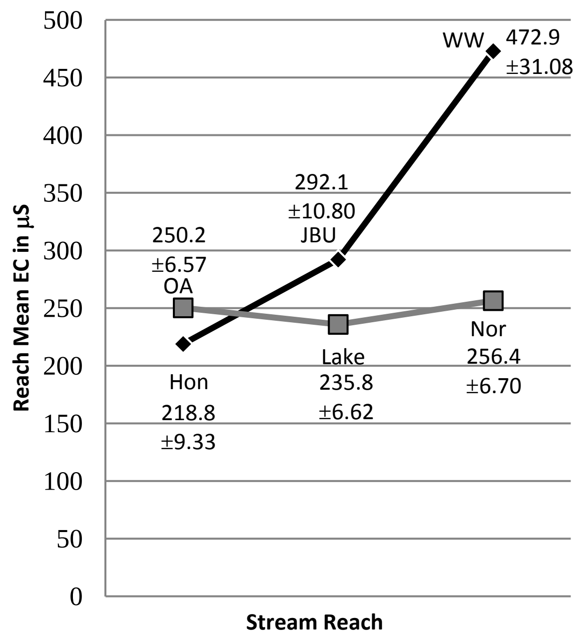

Fig. 6. The stream reach-specific mean (Reach Mean) for electrical conductivity (EC) in both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Mean ± standard error are indicated. µS/cm= microsiemens per centimeter.

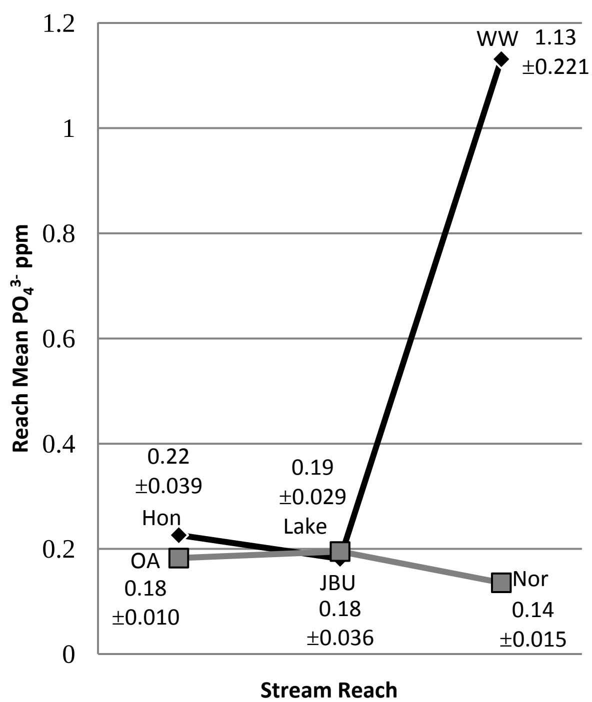

Fig. 7. The stream reach-specific mean (Reach Mean) for dissolved PO_4 in both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Mean ± standard error are indicated. ppm=parts per million.

T-test analyses of the Reach Mean for dissolved PO_4^{3-} revealed that levels remain relatively stable and constant throughout all of the Flint Creek study area and most of the Sager Creek study area. However an extremely dramatic change in dissolved PO_4^{3-} is seen in the WW reach of Sager Creek (Fig. 7). This reach's level of dissolved PO_4^{3-} was significantly higher than all of the dissolved PO_4^{3-} levels of all 3 Flint Creek reaches (Table 2). Although not included on this table, further analysis of the WW reach indicated that its dissolved PO_4^{3-} level was significantly higher than both the Hon reach (*p=6.67E-04*) and the JBU reach (*p=5.35E-04*).

Of the physiochemical parameters tested, Reach Mean values for pH and dissolved NO_3^- seemed to have the most stream specific variation. The pH Reach Mean of the Hon reach was only slightly basic, but increased for the JBU reach and held stable for the WW reach. However the pH Reach Mean of the OA reach was more basic than the Hon reach, then increased substantially at the Lake reach before dropping down to its original level at the Nor reach (Fig. 8). T-test significant differences between the pH Reach Mean values can be seen in Table 2.

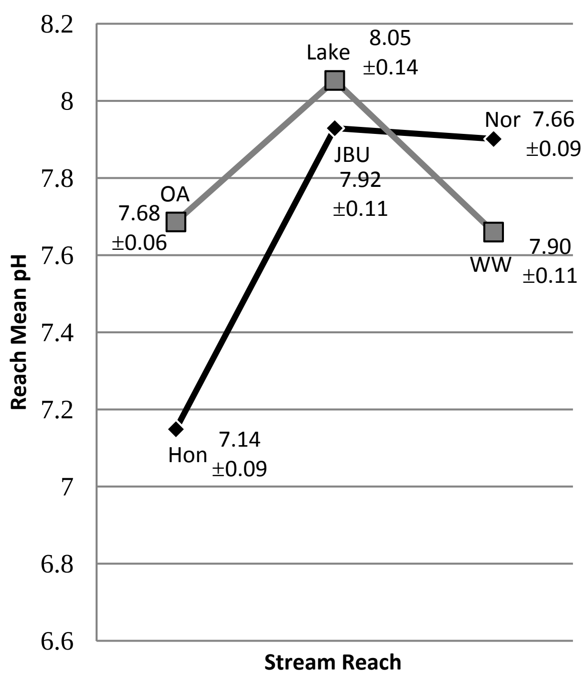

Fig. 8. The stream reach-specific mean (Reach Mean) for pH in both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Mean ± standard error are indicated.

Finally, the t-tests of the Reach Mean for dissolved NO_3^- revealed that FC had a steadily decreasing value throughout the study area while SC had much more erratic values. Both the Hon and WW reaches had comparable dissolved NO_3^- levels while the JBU dissolved NO_3^- level was substantially lower (Fig. 9). Significant difference in the levels of dissolved NO_3^- can be seen in Table 2.

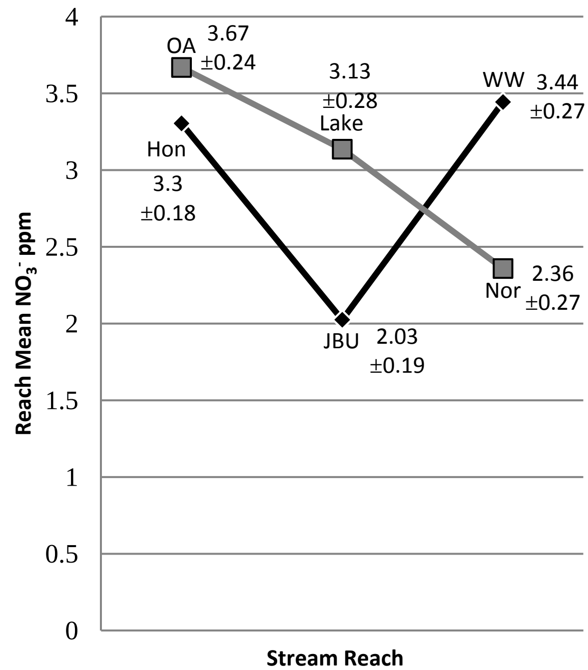

Fig. 9. The stream reach-specific mean (Reach Mean) for dissolved NO_3 in both Sager (Hon, JBU, WW) and Flint (OA, Lake, Nor) reaches. Mean ± standard error are indicated. ppm=parts per million.

Discussion

According to Paul and Meyer, (2001), streams that are impaired by urban development (i.e. urban stream syndrome) should see effects in three critical areas; physical, chemical and biological. Although some of these effects are seen in both Sager and Flint creeks, Sager Creek shows a higher degree of urban stream syndrome than Flint Creek.

Physical.---Siloam Springs, AR was incorporated as a township in 1881. At that time, much of the industry of the city revolved around tourism as many of the springs that fed into Sager Creek were advertised to have "healing properties". Thus, much of the downtown area was built directly on or around Sager Creek (Warden 2010). As the town has matured into a small city the amount of impervious surface (buildings, roads, parking lots, etc.,) that covers the watershed has increased substantially.

In addition, no less than 3 dams were constructed across the stream channel to make the water more accessible to citizens, with one dam currently still in place. In 1892 a severe flood took the lives of 3 citizens and destroyed much of the Siloam Springs downtown area (Warden 2010). As a result the main flow of the stream was channeled, first by the construction of stone and mortar walls and later by concrete retaining walls. At least 20 bridges have also been built across Sager Creek to allow for the passage of cars, trains, golf carts and pedestrians.

The main flow of the stream begins from an underground aquifer called Box Spring. The water from Box Spring emerges onto the Siloam Springs city golf course where it serves as a "water hazard" for approximately 325 m. A previous water quality assessment of Box Springs (GBM^{c} & Associates 2005) is available, however, a direct comparison between this historic study and the current study is difficult at best. In the current study, no samples were collected directly from Box Spring. The closest sampling site was the Honeycutt site which is downstream from the golf course. Also, in the historic study, the physiochemical tests utilized to test water quality were different from the tests used in the current study. However, for those tests that were similar some variations between the historic Box Springs water quality and the current Honeycutt site water quality are apparent. Honeycutt site water is slightly more acidic (pH 7.14) than historic Box Spring water (pH 6.3). Honeycutt site water contains less NO_3^- (3.3 ppm) than historic Box Spring water (5.1 ppm), but Honeycutt site water contains more PO_4^{3-} (0.22 ppm) than historic Box Spring water (0.052 ppm).

Approximately 11.4 x 10^7 liters/day of waste water effluent is released into Sager Creek from the Siloam Springs wastewater treatment plant (Wakefield 2013). All of these physical alterations to the natural hydrology and geomorphology of Sager Creek are found along the ~5.2 km study area.

The ~7.04 km Flint Creek study area has some of the same urban disturbances that are seen in Sager Creek only to a greater degree. For example, Flint Creek flows through a golf course for approximately 2.0 km. It has 3 intact dams; the largest of these was constructed in 1946 and forms the Siloam Springs City Lake. The spillway of the dam alters the flow of Flint Creek from its original stream bed, forcing an alternate route for approximately 350 m before rejoining the original stream bed. Water from the lake was originally utilized as a drinking water reservoir, but is currently employed as coolant for the nearby Southwestern Electric Power Company (SWEPCO) power plant. Between 6-10 million gallons of water is cycled through the power plant every day (Siloam Spring 2009).

However, Flint Creek shows either a reduced amount or complete lack of certain physical effects when compared to Sager Creek. For example, there are only 7 bridges for car or railroad traffic in the Flint Creek study area. This is a much smaller number of bridges per stream area, compared to Sager Creek; (*Flint Creek ~1 bridge/km of stream versus Sager Creek ~4 bridges/km of stream*). The city of Gentry is located within the Flint Creek watershed, but no part of the city is built around the main flow of the stream. Thus the amount of impervious surface surrounding Flint Creek is much smaller when compared to Sager Creek. In addition, most notably, the wastewater effluent from Gentry does not empty into Flint Creek.

There were only 2 physical effects that the present study investigated: temperature and water flow. It is plausible to expect that the Flint Creek Lake reach, which is just downstream of the Siloam Springs City Lake, would show elevated temperature due to the lake water's usage as coolant for the SWEPCO power plant. However, water removed from the lake for coolant is not returned to the lake but is instead released into a separate watershed. Thus it is not surprising that all of the statistical analyses for temperature showed no statistical differences between the streams or across any of the individual stream reaches.

Flint Creek has a relatively stable flow rate throughout the study area while Sager Creek shows an ever increasing rate of flow (Fig. 4). The percentage increase due to natural sources, (such as the influx of groundwater or the confluence of small springs), versus urban disturbances, (such as runoff from impervious surfaces or the influx of waste water effluent), is not known. However, a quick correlation study failed to show strong relationships between water flow and any other studied parameter. Other studies, however, have demonstrated that the types of physical changes described above result in detrimental effects on the hydrology and geomorphology of streams (Neller 1988, Booth and Jackson 1997, Hart and Finnelli 1999, Meyer and Wallace 2001, Brueggen-Boman and Bouldin 2012). Indirect effects of these physical alterations would also be reflected in changes within the biological systems (Klein 1979). For example, the level of impervious surface covering a watershed has become a very accurate predictor of urban impacts on streams (McMahon and Cuffney 2000).

Chemical.---Several previous studies have indicated that urbanization of streams tends to increase almost all chemical constituents within the stream including levels of dissolved metals, hydrocarbons, ammonium, dissolved solids, electrical conductivity and oxygen demand (Porcella and Sorenson 1980, Lenat and Crawford 1994, Latimer and Quinn 1998, USGS 1999). Many of these constituents were not investigated in this study. However, the effects of urbanization were strongly indicated in Sager Creek by the changing levels of total dissolved solids (TDS), electrical conductivity (EC) and dissolved PO_4^{3-}.

EC is a literal measurement of a solutions ability to conduct an electrical current. The number of dissolved ions in the solution (i.e. TDS), will obviously have a direct impact on the EC. The correlation between the two measurements is generally accepted as TDS (ppm) * 2 = EC (μS/cm) (McPherson 1995).

In laboratory studies, elevated levels of TDS have been shown to be detrimental to aquatic life. The mean TDS of rivers around the world is 120 ppm and detrimental effects on invertebrates have been detected at TDS levels of 280 ppm. However, the detrimental effects are both ion and species specific (Weber-Scannell et al. 2007). In lotic environments, pollution intolerant families of Ephemeroptera, Plecoptera and Trichoptera, seemed to be the most effected by elevated TDS. In general, a reduction in overall stream diversity was inversely correlated with an increase in populations of pollution tolerant macroinvertebrates (Timpano et al. 2010).

The results of this study indicate stable levels of TDS and EC within Flint Creek, while Sager Creek shows consistently elevating levels of both parameters (Figs. 5 and 6). The ions responsible for these elevated levels in Sager Creek are unknown, however, in other urban areas, elevated levels of these parameters are consistent with waste water treatment effluent and non-point source runoff from impervious services (Paul and Meyer 2001).

Waste water treatment effluent can also be a major source of dissolved PO_4^{3-} (LaValle 1975). The effluent from the Siloam Springs waste water treatment plant seems to have a significant influence on the levels of dissolved PO_4^{3-} compared to all other reaches within both Sager Creek and Flint Creek (Fig. 7). A previous publication, (Haggard et al. 2004) had already demonstrated this elevated PO_4^{3-} level downstream from the Siloam Springs waste water treatment plant. However, at that time, a limit for the amount of PO_4^{3-} that could be released from the plant had not been established. In December of 2009, the EPA's National Pollutant Discharge Elimination System (NPDES) permit program established a 30 day average limit of 1.0 ppm PO_4^{3-} release. In 2005, the annual average PO_4^{3-} released at the Siloam Springs waste water treatment plant was 3.5 ppm. Since 2013 the average annual release has been 0.4 ppm; an 88% reduction in PO_4^{3-} release (Myers 2014). However, in 2013, monthly averages ranged as low as 0.135 ppm up to 0.761 ppm with 4 months above 0.66 ppm. The NPDES permit also allows the treatment plant's weekly average to be as high as 1.5 ppm and still be in compliance (Myers 2014). Since the PO_4^{3-} samples in this study were grab samples collected and processed in a single day, and these samples represent the sum of all the PO_4^{3-} found in each creek rather than the PO_4^{3-} lever in effluent only, it is understandable how the PO_4^{3-} levels below the plant could be as high as indicated.

Though PO_4^{3-} is an essential nutrient for all forms of life, elevated levels can overstimulate algal growth, which can result in substantial trophic changes in the stream (USEPA 2010). Thus, an elevated level of PO_4^{3-}, particularly from waste water treatment effluent, is a definitive indicator of urban disturbance (USGS 1999, Winter and Duthie 2000).

Effects of urban stream syndrome were not clearly reflected in the measured values for pH (Fig. 8). Although there were significant differences between measured values of pH in the reaches of Sager Creek versus Flint Creek, all of the values fell within the suitable range of pH values (6.5-9.0) as established by the EPA (USEPA 1986). This was not surprising as most changes in the pH of urban streams occur during rain events.

Many urban areas have combined sewers that collect domestic sewage, industrial wastewater and rainwater runoff. This wastewater is then transported to a wastewater treatment facility. However during heavy rain events, the volume of waste water may be greater than the capacity of the sewer system or treatment plant. These combined sewers are designed to overflow during these events and discharge wastewater directly into the nearby streams (USEPA 2012a). During these events, swings in pH values, (4-8.7) can be seen depending on the amount of storm water versus domestic sewage is found in the combined sewer overflow (Kominkova 2012). Since no samples in this study were taken during rain events, significant changes in pH were not expected.

Streams effected by urban stream syndrome typically show elevated levels of dissolved NO_3^- (USGS 1999). However, this study did not find consistently high levels of NO_3^- in any of the studied reaches (Fig. 9). There were significant differences between some of the reaches, (Table 3), however, none of the dissolved NO_3^- levels are particularly alarming as none of them approach the maximum contamination levels of 10 ppm in drinking water (USEPA 2012b). Thus, the levels of dissolved NO_3^- in Sager Creek and Flint Creek do not clearly indicate urban disturbance in either stream.

Low levels of dissolved NO_3^- may be one of the reasons why levels of dissolved O_2 were high in both streams. Although a significant difference between the Sager Creek dissolved O_2 Stream Mean and Flint Creek dissolved O_2 Stream Mean was indicated (Table 2), both stream's Stream Mean values were slightly higher than maximum levels of dissolved O_2 for the mean stream temperatures (USEPA 2012c). When analyzed at the stream reach level, no significant differences were indicated for either stream (Table 3). High levels of NO_3^- laden pollution typically causes depleted O_2 levels within aquatic systems (Daniel et al. 2002, Kominkova 2012). Since there was no indication of consistently high levels of dissolved NO_3^- in either stream, it's probable that dissolved O_2 levels were equilibrated with atmospheric O_2 levels throughout both streams. Therefore, the levels of dissolved O_2 in both Sager and Flint creeks also do not indicate urban disturbance.

Biological.---The effects of urbanization on biological organisms has been demonstrated in microbes, invertebrates, fish, algae and plants. However more work seems to have been done on invertebrates than any other group (Paul and Meyer 2001). The general effect of urbanization is an overall decrease in invertebrate diversity. This is especially true in the sensitive orders of Ephemeroptera, Plecoptera and Trichoptera. However, pollution tolerant invertebrates such as the Chironomidae, oligochaete worms and some stream gastropods actually increase in abundance due to urbanization (Pratt et al. 1981, Hachmoller et al 1991, Thorne et al. 2000).

The results of this study confirmed these same results. Although the Overall Index of both SC and FC were not significantly different (Table 2.), the Reach Index of Sager Creek's reaches showed a strong tendency to be higher (i.e. more organic pollution) than the Flint Creek reaches. The one exception to this trend was the Flint Creek Lake Reach Index (Fig. 2). This reach is just downstream of the Siloam Springs City Lake and therefore shows the greatest level of physical disturbance. The approximately 350 m of altered flow is often across bedrock material rather than the gravel and cobble stream bed that dominates all other reaches. This reach's altered geomorphology is assumed to be the reason for the unusually high Reach Index when compared to the other Flint Creek reaches.

The Overall Diversity of Flint Creek compared to Sager Creek, however, is an indication of urban disturbance as there is an overall decrease in macroinvertebrate diversity in Sager Creek (Table 2). Additionally, the M/R values in Table 1 indicate the higher level of diversity within the Flint Creek reaches compared to the Sager Creek reaches. These results are consistent with a stream showing urban stream syndrome, particularly the increase in pollution tolerant arthropods in the Sager Creek reaches compared to the Flint Creek reaches and the lack of pollution intolerant arthropods, especially the Plecopterans, in Sager Creek.

Conclusion

The results of this study corroborated the findings of the Steuer's (2010) formula, specifically that Sager Creek shows a much higher degree of urban stream syndrome than Flint Creek. In recognition of the declining health of Sager Creek, the city of Siloam Springs has taken measures to improve the water quality of the Sager Creek watershed. This includes multimillion dollar improvements to the Siloam Springs wastewater treatment plant, the purchasing of land and the creation of wetlands along the headwaters and tributaries of Sager Creek, riparian zone restoration along the main channel of the stream, and the removal of one low-water bridge (Della Rosa 2010a,b). However, substantial improvement in the overall health of Sager Creek may require even more drastic measures and considerable time. According to Steuer's (2010) formula, a disturbance metric of 15 is the threshold where invertebrate taxa richness begins to dramatically decline and watersheds with rankings over 30 were found on the segment of the regression curve with the lowest slope. Thus, significant investments in mitigating activity such as the restoration of forested land within the Sager Creek watershed as well as more extensive wetlands may be necessary to see much improvement in stream health (Moore and Palmer 2005).

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Literature Cited

Arkansas Department of Environmental Quality. 1987. Physical, chemical and biological characteristics of least-disturbed reference streams in Arkansas' ecoregions. Volume 1: Data Compilation. 709 p.

Arkansas Watershed Information System (AWIS). 2006a. Watershed Report for Sager Creek (111101030502). Arkansas Natural Resource Commission. Little Rock (AR). <watersheds.cast.uark.edu/index.php> Accessed June 10 2013.

Arkansas Watershed Information System (AWIS). 2006b. Watershed Report for Flint Creek (111101030501). Arkansas Natural Resource Commission. Little Rock (AR). <watersheds.cast.uark.edu/index.php> Accessed June 10 2013.

Booth DB and **CR Jackson.** 1997. Urbanizationof aquatic systems: degradation thresholds, stormwater detection, and the limits of mitigation. Journal of the American Water Resources Association 33:1077-1090.

Brueggen-Boman TR and **JL Bouldin**. 2012. Characterization of temporal and spatial variation in subwatersheds of the Strawberry River, AR, prior to implementation of agricultural best management practices. Journal of the Arkansas Academy of Science 66:41-49

Daniel MHB, **AA Montebelo**, **MC Bernardes**, **JPHB Ometto**, **PB DeCamargo**, **AV Krusche**, **MV Ballester**, **RL Victoria** and **LA Martinelli**. 2002. Effects of urban sewage on dissolved oxygen, dissolved inorganic and organic carbon, and electrical conductivity of small streams along a gradient of urbanization in the Piracicaba River basin. Water, Air and Soil Pollution 136:189-2002

Della Rosa J. 2010a. City works to meet EPA changes. The Siloam Springs Herald Leader. 9/12

Della Rosa J. 2010b. Sager Creek work continues. The Siloam Springs Herald Leader. 9/19

Falcone J, **J Stewart**, **S Sobieszczyk**, **J Dupree**, **G McMahon** and **G Buell**. 2007. A comparison of natural and urban characteristics and the development of urban intensity indices across six geographic settings. U.S. Geological Survey Scientific Investigations Report 2007-5123. Reston (VA): USGS 56 p. <http://pubs.usgs.gov/sir/2007 /5123/> Accessed on 8 May 2013.

GBM[c] & Associates. 2005. Sager Creek Watershed Assessment: Completed for the City of Siloam Springs. p 73.

Hachmoller B, **RA Matthews** and **DF Brakke**. 1991. Effects of riparian community structure, sediment size, and water quality on the macroinvertebrate communities in a small, suburban stream. Northwest Scientist 65:125-132.

Haggard BE, **SA Ekka**, **MD Matlock** and **I Chaubey**. 2004. Phosphate equilibrium between stream sediments and water: potential effect of chemical amendments. Transactions of the American Society of Agricultural Engineers 47:1113-1118

Hart DD and **CM Finelli**. 1999. Physical-biological coupling in streams: the pervasive effects of flow on benthic organisms. Annual Review of Ecology and Systematics 30:363-395

Hilsenhoff WL. 1988. Rapid field assessment of organic pollution with a family-level biotic index. Journal of the North American Benthological Society 7:65-68.

Klein RD. 1979. Urbanization and stream quality impairment. Journal of the American Water Resources Association 15:948-963.

Korminkova D. 2012. The urban stream syndrome—a mini-review. The Open Environmental & Biological Monitoring Journal 5:24-29.

LaValle PD. 1975. Domestic sources of stream phosphates in urban streams. Water Research 9:913-915

Latimer JS and **JG Quinn**. 1998. Aliphatic petroleum and biogenic hydrocarbons entering Narragansett Bay from tributaries under dry weather conditions. Estuaries 21:91-107

Lenat DR and **JK Crawford**. 1994. Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. Hydrobiologia 294:185-199.

McMahon G and **TF Cuffney**. 2000. Quantifying urban intensity in drainage basins for assessing stream ecological conditions. Journal of the American Water Resources Association 36:1247-1262

McPherson L. 1995. Correlating conductivity to ppm of total dissolved solid. Water Engineering and Management. Arlington Heights (IL) Scranton Gillette Communications Inc. 3 p. <http://www.ryanherco.com/Markets/VendorArticles/Signet/ConductivityToPPM.pd>

Meyer JL, **MJ Paul** and **WK Taulbee**. 2005. Stream ecosystem function in urbanizing landscapes. Journal of the North American Benthological Society 24:602-612.

Meyer JL and **JB Wallace**. 2001. Lost linkages in lotic ecology: rediscovering small streams. *In:* Press M, N Huntly and S Levin, editors. Ecology: Achievement and Challenge. Boston (MA): Cambridge University Press. p 420.

Moore AA and **MA Palmer**. 2005. Invertebrate biodiversity in agricultural and urban headwater streams: implications for conservation and management. Ecological Applications 15:1169-1177.

Myers TA. 2014. Waste water treatment plant operational reports. City of Siloam Springs.

Needham JG and **PR Needham**. 1962. A guide to the study of freshwater biology. 5th ed. San Francisco (CA): Holden-Day, Inc. 108 p.

Neller RJ. 1988. A comparison of channel erosion in small urban and rural catchments, Armidale, New South Wales. Earth Surface Processes and Landforms 13:1-7

Omernik JM. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers 77:118-125.

Paul MJ and **JL Meyer**. 2001. Streams in the urban landscape. Annual review of Ecology and Systematics 32:333-365.

Porcella DB and **DL Sorenson**. 1980. Characteristics of non-point source urban runoff and its effects on stream ecosystems. 111 p. Available at: <http://www.epa.gov/nscep/index.html> Accessed 2013 May 30.

Pratt JM, **RA Coler** and **PJ Godfrey**. 1981. Ecological effects of urban storm water runoff on benthic macroinvertebrates inhabiting the Green River, Massachusetts. Hydrobiologia 83:29-42.

Sarver R. 2005. Taxonomic levels for macroinvertebrate identifications. Missouri Department of Natural Resources Air and Land Protection Division Environmental Services Program Standard Operating Procedures. p 30.

Siloam Springs. 2009. Siloam Springs—City Lake Makeover. City of Siloam Springs press release. 1/29/2009.

Simpson EH. 1949. Measurement of diversity. Nature 163:688.

Steuer JL. 2010. A generalized watershed disturbance-invertebrate relation applicable in a range of environmental settings across the continental United States. Urban Ecosystems 13:415-424

Thorne RSJ, **WP Williams** and **C Gordon**. 2000. The macroinvertebrates of a polluted stream in Ghana. Journal of Freshwater Ecology 15:209-217

Timpano AJ, **SH Schoenholtz**, **CE Zipper** and **DJ Soucek**. 2010. Isolating effects of total dissolved solids on aquatic life in cental Appalachian coalfield streams. Proceedings of National Meeting of the American Society of Mining and Reclamation 1:1284-1302

Triola MM and **MF Triola**. 2006. Biostatistics for the Biological and Health Sciences. Boston (MA): Pearson. 699 p.

U.S. Geological Survey (USGS). 1999. The quality of our nation's waters---nutrients and pesticides. Reston (VA); USGS. 4 p. <http://pubs.usgs.gov/fs/FS-116-99/pdf/fs-116-99.pdf> Accessed on 30 May 2013

U.S. Geological Survey (USGS). 2013. Effects of urbanization on stream ecosystems. Reston (VA); USGS. 4 p. <http://water.usgs.gov/nawqa/urban/html/faq.html> Accessed on 8 May 2013.

U.S. Environmental Protection Agency (USEPA). 1986. Quality criteria for water 1986. Washington(DC): USEPA 447 p. <http://yosemite.epa.gov/water/owrccatalog.nsf/9da204a4b4406ef885256ae0007a79c7/18888fcb7d1b9dc285256b0600724b5f!OpenDocument> Accessed on 16 May 2012.

U.S. Environmental Protection Agency (USEPA) Office of Water. 2004. Wadeable Streams Assessment: Field Operations Manual. Washington(DC): USEPA. 119 p. <www.epa.gov/owow/monitoring/wsa/wsa_fulldocument.pdf> Accessed on 5 June 2009.

U.S. Environmental Protection Agency (USEPA) Report on the Environment. 2010. Nitrogen and phosphorus in streams in agricultural watersheds. Washington (DC): USEPA. 5 p. <http://cfpub.epa.gov/eroe/index.cfm?fuseaction=detail.viewInd&lv=list.listByAlpha&r=219683&subtop=315> Accessed on 31 May 2013.

U.S. Environmental Protection Agency (USEPA) National Pollutant Discharge Elimination System. 2012a. Combined sewer overflow.Washington (DC): USEPA. 3 p. <http://cfpub.epa.gov/npdes/home.cfm> Accessed on 31 May 2013.

U.S. Environmental Protection Agency (USEPA) Water: Basic Information about Regulated Drinking Water Contaminants. 2012b. Basic Information about Nitrate in Drinking Water. Washington (DC): USEPA. 3 p.<http://water.epa.gov/drink/contaminants/basicinformation/nitrate.cfm> Accessed on 31 May 2013.

U.S. Environmental Protection Agency (USEPA) Water Monitoring and Assessment. 2012c. Dissolved oxygen and biochemical oxygen demand. Washington (DC): USEPA. 8 p. <http://water.epa.gov/type/rsl/monitoring/vms52.cfm> Accessed on 31 May 2013.

Vannote RL, **GW Minshall**, **KW Cummins**, **JR Sedell** and **CE Cushing**. 1980. The river continuum concept. The Canadian Journal of Fisheries and Aquatic Sciences 37:130-137

Voshell JR. 2002. A guide to common freshwater invertebrates of North America. Blacksburg, (VA): The McDonald & Woodward Publishing Company. 442 p.

Wakefield TS. 2013. Water quality assessment of Sager Creek utilizing physiochemical parameters and a family-level biotic index. Journal of the Arkansas Academy of Science 67:145-152

Walsh CJ, **AH Roy**, **JW Feminella**, **PD Cottingham**, **PM Groffman** and **RP Morgan**. 2005**.** The urban stream syndrome: current knowledge and the search for the cure. Journal of the North American Benthological Society 24:706-723

Warden D. 2010. Images of America: Siloam Springs. Charleston (SC): Arcadia Publishing 128 p.

Weber-Scannell PK and **LK Duffy**. 2007. Effects of total dissolved solids on aquatic organisms: a review of literature and recommendations for Salmonid species. American Journal of Environmental Sciences 3:1-6

Winter JG and **HC Duthie**. 2000. Export coefficient modeling to assess phosphorus lading in an urban watershed. Journal of the American Water Resources Association 36:1053-106