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Persistence of Urban Stream Syndrome Effects from Point Source and Non-Point Source Pollutants

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Running Title: Persistence of Urban Stream Syndrome

Abstract

In a previous study, Sager Creek, a small 1st-3rd order stream in northwest Arkansas was shown to be negatively impacted by urban land usage within the watershed, producing a stream that exhibited several indicators of urban stream syndrome. This included (1) physical disturbances: increases in impervious surfaces in the watershed, dams built across the stream, and alteration of the natural stream flow through the construction of retaining walls, (2) chemical disturbances: increases in electrical conductivity (EC) and total dissolved solids (TDS) as well as elevated PO_4 levels (3) and biological disturbances: low populations of pollution intolerant macroinvertebrate species and high populations of pollution tolerant species. It could be hypothesized that these negative impacts could be mitigated by both biological and physiochemical remediation processes downstream from the effluent of the Siloam Springs Wastewater Treatment Plant (SSWTP), the most heavily effected of the previous study sites. A three-year investigation to test this hypothesis was completed. Utilizing physiochemical properties and biological assessments, four stream reaches, two in the previous research site and two downstream, were assessed for negative urban impact. Some acquired data supported the hypothesis that negative effects are mitigated downstream, particularly a lowering of EC and TDS levels and an increase in macroinvertebrate diversity. However, a larger amount of data, including mean water temperature, total water flow, pH, dissolved O_2 and NO_3 levels and mean Family-level Biotic Indices supported the null hypothesis that reaches above, at and, below the SSWTP were all equivalent in investigated physiochemical parameters and biological indicators.

Key words: stream macroinvertebrates, waste water effluent, water pollution

Introduction

Urban Stream Syndrome (USS) (Meyer *et al*. 2005; Walsh *et al*. 2005) is a term used to describe steam ecosystems that have been negatively affected by urbanization. Elevated levels of stream nutrients and contaminants, altered channel morphology, increases in pollution tolerant species and a corresponding decrease in biotic richness are all indicators of USS (Paul and Meyer 2001; Meyer *et al*. 2005).

In previous publications (Wakefield 2013; Wakefield 2014) it was revealed that the upper reaches of Sager Creek demonstrate USS as a result of altered stream geomorphology and both point and non-point sources of stream pollution. The introduction of pollutants into a stream or river initiates a series of negative effects in the downstream water. The nature of these effects could be physical, biological and/or chemical in nature (Bartsch 1948). Although these previous studies confirmed these negative effects for the upper reaches of Sager Creek, what has not been assessed is how far downstream these negative effects persist.

In a lotic system, with a clear point source of organic pollution, such as untreated waste water, a series of zones are predicted to be found downstream from the pollution source: a septic zone, in which concentrations of dissolved oxygen are reduced to zero by the biological oxygen demand (BOD) of microbes breaking down organic pollutants; a recovery zone where re-aeration of the stream water causes increasing levels of dissolved oxygen; and finally a clean water zone where the effects of the point source pollution can no longer be detected (Bartsch 1948). Depending on the amount of untreated water, and the size of the stream, the septic and recover zones could persist for miles downstream from the point source.

However, modern wastewater treatment plants are meant to serve as both the septic and recovery zones, and treatment plant effluent is assumed to be most closely associated with water in the clean water zone (Bartsch

1948). But it has been shown that even for modern wastewater treatment plants, effluent often contains many anthropogenic chemicals including inorganic and organic micropollutants such as artificial sweeteners, caffeine, and pharmaceuticals such as Erythromycin, Tramadol, and Codeine (Daughton and Ternes 1999; Dyer and Wang 2002; Englert *et al*. 2013; Cardenas *et al.* 2016). Thus, the assigning of wastewater effluent as "clean water", is overstated.

The purpose of this study was to utilize stream macroinvertebrate populations and physiochemical testing to determine if the water downstream from the SSWTP is truly in a "clean water zone", or if the waste water effluent produced persistent negative effects on the downstream reaches of Sager Creek. The null hypothesis for this study was that all reaches would show the same level of negative effects as a result of USS (Meyer *et al.* 2005; Walsh *et al*. 2005). However, according to Bartsch (1948), we could predict that the water chemistry and biota of the reaches downstream from the SSWTP effluent would show evidence of a healthy lotic system.

Materials and Methods

Sager Creek is a 21.6 km, (USGS 2016) 1-3 order stream (Vannote *et al*. 1980) located in an Ozark Highlands Ecoregion of Northwest Arkansas (Omernick 1987). The forty km^2 Sager Creek watershed includes pastures for grazing or hay production (55%), the urban area around the city of Siloam Springs (30.5%), and small "islands" of forest (11%). The primary "urbanized" areas are concentrated around the head waters of the creek, while pasture and forested areas dominate in the downstream reaches (AWIS 2006) The main channel of Sager Creek flows through the city of Siloam Springs, receives the waste water treatment effluent downstream from the city and continues to flow into Oklahoma where it becomes a tributary of Flint Creek, which eventually flows into the Illinois River.

The methods used for sampling in Sager Creek were outlined in a previous publication (Wakefield 2014). In brief, Sager Creek was sampled from September of 2013 until June of 2015. Four riffle-dominated reaches were sampled in the stream (Fig. 1). The first reach is found on the campus of John Brown University (JBU) which is upstream from the Siloam Springs Wastewater Treatment Plant (SSWTP), but downstream from the Siloam Springs urban area. The second reach begins where the SSWTP effluent enters the creek (WW), and proceeds downstream. A small bridge that crosses the stream, approximately 2.5 kilometers downstream from

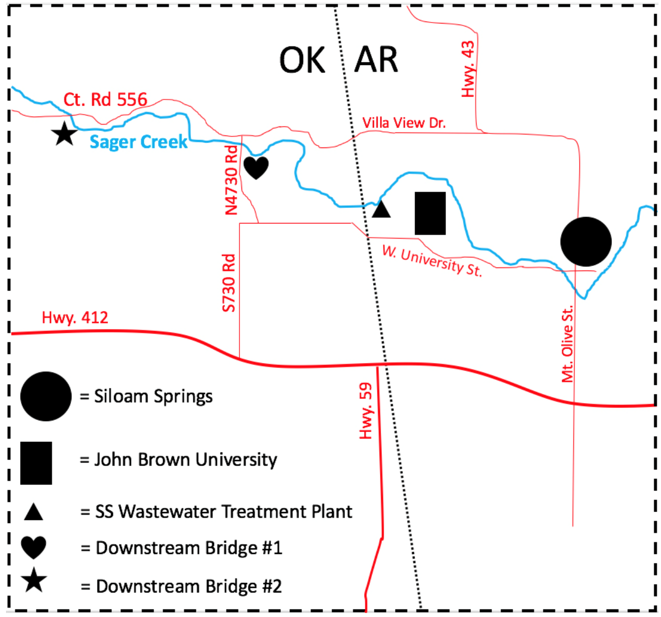

Fig 1. Map of Sager Creek indicating the location of the four sampled reaches.

the WW reach, was the location of the third reach, and was dubbed the downstream bridge #1 reach (DB1). Another small bridge crosses the stream, approximately 5 kilometers downstream from the WW reach, and was dubbed the downstream bridge #2 reach (DB2). Each sampling reach was divided into eight sampling sites, labeled A-H. During the three-year period, a total of 12 samples were collected from each reach, for a total of 48 separate samples (Table 1). Each sampling effort took approximately 3 hours to complete and one sample was collected per day. It should be noted that both the JBU and WW reaches are in Arkansas, while DB1 and DB2 are in the state of Oklahoma.

At each sampling site, organisms were captured in a 500-µm D-net. Net contents were poured through a 0.5 cm^2 mesh rock screen into a bucket. Both the D-net and the rock screen were inspected to remove all clinging organisms. The final sample was transferred into a collection container and preserved with 95% ethyl alcohol. All sampling sites were sampled in this same manner, with the exception of samples taken during May and June of 2015. Due to limited assistance and time, collections were made at only four of the eight sampling sites.

In the laboratory, each collected sample was poured into gridded counting tray and a subsample of 100 organisms was separated and identified to the family level (Needham and Needham 1962; Voshell 2002). A Hilsenhoff (1988) family-level biotic index (FBI) was generated from each subsample. This index utilizes 66

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Table 1. Sampling dates for each reach sampled during 2013-2015.

JBU	WW	DB1	DB2
9/20/13	9/30/13	10/7/13	10/11/13
10/16/13	10/23/13	10/28/13	11/1/13
11/4/13	11/11/13	11/18/13	12/2/13
11/25/13	1/20/14	1/29/14	2/12/14
2/14/14	2/19/14	2/26/14	3/7/14
3/12/14	3/19/14	4/2/14	4/9/14
4/16/14	4/23/14	4/28/14	4/30/14
9/17/14	10/1/14	10/8/14	10/22/14
10/29/14	11/5/14	11/19/14	12/3/14
1/30/15	2/11/15	2/25/15	3/16/15
3/11/15	3/30/15	4/6/15	4/20/15
5/19/15	6/2/15	6/3/15	6/24/15

insect families, in 8 different orders, as well as 2 crustacean groups, (Isopoda and Amphipoda), to produce the FBI. In the FBI, streams with higher levels of organic pollution are designated with higher numeric values on a scale of 0 to 10. However, the Hilsenhoff's FBI was developed utilizing insects and crustaceans native to Wisconsin. Obviously, the arthropods in Sager Creek could have different tolerance levels. To better reflect these levels, organic pollution tolerance values, from 0-10, where 10 indicates the most tolerance, were assigned according to a database provided by the Missouri Department of Natural Resources (Sarver 2005).

The same subsamples from each site, were also used to develop a family-level Simpson's Index of Diversity (SID), (Simpson 1949). The SID is an indication of diversity within the stream. When stream diversity is high the probability increases that a second organism taken from the stream will be different from the first organism taken from the stream. The SID is calculated on a scale of 0-1 where 0 indicates that all organisms collected were in the same family, or there is no diversity, and 1 that indicates an infinite diversity of organisms.

A mean SID and mean FBI were calculated for each reach per sample day from the 8 individual site's SID and FBI. The 12 individual mean SID and FBI were recorded for each of the 4 reaches during the sampling period. To calculate a reach-specific mean SID (Reach Diversity) and reach-specific mean FBI (Reach Index), all twelve of the individual reach mean SID and FBI were utilized.

Additionally, all organisms from each of the 100 organism sub-samples, were used to produce a mean number of individuals from each arthropod family per reach (Family Mean). These values were useful to compare the overall diversity of pollution tolerant versus pollution intolerant species along the stream.

Sager Creek water flow was calculated utilizing Environmental Protection Agency (EPA) standard procedures (USEPA 2004). Stream temperature, pH, electrical conductivity (EC) and total dissolved solids (TDS) data were collected using a Hanna Instruments HI 991300 Multiparameter Water Quality Meter. Tests for concentrations of dissolved nitrate (NO_3), (cadmium reduction method 8039), phosphate (PO_4), (USEPA method 365.2), and dissolved oxygen (O_2), (HRDO method 8166), were performed on unfiltered water using a Hach™ colorimeter (model DR/850) according to EPA standard procedures (USEPA 2004). Each test was performed three times and a mean value for each parameter was calculated. Mean values for each parameter were then pooled in the same manner as Reach Diversity and Reach Index to produce a reach-specific mean (Reach Mean) for each parameter.

Student t-tests (α=0.05) were used to test for significant differences between Reach Diversity, Reach Index, Family Mean, and Reach Mean values between each Sager Creek reach.

Results

Physiochemical Parameters.--- Of the 8 physiochemical parameters tested, only levels of dissolved phosphate (PO_4), total dissolved solids (TDS) and electrical conductivity (EC) showed any significant differences. The student t-test analysis indicated that the JBU reach had lower levels of EC and TDS than all 3 downstream reaches. Student t-test analysis also indicated that the JBU reach had lower PO_4 levels than all three downstream reaches. However, the WW reach had a lower PO_4 level than the DB2 reach, and the DB1 reach had a significantly lower PO_4 level than the DB2 reach (Table 2).

Macroinvertebrate Diversity.--- The Reach Diversity of the JBU reach was statistically equivalent to both the DB1 and DB2 reaches. The diversity of macroinvertebrates in the WW reach, though, was statistically lower than all other reaches (Table 2).

As in the previous study (Wakefield 2014), all eight of the insect orders and the 2 crustacean groups were collected in this study. But only 31 of the potential 66 families were collected and used in creating both the

Table 2. Physiochemical & diversity parameters tested along Sager Creek. Student t-tests p-values are significant to the 95% confidence interval. Shaded boxes and bold text indicate significant results. ppm= parts per million; μS/cm= microsiemen per centimeter. n=12 per mean value.

Parameter	Reach Comparison $\bar{x}$±SE		t-test
Reach Mean TDS (ppm)	JBU 152.25±6.14	WW 258.46±18.24	***p=3.15E-5***
		DB1 250.42±16.68	***p=2.67E-5***
		DB2 239.39±12.24	***p=8.19E-6***
	WW	DB1	nd
		DB2	nd
	DB1	DB2	nd

Parameter	Reach Comparison $\bar{x}$±SE		t-test
Reach Mean PO_4 (ppm)	JBU 0.221±0.043	WW 0.405±0.093	***p=1.16E-2***
		DB1 0.457±0.048	***p=2.49E-4***
		DB2 0.532±0.062	***p=2.05E-5***
	WW	DB1	nd
		DB2	***p=3.68E-2***
	DB1	DB2	***p=2.68E-2***

Parameter	Reach Comparison $\bar{x}$±SE		t-test
Reach Mean EC (μS/cm)	JBU 304.61±12.33	WW 517.89±36.32	***p=3.00E-5***
		DB1 501.69±33.52	***p=2.84E-5***
		DB2 478.86±24.42	***p=8.00E-6***
	WW	DB1	nd
		DB2	nd
	DB1	DB2	nd

Parameter	Reach Comparison $\bar{x}$±SE		t-test
Reach Diversity	JBU 0.762±0.026	WW 0.574±0.052	***p=1.94E-4***
		DB1 0.724±0.041	nd
		DB2 0.711±0.043	nd
	WW	DB1	***p=2.66E-3***
		DB2	***p=2.58E-2***
	DB1	DB2	nd

Parameter	t-test
Reach Mean Temp (°C)	nd
Reach Index	nd
Reach Mean NO_3 (ppm)	nd
Reach Mean O_2 (ppm)	nd
Reach Mean Water flow (m^3/s)	nd
Reach Mean pH	nd

Reach Diversity and Reach Index. Table 3 indicates that three families of Ephemeroptera, one family of Plecoptera, 3 families of Trichoptera, and one family each of Odonata, Diptera and Coleoptera showed significant results. All other insect families and crustacean orders showed no significant differences.

For the Ephemeropterans, all 3 families showed significant t-test differences. For the family Baetidae, statistical differences were noted between the JBU reach and the DB1 and DB2 reach. This family also showed a significant difference between the WW reach and DB1 and DB2 reach. The family Isonychiidae showed the same significant differences in reaches as was seen in the family Baetidae. For the family Leptophlebiidae, the only significant differences were seen between the JBU reach and the DB1 and DB2 reaches.

For the Trichopterans, all three families also showed significant t-test differences. Philopotamidae showed differences between all reach comparisons except for the comparison between DB1 versus DB2. Hydropsychidae also showed significant differences in every comparison except between JBU versus DB2. The Helicopsychidae were only found in small numbers at two of the reaches. This resulted in significant differences between only the JBU reach and both the WW and DB2 reach.

The Plecopteran family Perlidae, was also found in limited numbers and they were all at the downstream bridge reaches. This resulted in significant t-test differences in all comparisons except for the JBU versus

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Table 3. List of orders and families of aquatic insects and crustacean taxa collected, identified, and counted in Sager creek. Numbers at the end of each taxon indicates the pollution-tolerance value according to Sarver (2005). Student t-tests p-values are significant to the 95% confidence interval. Shaded boxes and bold text indicate significant results. n=12 per mean value.

Macroinvertebrate	Family Mean $\bar{x}$±SE		t-test
Ephemeroptera	JBU 40.92±7.85	WW 38.33±14.95	nd
Baetidae(4)		DB1 133.41±28.03	***p=1.06E-3***
		DB2 122.25±23.90	***p=1.06E-4***
	WW	DB1	***p=1.06E-5***
		DB2	***p=1.06E-6***
	DB1	DB2	nd
Leptophlebiidae(2)	JBU 4.75±1.97	WW 1.08±0.69	nd
		DB1 0.25±0.18	***p=2.07E-2***
		DB2 1.58±1.02	***p=3.48E-2***
	WW	DB1	nd
		DB2	nd
	DB1	DB2	nd
Isonychiidae(2)	JBU 2.08±0.91	WW 1.25±0.79	nd
		DB1 10.67±4.41	***p=4.37E-2***
		DB2 13.25±5.36	***p=2.96E-2***
	WW	DB1	***p=3.32E-2***
		DB2	***p=2.57E-2***
	DB1	DB2	nd
Caenidae(7)	nd		
Heptageniidae(4)	nd		
Leptohyphidae(4)	nd		
Ephemerellidae(1)	nd		
Ephemeridae(4)	nd		
Odonata	JBU 13.08±2.37	WW 34.92±11.63	***p=2.88E-2***
Coenagrionidae(9)		DB1 16.00±5.21	nd
		DB2 7.25±1.90	***p=1.53E-2***
	WW	DB1	***p=1.12E-2***
		DB2	***p=1.69E-2***
	DB1	DB2	nd
Calopterygidae(5)	nd		
Gomphidae(7)	nd		
Libellulidae(9)	nd		
Diptera	JBU 0.25±0.13	WW 0.00	***p=4.09E-2***
Tabanidae(8.5)		DB1 0.00	***p=4.09E-2***
		DB2 0.00	***p=4.09E-2***
	WW	DB1	nd
		DB2	nd
	DB1	DB2	nd
Ceratopogonidae(6)	nd		
Chironomidae(6)	nd		
Empididae(6)	nd		
Simuliidae(6)	nd		
Tipulidae(3)	nd		

Macroinvertebrate	Family Mean $\bar{x}$±SE		t-test
Trichoptera	JBU 151.75±19.8	WW 9.75±2.00	***p=1.18E-5***
Philopotamidae(3)		DB1 60.33±20.61	***p=3.78E-3***
		DB2 40.5±8.28	***p=4.10E-5***
	WW	DB1	***p=1.31E-2***
		DB2	***p=9.95E-4***
	DB1	DB2	nd
Hydropsychidae(4)	JBU 89.83±12.43	WW 183.41±57.64	***p=3.72E-2***
		DB1 48.66±13.37	***p=6.62E-4***
		DB2 72.42±13.52	nd
	WW	DB1	***p=7.37E-3***
		DB2	***p=2.86E-2***
	DB1	DB2	***p=1.45E-2***
Helicopsychida(3)	JBU 0.66±0.31	WW 0.00	***p=2.72E-2***
		DB1 0.16±0.11	nd
		DB2 0.00	***p=2.72E-2***
	WW	DB1	nd
		DB2	nd
	DB1	DB2	nd
Hydroptilidae(4)	nd		
Limnephilidae(3)	nd		
Polycentropidae(6)	nd		
Plecoptera	JBU 0.00	WW 0.00	nd
Perlidae(3)		DB1 1.83±0.44	***p=7.98E-4***
		DB2 4.00±1.20	***p=3.44E-3***
	WW	DB1	***p=7.98E-4***
		DB2	***p=3.44E-3***
	DB1	DB2	***p=4.28E-2***
Capniidae(1)	nd		
Coleoptera	JBU 38.75±7.74	WW 24.92±6.02	***p=2.72E-2***
Elmidae(4)		DB1 76.42±14.38	***p=5.62E-3***
		DB2 111.33±36.49	***p=3.17E-2***
	WW	DB1	***p=5.27E-4***
		DB2	***p=1.11E-2***
	DB1	DB2	nd
Psephenidae(4)	nd		
Lepidoptera			
Pyralidae(5)	nd		
Amphipoda(6.9)	nd		
Isopoda(8)	nd		

WW reach.

For the Coleopterans, the family Elmidae were found in all of the reaches sampled and significant t-test differences were noted for all comparisons except for the DB1 versus DB2 comparison.

The one family of Odonata, Coenagrionidae, was also collected at all the reaches, but the JBU reach showed significant t-test differences between both the WW and DB2 reaches. The WW reach also showed significant differences between both DB1 and DB2 reaches.

Although many different families of Dipterans were collected, the only family that showed any significant differences were the Tabanidae. This family was only collected at the JBU reach and was thus significantly different from all other compared reaches.

Discussion

According to Wakefield (2014), the upper reaches of Sager Creek show a significant amount of USS from the urban setting surrounding the stream, including altered geomorphology, altered water chemistry and altered biota. One of the most significantly affected reaches is the WW reach presumably from the negative impact of the SSWTP effluent. But, according to Bartsch (1948), this effluent should represent water that has already been through the septic zone and the recovery zone while in the treatment plant. Therefore, although the effluent may show a significant impact on overall stream health, the persistence of the impact should be relatively short-lived in the downstream reaches of the stream and the overall stream health should recover to the pre-effluent level (as represented by the JBU reach) or could even fully recover to a "clean water" level as it progresses downstream.

Physiochemical Parameters---The physiochemical symptoms of USS were inconsistent among the four Sager Creek reaches. Five of the eight parameters tested confirmed the null hypothesis, as there were no significant differences found between any of the reaches (Table 2). However, both TDS and EC showed significant statistical differences. This is not surprising considering that a previous study had already identified the WW reach as a point source for elevated TDS (Wakefield 2014) and that elevated EC is directly correlated with elevated TDS, (MacPherson 1995). Table 2 indicates that there is a rapid increase in concentration of TDS and EC at the WW reach and that both slowly decline the farther downstream the water progresses. This pattern is predictable and conforms to expectations of effluent released pollutants (Fono *et al.* 2006; Paul and Meyer 2001).

The effluent from a wastewater treatment plant can also be a significant source of dissolved PO_4 (LaValle 1975). Significant levels of dissolved PO_4 have already been demonstrated to be a major component of the SSWTP effluent (Haggard *et al*. 2004; Wakefield 2014). What is curious is that the level of dissolved PO_4 continues to increase as the water moves downstream (Table 2). This could be an indication that additional non-point sources of PO_4 are being added to the stream. This is a strong possibility as the downstream watershed is dominated by agricultural pasture and grazing land that could be leaching dissolved PO_4 into the stream (Sharpley and Sharpley 1994).

Biological.--- Additional "mixed" results are seen in the biological studies performed. Although the Reach Index showed no significant differences, Reach Diversity showed significant statistical difference (Table 2). In general, macroinvertebrate diversity is negatively correlated with stream pollution levels (Pratt *et al.* 1981; Hachmoller *et al.* 1991; Thorne *et al*. 2000). The JBU Reach Diversity was significantly higher than the WW reach but not the DB1 or DB2 reaches. The WW reach was significantly lower than both the DB1 and DB2 reaches. However, the DB1 and DB2 were not significantly different from each other. This pattern is predictable, if it is assumed that the downstream reaches are approaching pollution levels on par with the pre-effluent effected stream water.

Of the thirty-one insect families and Crustacean Orders collected, twenty-one showed no statistical difference (Table 3). For those families that did show significant differences, the t-test results of compared reaches are still problematic. For example, the Ephemeroptera, Plecoptera and Trichoptera (EPT) orders are typically thought of as being the most pollution sensitive. Thus, based on the Reach Diversity results, it could be predicted that the families of these three orders would show similar population levels in the JBU reach, DB1 reach and DB2 reach if the water quality is approaching the pre-effluent effected level. Alternatively, if the water quality is approaching a higher "clean water" stage then the DB1 and DB2 reaches might have even greater population levels than either the JBU or WW reach. For some of the EPT families these "expected" results are seen. This was true for the families Baetidae, Isonychiidae and Perlidae. The Coleopteran family Elmidae also reflects these expected results. However, for the families Leptophlebiidae, Philopotamidae and Helicopsychidae the JBU reach showed the highest population levels. This was also true for the Dipteran family Tabanidae.

What is not surprising is that the Odonate family Coenagrionidae shows a significantly higher population

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in the WW reach. This is predictable considering that the Coenagrionidae have one of the highest pollution tolerance levels. What is surprising, though, is that the Trichopteran family Hydropsychidae, with a low to mid-range tolerance level, also reaches its significantly highest population level in the WW reach.

These mixed results amongst the macroinvertebrate families could be reflective of the mixed results seen in the physiochemical characters. For example, the WW, DB1 and DB2 reaches were demonstrated to have significantly higher levels of TDS, EC and PO_4. It is possible that the families Leptophlebiidae, Philopotamidae and Helicopsychidae are particularly sensitive to one or more of these parameters, thus reducing their numbers downstream from the JBU reach. Whereas the families Baetidae, Isonychiidae and Perlidae may not be particularly sensitive to any of these parameters, and the pollutant that prevents them from flourishing in either the JBU or WW reaches is finally diluted away to a suitable level in the downstream reaches. If this were true, the identity of that pollutant has not been elucidated in this or any other previous studies.

Conclusion

Although particular findings in the physiochemical parameters and biological assessments indicate that the four reaches studied along Sager Creek are significantly different, the large number of non-significant differences in biological and physiochemical parameters would make it imprudent to completely reject the null hypothesis that all Sager Creek reaches would show the same level of negative effects as a result of USS.

As a final note, the significant effect of the SSWTP effluent on the downstream reaches of Sager Creek cannot be overemphasized. As Bartsch (1948) stated, the plant should serve as both the septic and recovery zones before the release of effluent. During normal operating procedures the plant seems to fulfill this role well enough that some stream recovery is evident in the downstream reaches as is seen in some of the macroinvertebrate families studied.

However, shortly after data collection for this study concluded, a major biological "upset" occurred at the SSWTP. In late September of 2015, the Sager Creek Foods cannery, located in the downtown area of Siloam Springs, AR, had a power failure that resulted in a significant release of untreated wastewater into the SSWTP. Unprepared for this influx, the treatment plants effluent became septic. Dissolved oxygen levels observed downstream from the plant fell below 1 mg/L (Smoot 2015). Warm water fish, such as *Lepomis cyanellus* (green sunfish), *L. macrochirus* (bluegill), and *Micropterus salmoides* and *M. dolomieu* (largemouth and smallmouth bass), require a dissolved oxygen level of approximately 5.5 mg/L (USEPA 1986), thus the resulting death of over 30,000 fish downstream of the plant. Although, the SSWTP is back to normal operating procedures (Myers 2016) the effluent from the plant will continue to pose a potential pollution risk for all the downstream reaches of Sager Creek.

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Literature Cited

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

Bartsch AF. 1948. Biological aspects of stream pollution. Sewage Works Journal 20: 292-302.

Cardenas MAR, I Ali, YL Foon, L Dawes, R Thier, and **J Rajapakse.** 2016. Removal of micropollutants through a biological wastewater treatment plant in a subtropical climate, Queensland-Australia. Journal of Environmental Health Science & Engineering 14:14.

Daughton CG and **TA Ternes.** 1999. Pharmaceuticals and personal care products in the environment: agents of subtle change? Environmental Health Perspectives 107:907-938.

Dyer SD and **XA Wang.** 2002. A comparison of stream biological responses to discharge from wastewater treatment plants in high and low population density areas. Environmental Toxicology and Chemistry 21:1065-1075.

Englert D, JP Zubrod, R Schulz, and **M Bundschuh.** 2013. Effects of municipal wastewater on aquatic structure and function in the receiving stream. Science of the Total Environment 454-455:401-410.

Fono LJ, EP Kolodziej, and **DL Sedlak.** 2006. Attenuation of wastewater-derived contaminants in an effluent-dominated river. Environmental Science and Technology 40:7257-7262.

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.

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.

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

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.

Myers T. 2016. Personal Communication, May 23. Mr. Tom Myers is the superintendent of the SSWTP.

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

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.

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.

Sharpley AN and **PJA Withers.** 1994. The environmentally-sound management of agricultural phosphorus. Fertilizer Research 39:133-146.

Smoot DE. 2015. Siloam Springs officials consider penalizing company for fish kill. Muskogee Phoenix. 12/7.

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

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

U.S. Geological Survey (USGS). 2016. The National Map Viewer. Reston (VA); <http://viewer.nationalmap.gov> Accessed on 25 May 2016.

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.

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

Wakefield TS. 2014. Urban stream syndrome in a small town: A comparative study of Sager and Flint Creeks. Journal of the Arkansas Academy of Science 68: 117-130

https://scholarworks.uark.edu/jaas/vol71/iss1/22
DOI: 10.54119/jaas.2017.7123

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 24:706-72.