1-1-2012

Effect of reservoir discharge and sanitary effluent on an urban stream

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Effect of reservoir discharge and sanitary effluent on an urban stream

(TITLE)

BY

Daniel Hiatt

THESIS

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF

Master of Science in Biological Sciences

IN THE GRADUATE SCHOOL, EASTERN ILLINOIS UNIVERSITY
CHARLESTON, ILLINOIS

2012
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Abstract

Eutrophication of aquatic ecosystems may occur from several sources, primarily from anthropogenic inputs. Excess nutrient deposition can result in eutrophication and community compositional shifts in organisms located in impacted ecosystems. In the Sangamon River located outside Decatur, IL, discharge from the local reservoir, which receives inputs from both a city landscape and agricultural landscape and a wastewater treatment plant (WWTP). These may result in a large influx of nutrients into this system. Increased nutrient levels have the potential to shift benthic periphyton, and macroinvertebrate communities and cause extinction of low tolerance native species. To examine the impacts of inputs for the WWTP and reservoir, sampling was performed above the WWTP (upstream sites) which encompassed the sampling points from the discharge of the Decatur reservoir down to the WWTP discharge, and sampling was performed downstream of the WTTP (downstream sites). PCA analyses show a significant difference between upstream and downstream sites. During periods of high flow from the dam, a detectable increase in available total oxidized nitrogen was found in the water column. Additional water chemistry tests found significant differences between upstream and downstream sites when examining nutrient levels based on high periods of discharge, and seasonal variation. Our results show that there is a significant relationship between increased TON, and NH_3 levels upstream of the sanitation district during periods of high flow (high reservoir discharge) and the downstream sites. This relationship shows that the reservoir is acting as a sink of nitrogen (as TON and NH_3) from the surrounding watershed, and a source of eutrophication in upstream sites. Analyses also showed periods of no difference between upstream sites and downstream sites as reservoir discharge increased, and a negative correlation between water nutrient values of the downstream sites during periods of higher discharge. The lack of difference seen between the sites at high discharge may be a result of dilution of the WWTP discharge by reservoir water. Community structure metrics found significant differences in MIBI (p = .00039), and IBI (p = .000839) scores between the two reaches with the UPS site having lower scores compared to the DNS a finding that previous studies showed based on diatom assemblages.

Overall, we found that high periods of discharge appear to mediate the influence of the nutrient input from the WWTP, which in itself caused significant changes in the macroinvertebrate, fish and benthic algal communities.

Acknowledgements

I would like to thank Drs. Pederson, Meiners and Colombo for their assistance in developing, and completing this project. I would also like to thank Eastern Illinois University, Illinois Lakes Management Association, the Illinois EPA and the Sanitary District of Decatur for assistance with funding. Lastly, I would like to thank the fish and aquatics research team for all of their help with sampling, lab work and long canoe trips to get everything finished.

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Introduction

In the United States, many of the Midwest lakes are man-made impoundments, or reservoirs. Often, these impoundments receive nutrient rich water from lotic systems that flow through agricultural areas. In addition, the increasing population in many Midwestern urban areas increases risk of pollution and runoff into these bodies of water resulting in further degradation of these water sources (Wetzel 1992). Lake and reservoir management will only be effective when people are able to link water quality to the aspects of these bodies of water that the public find important (Smith 1998).

Reservoirs can severely alter the biological structure of rivers both upstream and downstream of the impoundment. In areas where the dam results in highly controlled flow, the resulting impact is even greater (Cole and Landres 1996). The creation of a reservoir results in a massive shift in ecosystems both upstream, downstream and within the reservoir. Conversion of riverine ecosystems with lotic and riparian regions to a lake ecosystem may result in wetlands where tributaries feed into the reservoir, and alter or remove riparian vegetation, or result in a shift to a lacustrine ecosystem (Cole and Landres 1996). Low flow reaches, which result from dam operation, have significantly altered riparian vegetation. Many times these shifts result from increased mortality, shifts in physiology and morphology, and population structure of riparian vegetation (Smith et al. 1991, Stromberg and Pattern 1992). Dams that occur along mainstems of rivers may also alter temperature, sediment loading, nutrient levels and the natural flow variability of the river (Cole and Landres 1996).

In larger watersheds, reservoirs that serve many public purposes may be act as both a sink for upstream deposition and a source of excess nutrients to the downstream river reaches.

Eutrophication can result in many ecological problems including algal blooms, oxygen depletion, and a loss of species diversity (Wetzel 1992). Nutrient enrichment also presents numerous issues for cities and townships that utilize these water sources for the public water supply and recreation (S.R. Carpenter et al. 1998). Primary nutrients of concern with eutrophication in freshwater aquatic systems are phosphorous and nitrogen (U.S. EPA 1990), with the primary sources of these inputs resulting from agricultural, urban and industrial practices. The U.S. EPA (1996) listed eutrophication as the primary cause of impairment for approximately 50% of impaired lakes, and approximately 60% of impaired river reaches in the United States. Furthermore, they listed nonpoint source pollution such as agricultural, urban runoff and industrial practices, as the major source of water pollution in the U.S. (U.S. EPA 1990, 1996).

Agricultural land use practices are a primary concern due to the runoff of fertilizers and sediments into streams and lakes resulting in an increase in eutrophication (David et al. 1997). Agricultural watersheds export nutrients at considerably higher rates than undisturbed watersheds (Puckett 1995). A primary issue with agricultural inputs is the non-specific source dispersed over large areas, making mitigation difficult. Source identification is compounded by the importance of local weather events (Carpenter et al. 1998). Heavy rainfall events in agricultural watersheds increase local sediment export (as a byproduct of looser soil due to tilling or harvesting) and loading of sediments downstream, which may reduce algal and plant productivity through reduced light availability (Knoll 2003).

Dams may also affect the surrounding food webs by the alteration of flow rates, temperature, nutrients and sediment loading. The loss or alteration of riparian vegetation from impoundment may also reduce detritus resulting in a food web shift (Vanni et al. 2005). Reservoirs act as a sink for the upstream watershed and may become a source of nutrients to downstream river stretches, leading to potential changes in community structure of primary producers. Changes in primary producers may have cascading impacts throughout the entire food web by shifting population numbers of available prey/predators (Carpenter et al. 1998). Adams et al. (1983) showed that reservoir fish productivity is often unsupportable by autochthonous primary production and must receive additional support in the form of allochthonous inputs from the surrounding watershed. Land utilization, lake management practices, and industrial practices need tailoring to individual streams and rivers to reduce sediment and nutrient exports into reservoirs, which in turn may reduce downstream impacts.

Sangamon River Ecosystem

The Sangamon River is a major tributary to the Illinois River. The Sangamon River is approximately 402 km in length, with a watershed of roughly 2395 km^2 that is primarily rural agriculture. As of 1982, row crops were the largest land use in the watershed that feeds into Lake Decatur and accounted for 87% of the total area (Soil Conservation Service 1983). The Sangamon River begins from headwater streams in southern McLean County and flows South and West until it reaches a confluence with the Illinois River near Beardstown, IL. In 1920, impoundment began on the Sangamon River in Decatur, IL to form Lake Decatur. The original intent of the reservoir was to provide a source of water for the city of Decatur. This impoundment has experienced numerous problems since development. Between 1923 and 1983, the lake lost an approximate 35% of its storage volume due to siltation from the agricultural watershed (Fitzpatrick et al. 1987). The water quality of the lake is fair to moderate by Illinois EPA (IEPA) standards. However, the lake has high concentrations of nitrates and total dissolved solids as well as reoccurring issues with turbidity and bacterial growth (IEPA 1978, 2007).

In 1973, the USEPA conducted a survey of 31 Illinois lakes in a national eutrophication survey. Lake Decatur ranked 28 out of 31 in overall quality (U.S. EPA 1975). Criteria of a eutrophic lake include; algal blooms, excessive weeds, oxygen deficiency and may include a shift in community structure from one that requires high oxygen concentrations to one that can survive at low concentrations (U.S. EPA 1975). Additionally, a finalized report released by the Illinois EPA (2007) listed Lake Decatur as still impaired (numeric standards) by NO_3-N, TP, DO; impairments (assessment guideline based) TON, TSS, algal growth, chlordane, PCBs and the Sangamon River itself being impaired due to fecal coliform levels.

Sanitary District of Decatur

Downstream of the Lake Decatur dam is the Sanitary District of Decatur (SDD) wastewater treatment plant (WWTP). The WWTP facility was constructed in 1990 and is the primary treatment of water for the city of Decatur and surrounding towns. Primary treatment is followed by a two stage activated sludge biological process with effluent disinfection by chlorination prior to discharge (SDD website, www.sdd.dst.il.us). The SDD is capable of treating 41 million gallons per day (MGD) in dry weather and with recent improvements has increased wet weather flow capacity secondary treatment to 125 MGD (SDD website, www.sdd.dst.il.us).

Effluent discharge, even when treated appropriately, results in large amounts of nutrients being added to an aquatic system. These nutrient inputs are often related with a decrease in the quality of a water body (Howarth et al. 1996). Various biotic and abiotic processes influence nutrient transport, and retention time within streams (Stream Solute Workshop 1990) which determines the impact that WWTP effluent discharge may have on a stream or river environment. Marti et al. (2004) found that a streams' efficiency to remove effluent nutrients is determined by the amount and the quality of the water input. Sudden, large inputs and prolonged inputs from a WWTP may overwhelm a streams' ability to self-regulate nutrient levels via retention or downstream transport. This may result in excessive eutrophication, increases in algal biomass and plant crop, which has the potential to adversely affect the entire trophic web (Carpenter et al. 1998).

Study Objectives

The combination of the Lake Decatur dam and the WWTP of the Sanitary District of Decatur have the potential to result in two very dramatic alterations to the surrounding aquatic community. Measurement of nutrients and solids exported during discharge (seasonally, and during high precipitation events) is required to analyze potential impacts of a reservoir. Similar measurements are required to determine the input of nutrients from the WWTP effluent discharge. This will allow comparison of water quality between the dam and the WWTP, and the area below the WWTP to determine impacts.

Coinciding with the reservoir's discharge, additional testing was performed to assess nutrient levels downstream as influenced by the WWTP facility, and whether these inputs varied significantly from the upstream reach. Lastly, we examined whether community structure varied between these two reaches based on long-term fish and macroinvertebrate data. This lead to the primary hypotheses of:

(1) Nutrient levels in the Sangamon River downstream of the reservoir discharge will be significantly higher than the levels found in the upstream reach as a result of the WWTP discharge, and biotic indices are significantly different between these two reaches.

(2) High precipitation events and corresponding discharge volume from Lake Decatur will result in increased nutrient values in the Sangamon River both above and below the wastewater treatment plant.

Methods

Study Site

Eleven sites were selected along the main stem of the Sangamon River in relation to points of discharge from the SDD or the confluence of nearby streams within the boundary of Decatur, Illinois (Table 1). Sites ranged from the base of the Lake Decatur dam to a bridge crossing on County Highway 27 (South Lincoln Memorial Parkway) west of Decatur and downstream of the Sanitary District of Decatur's (SDD) discharge. Sites were separated as upstream (UPS) or downstream (DNS) in relation to the discharge of the SDD. Seven sites were located in the UPS reach extending from the dam of Lake Decatur down to a point just above the discharge of the SDD, and the remaining four sites were classified as DNS extending from below the SDD's discharge to the bridge on County Highway 27.

In Situ Field Sampling Protocol

Measurements of physical and chemical (abiotic) variables occurred on a monthly basis at all 11 sites ranging from June of 2002 through September of 2010. Water sampling collection started at the most upstream location near the dam and continued downstream to the furthest point at County Highway 27. Abiotic variables that were measured included pH, temperature, specific conductance, and dissolved oxygen (DO) using a Eureka/Manta Multi-Probe (Eureka Environmental Engineering, Austin, Texas). One liter samples were collected from just below the surface at each of the sites. Samples were transported on ice to the lab immediately after sampling for chemical analyses. In addition to the chemical variables analyzed for each site, discharge data was obtained from the United States Geological Survey gauging station (gage #05573540) located at the Route 48 Bridge in Decatur, IL to determine discharge for the sampling reaches. Discharge data was compiled and separated by event (discharge amount) and the number of events that occurred during the year, and broken into three flow categories; low (0-100 cfs), moderate (101-500 cfs), and high (>501 cfs).

Laboratory Protocol

Lab analyses were performed based on *Standard Methods for the Examination of Water and Wastewater, 16th Edition*, (APHA, AWWA, and WPCF, 1985). Solid determinations were performed for both suspended and total solids. Suspended solids were determined by filtering a known volume of sample through a glass fiber filter, total solids were measured by drying a known volume of sample in ceramic crucibles. Both solids were dried at 105°C over night to ensure that the samples were completely dried. Fixed and volatile fractions were determined for both dissolved and suspended solids along with total fixed, volatile, dissolved and suspended solid amounts. Hardness was determined using the EDTA-titrimetric method and titrated until the appropriate color developed. Alkalinity was determined using the appropriate titrimetric method and appropriate color indicators for pH change. Analyses for total phosphorous (TP) using the persulfate digestion method, and soluble reactive phosphate (SRP) using the ascorbic acid method were conducted. Total oxidized nitrogen (NO_2-N/NO_3-N) was analyzed through a cadmium reduction method. Ammonium nitrogen (NH_3-N) was determined through the phenate method. All nutrient tests were analyzed colorimetrically using a Beckman DU 530 Life Science UV/Vis Spectrophotometer at their respective wavelengths.

Invertebrate/Vertebrate sampling

Invertebrate sampling was done once a year using Hester-Dendy traps. Traps were deployed at each site and secured to cement blocks to help prevent washout during high flow events. Colonization occurred for 4 weeks prior to being collected and preserved in ethanol. MIBI scores were then calculated based upon upstream (UPS) and downstream (DNS) for each year where samplers were retrievable. Fish sampling occurred once per year and at each site using a simple seine net method collection done in a downstream movement along both banks. Fish were then stored in formalin (10%) and transported back to the lab for identification. IBI scores calculations are separated by UPS and DNS location on a yearly basis.

Statistical Analyses

PCA Analysis

Data was sub-sampled for statistical testing to the period from 2008-2010 as these data points were most complete than previous years. Principal Component Analysis (PCA) was used to examine patterns in physical and chemical properties of the sample sites. PCA allowed for the combination of the physical and chemical variables in order to determine similarity levels between the different sites and the two reaches (UPS vs. DNS). PCA values were then compared through ANOSIMS (analysis of similarity) to determine significance between variables. Pairwise comparisons between site location (and discharge were examined using ANOSIMs to examine significance (significance at $p \leq .05$) between the variables.

Incomplete monthly samples were discarded, as were any variables that were found to be highly correlated to remove redundancy from the ordinations. Correlations between original water chemistry values were checked using Primer6 (Primer-E Ltd., United Kingdoms) draftsman plots (scatter plot based graphs, variables that showed linear relationships were reduced ex; soluble reactive PO_4, dissolved PO_4 were removed due to strong linear relationships with total PO_4). ANOSIM (analysis of similarity) testing was done using Primer 6 to look at overall significance between UPS and DNS reaches along the Sangamon River.

Using the R statistical program (ANOVAs and T-tests) comparisons of nutrient levels with discharge, location, and seasonal patterns were performed and the interactions of each of all of these parameters. Comparisons between MIBI and IBI scores of the two reaches were also analyzed.

Results

Primer6 Analyses

Initial data were first compared through draftsman plots in order to examine potential redundancy in the PCA ordinations. Redundant variables as mentioned earlier were removed from the ordinations based on draftsman plots. A vector plot revealed correlations between measured variables and the PCA axes (Figure 1). These variables associated most heavily with the two axes include discharge along principal component axis 1 (PCA 1), and nutrient and temperature along PCA 2.

Sites were first broken down into a PCA showing UPS vs. DNS, which shows a distinct separation between the upstream and downstream reaches with the upstream locations showing a wide spread from the positive end to the negative end of both PC1 and sitting very near neutral on PC2. The downstream sites showed a relationship to the positive and negative ends of PC1 and a more negative-neutral relationship with PC2 (Figure 2). These values were then separated into seasonal differences (Figure 3). This showed a clear distinction between all of the seasons with fall samples having some slight overlap with spring samples and winter samples. Pairwise differences were also determined through the use of ANOSIM comparing season and location (Table 2, Figure 4) with significance at all comparisons, except winter (p = 0.01, winter p = .07). Differences are seen between similar comparison levels (e.g. fallup versus falldown - with each comparison being the season combined with the location of the site along the reach (upstream or downstream of the wastewater discharge). These differences are again seen in the significance levels of the pairwise comparisons that were performed and show that all the comparisons show a strong significant difference (p = 0.001, with winter P = 0.07, Table 2).

Sangamon Data		
WGS 84 16 UTM		
Site #		
1	S 0331957	4410760
3	S 0331893	4410915
4	S 0331200	4410921
5	S 0331050	4410964
6	S 0330660	4410704
7	S 0329396	4411139
8	S 0328882	4411029
9	S 0328591	4411019
11	S 0328114	4411133
12	S 0326374	4410231
14	S 0319796	4407348

Table 1. GPS points in WGS 84 UTM for the sampling locations along the mainstem of the Sangamon River in Decatur, IL.

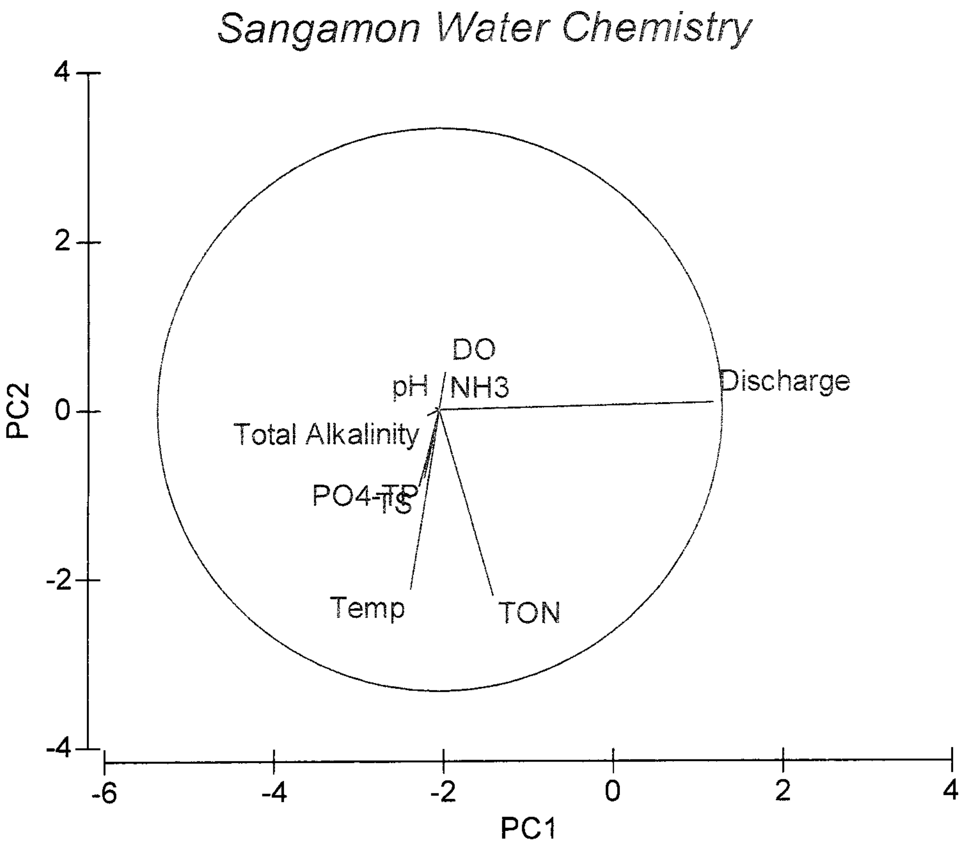

Sangamon Water Chemistry
PC2
PC1
4
2
0
-2
-4
-6
-4
-2
0
2
4
DO
pH
NH3
Discharge
Total Alkalinity
PO4-TP
TS
Temp
TON

Figure 1. Empty PCA plot showing correlations between the variables and their relationship to the PC axes. High correlations with PC2 are points that fall on the positive end of the axes and being related to dissolved oxygen (DO). Negative pairing with PC2 was found to be associated with PO_4-TP, TS, Temp and TON. Discharge was the primary factor found to be positively associated with PC1, with TON showing some weak correlation with PC1. Total Alkalinity, pH, Temp, PO_4-TP, and TS were found to be negatively correlated with PC1.

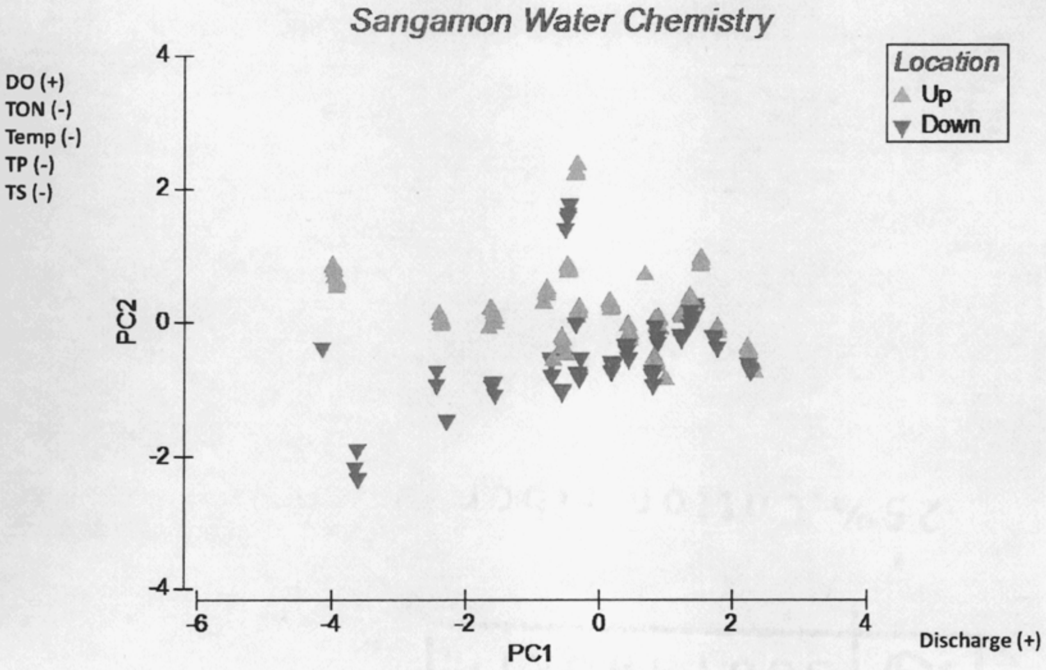

Sangamon Water Chemistry
DO (+)
TON (-)
Temp (-)
TP (-)
TS (-)
PC2
4
2
0
-2
-4
-6
-4
-2
0
2
4
PC1
Discharge (+)
Location
▲ Up
▼ Down

Figure 2. Upstream (UPS) and downstream (DNS) sites plotted against PC1, PC2. Clustering seen based on associated variables with most of the DNS sites negatively loading on PC2 while most of the UPS sites were found to load more on the positive side of PC2.

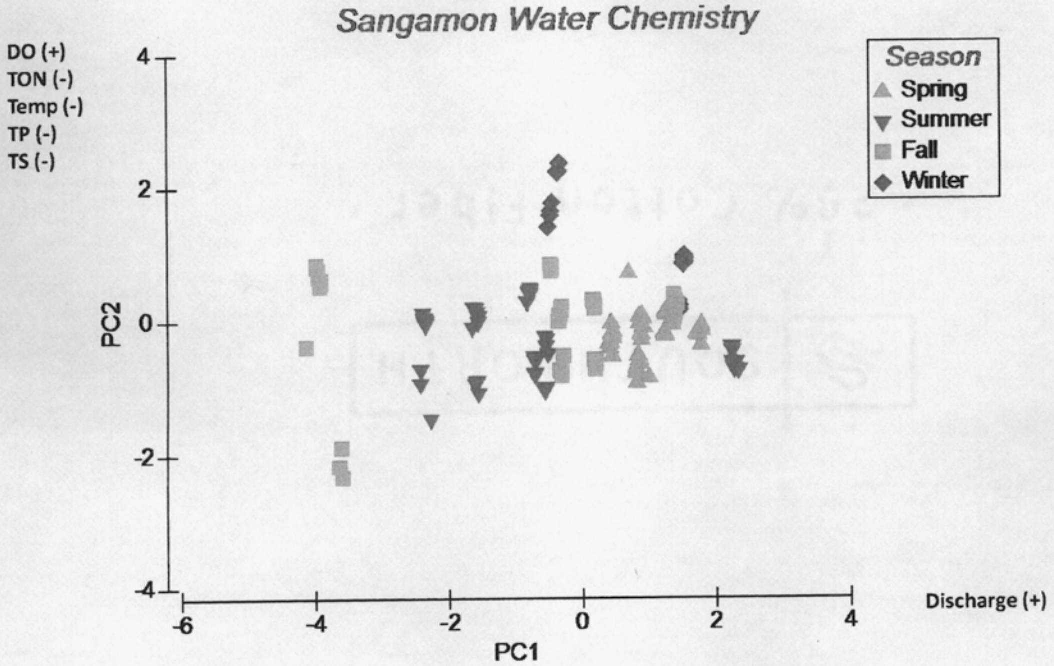

Sangamon Water Chemistry
DO (+)
TON (-)
Temp (-)
TP (-)
TS (-)
PC2
4
2
0
-2
-4
-6
-4
-2
0
2
4
PC1
Discharge (+)
Season
Spring
Summer
Fall
Winter

Figure 3. Seasonal patterning showing seasons vary quite widely with PC1 which is influenced solely by discharge and that intra-seasonal variations can occur depending upon discharge levels (p = .001).

Discharge categories were then paired with UPS and DNS locations and plotted in a final PCA (Figure 5). Again, this pairing shows a distinct separation at low discharge levels with the downstream sites more closely associated with the negative end of PC2 and the as discharge increases the sites move towards no significant difference. Significance values for these pairings are seen in Table 3, showing significant differences at low and moderate discharge between the two reaches ($p = .01$), and non-significance at high discharge ($p = 12.8$). Pairwise comparisons done by analysis of similarity (ANOSIM) between the reaches at similar flow regimes revealed significant difference between seasonal nutrient variations and discharge (Table 2). ANOSIM comparisons also found a significant difference between the sites when comparing low levels of discharge with location and no significant difference between the sites when discharge reached high levels (Table 3).

R analyses

R 2.13.1 (Statistical Package) was used to examine relationships between the locations and seasons. ANOVAs performed through R to examine differences between water chemistry when compared to discharge, season and location. Discharge (on a $\log_{10}$ scale) was plotted against the nutrient values of each reach and color coded by location to create a graph that shows relationships between the nutrient values and discharge between the different stream reaches (Figure 6). Physical variables for each reach were also plotted against discharge ($\log_{10}$) and color coded by site to examine potential differences in these values between the two reaches (figures 7, 8).

ANOVAs found significant differences when modeling the water nutrient variables (TON, PO_4TP and NH_3) against both location and discharge and found a

Table 2. Pairwise (ANOSIM) comparisons between the UPS/DNS sites of the Sangamon River based on seasons with all sites showing significance differences, except for the winter comparisons, which are not significantly different.

Pairwise Tests

Groups	R Statistic	Significance Level %
SpringUp, SpringDown	0.32	0.01
SummerUp, SummerDown	0.47	0.01
FallUp, FallDown	0.36	0.01
WinterUp, WinterDown	0.44	0.07

Figure 4. Season/Location (UPS/DNS) pairings along the Sangamon River plotted against PC1, PC2. Shows a distinct separation of the sampling reaches based on seasonality.

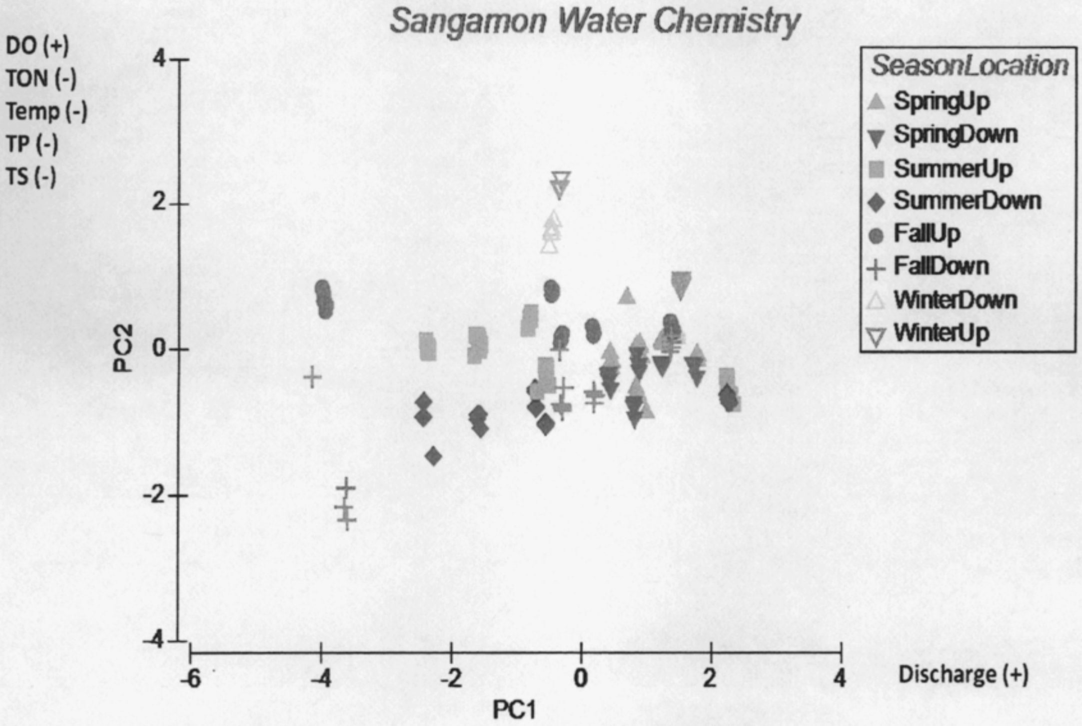

Sangamon Water Chemistry
DO (+)
TON (-)
Temp (-)
TP (-)
TS (-)
PC2
4
2
0
-2
-4
-6
-4
-2
0
2
4
PC1
Discharge (+)
SeasonLocation
▲ SpringUp
▼ SpringDown
■ SummerUp
◆ SummerDown
● FallUp
+ FallDown
△ WinterDown
▽ WinterUp

Figure 5. PCA graph colored and coded by discharge + location. Shows a significant difference between the two reaches at low and moderate flows.

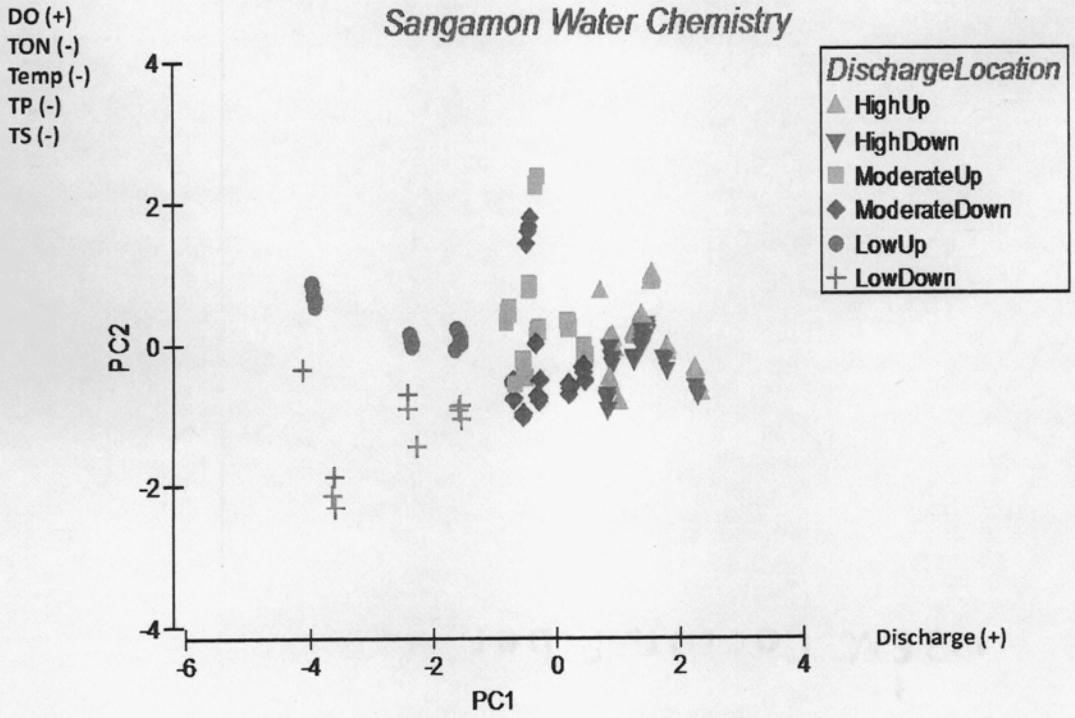
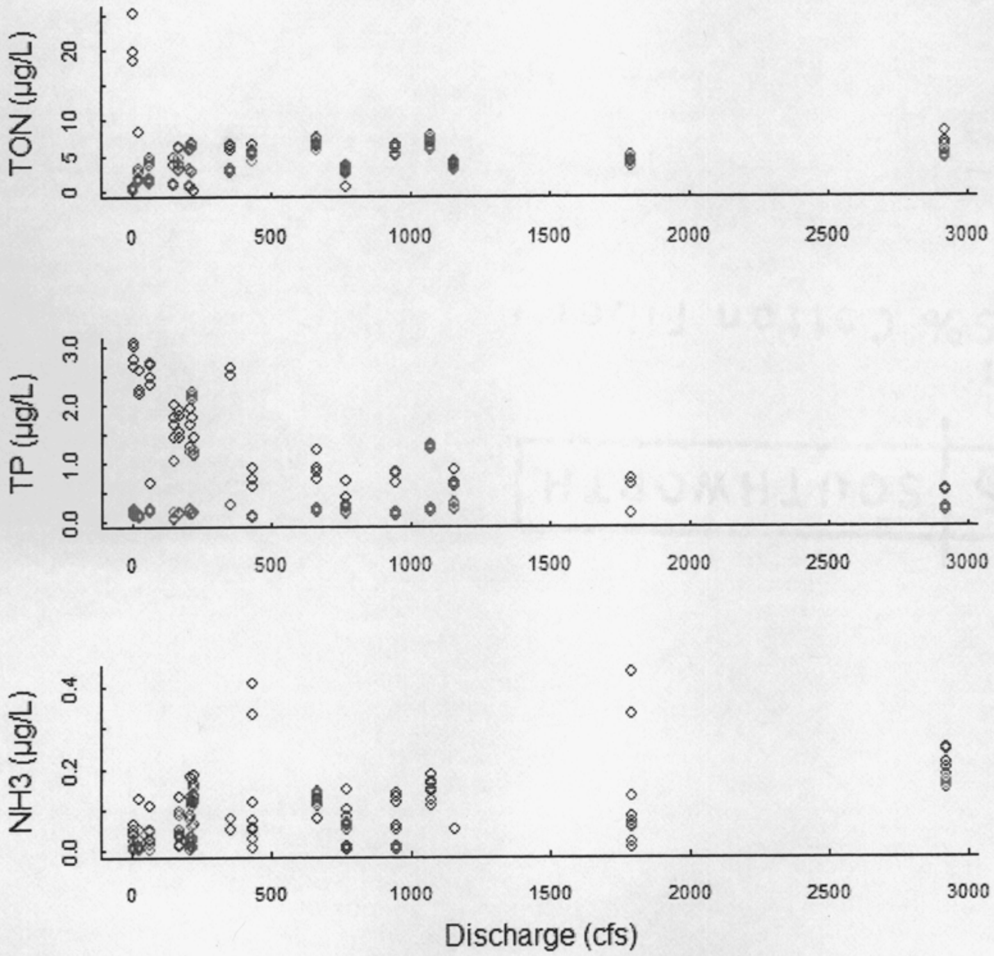

Sangamon Water Chemistry
DO (+)
TON (-)
Temp (-)
TP (-)
TS (-)
4
2
0
-2
-4
PC2
-6
-4
-2
0
2
4
PC1
Discharge (+)
DischargeLocation
▲ HighUp
▼ HighDown
■ ModerateUp
◆ ModerateDown
● LowUp
+ LowDown

Table 3. Pairwise (ANOSIM) comparison between Sangamon River sites based on UPS/DNS at similar levels of discharge. No significant difference is seen between the reaches at high discharge from the Decatur reservoir.

Pairwise Tests

Groups	R Statistic	Significance Level %
ModerateUp, ModerateDown	0.384	0.01
HighUp, HighDown	0.049	12.8
LowUp, LowDown	0.63	0.01

Figure 6. Water nutrients (excluding SRP due to correlation with TP) plotted against discharge (cfs) on a log scale and separated by season. Points are color coded by location in the stream reach (red = Downstream of the WWTP, blue = Upstream of the WWTP).


TON (µg/L)
0
5
10
20
TP (µg/L)
0.0
1.0
2.0
3.0
NH3 (µg/L)
0.0
0.2
0.4
0
500
1000
1500
2000
2500
3000
Discharge (cfs)

significant relationship between NH_3 and season (Table 5). Simple T-tests were performed to compare the differences between the two reaches based on MIBI (Table 6, Figure 9) and IBI (Table 7, Figure 10) scores and found significant differences between the two reaches (Table 8).

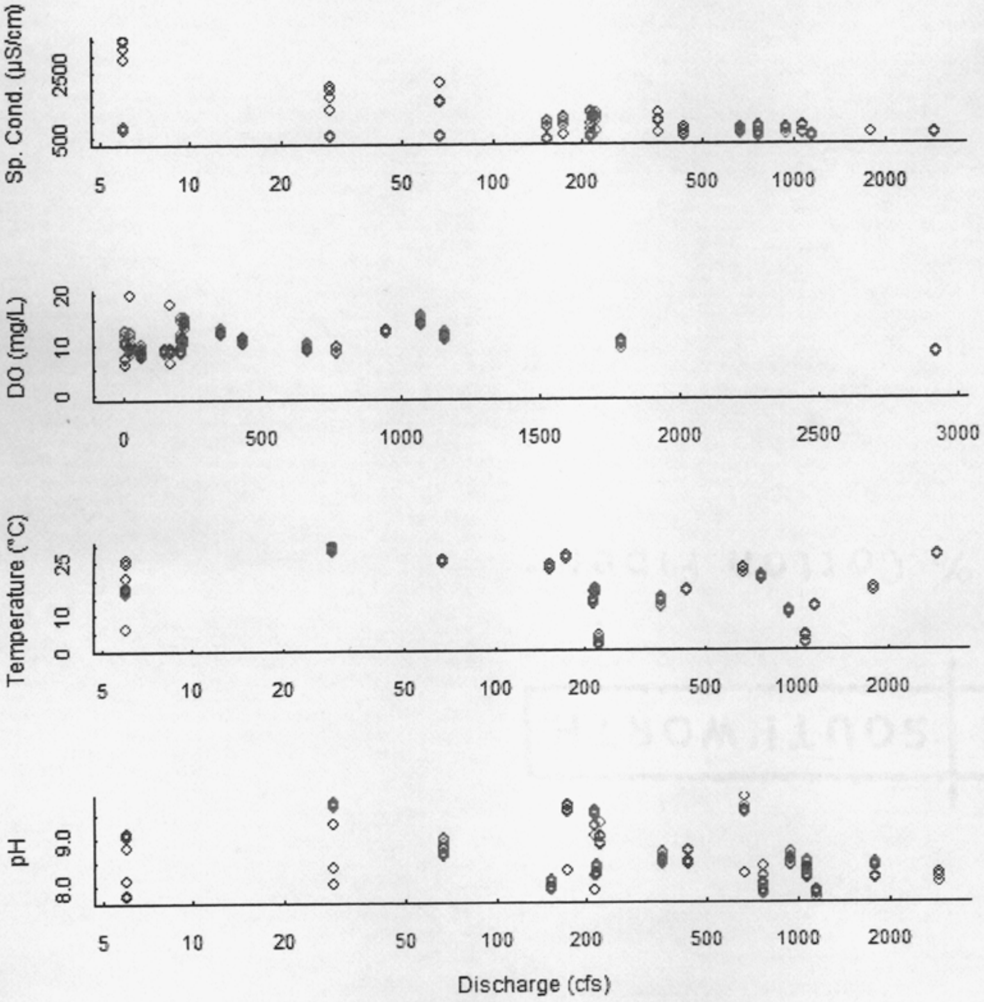
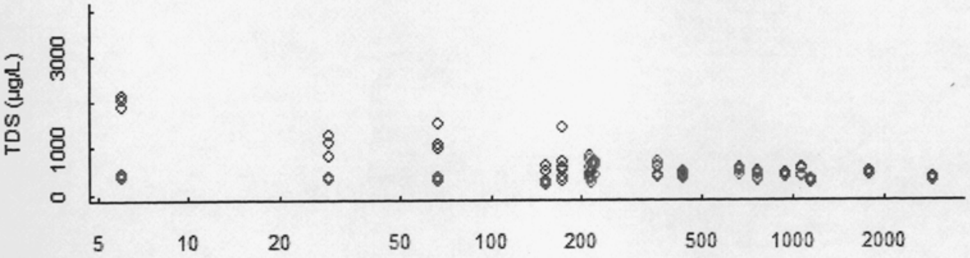
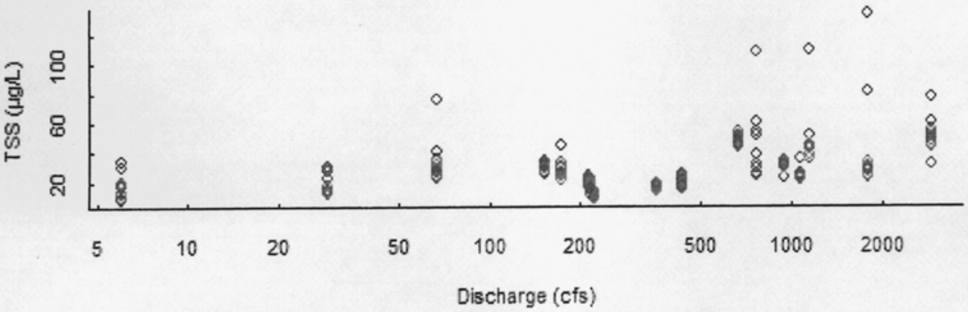

Sp. Cond. (µS/cm)
500
2500
5
10
20
50
100
200
500
1000
2000
DO (mg/L)
0
10
20
0
500
1000
1500
2000
2500
3000
Temperature (°C)
0
10
25
5
10
20
50
100
200
500
1000
2000
pH
8.0
9.0
5
10
20
50
100
200
500
1000
2000
Discharge (cfs)

Figure 7. Abiotic variables plotted against discharge (cfs) as a log(10) scale. Points are color coded by location (red = Downstream of the WWTP, blue = Upstream of the WWTP).


TDS (µg/L)
0
1000
3000
5
10
20
50
100
200
500
1000
2000


TSS (µg/L)
20
60
100
5
10
20
50
100
200
500
1000
2000
Discharge (cfs)

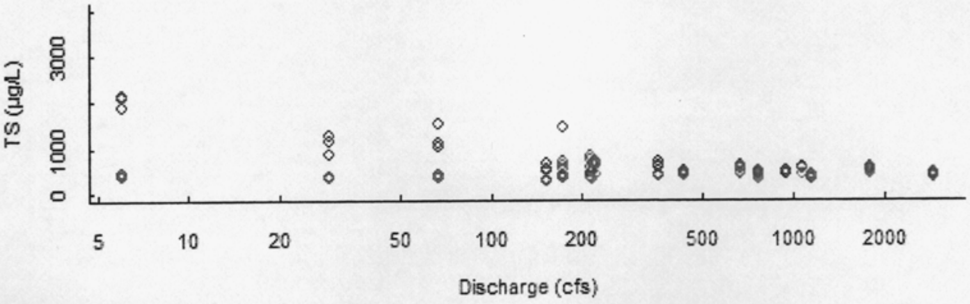

TS (µg/L)
0
1000
3000
5
10
20
50
100
200
500
1000
2000
Discharge (cfs)

Figure 8. Total forms of solids (µg/L) plotted against discharge (cfs) as a log(10) scale and color-coded by location (red = Downstream of the WWTP, blue = Upstream of the WWTP).

Response: TON

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Discharge	1	102.79	102.78	11.97	P < .05*
Season	3	29.64	9.87	1.15	0.329
Location	1	184.69	184.69	21.52	P < .05 *
Residuals	179	1535.84	8.58		

Response: PO4TP

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Discharge	1	6.27	6.27	18.58	P < .05 *
Season	3	2.43	0.810	2.40	0.0693
Location	1	41.68	41.68	123.52	P < .05*
Residuals	179	60.40	0.33		

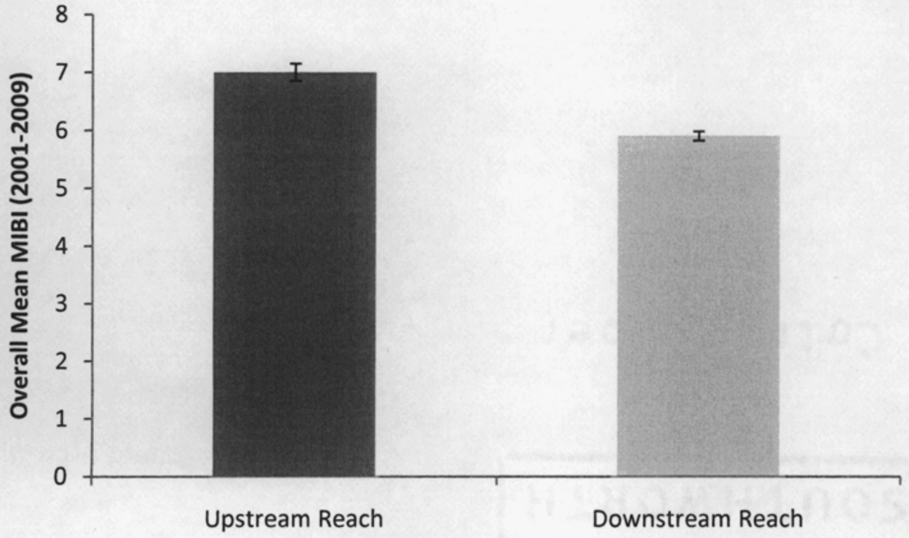
Response: NH3

	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Discharge	1	0.18	0.18	47.39	P <.05 *
Season	3	0.099	0.033	8.66	P <.05 *
Location	1	0.027	0.027	7.23	P < .05 *
Residuals	166	0.63	0.0038		

Table 4. ANOVA values water chemistry nutrient of data modeled against discharge, location and season. Asterisks denote significance of treatment. ANOVA performed through R statistical program.

Year	Upstream Reach	Downstream Reach
2001	7.3	5.9
2002	7.7	6.2
2003	7.1	5.6
2004	6.3	6.1
2005	6.8	5.7
2006	6.9	5.9
2007	6.8	5.9
2008	6.7	----
2009	----	----
overall mean	**7.0**	**5.9**

Table 5. Mean MIBI scores for the Sangamon River separated by location of upstream or downstream of the WWTP discharge.

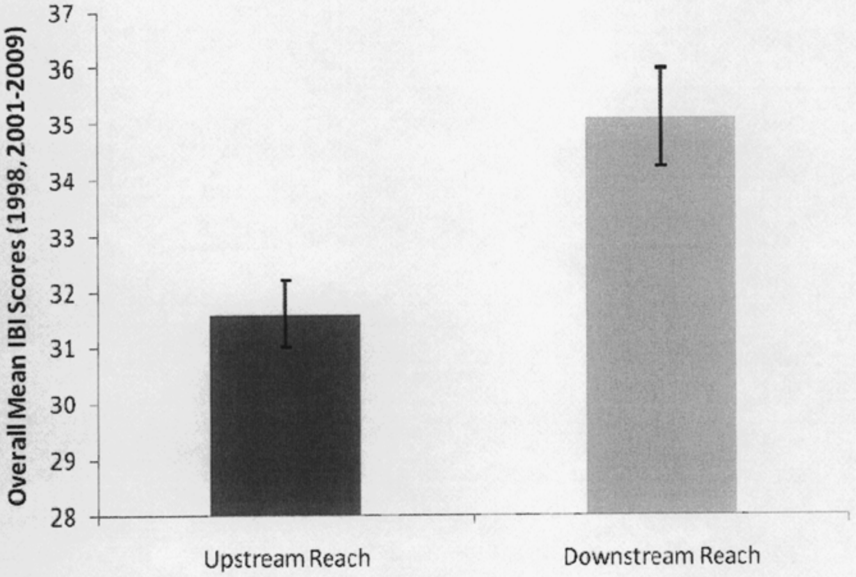


Overall Mean MIBI (2001-2009)
8
7
6
5
4
3
2
1
0
Upstream Reach
Downstream Reach

Figure 9. Overall, mean MIBI of upstream and downstream reaches based on taxon collected with Hester-Dendy traps.

Year	Upstream Reach	Downstream Reach
1998	29	33
2001	32	33
2002	30	34
2003	30	35
2004	30	31
2005	34	34
2006	34	40
2007	31	39
2008	34	36
2009	32	36
overall mean	**31.6**	**35.1**

Table 6. Mean IBI scores for the Sangamon River separated by location of upstream or downstream of the WWTP discharge.



Overall Mean IBI Scores (1998, 2001-2009)
37
36
35
34
33
32
31
30
29
28
Upstream Reach
Downstream Reach

Figure 10. Overall, mean IBI for years 1998, 2001-2009 with standard error bars based on fish assemblage data.

MIBI Scores	*UPS*	*DNS*
Mean	6.98	5.9
Variance	0.194	0.043
Pearson Correlation	0.145	
Df	6	
t Stat	6.24	
P(T<=t) one-tail	0.00039	
t Critical one-tail	1.94	

IBI Scores	*UPS*	*DNS*
Mean	31.6	35.1
Variance	3.6	7.65
Pearson Correlation	0.47	
Df	9	
t Stat	-4.41	
P(T<=t) one-tail	0.000839	
t Critical one-tail	1.83	

Table 7. T-test comparison of MIBI and IBI scores for the UPS and DNS reaches. Significant differences are found between the two sites.

Discussion

Large portions of the nutrient values recorded in this ecosystem were consistently related to the discharge of the Decatur Sanitary Districts WWTP. Even during periods of low discharge from Lake Decatur the reach located below the WWTP's discharge nutrient values were always greatly increased and the discharge volume of the WWTP rarely changed. Several studies have found that the increases of nutrients available in a water column downstream of a WWTP are capable of shifting the available type of nitrogen (N) (Marti 2004, Miltner and Rankin 1998). This shift usually resulted in a change from NO_3 to NH_3 (Marti 2004) resulting in a negative impact on biota, particularly fish species (Miltner and Rankin 1998). However, the data in our study found significantly increased average TON levels (NO_2/NO_3) and not highly elevated NH_3 levels (appendix a) excluding one extreme outlier of NH_3 during 2005. TON levels were elevated but were quite widely distributed in their yearly average (Table 4). The DNS reach shows a high level of TON, which fluctuated quite widely between years and for many years a higher average value of NH_3. Discharge also varied quite widely across all of the years of the study. Several years (2008 and 2009) had periods with large amounts of flooding during the summer months. Nutrient values were compared to discharge and an increase in nutrient values were observed particularly in the UPS reach for TON and NH_3 (Figure 5). While an increase was noted in the DNS reach for TON and NH_3, there was a very sharp decline in TP levels as discharge levels increased in the DNS reach. Overall increases appeared to be lower in the DNS for TON and NH_3, nutrients found in the DNS were consistently higher. This may be due to the WWTP discharge being stable in discharge volume and the nutrient loads that this effluent brings.

Additionally, there appears to be a relationship with seasonality. Higher average TON appears to be associated more closely with spring, most likely due to fertilizing of fields and the increase in runoff of these nutrients due to spring rains. TP tends to be higher on average in autumn months, which may again be due to agricultural practices and runoff following harvesting. NH_3 tended to occur in greater concentrations during the winter sampling periods. All of these increases may be coinciding with increased runoff typical with the respective seasons (Royer et al. 2006). Summer and portions of the fall nutrient levels seem to be more discharge driven with individual discrete occurrences. This coincides with many agricultural watersheds having a lower TMDL during low discharge periods, and higher TMDL during periods of high runoff (Royer et al. 2006).

The increase of available nutrients has the potential to result in a shift of the entire stream ecosystem as mentioned earlier. An impact upon the primary producers of a stream ecosystem has the potential to result in a large shift in macroinvertebrates due to increases of less “nutritious” algae, or larger algae resulting in a gape limitation of some primary consumers. This shift in primary producers and consumers would also have the potential to shift fish communities and perhaps result in increases of species that are more tolerant and a decline in lower tolerance organisms (Miltner and Rankin 1998). A previous study (Thomas 2003) showed that there are indeed differences in the assemblages of primary producers in these stream reaches. The UPS reaches showed reduced evenness, species richness and diversity during the sampling period of 2002-2003. Increased nutrient levels in the DNS section may be the driving factor for increased assemblage differences as the elevated levels would allow support of a larger population. Another potential impact is the discharge being released from the reservoir. With high discharge the UPS sites would be more likely to be scoured, reducing standing population of primary producers while sites further downstream would have a slight buffer in that the WWTP continually discharges creating a normally deeper area to prevent the hard scouring that a sudden increase in water level may cause.

Attempts to decrease nutrient values from a eutrophic state to an oligrotrophic state have shown changes in benthic invertebrates seen primarily as a move from chironimid-amphipod to oligochaete-gastropod community (Chambers et al. 2006). Chambers et al. (2006) also found that while nutrient levels may be decreased there is little noticeable impact upon the benthic algal biomass. Reductions in nutrient availability in the water column would have a greater impact upon planktonic forms. This would be more evident in species that are unable to absorb or uptake nutrients at as high a rate as benthic algae (Chambers et al. 2006, Vadeboncoeur and Lodge 2000). One possible reason for the lack of response by algae following a reduction of nutrients is the that even following stream nutrient reductions there may still be more than enough available to prevent growth limitation. This may be more troublesome in that the algal shifts may have already occurred due to release of nutrients from sediments that have higher than expected concentrations from nutrient sequestering during periods of high eutrophication.

Increases in discharge may result in a driving force that shifts the entire assemblage of a lotic system. Algal and riparian communities would be subject to scouring that occurs within high flow periods. Following a scouring event, the increased nutrients that are available in the water column may shift colonization or regrowth attempts of the local flora and fauna. In situations such as the Sangamon River, which suffers periodic flooding events and increased nutrient levels during, and following these high water events, the impact of scouring/abrasion may result in the ability of quicker growing organisms to establish in place of the original colonies. Biggs et al. (1999) found that scouring events with increased nutrients prior to and following the event increase return rate of algal biomass. The resulting influx of nutrients during a flood event from the Lake Decatur would assist in maintaining current benthic populations even with a strong scouring. Without some form of nutrient removal for the Lake Decatur watershed the potential benefits of periodic flooding to remove less desirable taxa (be they algal, or macroinvertebrate) for more favorable ones is not possible as the system would be locked in a negative feedback loop due to the increased availability of nutrients.

MIBI and IBI scores for the UPS and DNS reaches of the Sangamon River show distinct differences in the assemblages (Table 8, p = .0004. MIBI shows that the downstream stretch is actually considerably higher in quality in regards to macroinvertebrate samples (Table 6, Figure 10). Qualitative habitat assessment might allow for a more in-depth understanding of why these changes occur, along with a longer examination of algal assemblages between the two reaches.

Potential nutrient loading occurring from the WWTP discharge or as a result of Lake Decatur acting as a source of excessive nutrients in the UPS is a more easily examined phenomena albeit a less comprehensive study of the ecosystem. Reaching a full understanding of the aquatic ecosystem would require a more detailed assessment of both the abiotic water chemistry coupled with examinations of the biotic communities. Utilizing current fish and macroinvertebrate data, it is seen that there is a difference between the two reaches. The quality of these two assemblages is not clear currently due in part to a sampling bias of the pull-seine method of collection. Unfortunately, attempts at studying the algae and macroinvertebrates of this river reach have been compromised by a loss of sampling substrata. Algal traps were washed out during high flow events or removed by anthropogenic activities, along with the Hester-Dendy traps. The loss of these sampling devices resulted in a reduced ability to assess the impact of eutrophication on the primary producers and consumers.

Overall, we found that the UPS and DNS sampling sites varied quite widely in regards to their nutrient levels and MIBI scores while IBI scores were similar between the reaches. Nutrient levels were found to be closely associated with the nearby WWTP, in the downstream reach. The increased nutrient levels found downstream supported our hypothesis that we expected to find a significant difference between the two sites. With increasing discharge from the reservoir however, there was not a significant increase in nutrient levels in the UPS reach. There was also a reduction in downstream nutrients during high reservoir discharge. This resulted in us rejecting our second hypothesis that the reservoir was acting to increase nutrient loading during periods of high discharge. It actually appears that high levels of discharge from the reservoir result in a mediation effect upon the WWTP discharge reducing the downstream nutrient levels.

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Appendix A. Average nutrient values separated by year and stream reach. Values are recorded in mg/L.

Year	Reach	TON (mg/L)	NH_3 (mg/L)	PO_4-TP (mg/L)	PO_4-SRP (mg/L)
2002	UPS	6.97	6.18	1.74	0.599
	DNS	36.62	1.13	13.68	13.71
2003	UPS	29.79	20.53	2.44	0.58
	DNS	73.01	13.81	14.89	12.56
2004	UPS	10.65	33.80	2.47	0.82
	DNS	59.33	8.11	8.99	6.96
2005	UPS	23.83	2083.31	1.19	1.18
	DNS	73.83	3295.18	4.64	13.88
2006	UPS	45.22	89.78	1.95	0.64
	DNS	49.49	93.46	14.42	16.33
2007	UPS	3.03	1.17	0.96	0.40
	DNS	28.17	0.42	8.95	10.82
2008	UPS	18.56	0.40	1.49	0.66
	DNS	29.65	0.55	8.96	8.43
2009	UPS	33.18	0.74	1.92	0.77
	DNS	60.28	1.03	13.49	15.25

Appendix B. Discharge events for the Sangamon River from 2002-2009 separated based on discharge classes and frequency of events per number of days that events occurred.

Discharge classes	Cum events	Relative frequency overall	**	2002		2003		2004		2005	
0	265	264	0	0	4	4	0	0	0	0	0
500	4895	4630	192	192	314	310	217	217	207	207	264
1000	5958	1063	250	58	339	25	274	57	278	71	324
1500	6474	516	288	38	353	14	302	28	299	21	333
2000	6801	327	313	25	358	5	333	31	311	12	340
2500	7041	240	323	10	362	4	345	12	322	11	355
3000	7209	168	338	15	365	3	351	6	329	7	359
3500	7328	119	350	12	365	0	354	3	334	5	362
4000	7374	46	352	2	365	0	355	1	337	3	362
4500	7425	51	354	2	365	0	357	2	345	8	362
5000	7463	38	355	1	365	0	360	3	348	3	363
5500	7482	19	355	0	365	0	360	0	354	6	364
6000	7499	17	357	2	365	0	363	3	357	3	364
6500	7514	15	358	1	365	0	366	3	357	0	365
7000	7530	16	358	0	365	0	366	0	358	1	365
7500	7534	4	359	1	365	0	366	0	359	1	365
8000	7544	10	359	0	365	0	366	0	360	1	365
8500	7547	3	359	0	365	0	366	0	361	1	365
9000	7548	1	359	0	365	0	366	0	361	0	365
9500	7549	1	359	0	365	0	366	0	361	0	365
10000	7551	2	359	0	365	0	366	0	361	0	365
10500	7552	1	359	0	365	0	366	0	363	2	365
11000	7552	0	359	0	365	0	366	0	363	0	365
11500	7556	4	359	0	365	0	366	0	363	0	365
12000	7561	5	360	1	365	0	366	0	364	1	365
12500	7563	2	360	0	365	0	366	0	365	1	365
13000	7564	1	360	0	365	0	366	0	365	0	365
13500	7564	0	360	0	365	0	366	0	365	0	365

Discharge classes	Cum events	Relative frequency							
		overall	2006		2007		2008		2009
0	265	264	0	0	0	0	0	0	0
500	4895	4630	264	208	208	167	167	166	166
1000	5958	1063	60	279	71	238	71	254	88
1500	6474	516	9	291	12	280	42	284	30
2000	6801	327	7	311	20	300	20	319	35
2500	7041	240	15	332	21	314	14	330	11
3000	7209	168	4	346	14	322	8	337	7
3500	7328	119	3	351	5	328	6	342	5
4000	7374	46	0	359	8	332	4	344	2
4500	7425	51	0	361	2	337	5	350	6
5000	7463	38	1	363	2	341	4	352	2
5500	7482	19	1	365	2	341	0	352	0
6000	7499	17	0	365	0	344	3	353	1
6500	7514	15	1	365	0	345	1	355	2
7000	7530	16	0	365	0	346	1	355	0
7500	7534	4	0	365	0	348	2	358	3
8000	7544	10	0	365	0	349	1	361	3
8500	7547	3	0	365	0	352	3	362	1
9000	7548	1	0	365	0	355	3	363	1
9500	7549	1	0	365	0	355	0	363	0
10000	7551	2	0	365	0	355	0	363	0
10500	7552	1	0	365	0	355	0	363	0
11000	7552	0	0	365	0	357	2	363	0
11500	7556	4	0	365	0	357	0	363	0
12000	7561	5	0	365	0	358	1	363	0
12500	7563	2	0	365	0	359	1	363	0
13000	7564	1	0	365	0	360	1	363	0
13500	7564	0	0	365	0	363	3	363	0

Discharge classes	Cum events	Relative frequency overall	**	2002		2003		2004		2005	
14000	7564	0	360	0	365	0	366	0	365	0	365
14500	7564	0	360	0	365	0	366	0	365	0	365
15000	7564	0	360	0	365	0	366	0	365	0	365
15500	7564	0	360	0	365	0	366	0	365	0	365
16000	7564	0	360	0	365	0	366	0	365	0	365
16500	7565	1	360	0	365	0	366	0	365	0	365
17000	7565	0	360	0	365	0	366	0	365	0	365
17500	7565	0	360	0	365	0	366	0	365	0	365
18000	7565	0	360	0	365	0	366	0	365	0	365
18500	7565	0	360	0	365	0	366	0	365	0	365
19000	7565	0	360	0	365	0	366	0	365	0	365
19500	7565	0	360	0	365	0	366	0	365	0	365
20000	7566	1	361	1	365	0	366	0	365	0	365
minimum		0		0.1		0		4.5		0.21	
maximum		19600		19600		2880		6360		12100	
average		690		922		235		770		998	
standard dev		1228.65		1593.53		459.33		1098.76		1785.95	

Discharge classes	Cum events	Relative frequency								
14000	7564	0		2006		2007		2008		2009
14500	7564	0		0	365	0	363	0	363	0
15000	7564	0		0	365	0	363	0	363	0
15500	7564	0		0	365	0	363	0	363	0
16000	7564	0		0	365	0	364	1	363	0
16500	7565	1		0	365	0	364	0	363	0
17000	7565	0		0	365	0	364	0	363	0
17500	7565	0		0	365	0	365	1	363	0
18000	7565	0		0	365	0	365	0	363	0
18500	7565	0		0	365	0	365	0	363	0
19000	7565	0		0	365	0	365	0	363	0
19500	7565	0		0	365	0	365	0	363	0
20000	7566	1		0	365	0	366	1	363	0
				0	365	0	366	0	363	0
minimum		0		0.1		0.52		0.51		5.6
maximum		19600		6150		5230		19200		8940
average		690		462		783		1476		1048
standard dev		1228.65		782.09		1061.83		2722.37		1441.32

Appendix C. Sangamon nutrient values, physical parameters, and abiotic variables for the water years of 20008 and 2009.

Date	Location	D.O. (mg/L)	Temp. (°C)	pH	Cond. (µS/cm)	Discharge (cfs)	TON (ppm)	NH3 (ppm)
10/25/07	1	7.1	11.6	7.8	501.0	0.7	0.402	0.002
10/25/07	3	4.6	11.8	7.6	526.0	0.7	0.705	0.115
10/25/07	4	5.8	10.7	7.6	503.0	0.7	0.481	0.372
10/25/07	5	5.7	11.3	7.6	485.0	0.7	0.370	0.275
10/25/07	6	6.0	12.4	7.6	465.0	0.7	0.402	0.347
10/25/07	7	7.1	11.6	7.8	470.0	0.7	0.156	0.550
10/25/07	8	6.3	11.3	7.6	482.0	0.7	0.182	0.382
10/25/07	9	7.3	22.2	8.0	4279.0	0.7	6.304	0.050
10/25/07	11	7.3	21.3	8.0	4234.0	0.7	5.620	0.010
10/25/07	12	8.1	17.1	8.1	3934.0	0.7	5.620	0.010
10/25/07	14	10.0	13.2	8.3	3694.0	0.7	0.800	0.001
11/29/07	1	8.3	4.9	7.4	474.0	1.7	0.290	0.096
11/29/07	3	6.6	4.5	7.6	574.0	1.7	0.540	0.068
11/29/07	4	8.6	2.7	7.6	627.0	1.7	0.417	0.724
11/29/07	5	7.3	3.0	7.8	622.0	1.7	0.455	0.657
11/29/07	6	6.3	3.9	7.5	482.0	1.7	0.325	0.388
11/29/07	7	8.4	4.0	7.3	516.0	1.7	0.375	0.524
11/29/07	8	8.6	3.8	7.4	405.0	1.7	0.347	0.446
11/29/07	9	9.4	18.4	7.9	3987.0	1.7	7.220	0.116
11/29/07	11	8.7	16.8	7.9	3890.0	1.7	6.784	0.110
11/29/07	12	9.0	11.5	8.1	3681.0	1.7	7.212	0.126
11/29/07	14	13.3	6.9	8.2	2968.0	1.7	5.847	0.050
12/13/07	1	12.7	6.0	7.8	677.0	5.5	0.274	0.003
12/13/07	3	9.3	5.8	7.7	649.0	5.5	0.758	0.070
12/13/07	4	10.8	4.0	7.9	774.0	5.5	0.812	0.409
12/13/07	5	10.4	4.0	7.9	767.0	5.5	0.804	0.389
12/13/07	6	9.9	4.2	7.9	735.0	5.5	0.752	0.276

Date	Location	PO4 - TP (ppm)	PO4 - SRP (ppm)	TSS (ppm)	FSS (ppm)	VSS (ppm)
10/25/07	1	0.196	0.004	30.00	15.83	14.17
10/25/07	3	0.148	0.012	12.00	4.00	8.00
10/25/07	4	0.176	0.029	11.74	56.96	68.70
10/25/07	5	0.167	0.022	18.50	77.50	59.00
10/25/07	6	0.169	0.008	10.67	7.11	3.56
10/25/07	7	0.123	0.010	15.50	6.00	9.50
10/25/07	8	0.145	0.013	17.00	7.00	10.00
10/25/07	9	2.118	3.103	10.67	6.33	4.33
10/25/07	11	2.171	2.838	13.60	8.80	4.80
10/25/07	12	2.509	2.894	19.20	7.60	11.60
10/25/07	14	2.108	2.950	19.26	7.04	12.22
11/29/07	1	0.105	0.031	6.87	3.44	3.44
11/29/07	3	0.105	0.031	6.40	2.67	3.73
11/29/07	4	0.117	0.039	3.56	2.19	1.37
11/29/07	5	0.132	0.041	6.20	3.10	3.10
11/29/07	6	0.273	0.105	6.03	3.29	2.74
11/29/07	7	0.261	0.068	26.00	7.60	18.40
11/29/07	8	0.256	0.122	12.33	3.33	9.00
11/29/07	9	1.978	2.559	16.55	7.59	8.97
11/29/07	11	2.283	3.101	21.70	7.23	14.47
11/29/07	12	1.909	3.307	18.92	7.03	11.89
11/29/07	14	1.870	3.682	24.00	4.67	19.33
12/13/07	1	0.111	0.010	19.00	11.50	7.50
12/13/07	3	0.131	0.022	15.00	12.00	3.00
12/13/07	4	0.097	0.013	12.80	8.40	4.40
12/13/07	5	0.099	0.017	12.92	5.85	7.08
12/13/07	6	0.102	0.024	13.67	6.67	7.00

Date	Location	TDS (ppm)	FDS (ppm)	VDS(ppm)	TS (ppm)	TFS (ppm)	TVS (ppm)
10/25/07	1	310.00	120.17	189.83	340.00	136.00	204.00
10/25/07	3	333.33	92.00	241.33	345.33	96.00	249.33
10/25/07	4	316.26	138.29	177.97	328.00	81.33	246.67
10/25/07	5	297.50	-0.17	297.67	316.00	77.33	238.67
10/25/07	6	277.33	52.89	224.44	288.00	60.00	228.00
10/25/07	7	295.17	92.67	202.50	310.67	98.67	212.00
10/25/07	8	287.00	91.67	195.33	304.00	98.67	205.33
10/25/07	9	2648.00	245.67	2402.33	2658.67	252.00	2406.67
10/25/07	11	2654.40	237.87	2416.53	2668.00	246.67	2421.33
10/25/07	12	2467.47	241.73	2225.73	2486.67	249.33	2237.33
10/25/07	14	2354.07	220.96	2133.11	2373.33	228.00	2145.33
11/29/07	1	314.46	120.56	193.90	321.33	124.00	197.33
11/29/07	3	376.27	129.33	246.93	382.67	132.00	250.67
11/29/07	4	379.11	101.81	277.30	382.67	104.00	278.67
11/29/07	5	380.47	96.90	283.57	386.67	100.00	286.67
11/29/07	6	311.31	79.38	231.93	317.33	82.67	234.67
11/29/07	7	266.00	67.07	198.93	292.00	74.67	217.33
11/29/07	8	243.67	54.00	189.67	256.00	57.33	198.67
11/29/07	9	2458.11	232.41	2225.70	2474.67	240.00	2234.67
11/29/07	11	2439.63	238.10	2201.53	2461.33	245.33	2216.00
11/29/07	12	2281.08	219.64	2061.44	2300.00	226.67	2073.33
11/29/07	14	1834.67	183.33	1651.33	1858.67	188.00	1670.67
12/13/07	1	395.67	120.50	275.17	414.67	132.00	282.67
12/13/07	3	429.00	125.33	303.67	444.00	137.33	306.67
12/13/07	4	512.53	142.27	370.27	525.33	150.67	374.67
12/13/07	5	495.08	138.15	356.92	508.00	144.00	364.00
12/13/07	6	174.33	133.33	41.00	188.00	140.00	48.00