Exhibit K

Biotic Assessment of Water Quality in a Reach of the Sangamon River Receiving Effluent From the Sanitary District of Decatur

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Biotic assessment of water quality in a reach of the Sangamon River receiving effluent from the Sanitary District of Decatur

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EXECUTIVE SUMMARY

We utilize sampling locations associated with operation of SDD that were easily identified by prominent landmarks within the City of Decatur, Illinois, USA and have logged GPS coordinates for those sites. Sites were established initially in 1998 during an assessment of potential impacts of discharges from combined sewage overflow (CSO) facilities as well as the main treatment plant. All sites were located in the mainstem of the Sangamon River extending from just downstream of the dam, which impounds Lake Decatur to the Wyckles Road Bridge on the west edge of Decatur. Sites 1, 2, 3, 4, 5, 6, 7, and 8 are within the **UPSTREAM** reach extending from the dam to the discharge of the main treatment plant, and Sites 9, 11, 12 are located in the **DOWNSTREAM** reach which extends from the main treatment plant discharge to the Wyckles Road bridge. Throughout this reports, we will refer to general locations as either **UPSTREAM** or **DOWNSTREAM** of the SDD main treatment plant discharge. Form 2003 through 2005, samples also were collected from the Sangamon River at an additional **DOWNSTREAM** site (#14) located 1km north of the intersection of CR 600E and CR 800N, near the Lincoln Trail Homestead State Park. Site 2 (an open channel entering the Sangamon River from the Lincoln Park CSO) and Site 10 (located in Stevens Creek in Fairview Park) are distinct from other sites largely due to their location outside of the mainstem of the Sangamon River. Because these Sites are more or less isolated from reservoir or sanitary discharges, they have not included since 2002.

Levels of 12 water quality variables were determined form eleven mainstem sites in 2006. Previously, we documents that **UPSTREAM** and **DOWNSTREAM** reaches are distinct on the basis of their physical and chemical characteristics. Discharge from Lake Decatur is the primary input to the **UPSTREAM** reach, resulting in our observation of relatively higher variability in flow and nutrient concentrations. Conversely, stable and predictable instream flows observed in the reach **DOWNSTREAM** of the SDD facilitate development of more diverse biotic communities. Difference in the overall nature of the **UPSTREAM** and **DOWNSTREAM** reaches becomes less distinct during periods of high reservoir discharge. Sites **DOWNSTREAM** of SDD are characterized by lower pH, perhaps resulting from addition of CO_2 due to respiratory breakdown of organic matter in the wastewater treatment process. These sites may also have greater potential for instream primary productivity as a result of nutrient loading as indexed by higher levels of dissolved solids, conductivity, total alkalinity, oxidized nitrogen, and phosphorus. Suspended organic material including phytoplankton algae derived from the reservoir may be supporting heterotrophs in the upstream reach. We have established a new research effort that seeks to confirm **that SDD discharge may be facilitating a shift from a stream system that relies on allochthonous input of algae to one that relies on autochthonous instream primary productivity. Improvement of conditions in the UPSTREAM reach could be realized by maintenance of flow with the range of 200–400 cfs, measured at the Route 48 bridge.**

Collection of diatoms assemblage data was hampered by disappearance of greater than half of the artificial substrates that were deployed, either through vandalism or natural disturbance. Loss of the majority of samplers is a drawback to this aspect of the study and efforts are intended for upcoming sampling efforts to evaluate utilization of natural substrates to avoid past difficulties.

A total of 11 Hester-Dendy Multiplate samplers were placed along the main stem of the Sangamon River associated with the Sanitary District of Decatur for determination of macroinvertebrate communities. For the eleven sampling locations we were only able to collect data from eight sites along the stretch of the Sangamon River associated with the Sanitary District of Decatur. a total of 5828 organisms representing 19 macroinvertebrate taxa were collected. The MBI values ranged from 5.79 to 6.94 with the highest percent of organisms collected representing insects in the order Diptera. MBI scores for the 8 main channel sites assessed in 2006 were consistent with MBI values obtained during 1998 and 2001-2005. MBI scores averaged over all the years for **UPSTREAM** and **DOWNSTREAM** sites were 7.1 and 5.9 respectively. Both of these overall scores warrant a "good/fair rating." However. two-factor ANOVA revealed the difference in MBI values to be significant ($p<0.05$) between upstream and downstream sites. indicated that stream habitat quality is better at the **DOWNSTREAM** sites.

When comparing our observations with data collected in 1988 (IEPA report). and 1992 (IEPA report). MBI values for the Sangamon River associated with the Sanitary District of Decatur were significantly lower than values obtained during the 1988 survey but were generally similar to values obtained in the 1992 report. In addition. when comparing present MBI scores with scores determined during a 1998 stream assessment conducted by Eastern Illinois University. **a continuation of the trend of improved biotic integrity (as MBI) in the Sangamon River is noted, especially below the main outfall of the SDD.**

Stream quality in the Sangamon River basin was evaluated by fish population samples and the Index of Biotic Integrity. A total of 2317 fish of 26 species were collected as 11 sites during 2006. As in the previous sample periods the fish community in 2006 again was dominated by the family Cyprinidae (minnows and carp). Significant differences were not observed (>0.05) in community-based measures of diversity between **UPSTREAM** and **DOWNSTREAM** reaches. Stream quality in the Sangamon River basin as evaluated by fish population samples and the Index of Biotic Integrity ranged between 26 (site 6) to 44 (Site 12). indicated overall stream quality of poor to good. Overall mean IBIs for data polled form 1998. 2001-2006 were 31 and 34 for the **UPSTREAM** and **DOWNSTREAM** reaches. respectively. Differences were observed in community based measures of diversity between **UPSTREAM** and **DOWNSTREAM** reaches suggesting that overall habitat quality based on the fish community is improved in the **DOWNSTREAM** reach. **DOWNSTREAM** sites associated with the main treatment plant outfall from the Sanitary District of Decatur may have increased IBI rating due to the predictable instream flows and increased autochthonous primary production due in part to nutrient loading. In addition. all mainstream sites have maintained similar quality rating as those received in the previous basin surveys conducted in 1966 and 1983. **Based on fish community metrics, there has been no reduction in the quality of the Sangamon River section located near the Sanitary District of Decatur in the last 20 years.**

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Overall. biotic community structure and habitat characterization suggest that the Sangamon River from Lake Decatur to the Wyckle's Raod overpass in Decatur. IL is a homogeneous system. Established biocriteria including fish and macroinvertebrate indices suggest that discharge from the SDD main treatment plant actually enhances quality of this stream resource. Although fauna may be responding positively to elevated primary production derived from nutrient inputs to the stream, biotic communities of the Sangamon River most likely benefit from the more constant instream flows resulting from discharge of treated effluent. Data on benthic diatom community structure confirms that this group of organisms likely is the most sensitive to variable stream habitat quality. In future years, emphasis will be placed on evaluating the presumed positive impact of the SDD on stream communities relative to what we believe might be the detrimental effect of extremely variable flows upstream of the plant resulting from the unpredictable releases of water from Lake Decatur. In addition, we specifically intend to revisit utilization of water hardness as a variable for establishing water quality especially as it relates to concentrations of cations such as nickel and zinc. In 2007 and beyond, we will be making additional biotic collections in effort to determine the bioconcentrations of these elements in benthic algae, macroinvertebrates and fish. We have little doubt that enhancement of the flow regime in the Sangamon River due to the SDD more than compensates for any impact, real or perceived, that may arise from loading of nutrients or solids into the stream.

Introduction

Impoundment of rivers to create reservoirs used for irrigation purposes, as urban water supplies, and recreation, is commonplace. However, impoundments may impact downstream aquatic systems and their surrounding terrestrial habitats. Diminished water quality and availability, closures of fisheries, extirpation of species, groundwater depletion, and more frequent and intense flooding are increasingly distinguished as consequences of current river management associated with impoundments (Abramovitz 1996, Collier *et al* 1996, Naiman *et al* 1995). Specifically, dams can affect riverine systems by altering flow regime, changing nutrient and sediment loads, and modifying energy flow (Ligon *et al* 1995). As a result, river reaches downstream from a dam may no longer able to support native species, which will be reflected by reduced integrity of biotic communities. (Naiman *et al* 1995, NRC 1992).

A natural flow regime is critical for sustaining ecosystem integrity and native biodiversity in rivers (Poff, *et al.* 1997). Dams can have varying effects on downstream aquatic habitats depending on the purpose for which the dam was built. Impoundments used for urban water supplies reduce flow rates below the dam throughout the entire year (Finlayson et al. 1994) as well as increased daily and seasonal variability in flow regime (Finlayson et al. 1994, McMahon & Finlayson 2003). In addition, abiotic variables including temperature, dissolved oxygen, turbidity, pH, conductivity and solids concentrations are altered in the downstream river system (e.g., (Finlayson et al. 1994).

Along with stream impoundments, point source and non-point source pollution can have profound effects on the ecological integrity of river systems. Non-point sources of pollution may include agriculture, livestock grazing, and urbanization while sanitary discharge and industrial waste are examples of point source pollution. To reduce point source pollution, the Water Quality Act of 1972 encouraged wastewater treatment plants to upgrade their systems and, as a result, many communities were forced to build advanced tertiary water treatment facilities (Karr et al 1985). Yet these treatment facilities still export high concentrations of nutrients into rivers. Carpenter and Waite (2000) documented that concentrations of phosphorus were highest in streams draining agricultural basins and at sites influenced by wastewater discharges, while Twichell et al (2002) reported that sewage effluent inputs had elevated nitrate levels. These enhanced nutrient inputs can be expected to increase productivity within a river because primary productivity and detrital processing usually are limited by low ambient stream nutrient concentrations (Stockner and Shortreed 1978, Elwood et al 1981, Winterbourn 1990).

Physical habitat (e.g., flow regime, bottom substrate composition, instream cover, etc.) and chemical water quality must be suitable for support of individual species in lotic systems and maintenance of the integrity of aquatic communities. The Sangamon River offers an opportunity to study these relationships in a stream influenced by impoundment as well as point source discharges. The Sangamon River Basin is a 14,000 km^2 watershed covering all or portions of eighteen counties in central Illinois. More than 3540 km of streams within the basin course through glacial and alluvial deposits creating typically low gradient stream with sand and gravel substrates. Streams within the basin have been impacted for most of the past century, receiving inputs from both point and non-point sources. Current land use is 80% agricultural of which 85% is corn or soybeans. The great expanses of prairie that once existed in Illinois have been reduced to isolated hill and sand prairies coupled with remnants along highway and railroad right-of-ways and native deciduous woodlands now are limited to stream riparian areas. Major metropolitan areas associated with the Sangamon River are Bloomington, Decatur, and Springfield representing a combined population of more than 500,000 residents. Impoundments associated with urbanization include Lake Taylorville, Lake Sangchris, and Lake Springfield on the South Fork of the Sangamon; Clinton Lake on Salt Creek; as well as Lake Decatur.

With such influential factors at play, the status of the biotic integrity of the Sangamon River system is constantly in flux. In 1998-99 and continuing from 2001-2006, an intensive sampling program was initiated to document temporal and spatial heterogeneity of an 8.5 km urban reach of the Sangamon River beginning just below the Lake Decatur Dam and extending downstream to incorporate discharges from the Sanitary District of Decatur (SDD). This study has been intended to characterize stream habitat quality and to assess impacts resulting from ongoing municipal and reservoir management by evaluating biotic integrity at various trophic levels in the context of the physical and chemical nature of the Sangamon River.

Project History

We utilize sampling locations associated with operation of SDD that were easily identified by prominent landmarks within the City of Decatur, Illinois, USA and have logged GPS coordinates for those sites (Table 1). Sites were established initially in 1998 during an assessment of potential impacts of discharges from combined sewage overflow (CSO) facilities as well as the main treatment plant. All sites were located in the mainstem of the Sangamon River extending from just downstream of the dam, which impounds Lake Decatur to the Wyckles Road Bridge on the west edge of Decatur. Sites 1, 3, 4, 5, 6, 7, and 8 are within the **UPSTREAM** reach extending from the dam to the discharge of the main treatment plant, and Sites 9, 11 and 12 are located in the **DOWNSTREAM** reach which extends from the main treatment plant discharge to the Wyckles Road Bridge. Throughout this report, we will refer to general locations as either **UPSTREAM** or **DOWNSTREAM** of the SDD main treatment plant discharge. During 2003, samples also were collected from the Sangamon River at an additional DOWNSTREAM site (#14) located 1km north of the intersection of CR 600E and CR 800N, near the Lincoln Trail Homestead State Park. Site 2 (an open channel entering the Sangamon River from the Lincoln Park CSO) and Site 10 (located in Stevens Creek in Fairview Park) are distinct from other sites largely due to their location outside of the mainstem of the Sangamon River. Because these Sites are more or less isolated from reservoir or sanitary discharges, they are not included in sample protocol after 2003.

The Stream Habitat Assessment Procedure (SHAP), which evaluates lotic habitat quality using features considered important to biotic integrity, was performed by us during the month of July in 1998, 2001, and 2002 through 2006. At each stream site, two individuals independently assigned metrics related to substrate and instream cover, channel morphology and hydrology, and riparian and bank features to one of four habitat quality types using guidelines established by the Illinois Environmental Protection Agency (1994). The mean total score of the 15 metrics forms the basis of an overall habitat quality rating for the stream reach under consideration. Habitat quality of the **UPSTREAM** and **DOWNSTREAM** reaches were categorized on the basis of its SHAP score as follows: <59 = Very Poor; 59 - 100 = Fair; 100 - 142 = Good; > 142 = Excellent.

Average SHAP scores for **UPSTREAM** and **DOWNSTREAM** sites were 82 and 93, respectively. Nonetheless, physical habitat structure based on SHAP still results in classification of all mainstem sites as "fair" quality stream reaches indicating that the physical structure of the stream is homogeneous.

This overall physical structure provides a backdrop for the ability of the study reach to support a diverse flora and fauna. Routine assessment of characteristic water quality variables superimposed on substrate characteristics, channel morphology and bank features can aid in understanding the functioning of stream systems. Given that organisms exist within often-narrow ranges of tolerance for certain physical and chemical characteristics of their environment, analysis of these variables is imperative for understanding the potential for anthropogenic impacts to decrease biotic integrity of natural systems. As a result, we incorporated routine analyses of various physical and chemical features of the Sangamon River sites studied during 2002, which based on principal components analysis, revealed significant differences between the UPSTREAM and DOWNSTREAM reaches. Monitoring of relevant variables continues through 2007.

Qualitative judgements (good vs. bad) based on established biocriteria using data from 1998, 2000 -2006 were inconsistent. The Macroinvertebrate Biotic Index classified both reaches as GOOD/FAIR, although conditions are improved significantly DOWNSTREAM of the discharge from the SDD main treatment. And the Fish Index of Biotic Integrity calculated from 1998, 2001 through 2006 classified both reaches as FAIR, but was able to detect a significant difference between stream reaches with improved habitat DOWNSTREAM of the discharge from the SDD main treatment. **Also, since 2002 we have continued to refine our sampling protocol for development of benthic algae for monitoring stream habitat quality. Indices of diatom community structure did not differ between UPSTREAM and DOWNSTREAM reaches based on analysis of spring and fall sample periods. However, qualitative comparisons of shifts in community dominance were possible and clearly indicated promise for utility of these organisms for biomonitoring stream conditions.**

Methods

Field data collection and water chemistry determination

Water quality data were collected every two to four weeks from February to November, 2006. Sampling was initiated at the Lake Decatur dam and preceded downstream. While in the field, additional abiotic variables (dissolved oxygen, pH, conductivity, and temperature were determined) using Eureka Amphibian and Manta multiprove. Surface water samples were collected at 0.3 m below the surface and returned to the laboratory on ice and analyzed within generally accepted time limits. All sampling and analyses were conducted according to Standard Methods for Examination of Water and Wastewater (APHA, 1995).

In the laboratory, suspended and total solids determinations were made by drying residue collected on standard glass fiber filters as well as unfiltered samples placed into tared porcelain crucibles at 103-105 °C. Total dissolved solids were calculated by difference. Total phosphorus (following persulfate digestion) and soluble reactive phosphorus (utilizing filtered, undigested, sample aliquots) were determined using the ascorbic acid method. The phenate method was used for determination of ammonia nitrogen, and total oxidized nitrogen (NO_2-N + NO_3-N) was determined via the cadmium reduction method. Colorimetry of all nutrient analyses was determined using a Beckman DU 530 Life Science UV/Vis Spectrophotometer. Alkalinity was measured by titration to colorimetric endpoint methods. For all chemical analyses, due consideration was given to quality control and quality assurance procedures, including but not limited to parallel analyses of laboratory standards.

Macroinvertebrates

Macroinvertebrate samples were collected from 8 of the 11 sites using modified multiplate samplers (Hester and Dendy 1962). Substrates were placed on the stream bottom for periods of six weeks, beginning July 10, 2006 to allow colonization. Samplers were collected with aid of a dip-net, in order to avoid loss of invertebrates, and placed in wide-mouth plastic containers. All organisms were preserved in the field with 95% ethanol containing rose bengal. After sorting, macroinvertebrates were identified to the lowest possible taxonomic level and data were used to calculate a Macroinvertebrate Biotic Index (MBI) according to Hilsenhoff (1982). In this method, each taxon is assigned a pollution tolerance value ranging from zero to eleven based on available literature and previous field experience. Based on present assessment methods, MBI values reflect water quality as follows (IEPA 1988): < 5.0 - Excellent: 5.0 - 6.0 - Very good: 6.1 - 7.5 - Good/Fair: 7.6 - 10.0 - Poor: > 10.0 - Very Poor. Macroinvertibrate Biotic Index scores for 2006 were compared to those data, which were pooled from 1998, 2001 through 2005.

Fish

Fish were sampled on 12-13 of July 2006 by hand seining, with attempts to standardize sampling effort at each site. Fish were identified to species, counted and returned to the stream alive when possible, although voucher specimens were preserved and retained. When field identifications were not practical, specimens were preserved in ten percent formalin and returned to the laboratory. Species richness and evenness (Pielou, 1977) were used as fundamental measures of diversity. Fish community data also were used to determine the community-based Index of Biotic Integrity (IBI), which uses twelve metrics in three categories to appraise fish communities (Karr et al., 1986). Values of 1, 3, and 5 are assigned for each metric, and the values for the individual metrics are then summed to generate a score from 12 to 60. Calculation of IBI values was aided by an interactive program written in Basic for use on an IBM-PC (Bickers et al., 1988). The utility of IBI scores is that they enable qualitative characterization of streams, as follows: 51-60 – excellent: comparable to best situations without human disturbance, 41-50.9 – good: good fishery for gamefish: species richness may be below expectations, 31-40.9 – fair: bullheads, sunfish, and carp predominate: diversity and intolerants reduced, 21-30.9 – poor: fish dominated by omnivores and tolerant forms: diversity notably reduced, <21 – very poor: few fish of any species present, no sport fishery exists. Fish IBI scores for 2006 were compared to those data, which were pooled from 1998, 2001 and 2002 through 2005.

Benthic algal (diatom) samples

Artificial substrates were continuously exposed at 11 sites in the main channel of the Sangamon River from 10 July - 31 July during 2007. Substrates were 1 x 3 inch clean glass microscope slides suspended at the surface of the stream in commercially available periphytometers (Wildco, Inc.). Unfortunately, all but 2 substrates were lost due either to natural occurrence (i.e., high discharge events) or due to vandalism. As such. further analysis of diatom assemblages were not pursued as results would have been uninformative or inconclusive.

Results

Water chemistry

Levels of 12 separate water quality variables were determined for eleven mainstem sites in 2006 (Table 3). The trend established in prior sampling years continued throughout this recent sampling period. with levels for each of the variables being generally higher in DOWNSTREAM locations. Most notably. higher concentrations of forms of phosphorus and nitrogen were observed along with a general trend of elevated conductivity. presumably resulting from discharge from the main treatment plant of the Sanitary District of Decatur. Water chemistry continued to be relatively homogeneous over the entire study reach during periods of high discharge from the dam which impounds Lake Decatur.

Macroinvertebrates

A total of 11 Hester-Dendy Multiplate samplers were placed along the main stem of the Sangamon River associated with the Sanitary District of Decatur for determination of macroinvertebrate communities. For the eleven sampling locations we were only able to collected data for eight sites along the stretch of the Sangamon River associated with the Sanitary District of Decatur. a total of 5828 organisms representing 19 macroinvertebrate taxa were collected (Table1). The MBI values ranged from 5.77 to 6.94 for the eight sites with the highest percent of organisms collected representing insects in the order Diptera.

MBI scores for the 8 main channel sites assessed in 2006 were consistent with MBI values obtained during 1998 and 2001 - 2005. MBI scores averaged over the seven year for **UPSTREAM** and **DOWNSTREAM** sites were 7.1 and 5.9. respectively (Table 2). Both of these overall scores warrant a "good/fair rating." However. two-factor ANOVA revealed the difference in MBI values to be significant ($p<0.05$) between upstream and downstream sites. indicating that stream habitat quality is better at the **DOWNSTREAM** sites.

Fish

A total of 2317 fish of 26 species from 10 families were collected at 11 sites during July 2006 (Table 3). As in the previous sample periods the fish community in 2006 again was dominated by the family Cyprinidae (minnows and carp). Significant differences were not observed ($p>0.05$) in community-based measures of diversity between **UPSTREAM** and **DOWNSTREAM** reaches. Stream quality in the Sangamon River basin as evaluated by fish population samples and the Index of Biotic Integrity ranged from 28 (Sites 6) to 44 (Site 12). indicating overall stream quality of poor to good. Overall mean IBIs for data pooled from 1998. 2001-2006 were 31 and 34 for the **UPSTREAM** and **DOWNSTREAM** reaches. respectively. Two-factor ANOVA confirmed this difference to be significant ($p<0.05$). suggesting that overall habitat quality. based on the fish community. is improved in the **DOWNSTREAM** reach.

Diatom community structure

Because only two of the 11 samplers placed in the stream were recovered. further analysis of the diatom assemblage was not attempted.

Discussion

Overall, the Sangamon River extending from the dam, which impounds Lake Decatur to the Wyckles Road Bridge, can be considered a fair quality aquatic system with minimal habitat variety. Although there is significant variation in physical habitats UPSTREAM and DOWNSTREAM of the SDD, variability in SHAP ratings were primarily dependent upon such factors as substrate stability, pool variability and quality due to stream flow, and loss or reduction of riparian zone vegetation that had occurred at each specific site. The primary difference between **UPSTREAM** and **DOWNSTREAM** reaches is attributable indirectly to metrics related to flow. The **DOWNSTREAM** reach receives continuous flow from SDD, whereas **UPSTREAM** flow varies greatly due to unpredictable reservoir discharges. Such alterations have lead to simplification of stream habitat with concomitant reduction in species diversity and biotic integrity and an overall decline in quality of the aquatic resource.

Based on physical habitat structure as measured by SHAP, the reaches of the Sangamon River, which we studied, are indistinguishable. However, PCA confirms that **UPSTREAM** and **DOWNSTREAM** reaches are distinct on the basis of their physical and chemical characteristics. Discharge from Lake Decatur is the primary input to the **UPSTREAM** reach, resulting in our observation of relatively higher variability in flow and nutrient concentrations. Conversely, stable and predictable instream flows observed in the reach **DOWNSTREAM** of the SDD facilitate development of more diverse biotic communities as confirmed by work conducted in other riverine systems (Sanders 1969; Fisher 1983; Peckarsky 1983; Ward & Stanford 1983; Reice 1985; Ross *et al.* 1985; Walde 1986; Resh *et al.* 1988). Difference in the overall nature of the **UPSTREAM** and **DOWNSTREAM** reaches becomes less distinct during periods of high reservoir discharge.

We also believe that drastic reduction of instream flow resulting by routine elimination of reservoir discharge is detrimental to habitat quality in the **UPSTREAM** reach. Overall, results suggest that a threshold exists with respect to flow, i.e. periods when discharge is less than 400 cfs. When flow is below this threshold, the **UPSTREAM** and **DOWNSTREAM** reaches are discrete while they appear to behave as a continuum when discharge exceeds 400 cfs. This suggests that water quality is compromised in the reach of the Sangamon River extending downstream from the dam to the discharge of the main treatment plant of the Sanitary District of Decatur as a result of management to maintain reservoir levels by eliminating outflow. In contrast, effective management of Sangamon River may require maintenance of instream flow above the proposed threshold (400 cfs) by continuous discharge from Lake Decatur.

Sites **DOWNSTREAM** of SDD are characterized by lower pH, perhaps resulting from addition of CO_2 due to respiratory breakdown of organic matter in the wastewater treatment process. These sites may also have greater potential for instream primary productivity as a result of nutrient loading as indexed by higher levels of dissolved solids, conductivity, total alkalinity, oxidized nitrogen, and phosphorus. Elevated concentrations of suspended solids and chlorophyll *a* that occur in the **UPSTREAM** sites indicate that suspended organic material including phytoplankton algae derived from the reservoir may be supporting heterotrophs in the upstream reach. In contrast, **DOWNSTREAM** sites are maintained by autochthonous primary productivity that is supported by relatively higher concentrations of plant nutrients derived from the sanitary discharge. We conclude that SDD discharge may be facilitating a shift from a stream system that relies on allochthonous input of algae to one that relies on autochthonous instream primary productivity.

Qualitative evaluation of the two stream reaches requires assessment of stream biota to determine whether or not differences in the two stream reaches are reflected by higher trophic levels. Such an evaluation of overall stream habitat quality can be made via biotic indices involving macroinvertebrates and fish. taxa that have become widely used for biotic assessments. **DOWNSTREAM** sites were characterized during 1998. 2001-2006 by significantly lower MBI scores and higher IBI values. indicative of improved habitat quality capable of supporting diverse biota and a variety of different trophic levels. **DOWNSTREAM** sites associated with the main treatment plant outfall from the SDD may have increased integrity due to predictable instream flows and increased autochthonous primary production due in part to nutrient loading.

When comparing our observations made during the 2006 sampling period with data collected in 1992 (IEPA report). 1998 (Sanitary District of Decatur) and 2001-2005 (Sanitary District of Decatur) both IBI and MBI values for **DOWNSTREAM** sites associated with the main treatment plant outfall were generally similar or slightly improved compared to values obtained during all previous sampling periods. Thus the upgrades performed to the main plant in 1990 and the Lincoln CSO in 1992 by the sanitation district have lead direct to improvement of the water quality of the Sangamon River which has been maintained over the past seven years. Additionally. there has been no reduction in the quality of the Sangamon River section located near the Sanitary District of Decatur in the last 20 years.

Utility of benthic diatoms for biological monitoring was confirmed by our extensive analysis of communities which developed on artificial substrates during 2002 and 2003. However. collection of samples using artificial substrates may need to be reconsidered. Excessive loss of samplers due to extreme discharge events or vandalism compromises the utility of this methodology. Attempts will be made in the future to utilize collections from naturally occurring substrates.

Table 1. List of the 13 sites utilized by the Department of Biological Sciences for studies conducted on reaches of the Sangamon River associated with the Sanitary District of Decatur.

Site #1 - Lincoln Park - above outfall
Site #2 - Lincoln Park - outfall canal
Site #3 - Lincoln Park - below outfall
Site #4 - Oakland (Lincoln Park Drive) - above outfall
Site #5 - Oakland (Lincoln Park Drive) - below outfall
Site #6 - 7th Ward - upstream of outfall
Site #7 - 7th Ward - downstream of outfall
Site #8 - SDD Main Treatment Plant - upstream of main outfall
Site #9 - SDD Main treatment Plant - downstream of main outfall
Site #10 - Stevens Creek in Fairview Park
Site #11 - Sangamon River - downstream of Stevens Creek
Site #12 - Sangamon River at Wyckles Road
Site # 14 - near the Lincoln Trail Homestead State Park. 1km north of the intersection of CR 600E and CR 800N

Table 2. Measured water quality variables for 11 mainstem sites in the Sangamon River associated with the SDD.

Date	Location	D.O.	Temp.	pH	Cond.	total Alkalinity	TON	NH3	PO4 - TP	PO4 - SRP	TSS	TS	TDS
2/2/06	1	15.3	2.5	5.2	1256	276	0.44		0.06	DL	6.0	389.3	383.3
2/23/06	1	19.9	2.7	5.0	313	249	5.60		DL	DL	8.8	400.0	391.2
4/20/06	1	29.8	18.4	10.4	602	249	0.56		0.17	0.04	10.0	422.7	412.7
5/9/06	1	9.9	18.5	8.3	544	197	7.97		0.18	0.07	30.0	370.7	340.7
6/6/06	1	7.5	23.8	8.0	521	131	6.44	0.27	0.22	0.01	31.0	360.0	329.0
6/29/06	1	6.3	24.7	8.3	507	249	0.39	0.22	0.21	0.02	13.0	302.7	289.7
8/9/06	1	7.9	26.7	7.3	341	158	0.96	0.48	0.35	0.23	25.0	225.3	200.3
9/15/06	1	9.4	22.6	8.4	531	276	7.80	0.35	0.42	0.22	11.0	144.0	133.0
10/13/06	1	12.6	11.6	8.5	606	236	0.08	0.06	0.12	0.04	17.0	376.0	359.0
11/16/06	1	7.1	7.8	9.0	711	249	3.67	0.14	0.11	DL	22.0	372.0	350.0
2006 Average	**1**	**12.6**	**19.3**	**7.8**	**593**	**227**	**3.39**	**12.92**	**0.18**	**0.05**	**17.4**	**336.3**	**318.9**
2/2/06	3	14.0	2.4	4.5	1276	263	0.47		0.05	DL	6.8	384.0	377.2
2/23/06	3	15.6	2.5	4.5	364	236	5.84		DL	DL	8.8	401.3	392.5
4/20/06	3	29.6	18.4	10.4	602	164	0.55		0.16	0.03	12.0	445.3	433.3
5/9/06	3	10.2	18.5	8.3	544	197	8.55		0.19	DL	31.0	366.7	335.7
6/6/06	3	6.8	23.8	8.0	520	197	7.00	0.21	0.26	0.02	30.0	357.3	327.3
6/29/06	3	6.7	24.4	8.3	518	223	0.42	0.12	0.21	0.02	18.0	314.7	296.7
8/9/06	3	7.9	26.7	7.8	345	184	1.36	0.44	0.36	0.28	27.0	217.3	190.3
9/15/06	3	9.0	22.3	8.5	542	263	8.34	0.38	0.40	0.25	7.0	160.0	153.0
10/13/06	3	13.1	10.9	8.4	613	289	0.21	0.07	0.17	0.06	20.0	378.7	358.7
11/16/06	3	7.2	7.8	9.0	709	315	3.97	0.16	0.11	DL	23.0	374.7	351.7
2006 Average	**3**	**12.0**	**19.1**	**7.8**	**603**	**233**	**3.67**	**15.37**	**0.19**	**0.05**	**18.4**	**340.0**	**321.6**

Table 2. (cont.)

Date	Location	D.O.	Temp.	pH	Cond.	total Alkalinity	TON	NH3	PO4 - TP	PO4 - SRP	TSS	TS	TDS
2/2/06	4	15.7	3.1	3.2	1155	263	0.48		0.05	DL	4.0	381.3	377.3
2/23/06	4	13.7	2.4	4.1	362	164	6.11		DL	DL	9.6	397.3	387.7
4/20/06	4	28.1	18.4	10.4	603	236	0.52		0.17	0.04	19.0	434.7	415.7
5/9/06	4	9.5	18.4	8.2	552	210	8.49		0.17	DL	32.0	392.0	360.0
6/6/06	4	7.5	23.5	8.1	528	223	7.30	0.32	0.24	0.00	34.0	366.7	332.7
6/29/06	4	7.0	24.4	8.3	516	210	0.41	0.13	0.22	0.03	21.0	329.3	308.3
8/9/06	4	8.0	26.3	7.7	353	158	1.33	0.23	0.36	0.26	34.0	230.7	196.7
9/15/06	4	9.2	21.9	8.5	545	263	8.37	0.43	0.36	0.23	13.0	162.7	149.7
10/13/06	4	11.8	9.8	7.7	566	263	0.59	0.10	0.25	0.09	18.0	372.0	354.0
11/16/06	4	7.2	7.8	9.1	710	315	4.03	0.21	0.11	DL	22.0	354.7	332.7
2006 Average	**4**	**11.8**	**18.8**	**7.5**	**589**	**230**	**3.76**	**10.07**	**0.19**	**0.05**	**20.7**	**342.1**	**321.5**
2/2/06	5	10.1	2.4	3.4	1206	276	0.47		0.05	DL	6.0	397.3	391.3
2/23/06	5	18.3	2.4	4.2	362	197	5.87		DL	DL	11.2	393.3	382.1
4/20/06	5	28.9	18.4	10.4	603	210	0.54		0.16	0.04	9.0	422.7	413.7
5/9/06	5	9.6	18.5	8.3	547	210	8.49		0.17	DL	39.0	390.7	351.7
6/6/06	5	7.8	23.7	8.0	522	210	6.94	0.26	0.25	DL	30.0	362.7	332.7
6/29/06	5	6.9	24.4	8.3	515	210	0.41	0.16	0.20	0.02	20.0	309.3	289.3
8/9/06	5	7.9	26.1	7.6	346	158	1.30	0.43	0.35	0.26	36.0	242.7	206.7
9/15/06	5	8.9	21.9	8.4	545	263	8.29	0.42	0.39	0.24	15.0	180.0	165.0
10/13/06	5	8.5	9.5	7.8	565	236	0.61	0.10	0.25	0.10	16.0	356.0	340.0
11/16/06	5	7.1	7.8	9.1	710	289	3.79	0.21	0.12	DL	25.0	376.0	351.0
2006 Average	**5**	**11.4**	**18.8**	**7.5**	**592**	**226**	**3.67**	**9.63**	**0.19**	**0.05**	**20.7**	**343.1**	**322.3**

Table 2. (cont.)

Date	Location	D.O.	Temp.	pH	Cond.	total Alkalinity	TON	NH3	PO4 - TP	PO4 - SRP	TSS	TS	TDS
2/2/06	6	12.5	3.4	3.7	1063	328	0.47		0.06	DL	6.4	384.0	377.6
2/23/06	6	14.8	2.2	4.0	362	276	5.81		DL	DL	10.4	410.7	400.3
4/20/06	6	27.5	18.4	10.4	603	249	0.53		0.17	0.03	9.0	422.7	413.7
5/9/06	6	9.1	18.4	8.2	545	197	8.37		0.19	DL	39.0	390.7	351.7
6/6/06	6	7.1	23.5	8.0	523	223	6.85	0.28	0.28	0.00	39.0	377.3	338.3
6/29/06	6	6.5	24.4	8.2	524	249	0.42	0.33	0.24	0.01	18.0	346.7	328.7
8/9/06	6	6.6	26.2	7.6	366	158	1.30	0.50	0.38	0.28	30.0	240.0	210.0
9/15/06	6	9.3	21.8	8.3	553	289	7.91	0.35	0.38	0.20	5.0	181.3	176.3
10/13/06	6	12.1	10.5	8.3	728	276	0.30	0.06	0.09	0.00	20.0	458.7	438.7
11/16/06	6	6.8	7.9	9.0	686	289	3.52	0.12	0.10	DL	22.0	364.0	342.0
2006 Average	**6**	**11.2**	**18.9**	**7.6**	**595**	**253**	**3.55**	**6.84**	**0.19**	**0.03**	**19.9**	**357.6**	**337.7**
2/2/06	7	9.4	3.3	3.3	1063	263	0.47		0.05	DL	4.8	393.3	388.5
2/23/06	7	13.1	2.2	4.1	362	249	5.81		DL	DL	12.8	393.3	380.5
4/20/06	7	28.1	18.4	10.4	603	243	0.54		0.16	0.03	14.0	441.3	427.3
5/9/06	7	9.0	18.4	8.3	547	190	8.70		0.21	DL	39.0	381.3	342.3
6/6/06	7	7.5	23.6	7.9	523	210	6.82	0.29	0.27	0.00	42.0	380.0	338.0
6/29/06	7	6.5	24.5	8.2	525	223	0.41	0.15	0.28	0.00	22.0	346.7	324.7
8/9/06	7	6.5	24.5	8.2	525	171	1.21	0.46	0.40	0.27	70.0	306.7	236.7
9/15/06	7	8.7	21.8	8.2	552	144	7.88	0.33	0.38	0.20	14.0	197.3	183.3
10/13/06	7	14.1	9.7	8.2	736	289	0.23	0.08	0.17	0.00	66.0	522.7	456.7
11/16/06	7	6.8	7.9	9.0	686	263	3.19	0.11	0.11	DL	20.0	360.0	340.0
2006 Average	**7**	**11.0**	**18.6**	**7.6**	**612**	**224**	**3.53**	**7.72**	**0.20**	**0.03**	**30.5**	**372.3**	**341.8**

Table 2. (cont.)

Date	Location	D.O.	Temp.	pH	Cond.	total Alkalinity	TON	NH3	PO4 - TP	PO4 - SRP	TSS	TS	TDS
2/2/06	8	8.5	3.4	3.4	1021	263	0.53		0.06	DL	5.6	386.7	381.1
2/23/06	8	14.0	2.1	3.8	362	158	5.72		0.00	DL	12.0	398.7	386.7
4/20/06	8	27.4	18.4	10.4	603	223	0.53		0.16	0.03	8.0	422.7	414.7
5/9/06	8	8.9	18.4	8.2	547	197	8.46		0.16	DL	43.0	406.7	363.7
6/6/06	8	7.2	23.5	8.0	522	210	6.91	0.29	0.26	0.00	47.0	392.0	345.0
6/29/06	8	6.6	24.6	8.3	531	223	0.40	0.14	0.23	0.00	16.0	332.0	316.0
8/9/06	8	7.7	26.1	7.6	375	197	1.36	0.33	0.34	0.24	11.0	232.0	221.0
9/15/06	8	9.3	21.5	8.2	559	289	7.91	0.31	0.37	0.20	13.0	205.3	192.3
10/13/06	8	10.1	10.4	8.0	694	289	0.21	0.06	0.14	0.03	31.0	433.3	402.3
11/16/06	8	7.0	7.8	9.1	696	289	3.52	0.11	0.11	DL	23.0	376.0	353.0
2006 Average	**8**	**10.7**	**18.9**	**7.5**	**591**	**234**	**3.56**	**7.28**	**0.18**	**0.03**	**21.0**	**358.5**	**337.6**
2/2/06	9	8.3	4.2	3.6	1288	236	0.51		0.67	0.53	6.8	508.0	501.2
2/23/06	9	12.8	4.3	4.1	485	354	6.17		0.81	0.81	11.6	518.7	507.1
4/20/06	9	27.3	18.4	10.4	632	236	0.53		0.22	0.17	13.0	440.0	427.0
5/9/06	9	8.7	18.7	8.2	741	210	8.49		0.85	0.62	41.0	489.3	448.3
6/6/06	9	7.2	23.6	7.9	817	249	6.56	0.27	1.23	1.02	44.0	532.0	488.0
6/29/06	9	6.8	25.5	8.1	1815	236	0.43	0.17	2.53	3.08	14.0	1122.7	1108.7
8/9/06	9	8.0	26.8	7.8	1455	249	3.90	0.29	2.04	3.02	35.0	780.0	745.0
9/15/06	9	9.2	24.0	8.2	2526	407	5.92	0.18	3.62	4.43	8.0	1133.3	1125.3
10/13/06	9	11.0	21.2	8.1	3981	420	0.78	0.13	2.27	2.51	15.0	2064.0	2049.0
11/16/06	9	6.1	9.0	8.9	1005	302	3.76	0.01	1.23	1.12	18.0	496.0	478.0
2006 Average	**9**	**10.5**	**20.9**	**7.5**	**1475**	**290**	**3.70**	**4.23**	**1.55**	**1.73**	**20.6**	**808.4**	**787.8**

Table 2. (cont.)

Date	Location	D.O.	Temp.	pH	Cond.	total Alkalinity	TON	NH3	PO4 - TP	PO4 - SRP	TSS	TS	TDS
2/2/06	11	9.0	4.1	3.5	1165	276	0.47		0.53	0.34	6.8	458.7	451.9
2/23/06	11	13.4	4.3	4.0	470	354	6.35		1.21	1.33	8.4	653.3	644.9
4/20/06	11	27.4	18.4	10.4	645	236	0.50		0.40	0.22	13.0	458.7	445.7
5/9/06	11	8.6	18.7	8.2	740	210	8.52		0.92	0.73	42.0	514.7	472.7
6/6/06	11	7.2	23.6	7.9	778	249	6.56	0.23	1.26	0.97	47.0	524.0	477.0
6/29/06	11	6.9	25.7	8.2	1851	381	0.51	0.21	2.45	3.08	15.0	1106.7	1091.7
8/9/06	11	7.3	27.0	7.8	1523	302	4.10	0.42	2.00	3.15	21.0	782.7	761.7
9/15/06	11	9.5	23.8	7.3	2395	381	5.98	0.15	3.44	4.47	5.0	1109.3	1104.3
10/13/06	11	11.5	19.7	8.3	4035	407	0.80	0.14	2.25	2.68	89.0	2229.3	2140.3
11/16/06	11	6.1	8.5	9.0	871	315	3.61	DL	0.83	0.66	19.0	446.7	427.7
2006 Average	**11**	**10.7**	**20.7**	**7.5**	**1447**	**311**	**3.74**	**6.30**	**1.53**	**1.76**	**26.6**	**828.4**	**801.8**
2/2/06	12	16.0	2.7	2.8	145	289	0.48		0.52	0.32	7.6	484.0	476.4
2/23/06	12	13.9	3.8	3.9	463	354	6.29		1.36	1.33	8.0	642.7	634.7
4/20/06	12	26.5	18.1	10.4	655	263	0.51		0.36	0.23	22.0	465.3	443.3
5/9/06	12	8.4	18.3	8.2	751	236	8.81		0.82	0.65	39.0	508.0	469.0
6/6/06	12	6.9	22.5	8.0	741	236	7.57	0.21	0.98	0.77	43.0	500.0	457.0
6/29/06	12	5.9	23.7	8.1	1676	394	0.59	0.23	2.27	2.75	20.0	1018.7	998.7
8/9/06	12	7.7	26.2	7.9	1418	302	4.04	0.55	1.79	2.51	36.0	737.3	701.3
9/15/06	12	8.6	22.1	8.2	2252	407	6.13	0.14	3.08	3.62	13.0	1050.7	1037.7
10/13/06	12	9.4	15.3	8.0	3229	433	0.80	0.16	2.14	2.27	32.0	1700.0	1668.0
11/16/06	12	6.5	8.3	8.9	810	289	3.61	DL	0.62	0.47	25.0	416.0	391.0
2006 Average	**12**	**11.0**	**19.3**	**7.4**	**1214**	**320**	**3.88**	**11.00**	**1.39**	**1.49**	**24.6**	**752.3**	**727.7**

Table 2. (cont.)

Date	Location	D.O.	Temp.	pH	Cond.	total Alkalinity	TON	NH3	PO4 - TP	PO4 - SRP	TSS	TS	TDS
2/2/06	14	16.5	3.3	2.6	1181	302	0.50		0.59	0.33	20.0	497.3	477.3
2/23/06	14	18.5	4.2	3.8	734	341	6.50		1.33	1.33	12.8	705.3	692.5
4/20/06	14	26.1	18.3	10.4	655	236	0.53		0.36	0.23	27.0	469.3	442.3
5/9/06	14	8.0	18.2	8.2	761	246	8.61		0.85	0.60	46.0	549.3	503.3
6/6/06	14	7.0	22.6	8.0	775	263	7.48	0.20	1.09	0.80	75.0	542.7	467.7
6/29/06	14	6.3	23.3	8.1	1437	433	0.56	0.38	2.08	2.16	24.0	872.0	848.0
8/9/06	14	7.7	25.9	8.3	1830	302	4.78	0.59	1.83	3.28	41.0	976.0	935.0
9/15/06	14	8.9	21.2	8.3	2100	381	5.58	0.19	2.77	3.89	12.0	965.3	953.3
10/13/06	14	10.6	12.3	8.6	3829	551	0.76	0.13	2.29	2.27	6.0	2040.0	2034.0
11/16/06	14	6.3	8.5	8.8	896	368	3.79	0.02	0.93	0.71	36.0	472.0	436.0
2006 Average	**14**	**11.6**	**18.8**	**7.5**	**1420**	**342**	**3.91**	**7.86**	**1.41**	**1.56**	**30.0**	**808.9**	**779.0**

Table 3. Macroinvertebrate data collected in 2006 from the 8 Sangamon River sample sites associated with the Decatur Sanitation District

order	family	tol value	site 1	site 3	site 5	site 6	site 7	site 9	site 11	site 12
Ephemeroptera	Baetidae	4	3	22	22		45	29	20	41
	Caenidae	6		7	33		34	35	16	
	Ephemeridae	5	8	3	2					
	Heptagenidae	3						8	7	14
Odonata	Coenagrionidae	6		56	22	7	3	30		21
	Gomphidae	5				1	5		12	
Trichoptera	Polycentropodidae	6	65	45	77	56	33	23	64	
Hydropsychidae	Hydropsychide	4	1	3			2	13	100	17
Coleoptera	Dryopidae	4								
	Curculionidae	4					2			
	Elmidae	5		1			5	3	6	7
	Haliphilidae	4					3	1		4
Diptera	Chironomidae	7	645	1132	766	890	677	165	199	174
	Culcidae	8	9		4					
	Simuliidae	7								
	Ceratopogonidae	5						11	18	4
	Tipulidae	4					17	8		8
	Oligochaeta	8	13	18						
Mollusks		6	5	3						
Annelida		10		11		5				
Megaloptera		3								
Turbellaria		6					6			3

	site 1	site 3	site 5	site 6	site 7	site 9	site 11	site 12
Total Number	749	1301	926	959	832	326	442	293
# of families	6	10	7	6	10	13	9	11
MBI	6.898531	6.890085	6.786177	6.947862	6.635817	6.076687	5.778281	5.935154

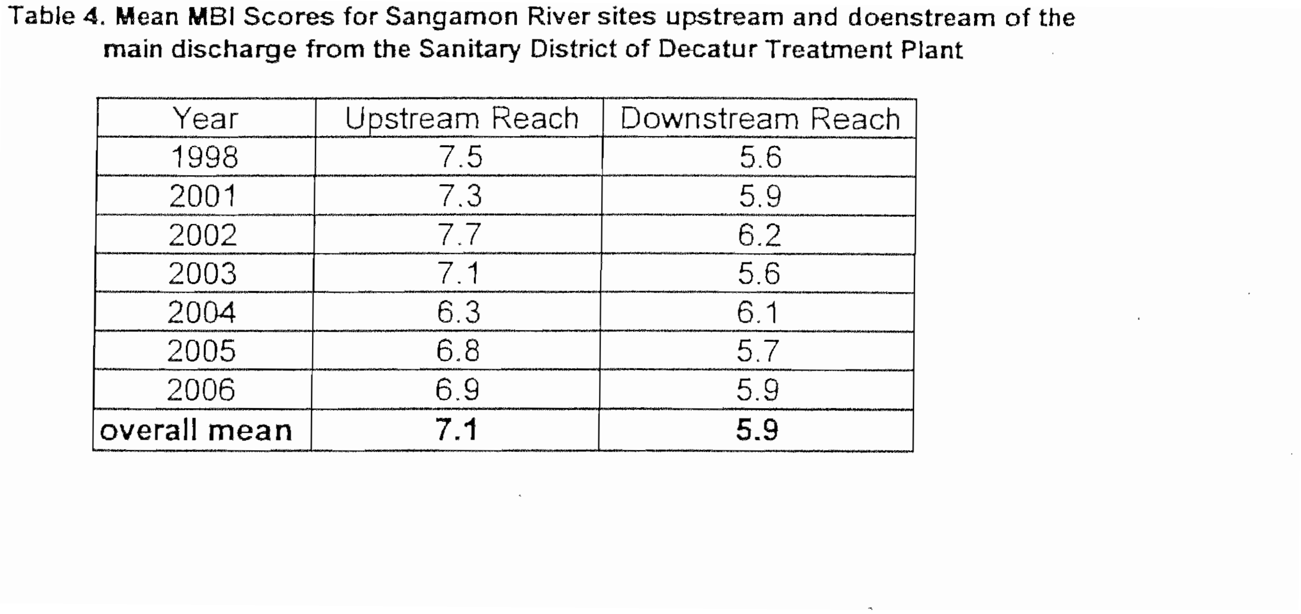

Table 4. **Mean MBI** Scores for Sangamon River sites upstream and doenstream of the main discharge from the Sanitary District of Decatur Treatment Plant

Year	Upstream Reach	Downstream Reach
1998	7.5	5.6
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
overall mean	**7.1**	**5.9**

Table 5. Fish data collected at 11 sites in the Sangamon River for the Sanitary District of Decatur.

Common Name	Scientific Name	site 1	site 3	site 4	site 5	site 6	site 7	site 8	site 9	site 11	site 12	site 13
Black Crappie	Pomoxis nigromaculatas		1									
Blackside Darter	Percina maculata				1						1	3
Blackstripe Topminnow	Fundulus notatus									1		
Bluegill	Lepomis macrochirus		4			1				1	1	
Bluntnose Minnow	Pimephales notatus	20	17	4	14	46	2	2		20	21	44
Brook Silverside	Labidesthes sicculus		2	2								
Channel Catfish	Ictalurus punctatus						1				3	1
Freshwater Drum	Aplodinotus grunniens	1	5			1						
Gizzard Shad	Dorosoma cepedianum	1		51		1	34	3				1
Golden Redhorse	Moxostoma erythrurum									1	1	
Green Sunfish	Lepomis cyanellus		3								3	
Johnny Darter	Etheostoma nigrum			6	10	1				8	22	
Largemouth Bass	Micropterus salmoides	9	7	2	1						1	
Logperch	Percina caprodes	5				1		1				1
Mosquitofish	Gambusia affinis	6	2	3		8				2	2	
Northern Hogsucker*	Hypentelium nigricans											
Orangespotted Sunfish	Lepomis humilis	1	13									
Orangethroat Darter	Etheostoma spectabile	3		4	1	19	9	6		2	5	12
Pumpkinseed	Lepomis gibbosus											1
Quillback	Carpiodes cyprinus							2		3		
Red Shiner	Cyprinella lutrensis	14	11	113	26	13	18	72	260	397	53	127
Redear Sunfish*	Lepomis microlophus											
Redfin Shiner	Lythrurus umbratilis									1		
Sand Shiner	Notropis stramineus	7	19	20	6	2	8	26	44	448	2	36
Slenderhead Darter	Percina phoxocephala											
Shortnoise Gar*	Lepisosteus platostomus											
Spotfin Shiner*	Cyprinella spiloptera											
Striped Bass	Morone saxatilis							1				
Striped Shiner*	Luxilus chrysocephalus											
Suckermouth Minnow	Phenacobius mirabilis			7	20	3		7		3	17	26
White Crappie	Pomoxis annularis	1	4								1	
White Sucker	Catostomas commersoni									2		4

*There were No Individuals Found

Total Number of Individuals	68	88	212	79	96	72	120	304	889	133	256
Total Taxa	11	12	10	8	11	6	9	2	13	14	11
Index of Biotic Integrity (IBI) Score	38	40	36	36	28	28	36	36	42	44	40
Mean IBI Upstream	34.57										
Mean IBI Downstream	40.50										

Table 6. **Meab** IBI scores for Sangamon River sites upstream and downstream of the main dischsrge from the Sanitary District of Deactur Treatment Plant

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
overall mean	**31**	**34**

Exhibit L

Biotic Assessment of Water Quality in a
Reach of the Sangamon River Receiving Effluent
From the Sanitary District of Decatur
Eastern Illinois University Report
July 2008

Biotic assessment of water quality in a reach of the Sangamon River receiving effluent from the Sanitary District of Decatur

REPORT FOR YEAR - 2007

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Introduction

Impoundment of rivers to create reservoirs used for irrigation purposes, as urban water supplies, and recreation, is commonplace. However, impoundments may impact downstream aquatic systems and their surrounding terrestrial habitats. Diminished water quality and availability, closures of fisheries, extirpation of species, groundwater depletion, and more frequent and intense flooding are increasingly distinguished as consequences of current river management associated with impoundments (Abramovitz 1996, Collier *et al* 1996, Naiman *et al* 1995). Specifically, dams can affect riverine systems by altering flow regime, changing nutrient and sediment loads, and modifying energy flow (Ligon *et al* 1995). As a result, river reaches downstream from a dam may no longer able to support native species, which will be reflected by reduced integrity of biotic communities. (Naiman *et al* 1995, NRC 1992).

A natural flow regime is critical for sustaining ecosystem integrity and native biodiversity in rivers (Poff, *et al.* 1997). Dams can have varying effects on downstream aquatic habitats depending on the purpose for which the dam was built. Impoundments used for urban water supplies reduce flow rates below the dam throughout the entire year (Finlayson et al. 1994) as well as increased daily and seasonal variability in flow regime (Finlayson et al. 1994, McMahon & Finlayson 2003). In addition, abiotic variables including temperature, dissolved oxygen, turbidity, pH, conductivity and solids concentrations are altered in the downstream river system (e.g., (Finlayson et al. 1994).

Along with stream impoundments, point source and non-point source pollution can have profound effects on the ecological integrity of river systems. Non-point sources of pollution may include agriculture, livestock grazing, and urbanization while sanitary discharge and industrial waste are examples of point source pollution. To reduce point source pollution, the Water Quality Act of 1972 encouraged wastewater treatment plants to upgrade their systems and, as a result, many communities were forced to build advanced tertiary water treatment facilities (Karr et al 1985). Yet these treatment facilities still export high concentrations of nutrients into rivers. Carpenter and Waite (2000) documented that concentrations of phosphorus were highest in streams draining agricultural basins and at sites influenced by wastewater discharges, while Twichell et al (2002) reported that sewage effluent inputs had elevated nitrate levels. These enhanced nutrient inputs can be expected to increase productivity within a river because primary productivity and detrital processing usually are limited by low ambient stream nutrient concentrations (Stockner and Shortreed 1978, Elwood et al 1981, Winterbourn 1990).

Physical habitat (e.g., flow regime, bottom substrate composition, instream cover, etc.) and chemical water quality must be suitable for support of individual species in lotic systems and maintenance of the integrity of aquatic communities. The Sangamon River offers an opportunity to study these relationships in a stream influenced by impoundment as well as point source discharges. The Sangamon River Basin is a 14,000 km^2 watershed covering all or portions of eighteen counties in central Illinois. More than 3540 km of streams within the basin course through glacial and alluvial deposits creating typically low gradient stream with sand and gravel substrates. Streams within the basin have been impacted for most of the past century, receiving inputs from both point and non-point sources. Current land use is 80% agricultural of which 85% is corn or soybeans. The great expanses of prairie that once existed in Illinois have been reduced to isolated hill and sand prairies coupled with remnants along highway and railroad right-of-ways and native deciduous woodlands now are limited to stream riparian areas. Major metropolitan areas associated with the Sangamon River are Bloomington, Decatur, and Springfield representing a combined population of more than 500,000 residents. Impoundments associated with urbanization include Lake Taylorville, Lake Sangchris, and Lake Springfield on the South Fork of the Sangamon; Clinton Lake on Salt Creek; as well as Lake Decatur.

With such influential factors at play, the status of the biotic integrity of the Sangamon River system is constantly in flux. In 1998-99 and continuing from 2001-2006, an intensive sampling program was initiated to document temporal and spatial heterogeneity of an 8.5 km urban reach of the Sangamon River beginning just below the Lake Decatur Dam and extending downstream to incorporate discharges from the Sanitary District of Decatur (SDD). This study has been intended to characterize stream habitat quality and to assess impacts resulting from ongoing municipal and reservoir management by evaluating biotic integrity at various trophic levels in the context of the physical and chemical nature of the Sangamon River.

Project History

We utilize sampling locations associated with operation of SDD that were easily identified by prominent landmarks within the City of Decatur, Illinois, USA (Table 1). Sites were established initially in 1998 during an assessment of potential impacts of discharges from combined sewage overflow (CSO) facilities as well as the main treatment plant. All sites were located in the mainstem of the Sangamon River extending from just downstream of the dam, which impounds Lake Decatur to the Wyckles Road Bridge on the west edge of Decatur. Sites 1, 3, 4, 5, 6, 7, and 8 are within the **UPSTREAM** reach extending from the dam to the discharge of the main treatment plant, and Sites 9, 11 and 12 are located in the **DOWNSTREAM** reach which extends from the main treatment plant discharge to the Wyckles Road Bridge. Throughout this report, we will refer to general locations as either **UPSTREAM** or **DOWNSTREAM** of the SDD main treatment plant discharge. During 2003, samples also were collected from the Sangamon River at an additional DOWNSTREAM site (#14) located 1km north of the intersection of CR 600E and CR 800N, near the Lincoln Trail Homestead State Park. Site 2 (an open channel entering the Sangamon River from the Lincoln Park CSO) and Site 10 (located in Stevens Creek in Fairview Park) are distinct from other sites largely due to their location outside of the mainstem of the Sangamon River. Because these Sites are more or less isolated from reservoir or sanitary discharges, they are not included in sample protocol after 2003.

The Stream Habitat Assessment Procedure (SHAP), which evaluates lotic habitat quality using features considered important to biotic integrity, was performed by us during the month of July in 1998, 2001, and 2002 through 2006. At each stream site, two individuals independently assigned metrics related to substrate and instream cover, channel morphology and hydrology, and riparian and bank features to one of four habitat quality types using guidelines established by the Illinois Environmental Protection Agency (1994). The mean total score of the 15 metrics forms the basis of an overall habitat quality rating for the stream reach under consideration. Habitat quality of the **UPSTREAM** and **DOWNSTREAM** reaches were categorized on the basis of its SHAP score as follows: <59 = Very Poor; 59 - 100 = Fair; 100 - 142 = Good; > 142 = Excellent. Average SHAP scores for **UPSTREAM** and **DOWNSTREAM** sites were 84 and 95, respectively. Nonetheless, physical habitat structure based on SHAP still results in classification of all mainstem sites as "fair" quality stream reaches indicating that the physical structure of the stream is homogeneous.

This overall physical structure provides a backdrop for the ability of the study reach to support a diverse flora and fauna. Routine assessment of characteristic water quality variables superimposed on substrate characteristics, channel morphology and bank features can aid in understanding the functioning of stream systems. Given that organisms exist within often-narrow ranges of tolerance for certain physical and chemical characteristics of their environment, analysis of these variables is imperative for understanding the potential for anthropogenic impacts to decrease biotic integrity of natural systems. As a result, we incorporated routine analyses of various physical and chemical features of the Sangamon River sites studied since 2002, which based on principal components analysis, revealed significant differences between the UPSTREAM and DOWNSTREAM reaches. Monitoring of relevant variables continues through 2008.

Qualitative judgements (good vs. bad) based on established biocriteria using data from 1998, 2000 -2007 were consistent. The Macroinvertebrate Biotic Index classified both reaches as GOOD/FAIR, however, the MBI downstream was significantly different from the upstream MBI, indicating conditions significantly improved DOWNSTREAM of the discharge from the SDD main treatment. And the Fish Index of Biotic Integrity calculated from 1998, 2001 through 2007 classified both reaches as FAIR, but was able to detect a significant difference between stream reaches with improved habitat DOWNSTREAM of the discharge from the SDD main treatment. **Also, since 2002 we have continued to refine our sampling protocol for development of benthic algae for monitoring stream habitat quality. Indices of diatom community structure did not differ between UPSTREAM and DOWNSTREAM reaches based on analysis of spring and fall sample periods. However, qualitative comparisons of shifts in community dominance were possible and clearly indicated promise for utility of these organisms for biomonitoring stream conditions.**

Methods

Field data collection and water chemistry determination

Water quality data were collected on six occasions from May to December, 2007.

Sampling was initiated at the Lake Decatur dam and preceded downstream. While in the field, additional abiotic variables (dissolved oxygen, pH, conductivity, and temperature were determined) using Eureka Amphibian and Manta multiprobe. Surface water samples were collected at 0.3 m below the surface and returned to the laboratory on ice and analyzed within generally accepted time limits. All sampling and analyses were conducted according to Standard Methods for Examination of Water and Wastewater (APHA, 1995). In the laboratory, suspended and total solids determinations were made by drying residue collected on standard glass fiber filters as well as unfiltered samples placed into tared porcelain crucibles at 103-105 °C. Total dissolved solids were calculated by difference. Total phosphorus (following persulfate digestion) and soluble reactive phosphorus (utilizing filtered, undigested, sample aliquots) were determined using the ascorbic acid method. The phenate method was used for determination of ammonia nitrogen, and total oxidized nitrogen (NO_2-N + NO_3-N) was determined via the cadmium reduction method. Colorimetry of all nutrient analyses was determined using a Beckman DU 530 Life Science UV/Vis Spectrophotometer. Alkalinity and hardness were measured by titration to colorimetric endpoint methods. For all chemical analyses, due consideration was given to quality control and quality assurance procedures, including but not limited to parallel analyses of laboratory standards.

Macroinvertebrates

Macroinvertebrate samples were collected from 9 of the 11 sites using modified multiplate samplers (Hester and Dendy 1962). Substrates were placed on the stream bottom for periods of six weeks, beginning July 9, 2007 to allow colonization. Samplers were collected with aid of a dip-net, in order to avoid loss of invertebrates, and placed in wide-mouth plastic containers. All organisms were preserved in the field with 95% ethanol containing rose bengal. After sorting, macroinvertebrates were identified to the lowest possible taxonomic level and data were used to calculate a Macroinvertebrate Biotic Index (MBI) according to Hilsenhoff (1982). In this method, each taxon is assigned a pollution tolerance value ranging from zero to eleven based on available literature and previous field experience. Based on present assessment methods, MBI values reflect water quality as follows (IEPA 1988): < 5.0 - Excellent; 5.0 - 6.0 - Very good; 6.1 - 7.5 - Good/Fair; 7.6 - 10.0 - Poor; > 10.0 - Very Poor. Macroinvertibrate Biotic Index scores for 2007 were compared to those data, which were pooled from 1998, 2001 through 2006.

Fish

Fish were sampled on 9-11of July 2007 by hand seining, with attempts to standardize sampling effort at each site. Fish were identified to species, counted and returned to the stream alive when possible, although voucher specimens were preserved and retained. When field identifications were not practical, specimens were preserved in ten percent formalin and returned to the laboratory. Species richness and evenness (Pielou, 1977) were used as fundamental measures of diversity. Fish community data also were used to determine the community-based Index of Biotic Integrity (IBI), which uses twelve metrics in three categories to appraise fish communities (Karr et al., 1986). Values of 1, 3, and 5 are assigned for each metric, and the values for the individual metrics are then summed to generate a score from 12 to 60. Calculation of IBI values was aided by an interactive program written in Basic for use on an IBM-PC (Bickers et al., 1988). The utility of IBI scores is that they enable qualitative characterization of streams, as follows: 51-60 – excellent: comparable to best situations without human disturbance, 41-50.9 – good: good fishery for gamefish: species richness may be below expectations, 31-40.9 – fair: bullheads, sunfish, and carp predominate: diversity and intolerants reduced, 21-30.9 – poor: fish dominated by omnivores and tolerant forms: diversity notably reduced, <21 – very poor: few fish of any species present, no sport fishery exists. Fish IBI scores for 2007 were compared to those data, which were pooled from 1998, 2001 and 2002 through 2006.

Benthic algal (diatom) samples

Artificial substrates were continuously exposed at 11 sites in the main channel of the Sangamon River from 10 July - 31 July during 2007. Substrates were 1 x 3 inch clean glass microscope slides suspended at the surface of the stream in commercially available periphytometers (Wildco, Inc.). Unfortunately, all but 2 substrates were lost due either to natural occurrence (i.e., high discharge events) or due to vandalism. As such, further analysis of diatom assemblages were not pursued as results would have been uninformative or inconclusive.

Results

Water chemistry

Levels of 13 separate water quality variables were determined for eleven mainstem sites in 2006 (Table 2). Principle Components Analysis confirmed multivariate differences between river reaches **UPSTREAM** and **DOWNSTREAM** of sanitary discharge. The trend established in prior sampling years continued throughout this recent sampling period, with levels for each of the variables being generally higher in **DOWNSTREAM** locations. Most notably, higher concentrations of forms of phosphorus and nitrogen were observed along with a general trend of elevated conductivity, presumably resulting from discharge from the main treatment plant of the Sanitary District of Decatur. Water chemistry continued to be relatively homogeneous over the entire study reach during periods of high discharge from the dam which impounds Lake Decatur.

Macroinvertebrates

A total of 11 Hester-Dendy Multiplate samplers were placed along the main stem of the Sangamon River associated with the Sanitary District of Decatur for determination of macroinvertebrate communities. For the eleven sampling locations we were only able to collected data for nine sites along the stretch of the Sangamon River associated with the Sanitary District of Decatur, a total of 6743 organisms representing 21 macroinvertebrate taxa were collected (Table 3). The MBI values ranged from 5.7 to 6.9 for the nine sites with the highest percent of organisms collected representing insects in the order Diptera.

MBI scores for the 9 main channel sites assessed in 2007 were consistent with MBI values obtained during 1998 and 2001 - 2006. MBI scores averaged over the seven year for **UPSTREAM** and **DOWNSTREAM** sites were 7.05 and 5.85, respectively (Table 2).

Both of these overall scores warrant a "good/fair rating." However, two-factor ANOVA revealed the difference in MBI values to be significant ($p<0.05$) between upstream and downstream sites, indicating that stream habitat quality is better at the **DOWNSTREAM** sites.

Fish

A total of 2180 fish of 19 species from 10 families were collected at 11 sites during July 2007 (Table 4). As in the previous sample periods the fish community in 2007 again was dominated by the family Cyprinidae (minnows and carp). Significant differences were not observed ($p>0.05$) in community-based measures of diversity between **UPSTREAM** and **DOWNSTREAM** reaches. Stream quality in the Sangamon River basin as evaluated by fish population samples and the Index of Biotic Integrity ranged from 29 (Sites 3 and 6) to 41 (Site 14), indicating overall stream quality of poor to good. Overall mean IBIs for data pooled from 1998, 2001-2007 were 31 and 35 for the **UPSTREAM** and **DOWNSTREAM** reaches, respectively. Two-factor ANOVA confirmed this difference to be significant ($p<0.05$), suggesting that overall habitat quality, based on the fish community, is improved in the **DOWNSTREAM** reach.

Diatom community structure

Because only two of the 11 samplers placed in the stream were recovered, further analysis of the diatom assemblage was not attempted.

Discussion

Overall, the Sangamon River extending from the dam, which impounds Lake Decatur to the Wyckles Road Bridge, can be considered a fair quality aquatic system with minimal habitat variety. Although there is significant variation in physical habitats UPSTREAM and DOWNSTREAM of the SDD, variability in SHAP ratings were primarily dependent upon such factors as substrate stability, pool variability and quality due to stream flow, and loss or reduction of riparian zone vegetation that had occurred at each specific site. The primary difference between **UPSTREAM** and **DOWNSTREAM** reaches is attributable indirectly to metrics related to flow. The **DOWNSTREAM** reach receives continuous flow from SDD, whereas **UPSTREAM** flow varies greatly due to unpredictable reservoir discharges. Such alterations have lead to simplification of stream habitat with concomitant reduction in species diversity and biotic integrity and an overall decline in quality of the aquatic resource.

Based on physical habitat structure as measured by SHAP, the reaches of the Sangamon River, which we studied, are indistinguishable. However, PCA confirms that **UPSTREAM** and **DOWNSTREAM** reaches are distinct on the basis of their physical and chemical characteristics. Discharge from Lake Decatur is the primary input to the **UPSTREAM** reach, resulting in our observation of relatively higher variability in flow and nutrient concentrations. Conversely, stable and predictable instream flows observed in the reach **DOWNSTREAM** of the SDD facilitate development of more diverse biotic communities as confirmed by work conducted in other riverine systems (Sanders 1969;

Fisher 1983; Peckarsky 1983; Reice 1985; Ross *et al.* 1985; Walde 1986; Resh *et al.* 1988). Difference in the overall nature of the **UPSTREAM** and **DOWNSTREAM** reaches becomes less distinct during periods of high reservoir discharge.

We also believe that drastic reduction of instream flow resulting by routine elimination of reservoir discharge is detrimental to habitat quality in the **UPSTREAM** reach. Overall, results suggest that a threshold exists with respect to flow, i.e. periods when discharge is less than 400 cfs. When flow is below this threshold, the **UPSTREAM** and **DOWNSTREAM** reaches are discrete while they appear to behave as a continuum when discharge exceeds 400 cfs. This suggests that water quality is compromised in the reach of the Sangamon River extending downstream from the dam to the discharge of the main treatment plant of the Sanitary District of Decatur as a result of management to maintain reservoir levels by eliminating outflow. In contrast, effective management of Sangamon River may require maintenance of instream flow above the proposed threshold (400 cfs) by continuous discharge from Lake Decatur.

Interpretation of PCA Factor Analysis provides insight into functioning of the **UPSTREAM** and **DOWNSTREAM** reaches. Sites **DOWNSTREAM** of SDD may have greater potential for instream primary productivity as a result of nutrient loading as indexed by higher levels of dissolved solids, conductivity, total alkalinity, oxidized nitrogen, and phosphorus. We believe that suspended organic material including phytoplankton algae derived from the reservoir may be supporting heterotrophs in the **UPSTREAM** sites. In contrast, **DOWNSTREAM** sites are maintained by autochthonous primary productivity that is supported by relatively higher concentrations of plant nutrients derived from the sanitary discharge. We conclude that SDD discharge may be facilitating a shift from a stream system that relies on allochthonous input of algae to one that relies on autochthonous instream primary productivity.

Qualitative evaluation of the two stream reaches requires assessment of stream biota to determine whether or not differences in the two stream reaches are reflected by higher trophic levels. Such an evaluation of overall stream habitat quality can be made via biotic indices involving macroinvertebrates and fish, taxa that have become widely used for biotic assessments. **DOWNSTREAM** sites were characterized during 1998, 2001-2007 by significantly lower MBI scores and higher IBI values, indicative of improved habitat quality capable of supporting diverse biota and a variety of different trophic levels. **DOWNSTREAM** sites associated with the main treatment plant outfall from the SDD may have increased integrity due to predictable instream flows and increased autochthonous primary production due in part to nutrient loading.

When comparing our observations made during the 2007 sampling period with data collected in 1992 (IEPA report), 1998 (Sanitary District of Decatur) and 2001-2006 (Sanitary District of Decatur) both IBI and MBI values for **DOWNSTREAM** sites associated with the main treatment plant outfall were generally similar or slightly improved compared to values obtained during all previous sampling periods. Thus the upgrades performed to the main plant in 1990 and the Lincoln CSO in 1992 by the sanitation district have lead direct to improvement of the water quality of the Sangamon River which has been maintained over the past seven years. Additionally, there has been no reduction in the quality of the Sangamon River section located near the Sanitary District of Decatur in the last 20 years.

Additional fish and invertebrate specimens had been collected for determination of tissue levels of zinc and nickel, but analyses were not conducted upon request by the Sanitary District of Decatur. Samples have been retained in the event those analyses are requested at a future date. Instead, we conducted a comprehensive literature review of the effects of these two metals on aquatic ecosystems (Appendix A).

During the next contract year, special projects are intended to determine the effects of sanitary effluent on benthic algal assemblage structure and productivity using a bioassay approach. This is intended to allay difficulties we have had with loss of artificial substrates. In addition, we are planning to initiate an investigation of nutrient loading to and export from Lake Decatur.

Table 1. List of the 13 sites utilized by the Department of Biological Sciences for studies conducted on reaches of the Sangamon River associated with the Sanitary District of Decatur.

Site #1 - Lincoln Park - above outfall
Site #2 - Lincoln Park - outfall canal
Site #3 - Lincoln Park - below outfall
Site #4 - Oakland (Lincoln Park Drive) - above outfall
Site #5 - Oakland (Lincoln Park Drive) - below outfall
Site #6 - 7th Ward - upstream of outfall
Site #7 - 7th Ward - downstream of outfall
Site #8 - SDD Main Treatment Plant - upstream of main outfall
Site #9 - SDD Main treatment Plant - downstream of main outfall
Site #10 - Stevens Creek in Fairview Park
Site #11 - Sangamon River - downstream of Stevens Creek
Site #12 - Sangamon River at Wyckles Road
Site # 14 - near the Lincoln Trail Homestead State Park. 1km north of CR 600E and CR 800N

Table 2. Measured water quality variables for 11 mainstem sites in the Sangamon River associated with the SDD.

Date	Site	DO	Temp	pH	Cond	Hardness	Total Alkalinity	TON	NH4	PO_4 . TP	PO_4 - SRP	TSS	TS	TDS
6/26/07	1					253.1	209.4	0.91	0.12	0.24	0.14	14.5	234.7	220.2
8/23/07	1	6.9	27.0	9.2	562.0	271.4	251.3	0.17	0.05	0.11	0.11	24.0	425.3	401.3
9/27/07	1	4.4	20.9	8.3	516.0	236.7	223.4	0.15	0.19	0.15	0.07	26.2	384.0	357.8
10/25/07	1	7.1	11.6	7.8	501.0	261.2	195.4	0.37	0.00	0.19	0.04	30.0	340.0	310.0
11/29/07	1	8.3	4.9	7.4	474.0	212.2	167.5	0.27	0.10	0.11	0.04	6.9	321.3	314.5
12/13/07	1	12.7	6.0	7.8	677.0	253.1	209.4	0.25	0.03	0.11	0.01	19.0	414.7	395.7
6/26/07	3					253.1	223.4	0.84	0.11	0.22	0.12	22.5	226.7	204.2
8/23/07	3	4.5	26.1	8.7	634.0	281.6	258.3	0.49	0.15	0.12	0.09	15.0	457.3	442.3
9/27/07	3	4.4	20.6	7.9	625.0	257.1	230.3	0.39	0.12	0.15	0.06	29.2	458.7	429.4
10/25/07	3	4.6	11.8	7.6	526.0	228.6	237.3	0.64	0.12	0.15	0.03	12.0	345.3	333.3
11/29/07	3	6.6	4.5	7.6	574.0	271.4	209.4	0.49	0.05	0.11	0.04	6.4	382.7	376.3
12/13/07	3	9.3	5.8	7.7	649.0	255.1	209.4	0.68	0.09	0.13	0.02	15.0	444.0	429.0
6/26/07	4					249.0	209.4	1.16	0.09	0.24	0.13	24.5	249.3	224.8
8/23/07	4	5.5	27.0	8.8	559.0	263.3	230.3	0.16	0.03	0.15	0.11	33.0	425.3	392.3
9/27/07	4	4.4	20.4	7.8	653.0	281.6	258.3	0.17	0.05	0.14	0.09	16.0	460.0	444.0
10/25/07	4	5.8	10.7	7.6	503.0	293.9	223.4	0.44	0.29	0.17	0.04	11.7	328.0	316.3
11/29/07	4	8.6	2.7	7.6	627.0	287.8	265.2	0.38	0.66	0.12	0.05	3.6	382.7	379.1
12/13/07	4	10.8	4.0	7.9	774.0	283.7	237.3	0.72	0.33	0.10	0.01	12.8	525.3	512.5
6/26/07	5					249.0	209.4	1.16	0.10	0.23	0.13	22.0	270.7	248.7
8/23/07	5	6.4	27.1	9.0	583.0	261.2	258.3	0.70	0.05	0.13	0.09	33.0	420.0	387.0
9/27/07	5	3.9	20.5	7.8	648.0	293.9	237.3	0.17	0.05	0.16	0.09	18.5	466.7	448.2
10/25/07	5	5.7	11.3	7.6	485.0	273.5	195.4	0.37	0.28	0.17	0.02	18.5	316.0	297.5
11/29/07	5	7.3	3.0	7.8	622.0	283.7	265.2	0.41	0.60	0.13	0.05	6.2	386.7	380.5
12/13/07	5	10.4	4.0	7.9	767.0	285.7	237.3	0.72	0.31	0.10	0.02	12.9	508.0	495.1
6/26/07	6					289.8	223.4	1.11	0.09	0.23	0.12	35.0	293.3	258.3
8/23/07	6	5.4	27.0	8.2	656.0	265.3	258.3	0.36	0.05	0.11	0.09	20.0	425.3	405.3
9/27/07	6	6.6	22.4	7.6	746.0	326.5	286.2	0.11	0.05	0.15	0.05	14.2	530.7	516.4
10/25/07	6	6.0	12.4	7.6	465.0	302.0	223.4	0.34	0.40	0.14	0.04	10.7	288.0	277.3
11/29/07	6	6.3	3.9	7.5	482.0	224.5	223.4	0.30	0.36	0.26	0.11	6.0	317.3	311.3
12/13/07	6	9.9	4.2	7.9	735.0	279.6	216.4	0.67	0.23	0.10	0.03	13.7	492.3	478.7
6/26/07	7					244.9	223.4	1.20	0.12	0.23	0.13	42.0	306.7	264.7
8/23/07	7	4.7	26.8	8.0	671.0	0.0	279.2	0.43	0.07	0.08	0.06	28.0	474.7	446.7
9/27/07	7	5.7	18.8	7.6	595.0	273.5	258.3	0.05	0.02	0.15	0.05	32.5	410.7	378.2
10/25/07	7	7.1	11.6	7.8	470.0	228.6	209.4	0.15	0.41	0.13	0.04	15.5	310.7	295.2
11/29/07	7	8.4	4.0	7.3	516.0	222.4	230.3	0.35	0.48	0.25	0.08	26.0	292.0	266.0
12/13/07	7	9.9	4.2	7.9	739.0	269.4	230.3	0.67	0.22	0.11	0.03	14.5	494.7	480.2
6/26/07	8					249.0	223.4	1.02	0.11	0.24	0.12	43.0	330.7	287.7
8/23/07	8	4.0	27.5	8.0	697.0	324.5	286.2	0.21	0.05	0.19	0.14	15.5	474.7	459.2
9/27/07	8	4.7	21.1	7.6	582.0	253.1	272.2	0.04	0.05	0.18	0.08	16.9	386.7	369.8
10/25/07	8	6.3	11.3	7.6	482.0	244.9	195.4	0.18	0.30	0.15	0.01	17.0	304.0	287.0
11/29/07	8	8.6	3.8	7.4	405.0	195.9	188.5	0.32	0.41	0.25	0.13	12.3	256.0	243.7
12/13/07	8	9.2	3.7	7.8	733.0	244.9	195.4	0.58	0.33	0.15	0.07	15.3	470.7	455.3
6/26/07	9					257.1	223.4	1.42	0.11	0.59	0.52	25.0	404.0	379.0
8/23/07	9	6.4	30.3	8.4	4031.0	504.1	684.0	5.32	0.15	1.62	0.42	7.6	2644.0	2636.4
9/27/07	9	6.0	27.5	8.0	4283.0	465.3	718.9	5.38	0.05	2.00	2.53	7.0	2741.3	2734.3
10/25/07	9	7.3	22.2	8.0	4279.0	449.0	544.4	5.67	0.05	1.94	2.86	10.7	2658.7	2648.0
11/29/07	9	9.4	18.4	7.9	3987.0	477.5	474.6	6.46	0.12	1.86	2.39	16.6	2474.7	2458.1
12/13/07	9	7.7	17.0	7.8	3134.0	440.8	307.1	6.44	0.05	1.45	2.52	7.3	1966.7	1959.3

Table 2. continued

Date	Site	DO	Temp	pH	Cond	Hardness	Total Alkalinity	TON	NH4	PO_4 . TP	PO_4 - SRP	TSS	TS	TDS
6/26/07	11					273.5	223.4	1.64	0.12	0.60	0.43	50.5	468.0	417.5
8/23/07	11	6.3	30.4	8.4	3941.0	514.3	663.1	6.37	0.05	1.73	0.42	10.8	2565.3	2554.5
9/27/07	11	5.9	27.0	8.0	4181.0	471.4	698.0	4.89	0.05	1.93	2.55	8.2	2685.3	2677.2
10/25/07	11	7.3	21.3	8.0	4234.0	510.2	670.1	5.06	0.05	1.99	2.62	13.6	2668.0	2654.4
11/29/07	11	8.7	16.8	7.9	3890.0	473.5	488.6	6.08	0.11	2.14	2.88	21.7	2461.3	2439.6
12/13/07	11	8.2	15.1	7.8	3080.0	340.8	223.4	2.04	0.05	0.52	0.36	13.7	638.7	625.0
6/26/07	12					269.4	237.3	1.76	0.17	0.56	0.43	93.5	470.7	377.2
8/23/07	12	7.0	29.8	8.2	3900.0	532.6	698.0	6.03	0.11	1.88	0.42	19.0	2604.0	2585.0
9/27/07	12	7.2	24.3	8.1	4300.0	467.3	732.9	5.36	0.07	1.73	2.23	12.0	2729.3	2717.3
10/25/07	12	8.1	17.1	8.1	3934.0	424.5	725.9	6.02	0.05	2.29	2.67	19.2	2486.7	2467.5
11/29/07	12	9.0	11.5	8.1	3681.0	477.5	467.7	6.46	0.13	1.80	3.07	18.9	2300.0	2281.1
12/13/07	12	11.0	9.0	7.9	2043.0	357.1	279.2	5.95	0.12	1.35	1.77	12.9	1294.7	1281.8
8/23/07	14	10.4	29.2	8.1	3438.0	471.4	621.2	6.37	0.06	1.78	0.44	20.0	2250.7	2230.7
9/27/07	14	8.9	22.3	8.3	4007.0	483.7	663.1	7.51	0.05	1.57	2.60	37.9	2625.3	2587.4
10/25/07	14	10.0	13.2	8.3	3694.0	412.2	390.9	0.72	0.04	1.93	2.72	19.3	2373.3	2354.1
11/29/07	14	13.3	6.9	8.2	2968.0	428.6	467.7	5.26	0.05	3.41	1.76	24.0	1858.7	1834.7
12/13/07	14	11.0	7.6	8.6	2202.0	353.1	202.4	5.75	0.15	1.43	1.82	27.7	1402.7	1375.0

	Site	DO	Temp	pH	Cond	Hardness	Alkalinity	TON	NH4	PO4 - TP	PO4 - SRP	TSS	TS	TDS
Average	1	7.9	14.1	8.1	546.0	246.9	209.4	0.24	0.07	0.13	0.05	21.2	377.1	355.9
Average	3	5.9	13.8	7.9	601.6	258.8	228.9	0.54	0.11	0.13	0.05	15.5	417.6	402.1
Average	4	7.0	13.0	7.9	623.2	282.0	242.9	0.37	0.27	0.14	0.06	15.4	424.3	408.8
Average	5	6.7	13.2	8.0	621.0	279.6	238.7	0.47	0.26	0.14	0.05	17.8	419.5	401.6
Average	6	6.8	14.0	7.8	616.8	279.6	241.5	0.36	0.22	0.15	0.06	12.9	410.7	397.8
Average	7	7.2	13.1	7.7	598.2	198.8	241.5	0.33	0.24	0.14	0.05	23.3	396.5	373.2
Average	8	6.6	13.5	7.7	579.8	252.7	227.5	0.27	0.23	0.18	0.09	15.4	378.4	363.0
Average	9	7.4	23.1	8.0	3942.8	467.3	545.8	5.85	0.08	1.77	2.14	9.8	2497.1	2487.2
Average	11	7.3	22.1	8.0	3865.2	462.0	548.6	4.89	0.06	1.66	1.77	13.6	2203.7	2190.1
Average	12	8.5	18.3	8.1	3571.6	451.8	580.7	5.96	0.10	1.81	2.03	16.4	2282.9	2266.5
Average	14	10.7	15.8	8.3	3261.8	429.8	469.1	5.12	0.07	2.02	1.87	25.8	2102.1	2076.4

variable	units
DO	mg L-1
Temp.	oC
pH	
Cond	uS
Hardness	mg L-1
Alkalinity	mg L-1
TON	mg L-1
NH4	mg L-1
PO4 - TP	mg L-1
PO4 - SRP	mg L-1
TSS	mg L-1
TS	mg L-1
TDS	mg L-1

Figure 1. Principle Components Analysis of water chemistry in at 11 mainstem sites in the Sangamon River associated with the Decatur Sanitary District.

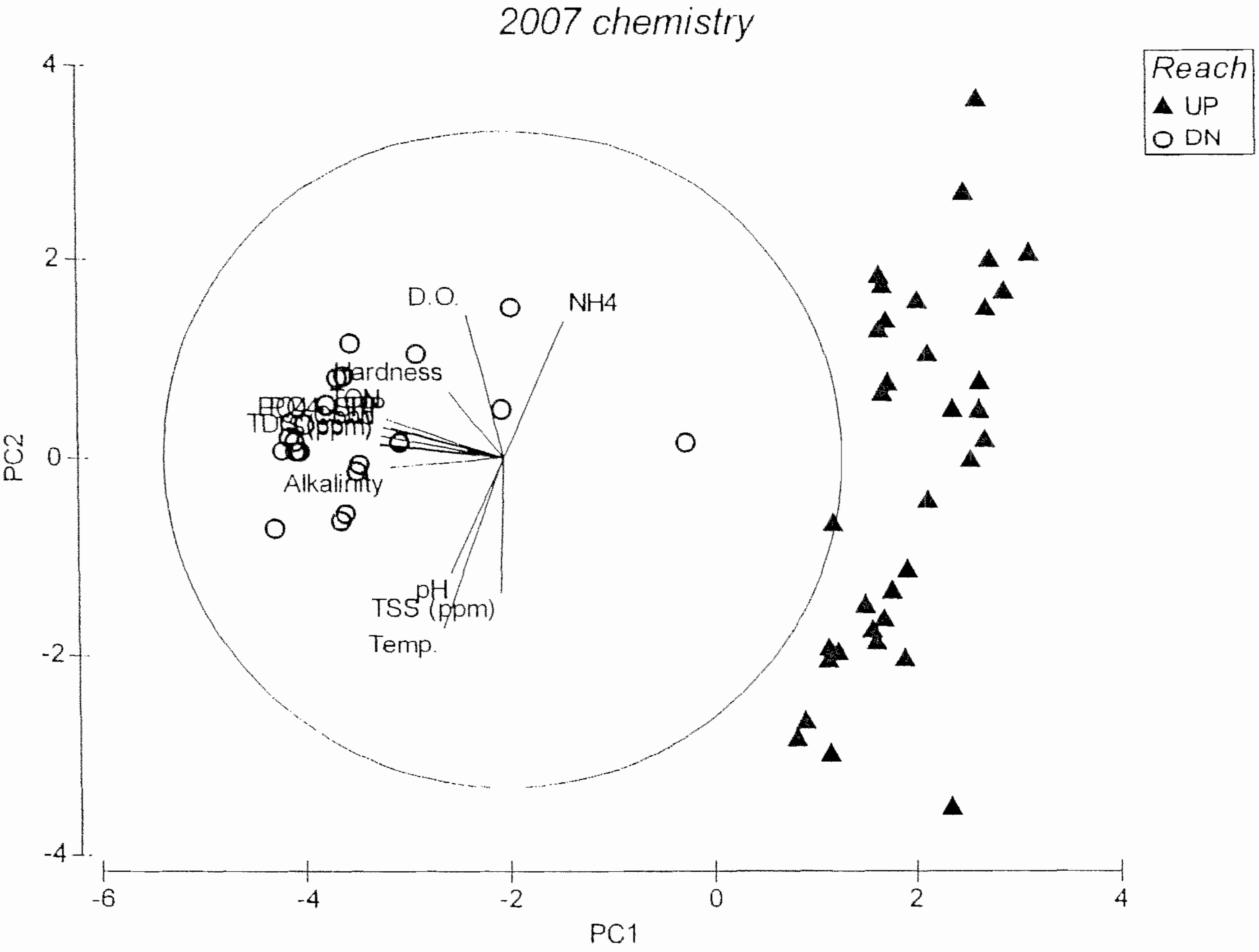

Table 3. Macroinvertebrate data collected in 2007 from the 9 Sangamon River sample sites associated with the Decatur Sanitation District

order	family	tol value	site 1	site 3	site 4	site 5	site 6	site 8	site 9	site 11	site 12
Ephemeroptera	Baetidae	4	2	4		38		34	38	41	41
	Caenidae	6	18	23	11	34	44	22	23	23	11
	Ephemeridae	5	9		5					8	
	Heptagenidae	3							18	7	16
Odonata	Coenagrionidae	6	31	78	44	15	7	6	27		22
	Gomphidae	5					1			14	
Trichoptera	Polycentropodidae	6	88	32	76	39	56	41	16	44	
Hydropsychidae	Hydropsychide	4		5				3	9	88	17
Coleoptera	Dryopidae	4									
	Curculionidae	4	1					6		8	10
	Elmidae	5		4				5	10	6	7
	Haliphilidae	4			3			4	4		4
Diptera	Chironomidae	7	735	1419	889	541	337	558	278	209	155
	Culcidae	8	14	4		6					
	Simuliidae	7	6		8						
	Ceratopogonidae	5							27	18	3
	Tipulidae	4						23	9	12	11
	Oligochaeta	8	12	19	31	11					
Mollusks		6		4							
Annelida		10	21	11	18	17	18				
Megaloptera		3									
Turbellaria		6						4	2	7	5
	Total		937	1603	1085	701	463	706	461	485	302
	# of families		11	11	9	8	6	11	12	13	12
	MBI		**6.92**	**6.93**	**6.94**	**6.81**	**6.88**	**6.58**	**6.15**	**5.68**	**5.77**

Up = 6.84 Down = 5.87

Table 4. Fish data collected in 2007 from the Sangamon River sample sites associated with the Decatur Sanitation District

Species	Genus	Species	Site1	Site3	Site4	Site5	Site6	Site7	Site8	Site9	Site11	Site12	Site14
blackstripe topminnow	*Fundulus*	*notatus*	0	0	0	0	0	0	0	1	3	0	6
bluegill	*Lemopis*	*macrochirus*	4	43	2	10	13	3	4	1	5	0	0
bluntnose minnow	*Pimphales*	*notatus*	24	168	44	10	40	110	8	54	97	10	112
brook silverside	*Labidesthes*	*sicculus*	27	38	7	2	57	19	22	4	0	3	1
bullhead minnow	*Pimphales*	*vigilax*	1	0	4	34	42	47	11	18	12	13	2
channel catfish	*Ictalurus*	*punctatus*	1	1	2	1	1	3	1	0	0	0	0
fathead minnow	*Pimphales*	*promelas*	0	0	1	0	0	0	0	0	0	0	0
gizzard shad	*Dorosoma*	*cepedianum*	4	239	17	31	4	4	0	0	0	0	0
golden redhorse	*Moxostoma*	*erythrurum*	0	1	0	0	0	0	0	0	0	0	0
johnny darter	*Etheostoma*	*nigrum*	0	0	0	0	0	1	0	1	4	0	8
mosquitofish	*Gambusia*	*affinis*	0	0	0	0	3	14	11	6	12	0	0
quillback	*Carpoides*	*cyprinus*	0	0	0	0	0	0	0	10	8	0	0
red shiner	*Cyprinella*	*lutrensis*	0	0	0	0	0	2	0	3	0	0	0
sand shiner	*Notropis*	*ludibundus*	0	9	69	0	5	14	43	54	43	27	26
smallmouth bass	*Micropterus*	*dolomieu*	0	0	0	0	0	0	0	1	3	1	5
spotted bass	*Micropterus*	*punctulatus*	0	1	1	0	0	1	0	3	5	2	3
steelcolored shiner	*Cyprinella*	*whipplei*	0	41	20	12	27	70	46	65	23	7	18
suckermouth minnow	*Phenacobius*	*mirabilis*	0	0	0	1	0	2	1	0	0	0	0
yellow bullhead	*Ameiurus*	*natalis*	0	0	0	1	0	0	0	0	0	0	0
		Total	61	541	167	102	192	290	147	221	215	63	181
		Richness	6	9	9	9	9	13	9	13	11	7	9
		IBI	32	29	34	35	29	30	31	37	39	40	41

Up = 31.43

Down = 39.25

APPENDIX A. Potential Effects of Zinc and Nickel on Stream Ecosystems

Introduction

Both zinc and nickel are naturally occurring elements (ATSDR 2005). Zinc is widely distributed in nature, constituting 20–200 ppm (by weight) of the Earth's crust (Goodwin 1998), but it is not found as elemental zinc in nature (Lloyd and Showak 1984). Nickel ranks 24th in order of abundance in the earth's crust, with an average concentration of 0.0086%; the concentration of nickel increases towards the center of the earth. It is estimated to comprise 0.22% of the mantel and 5.8% of the core, thus making it the fifth most abundant element on earth (USDHHS 2005; Duke 1980).

Both elements are naturally occurring, and both are considered micronutrients and have have variable solubility in aqueous solutions (Table A1). Nutrients flow in biogeochemical cycles that form the chemical building blocks of life. They are divided into two categories: macronutrients and micronutrients. Macronutrients are required by all organisms in large quantities and include: water, carbon, hydrogen, oxygen, nitrogen, phosphorus, sulfur, and calcium. Micronutrients, like zinc are only required in trace quantities (Audesirk 1996). The National Academy of Science estimates the Recommended Dietary Allowance (RDA) for zinc is 11mg/d for men and 8mg/d for women (ATSDR 2005).

The Environmental Protection Agency (EPA) has identified zinc at 985 of the 1,662 National Priority List sites and nickel at 882 of the sites (ATSDR 2005). Zinc is a naturally occurring element, but due to its reactivity (amphoteric: capable of acting chemically either as an acid or as a base) it is not found as a free element in nature. There are approximately 55 forms of mineralized zinc that are released into the environment from both natural and anthropogenic sources; however, releases from anthropogenic sources far outweigh those from natural sources. The most common anthropogenic pollutants are: zinc oxide(ZnO), zinc chloride($ZnCl_2$), zinc sulfate($ZnSO_4$), zinc acetate($Zn(C_2H_3O_2)_2$), zinc cyanide($Zn(CN)_2$), zinc phosphate($Zn(PO_4)_2$), zinc chromate($ZnCrO_4$), and zinc hydroxide($Zn(OH)_2$) (Goodwin 1998; WHO 2001).

Nickel and its compounds are naturally occurring, however the EPA has designated it a toxic pollutant under the Federal Water Pollution Control Act and the National Pollution Discharge Elimination System. The most commonly used and released forms of nickel are: nickel sulfate($NiSO_4$), nickel ammonium sulfate($Ni(NH_4)_2(SO_4)_2$), nickel chloride($NiCl_2$), nickel hydroxide($Ni(OH)_2$), nickel fluoride(NiF_2), nickel nitrate($Ni(NO_3)_2$), nickel acetate($Ni(CH_3CO)_2$), nickel oxide(NO), and nickel carbonate($NiCO_3$) (ATSDR 2005; Eisler 1998).

Zinc and Nickel in the Environment

Both zinc and nickel are naturally occurring elements. Zinc is a bluish-white metal that dissolves readily in strong acids. In nature, zinc occurs as three compounds: sulfide, oxide, and carbonate (Eisler, 1993). In typical riverine environments 90% of zinc is present as aquo ions $(Zn(H_2O)_6)^{2+}$ (Spear, 1981). Elemental nickel is a hard, lustrous, silvery white metal, and is insoluble in water (EPA 2003). Like zinc, in nature nickel is found in multiple compounds: chloride, sulfate, nitrate, hydroxide, and carbonate (Eisler 1998). Both elemental compounds have varying degrees of solubility in water.

Both zinc and nickel are characterized as heavy metals, which is a loose term that encompasses any of the high atomic weight metals (Nebel et al. 2000). A major problem with heavy metals is that unlike organic pollutants, they are not broken down by bacteria. Since they are not degraded they can bioaccumulate in the water column and sediment, leading to biomagnification in the food chain (Owen et al. 1995). Heavy metals are extremely toxic because, as ions or certain compounds, they are soluble in water and may be readily absorbed into the body. Once in the body they tend to combine with and inhibit the functions of vital enzymes. Even very minute concentrations can have severe physiological and neurological consequences (Nebel et al. 2000; Owen et al. 1995).

In nature both elements are regulated by biogeochemical cycles. Chemical and physical degradation of rocks and soil release nutrients that are available for biotic uptake. As those organism die they re-release their nutrients into the soil or atmosphere. Zinc and nickel can also be introduced into the environment as soil dust, from volcanic gas and ash, and forest fires (Eisler 1998). The cycles perpetuate themselves, as the nutrients are released from the earth they are absorbed and released into the atmosphere where they precipitate back to earth, and leach back into the soil (Nebel et al. 2000). This cycle is drastically thrown out of equilibrium due to anthropogenic stressors. Human induced sources of zinc and nickel include: mining, smelting, combustion of fossil fuel and solid waste, electroplating, domestic and industrial sewage, road surface runoff, and erosion of agricultural soils (Eisler 1993; Eisler 1998; EPA 2003). Normal background concentrations of zinc and nickel vary vastly depending on the ecosystem and other confounding factors (Table 2).

Zinc

Zinc is a ubiquitous micronutrient that is essential for normal growth, reproduction, and wound healing of biotic organisms (Audesirk 1996; Eisler 1993). Zinc is a cofactor for more than 200 enzymes that are fundamental for maximum catalytic activity, cellular respiration, chemical detoxification, metabolism, and neurotransmitter synthesis (Vesela et al. 2006; Eisler 1993; Rai et al. 198; Wright et al. 2007). Its primary metabolic effect is on zinc-dependent enzymes that regulate the biosynthesis and catabolic rates of RNA and DNA (EPA 2003; Eisler 1993). Acute and chronic toxicities of zinc are variable by organism (Table A4).

Synergism and antagonism with other variables

The environment and interactions with other chemicals produce radically altered patterns of accumulation, metabolism, and toxicity; some of which are beneficial to organisms whereas others are harmful (Eisler, 1993). Zinc bioavailability and toxicity to aquatic organisms are highest under conditions of low pH, low alkalinity, low dissolved oxygen, and elevated temperatures (Weathereley et al. 1980).

Copper: The toxicity of zinc is believed to be due to its interactions with copper (ATSDR 2005). Mixtures of zinc and copper are general acknowledged to be more than additive in toxicity to a wide variety of aquatic organisms, including marine fish (Eisler, 1984), freshwater fish (Hilmy et al., 1987), and amphipods (de March, 1988). Several studies have demonstrated that increased levels of copper can decrease the absorption of zinc (EPA, 2003). Likewise, increasing zinc concentrations in ambient water depresses copper accumulations in tissues of juvenile catfish (*Clarias lazera*) (Himly et al., 1987).

Cadmium: Zinc has been shown to diminish the toxic effects of cadmium (Eisler, 1993; Brzóska et al., 2001). Exposure to zinc has been shown to protect embryos of toads and other amphibians against cadmium induced developmental malformations (Rivera et al., 1990; Herkovits & Perez-Coll, 1990). Pre-exposure of 10µgZn/L for two weeks to freshwater amphipod (*Gammarus pulex*) protected against the toxic effects of 500µgCd/L for 96h (Howell, 1985). Aqueous solutions of Zinc-Cadmium mixtures are usually additive in toxicity to aquatic organisms, including fresh and marine fish, amphipods, and copepods (Ahsanullah et al., 1988; Verriopoulos and Dimas, 1988; Eisler and Gardner, 1973). Mixtures of zinc and cadmium are less toxic to *Daphnia magna* than the individual elements (Eisler, 1993). Zinc exhibits antagonistic effects on uptake of cadmium by gills and tissues of the freshwater clam (*Anodonta cygea*) and other *Anodonta*, but accelerated cadmium transport from the gills to internal organs (Hemelraad et al. 1987). Exposure to cadmium may cause changes in the distribution of zinc since they both compete for a common transport carrier system in renal proximal cells. This can cause zinc accumulation in the liver and kidney, particularly if dietary intake of zinc is marginal (ATSDR 2005; Gachot and Poujeol 1992).

Lead: Zinc is believed to increase the toxicity of lead, but data are conflicting (ATSDR 2005). Lead-zinc mixtures were more than additive in toxicity to marine copepods, and marine fish accumulate lead up to 10 times faster in seawater with elevated zinc concentrations (Verriopoulos and Dimas 1988; Eisler 1981). In terrestrial animals zinc tends to protect against lead toxicosis (Eisler 1993).

Zinc Bioaccumulation and Biotic Affects

Zinc does not volatize from soil or water, but is deposited primarily in sediments through absorption and precipitation. Zinc complexes with various organic and inorganic groups to affect its biological activity and mobility in aquatic environments. The level of dissolved zinc in water increases as the water's acidity increases (ATSDR 2005). The relationship between biota and sediment concentrations is not proportional; the biota contains relatively little zinc compared to the sediment. Zinc bioaccumulates moderately in aquatic organisms, bioconcentration is higher in crustaceans and bivalve species than in fish. In some fish, it has been observed that the level of zinc found in their bodies did not directly relate to the exposure concentrations. It has been shown that bioaccumulation of zinc in fish is inversely related to the aqueous exposure (McGeer et al. 2003). This suggests that fish placed in environments with lower zinc concentrations can sequester zinc in their bodies (ATSDR 2005). Fish zinc concentrations tend to be higher in urban areas, eggs, viscera, the liver, and lowest in muscle tissue. Accumulation is positively correlated with metallothionein concentrations, and is lower in all tissues with increasing growth and age (Eisler 1981; Eisler & LaRoche 1972; Grady et al. 1989).

In lakes containing 1,150 mg Zn/kg sediment and 209-253 μg Zn/L in the water column, white sucker (*Catostomus commersoni*) females did not grow after sexual maturity and had increased incidences of spawning failure. Alterations in growth and reproduction were related, in part, to nutritional deficiencies as a result of chronic effects of elevated sediment zinc on the food base of the sucker, that is invertebrate fauna was largely absent from the ecosystem (Munkittrick and Dixon 1989).

Miller et al. (1991) conducted a study to determine the relationship between concentrations of copper and zinc in water, sediment, benthic invertebrates, and tissues of White Sucker (*Catostomus commersoni*) from six contaminated Ontario lakes. The degree of metal contamination in the lakes varied progressively and were compared to two reference lakes. They discovered a direct correlation between Zn concentrations in invertebrates and sediment, but not with water concentrations. Concentrations of Zn and Cu in fish tissue were strongly correlated with waterborne metal levels rather than those in sediments. The concentrations of Zn in the liver, kidney, gill, bone and stomach were all significantly correlated to waterborne concentrations. Concentrations in the kidney, bone, and stomach were, to a less extent correlated with sediment Zn levels. They did not discover a relationship between fish tissue metal concentrations and invertebrate metal concentrations. While there were no gender differences in concentrations in liver, kidney, bone, and stomach, there were significant differences in gonadal tissue. Zinc concentrations were higher in ovaries than in testes.

Nickel

Nickel is an essential trace element in animals, although little is know about its functional importance. It is considered a micronutrient based on studies of nickel deficiency in several animal species (e.g. rats, chickens, cows, goats). Nickel deficiency primarily affects the liver and can cause abnormal cellular morphology, oxidative metabolism, and fluctuating lipid levels. It has also been shown that decreased growth and hemoglobin concentrations as well as impaired glucose metabolism can be linked to nickel deficiencies (USDHHS 2005; Zaroogain et al. 1984). Acute and chronic toxicities of zinc are variable by organism (Table A5).

Synergism and antagonism with other variables

Among animals, plants, and microorganisms, nickel interacts with at least 13 essential elements: calcium, chromium, cobalt, copper, iodine, iron, magnesium, manganese, molybdenum, phosphorus, potassium, sodium, and zinc (Nielsen 1980). At the cellular level, nickel interferes with enzymatic functions of calcium, iron, magnesium, manganese, and zinc (Kasprzak 1987). Mixtures of metals (arsenic, cadmium, copper, chromium, mercury, lead, zinc) containing nickel salts are more toxic to daphnids and fishes than the individual compounds (Enserink et al. 1991).

Nickel is less-than-additive in toxicity to aquatic algae in combination with zinc (WHO 1991). It is thought that Zinc competes with Nickel in binding to DNA and proteins which diminishes the toxicity of nickel. Zinc binding sites of DNA-binding proteins, known as "finger loop domains," are likely molecular targets for metal toxicity. Interfering with these binding sites may disrupt nickel-induced gene expression, cleave DNA, and hinder mitosis (WHO 1991; USPHS 1993).

Nickel also interacts with chelating agents, phosphates, viruses, vitamins, and polycyclic aromatic hydrocarbons (PAHs) (Eisler 1998). Chelating agents mitigate the toxicity of nickel by stimulating nickel excretion (USPHS1993; USDHHS 2005). Chelators reduced the toxicity of nickel to aquatic plants, presumably by lowering nickel bioavailability (WHO 1991). Lipophilic chelating agents, such as triethylenetetramine and Cyclam (1,4,8,11-tetraazacyclotetradecane) are more effective in abating nickel toxicity than hydrophilic agents like EDTA, cyclohexanediamine tetraacetic acid, and hydroxyethylenediamine triacetic acid. Lipophilic agents are believed to be more effective due to their ability to bind to nickel both intracellularly and extracellularly, while hydrophilic agents can only bind extracellularly (USPHS 1993; USDHHS 2005).

Nickel Bioaccumulation and Biotic Affects

Nickel does not appear to concentrate in aquatic organisms or small terrestrial mammals, however, studies have shown that plants can take up and accumulate nickel (USDHHS 2005). Nickel concentrations in carnivorous fish (e.g. Lake Trout) did not increase significantly with age, and had a mean bioconcentration factor (BCF) of 36. The concentration of nickel in mussels (*Crassostrea virginica*) and oysters (*Mytilis edulis*) treated with 5 and 10µg/kg seawater for 12 weeks averaged 9.26 ± 3.56 and 12.96 ± 5.15µg/g dry weight for *C. virginica*, and 10.04 ± 2.66 and 16.43 ± 3.19µg/g dry weight for *M. edulis*. There was a significant linear relationship found between nickel uptake by both species and seawater nickel concentrations. There was an inverse relationship between tissue nickel concentrations and dry weight for both species. However, after a 28 week depuration period in which the treated species were returned to ambient flowing water, nickel concentrations in *C. virginica* were reduced 73 and 89% and *M. edulis* were reduced 48 and 68% respectively (Zaroogian et al. 1984).

McGeer et al (2003) examined BCF's of various aquatic organisms (e.g. algae, arthropods, mollusks, and fish) as a group based on whole body metal and exposure concentrations. For exposure concentrations within the range of 5-50µg/L nickel in water a mean BCF value of 106±56 was obtained. The results indicate an inverse correlation between BCF values and exposure concentration. There was no evidence that nickel biomagnifies in aquatic food chains, and even indicated that nickel concentrations in aquatic organisms decrease with increasing trophic level. Likewise, the U.S. Geological Survey National Water-Quality Assessment (NAWQA) Program found no statistically significant correlations between nickel sediment concentrations and nickel concentrations in liver and tissue samples of fish (USGS 2000).

Toxic heavy metals, including Ni and Zn introduced into aquatic environments anthropogenically tend to accumulate in sediment. It is believed that metals reacting with sulfides control the toxicity by controlling porewater (the water filling the spaces between grains of sediment USGS.) metal concentrations. Acid-volatile sulfide (AVS), a component of iron sulfide can create stable metal sulfide precipitates in sediments that dictate the behavior of divalent metals (Cd, Cu, Ni, Pb, Zn) (Lee 2000; Ankley et al. 1991).

Summary

Both nickel and zinc are naturally occurring elements. Their compounds and concentrations are dictated by earth's biogeography and anthropogenic sources. There is research stating that zinc biomagnifies in aquatic organisms, while the researchers and data on nickel accumulation are far more ambiguous. Both elements exhibit synergistic and antagonistic reactions with other metals and chemicals, however, the data is limited. While there have been experiments dealing with the bioaccumulation of heavy metals, the data is incomplete when considering all of earth's organisms in proportion to the amount of organisms studied. It is hard to conclude the affects of zinc and nickel on the environment when there are so many confounding factors that can alter their behavior.

Table A1. Solubility of Zinc and Nickel Compounds in Water.(Eisler1993; Eisler 1998).

Index	Solubility g/L
Zinc Chloride	61.4
Zinc Sulfate (monohydrate)	5.38
Nickel Chloride (hexahydrate)	2.400-2.500
Nickel Sulfate (hexahydrate)	2.400-2.500
Nickel Nitrate	45
Nickel Hydroxide	.13
Nickel Carbonate	.09

Table A2. Physiochemical Factors Affecting Pollutants Toxicity (Babich et al 1983; Ford et al 1995; Kiffney et al. 1996)

pH (acidity/alkalinity
E_h(oxidation-reduction potential)
Aeration status (aerobic, microaerobic, anaerobic)
Buffering capacity
Inorganic anionic composition
Inorganic cationic composition
Water content
Clay mineralogy
Hydrous metal oxides
Organic matter
Cation exchange capacity
Anion exchange capacity
Temperature
Solar radiation
Hydrostatic pressure
Osmotic pressure
Water hardness
Turbidity
Altitude

Table A3. Background Concentrations of Zinc and Nickel.(Eisler 1993; Eisler 1998; EPA 2003; Barceloux 1999; ATSDR 2005) (Concentrations are subjected to geographical differences)

Index	Zn	Ni
Terrestrial	70mg/kg	4-80ppm
Marine	<10µg/L	<7.1µg/L
Brackish/Estuaries	>10µg/L	
Lakes/Reservoirs	<40µg/L	0.1-10µg/L
Rivers/Streams	<40µg/L	0.1-10µg/L
Drinking water	<5mg/L	<10µg/L

Table A4. Acute and Chronic Toxicity of Zinc

Species	Conc.	Effects	Reference
Algae			
Selenastrum			
S. cupricornutum	40-69ppb	95% growth inhibition 14d	18
S. cupricornutum	100ppb	100% growth inhibition 7d	18
Scenedestrum quadriccuda	300µg/g	Lethal	47
Scenedestrum capricoinutum	100µg/g	100% growth inhibition 7 days	42
Arthropods			
Daphnia magna	1340mg/kg Whole body	Reproduction. LD 10	18
	2690mg/kg Whole body	Mortality,ED50:Lethal body burden after 21 days	18
	5-14µg/g	LC50 72h @ 30°C	43
	68-655µg/g	LC50 96h	32
	100µg/g	LC50 48h	35
	560µg/g	LC50 24h @ 25°C	35
Daphnia pulix	253µg/g	LC50 96h	43
	500µg/g	LC50 24h @25°C	39
	1550µg/g	LC50 24h @ 5°C	439
Hyallella azteca	66µg/g	Mortality, LC50	11
Tanytarsus disimilis	37µg/g	LC50 10days	43,47
Diatom			
Nitzschia closterium	271-300µg/g	LC50 4 days: Growth inhibition	43
Dynoflagellate			
Procentrum micans	319µg/g	LC50: Growth inhibition	43

Table A4. continued

Species	Conc.	Effects	Reference
Rotifer			
Philodena acutiformus	500µg/g	LC50 48h @25°C	43
Annelid			
Capitella capitata (Adult)	1250µg/g	LC50 28 days	47
Fish			
Pimephales promeles			
Larvae	600µg/g	LC50 96h	39
Adult	800µg/g	LC50 30days	39

Table A5. Acute and Chronic Toxicity of Nickel

Species	Conc.	Effects	Reference
Algae & Macrophytes			
Anabaena inequalis	125µg/L	Growth inhibited	50
	10mg/L	Photosynthesis inhibited	50
Anacystis nidulans	160µg/L	Growth inhibited 50%	49
(Blue-Green)	50mg/L	No growth in 14 days	29
Scenedesmus acutiformis	1.6mg/L	Growth reduced 47%	50
	3.0mg/L	Growth reduced 82%	50
Diatom			
Navicula pelliculosa	100µg/L	Growth inhibited 50% in 14days	50
Mollusks			
Juga plicifera	237µg/L	LC50(96h)	50
(Freshwater snail)			
Lamellidens marginalis	110m/L	LC50(96h)	40
(Freshwater mussel)			
Arthropods			
Copepods			
Eudiaptomus padanus	3.6mg/L	LC50(48h)	9
Cyclops abyssorum Prealpinus	15.0mg/L	LC50(48h)	9
Daphnids			
Ceriodaphnia dubia	13.0µg/L	LC50(48h)@ pH8.0-8.5	38
	>200µg/L	LC50(48h)@ pH6.0-6.5	38
Daphnia hyaline	1.9mg/L	LC50(48h)	9
Daphnia magna	360µg/L	LC50(21days)	9
	100µg/L	Growth inhibited in 9 days	42
Annelids			
Lumbriculus variegates	26mg/L	LC50(96h)@ pH8.0-8.5	38
	100mg/L	LC50(96h)@ pH6.0-6.5	38
Fishes			
Cyprinus carpio	1.3-40.0mg/L	LC50(96h)	42.4
(Common Carp)			
Ictalurus punctatus	38µg/L	LC10	10
(Channel Catfish)	710µg/L	LC50	10

Table A5. continued

Species	Conc.	Effects	Reference
Micropterus salmoides	61-185µg/L	LC10	10
(Largemouth Bass)	1.48-2.84mg/L	LC50	10
Pimephales promelas	3.1mg/L	LC50(96h)@ pH8.0-8.5	38
(Fathead minnow)	>4.0mg/L	LC50(96h)@ pH6.0-6.6	38
Amphibians			
Ambystoma opacum	410µg/L	LC50	10
(Marbled Salamander)			

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